Expeto Platform Guide

v3.3.22

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Table of contents

1. Overview 3
   1.1 Expeto Platform Overview 3
   1.2 Frequently Asked Questions 6
2. xControl 8
   2.1 Expeto xControl 8
   2.2 Getting Started 11
   2.3 User Guide 14
   2.4 Installation 76
3. xView 89
   3.1 xView Guide 89
   3.2 xView Architecture 91
   3.3 Accessing xView 95
   3.4 Custom Alerts and Rules 98
   3.5 Data Sources and Exporters 101
   3.6 Metric Labels and Conventions 104
   3.7 Metrics 110
   3.8 Monitored Endpoints 122
   3.9 Alerts 126
4. xCore 204
   4.1 Expeto xCore 204
   4.2 Architecture 206
   4.3 Installation 210
   4.4 Expeto CLI Guide for Operations 259
5. xRouter 261
   5.1 Expeto xRouter 261
   5.2 Installation 262
6. Testing 283
   6.1 Testing at Expeto 283
   6.2 How Expeto Tests 285
   6.3 Test Environment and Tooling 288
   6.4 How to Read and Run a Procedure 294
   6.5 Continuous verification 298
   6.6 Acceptance test catalog 325
   6.7 Standards Coverage 520
   6.8 Campaign Planning and Results 528

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1. Overview

1.1 Expeto Platform Overview

The Expeto Platform is a software extension to a mobile operator's core network. It lets the operator offer private mobile networking to its enterprise customers on the operator's own SIMs: the same subscriber identity works on the public macro network and on private radios at the customer's site, and in both cases the device arrives on the enterprise's own IT network as an ordinary endpoint, with a private address, the customer's subnets, and the customer's security policy.

The Expeto Platform is licensed to and hosted by the mobile operator, or by the operator's enterprise customer for the on-site elements. The operator is Expeto's customer; the enterprise is the operator's customer.

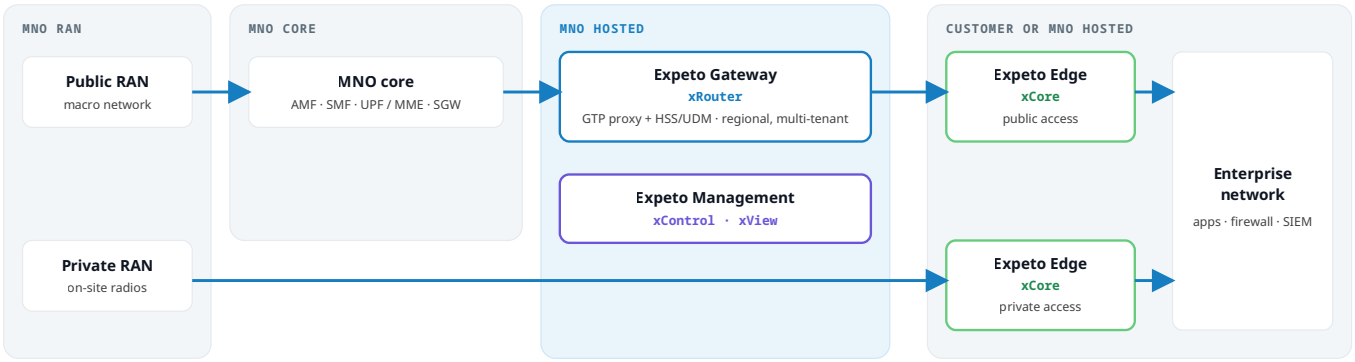
1.1.1 Product groups and component names

Expeto's commercial material uses three product group names. The software and this documentation use the component names. This table describes the mapping:

Product group	Component	What it is	Where it runs
Expeto Edge	xCore	A complete, dedicated 4G EPC and 5G SA core for one enterprise customer: MME, SGW and PGW for 4G; AMF, SMF and UPF for 5G. Terminates the RAN, holds the customer's traffic policy in the SMF, and is the point where user traffic enters the enterprise network.	Customer site, a customer-controlled cloud, or hosted by the operator as a managed service. One logically dedicated instance per customer; no instance serves two customers.
Expeto Gateway	xRouter	The bridge from the operator's public network into a customer's xCore. Contains the GTP proxy and the HSS, with its HLR functions, that authenticates subscribers on the public-radio path. One xRouter serves many customers, with a separate secure link to each customer's xCore.	Operator data center, alongside the operator's core.
Expeto Management	xControl and xView	xControl is the multi-tenant portal and REST API for provisioning, policy and role-based access: the operator sees every customer; each customer sees only its own subscribers, sites and policies. xView is the operator's operations view, built on VictoriaMetrics and Grafana and queried in PromQL, for platform health, alarms and analytics, and it feeds the operator's own OSS tools.	Operator data center. Installed once, serving every xRouter and every xCore the operator deploys.

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1.1.2 How the pieces fit together



A subscriber reaches its enterprise network by one of two access paths.

Public radio. The device attaches to the operator's macro network: 4G, 5G non-standalone, which is anchored on the 4G core, or 3G. The operator's core hands the session to xRouter over standard 3GPP interfaces. xRouter authenticates the subscriber against its own HSS and forwards the user plane to the customer's dedicated xCore over a secure link. The link is provided by the operator and carries user-plane traffic only; signaling and authentication are handled at xRouter and never traverse it. The implementation of the link is the operator's choice; IPsec is one option where a customer's accreditation requires it.

Private radio. The device attaches to radios on the customer's site, which connect directly to xCore. The entire path, including authentication against a local HSS or UDM inside xCore, stays inside the customer's trust domain. xRouter is not involved, and the site continues to operate if its backhaul is lost.

On both paths the user plane terminates in xCore and is delivered to the enterprise's corporate subnets, where the customer's own firewall, DLP, inspection and SIEM apply. Employee, IoT and application traffic can be segmented into separate subnets from the same xCore.

Management. xControl reaches every xCore and xRouter through a software agent that opens an outbound TLS connection on port 443 from the managed component. That channel carries configuration and policy down, and call detail records and metrics up. It is a management channel, separate from the 3GPP control plane: if xControl is unreachable, xCore keeps authenticating devices, attaching sessions and carrying traffic, queues its metrics, and reconciles when the connection returns. Emergency changes during an extended outage can be made from a CLI on xCore directly.

1.1.3 Hosting and deployment

All components run on Kubernetes. xRouter, xControl and xView are deployed in the operator's data center on the container platform the operator already runs (Red Hat OpenShift, VMware Tanzu, Canonical MicroK8s, or a managed Kubernetes service); geographic redundancy is a second cluster. xCore is deployed per customer in one of three places: the customer's data center, a customer-controlled cloud, or the operator's environment as a managed service. When the operator hosts xCore, customer instances are logically separate and may share physical infrastructure. Deployment is infrastructure-as-code: Expeto ships Helm charts and operators that carry the operational knowledge, the operator or its hardware partner installs the cluster, and the core is deployed jointly.

1.1.4 How this documentation is organized

The remaining sections are written per component, using the component names throughout.

Section	Covers
xControl	The management portal and REST API: customers, sites, systems, subscribers, profiles, APNs, reports, accounts and roles.
xView	Operator monitoring: dashboards, metrics, alarms and integration with OSS tools.
API	The xControl REST API reference: every endpoint, with schemas and request samples.

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Section	Covers
xCore	Expeto Edge: deployment, configuration, radio integration, high availability and operations.
xRouter	Expeto Gateway: integration with the operator core, secure links to customer xCores, subscriber identity.
Testing	Acceptance test catalog, partner acceptance pack and the 3GPP standards compliance statement.

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1.2 Frequently Asked Questions

Short answers to the questions installers and operators ask most often, with links to the pages that cover each topic in full.

1.2.1 Platforms and installation

Can Expeto set up Kubernetes for us?

Expeto does not provide Kubernetes services. Many providers offer day 0, 1 and 2 support for the platforms Expeto installs on. The xCore platform notes cover Red Hat OpenShift, VMware Tanzu, Canonical MicroK8s and Amazon EKS; other conformant Kubernetes distributions work when they meet the prerequisites. Not every cloud platform supports the advanced routing and scaling features that large deployments need.

I have a Docker-based install and I want to migrate to Kubernetes

Build a Kubernetes cluster on separate nodes and install there. In-place migration from a Docker-based install is not supported.

Which chart installs xCore?

The `xfabric` chart, which installs the xCore operator; the core itself is described by a `Site` resource. The `xcore` chart of the 3.3 releases is deprecated. See xCore.

1.2.2 Sizing and networking

How many sessions can a user plane hold?

On an xCore, each user plane's session table is set by `numberOfSessions` on its entry in the Site (default 3000), and is fixed once the user plane exists, so size it for the peak. On an xRouter, `nfcm.dataNetwork.numSessions` in the chart values sets it. Each session uses memory on the user plane; the sizing guide gives the figures to plan with.

How do I attach additional networks to a user plane, the AMF or the MME?

On an xCore, declare the network as an attachment in the Site and reference it from the interface that uses it; see Define and apply a Site. On an xRouter, add it under `global.networks` in the chart values; see the values.yaml reference.

How do I add static routes?

On an xCore, add `routes` to the user plane's `n3` or `n6` entry in the Site; the running pods apply them without a restart. Routes the worker nodes themselves need go in the Site's `nodeConfig`. See the Site resource reference.

On an xRouter, chain the route-override CNI plugin, which the chart bundles, after the interface plugin of the network in `global.networks`:

```
global:
  networks:
    n6:
      cniVersion: 0.3.1
      plugins:
        - type: macvlan       # or ipvlan, host-device, sriov, bridge
          master: eth0        # the node interface carrying the segment
        - type: route-override
          flushroutes: false
          #delroutes:
          #  - dst: 192.0.2.0/24
          #addroutes:
          #  - dst: 192.0.2.0/24
          #    gw: 192.0.2.1
```


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I can see GTP packets arrive on a node, but why don't they arrive at the SMF or UPF pod?

Check for Services of type NodePort that are left over from an earlier configuration. A NodePort Service installs firewall rules on the worker nodes that can stop packets from reaching the pods **unless** they come through the NodePort Service itself. Verify the rules on the worker node:

```
iptables -L -t nat
```

1.2.3 MicroK8s

I updated the DNS server on a single-host MicroK8s install but still see name resolution errors

Restart MicroK8s so it uses the new DNS servers:

```
sudo microk8s stop && sudo microk8s start
```

I get certificate errors from kubectl logs or when containers start on MicroK8s

If the host's IP address has changed, recreate the CA certificate so it includes the new address:

```
sudo microk8s refresh-certs --cert ca.crt
```


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2. xControl

2.1 Expeto xControl

xControl is the management plane of the Expeto Platform. It is a multi-tenant web application and REST API, hosted by Expeto or deployed in a Mobile Network Operator's (MNO) own Kubernetes cluster, from which the MNO and its enterprise customers provision Mobile Assets, define network segments and policies, and monitor every Site they operate.

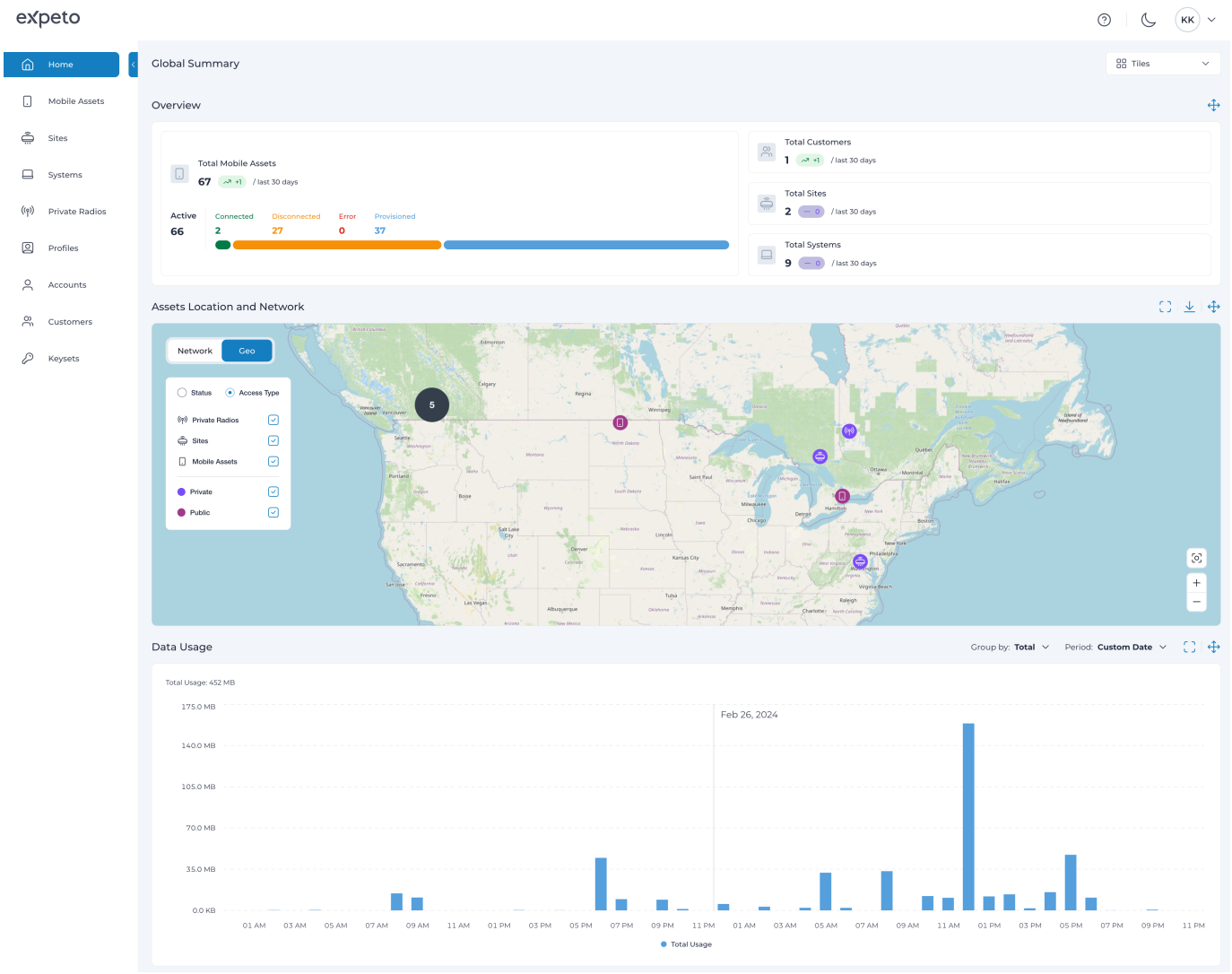
Each xCore and xRouter Site runs an Expeto Agent that connects outbound to xControl over TLS. The Agent keeps the Site's subscriber data and configuration in sync and reports sessions, usage and metrics back. A Site never needs an inbound connection, and it keeps serving traffic while its connection to xControl is down: changes made in the meantime are queued and delivered when the Agent reconnects.

2.1.1 What you manage in xControl

- **Mobile Assets**: SIM and eSIM provisioning, bulk import, update and delete, status and session history.
- **Sites and Systems**: the Sites you operate and the network segments (Systems) they serve, each with its own IP range.
- **Policy**: System Profiles with service levels and data limits, APNs, Roaming Profiles and Carrier Groups.
- **Private Radios**: eNodeB and gNodeB registration for private radio Sites.
- **Accounts and Customers**: nested tenancy with Role-Based Access Control (RBAC).
- **Monitoring**: dashboards, reports, revision history and, when it is installed alongside, xView.

Everything the web interface offers is also available through the REST API.

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2.1.2 Components

An xControl installation is a single Helm release. Its parts, and the URL path each one is served under, are:

Component	Role	Path
API server	Backend for the web interface and the REST API, and the endpoint the Agents connect to.	`/`
Frontend	The web interface.	`/ngui`
Keycloak	Single sign-on for xControl users.	`/auth`
ActiveMQ	Message broker carrying events between the API server and the Agents.	`/events`
PostgreSQL	The database, run as a CloudNativePG cluster.	internal
Documentation	This guide and the End-User Guide.	`/admin-docs` , `/docs`
xView (optional)	Metrics storage, alerting and Grafana dashboards for the whole platform.	`/nms`

The Installation section covers cluster requirements, the Helm install and day-two operation.

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2.1.3 Role based permissions

xControl is multi-tenant. Accounts belong to Customers, Customers can be nested, and every Account carries a role that determines which functions and which data it can reach. A subordinate Account only sees the Customers, Sites and Mobile Assets inside its own branch of the hierarchy.

Roles are predefined and assigned when an Account is created or edited. See Role Permissions for the full matrix.

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2.2 Getting Started

Expeto xControl is accessed through a web browser or by using an API client.

For instructions on how to access and interact with the API, see the API Reference.

2.2.1 Log in to Expeto xControl

To log in to Expeto xControl:

1. Using a web browser, go to the URL where your xControl is hosted or access the SaaS hosted instance at admin.expeto.io
2. Log in with your Account credentials.

> **Note**
>
> The username for login is a valid email address. The use of usernames that are not email addresses has been deprecated.

2.2.2 Change Password

Account password syntax requirements are as follows:

- Must be at least 8 characters long
- Must contain a number
- Must contain an uppercase letter
- Must contain a special character

Passwords are never exposed as plain text in the Expeto xControl GUI.

To change your password:

1. Login with your existing password.
2. Click your Account name in the upper right corner of the application.
3. Select **User Account**. The Account page appears.
4. To change your login password, click **Edit**, type the new password and click **Submit**.

If you have forgotten your password, click the link on the log in prompt, provide your email address, and click **Request Password Reset**.

To change the password of any Account:

1. Navigate to Accounts.
2. Select an Account and click **Edit**. The Account parameters are displayed. Note that the Password field is empty because the existing password is never displayed.
3. Type a new Password using the syntax requirements. The password characters are hidden.
4. Click **Submit**.

2.2.3 Assign Roles to an Account



Each Account must be assigned a role. The role determines the permissions given to the Account for accessing and interacting with Expeto xControl features.

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To assign a role:

1. Navigate to Accounts.
2. Click **New** or select an existing Account and click **Edit**. The Account properties appear.
3. Click **Role** and select from the available roles.

The following roles are available:

ADMIN

The highest level of access for network administration. The ADMIN role grants access to networks belonging to all Customers and child Customers.

CUSTOMER_ADMIN

The standard access for network administration. Network access is restricted to a single Customer (and any child Customers) associated with the Account.

READ_ONLY

Restricted access to the network. Provides read-only access for monitoring the network. Access is restricted to the Customer (and child Customers) associated with the Account. No create or delete permissions are granted. No changes to the network can be made.

Users assigned with either the ADMIN and CUSTOMER_ADMIN role can create a new account and assign a role, or change the role of an existing account.

You cannot assign a role with more permissions than your current role. For example, a user with a CUSTOMER_ADMIN role cannot create an account with the more powerful ADMIN role.

Each role exist to provide different levels of access to network and management features. For complete list of roles and their permissions, see Roles and Permissions.

2.2.4 Navigation

Use following navigation menu items to access xControl features:

Home

The default landing page for Expeto xControl is an interactive dashboard.

Select filters from dropdown menus to refresh graphs accordingly. Click Sites, Systems, and Mobile Asset sections to drill into more details.

Sites

A Site is the physical server where a single instance of the Expeto xCore is installed.

Systems

Systems are defined by a network IP address range expressed in CIDR notation. Create a single System for each Site, or segment your network into multiple Systems, assigning each System a unique network IP block or subnet. A System can be shared between Sites in different physical locations, allowing seamless access to the System's Mobile Assets.

Multiple Systems can be used for creating secure separation of devices using network segmentation. Extensions set at a System level are applied to all Mobile Assets belonging to the System unless explicitly overridden.

Private Radios

Private Radios (eNodeB/gNodeB) facilitate the communication from/to 4G/5G devices to private network core.

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Mobile Assets

A Mobile Asset is a 4G/LTE or 5G device identified on the network by its SIM card. Each Mobile Asset has a unique IMSI value that serves as the primary identifier. Add Mobile Assets to Systems individually, or collectively by using the bulk import feature.

A Mobile Asset's *state* can be set to Active or Inactive which allows or disallows access to the network. A Mobile Asset's *status* such as 'Provisioned' or 'Connected' reflects stages in the Mobile Asset provisioning lifecycle.

Values for any Extensions (custom parameters) explicitly set at the Mobile Asset level override parameters set in the Customer, or System Profile level.

System Profiles

A System Profile is associated with a System and contains an APN name, bandwidth configuration, plus any Extensions.

A System Profile is available only for Mobile Assets belonging to the associated System. The same System Profile can be applied to multiple Mobile Assets. Extensions set in the Profile override the same parameter values set at the Customer or System level.

For example, *Gold*, *Silver*, and *Bronze* System Profiles can be configured to permit different levels of bandwidth.

A Mobile Asset must be assigned a System Profile.

Customers

A Customer can own Sites and have multiple Expeto Accounts. A Customer hierarchy can be created. For example, a parent Customer can manage any of its child Customers' networks. Each child Customer manages their own network, but cannot manage their parent Customer's network.

Extensions set at the Customer level create default settings that apply across all Sites, Systems, System Profiles, and Mobile Assets belonging to the Customer. These default settings can be explicitly overridden.

Accounts

An Account includes a username (email address) and password combination plus an assigned role. A user account must belong to an existing Customer. Expeto xControl is multi-tenant, supporting simultaneous access to multiple accounts.

The pre-defined role associated with the account determines access to Expeto xControl features and permissions.

Reports

Generation of on-demand reports is a task available to Admin and Customer Admin roles. Input parameters involve setting a time frame for the report and specifying the Customer, and optional child Customers to examine. Multiple report types are available providing different levels of data granularity such as Summary of Usage by IMSI and Summary of Usage by Site.

The generated report is in text/CSV format and can be downloaded. To generate and download files, see Generate Usage Reports.

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2.3 User Guide

2.3.1 Dashboard

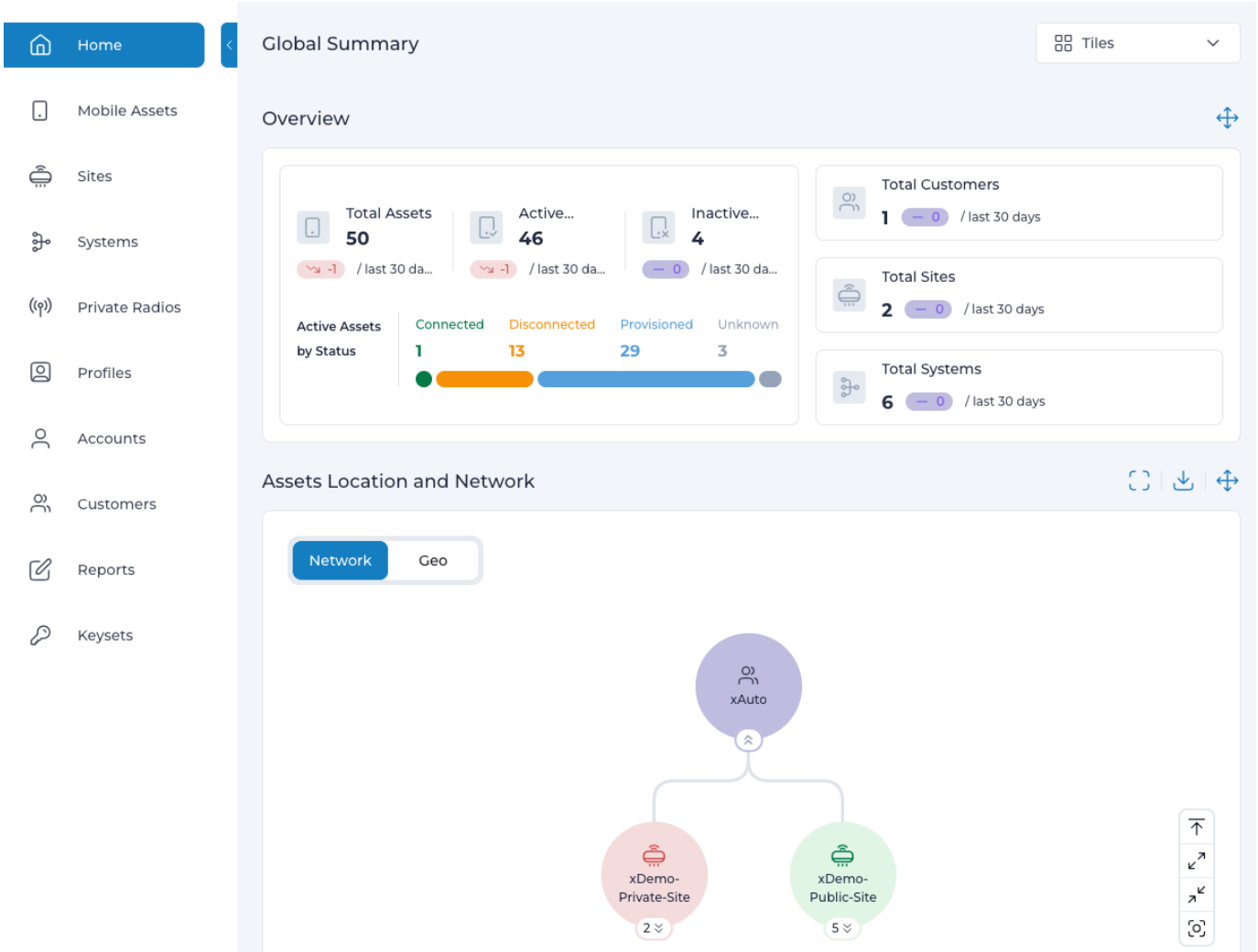
Overview

The dashboard provides administrators with real-time visual monitoring of key network components, including Mobile Assets, Sites, and Systems. It offers both static and interactive panels for quick insights into the network's status and trends. Context-specific panels are available on related pages, such as Customers, Sites, Systems, and Mobile Assets, enabling more targeted analysis.

Key features include:

- **Overview Metrics**: Displays counts and 30-day trends for Mobile Assets, Sites, and Systems, helping administrators identify issues and monitor performance changes.
- **Network Topology**: An interactive map of Customers, Sites, and Systems, showing their relationships for easier navigation and analysis.
- **Geographical Map**: Provides a location-based view of Mobile Assets, Sites, and Private Radios, with filtering options for access type and status.
- **Data Usage History**: Graphs displaying network data usage over time, configurable by date range and grouping criteria for deeper insights.

The dashboard integrates seamlessly with xControl and supports advanced monitoring through third-party tools like Datadog.

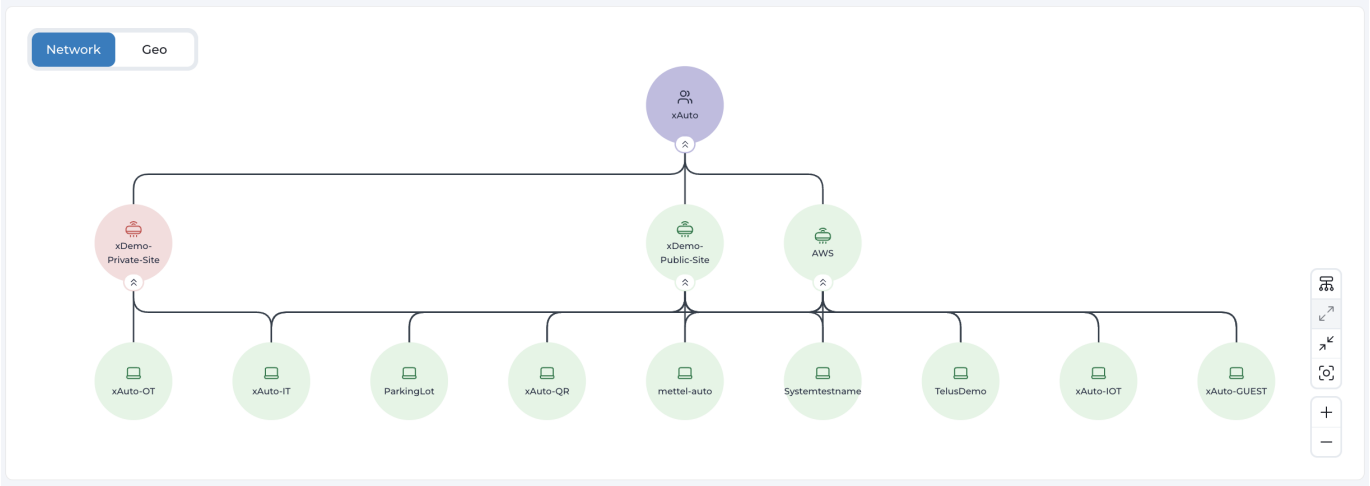


Click a panel to navigate to the corresponding component page to see more information.

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Network Topology

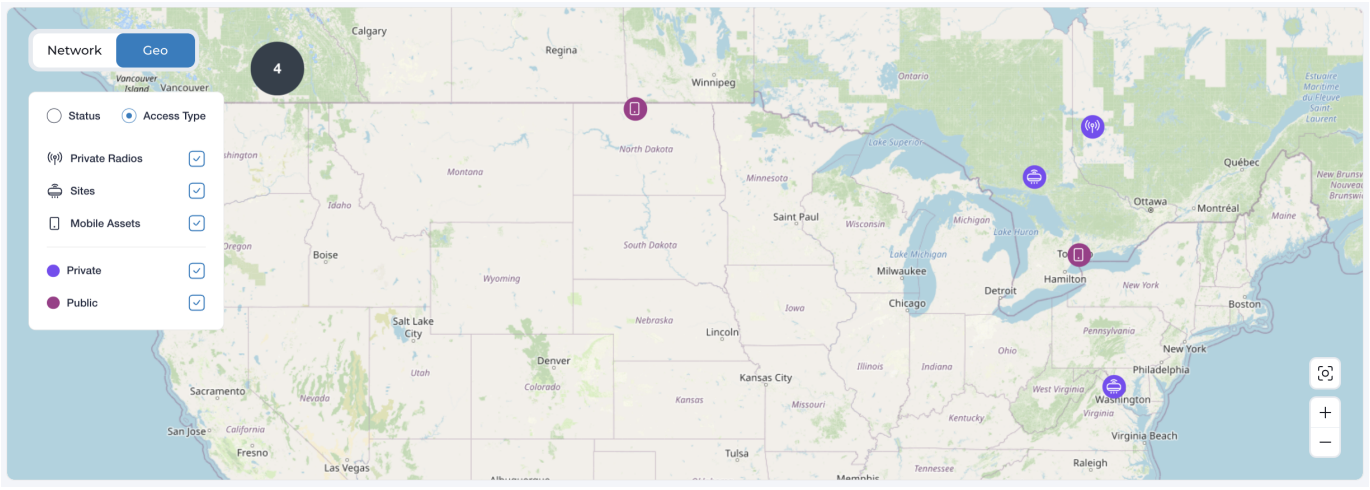
Interactive network topology view of Customers, Sites and Systems and their relations.



Hover your mouse over the nodes bars to view details and navigate to the entity.

Geographical Map

Geographical map displays locations of Mobile Assets, Sites and Private Radios.



Hover your mouse over the map items to view details.

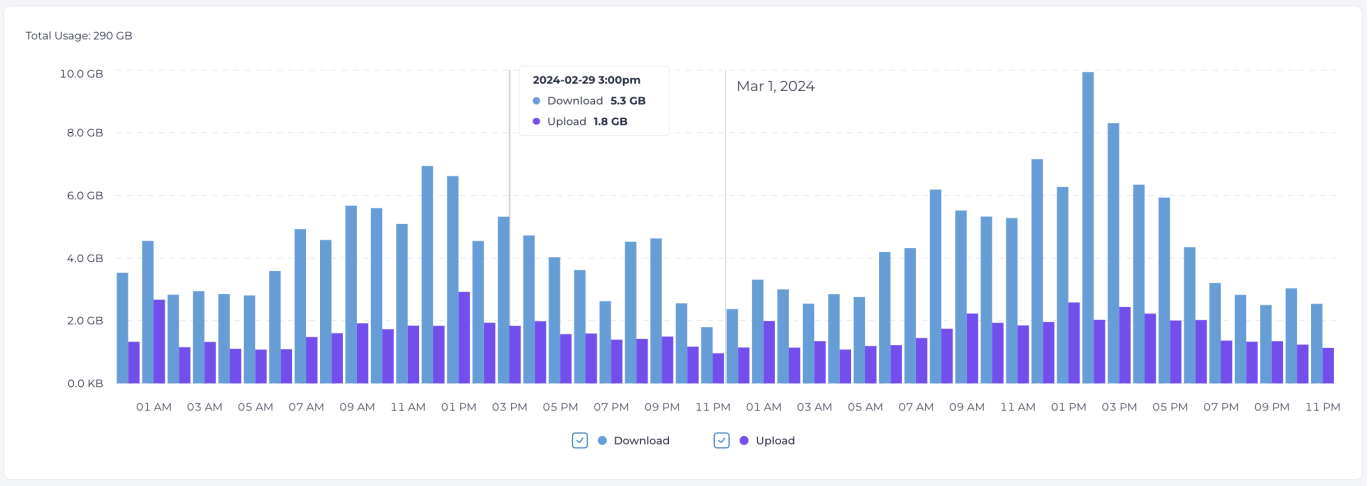
Select **Status** or **Access Type** to view Mobile Assets, Sites and Private Radios by their Access Type (Private or Public). Then select filter by specific Access Type or Status.

Click on the Fit button anytime to recenter the map to fit all the items in the view.

Data Usage

Data Usage panel panels contain graphs displaying network data usage history based on configurable criteria.

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Hover your mouse over the graph\'s vertical bars to view finer statistical details.

!!! note Data usage graphs are also available in Mobile Assets, Sites, Systems, Customers pages and in their details pages.

GROUPING

Customize the graph by selecting the **Group By**: *Total*, *AccessType*, or *Direction*. This increases granularity by providing a comparative view of how much bandwidth, for example, each Mobile Asset or System has used.

Grouping by *Direction* displays the usage data broken into download and upload metrics.

SETTING DATE RANGE

Select one of the **Period** options from the dropdown menu, or click the existing range to access the calendar, then manually choose a start and end date.

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2.3.2 Mobile Assets

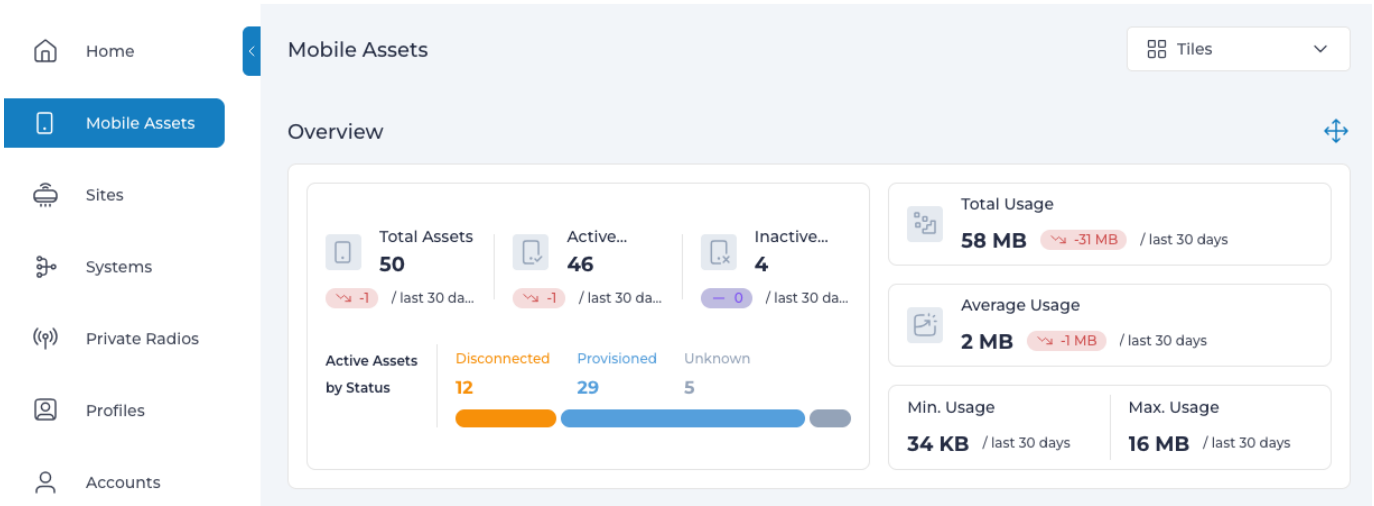
Manage Mobile Assets

Mobile Assets

Mobile Assets are 4G/LTE or 5G devices identified on the network by their SIM card and uniquely defined by their **IMSI** (International Mobile Subscriber Identity). These assets, which include smartphones, IoT devices, industrial equipment, and autonomous systems, enable data transfer, telemetry, and operational tasks within private and public mobile networks. Additional identifiers, such as the Mobile Station Integrated Services Digital Network (MSISDN) number, further distinguish Mobile Assets and facilitate their integration into network operations.

In Expeto xControl, Mobile Assets are managed to ensure proper authentication, security, and network functionality. They are configured to belong to specific **Customers**, assigned to **Systems**, and associated with **System Profiles** that define bandwidth, access permissions, and other operational parameters. Administrators can add Mobile Assets individually or in bulk using the **Bulk Import** feature, ensuring streamlined onboarding and efficient network management. Proper configuration of Mobile Assets is essential for maintaining network integrity and optimizing resource allocation.

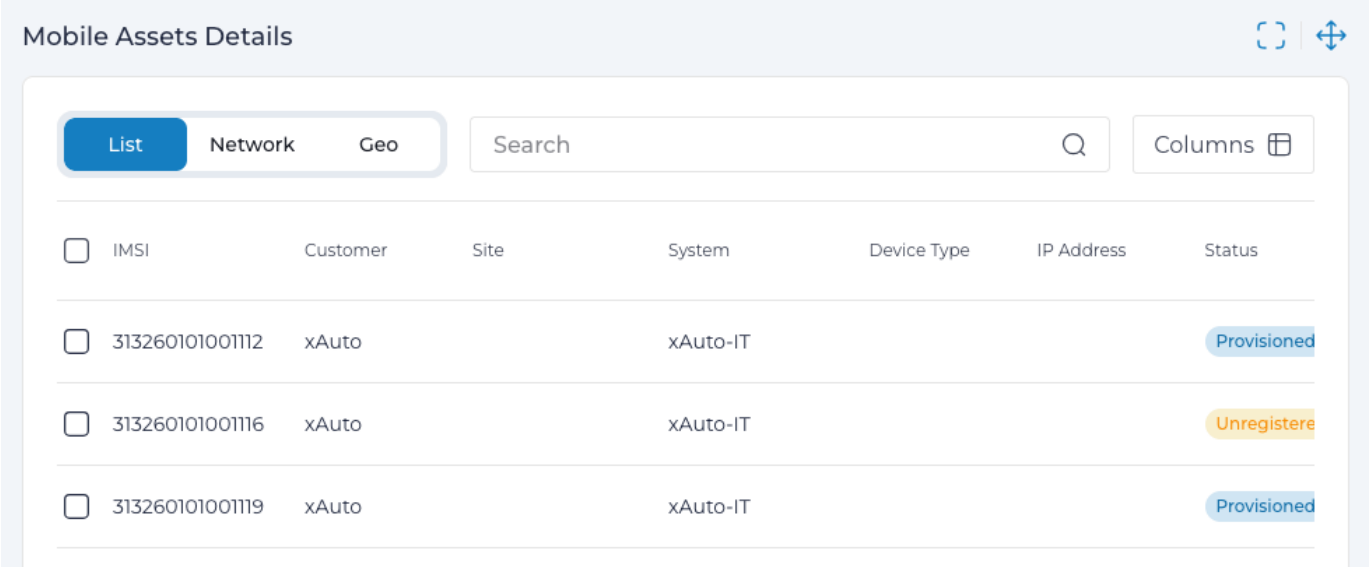
To manage Mobile Assets, navigate to the **Mobile Assets** section in the left navigation panel. This section allows you to view and organize Mobile Assets, manage their status, terminate sessions, and configure advanced properties such as extensions.



MOBILE ASSET LIST

The **Mobile Asset List** displays key details for each Mobile Asset in a tabular format. By default, the following columns are included:

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Column	Description
IMSI	A unique numeric identifier for the Mobile Asset. Click the IMSI link or expand the entry to view detailed information.
Customer	The customer associated with the Mobile Asset. A single Customer may own multiple Sites, Systems, and Mobile Assets.i
Site	The physical location where the Expeto xCore is installed and where the Mobile Asset is attached.
System	The System to which the Mobile Asset is assigned, including one or more network gateways owned by the Customer.
Device Type	The type of device used to access the System.
Status	The current operational status of the Mobile Asset, derived from Gateway and database session states.
IMEI	A unique serial number assigned to the device by the manufacturer.
IP Address	The IP address currently assigned to the Mobile Asset.

Customize Columns

You can adjust the displayed columns to suit your needs:

1. Click the **Column Chooser** icon. 

2. Check or uncheck columns to add or remove them from the list view.

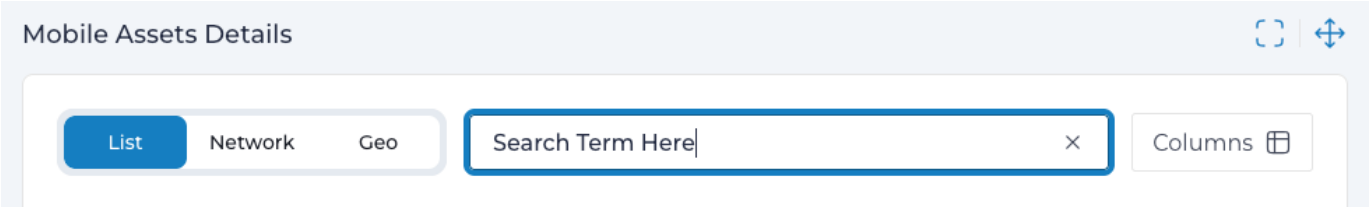
The flexibility of the column chooser allows you to focus on the most relevant details for managing Mobile Assets effectively.

SEARCHING

The **Deep Search** feature allows you to locate Mobile Assets based on any associated property, not just those visible in the list.

This powerful search capability supports case-insensitive queries and partial text matches, making it easy to find specific Mobile Assets.

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Note

- Wildcards are not supported in the search field.
- For more help on search, see Search Tips

Using Boolean Operators

You can refine your searches further by using boolean operators to narrow results. This is particularly useful for searching by labels, properties, or statuses.

Example Searches

- **Search by Network Type**: Type `4G` to find all Mobile Assets with 4G network sessions.
- **Search by Status**: Type `err` to list all entries with an Error status.
- **Search by Username**: Enter a username associated with a Mobile Asset.
- **Search by Label**: Use labels such as `sim-type` or `sim-type=UICC` to filter specific Mobile Assets based on extensions or tags.

Info

- For more help on search, see Search Tips

ADD A MOBILE ASSET

Note

- To add a Mobile Asset, the **Add Mobile Asset** permission is required. The **CUSTOMER_ADMIN** role does not include this permission.
- Additionally, your configuration must have a - **Customer**, **Site**, **System**, and **System Profile** already created.

Steps:

1. Navigate to **Mobile Assets**.
2. Click **New** and fill in the required parameters.
3. Click **Submit** to save the new Mobile Asset.

Identification and SIM Authentication Properties

When adding a Mobile Asset, several properties must be configured to ensure proper authentication, network access, and alignment with system requirements. These properties are categorized into two main groups: **Identification and SIM Authentication** and **Network Access and Inherited Properties**.

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Identification and SIM Authentication Properties

Property	Description
IMSI (Required)	The International Mobile Subscriber Identity, a unique numeric identifier for the Mobile Asset. Includes: Mobile Country Code (MCC), Mobile Network Code (MNC), and Mobile Asset Identification Number (MSIN).
MSISDN (Required)	The phone number associated with the Mobile Asset, used for communication and identification within the network.
ICCID (Optional)	The Integrated Circuit Card Identification Number, an 18–22 digit code printed on the SIM card. Includes information about the country, home network, and unique SIM identifier.
K (Required)	The SIM's 32-character hexadecimal secret key. With a Keyset, enter it encrypted under the batch's transport key, exactly as the SIM vendor delivered it.
OPC (Required)	The 32-character hexadecimal OPc, derived from `K` and the operator variant (OP) when the SIM is personalised. With a Keyset whose K4 Field Type is **K And OPC**, enter it encrypted, as delivered.
Keyset	Select from existing Keysets for SIM authentication security. Only Keysets mapped to an HSS Keyset ID and associated with the current Site are available. A Keyset can be assigned to a Mobile Asset only once. For more details, see Add a Keyset.

Network Access and Inherited Properties

Property	Description
Status	Specifies the current state of the Mobile Asset:
	- **Active**: Allows the Mobile Asset to access the network.
	- **Inactive**: Temporarily restricts network access without deleting the Mobile Asset.
Extensions	Custom parameters applied to the Mobile Asset. Extensions at the Mobile Asset level override parameters set at the Customer, System, or System Profile levels. For more information, see Customize with Extensions.
Customer	The Enterprise owner of the Mobile Asset, linking it to the Customer's network and settings.
System	The Mobile Asset can be assigned to one System, which defines the network IP address range and related configurations.
Profile	Profiles govern bandwidth limitations, extensions, and access settings. Each Mobile Asset must have one System Profile assigned, which can apply standardized settings or tiered service levels (e.g., *Gold*, *Silver*, *Bronze*). Extensions set at the System Profile level override those set at the System or Customer level.

ADD MULTIPLE MOBILE ASSETS FROM A FILE

1. Navigate to **Mobile Assets**.
2. Click the **Import** button and select **Bulk Import**.
3. Follow the prompts to upload and import an `.out` file.

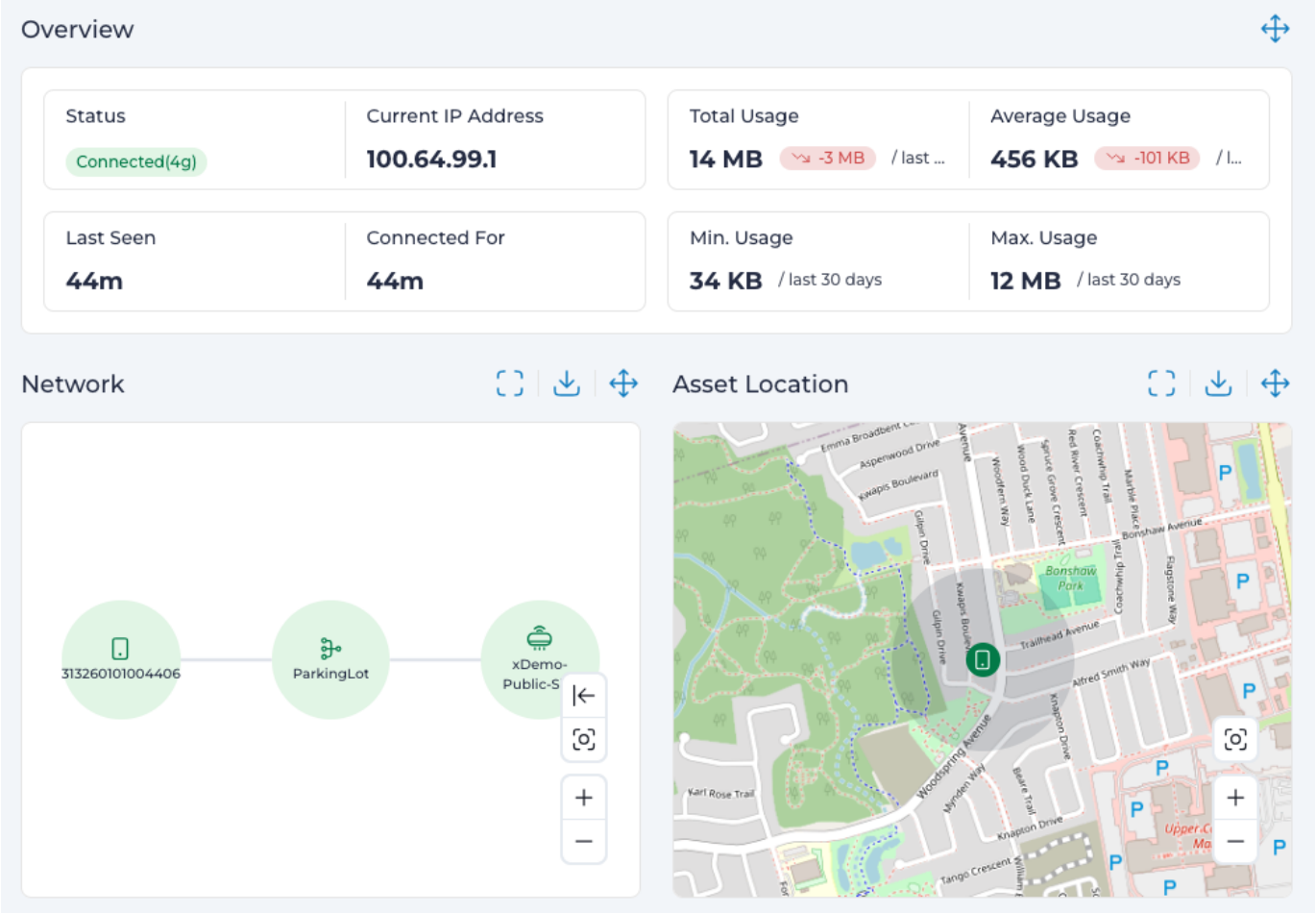
For detailed information on the required file format and the Bulk Import process, see Perform Bulk Actions.

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VIEW / EDIT A MOBILE ASSET

Clicking on the IMSI number in the main Mobile Asset list opens the Mobile Asset Details page. This page provides detailed information about the selected Mobile Asset, including its current status, associated customer and system, IP address, and additional configuration details. Use this view to manage and analyze the Mobile Asset's settings and activity.

The Mobile Asset status is updated in real time and derived from the Mobile Asset's activity recorded in the database and network.



Section Name	Description
Status	Indicates the current connection status of the Mobile Asset.
IP Address	The current IP Address of the Mobile Asset.
Time Connected/Time Since Connected	The amount of time since the PGW session started, or the time elapsed since the previous PGW session stopped.
Last Seen	The time the last verification was made to a connected SIM, or the disconnect time of the last active session.
Total Usage	The amount of data used in during the last 30 days. Includes both upload and download.
Average Usage	The average data used in during the last 30 days. Includes both upload and download.
Minimum Usage	The minimum amount of data bandwidth in a day in the last 30 days. Includes both upload and download.

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Section Name	Description
Maximum Usage	The maximum amount of data bandwidth in a day in the last 30 days. Includes both upload and download.

The following tables show normal and warning status values:

Normal Status Values

Status	Technical Notes	Reason
Provisioned	The mobile asset is registered in the database, but has never has an active session on the network.	This is the initial status for a Mobile Asset.
Registered(HSS)	The mobile asset has authenticated but does not have a current data session (over data/user plane) on the network.	The device may been powered off, moved out of range, or the SIM card removed. The Disconnected status has expired. Alternatively, the mobile asset is an SMS/IoT device where data plane session is not applicable/available, and the data is transferred over control plane.
Connected(4g)	The registered mobile asset has an active data session on the network.	The normal state of an active Subscriber Session. The IP address and network type (3G, 4G or 5G) are displayed.
Disconnected	The mobile asset's active session on the network was closed	The active session on the network ended recently. This status occurs when the device is put on airplane mode, or the SIM card is physically removed.

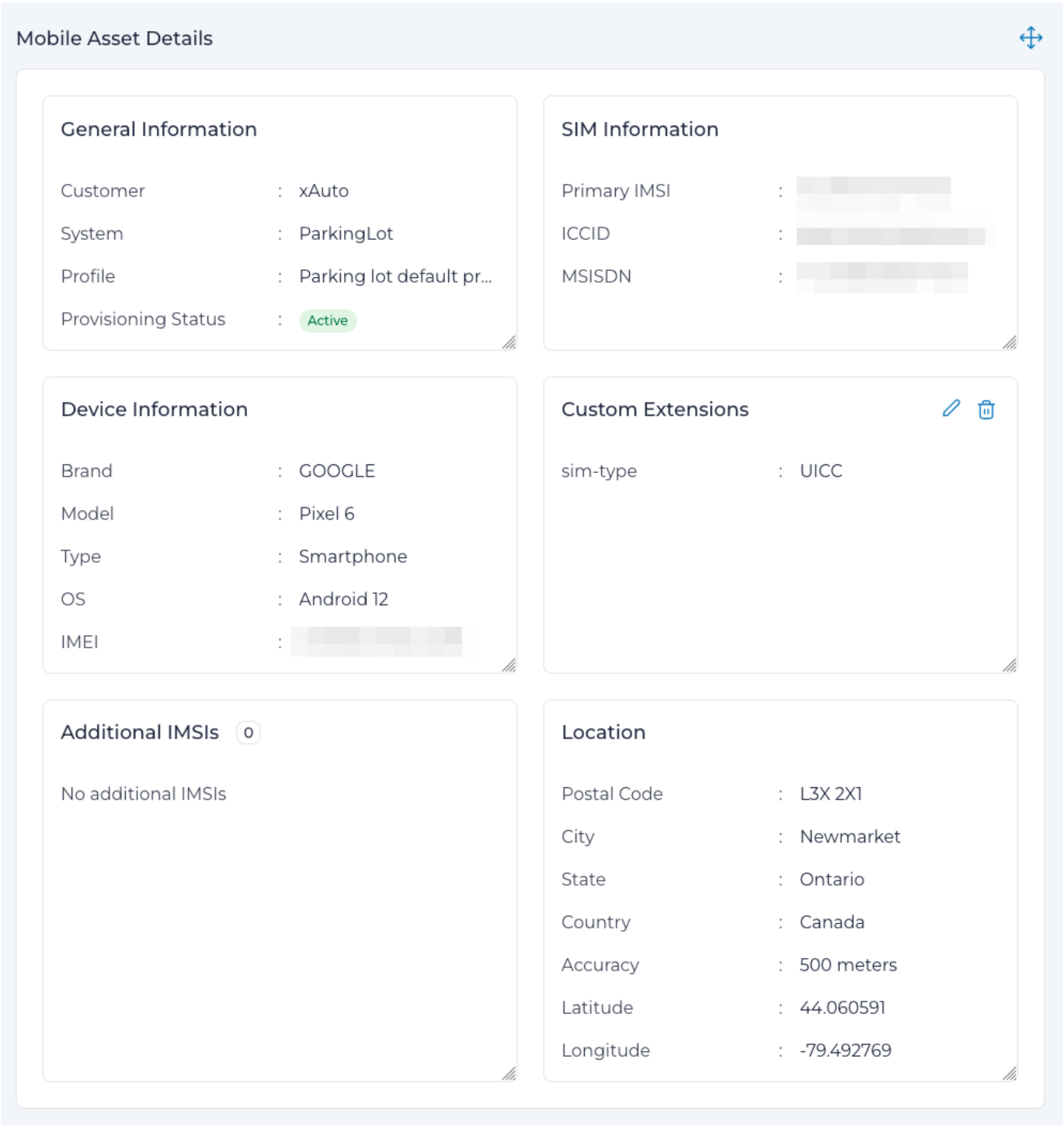
Warning Status Values

The following values indicate a problem with normal Mobile Asset operation. Additional troubleshooting may be required.

Status	Technical Notes	Reason
Connected(PGW)	Warning. The mobile asset is actively connected to the network; however, there is not associated database record.	The mobile asset database server may be down.
Unregistered	The mobile asset had a previously active session, but is now detach from both the mobile asset database and the network.	The device has been powered off or moved out of range.
Error(PGW)	Error state for the network connection.	Causes can include network connection problems to the Gateway, or Gateway failure.
Error(HSS)	Error state for the network connection.	Causes can include network connection problems to the database, or database failure.
Unknown	The status was unable to be determined.	Cause unknown.

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MOBILE ASSET DETAILS



The **Mobile Asset Details** section provides a comprehensive overview of the Mobile Asset, organized into the following sections:

General Information

Displays essential information about the Mobile Asset's network assignment and status:

- **Customer**: The entity to which the Mobile Asset is assigned (e.g., "xAuto").
- **System**: The network system associated with the Mobile Asset (e.g., "ParkingLot").
- **System Profile**: The system profile applied to the Mobile Asset, defining its bandwidth and network settings.
- **Provisioning Status**: Indicates whether the Mobile Asset is active or inactive in the network.

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SIM Information

Shows identifiers for the Mobile Asset's SIM card:

- **Primary IMSI**: The main IMSI associated with the SIM card.
- **ICCID**: The unique SIM card identifier.
- **MSISDN**: The phone number associated with the SIM card.

Device Information

Provides details about the Mobile Asset's hardware and software:

- **Brand**: The manufacturer of the device (e.g., "Google").
- **Model**: The device model (e.g., "Pixel 6").
- **Type**: The type of device (e.g., "Smartphone").
- **OS**: The operating system version (e.g., "Android 12").
- **IMEI**: The unique identifier for the device.

Custom Extensions

Lists any custom parameters or extensions applied to the Mobile Asset:

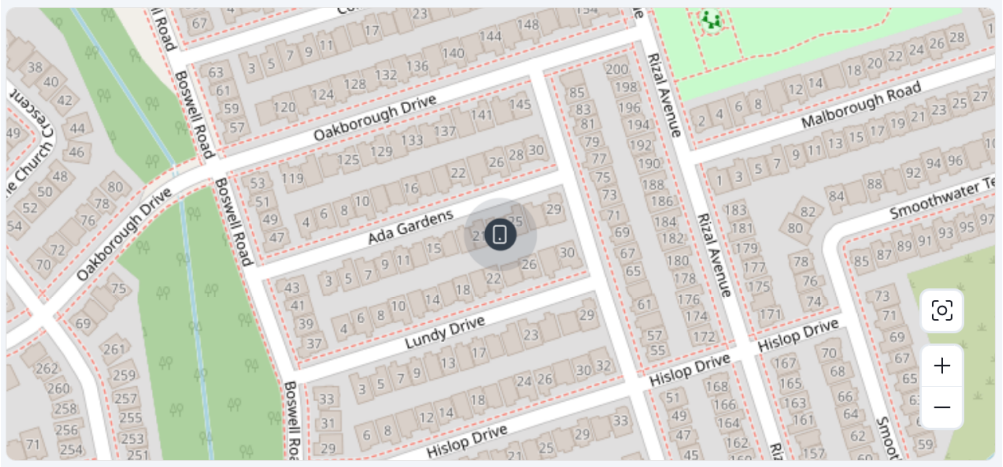
> **Example**
>
> **sim-type** set to **UICC**.

Additional IMSIs

Displays alias IMSIs associated with the primary IMSI, if any. If no alias IMSIs are configured, this panel will indicate that there are no additional IMSIs.

Location Map

The **Location Map** provides an approximate location of a Mobile Asset when it is connected to a public or public/private network. This feature is useful for tracking device activity and ensuring network coverage across various areas.



How Location is Determined

Location data is derived from cell tower triangulation, which estimates the Mobile Asset's position based on signals from nearby towers. Accuracy may vary depending on tower placement:

- **Accuracy Range**: Typically between 500 meters and 1500 meters.

Viewing Location Details

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Hover over the location marker on the map to view additional data about the Mobile Asset's position:

- **Coordinates**: Latitude and longitude of the Mobile Asset.
- **Accuracy Value**: Indicates the confidence in the location estimate.

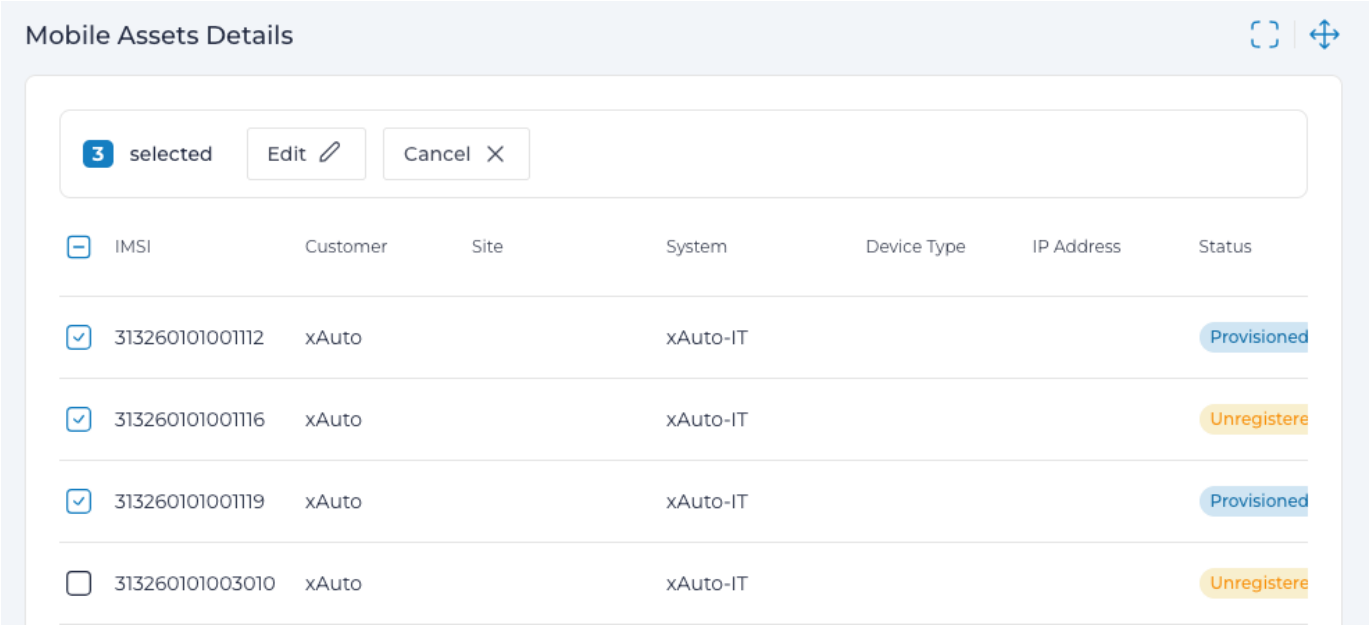
> **Note**
>
> A lower accuracy value represents higher precision and a smaller margin of error.

> **Note**
>
> The location map is available only for Mobile Assets connected via public or public/private networks. It does not apply to private-only networks.

MOBILE ASSET ACTIONS

Activate or Deactivate Mobile Assets

Activating or deactivating a Mobile Asset controls its ability to connect and initiate a network session:



- **Active**: The Mobile Asset can initiate and maintain active sessions.
- **Inactive**: The Mobile Asset is temporarily disabled and cannot have an active session.

This functionality is useful for temporarily restricting access without permanently deleting the Mobile Asset.

Activate or Deactivate a **Single** Mobile Asset

1. Navigate to the **Mobile Assets** section.
2. Locate the desired Mobile Asset in the list and click its **IMSI** link.
3. In the details view, click **Edit**.
4. For the **Status** field, select either **Active** or **Inactive**.
5. Click **Submit** to save your changes.

Bulk Activate/Deactivate **Multiple** Mobile Assets

1. Navigate to the **Mobile Assets** section.

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2. Select the checkboxes next to the Mobile Assets you wish to modify.
3. Click the **Edit** button.
4. Leave all fields blank except for the **Status** field.
5. Choose **Active** or **Inactive** from the **Status** dropdown.
6. Click **Submit** to apply the changes.

This bulk operation streamlines the management of multiple Mobile Assets, ensuring efficient status updates across the network.

Cancel Session

To cancel (terminate) a Mobile Asset session:

1. Navigate to the Mobile Assets.
2. Find the Mobile Asset in the list and click the IMSI link.
3. Click the more button (...) and then click **Cancel Session**.

> **Note**
>
> This action triggers a series of network events to terminate the Mobile Asset's session:
>
> - **For 4G/LTE networks**: The Home Subscriber Server (HSS) sends a **Cancel-Location-Request (CLR)** to the Mobility Management Entity (MME). This instructs the network to withdraw the user subscription associated with the IMSI, effectively deregistering the Mobile Asset.
> - **For 5G Standalone (SA) deployments**: The Unified Data Management (UDM) service notifies registered Network Functions, such as the Access and Mobility Management Function (AMF), of the session deregistration. This action signals the network to terminate the active session.
> - **Session Termination**: Once deregistration is complete, the Mobile Asset's session is fully terminated and removed from the network.
> - **Session Restoration**: After termination, the Mobile Asset may initiate a new session request, depending on the device configuration and network policies. This allows the session to be restored if necessary.

ADDITIONAL IMSIS

Expeto xControl supports **Multi-IMSI SIM cards**, which allow a single SIM card to host multiple IMSIs (International Mobile Subscriber Identities). These SIM cards provide flexibility for devices that need to operate in multiple network environments or require fallback identities for redundancy.

Understanding Primary and Alias IMSIs

- The **Primary IMSI** is the main identifier for the SIM card and is used as the default identity for network operations.
- **Alias IMSIs** are secondary identities that can be added to the SIM card. These are typically used for specific use cases, such as enabling multi-network access, testing, or separating specific traffic.

Adding an Alias IMSI

Alias IMSIs can be added to the primary IMSI to extend the functionality of the Mobile Asset. To add an alias IMSI:

1. Navigate to the **IMSI** section in the Mobile Asset details.
2. Click the **Add** ⊕ button.
3. Enter the alias IMSI value in the provided field.
4. Click **Save** to confirm.

Once added:

- All IMSIs, including the primary IMSI and alias IMSIs, appear in the **IMSI** section of the Mobile Asset details.
- Only the **Primary IMSI** is displayed in the main **Mobile Assets** list for clarity.

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> **Note**
>
> The primary IMSI remains the default identity for all operations, including network authentication and configuration.

Limitations and Considerations

- **Static IP Address**: Any static IP address assigned to the Mobile Asset applies exclusively to the primary IMSI. Alias IMSIs cannot have separate static IPs.
- **MSISDN**: The phone number (MSISDN) is also tied only to the primary IMSI and cannot be assigned to alias IMSIs.

Use Cases for Multi-IMSI Support

- **Network Redundancy**: Allows devices to switch seamlessly between networks if the primary IMSI is unavailable or lacks coverage.
- **Regional Customization**: Alias IMSIs can be used for devices that operate in different countries, enabling compliance with local network requirements.
- **Testing and Validation**: Alias IMSIs can be assigned for testing new network setups without disrupting the primary IMSI's configuration.

Multi-IMSI functionality provides robust flexibility for managing Mobile Assets in diverse and complex network environments. By leveraging alias IMSIs, administrators can ensure seamless connectivity and adaptability across multiple scenarios.

SET EXTENSIONS FOR MOBILE ASSETS

Click **Edit** in the Mobile Asset Details page.

Extensions are key value pairs.

There are specific extensions used to provide functionality not yet available through the xControl GUI. For example, setting a static IP address for a Mobile Asset.

> **Example**
>
> `ip=100.64.12.123`

Other extensions are used to tag Mobile Assets with labels that help find the Mobile Asset during search queries.

> **Example**
>
> `deviceType=samsung` `user=Joe`

For more information on creating Extensions, see Extensions.

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Bulk Actions

OVERVIEW

The Bulk Actions feature in Expeto xControl streamlines the management of multiple Mobile Assets by enabling the following operations:

- **Bulk Import**: Add Mobile Assets in large quantities using a `.out` file. This method ensures efficient data entry and allows configuration of parameters such as Customer, System, System Profile, Keyset, and initial status.
- **Bulk Update**: Modify or configure multiple Mobile Assets simultaneously. Updates can include changing status, assigning a System Profile, adding Extensions, or moving assets to a new System. This can be done directly or via a CSV file export/import process.
- **Bulk Delete**: Permanently remove multiple Mobile Assets from the list, freeing up resources and decluttering your network configuration.

These tools reduce manual effort, ensure data consistency, and enable administrators to efficiently manage large-scale Mobile Asset deployments.

BULK IMPORT

The bulk import feature streamlines the process of adding multiple Mobile Assets to the system by uploading an `.out` file. This file contains the required details, such as IMSI values, along with optional configuration parameters. Once imported, the Mobile Assets are listed under the chosen System in the Mobile Asset list.

Key Features:

- Supports importing Mobile Asset details in bulk using a `.out` file.
- Allows configuration of parameters such as Customer, System, System Profile, Keyset, and initial status.
- Includes validation checks to ensure file accuracy and proper mapping of columns.
- Provides flexibility to add Extensions for custom parameters.

How to Perform a Bulk Import

1. Navigate to the **Mobile Assets** page.
2. Click the **Import** button: , then select **Bulk Import**.
3. On the **Select file** step, choose the `.out` file to import.
    - If the file format is incorrect or validation errors occur, you will be notified.
    - If the file format is valid, the columns found in the file are listed.
4. Click **Continue** and assign the Expeto parameters to the Mobile Assets on the **Technical Information** step:
    - **Customer**: Select the associated Customer.
    - **System**: Choose the target System. Only Systems with a Mobile Asset store are listed.
    - **System Profile**: Assign a System Profile for the Mobile Assets.
    - **Roaming Profile**: Optionally, assign a Roaming Profile.
    - **Keyset**: Select the Keyset of the SIM batch, mapped to the Site's HSS Keyset Identifier. The K and OPc values in the file are imported exactly as the SIM vendor encrypted them; the Site's subscriber store decrypts them with the batch's transport key.
    - **Status**: **Active** enables network access immediately; **Inactive** prevents it until the Mobile Assets are activated.
    - **Overwrite if existing**: Replace any existing Mobile Asset with the same IMSI. If this option is cleared and duplicates are found, the import fails.
5. Click **Continue** and add any **Extensions** to set custom parameters for all imported Mobile Assets. For example, to record the import date, use the key `importDate` and the value `January20`.
6. Click **Submit** to complete the import process. The imported Mobile Assets will appear in the list.

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Notes and Tips

> **Note**
>
> Only the `.out` file format is supported for bulk imports.

> **Tip**
>
> Consider creating a "parking lot" System to temporarily store Mobile Assets during bulk imports.

File Content and Validation

Before importing, the `.out` file undergoes a validation process to ensure proper formatting and headers. Common validation errors include:

- Missing or invalid headers.
- Missing mappings for required fields.
- Incorrect IMSI formats.
- Mismatched column counts.

Required Fields:

- **ICCID**: The Integrated Circuit Card Identifier, engraved on the SIM card.
- **KI**: The SIM's secret key (K), encrypted by the SIM vendor under the batch's transport key.
- **IMSI**: The International Mobile Subscriber Identity, uniquely identifying each Mobile Asset.

> **Note**
>
> Auxiliary IMSI values are ignored during the import process.

Example `.out` File:

Below is an example of a properly formatted `.out` file:

```
****************************************
*      HEADER DESCRIPTION         *
****************************************
Customer: AcmeCorp
Quantity: 6
Type:     PLUG-IN
Profile:  1.0
Batch:
*
Transport_key:
*
Graph_ref : 2.0

Address1: AcmeCorp
Address2: TBC Address3
Address4: TBC Address5
Artwork:  <artwork file>

****************************************
*      INPUT VARIABLES            *
****************************************
Var_In_List:

IMSI1:    123799534412226
IMSI2:    456060048546604
SER_NB:  1924120429575334375

****************************************
*      OUTPUT VARIABLE            *
****************************************
var out:ICC_ID/KI/IMSI/IMSI2/OPc/PIN1/PUK1/PIN2/PUK2/ADM
1924120429575334375 '8978B79E7C104F678FA5C336509DB188 123799534412226 456060048546604 6F2E82855DEE7C893CB1F7A72FD08B57 0000 05185749 2847 60978080 76183215
1924120429575334376 '8978B79E7C104F678FA5C336509DB188 123799534412227 456060048546605 6F2E82855DEE7C893CB1F7A72FD08B57 0000 05185749 2847 60978080 76183215
```


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```
1924120429575334377 '8978B79E7C104F678FA5C336509DB188 123799534412228 456060048546606 6F2E82855DEE7C893CB1F7A72FD08B57 0000 05185749 2847 60978080 76183215
1924120429575334378 '8978B79E7C104F678FA5C336509DB188 123799534412229 456060048546607 6F2E82855DEE7C893CB1F7A72FD08B57 0000 05185749 2847 60978080 76183215
1924120429575334379 '8978B79E7C104F678FA5C336509DB188 123799534412230 456060048546608 6F2E82855DEE7C893CB1F7A72FD08B57 0000 05185749 2847 60978080 76183215
1924120429575334380 '8978B79E7C104F678FA5C336509DB188 123799534412231 456060048546609 6F2E82855DEE7C893CB1F7A72FD08B57 0000 05185749 2847 60978080 76183215
```

BULK UPDATE

The Bulk Update feature enables administrators to modify existing values or apply new configurations to multiple Mobile Assets simultaneously. This streamlined process allows for efficient management of Mobile Assets with consistent updates.

Common Bulk Update Tasks

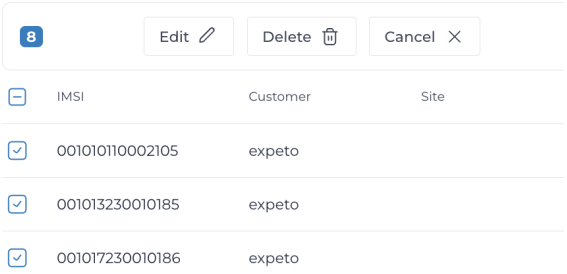
The following tasks can be performed using the Bulk Update feature:

- **Activate or Deactivate Mobile Assets**: Change the status of selected Mobile Assets.
- **Move Mobile Assets to a New System**: Relocate all selected assets to a single target System.
- **Assign a System Profile**: Apply a System Profile to selected Mobile Assets. System Profiles are System-specific; you must select a System before assigning a System Profile.
- **Add Extensions**: Assign the same custom Extensions to all selected Mobile Assets.

> **Note**
>
> To modify the status of Mobile Assets across different Systems without changing their System assignments, use the **Bulk Update - CSV** feature.

Steps to Perform a Bulk Update

1. Navigate to the **Mobile Assets** page.
2. Select the Mobile Assets to update:
   - Use the checkboxes to select individual Mobile Assets or select all using the "Select All" checkbox.



3. Click **Edit**. The Update page displays the number of Mobile Assets selected for modification.
4. Provide updated values for the selected Mobile Asset parameters. Existing values will be replaced by the new inputs.
5. Click **Save** to confirm and apply the updates. You will be prompted to verify the request before changes are applied.

BULK DELETE

The **Bulk Delete** feature allows you to permanently remove multiple Mobile Assets from the Mobile Asset list. This action is irreversible unless specific System-level permissions are available to restore deleted assets.

> **Warning**
>
> Once deleted, Mobile Assets cannot be recovered without System-level permission. Ensure you have the necessary access and have confirmed the selection before proceeding.

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Steps to Perform a Bulk Delete

1. Navigate to the **Mobile Assets** page.
2. Select the Mobile Assets you want to delete:
    - Use the checkboxes to select individual Mobile Assets or select all using the "Select All" checkbox.
3. Click **Delete** to initiate the removal process.
4. A confirmation dialog will appear. Click **OK** to confirm and complete the deletion.

> **Note**
>
> Always double-check your selection to avoid accidental deletion of critical Mobile Assets.

EXPORT TO CSV

The **Export to CSV** feature allows you to download a file containing the current configuration of all Mobile Assets for editing or record-keeping purposes.

Steps to Export a CSV File

1. Navigate to the **Mobile Assets** page.
2. Click the **Export** button .

> **Note**
>
> The exported CSV file contains data for all Mobile Assets in the system. It is not possible to export a file for selected Mobile Assets only.

Updating and Re-Importing the CSV File

To make changes using the exported file:

1. Open the downloaded CSV file in a text editor or spreadsheet application.
2. Modify the desired values and save the file with a `.csv` extension.
3. Navigate to the **Mobile Assets** page and click **Bulk Actions**.
4. Select **Bulk CSV Update**.
5. Click **Choose File** and upload the modified `.csv` file. Click **Next** to proceed.
6. The file is verified for formatting errors. If no issues are found, click **Submit** to apply the updates.

CSV File Format

When preparing a CSV file for bulk updates, ensure the required columns are correctly formatted and all necessary information is included.

Required Columns

Column	Description
IMSI	The IMSI value cannot be updated. This required value identifies the Mobile Asset and must be unique within the CSV file.
ICCID	The ICCID associated with the IMSI. This cannot be updated. Leave the field empty if no change is needed.
MSISDN	The MSISDN associated with the IMSI. This cannot be updated. Leave the field empty if no change is needed.

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Column	Description
STATUS	The status of the Mobile Asset. Valid values are **ACTIVE** or **INACTIVE**.
SYSTEM	The System ID where the Mobile Asset is assigned. Copy the System ID value from the URL of the selected System (e.g., `https://admin.example.com/ngui/sys/**123295600**`). Optionally, add the System name after the ID (e.g., `123295600 default`). The System name must match the ID.
SYSTEMPROFILE	The System Profile ID to assign to the Mobile Asset. Copy the System Profile ID value from the URL of the selected System Profile (e.g., `https://admin.example.com/%7CxControlURLPath%7C/system-profiles/**98144**`).
EXT:	Extensions are key-value pairs used for additional parameters or overrides. Each **EXT:** column represents an extension key, with corresponding values in the rows. Leave the cell empty to remove the extension. Example: For the extension `brand=acme` , use a column header `EXT:brand` and the value `acme` .

Example File Structure

An example of a CSV file structure is shown below:

```
IMSI,            ICCID,                 MSISDN,          STATUS, SYSTEM, PROFILE
001021000000000, 123098123894000000000, 101021000000000, ACTIVE, 709 Demo-6_2, 859 subscriberProfile6_2
001021000000001, 123098123894000000001, 101021000000001, INACTIVE, 708   Demo-6_1, 858

001021000000002, 123098123894000000002, 101021000000002, ACTIVE, , 858
```

To change a parameter value, edit the corresponding cell in the row for the Mobile Asset. Leave the cell blank to set the value to `null` .

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Session Details

This document provides a guide for examining session and SMS event logs for Mobile Assets in Expeto xControl. Event logs allow administrators to monitor and analyze the network activity and communication history of Mobile Assets, offering insights into both subscription (control plane) and data (user plane) sessions, as well as SMS messaging details.

Session event logs include timestamped records of subscription and data session events, categorized by types such as HSS (control plane) and PGW (user plane). Administrators can review session states, network operator interactions, and manual changes like airplane mode activations. SMS event logs track the origin, status, and potential failure causes of text messages sent by or to Mobile Assets, with details about the source types and specific error codes for failed delivery attempts. These tools enable effective troubleshooting and network management.

SESSION EVENT LOG

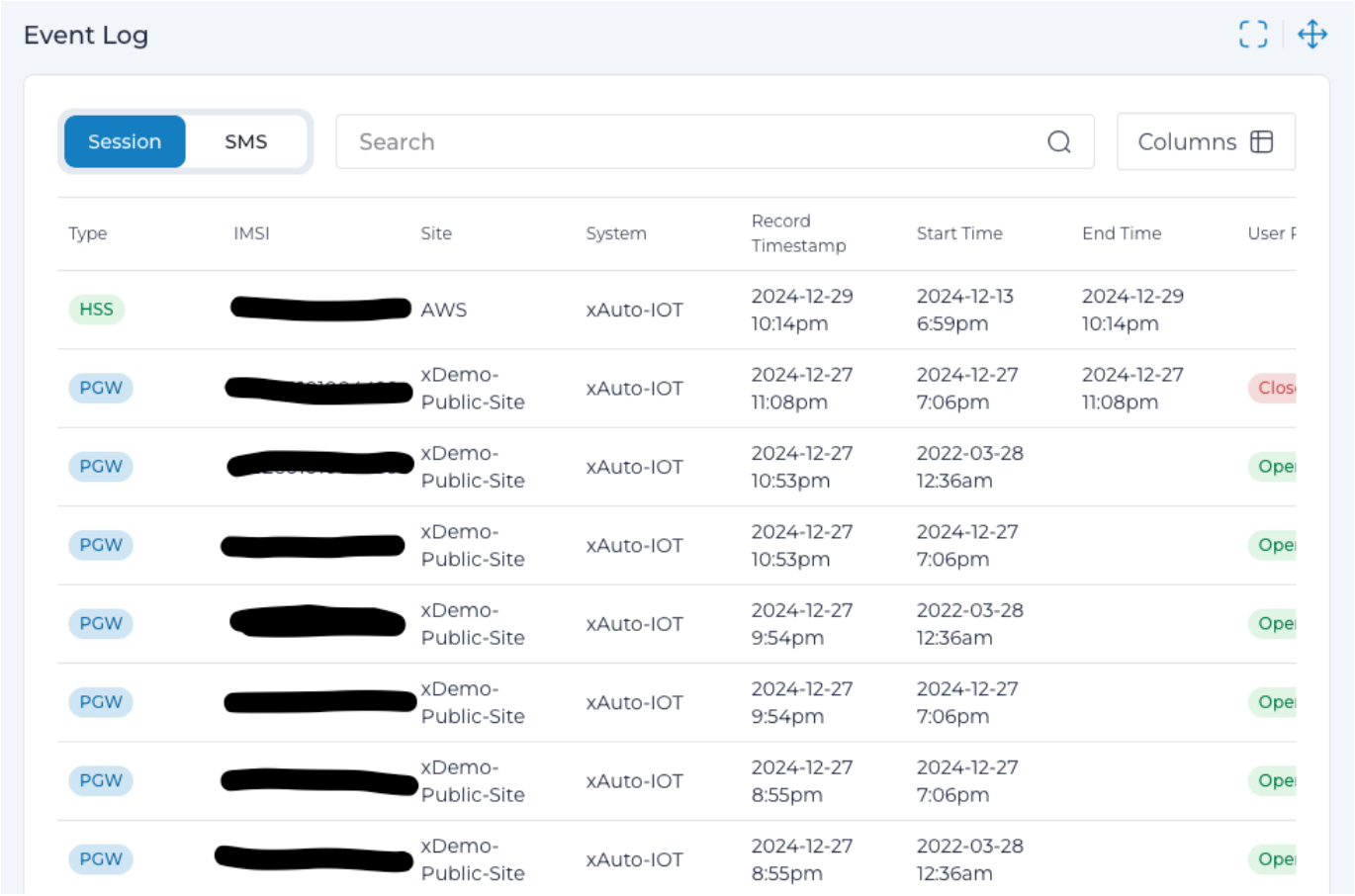
The Event Logs panel on the Mobile Asset page provides details about session activity, including the Mobile Asset's current state, last-seen timestamp, and assigned IP address. For public/private sites, the associated xRouter site (e.g., "AWS") is also displayed.

View Session Event Logs

To access the **Session Event Log** for a Mobile Asset:

1. Navigate to **Mobile Assets**.
2. Click the IMSI of the Mobile Asset. The Mobile Asset details page will open.
3. In the **Event Log** section, click **Session**.

The session history panel displays events in reverse chronological order, including details such as country, network operator, IMSI and IMEI values, system and site names, and more.



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Customize Columns

To modify the displayed columns:

1. Click the **Column Chooser** 

icon.
2. Check or uncheck columns to add or remove them from the view.

> **Note**
>
> Hover over a column name in the list for a brief description of its content.

Key Information in Session Logs

- **Timestamp**: Indicates when the event occurred, session start time, and if applicable, session end time.
- **Entry Type**: Specifies whether the event is related to the HSS (control plane) or PGW (user plane).

Session events typically result from network interactions, such as keep-alive pings between the network operator and the Mobile Asset. Manual changes, like placing a device in airplane mode, are also captured.

ENTRY TYPE - HSS

HSS (Home Subscriber Server) type entries record the subscription (control plane) session events of a Mobile Asset. These events pertain to the authentication and management of Mobile Assets as they connect to the network. Mobile Assets in a public/private site connecting through a public network are routed to the xRouter site, where authentication is performed against HSS records.

Subscription Session States

The subscription session can transition through the following states:

State	Description
Attached	The Mobile Asset successfully establishes a connection to the network.
Deleted	The subscription session is removed, indicating the Mobile Asset is no longer attached.
Provisioned	The Mobile Asset's subscription information is configured and ready for use.

Attach Process Overview

When a Mobile Asset (User Equipment or UE) initiates an attach request:

1. The HSS authenticates the Mobile Asset using its subscription data.
2. Upon successful authentication, the default bearer is established.
3. The attach process is completed, and the request is accepted.
4. The Mobile Asset is then able to initiate a data session with the Packet Gateway (PGW).

These events ensure that Mobile Assets are authenticated and managed securely, enabling them to access the network while maintaining control over their session states.

ENTRY TYPE - PGW

PGW (Packet Gateway) entries track data (user plane) session events for Mobile Assets, detailing the state of data sessions.

Data Session States

- **Open**: The data session has started and is currently active.
- **Closed**: The data session has ended and is no longer active.

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Identifying Session States

- A session with a **Start Time** but no **End Time** is still open.
- A subsequent entry may show an **End Time**, indicating the session is closed, or confirm the session remains open.

These entries provide critical insights into data session activity, allowing administrators to monitor and manage connectivity effectively.

EXAMINE SMS LOG EVENTS

To view SMS event log details for a Mobile Asset:

1. Navigate to **Mobile Assets**.
2. Click the IMSI of the desired Mobile Asset to open its details page.
3. In the **Event Log** section, click **SMS** to access the SMS event logs.

SOURCE TYPES

Source types indicate the origination device or application for an SMS message. If the source is **MO** or **MAP**, the message is classified as outgoing. The table below explains the various source types:

Source Type	Description
MO	Mobile Originator.
CLI	Command Line.
MSC	Mobile Switching Center (the SMS Gateway).
SMPP	SMPP (Short Message Peer-to-Peer) Gateway.
LOCAL	Local device or application.
REMOTE	External device or application.
MAP	Mobile Application Part Protocol, such as MAP V4. Used to query HLR/HSS for customer location.
SOAP	SOAP client.
UNKNOWN	Device or application type is not known.

Failure Causes

Failure causes indicate the result of the last attempt to deliver an SMS message. The table below lists common failure causes and their meanings:

Failure Cause	Description
None	No attempt was made to deliver the message.
NoMSCResponse	No response from the Mobile Switching Center.
NoSuchDest	Target cannot be identified.
NoUserResponse	No response from the recipient.
NoMemoryOnHandset	Recipient's handset lacks sufficient memory.
Success	Message delivered successfully.

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Failure Cause	Description
CommsFail	Communication failure occurred.
NetError	Network error encountered.
SMSCCongestion	SMS Center is congested.
SMPPDisconnect	Disconnection from the SMPP Gateway.
NoSuchSMPPUser	SMPP user cannot be identified.
Rejected	Message delivery was rejected.
Discarded	Message was discarded without delivery.
AbsentSub	Subscriber is not reachable.
BusyForMTSMS	Subscriber is busy for MT SMS.
IllegalSub	Subscriber credentials are invalid or illegal.
IllegalEquipment	Equipment is invalid or unauthorized.
ProtError	Protocol error encountered.
EquipNotSupp	Equipment does not support the message type.
DataError	Data-related error occurred.
Barring	Text message blocking is enabled.
NotProv	Authentication credentials not provided.
InvalidMsgRef	Invalid message reference.
IncorrectMsg	Message format or content is incorrect.
InvalidMandatoryInfo	Required information is missing or invalid.
InvalidMsgType	Message type is not valid.
NotCompatible	Device or application is not compatible.
IEError	Information Element error occurred.
TempFailure	Temporary failure, retry might succeed.
ProviderError	Error from the service provider.
SMDelFail	Short Message delivery failed.
AbsentSubSMPP	Subscriber is unreachable via SMPP.
UnidentifiedDest	Destination is not identified.
NoSuchDestOffNet	Destination is not found in off-net routing.

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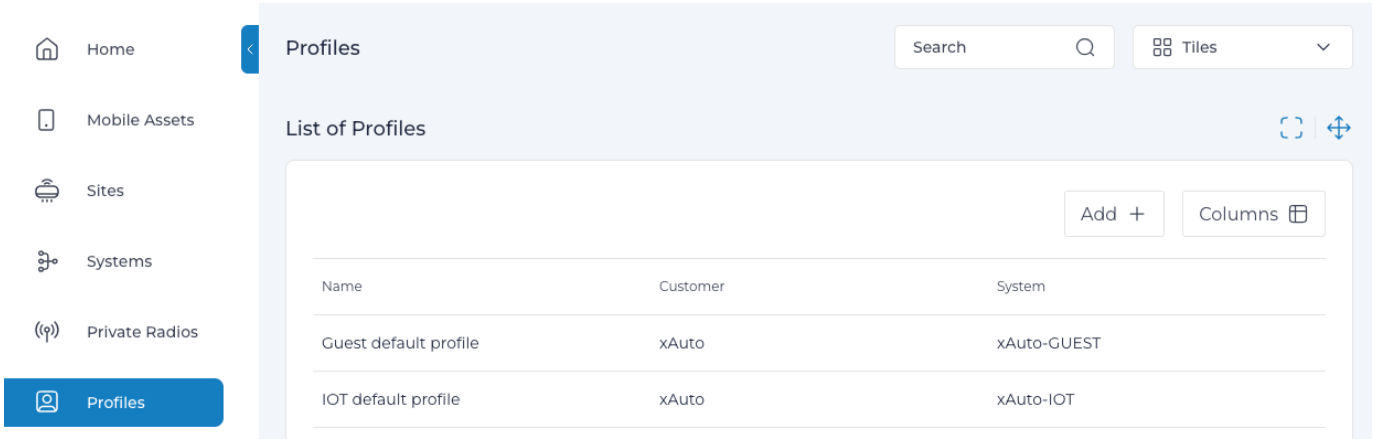
2.3.3 System Profiles

System Profiles

System Profiles are primarily used for selecting mobile asset (subscriber) service (APN) and their service quality such as bandwidth. A System Profile includes an order list of applicable APN profiles and additional extension values for setting custom parameters. Each APN profile in the System Profile, includes a reference to APN object and maximum download and upload bit rates values. The maximum download and upload values in the APN profiles overrides the values configured in the APN object for the System Profile. Otherwise, maximum download and upload vales from the APN object is used by the System Profile.

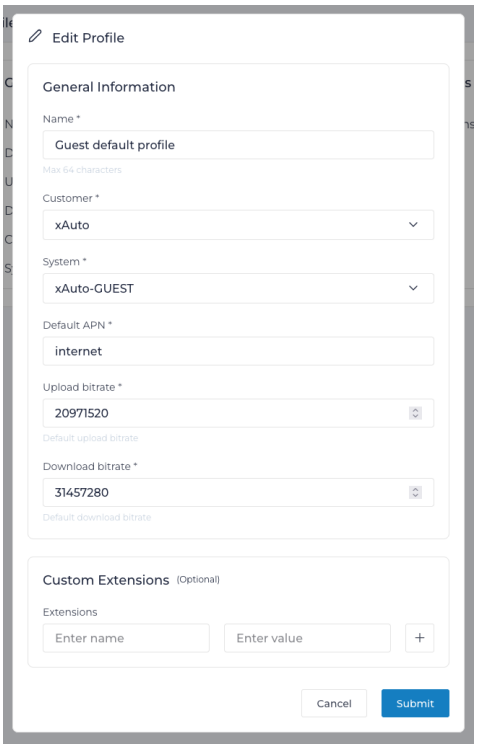
> **Note**
>
> They can be applied only to Mobile Assets belonging to the Systems specified in the System Profile.

Multiple System Profiles can be created and made available for Mobile Assets of the same System. For example, create tiered service levels by creating three Profiles (bronze, silver, and gold) each with successively higher bandwidth levels. Different APN profile is applied depending on the APN used by the mobile asset to connect the network.



Add or Edit a System Profile

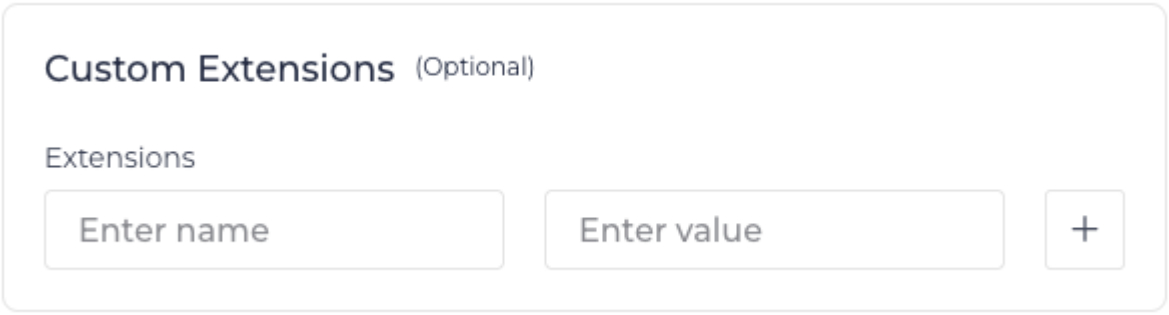
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1. Navigate to System Profiles.
2. Click **Add** or click an existing System Profile **Name** to edit.
3. Type a Name of the Profile. For example: *Gold*
4. Click **Customer** and select a Customer from the list. The Profile is only available for the selected Customer.
5. Click **System** and select one or more System from the list. Once selected, the System Profile is only available for Mobile Assets accessing this System.
6. Click **Submit**.

Set Extensions for Profiles

In the Edit Profile dialog box, you can add custom extensions.



Note

Extensions set in the System Profile override the same Extensions set at the Customer and System level.

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> **Info**
>
> For more information on creating Extensions, see Extensions page.

Add APN Profiles for the System Profiles

1. Select **APN Profiles** tab.
2. Click **Add APN Profile**.
3. Select **APN** from the list.
4. (Optional) Enter **Upload Bitrate** and **Download Bitrate** override values.
5. (Optional) Select **QoS** from the list.
6. (Optional) **Carrier APN Overrides**: You can define carrier-specific QoS and bitrate overrides.
    - Click **Add Carrier Override**.
    - Select a **Carrier**.
    - Specify carrier-specific **Download**, **Upload**, or **QoS** values, all are optional but at least one is required.
7. Click **Submit**.

> **Note**
>
> Carrier APN Overrides take precedence over both the APN Profile values and the APN Global values for subscribers roaming on the specified carrier.

UNDERSTANDING QOS/QCI AND CARRIER OVERRIDES

In 3GPP mobile networks, the **Quality of Service (QoS)** and specifically the **QoS Class Identifier (QCI)** determine how data traffic is prioritized and treated by the radio network. QCI is a scalar value that defines specific packet delay budgets, packet error loss rates, and priority levels.

Standard vs. Operator-Defined QCI

The 3GPP specifications define two categories of QCI values: * **Standardized QCI Values:** These values (typically 1–9 and certain others like 65, 66, 69, 70) are defined globally by 3GPP. Every network operator following the spec should treat these values with the same characteristics (e.g., QCI 1 is always for conversational voice with a 100ms delay budget). * **Operator-Specific QCI Values:** Operators are permitted to define their own custom QCI values (typically in the range of 128–254). These values allow for proprietary QoS levels tailored to specific enterprise needs or unique applications.

The Importance of Carrier Overrides for Custom QCIs When roaming, using operator-specific QCIs becomes a challenge. A custom QCI value defined on your home network (HPLMN) will likely not be recognized by a roaming partner's network (VPLMN). If a device attempts to attach using a custom QCI that the VPLMN doesn't support, the session may be downgraded to a default best-effort level or, in some cases, the attach request may be rejected entirely.

By using **Carrier APN Overrides**, you can ensure that your devices always request a safe, standardized QCI value (like QCI 9) when roaming, while still utilizing your high-performance custom QCIs while on your home network.

Similarly, the **Aggregate Maximum Bit Rate (APN-AMBR)** dictates the maximum upload and download bandwidth allowed across all non-guaranteed bearers for that APN.

Why Override per Carrier? When a mobile asset leaves your home network and roams onto a partner's network (Visited PLMN / VPLMN), the network must agree on the QoS parameters. Different roaming partners often have different infrastructure capabilities, Service Level Agreements (SLAs), or pricing models.

Configuring **Carrier APN Overrides** allows administrators to dynamically adjust the requested QCI and bitrates depending on the network the device attaches to. This is crucial for: - **Cost Control:** Throttling download/upload bitrates (AMBR) when assets roam onto expensive partner networks. - **SLA Compliance:** Downgrading a high-priority QCI to a standard best-effort QCI if the roaming partner does not support

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or heavily charges for premium QoS classes. - **Compatibility:** Ensuring the attach request isn't rejected by a Visited PLMN that doesn't recognize a specific custom QCI value configured on your home network.

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2.3.4 Sites

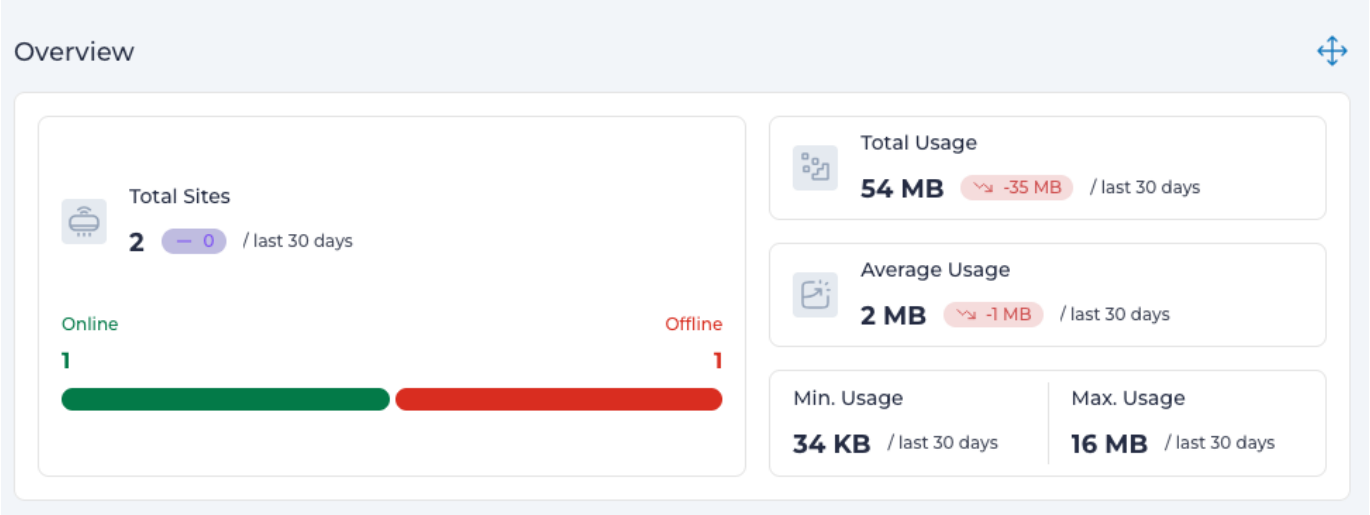
Sites

A **Site** represents a deployed instance of the Expeto xCore or xRouter, which can be installed either on-premise or as a virtual instance. Sites are the foundation for managing networked systems and devices, providing centralized control, monitoring, and configuration of Expeto-enabled private mobile networks. Each Site serves as a gateway for managing Systems, Mobile Assets, and network policies.

> **Note**
>
> For SaaS-hosted xControl instances, contact Expeto Support to add or remove Sites.

Site Status

Navigate to the **Sites** section to view a list of all Sites available in your network. Each Site's status is displayed as either **Connected** or **Disconnected**:

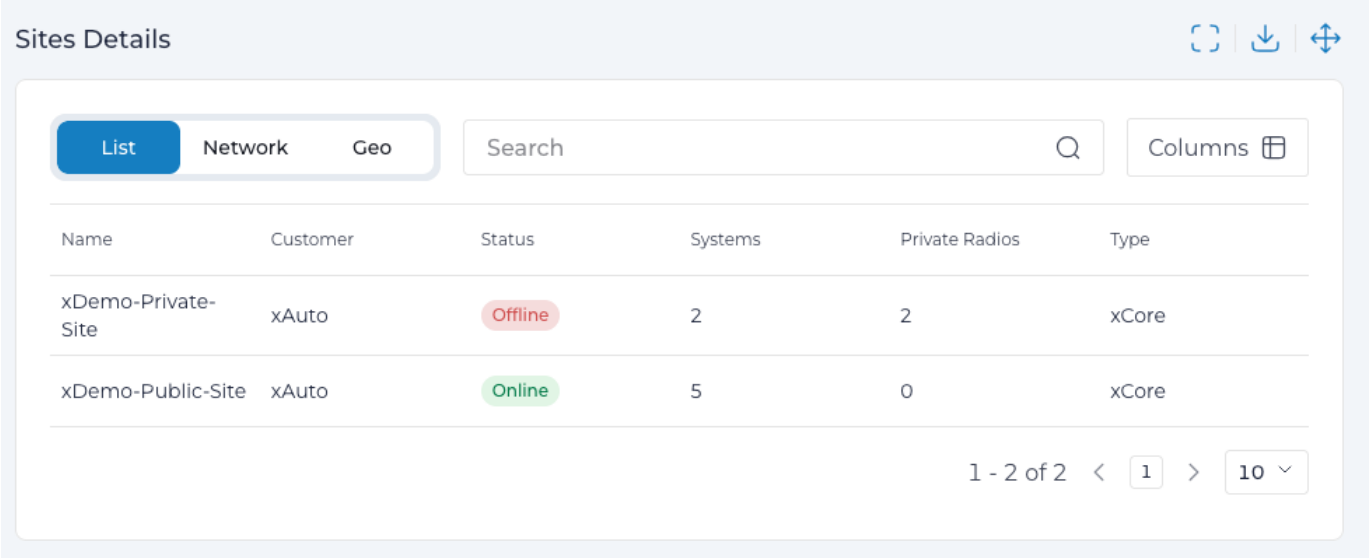


- A Site is marked as **Disconnected** when its Agent has not been in contact for 5 minutes.
- Additional information available for each Site includes:
  - **Network Topology**: The network configuration of connected assets.
  - **Data Metrics**: Bandwidth usage statistics (total, average, min, max)

Site Details

Click the name of a Site in the **Sites** list to view detailed information about the Site. The following parameters are displayed:

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Column Name	Description
Name	Identifies the Site in the GUI. Maximum 64 characters.
Location	Optional geographic information about the Site.
UUID	An autogenerated unique identifier for the Site in hexadecimal format.
Agent Version	The version of the Expeto Agent running on the Site (e.g., 1.1.6730).
IP Address	The IP address of a **Connected** Site.
Last Seen	The timestamp indicating when the Site was last connected.
Extensions	Custom key-value pair parameters configured for the Site.

Additional options available:

Overview Metrics, Network Topology, Geographical Location (if configured), Associated Systems, Associated Private Radios, Data Usage History.

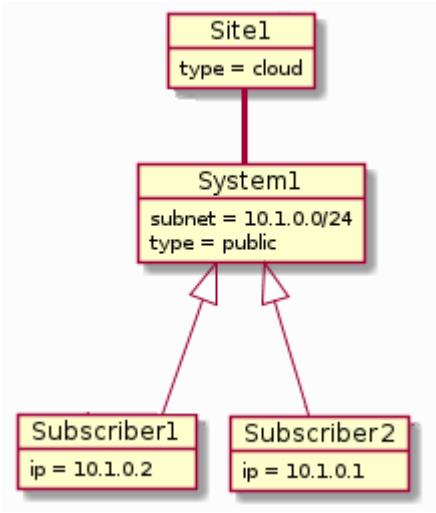
Common Site Scenarios

Sites can be configured in various ways depending on network requirements. The following scenarios illustrate typical single-Site and dual-Site installations, highlighting their features and potential use cases.

SINGLE-SITE SCENARIO

The graphic below demonstrates a single-Site deployment with one System:

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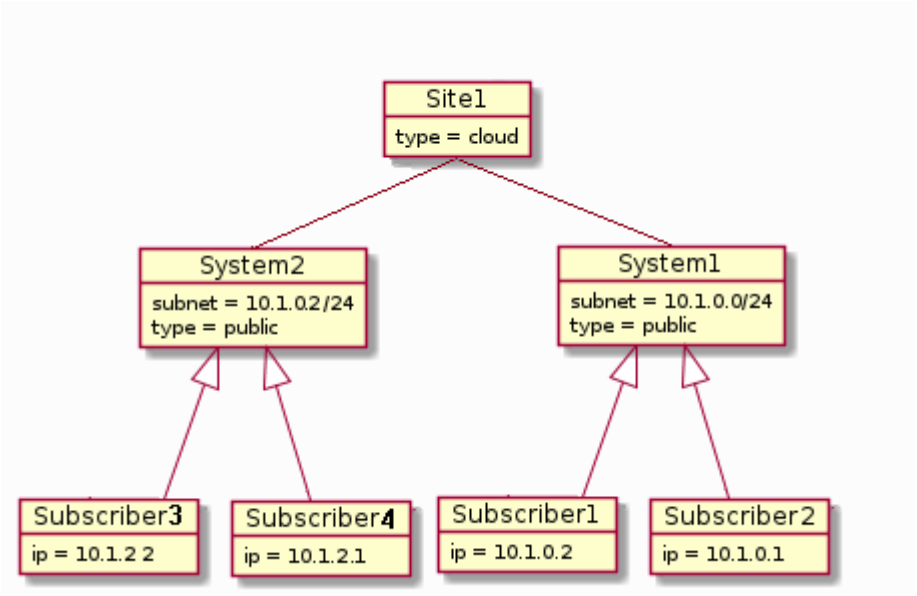


Key Features:

- Each Subscriber can be assigned a static IP address from the System's subnet.
- All Subscribers access the same network, but individual network policies can be applied.

> **Example**
>
> One Subscriber could be assigned a System Profile with higher data throughput.

Adding an additional System within the same Site enables **network segmentation**, as shown in the diagram below:

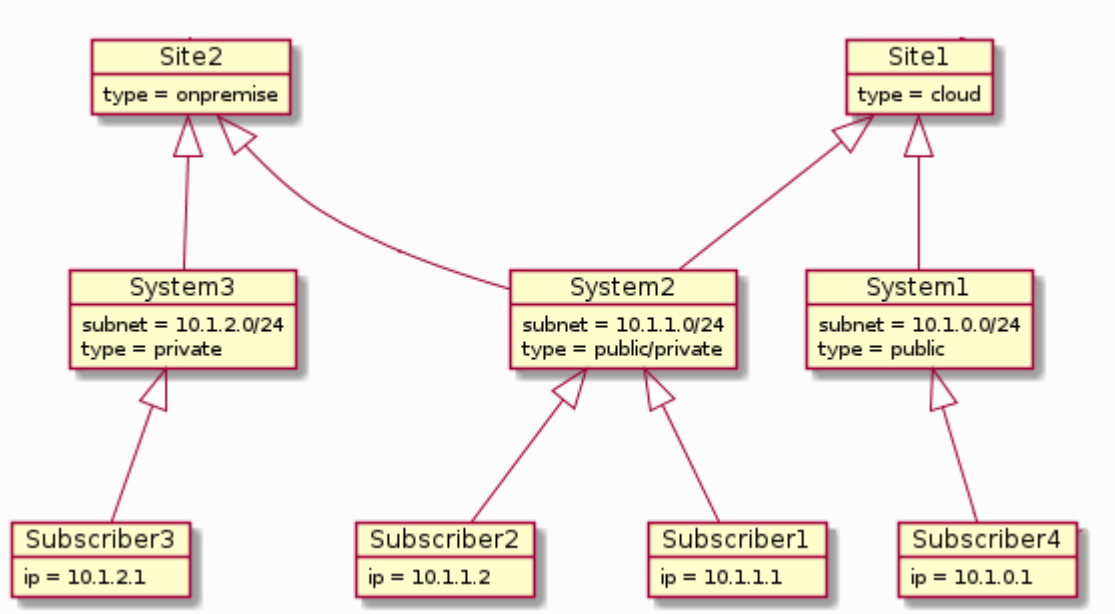


- **Network Segmentation**: Allows restrictions on Subscribers to specific parts of the network.
- Policies can now be enforced at the System level, providing more granular control.

DUAL-SITE SCENARIO

A dual-Site setup enables segmentation of a network across two locations. The diagram below demonstrates this configuration, featuring one shared System and two Site-specific Systems:

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Key Characteristics:

- One Site is **on-premise**, while the other is **virtual**.
- Each System is assigned a **unique subnet** for clear traffic separation.
- Subscribers assigned to the **shared System (System2)** can roam seamlessly between the two Sites.
- Subscribers assigned to **System1** and **System3** are restricted to **Site1** and **Site2**, respectively.

Example Use Case: Industrial Manufacturing

This dual-Site setup is ideal for industrial environments with distinct operational needs:

1. **Site1 (Cloud-based Instance)**:
    - Hosts an IT Operations network (**System1**) for office computers and printers connected via the Internet.
2. **Site2 (On-premise Instance)**:
    - Contains a dedicated SCADA network (**System3**) installed behind a corporate firewall.
    - Operates as a private, low-trust or zero-trust network with no Internet access.
    - Robotic devices within this network are assigned static IP addresses.

Employees requiring access to both the SCADA network and the IT Operations network have their devices registered with the **shared System (System2)**, enabling seamless communication across both Sites.

> **Note**
>
> The two Sites in this scenario could also be both on-premise, deployed in different geographic locations.

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2.3.5 Systems

Systems

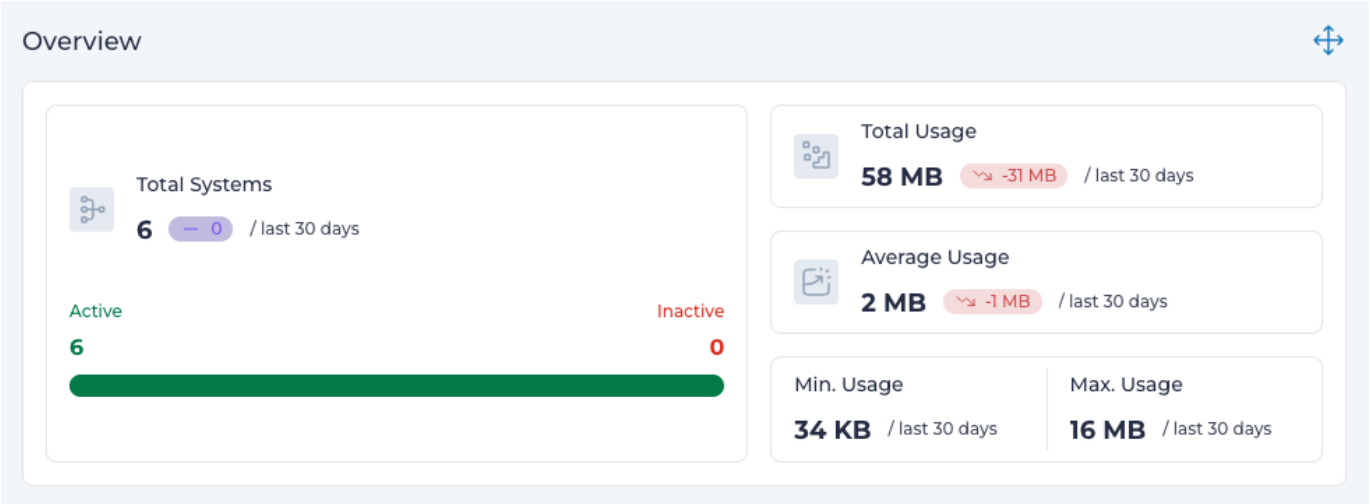
A **System** maps to a subnet in your network, creating logical divisions and ensuring secure separation for different types of Subscribers on a corporate network.

For instance, you can define one System for a subnet accessed by IoT devices and another for an employee subnet. Similarly, you might configure separate Systems for production and test environments.

Each System is served at a Site by an anchor user plane, the one whose System ID matches:

- a **PGW-U** for 4G/LTE devices,
- a **UPF** session anchor for 5G devices,
- or one user plane anchoring both, on a combined 4G and 5G xCore.

The anchor holds the System's address pool and connects to the local IT network the System represents.



Create a System

Follow these steps to create a new System:

1. Navigate to the **Systems** section in Expeto xControl.
2. Enter a unique **Name** for the System.
    - Maximum 64 characters, no special characters or spaces are allowed.
3. Select **Enable** or **Disable** to activate or deactivate the System.
4. Click **Customer** and choose a Customer from the list.
    - The System will only be available for the selected Customer.
5. Click **Site(s)** and select one or more applicable Sites.
6. Enter the **Network** CIDR range for the System (e.g., `100.64.9.0/24`).
    - Each CIDR block must be unique and not conflict with other addresses in the broader network.
    - Multiple CIDR blocks can be assigned to the same System if needed.
7. Click **Submit** to save the new System.

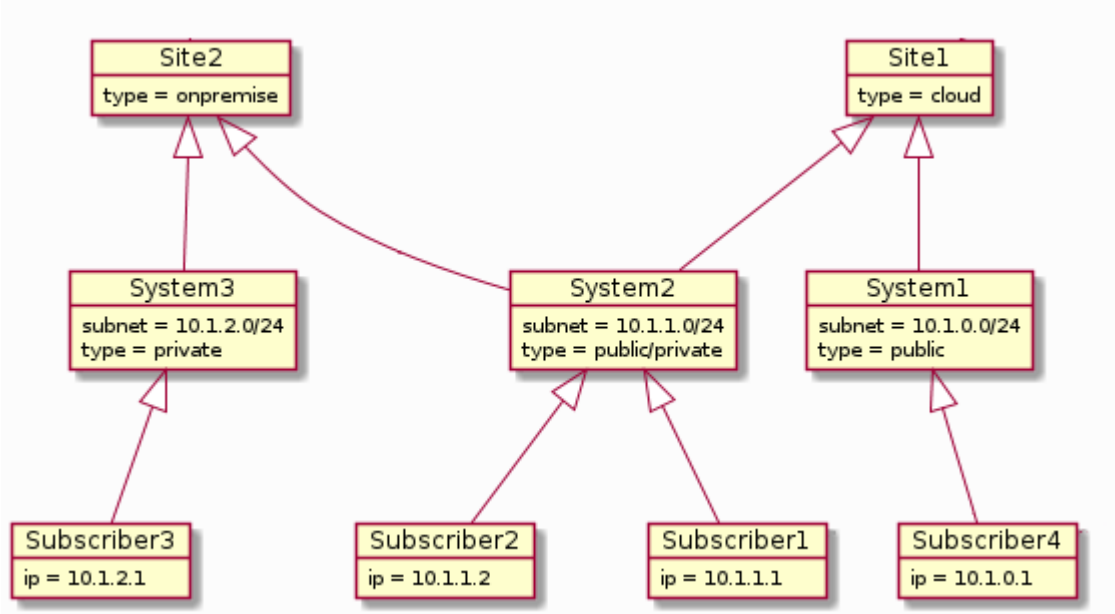
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> **Note**
>
> Your installation may include pre-configured Systems with assigned CIDR ranges. Permissions to create new Systems and assign CIDR ranges may not be granted, depending on your role.

> **Note**
>
> If your corporate network Gateway is using Network Address Translation (NAT), you can create two systems with overlapping ranges for the same network.

Create a Shared System

A **Shared System** enables seamless access for Subscribers across multiple Sites owned by the same Customer, even if the Sites are in different physical locations. This setup is ideal for ensuring consistent connectivity and unified management of network resources.



1. Navigate to the **Systems** section in Expeto xControl.
2. Choose one of the following options:
3. Click **New** to create a new System.
4. Select an existing System and click **Edit**.
5. In the **Sites** field, select one available Site.
6. Add additional Sites by selecting them from the list.
7. Multiple Sites will be separated by commas in the configuration.
8. Click **Submit** to save the Shared System.

> **Note**
>
> Shared Systems are only available for Sites under the same Customer. Ensure that all associated Sites belong to the same Customer before configuring the Shared System.

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Move Subscribers Between Systems

A Subscriber belongs to one System only, but can be moved between Systems by editing the Subscriber properties.

Set Extensions

Extensions set at a System level are applied to all Subscribers belonging to the System unless explicitly overridden.

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2.3.6 Configure APNs

==========  APNs

Define an **Access Point Name (APN)** for a customer network to configure its Quality of Service (QoS), including default maximum upload and download bitrates.

In a 3GPP mobile network, an APN acts as the gateway between the cellular network and the public or private data network (e.g., the Internet, an enterprise intranet). The APN defines critical network parameters: * **Routing:** How and where the mobile asset's data traffic is routed once it leaves the radio access network. * **Quality of Service (QoS):** The priority and packet treatment of the data stream. * **Bandwidth Allocation (AMBR):** The default aggregate maximum upload and download bitrates allowed for the connection.

These base APNs (often referred to as *APN Globals*) are then incorporated into **System Profiles**, where you can further define tiered service levels, override default bandwidth limitations, or specify carrier-specific QoS overrides when a mobile asset roams onto another network.

APNS VS. ROAMING PROFILES

While APNs govern *how* a mobile asset connects to the network (its gateway, QoS, and bandwidth), **Roaming Profiles** govern *where* the asset is physically allowed to connect. Use Roaming Profiles to enforce steering of roaming policies and restrict the actual Carriers (PLMNs) the device can use.

> **Note**
>
> The **Create APN** permission is required to perform these actions.

Create or Edit an APN

1. Navigate to the **APNs** section in the admin interface.
2. Click **Add** to create a new APN or click an existing APN to edit it.
3. Type a **Name** for the APN (e.g., *internet*, *m2m.private*).
4. Click **Customer** and select the appropriate Customer from the list. The APN is only available for the selected Customer and its associated System Profiles.
5. Select the baseline **QoS** profile from the available list.
6. Specify the base **Upload Bitrate** and **Download Bitrate** in bits per second. These fields define the default Aggregate Maximum Bit Rate (AMBR) for data transfer.
7. Click **Submit**.

> **Overriding APN Defaults**
>
> The bitrates and QoS values set here are considered the baseline limits. You can override these limits on a per-profile or per-carrier basis when building out your **System Profiles**.

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2.3.7 Carriers

Overview

The **Carriers** section provides tools for managing individual mobile network carriers and grouping them into **Carrier Groups**. This functionality is essential for configuring 3GPP roaming restrictions through Roaming Profiles, allowing administrators to precisely control which networks their mobile assets can attach to globally.

Key features include:

- **Carrier List**: Displays a comprehensive database of Public Mobile Network Carriers, including their Mobile Country Code (MCC), Mobile Network Code (MNC), and Public Land Mobile Network (PLMN) identifiers.
- **Carrier Groups**: Allows administrators to create logical groupings of carriers (e.g., "North American Partners", "High-Bandwidth Providers").
- **Integration with Roaming Profiles**: Carrier Groups form the foundational building blocks for Roaming Profiles, defining the allowed networks for subscribers.

Manage Carriers

The system maintains a database of mobile network carriers. While many carriers are pre-populated, you may need to view their details or add specific private or regional carriers.

CARRIER ATTRIBUTES

Each carrier is defined by several key attributes: - **MCC**: Mobile Country Code (e.g., 310 for US). - **MNC**: Mobile Network Code. - **PLMN**: The combination of MCC and MNC (e.g., 310410). - **Name/Brand**: The commercial name of the operator. - **Status**: The operational status of the network.

VIEWING CARRIERS

1. Navigate to the **Carriers** section in the admin interface.
2. The list displays all available carriers. You can use the search functionality to find specific carriers by name, country, or PLMN.
3. Click on a specific carrier to view its full details, including supported bands and operational mode.

Manage Carrier Groups

Carrier Groups are custom collections of carriers. Rather than assigning individual carriers to a Roaming Profile, you create Carrier Groups to manage roaming policies more efficiently.

CREATE A CARRIER GROUP

1. Navigate to the **Carrier Groups** section.
2. Click the **Add** button to create a new group.
3. In the dialog, provide a **Name** (e.g., "EU Roaming Partners") and an optional **Description**.
4. Navigate to the **Carriers** tab within the group configuration.
5. Select the specific carriers you want to include in this group. You can search by country or operator name to find them quickly.
6. Click **Submit** to save the Carrier Group.

EDIT A CARRIER GROUP

1. From the **Carrier Groups** list, click on the name of the group you wish to edit.
2. You can update the name, description, or modify the list of included carriers by checking or unchecking them in the **Carriers** list.
3. Click **Submit** to save your changes.

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> **Warning**
>
> Modifying a Carrier Group will immediately affect all Roaming Profiles that use it, which in turn impacts the roaming capabilities of all subscribers assigned to those profiles.

Using Carrier Groups in Roaming Profiles

Once you have defined your Carrier Groups, they are ready to be used in **Roaming Profiles**.

A Roaming Profile acts as a policy that specifies which Carrier Groups are allowed. For detailed instructions on creating and applying these profiles to Systems, Sites, or individual Subscribers, please see the Configure Roaming Profiles guide.

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2.3.8 Configure Roaming Profiles

==========

Roaming Profiles provide 3GPP roaming restrictions by defining which Carrier Groups a subscriber is allowed to attach to. They can be applied at the System, Site, or Subscriber level.

UNDERSTANDING 3GPP ROAMING RESTRICTIONS

In 3GPP mobile networks, roaming occurs when a mobile asset leaves the coverage area of its Home Public Land Mobile Network (HPLMN) and attempts to attach to a Visited Public Land Mobile Network (VPLMN). Without explicit restrictions, a device might connect to any available VPLMN that has a roaming agreement with the home network.

Roaming Profiles allow administrators to enforce network selection policies, effectively steering roaming traffic by strictly defining the physical networks (Carriers/PLMNs) a device is permitted to use globally. This granular control is essential for: - **Cost Management:** Blocking expensive roaming partners and forcing devices to connect only to partners with favorable data rates. - **Security & Compliance:** Restricting attachments to trusted national carriers, preventing data from traversing foreign networks, and satisfying data sovereignty requirements. - **Service Quality:** Ensuring devices attach to networks that support specific features (like 5G SA) or offer superior SLAs and coverage, rather than simply connecting to the first available signal.

Carrier Groups

A Carrier Group is a collection of Carriers used within Roaming Profiles to define sets of allowed or restricted networks. Before creating a Roaming Profile, you must define the Carrier Groups that represent the sets of networks you want to manage.

For detailed instructions on creating and managing these groups, see Manage Carriers and Carrier Groups.

Roaming Profiles

Once Carrier Groups are defined, you can create Roaming Profiles.

1. Navigate to **Roaming Profiles**.
2. Click **Add** or select an existing profile to edit.
3. Type a **Name** and **Description**.
4. Select the **Customer** this profile belongs to.
5. In the **Allowed Carrier Groups** tab, select one or more Carrier Groups that subscribers using this profile are permitted to roam on.
6. Click **Submit**.

Applying Roaming Profiles

Roaming Profiles can be applied at different levels of the hierarchy. If a Roaming Profile is set at multiple levels, the most specific one (Subscriber) takes precedence.

APPLY TO A SYSTEM

1. Navigate to **Systems**.
2. Edit a System and select the desired **Roaming Profile**.
3. Click **Submit**.

APPLY TO A SITE

1. Navigate to **Sites**.
2. Edit a Site and select the desired **Roaming Profile**.
3. Click **Submit**.

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APPLY TO A SUBSCRIBER

1. Navigate to **Subscribers**.
2. Edit a Subscriber and select the desired **Roaming Profile**.
3. Click **Submit**.

> **Note**
>
> When a Roaming Profile is assigned to a System or Site, all Subscribers within that System or Site will inherit that profile unless they have a specific Roaming Profile assigned to them directly.

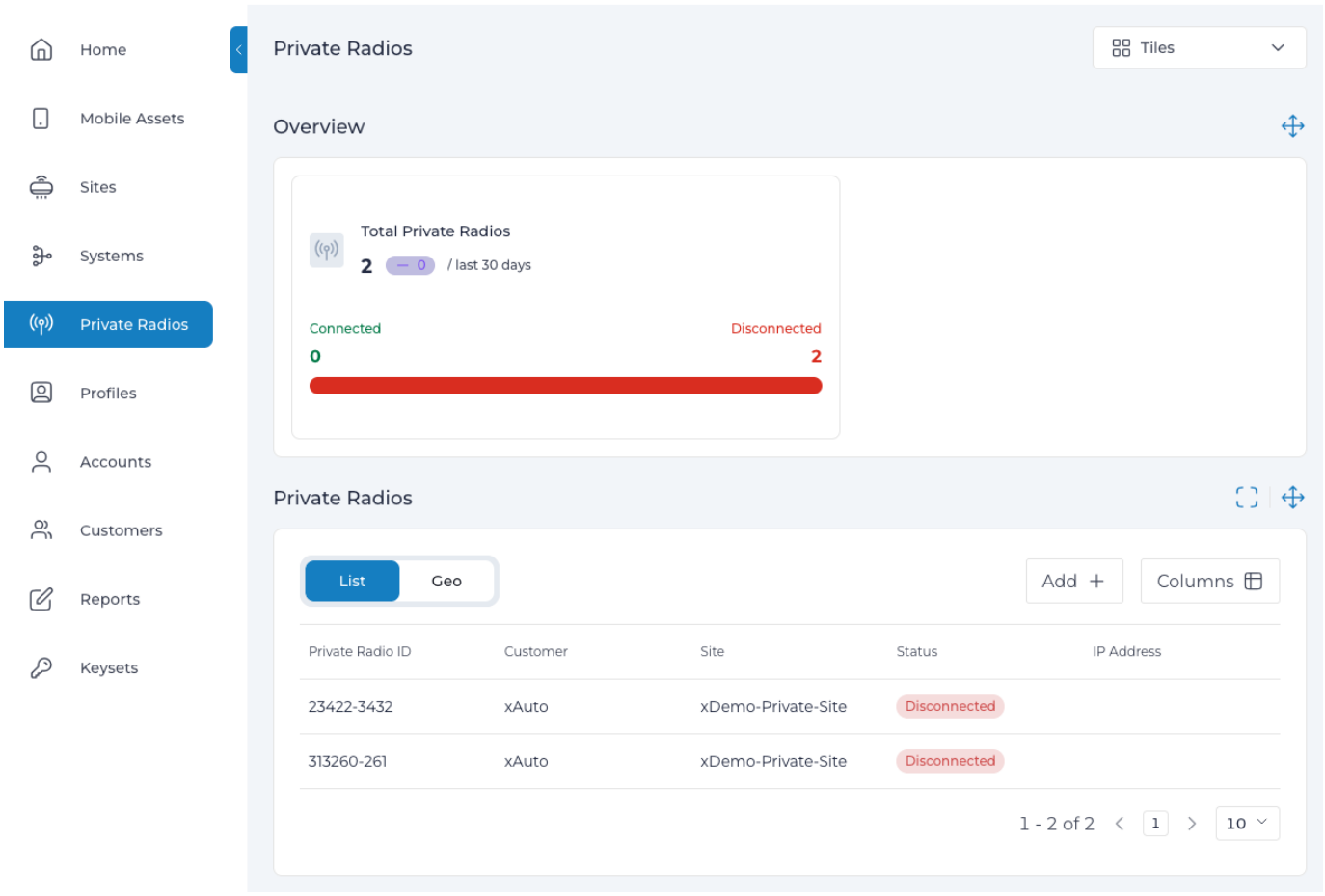
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2.3.9 Private Radios

Private Radios

The **Manage Private Radios** page provides tools for administering optional eNodeB/gNodeB radios within the Expeto xControl system. These radios can be added, enabled, disabled, or removed and are used to facilitate communication between 4G/5G devices and the Expeto xCore if they are part of the network configuration.

This page allows administrators to configure new Private Radios with unique identifiers, manage their operational states (enable/disable), and remove radios as needed. Real-time status updates indicate whether a Private Radio is connected, disconnected, enabled, or disabled, providing a streamlined way to manage this optional component of the network infrastructure.



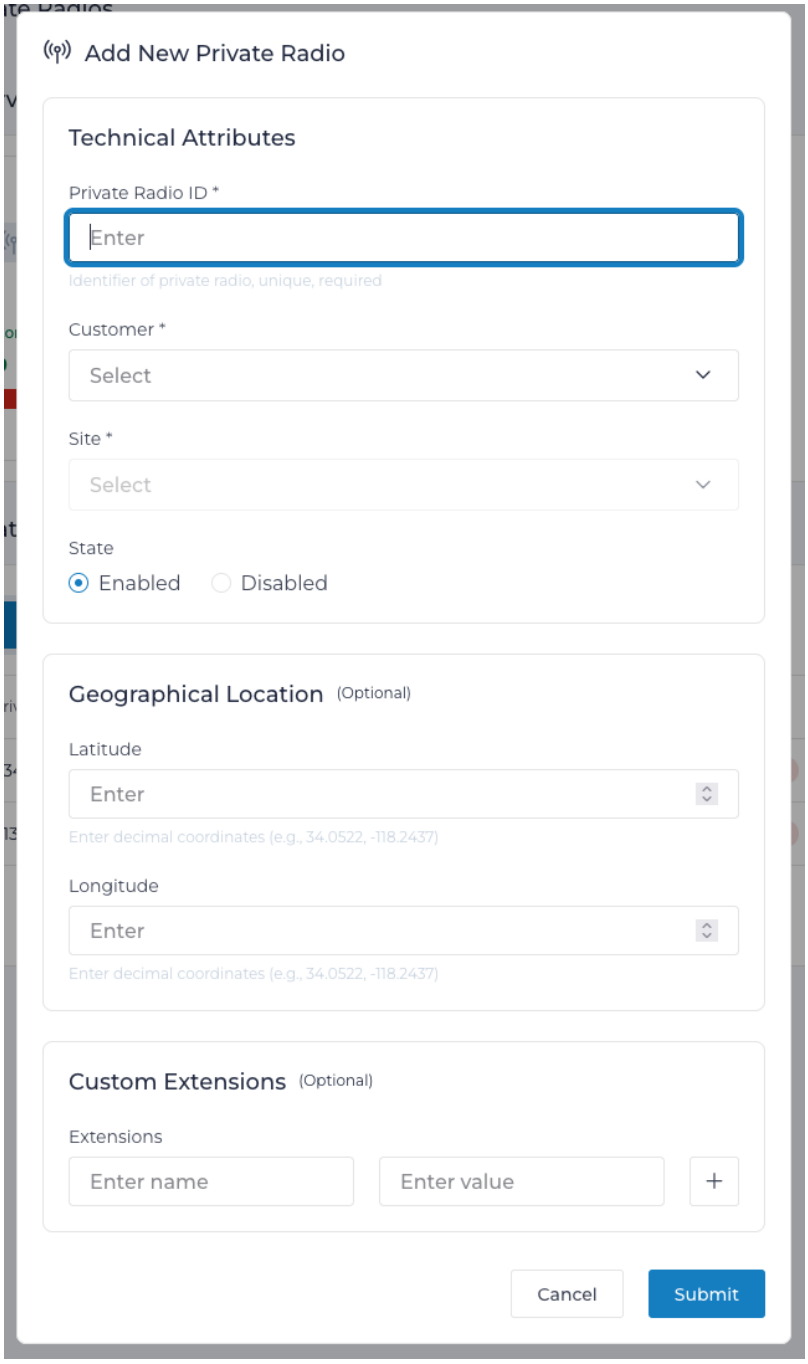
Private Radio Status

The following statuses describe the operational state of a Private Radio:

Status	Description
Enabled	The Private Radio configuration has been added to the Site and is waiting to connect with the physical unit.
Disabled	The Private Radio is configured in the System but will not accept connections.
Connected	The connection between the Expeto xCore and the Private Radio is established.
Disconnected	The connection between the Expeto xCore and the Private Radio is broken.

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Add a New Radio



To add a new Private Radio, you must provide a unique identifier in the format:

`<PLMN>-<Cell ID>`

- **PLMN**: The Public Land Mobile Identifier, which consists of:
  - **MCC (Mobile Country Code)**: A 3-digit code representing the country.
  - **MNC (Mobile Network Code)**: A 2-3 digit code identifying the network carrier.
- **Cell ID**: A 1-6 digit identifier for the specific cell tower.

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Example

The identifier `54206-123` breaks down as follows:

- **542**: MCC for Fiji.
- **06**: MNC for the fictional FijiFone Carrier.
- **123**: Cell tower identifier.

STEPS TO ADD A PRIVATE RADIO

1. Navigate to **Private Radios** in the Expeto xControl menu.
2. Click **Add** to open the New eNodeB page.
3. Enter the **eNodeB/gNodeB identifier** in the required format.
4. Select the **Customer** associated with the Private Radio.
5. Choose the relevant **Site** where the Private Radio will be deployed.
6. Set the initial **Status** to **Enabled** or **Disabled**.
7. Optionally, provide the **Longitude** and **Latitude** of the Private Radio's geographical location.
8. Click **Submit** to save the new Private Radio configuration.

Enable or Disable a Radio

1. Click the eNodeB ID. The details of the eNodeB appear.
2. Click **Edit**.
3. Select State **Enable** or **Disable**.
4. Click **Submit**.

Remove a Radio

---

1. Click the eNodeB ID. The details of the eNodeB appear.
2. Click **Delete**.

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2.3.10 Reports

> **Note**
>
> The appropriate Generate Reports permission is required to access this functionality.

Overview

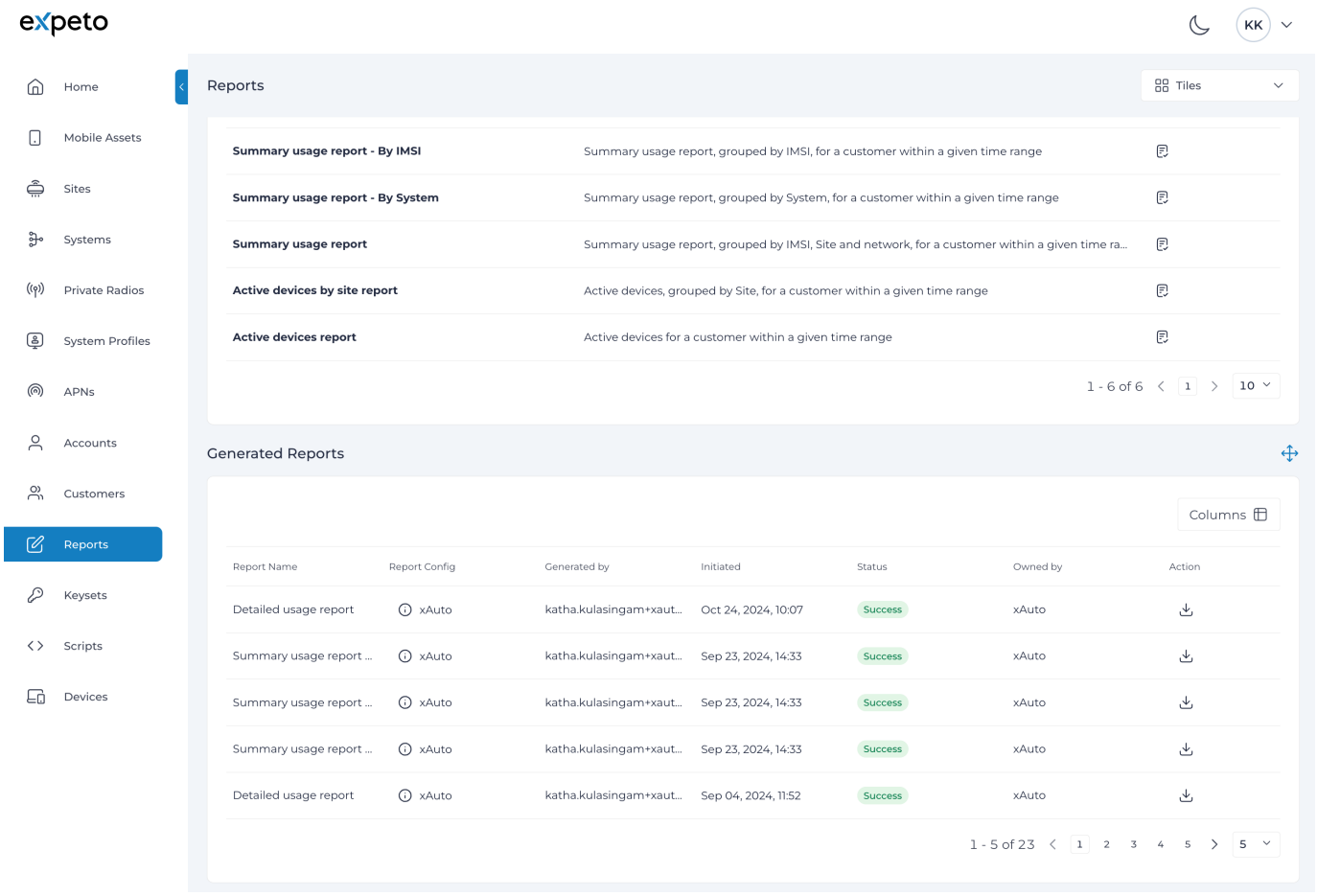
The Reports feature in xControl allows administrators to generate various types of Call Detail Reports (CDRs) on-demand for billing, auditing, and informational purposes. Reports can be customized for a specific Customer and date range, capturing critical insights into data usage, network activity, and subscriber details.

Administrators can access generated reports in the following ways:

- Download directly from **Files** within the xControl interface.
- Retrieve via a GET call to an API endpoint.
- Access through a previously configured SFTP connection.

The scope and content of each report depend on the selected report type and generation parameters. For example, reports can detail data usage per Subscriber in bytes or aggregate usage by Site.

This robust reporting system supports flexible access and granular customization, enabling organizations to monitor their network operations effectively and optimize resource allocation.



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Generating a Report

To generate a report:

1. Navigate to the **Reports** section in xControl.
    - The **Available Reports** panel lists predefined report types with descriptions.
    - The **Generated Reports** panel shows previously created reports.
2. Locate the desired report type in the **Available Reports** panel and click the **Generate** icon.
3. Fill in the required parameters (e.g., date range, customer) and click **Submit**.
4. A new entry will appear in the **Generated Reports** panel with a **Pending** status.
5. Once complete, the status will update to **Success**.
    - Click the **Download** icon to retrieve the report.

Report Types

The table below lists standard report types. Additional custom templates may be available for your Enterprise.

Report Type	Description	Includes
Detailed Usage Report	Comprehensive report covering all usage activity for a Customer.	Customer Name, CustomerID, ICCID, MSISDN, IMEI, IP Address, MCC, MNC, Network Operator Name, Operator Country, Operator Mode, Start Time, End Time, Bytes, MBs, GBs, Site, SiteID, System, SystemID.
Summary Usage Report - By IMSI	Focused report showing Subscriber IMSI usage for a given Customer.	IMSI, ICCID, MSISDN, Bytes, MBs, GBs.
Summary Usage Report - By System	Report showing System-level usage for a Customer.	System Name, System ID, Bytes, MBs, GBs.
Summary Usage Report	Usage grouped by IMSI, Site, and Network Operator for a Customer.	Customer, CustomerID, Site, SiteID, IMSI, ICCID, MSISDN, MCC, MNC, Operator Name, Operator Country, Operator Mode, Bytes, MBs, GBs.
Active Devices by Site Report	Text/CSV report showing all active Subscribers grouped by Customer and Site.	Site Name, Site ID, IMSI, MSISDN, MCC, MNC, Network Operator Name, Bytes, MBs, GBs.
Active Devices Report	Text/CSV report showing the total number of connected devices for a Customer.	Count of connected devices for a Customer.

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Report Generation Parameters

Use the following parameters to customize the content and scope of your report:

Parameter	Description
Date-range	Click the date field and use the calendar to specify the *start date* and *end date*. Quick-select options include **Last Week**, **This Week**, **Last Month**, and **This Month**.
Timezone	Pre-populated with your current timezone. To change it, click **Timezone** and search for a city (e.g., *Paris* applies *Europe/Paris-CEST* timezone).
Customer	Select a Customer from the list. The report is restricted to the selected Customer and optionally includes child Customers.
Customer Extensions to Extract	Specify one or more customer-level Extensions to include in the report. Separate multiple Extensions with commas. Columns are created for each extension, even if not configured (empty values appear).
Include Child Customers	Checkbox. Includes usage details for the parent Customer, its child Customers, and all subsequent child Customers.
Write Row Count in Footer	Checkbox. Adds the total number of rows at the end of the CSV file.

> **Note**
>
> Even if the customer-level Extension is not configured, the report will include a column for the extension with blank (empty) values.

View the Report

After generating a report, you can download it as a CSV file for further analysis in programs such as MS Excel. Refer to Importing to Excel for instructions on correctly handling the data.

STEPS TO DOWNLOAD A REPORT:

1. Navigate to **Reports**.
2. Locate the **Generated Reports** panel. The most recently generated report is listed at the top.
3. Click the **download** icon next to the desired report to download the file.

Once downloaded, you can open the file in a spreadsheet tool to view and analyze the report data.

Importing to Excel

> **Warning**
>
> By default, MS Excel may treat MSISDN and ICCID values as numerical data with exponents, resulting in raw data loss. Follow the steps below to prevent data display issues for these fields.

STEPS TO IMPORT THE REPORT IN MS EXCEL:

1. Open a blank workbook in MS Excel.
2. Go to the **Data** tab and click **Get Data**.
3. Select **From File** and then click **From Text/CSV**. This will open the file selection dialog.

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4. Choose the CSV report file you downloaded. A preview page of the file will appear.
5. **Important!** - For Data Type Detection, select **Do not detect data types**.
    - The raw values (like MSISDN and ICCID) will now display correctly in the preview.
6. Click **Load** to import the data into your workbook.

ADDITIONAL TIP:

To ensure the data remains intact, format the relevant columns (e.g., MSISDN and ICCID) as **Text** after importing. This prevents further transformations that might alter the raw values.

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2.3.11 SFTP

Overview

This document provides guidance on configuring Secure File Transfer Protocol (SFTP) connections to securely transfer Call Detail Billing Records (CDR) reports. These reports, available in GZIP format, can be accessed through REST API calls by default or delivered via SFTP for enhanced automation and security.

Key highlights include:

- **SFTP Configuration**: Detailed instructions on setting up an SFTP connection, including required parameters such as hostname, port, username, private key, and optional remote directory paths.
- **SSH Key Pair Generation**: Steps to create the public and private keys used for secure encryption and decryption in OpenSSH format. The guide also emphasizes the importance of passphrases for encrypting private keys.
- **Supported Algorithms**: Information on recommended cryptographic algorithms, such as RSA and ECDSA, with examples of their usage and customizable key sizes.

This process ensures encrypted file transfer and facilitates the secure delivery of CDR reports for billing and informational purposes.

Configure an SFTP Connection

Call Detail Billing Records (CDR) reports are provided in compressed GZIP format. These reports can be accessed via REST API calls (default) or delivered through a configured SFTP connection. Each file includes a timestamp in its name, representing the GMT time of generation in the format `yyyyMMdd_HHmmss`.

> **Example**
>
> `ExpetoDailyDetailedTraffic20210214_114423_Prod.gz` This file was generated on February 14th, 2021, at 11:44:23.

Secure File Transfer Protocol (SFTP) enables encrypted, secure server-to-server file transfers. Configuring an SFTP connection involves setting up specific parameters to establish the connection and facilitate the secure delivery of reports.

STEPS TO CONFIGURE AN SFTP CONNECTION

Provide the following information to set up an SFTP connection:

Parameter	Description
Name	A unique identifier for the SFTP connection configuration.
Hostname	The hostname or IP address of the target machine.
Port	The port number for the SFTP connection. Default: `22`.
Username	The username associated with the target SFTP server.
Private Key	The private key required to establish the connection. Paste the key contents into the provided field.
Remote Directory	(Optional) The folder path on the remote server where files will be delivered.

By completing this configuration, you enable secure and automated file delivery through SFTP.

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Generate an SSH Key Pair

SFTP connections rely on an SSH key pair, which consists of a public and private key. The public key encrypts data, while the private key decrypts it. The keys are generated in OpenSSH format using the ssh-keygen command.

After generating the keys, the private key must be copied and added to the SFTP connection configuration.

STEPS TO GENERATE AN SSH KEY PAIR

1. **Run the ssh-keygen Command** Use the command line to generate the key pair, specifying the desired algorithm and key size. Example command: `ssh-keygen -t rsa -b 4096 -m PEM` For details on supported algorithms and key sizes, see the Algorithms section.
2. **Specify the Save Location** Enter the file name or accept the default location to store the generated keys.
3. **Set a Passphrase (Optional)** Enter a passphrase to encrypt the private key. Without a passphrase, the private key will be stored as plain text. Verify the passphrase by re-entering it.
4. **Locate the Generated Files** Two files will be created:
    - *key_filename* — Contains the private key.
    - *key_filename.pub* — Contains the public key.

> **Example**
>
> id_rsa id_rsa.pub

1. **Copy the Private Key** Open the private key file (e.g., id_rsa) in a text editor and copy its contents.
2. **Paste the Private Key into Expeto xControl** In Expeto xControl, click **Add SFTP Connection** and paste the private key contents into the **Private Key** field.

Once configured, the private key ensures secure authentication for your SFTP connection.

Algorithms

When generating SSH key pairs, the choice of algorithm and key size determines the level of encryption and compatibility. Below are the supported algorithms for SFTP key generation.

RSA ALGORITHM

The RSA algorithm is widely used and supports variable key sizes for enhanced security. The recommended key size is 4096 bits.

Commands:

- Generate a 4096-bit key: `ssh-keygen -t rsa -b 4096 -m PEM`
- Generate keys with alternate sizes: `ssh-keygen -t rsa -m PEM` `ssh-keygen -t rsa -b 2048 -m PEM` `ssh-keygen -t rsa -b 8192 -m PEM`

Default Size: If the `-b` flag is not specified, the default key size is 3072 bits.

ECDSA ALGORITHM

ECDSA (Elliptic Curve Digital Signature Algorithm) offers enhanced security with smaller key sizes compared to RSA.

Commands:

- Generate a key with the default size (256 bits): `ssh-keygen -t ecdsa -m PEM`
- Generate keys with specific sizes: `ssh-keygen -t ecdsa -b 384 -m PEM` `ssh-keygen -t ecdsa -b 521 -m PEM`

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> **Warning**
>
> **DSA Algorithm**: DSA key types are not supported and should not be used.

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2.3.12 Role Permissions

The **Roles and Permissions** section provides a comprehensive breakdown of access rights and operational capabilities in the xControl system. This ensures that administrators can manage resources efficiently while maintaining secure and role-specific access controls.

Key highlights include:

- **Object Permissions**: Defines the Create, Read, Update, and Delete (CRUD) permissions for various system objects, such as Mobile Assets, Sites, Systems, and Accounts, across roles like **ADMIN**, **CUSTOMER_ADMIN**, and **READ_ONLY**.
- **Command Permissions**: Maps specific actions and commands (e.g., bulk import, report generation, API token creation) to roles, offering clarity on who can execute these tasks.
- Visual indicators for permissions, such as icons for Create, Read, Update, and Delete, make it easy to understand access levels at a glance.

This structure provides the flexibility to manage user roles while ensuring compliance with organizational policies and operational needs.

Object Permissions

The table below lists objects in xControl and the permissions for each role to create, read, update, and delete these objects.

Object	ADMIN	CUSTOMER_ADMIN	READ_ONLY
Mobile Assets	⊕ 👁 ✎ 🗑	👁 ✎	👁
Site	⊕ 👁 ✎ 🗑	👁	👁
APN	⊕ 👁 ✎ 🗑	👁	👁
System	⊕ 👁 ✎ 🗑	👁	👁
System Profile	⊕ 👁 ✎ 🗑	👁	👁
Account	⊕ 👁 ✎ 🗑	⊕ 👁 ✎ 🗑	👁
Account Audit Logs	👁	👁	👁
Customer	⊕ 👁 ✎ 🗑	⊕ 👁 ✎ 🗑	👁
Keyset	⊕ 👁 ✎ 🗑	👁	👁
Keyset Mapping	⊕ 👁 ✎ 🗑		
Monitoring Endpoint	⊕ 👁 ✎	⊕ 👁 ✎	👁
Private Radio	⊕ 👁 ✎ 🗑	⊕ 👁 ✎ 🗑	👁
SFTP Access Connection	⊕ 👁 ✎ 🗑	⊕ 👁 ✎ 🗑	👁

⊕ = Create 👁 = Read/List ✎ = Edit/Update 🗑 = Delete

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Command Permissions

The table below maps available commands and actions in xControl to specific roles.

Commands	ADMIN	CUSTOMER_ADMIN
Mobile Assets		
Bulk Delete	✓	
Bulk Import	✓	
Bulk Update	✓	
Cancel Session	✓	
Export to CSV	✓	
Accounts		
Create API Token	✓	✓
Delete API Token	✓	✓
Reports		
Generate Reports	✓	✓

Note

Per-object revision history — the change log showing who created, updated, deleted, or restored an object — is restricted to superuser accounts and is not granted to any role in this table.

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2.3.13 Revision History

Revision history is the change log for an individual object in xControl. Where the Audit log records who tried to sign in, revision history records who changed *what* — every creation, update, deletion, and restoration of an Account, Mobile Asset, Customer, Site, or System, with the administrator and IP address responsible.

Use it to answer questions after the fact: when a System Profile assignment changed, who deactivated a Mobile Asset, or whether a missing Customer was deleted or never existed.

> **Note**
>
> Revision history is available to superuser accounts only. The **History** button is not shown to other roles. Contact Expeto Support if you need a change investigated on your network.

Opening the history for an object

1. Navigate to the details page of the object — an Account, Mobile Asset, Customer, Site, or System.
2. Click **History**. The revision history for that object appears, newest change first.

Each object keeps its own independent trail. There is no combined, system-wide change log.

Reading a revision

Every entry in the list describes one change:

- **Timestamp**: when the change was committed, to the second.
- **Administrator**: the account that made the change, with its initials shown alongside.
- **IP**: the address the change was submitted from.
- **Action**: what kind of change it was — see the table below.
- **Changed fields**: a chip for each field the change touched. A revision that altered only the status shows a single `status` chip.

ACTIONS

Action	Meaning
created	The object was created. This is the oldest entry in any trail.
made an update	One or more fields changed. The changed-field chips say which.
deleted	The object was deleted.
undeleted	A previously deleted object was restored.

> **Important**
>
> A deletion and a restoration are separate entries, and a restored object keeps its full trail across both. Check the action on the newest entry before concluding that an object was removed — a **deleted** entry followed by an **undeleted** entry means the object is live again.

VIEWING THE CHANGE ITSELF

Click **Expand Diff** on any entry to see the object before and after the change, with the modified lines highlighted. The oldest entry instead offers **Expand Data**, which shows the object as it was first created — there is no earlier state to compare against.

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Navigating a long trail

Long-lived objects accumulate large trails, so the list is paginated with the newest changes on the first page. Use the numbered pager beneath the list to move through it; the count above the pager shows which revisions you are looking at and how many exist in total.

Expanding the oldest entry on a page still shows a diff against the change immediately before it, even though that change sits on the next page.

History for deleted objects

The history page does not require the object to still exist. A deleted Account, Site, or System is no longer listed in the interface, but its revision history remains reachable, and the page is titled from the object's last known state rather than from a bare ID.

This is deliberate: the trail of a deleted object is usually the one you most need, because it is the only record of who deleted it and when.

Related

- Manage Accounts — the Audit log of sign-in attempts.
- Role Permissions — which roles can see what.

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2.3.14 Search Tips and Tricks

Overview

The search functionality allows users to efficiently filter and locate specific entries across various lists, including:

- Mobile Assets
- Sites
- Systems
- System Profiles
- Accounts
- Audit (authentication attempts)

Searches can target all associated properties, whether or not they are displayed in the list view. This flexibility is enhanced by support for case-insensitive searches, partial-text queries, Boolean operators, parameter-based searches, and custom extensions.

While wildcards are not supported, the wide range of search methods ensures precise and efficient filtering.

Search Examples

GENERAL SEARCH TECHNIQUES

The following table outlines common search techniques applicable across multiple domains:

Search Type	Description	Example
Full Text	Use full text to focus on specific values. To eliminate partial matches, use single quotes.	`'823'` finds 823 but not 8234.
Partial Text	Use a minimum of 3 characters to find matches containing the input string.	`andr` finds all Android devices.
Boolean	Use Boolean operators (`AND` , `OR` , `NOT`) to refine searches.	`andr AND Canada` finds all Android devices in Canada.
Parameters	Search for a specific parameter value with or without single quotes.	`ICCID=89123` finds Mobile Assets containing `89123` ; `'ICCID=8912312312312312312'` finds exact matches.
Extensions	Custom parameters can be used to tag objects and search accordingly.	`user=joe` finds Mobile Assets tagged with the user value `Joe` (and `Joey` unless quoted).
Sessions	Search by session state.	`open` finds active sessions; `closed` finds disconnected sessions.

DOMAIN-SPECIFIC SEARCHES

Mobile Assets

Field	Description	Example
ID	The numerical suffix of an API endpoint URI for a Mobile Asset.	`id=222228100`
IMSI	Search by International Mobile Subscriber Identity.	`imsi=310150123456789`

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Field	Description	Example
Status	Filter by Mobile Asset state. Supported states: `Connected`, `Disconnected`, `Provisioned`, `Error`.	`status=connected`
System	Search by the name of the System associated with the Mobile Asset.	`system=MainNetwork`
Customer	Search by the Customer associated with the Mobile Asset.	`customer=AcmeCorp`
Location	Search by city name.	`location=chicago`
Country	Search by country code or name.	`country=ca` or `country=canada`
IMEI	Search by the device's International Mobile Equipment Identity.	`imei=123456789012345`

Sites

Field	Description	Example
ID	The numerical suffix of an API endpoint URI for a Site.	`id=333338900`
Customer	Search by Customer associated with the Site.	`customer=AcmeCorp`

Systems

Field	Description	Example
ID	The numerical suffix of an API endpoint URI for a System.	`id=444449700`
Customer	Search by Customer associated with the System.	`customer=AcmeCorp`

Accounts

Field	Description	Example
Email	Search by the account's email address.	`email=user@example.com`
External ID	Search by the alternate ID assigned to the account. Bare terms match it too.	`externalId=EMP-4471`
Customer	Search by the Customer associated with the account.	`customer=AcmeCorp`
Last Login Before	Find accounts with no successful sign-in since the given date, including accounts that have never signed in. The date must be in `YYYY-MM-DD` form and is evaluated as midnight UTC.	`lastLoginBefore=2025-01-10`

Audit

The **Audit** log records authentication attempts. Its search covers every recorded attempt, not only the rows on screen.

Field	Description	Example
Email	Search by the email address on the attempt.	`email=user@example.com`
IP	Search by the IP origin of the attempt.	`ip=192.0.2`
Type	Filter by outcome: `success`, `failure`, or `unknown`. `failed` and `error` are synonyms of `failure`.	`type=failure`

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Field	Description	Example
Account	Restrict results to one account, by account ID.	`account=123271682`
Customer	Search by the Customer that owns the account.	`customer=AcmeCorp`

Sessions

Field	Description	Example
Open	Find all currently active sessions.	`status=open`
Closed	Find all disconnected sessions.	`status=closed`

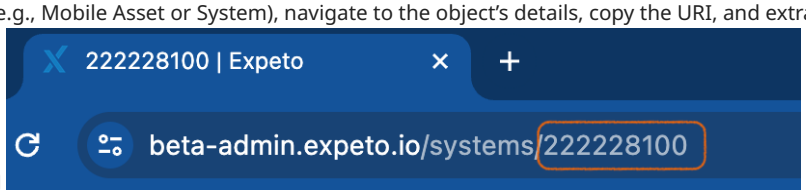
Extensions

Field	Description	Example
**Custom Tags **	Search for objects tagged with specific custom parameters. For example, search for `user=joe` to find assets tagged with `joe`.	`user=joe`

ADDITIONAL NOTES

- Searching by **location** or **country** includes both the device location (if available) and carrier details.
- To find an object's **ID** (e.g., Mobile Asset or System), navigate to the object's details, copy the URI, and extract the numerical identifier.

Example: `id=222228100`



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2.3.15 Extensions

Overview

Extensions are a powerful tool in Expeto xControl that allow users to customize configurations and extend functionalities beyond the standard GUI settings. They enable flexibility in managing Mobile Assets, System Profiles, Systems, Sites, and Customers by providing additional parameters that can enhance network operations.

Key features of Extensions include:

- Adding custom configurations, such as static IP addresses, to provide stability and reliability for connected devices.
- Tagging network elements with labels for better organization and easier searches.
- Enhancing features through scripts for tasks not available in the GUI.
- Strengthening security measures, such as IMEI locking, to restrict network access to authorized devices.

Extensions follow a hierarchical structure, enabling higher-level configurations to be overridden at more specific levels for greater control. They are instrumental in improving asset management, optimizing configurations, and ensuring secure and efficient network operations.

Searching for Mobile Assets with Extensions

Extensions enhance search functionality by allowing you to locate Mobile Assets or other entities based on custom labels or parameters. For example, if an extension labeled **Membership VIP** is applied to a Mobile Asset, searching for "vip" in the Mobile Assets list will return all assets tagged with this extension.



Extensions can be applied at different levels, such as the System Profile, System, or Mobile Asset. Conflicting extensions may exist, and searches will return all matching values.

Use Cases for Extensions

ADD A LABEL TO A MOBILE ASSET

A common use of Extensions is to add labels to Mobile Assets for easier identification and organization. Labels can also be used as search criteria in the search field. For example:

- To find all objects tagged with a specific label, search for the label name (e.g., **sim-type** or **user**).
- To find a specific value for a label, use `label=value` (e.g., **sim-type=UICC** or **user=lisa**).



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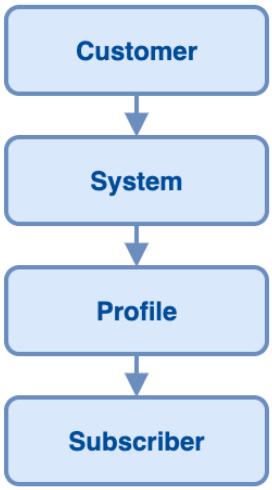
USING EXTENSIONS IN SCRIPTS

Extensions can be used to enhance functionality not currently available through the GUI. By tagging a Mobile Asset with an extension, you can find it using search or integrate it into scripts for automation.

Extension Hierarchy

Extensions follow a hierarchy, where values set at higher-level entities can be overridden by conflicting values set at lower levels. The hierarchy is as follows:

1. Customer
2. Site
3. System
4. System Profile
5. Mobile Asset



Note

While lower-level values override higher-level ones for functionality, searches use a logical OR and return all matches.

ASSIGN A STATIC IP ADDRESS

Assigning a static IP address to a Mobile Asset provides stability and reliability, especially for IoT devices requiring constant connectivity. A static IP address allows direct remote access to the device and can be whitelisted for firewall rules.



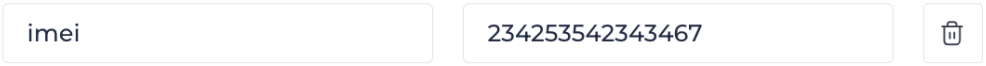
Conditions for Static IP Assignment:

- The keyword *ip* must be in lowercase.
- The IP address must belong to the subnet of the attached Mobile Asset.
- The IP address must be designated for static assignment and excluded from the dynamic IP pool.
- The device's APN must be configured correctly; otherwise, it will default to dynamic addressing.

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CONFIGURE IMEI LOCKING

The IMEI is a unique serial number assigned to a device by the manufacturer. IMEI locking enhances security by ensuring that a SIM card is used only in its designated device. If locked, the SIM card cannot access the network if moved to a different device.



Conditions for IMEI Locking:

- The keyword *imei* must be in lowercase.
- The value must be exactly 15 characters unless using the wildcard `*`.
- An IMSI can be locked to only one IMEI.

> **Note**
>
> You can display the IMEI on many devices by dialing `*#06#`.

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2.3.16 Key Sets

Keysets are collections of encryption keys and algorithms used to authenticate SIM cards and establish secure communication between Mobile Assets and the network. They ensure mutual trust and encrypted interactions, safeguarding the integrity of the system.

This section provides tools to manage Keysets, including adding new Keysets, mapping them to HSS Keyset Identifiers at specific Sites, and applying them during Mobile Asset setup. Proper Keyset management is essential for secure and efficient network operations.

Enable Keyset Authentication

Keyset authentication ensures secure communication and mutual trust between the SIM card and the network. It uses encryption keys and algorithms to verify the authenticity of Mobile Assets. Keysets are collections of encryption keys and algorithms that ensure secure SIM authentication and network integrity.

- **Loading Keysets**: Performed by the Expeto Site Installer during site setup: the SIM batch's transport key is loaded into the Site's subscriber store under the HSS Keyset Identifier.
- **Adding and Mapping Keysets**: Performed by a Network Administrator with Keyset permissions using Expeto xControl. The Site must have Keyset Mapping enabled by the Expeto Site Installer.
- **Applying Keysets**: Network Administrators assign Keysets when adding Mobile Assets (individually or via Bulk Import).

> **Note**
>
> A Keyset can only be assigned once to a Mobile Asset and cannot be changed.

Add a Keyset

Keysets are essential for enabling encrypted authentication and ensuring secure communication between Mobile Assets and the network. Adding a Keyset creates a reference that can be used during Mobile Asset configuration.

1. Navigate to the **Keysets** section in Expeto xControl. The list of existing Keysets will be displayed.
2. Click **New** to create a new Keyset.
3. Enter the following details:
    - **Name**: Provide a unique name for the Keyset.
    - **Customer**: Select the Customer that will use this Keyset.
    - **K4 Field Type**: Select which values of the SIM batch the SIM vendor encrypted under the transport key: **K Only**, or **K And OPC** when the OPc is encrypted as well. **None** means neither is encrypted.
4. Click **Submit** to save the new Keyset.

Once added, the Keyset will appear in the Keyset list and can be used for Mobile Assets at any Site belonging to the selected Customer.

> **Note**
>
> To enable encrypted authentication, the Keyset must be mapped to the HSS Keyset Identifier. See the next section for details.

Map a Keyset

Mapping a Keyset links it to the corresponding HSS Keyset Identifier (KSI) at a specific Site, enabling secure authentication for Mobile Assets. This step is essential to complete the Keyset configuration process.

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> **Note**
>
> The **Add Mobile Asset** permission is required to perform this task. The **CUSTOMER_ADMIN** role does not include the **Add Keyset Mapping** permission.

BEFORE YOU BEGIN

Ensure the following prerequisites are met:

- **Keyset Mapping**: Must be enabled for the Site by a Site Installer.
- **Keyset Loading**: The Site Installer must load the Keyset into the HSS.
- **HSS Keyset Identifier**: The Site Installer must provide the HSS Keyset Identifier.

TO MAP A KEYSET:

1. Navigate to the **Sites** section in Expeto xControl.
2. Select the Site where the Keyset will be mapped and click **Edit**.
3. Select the **Keyset Mappings** tab. If Keyset Mapping is not yet enabled for the Site, switch **Enable** on.
4. Click **Add Keyset Mapping**.
5. Select the **Keyset**.

   If no Keyset names are available, ensure you have added a Keyset.
6. Enter the **HSS Identifier** provided by the Site Installer: a whole number, such as `1`. It must equal the name the transport key was loaded under in the Site's subscriber store. `0` is reserved for Mobile Assets whose K is not encrypted.
7. Optionally, enter an **HSS Description** (for example, *Keyset for SIM batch 12*).
8. Click **Submit** to save the mapping.

> **Note**
>
> - The same Keyset can be referenced by multiple Sites owned by the same Customer.
> - Keysets must be loaded individually into each Site's HSS database.
> - The Keyset name must remain consistent across Sites, but the HSS Keyset Identifier may vary depending on how the Keyset was loaded.
>
> Mapping ensures that the Keyset is properly associated with the Site and can be used for Mobile Asset authentication.

Understanding SIM Authentication Security

Every SIM shares two secrets with the network: its key `K`, and `OPc`, a value derived from `K` and the operator variant. The network never sends either over the air. It authenticates the SIM with a challenge computed from them, and the SIM authenticates the network in return.

WHAT A KEYSET PROTECTS

The SIM vendor delivers each batch with `K`, and usually `OPc`, encrypted under the batch's transport key. The Keyset names that batch in xControl, and its **K4 Field Type** records which of the two values are encrypted. xControl stores the encrypted values as delivered and never holds the transport key. The Agent provisions the encrypted values into the Site's subscriber store with the HSS Keyset Identifier of the Keyset Mapping, and the subscriber store decrypts them with the transport key loaded under that identifier. A Mobile Asset's `K` and `OPc` therefore exist in clear only inside the subscriber store.

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THE AUTHENTICATION PROCESS

1. **Challenge.** When the device attaches or registers, the subscriber store generates a random challenge (`RAND`), an authentication token (`AUTN`) and the expected response (`XRES`) from the SIM's `K` and `OPc` and a sequence number.
2. **Network authentication.** The SIM checks `AUTN` with its own `K` and `OPc` . A valid token proves the challenge comes from the home network; the sequence number in it protects against replayed challenges.
3. **Device authentication.** The SIM computes its response (`RES`) from the challenge. The network compares it with `XRES` : the MME on 4G, the AUSF on 5G. A match authenticates the SIM, and both sides derive the keys that protect the device's signalling and traffic.

KEY TAKEAWAYS

- `K` and `OPc` never leave the subscriber store in clear and are never sent to the device.
- The transport key is loaded into each Site's subscriber store, never into xControl.
- A wrong transport key, or a Keyset Mapping whose identifier differs from the name the key was loaded under, fails every authentication of that batch.

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2.4 Installation

2.4.1 Planning and Prerequisites

This page lists what a Kubernetes cluster needs before xControl is installed on it, what to obtain from Expeto, and the decisions to make before you write the `values.yaml` for the install. Work through it once; the install page assumes everything here is in place.

Cluster requirements

Requirement	Detail
Kubernetes	A conformant cluster running Kubernetes 1.29 or later. `kubectl` (or `oc` on OpenShift) access with rights to create namespaces, CustomResourceDefinitions and cluster-scoped RBAC, because the chart installs the CloudNativePG operator.
Nodes	Three worker nodes. The database runs as a three-instance PostgreSQL cluster with one instance per node; on fewer nodes the extra instances stay `Pending`. Node sizes are in the sizing guide.
Storage	A default StorageClass providing `ReadWriteOnce` volumes. The database claims three volumes of 42 GiB each by default; xView adds 20 GiB for metrics. All of it should be redundant SSD-class storage.
Ingress controller	Any controller with an `IngressClass`. The chart renders Ingress objects for the dialects it knows: standard (including the open-source ingress-nginx), the NGINX Inc. operator, the OpenShift router, HAProxy and the AWS load balancer controller. The dialect is detected from the installed `IngressClass` objects.
DNS	One DNS name for the installation, for example `xcontrol.example.com`, resolving to the ingress controller. Users, Agents and xView reach xControl through that name.
TLS	A certificate for that name. Either let cert-manager issue it (the chart marks its Ingress objects for ACME when asked), reference an existing TLS Secret, or terminate TLS in front of the cluster.
cert-manager	Optional. The chart can install it as a dependency when the cluster has none. Do not enable that on a cluster that already runs cert-manager, for example through an OpenShift operator.
Outbound access	The nodes pull images from `docker.expeto.io`, and the machine running Helm pulls charts from `repo.expeto.io`.
Inbound access	Users on the ingress name over HTTPS. Every Site's Agent also connects to that name over HTTPS; nothing else is inbound. xControl itself makes no connection to the Sites.

Tools

- `kubectl` (or `oc`), configured for the target cluster and namespace.
- Helm 3.17 or later. Upgrades of release 3.3.22 and later adopt the bundled CustomResourceDefinitions with `--take-ownership`, which earlier Helm versions lack.
- `jq`, used by the credential commands on the install page.

Any GitOps system that renders Helm charts, such as Argo CD or Flux, works as well. See GitOps installs below for the values that change in that mode.

What to obtain from Expeto

Expeto Support issues one set of credentials per installation. The same username and password authenticate both the Helm repository and the container registry, and the chart writes them into the image pull Secret it creates.

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Decisions to make before installing

Decision	Value	Notes
Hostname	`global.config.primaryDomain`	The DNS name above. Additional names go in `global.config.extraDomains`.
TLS	`global.config.acmeTls`	`true` annotates every Ingress for cert-manager's ACME issuer. Alternatively set a TLS Secret under `global.config.frontend.ingress.tls`.
Ingress dialect	`global.config.frontend.ingress.flavor`	Detected on a live install. Set it explicitly whenever the chart is rendered without cluster access, which is the case in GitOps pipelines and with `helm template`.
Monitoring	`xview.enabled` or `kubemonitoring.enabled`	xView is the platform monitoring system and includes Grafana; `kubemonitoring` is a namespace-scoped Prometheus for the xControl workloads alone. Enable one of the two, never both: the chart refuses to install with both enabled.
Database topology	`cluster.mode`	`standalone` for a single installation. `replica` builds a hot standby of another installation at a second site; see Upgrade, backup and geo-redundancy.
Backups	`cluster.backups`	Continuous WAL archiving and scheduled base backups to S3-compatible object storage. Decide the bucket and retention before go-live.
Platform	`global.k8sPlatform`	Detected. Override only when rendering offline for a specific platform (`openshift`, `eks`, `aks`, `microk8s`, `tanzu`).

GitOps installs

When a pipeline renders the chart and applies the manifests, Helm's cluster lookups return nothing. Set these values so the rendered output does not depend on them:

```
global:
  createSecrets: false      # supply the database and application Secrets yourself
  config:
    frontend:
      ingress:
        flavor: standard    # or the dialect your controller speaks
imagePullSecrets:
  - name: expeto
    create: false           # the pull Secret already exists in the namespace
```

Render once with `helm template` to see the names and shape of the Secrets the chart expects, then create them from your secret store before the first sync.

Namespace

Install xControl into its own namespace. The examples in this section use `xcontrol` as both the namespace and the Helm release name. On OpenShift, create a project instead of a namespace.

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2.4.2 Install with Helm

xControl is installed as one Helm release from Expeto's chart repository. This page takes you from an empty namespace to the first login; it assumes the cluster meets the prerequisites and that you have the credentials issued by Expeto Support.

Add the Helm repository

```
helm repo add expeto https://repo.expeto.io/repository/ngc \
  --username '<username>' --password '<password>'
helm repo update
helm search repo expeto/xcontrol
```

The search must list the `xcontrol` chart. If it does not, check the credentials and that the machine can reach `https://repo.expeto.io`.

Write the values file

Keep the deployment-specific settings in a `values.yaml` file under version control; it is the source of truth for the installation and the input to every later upgrade. A minimal file for a cluster with a working ingress controller and a cert-manager ACME issuer looks like this:

```
global:
  config:
    primaryDomain: xcontrol.example.com
    acmeTls: true
xview:
  enabled: true
kubemonitoring:
  enabled: false
```

- `global.config.primaryDomain` is the hostname on every Ingress the chart renders and the base of every URL xControl hands out, so it must be the name users and Agents resolve.
- `global.config.acmeTls` annotates the Ingress objects for cert-manager. Leave it `false` when TLS terminates elsewhere or when you reference an existing certificate Secret instead.
- `xview.enabled` installs the monitoring system alongside xControl. `kubemonitoring` is the alternative Prometheus-only option; the two are mutually exclusive.

Every other value has a working default. The configuration reference lists the ones you are most likely to change.

> **Note**
>
> Registry credentials are passed on the command line rather than stored in the values file. The chart writes them into the `expeto` image pull Secret and never reads them again.

Install

```
kubectl create namespace xcontrol
helm install xcontrol expeto/xcontrol -n xcontrol -f values.yaml \
  --set imageCredentials.username='<username>' \
  --set imageCredentials.password='<password>' \
  --set imageCredentials.email='user@example.com'
```

Quote every `--set` value in single quotes so the shell and Helm's type coercion leave it alone.

The release installs the CloudNativePG operator and its CustomResourceDefinitions, bootstraps the PostgreSQL cluster, runs the database migrations, imports the Keycloak realm and then starts the API server and the frontend. Expect several minutes on a fresh cluster, most of it spent pulling images and initialising the three database instances.

```
kubectl -n xcontrol get pods -w
```


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When the install has settled, the namespace contains these workloads (names carry the release name as a prefix):

Workload	Kind	Purpose
`xcontrol-api`	Deployment	API server
`xcontrol-frontend`	Deployment	Web interface
`keycloak`	StatefulSet	Single sign-on
`activemq`	StatefulSet	Message broker
`cloudnative-pg`	Deployment	PostgreSQL operator
`cluster-1` , `cluster-2` , `cluster-3`	Pods	PostgreSQL instances managed by the operator
`expeto-docs-full` , `expeto-docs-user`	Deployment	Platform Guide and End-User Guide
`xview-deployment` , `grafana-operator` , `victoria-metrics-operator` , `vmsingle-*` , `vmagent-*` , `vmalert-*` , `vmalertmanager-*` , `vmauth-*` , `kube-state-metrics` , `prometheus-node-exporter`	Deployments, StatefulSets, DaemonSet	xView, when enabled

Helm also prints the commands below in its release notes.

First login

The install generates an administrator Account and stores its credentials in a Secret named `<release>-xcontrol-admin-credentials` :

```
kubectl -n xcontrol get secret xcontrol-xcontrol-admin-credentials \
  -o jsonpath='{.data.username}' | base64 -d; echo
kubectl -n xcontrol get secret xcontrol-xcontrol-admin-credentials \
  -o jsonpath='{.data.password}' | base64 -d; echo
```

Open `https://xcontrol.example.com/ngui/` , sign in through Keycloak with those credentials, and change the password as described in Getting Started.

The Keycloak administration console is at `https://xcontrol.example.com/auth/` . Its `admin` user's password is in the `<release>-keycloak-admin` Secret under the `password` key. xControl users live in the `expeto` realm.

OpenShift

The chart detects OpenShift and switches to the router's Ingress dialect, OpenShift-compatible security context constraints and the project's assigned user ID range. Two things differ from a plain Kubernetes install:

- Create a project instead of a namespace (`oc new-project xcontrol`) and use `oc` where this guide says `kubectl` .
- Leave `cert-manager.enabled` and `kubemonitoring.enabled` at `false` . OpenShift's cluster operators own the cert-manager and Prometheus CustomResourceDefinitions, and a second copy installed by Helm fails on the ownership conflict. Use the cert-manager Operator from OperatorHub for certificates and xView for monitoring.

Next steps

Continue with Verify the installation to confirm the endpoints answer and to connect the first Site.

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2.4.3 Configuration Reference

The xControl chart is configured entirely through Helm values. This page lists the values an installer or operator of the deployment is most likely to set, grouped the way they appear in `values.yaml`. Run `helm show values expeto/xcontrol` for the complete file with its inline comments, and keep your overrides in the `values.yaml` you install from.

Values not listed here have defaults that suit a production install.

Images and credentials

Value	Default	Purpose
`image.repository`	`docker.expeto.io`	Registry the xControl images are pulled from.
`image.tag`	chart `appVersion`	Override to pin a specific build.
`imageCredentials.username`, `.password`, `.email`	unset	Registry credentials written into the pull Secret. Pass them with `--set` at install and upgrade time.
`imagePullSecrets[].name`, `.create`	`expeto`, `true`	Name of the pull Secret and whether the chart creates it. Set `create: false` when the Secret is managed outside Helm.
`global.imageRegistry`	`docker.expeto.io`	Registry for the dependency charts' images. Point it at a mirror for air-gapped clusters.

Hostname, ingress and TLS

Value	Default	Purpose
`global.config.primaryDomain`	`xcontrol.example.com`	Hostname of the installation. Used on every Ingress and in every URL xControl issues.
`global.config.extraDomains`	unset	Additional hostnames the Ingress objects answer on.
`global.config.acmeTls`	`false`	Annotate the Ingress objects for cert-manager's ACME issuer (`kubernetes.io/tls-acme`). Requires a default issuer in the cluster.
`global.config.frontend.basePath`	`ngui`	Path of the web interface.
`global.config.frontend.ingress.flavor`	detected	Ingress controller dialect: `standard`, `nginx-mergeable`, `haproxy-openshift`, `haproxy` or `alb`. Set explicitly for GitOps renders.
`global.config.frontend.ingress.defaultClassName`	unset	`IngressClass` to request when the cluster has more than one.
`global.config.frontend.ingress.tls.secretName`	unset	Existing TLS Secret to use instead of an ACME certificate.
`global.config.frontend.ingress.annotations`	unset	Annotations added to every generated Ingress, for example external-dns hints.

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Value	Default	Purpose
`global.config.frontend.ingress.alb.*`	unset	AWS load balancer controller settings (`scheme` , `certificateArn` , `groupOrder`) when the flavor is `alb` .
`global.config.frontend.ingress.nginx-mergeable.*`	unset	Issuer or wildcard Secret for the master Ingress when the flavor is `nginx-mergeable` .
`ingress-nginx.enabled`	`false`	Install the reference ingress-nginx controller as a dependency. Only for clusters that have no ingress controller at all.
`global.networks.ingress`	`create: false`	MetalLB address pool and advertisement for the ingress controller's LoadBalancer Service on bare-metal clusters.

Single sign-on

Value	Default	Purpose
`global.config.keycloak.realm.name`	`expeto`	Realm that holds the xControl users.
`global.config.keycloak.realm.accessTokenLifespan`	`300`	Access token lifetime in seconds.
`global.config.keycloak.realm.ssoSessionIdleTimeout`	`1800`	Idle timeout of a browser session in seconds.
`global.config.keycloak.realm.ssoSessionMaxLifespan`	`36000`	Maximum lifetime of a browser session in seconds.
`keycloak.production`	`false`	Keycloak production mode. Set `true` for a production install.
`keycloak.resources`	preset	CPU and memory for the Keycloak pod.

Database

The database is a PostgreSQL cluster managed by the CloudNativePG operator, installed by the chart.

Value	Default	Purpose
`cloudnative-pg.enabled`	`true`	Install the operator. Disable on a cluster that already runs it (it is cluster-scoped, one copy per cluster).
`cluster.mode`	`standalone`	`standalone` , `replica` (hot standby of another installation) or `recovery` (rebuild from a backup).
`cluster.cluster.instances`	`3`	PostgreSQL instances. Each needs its own node.
`cluster.cluster.storage.size`	`42Gi`	Data volume per instance.
`cluster.cluster.storage.storageClass`	default class	StorageClass for the data volumes.

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Value	Default	Purpose
`cluster.cluster.postgresql.synchronous`	`any` , `1`	Synchronous replication: one standby must confirm every commit.
`cluster.cluster.postgresql.parameters`	see file	Tuning such as `shared_buffers` , `work_mem` , `max_connections` .
`cluster.backups.enabled`	`false`	Continuous WAL archiving and scheduled base backups to object storage.
`cluster.backups.endpointURL` , `.provider` , `.s3.*`	unset	Object store endpoint, region, bucket, path and credentials.
`cluster.backups.scheduledBackups[].schedule`	see file	Base backup schedule in CloudNativePG's six-field cron form (seconds first); `0 0 0 * * *` is daily at midnight.
`cluster.backups.retentionPolicy`	`3d`	How long backups are kept.
`cluster.recovery.*`	unset	Source object store and cluster name when `cluster.mode` is `recovery` .
`cluster.replica.*`	unset	Primary connection details when `cluster.mode` is `replica` ; the primary's release notes print the exact command.
`global.database.waitForWritable`	`true`	Hold application pods in an init container until the database accepts writes, so a standby site waits instead of crash-looping.
`global.database.passwords.*` , `global.database.encodedPasswords.*`	unset	Fix the superuser and per-role passwords instead of generating them, needed when a replica must match its primary.
`global.createSecrets`	`true`	Generate all application Secrets with random passwords. Set `false` under GitOps and supply them yourself.

Application

Value	Default	Purpose
`jvm.memorySize`	`2g`	Heap of the API server JVM.
`volume.size`	`512Mi`	Working volume for xControl state.
`deployments.api.autoscaling.enabled`	`false`	Horizontal Pod Autoscaler for the API server; `minReplicas` , `maxReplicas` and `targetCPUUtilizationPercentage` alongside.

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Value	Default	Purpose
`resources`	unset	Requests and limits for the API server container.
`nodeSelector` , `tolerations` , `affinity`	unset	Standard scheduling controls for the API server.
`global.manualNodeConfig`	`true`	xControl needs no kernel or NIC tuning, so the node-configuration DaemonSet is not deployed.

Monitoring and documentation

Value	Default	Purpose
`xview.enabled`	`false`	Install xView (VictoriaMetrics, Grafana, alerting) with the release. Mutually exclusive with `kubemonitoring.enabled` .
`xview.storage.size`	`200Mi`	Grafana storage.
`xview.victoria-metrics-k8s-stack.*`	see file	Metrics retention, storage and dashboard settings; see xView.
`kubemonitoring.enabled`	`true`	Namespace-scoped Prometheus for the xControl workloads only. Disable when xView is enabled and on OpenShift.
`expeto-docs.ingress.enabled`	`true`	Serve the Platform Guide and End-User Guide from the installation.

Geo-redundancy

Value	Default	Purpose
`xcontrol-operator.enabled`	`false`	Deploy the cross-site failover witness. Only meaningful on a third cluster that can reach both sites' Kubernetes APIs; see Upgrade, backup and geo-redundancy.
`xcontrol-operator.mode`	`monitor`	`monitor` observes and alerts; `witness` arms automatic failover after `config.witness.failAfter` .
`xcontrol-operator.config.sites.<name>.*`	unset	Namespace, cluster name, Postgres host and optional kubeconfig Secret for each site.

Platform

Value	Default	Purpose
`global.k8sPlatform`	detected	Force a platform profile (`openshift` , `eks` , `aks` , `microk8s` , `tanzu`) when rendering without a cluster.
`global.defaultUid`	`337`	User ID for the non-root containers. OpenShift assigns its own range and the chart follows it.
`global.eks.karpenter.*`	disabled	Karpenter node provisioning on EKS.
`spring.profiles`	`sql,keycloak,fast,k8s`	Application profiles. Do not change on a production install.

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2.4.4 Verify the Installation

After `helm install` reports success, confirm that every tier of xControl answers before you hand the installation over or connect the first Site. The checks below take a few minutes and need only `kubectl` and a browser.

Workloads

All pods in the namespace must be `Running` (or `Completed` for one-off jobs) with no restarts accumulating:

```
kubectl -n xcontrol get pods
kubectl -n xcontrol get pods --field-selector=status.phase!=Running,status.phase!=Succeeded
```

The second command lists anything unhealthy and should print nothing. A pod stuck in `Init` is usually waiting for the database: `kubectl -n xcontrol describe pod <pod>` names the init container, and `kubectl -n xcontrol get clusters.postgresql.cnpg.io` shows whether the PostgreSQL cluster is `Cluster in healthy state`.

Helm's own smoke test connects to the API server from inside the cluster:

```
helm test xcontrol -n xcontrol
```

Endpoints

Every Ingress must carry the hostname you configured and an address:

```
kubectl -n xcontrol get ingress
```

Then, from a machine that resolves the hostname:

Check	URL	Expected
API liveness	`https://xcontrol.example.com/alive`	HTTP 200
Web interface	`https://xcontrol.example.com/ngui/`	The login page, redirected through Keycloak
Single sign-on	`https://xcontrol.example.com/auth/realms/expeto`	Realm metadata as JSON
Platform Guide	`https://xcontrol.example.com/admin-docs/`	This documentation
xView, when enabled	`https://xcontrol.example.com/nms/`	Grafana, signed in through Keycloak

```
curl -sS -o /dev/null -w '%{http_code}\n' https://xcontrol.example.com/alive
```

Sign in to the web interface with the administrator credentials from the install page and confirm the Dashboard loads.

Connect the first Site

A Site in xControl represents one xCore or xRouter installation. Its Agent authenticates with a Site identifier and an API token that you create here before installing the core.

1. In the web interface, go to **Sites** and click **Add** to create the Site. Give it the name the network team knows it by, select its **Customer**, and set **Site type** to **xCore** or **xRouter**. The Site's numeric identifier appears in its URL and on its detail page; the core's Helm values refer to it as the site ID.
2. Open the Site, click **Edit** and select the **API Tokens** tab.
3. Switch **Enable** on to allow API tokens for this Site, then click **Add** and name the token. Copy the token value when it is shown; it is the core's `apiToken` and is not displayed again.
4. Create at least one System under the Site so the core has a network segment to serve, following Systems.

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Through the REST API the same steps are `POST /v1/sites`, `POST /v1/site-feature-api-tokens` with `type: api_token_site_feature`, and `POST /v1/sites/command/createToken`.

Once the core is installed with that Site identifier and token, the Site shows **Connected** in the Sites list within a minute, and its Agent version and IP address appear on the detail page. A Site that stays **Disconnected** has not reached xControl: check that the core resolves and can reach `https://xcontrol.example.com` on port 443, and that its Helm values carry the right identifier and token.

Where to look when something fails

Symptom	Where to look
Pods `Pending`	`kubectl -n xcontrol describe pod <pod>`: node resources, or a PersistentVolumeClaim with no StorageClass to bind to.
Database instances not all ready	`kubectl -n xcontrol describe clusters.postgresql.cnpg.io`; one instance per node is required.
Login page loads, sign-in fails	Keycloak pod logs: `kubectl -n xcontrol logs statefulset/xcontrol-keycloak`.
API answers, web interface blank	Browser console for a blocked cross-origin request; the frontend and API must share the hostname.
Certificate errors	`kubectl -n xcontrol get certificates,certificaterequests` when cert-manager issues the certificate; the issuer must be able to solve the ACME challenge on the hostname.
Agent never connects	API server logs: `kubectl -n xcontrol logs deployment/xcontrol-xcontrol-api`, filtered on the Site identifier.

For platform-wide monitoring and alerting after go-live, see xView and the xControl alerts.

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2.4.5 Upgrade, Backup and Geo-Redundancy

This page covers the day-two operation of an xControl installation: upgrading the release, backing up and restoring the database, running a hot standby at a second site, and switching roles between sites. Everything here is driven by the same `values.yaml` you installed from.

Upgrade

Upgrade by re-running Helm with the same values file and the credentials:

```
helm repo update
helm upgrade xcontrol expeto/xcontrol -n xcontrol -f values.yaml \
  --set imageCredentials.username='<username>' \
  --set imageCredentials.password='<password>' \
  --set imageCredentials.email='user@example.com'
```

The values file is yours: it holds every setting of the installation, lives in version control, and is passed on every upgrade together with the credentials, exactly as at install time. Anything it does not mention takes the chart's default for the new release. If no values file is kept, `helm upgrade xcontrol expeto/xcontrol -n xcontrol --reuse-values` carries the current release's values forward, credentials included.

Database migrations run automatically before the new API server starts. Pin a version with `--version` when you need to control exactly which chart is installed, and review `helm diff` output or a `helm template` render before upgrading a production installation.

> **Important**
>
> Never change a running installation with `kubectl edit` or `kubectl scale`. The next `helm upgrade` re-applies the values file and reverts the change. Put every setting in `values.yaml`.

ADOPT THE CUSTOMRESOURCEDEFINITIONS ONCE

From release 3.3.22 the chart installs and upgrades the CustomResourceDefinitions of the operators it bundles itself: CloudNativePG, the Prometheus Operator and, with xView, VictoriaMetrics. Helm installs them on the first install but does not own them yet, so the first upgrade after an installation of 3.3.22 or later, and the upgrade from 3.3.21 or earlier to 3.3.22, stops before changing anything and prints the command that adopts them. Run that one upgrade with `--take-ownership` and `global.crds.ignoreOwnershipCheck=true`, which needs Helm 3.17 or later:

```
helm upgrade xcontrol expeto/xcontrol -n xcontrol -f values.yaml --take-ownership \
  --set global.crds.ignoreOwnershipCheck=true \
  --set imageCredentials.username='<username>' \
  --set imageCredentials.password='<password>' \
  --set imageCredentials.email='user@example.com'
```

Later upgrades need neither setting. A CustomResourceDefinition that another Helm release or OLM manages stops the upgrade with a message naming the manager; on OpenShift the platform keeps the Prometheus Operator's and the chart leaves them alone.

Scaling the API server

The API server is the only stateless tier you scale. Enable the Horizontal Pod Autoscaler in `values.yaml`:

```
deployments:
  api:
    autoscaling:
      enabled: true
      minReplicas: 2
      maxReplicas: 4
      targetCPUUtilizationPercentage: 80
```

Keycloak, ActiveMQ and the database are sized through their own sections of the values file; see the configuration reference and the sizing guide.

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Database backups

The PostgreSQL cluster is managed by the CloudNativePG operator, which archives write-ahead logs continuously and takes scheduled base backups to S3-compatible object storage when backups are enabled:

```
cluster:
  backups:
    enabled: true
    provider: s3
    endpointURL: https://s3.example.com
    s3:
      region: us-east-1
      bucket: xcontrol-backups
      path: /production
      accessKey: <access key>
      secretKey: <secret key>
    scheduledBackups:
      - name: daily
        schedule: "0 0 0 * * *"     # six fields, seconds first: daily at midnight
        backupOwnerReference: self
    retentionPolicy: 30d
```

Check the state of backups with the operator's resources:

```
kubectl -n xcontrol get backups.postgresql.cnpg.io
kubectl -n xcontrol get scheduledbackups.postgresql.cnpg.io
```

Keep the `values.yaml` and the Secrets it generated (`kubectl get secret -n xcontrol -o yaml`) alongside the backups. Together they are sufficient to rebuild the installation.

Restore

To rebuild an installation from object storage, install a new release with `cluster.mode` set to `recovery` and point it at the backup:

```
cluster:
  mode: recovery
  recovery:
    method: object_store
    clusterName: xcontrol-cluster       # name of the cluster that wrote the backups
    provider: s3
    endpointURL: https://s3.example.com
    s3:
      region: us-east-1
      bucket: xcontrol-backups
      path: /production
      accessKey: <access key>
      secretKey: <secret key>
```

The operator restores the latest base backup, replays the archived logs and then hands the cluster to the application. Because the application passwords are stored in the database, set `global.database.passwords` (or `encodedPasswords`) to the values of the original installation so the new Secrets match the restored roles.

Hot standby at a second site

An xControl installation can run a streaming replica of its database in another Kubernetes cluster. The replica site runs the full chart, with its application pods held back until its database is promoted, so it becomes a working xControl within minutes of a failover. Local failover inside one cluster (a lost node or instance) needs none of this: the operator promotes a synchronous standby automatically without data loss.

The primary's Helm release notes (`helm get notes xcontrol -n xcontrol`) print the exact command for its replica, including the encoded passwords the replica must share. In outline:

1. Copy the shared certificate authority Secret `expeto-shared-ca` from the primary's namespace to the replica's cluster and namespace.
2. Install the chart at the replica site with `cluster.mode=replica` , `cluster.replica.primary` set to the primary's release name, the `pg_basebackup` origin pointing at the primary's externally reachable PostgreSQL host, and `cluster.cluster.certificates.serverAltDNSNames` set to the replica's own externally reachable host.
3. Re-run that command after every upgrade of the primary so the replica's credentials stay in step.

The `kubectl-xcontrol` plugin performs the same steps in one command:

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```
kubectl xcontrol init                          # record both sites' contexts and namespaces
kubectl xcontrol install-replica --to <standby site> --chart expeto/xcontrol -- -f values.yaml
kubectl xcontrol status                        # roles and health of both sites
```

Switchover and failover

Role changes between sites are always run with the plugin; it patches the CloudNativePG cluster resources directly and guarantees the ordering.

Situation	Action
Planned maintenance at the primary site	`kubectl xcontrol switchover --to <site>` demotes the primary cleanly and promotes the replica with zero data loss.
Primary site lost	`kubectl xcontrol failover --to <site> --confirm` promotes the replica. Writes not yet replicated are lost.
Recovered former primary	`kubectl xcontrol rejoin --site <site> --confirm` re-bootstraps it as a replica. Never let a fenced former primary take writes again without this step.
Database pod or node lost inside one site	Nothing. The operator promotes a local standby automatically.
Sites partitioned but the replica still streams	Nothing. Do not force a failover during a partition.

After a switchover or failover the cluster resources no longer match each release's declared `cluster.mode`. Re-run the `helm upgrade` for both releases with the roles swapped in their values at the next opportunity; an upgrade with the old values would otherwise re-assert the old roles.

FAILOVER WITNESS

The chart can deploy a witness (`xcontrol-operator.enabled=true`) at a third location that watches both sites. In `monitor` mode it counts down a failing primary and alerts; a human then runs the failover after checking the blast radius. `witness` mode arms automatic failover after `config.witness.failAfter` . Arm it only from a genuine third location, after failover drills and with an alert path for every witness log line: with two sites there is no quorum, a witness that cannot reach the primary cannot tell a dead site from a network partition, and a promotion during a partition creates a split brain. The witness never fails back; returning a site to service is always a deliberate step.

```
helm install failover-witness expeto/xcontrol -n xcontrol-witness --create-namespace \
  --set xcontrol-operator.enabled=true \
  --set xcontrol-operator.mode=monitor \
  --set xcontrol-operator.config.sites.site-a.namespace=xcontrol \
  --set xcontrol-operator.config.sites.site-a.cluster=xcontrol-cluster \
  --set xcontrol-operator.config.sites.site-a.host=xcontrol-cluster-rw.xcontrol.svc.cluster.local \
  --set xcontrol-operator.config.sites.site-b.namespace=xcontrol \
  --set xcontrol-operator.config.sites.site-b.cluster=xcontrol-standby-cluster \
  --set xcontrol-operator.config.sites.site-b.host=xcontrol-standby-cluster-rw.xcontrol.svc.cluster.local \
  --set xcontrol-operator.config.sites.site-b.kubeconfigSecret=site-b-kubeconfig \
  --set xcontrol-operator.config.witness.failAfter=3m
```

Sites in the witness's own cluster are reached with its service account; remote clusters through kubeconfigs mounted from Secrets.

Uninstall

```
helm uninstall xcontrol -n xcontrol
kubectl delete namespace xcontrol
```

Helm does not remove the CloudNativePG CustomResourceDefinitions or the PersistentVolumeClaims of the database. Delete the claims only when you are certain the data is no longer needed, and keep the CustomResourceDefinitions if another release on the cluster uses the operator.

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3. xView

3.1 xView Guide

xView is the monitoring system for the Expeto Platform. It collects metrics from every site in a deployment — xCore and xRouter alike — as well as from xControl and the infrastructure they all run on, stores them centrally, evaluates alerts against them, and presents them as dashboards. The result is one operational view of an estate that may span many sites, customers and networks.

This page introduces xView and points to the reference material. If you are trying to understand how the data reaches xView, start with xView Architecture; if you just want to look at a dashboard, go to Accessing xView.

3.1.1 What xView does

- **Collects** metrics from the network functions, hosts and Kubernetes clusters at every xCore and xRouter site, and from xControl itself.
- **Stores** them centrally, alongside xControl, with a retention window covering a month of operational history.
- **Evaluates alerts** continuously, so a developing problem raises a notification rather than waiting to be noticed.
- **Presents** the result as dashboards covering the whole deployment, a single site, or a single component.

Two properties of the design are worth knowing up front, because they explain most of what you will observe:

Sites are never connected to from outside. A site may sit inside an enterprise network, behind a firewall the platform cannot reach through. So no site is polled: the Expeto Agent at each site pushes its metrics outward to xControl, and xView collects from xControl. Only outbound connectivity is ever required at a site, whether it is an xCore or an xRouter.

Every metric carries the identity of where it came from. Site and customer labels are attached centrally as metrics arrive, so one alert rule covers every site, and any query can be narrowed to a customer or a site without per-site configuration. This is covered in Metric Labels and Conventions.

3.1.2 What xView is built from

xView is assembled from established open-source monitoring components, configured and integrated for the platform, with Expeto's own alert rules, dashboards and collection configuration on top:

- **VictoriaMetrics** stores the metrics and answers queries. It speaks PromQL, so existing Prometheus knowledge, queries and exporters carry over unchanged.
- **vmagent** scrapes the configured targets; **vmalert** evaluates the alert rules; **Alertmanager** routes what fires.
- **Grafana** provides the dashboards and an interactive query interface.
- **node_exporter** and **kube-state-metrics** cover host and Kubernetes health.

The full component list, with upstream documentation links, is in xView Architecture.

3.1.3 Suspending monitoring for planned work

Taking a site down for maintenance without suppressing its alerts produces a flood of notifications for a problem you already know about. Mark the Site's state in xControl instead — the platform's alert rules all honor it.

The procedure is in suspending monitoring for a site.

3.1.4 How alerts work

Every alert is defined by a PromQL expression evaluated on a schedule, a duration the condition must hold, a severity, and annotations that describe what happened.

An alert becomes **pending** the moment its expression is true, and **firing** once it has stayed true for the configured duration. That delay is what prevents a brief spike from paging anyone. It clears automatically when the expression stops being true.

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Some alerts escalate. Where a condition matters more the longer it persists, the alert has Tier2 and Tier3 variants that fire after longer durations — a site out of contact for four hours is a different problem from one out of contact for five minutes, and they are distinguishable without anyone having to watch the clock.

Severity is the intended response:

Severity	Meaning
Critical	Service is impacted or imminently at risk — act now.
Warning	Something is wrong and needs investigation soon, but service is not yet impacted.
Info	An awareness signal. Review, but no immediate action is implied.

Alerts carry labels identifying the customer, site and component affected, and their annotations quote both the human-readable names and the stable identifiers, so a notification is actionable without having to look anything up.

> **Important**
>
> Alert delivery is configured per deployment. Until Alertmanager has a receiver configured, alerts fire and are visible in the interfaces but no notification is sent — see alert delivery.

3.1.5 Where to go next

If you want to	Read
Understand how metrics reach xView	xView Architecture
Open a dashboard or run a query	Accessing xView
Know which exporter produces what	Data Sources and Exporters
Write a query or an alert expression	Metric Labels and Conventions
Add alerts of your own	Custom Alerts and Rules
Look up a specific metric	xCore Metrics, xControl Metrics, Infrastructure Metrics
See every scrape job	Monitored Endpoints
Understand an alert that has fired	xCore, xControl, Platform and Infrastructure, Kubernetes and Monitoring Stack

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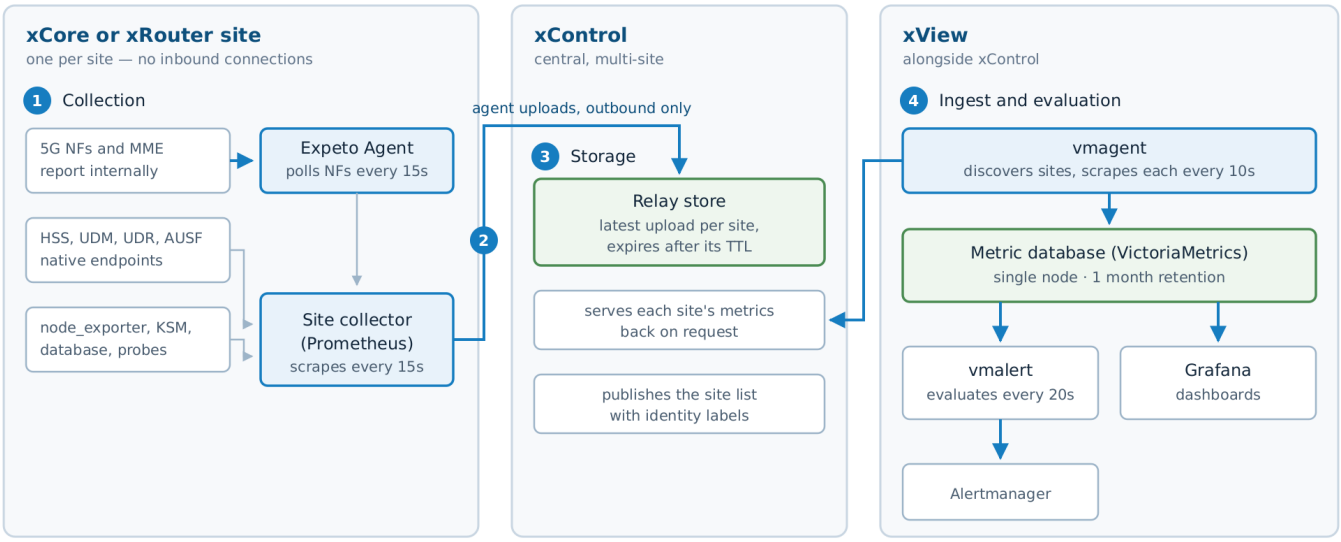
3.2 xView Architecture

xView collects metrics from every site in a deployment — xCore and xRouter alike — and stores them centrally, next to xControl, where alerts are evaluated and dashboards are drawn. This page explains how the metrics get there: what runs at a site, how a site's data reaches xControl without any inbound connection, and what xView does with it once it arrives.

xCore and xRouter are monitored by exactly the same mechanism: the same Expeto Agent relays what the site collector holds, so everything below applies to either; where this page says "a site", read "an xCore or xRouter site". The xRouter chart installs the site collector; on an xCore it is enabled at installation, as described in Verify the installation. xView additionally scrapes xControl directly, and the Kubernetes infrastructure of the cluster it runs in.

The one design constraint that shapes everything else is that **a site is never connected to from outside**. A site may sit behind a firewall the platform cannot reach through, so no site is polled. Instead each site pushes outward to xControl, and xView collects from xControl.

3.2.1 The path a metric takes



A single measurement — say a PFCP message counter in the SMF — travels four stages:

1. **Collection at the site.** The measurement is exposed by an exporter and scraped by the site collector, a Prometheus instance running inside the site's cluster.
2. **Relay to xControl.** The Expeto Agent reads the collector's accumulated metrics and uploads them to xControl over the same outbound connection it already uses for configuration.
3. **Storage at xControl.** xControl keeps the most recent upload from each site and serves it back on request.
4. **Ingest at xView.** xView discovers the sites from xControl and scrapes each one's metrics through xControl, writing them into its own database, where alerts and dashboards read them.

Stage 1 — collection at the site

Not every network function exposes metrics the same way, and this is the part that surprises people most often. There are three routes, described in full in Data Sources and Exporters:

- **The Expeto Agent acts as the exporter** for the 5G network functions and the MME. Those functions do not serve a metrics endpoint of their own; they report counters internally, and the agent polls them every 15 seconds and republishes everything as Prometheus metrics on its own endpoint. Most `xcore_*` metrics you will ever query arrive this way.

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- **Some functions expose Prometheus natively** — HSS, UDM, UDR and AUSF each serve their own metrics endpoint, which the collector scrapes directly.
- **Third-party exporters** cover everything that is not an Expeto component: hosts, Kubernetes objects, the site database, and synthetic probes.

The site collector scrapes all of these every 15 seconds and keeps roughly three days of history in no more than 10 GB. That local history is a buffer, not an archive — it exists so a temporary loss of connectivity to xControl does not lose data outright.

Stage 2 — relay to xControl

The Expeto Agent runs a metric upload loop. For each monitoring endpoint configured for the site, it fetches that endpoint's URL and posts the response to xControl:

- It requests compressed data and **relays the compressed bytes without decompressing them**, so a site's upload stays small over what is often a constrained link.
- It posts to xControl with a time-to-live equal to the endpoint's scrape interval, so xControl knows exactly how long the data it is holding should be considered current.
- Fetches use short timeouts — a few seconds — so a wedged endpoint delays one upload rather than stalling the loop.

In a standard deployment the endpoint the agent fetches is the site collector's federation endpoint, which returns every series the collector holds in one response. This is why the whole of a site's monitoring arrives at xControl as a single upload, rather than xView having to know about each exporter at each site.

Monitoring endpoints are configuration, not code: they are records in xControl, one per site, each with a URL, a scrape interval and a job name. Adding a new source of metrics at a site is an xControl change, described in Data Sources and Exporters.

Stage 3 — storage at xControl

xControl stores the most recent upload per site and serves it back on demand. Two details matter operationally:

- **It is a cache, not a proxy.** When xView asks xControl for a site's metrics, xControl answers from the stored copy. It does not reach out to the site. A site that is unreachable therefore cannot slow down or block the central scrape.
- **Stored data expires.** Each upload carries a time-to-live. Once it lapses without a fresh upload, the request for that site's metrics fails rather than returning stale numbers.

xControl also publishes the list of sites to monitor, with each site's identity labels attached. That list is what xView uses to discover what to scrape.

Stage 4 — ingest at xView

xView's collection agent, vmagent, asks xControl for the site list every few seconds and scrapes each site's stored metrics through xControl. Every scrape is honored-labels, meaning the identity labels already present in a site's data take precedence over anything the scrape would add — see Metric Labels and Conventions.

Because a whole site arrives in one response, these scrapes are far larger than a normal Prometheus scrape, and xView raises its maximum scrape size well above the default to accommodate them. An undersized limit shows up as a site whose metrics stop arriving while the site itself is healthy.

From there:

- Samples are written to the metric database, a single-node VictoriaMetrics instance.
- The rule evaluator reads the database every 20 seconds, evaluates every alert rule, and sends anything firing to Alertmanager.
- Grafana queries the same database for dashboards.

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3.2.2 Freshness: how old is the data you are looking at?

Each stage adds delay, and they add up:

Stage	Typical delay
Network function to the agent	up to 15s
Agent to the site collector	up to 15s
Collector to xControl, via the agent's upload	one scrape interval
xControl to xView	up to 10s
Rule evaluation	up to 20s

In practice a change at a site is visible centrally within about a minute, and an alert on it fires within the alert's own `for` duration on top of that. When a site is first brought up, allow several minutes before concluding that its metrics are missing — the discovery, scrape and reload steps all have to complete before the first sample lands.

> **Note**
>
> This is a pull pipeline with a store-and-forward stage in the middle, so it is normal for central data to lag a site by tens of seconds. Do not use xView timestamps to reason about the ordering of events inside a site; use the site's own logs for that.

3.2.3 What happens when a site goes offline

The failure path is worth knowing because it explains the alert you will actually see:

1. The site stops uploading, because the agent cannot reach xControl.
2. The stored copy at xControl reaches its time-to-live and expires.
3. xView's next scrape for that site fails, and the `up` metric for it goes to zero.
4. xCoreAgentOutOfContact fires, escalating to its Tier2 and Tier3 variants if the condition persists.

Metrics collected at the site during the outage are not backfilled when it recovers; the site's local collector holds them, but only the most recent upload is ever transferred. Expect a gap in central data for the duration of the outage.

To suppress alerts for planned work, mark the site's state rather than silencing individual alerts — see suspending monitoring.

3.2.4 What xView is made of

xView is a Helm chart. It has no application code of its own: it deploys, configures and integrates well-established open-source components, and adds Expeto's alert rules, dashboards and scrape configuration on top.

Component	Role	Upstream
VictoriaMetrics (single-node)	The metric database	docs.victoriametrics.com
vmagent	Scrapes targets and writes to the database	vmagent
vmalert	Evaluates alert and recording rules	vmalert
Alertmanager	Routes, groups and delivers firing alerts	Alertmanager
VictoriaMetrics Operator	Manages the above as Kubernetes resources	operator
Grafana, via Grafana Operator	Dashboards and visual exploration	Grafana, operator

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Component	Role	Upstream
kube-state-metrics	Kubernetes object state	kube-state-metrics
node_exporter	Host-level metrics	node_exporter

Two consequences of this design are worth stating plainly:

- **Anything you know about Prometheus applies.** VictoriaMetrics speaks PromQL, the alert rules are ordinary Prometheus rules, and Prometheus-format exporters work unchanged. Rules written as Kubernetes `PrometheusRule` objects are converted automatically — see Custom Alerts and Rules.
- **The database is single-node.** It is not a clustered or replicated store. Size and protect its storage accordingly, and treat long-term retention of metrics as a separate concern from the operational window xView keeps.

3.2.5 Storage and retention

	Default
Retention	1 month
Database storage	20 GiB
Database replicas	1
Site collector retention	3 days, capped at 10 GB

Retention is a deployment-time setting. Raising it raises the storage requirement roughly in proportion, and the number of sites is the dominant factor in how fast that storage fills, since every site contributes its full metric set.

3.2.6 Where to go next

- Data Sources and Exporters — every exporter, what it covers, and how to add one
- Metric Labels and Conventions — the labels attached along this path
- Monitored Endpoints — every scrape job in a standard deployment
- Accessing xView — dashboards, queries and alert delivery

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3.3 Accessing xView

xView presents its data through Grafana, which is reachable from a browser at the same hostname as xControl. The rest of the monitoring stack — the metric database, the rule evaluator and Alertmanager — has no public interface by design, and is reached directly when you need it.

3.3.1 Grafana

Grafana is served under the `/nms` path of your xControl hostname:

```
https://xcontrol.example.com/nms
```

Signing in

Sign in with **Expeto Keycloak SSO**, using the same identity you use for xControl. Access is granted by role: an account holding the administrator or superuser role gets Grafana's Admin role, which allows creating and editing dashboards. Other accounts get read access to what has been shared with them.

A local administrator account also exists for break-glass access, for cases where the identity provider itself is unavailable. Its credentials are held in a Kubernetes secret named `<release>-xview-admin-credentials`:

```
kubectl get secret <release>-xview-admin-credentials -n <namespace> \
  -o jsonpath='{.data.GF_SECURITY_ADMIN_PASSWORD}' | base64 -d
```

> **Warning**
>
> The local account bypasses single sign-on and its actions are not attributable to a person. Use SSO for routine work and keep the local credentials for recovery.

Data sources

Two data sources are configured and ready to query:

Name	Contains
Expeto-NMS	The metric database. The default data source — every shipped dashboard uses it.
Expeto-Alertmanager	Current alert state, for the alerting views

Shipped dashboards

Dashboards are organized into two folders. **Expeto's dashboards** cover the platform:

Dashboard	Shows
Overview	The whole deployment at a glance: xControl and xView health, a per-customer summary, and current alerts
Site	One site in depth — devices, radios, network function counts, throughput, capacity and host health
Sitev2	A revised per-site view, organized by subsystem: devices, CPU, networking, containers, disk, memory and the agent
xCore Public	The xCore itself: resources, quality of service and signalling rates

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Dashboard	Shows
xControl	xControl internals — queues, database, JVM memory, thread pools and error logs
Alerts	Firing and pending alerts, with a per-customer breakdown
Infrastructure alerts	The same view organized by host rather than by customer
Log Errors	Error and fatal log volume, by source, site and logger

The second folder holds the **infrastructure dashboards** that come with the monitoring stack — Kubernetes cluster, node, pod and namespace views, etcd, CoreDNS, and the monitoring components' own dashboards. These are upstream dashboards, documented by VictoriaMetrics and the Kubernetes mixin projects.

> **Note**
>
> The shipped dashboards are managed by the deployment and are not editable in place — changes would be reverted on the next upgrade. To adapt one, copy it (**Dashboard settings → Save as**) into a folder of your own and edit the copy.

Running a query

Grafana's **Explore** view is the quickest way to run a PromQL query against the metric database. Select the **Expeto-NMS** data source and enter an expression, for example:

```
sum by (site) (xcore_mme_resource_imsi_attached)
```

Metric Labels and Conventions covers the labels available and the query patterns worth knowing; xCore Metrics lists what there is to query.

3.3.2 Reaching the other components

The metric database, the rule evaluator, Alertmanager and the scraper are internal services with no ingress. Reach them with a port-forward when you need to inspect them directly — most often to confirm that a scrape target is healthy, or that a rule is loaded and evaluating.

Forward the metric database:

```
kubectl port-forward -n <namespace> svc/vmsingle-<release>-victoria-metrics-k8s-stack 8428:8428
```

Then browse to `http://localhost:8428/vmui` for an interactive query interface, or query the API directly:

```
curl -s 'http://localhost:8428/api/v1/query?query=up{job="site"}' | python3 -m json.tool
```

The other components follow the same pattern:

Component	Service	Port	Useful for
Metric database	`vmsingle-<release>-victoria-metrics-k8s-stack`	8428	Queries, the `vmui` interface, checking what data exists
Scraper	`vmagent-<release>-victoria-metrics-k8s-stack`	8429	Scrape target health — which targets are up, and why one is failing
Rule evaluator	`vmalert-<release>-victoria-metrics-k8s-stack`	8080	Which rules are loaded, and which are firing
Alertmanager	`vmalertmanager-<release>-victoria-metrics-k8s-stack`	9093	Current alerts, silences and routing

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> **Tip**
>
> When a site's metrics are missing, the scraper's targets page is the first place to look. It reports the last scrape result per target, which distinguishes "xView never tried" from "xView tried and the request failed" — and those have entirely different causes.

3.3.3 Checking which sites are reporting

A quick health check across the estate, run against the metric database:

```
up{job="site"}
```

Every site should return `1`. A site returning `0` is not relaying metrics — see the failure path in xView Architecture — and will be raising xCoreAgentOutOfContact.

To see how fresh each site's data is:

```
time() - max by (site) (timestamp(up{job="site"} == 1))
```

3.3.4 Alert delivery

Firing alerts are sent to Alertmanager, which routes them onward. **Routing is configured per deployment.** Until a receiver is configured, alerts fire and are visible in Grafana and in the rule evaluator, but no notification is sent.

Configuring this is Alertmanager's own domain — its configuration reference covers receivers, routing trees, grouping and inhibition. Route on the `severity` label, and use the `customer` and `site` labels to direct alerts to whoever is responsible for that part of the estate. Contact Expeto support to have this wired into your notification or ticketing system.

To add alerts of your own, see Custom Alerts and Rules.

3.3.5 Related pages

- xView Architecture — what you are looking at and how it got there
- Custom Alerts and Rules — adding your own alerts
- Metric Labels and Conventions — writing queries against platform labels

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3.4 Custom Alerts and Rules

xView ships a default set of alerts covering the platform and the infrastructure it runs on. You can add your own alongside them, without modifying anything Expeto ships and without a redeploy.

Alerts are Kubernetes resources. You write a rule as a `VMRule` object, apply it with `kubectl`, and xView's rule evaluator picks it up automatically — it selects every `VMRule` in the cluster, in any namespace. The same mechanism defines recording rules, which precompute an expression on a schedule.

Before writing a rule, read Metric Labels and Conventions. Rules that use the platform's identity labels work across every site and customer; rules that hard-code a site name have to be rewritten each time the estate changes.

3.4.1 Writing a rule

A `VMRule` holds one or more named groups, each containing rules. The rule body is ordinary Prometheus alerting-rule syntax, so any rule you have written for Prometheus transfers unchanged.

```
apiVersion: operator.victoriametrics.com/v1beta1
kind: VMRule
metadata:
  name: acmecorp-custom-alerts
  namespace: expeto-monitoring
spec:
  groups:
    - name: AcmeCorpCapacity
      rules:
        - alert: SiteAttachFailureRateHigh
          expr: |
            sum by (site, siteId, customer, customerId) (
              rate(xcore_mme_nas_total{message="att", type="reject",
                                       site_state!~"decommissioned|maintenance"}[10m])
            )
            /
            sum by (site, siteId, customer, customerId) (
              rate(xcore_mme_nas_total{message="att", type="request",
                                       site_state!~"decommissioned|maintenance"}[10m])
            ) > 0.05
          for: 15m
          labels:
            severity: warning
          annotations:
            summary: "Attach failure rate above 5% at {{ $labels.site }} for {{ $labels.customer }}"
            description: >-
              More than 5 percent of attach requests at {{ $labels.site }}({{ $labels.siteId }})
              for {{ $labels.customer }}({{ $labels.customerId }}) have been rejected for the
              last 15 minutes.
```

Applied with:

```
kubectl apply -f acmecorp-custom-alerts.yaml
```

Fields

Field	Required	Purpose
`spec.groups[].name`	yes	Names the group. Rules in a group are evaluated in order, so a recording rule can feed a later rule in the same group.
`spec.groups[].interval`	no	How often to evaluate this group. Defaults to the deployment's evaluation interval.
`rules[].alert`	one of	The alert name. Use PascalCase, matching the shipped alerts.
`rules[].record`	one of	The name of a recording rule's output series instead of an alert.
`rules[].expr`	yes	The PromQL expression. An alert fires for every series the expression returns.

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Field	Required	Purpose
rules[].for	no	How long the condition must hold before firing. Omit for immediate.
rules[].labels	no	Labels added to the alert. Set severity here.
rules[].annotations	no	Human-readable text. summary and description are the conventional keys.

Conventions worth following

The shipped rules follow a handful of conventions. Matching them means your alerts group, route and read the same way as everything else:

- **Set severity** to critical, warning or info. Alert routing is usually configured on this label, so an alert with a severity outside that set may not be delivered at all.
- **Exclude suspended sites** with site_state!~"decommissioned|maintenance" in the expression. Without it your alert will fire for sites that are deliberately down for maintenance.
- **Carry identity through the aggregation.** Group by site, siteId, customer and customerId so the labels are available to the annotations — an alert that has been aggregated down to a single number cannot say which site it is about.
- **Write annotations that name the site and customer**, using {{ $labels.site }} and {{ $labels.customer }}, with the identifiers in the description. This is what makes an alert actionable in a notification that carries no other context.
- **Put the reasoning in description**, and keep summary to one line.

> **Warning**
>
> Do not edit the alert rules xView ships. They are managed by the Helm release and any change will be reverted on the next upgrade. To change one, copy it into a VMRule of your own and adjust it there — and be aware both will then evaluate, so also arrange to suppress the original if you do not want it firing alongside yours.

3.4.2 Checking that a rule was accepted

The operator validates each VMRule as it is applied and reports the outcome on the object itself. This is the fastest way to catch a malformed expression:

```
kubectl get vmrules -A
```

The output carries **Status** and **Sync Error** columns. A rule that failed to parse shows the error there:

```
kubectl describe vmrule acmecorp-custom-alerts
```

An accepted rule is loaded within a few seconds. To confirm it is being evaluated, and to see whether it is currently firing, open the rule evaluator's interface or the **Alerting** section of Grafana — see Accessing xView.

> **Tip**
>
> Develop the expression before you wrap it in a rule. Run it as a query first, in Grafana's Explore view or against the metric database directly, and confirm it returns the series you expect — including the identity labels your annotations reference. A rule whose expression returns nothing never fires and looks identical to one that is working.

3.4.3 Recording rules

A recording rule evaluates an expression on a schedule and stores the result as a new series. Use one when an expression is expensive, or when several dashboards and alerts share the same subexpression:

```
apiVersion: operator.victoriametrics.com/v1beta1
kind: VMRule
metadata:
  name: acmecorp-recording-rules
```


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```
  namespace: expeto-monitoring
spec:
  groups:
    - name: AcmeCorpAggregates
      interval: 1m
      rules:
        - record: site:attach_requests:rate5m
          expr: |
            sum by (site, siteId, customer, customerId) (
              rate(xcore_mme_nas_total{message="att", type="request"}[5m])
            )
```

The convention for a recorded series name is `level:metric:operation` — here, an attach-request rate aggregated to the site level. The result is queryable like any other metric.

3.4.4 Alerts written as PrometheusRule

xView also accepts standard `PrometheusRule` objects. They are converted automatically, so existing rules from a Prometheus-based system can be applied unchanged:

```
apiVersion: monitoring.coreos.com/v1
kind: PrometheusRule
metadata:
  name: acmecorp-imported-rules
  namespace: expeto-monitoring
spec:
  groups:
    - name: AcmeCorpImported
      rules:
        - alert: ExampleAlert
          expr: up == 0
          for: 5m
          labels:
            severity: warning
```

For new work prefer `VMRule` — it is the native form, and the converted copy of a `PrometheusRule` is what actually gets evaluated, which is one more indirection to reason about when something is wrong.

3.4.5 Making sure an alert reaches someone

A firing alert is sent to Alertmanager, which decides what to do with it. **Alert delivery is configured per deployment**: until Alertmanager has a receiver configured for your environment, an alert will fire and be visible in the interfaces without notifying anyone.

Configuring receivers, routing and grouping is Alertmanager's own domain, and its configuration documentation is the reference. Route on the `severity` label, and use the `customer` and `site` labels to direct alerts to the team responsible for that part of the estate. Talk to Expeto support about wiring this into your existing notification or ticketing system.

3.4.6 Related pages

- Metric Labels and Conventions — the labels to write rules against
- Accessing xView — where to see rules and firing alerts
- xCore Alerts — the shipped alerts, useful as worked examples

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3.5 Data Sources and Exporters

This page lists every source of metrics in a standard deployment: which component produces each metric, which exporter exposes it, and where the upstream documentation for that exporter lives. It also covers how to add a source of your own.

If you are looking for the metrics themselves rather than where they come from, see xCore Metrics, xControl Metrics and Infrastructure Metrics.

3.5.1 Three routes into xView

An exporter is a process that presents measurements over HTTP in the Prometheus text format, so a collector can scrape it. At a site — xCore or xRouter, which are monitored identically — metrics reach the collector by one of three routes, and knowing which applies to a component tells you where to look when its metrics go missing.

The Expeto Agent as exporter

This is the route most xCore metrics take, and it is the one that surprises people. The 5G network functions and the MME do not serve a metrics endpoint. They report their counters internally over their own management interfaces, and the Expeto Agent collects from each of them every 15 seconds and republishes the whole set as Prometheus metrics on a single endpoint of its own.

The practical consequences:

- **The agent is a single point of collection.** If the agent is down, metrics for every network function it fronts stop — the functions themselves may be perfectly healthy. That is what xCoreAgentOutOfContact distinguishes.
- **Every metric collected this way is labelled** `job="xAgent"`, whichever network function produced it. The function is identified by `nfnode` and `nfnodeip`, not by the job.
- **Resolution is bounded by the poll interval.** A counter that moves and moves back inside 15 seconds is not visible centrally.

Components on this route: AMF, SMF, UPF, NRF, NSSF, UDSF, NFCM and the MME.

Native Prometheus endpoints

Some components serve their own metrics endpoint, which the site collector scrapes directly. These appear under their own job names, so a failure is attributable to that component alone.

Component	Job	Path
HSS	`hss`	`/hss/prometheus`
UDM	`udm`	`/prometheus`
UDR	`udr`	`/prometheus`
AUSF	`ausf`	`/prometheus`
Expeto Agent	`xAgent`	`/metrics`
xControl	`xControl`	`/metrics`

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Third-party exporters

Everything that is not an Expeto component is covered by a standard open-source exporter. These are well-documented upstream, and we do not restate their metrics here — the links below are the reference.

Exporter	Covers	Job	Upstream documentation
node_exporter	Host CPU, memory, disk, filesystem and network health for every cluster node	`node`	prometheus/node_exporter
kube-state-metrics	State of Kubernetes objects: deployments, pods, nodes, PVCs	`k8s`	kubernetes/kube-state-metrics
cAdvisor (in the kubelet)	Per-container CPU, memory, filesystem and network usage	`kubelet`	google/cadvisor
mysqld_exporter	Site database health, including Galera cluster state	`mariadb-galera`	prometheus/mysqld_exporter
postgres_exporter	xControl's database	`postgres`	prometheus-community/postgres_exporter
blackbox_exporter	Synthetic reachability probes from a site	`blackbox`	prometheus/blackbox_exporter

The monitoring stack also exports its own metrics — vmagent, vmalert, the metric database, Alertmanager and Grafana each expose an endpoint, and xView scrapes all of them so that a failure of monitoring is itself visible. Those are documented upstream by VictoriaMetrics, Prometheus Alertmanager and Grafana.

Java runtime metrics

xControl and the Expeto Agent are JVM applications. Alongside their application metrics they export standard JVM and process metrics — heap and non-heap memory, thread counts, garbage collection, class loading, file descriptors and process CPU — under the usual `jvm_*` and `process_*` names defined by the Prometheus Java client. xControl additionally exports connection-pool, HTTP server and message-broker metrics; see xControl Metrics.

3.5.2 Adding a source of metrics

A site's monitoring endpoints are configuration held in xControl, not something compiled into a release. Adding one makes a new exporter's metrics flow through the existing pipeline without any change to xView.

A monitoring endpoint has these fields:

Field	Meaning
`name`	Identifies the endpoint. Becomes the `xName` label on everything it produces.
`jobName`	The `job` label applied to the scraped metrics.
`metricsUrl`	The HTTP or HTTPS URL to fetch.
`scrapedBy`	Whether the Expeto Agent fetches it, or the site collector does.
`scrapeInterval`	How often to fetch it, in seconds. Also sets how long xControl considers an upload current.
`status`	Whether the endpoint is enabled.

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The `scrapedBy` field selects the route:

- **Agent** — the Expeto Agent fetches the URL and relays the response to xControl. This is the route used for the site's own collector, and it is the right choice for anything that must traverse the outbound-only path to xControl.
- **Collector** — the site collector scrapes the target directly, as one more target inside the cluster. Use this for an exporter that runs at the site, so its metrics are included in the collector's data and relayed with everything else.

> **Important**
>
> `scrapeInterval` does double duty for agent-scraped endpoints: it is both the fetch period and the time-to-live attached to the upload at xControl. Setting it much longer than the central scrape interval means xView will periodically find the stored data expired and record a failed scrape. Keep it close to the platform default unless you have a reason not to.

> **Tip**
>
> Prefer pointing a new exporter at the **site collector** and letting the existing relay carry it centrally, rather than adding a second agent-scraped endpoint. One upload per site keeps the number of central scrapes proportional to the number of sites rather than to the number of exporters.

Metrics from a new endpoint arrive with the site's identity labels attached automatically — see Metric Labels and Conventions. Nothing needs to be configured in xView itself.

3.5.3 Related pages

- xView Architecture — how these sources are collected and relayed
- Monitored Endpoints — every scrape job in a standard deployment
- Metric Labels and Conventions — the labels attached to what these exporters produce

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3.6 Metric Labels and Conventions

Every metric xView stores carries labels, and they do two jobs. Some identify *where* a measurement came from — which site, which customer, which network function — and xView attaches those itself as metrics travel in from the sites. Others describe *what* was measured, and those come from the component that produced the metric.

This page specifies both: the identity labels the platform adds to every xCore metric, and the convention Expeto components follow when labelling protocol traffic. Read it before writing a PromQL query, an alert rule or a dashboard — nearly every useful query aggregates over one of these labels.

3.6.1 Identity labels

These labels answer "where did this come from?". They are attached automatically; no component has to emit them.

Label	Meaning	Attached by	Example
`site`	Human-readable Site name, as configured in xControl	xControl, at discovery	`AcmeCorp-Plant-01`
`siteId`	Stable identifier for the Site, as a full API URI	xControl, at discovery	`https://api.example.com/v1/sites/81251`
`customer`	Human-readable Customer name	xControl, at discovery	`AcmeCorp`
`customerId`	Stable identifier for the Customer, as a full API URI	xControl, at discovery	`https://api.example.com/v1/customers/20806`
`site_state`	Operational state of the Site; suppresses alerts when set	Site extension in xControl	`maintenance`
`xName`	Name of the monitoring endpoint the metrics came from	The Expeto Agent	`xAgent`
`vmName`	Name of the xView deployment that collected the metric	xView	`expeto-central`
`cluster`	Name of the cluster xView is running in	xView	`expeto-central`
`nfnode`, `nfnodeip`	The individual network function instance a metric describes	The Expeto Agent	`mme-a`, `192.0.2.122`
`job`	The scrape job that collected the metric	The scrape configuration	`xAgent`
`instance`	The target address that was scraped	Prometheus convention	`192.0.2.10:9767`

Important

`siteId` and `customerId` are **full URIs, not numbers**. Match them with `=~".*/v1/sites/81251"` or compare them to the value exactly as it appears; a query written as `siteId="81251"` matches nothing. The URI is stable across renames, which is why alert annotations quote it alongside the human-readable name.

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Where identity labels are attached

Identity labels are added **at xControl**, when it publishes the list of sites for xView to scrape — not at the site and not by the network functions. This matters in two ways.

First, renaming a Site in xControl changes the `site` label on everything that site reports from the next scrape onward, with no change at the site itself.

Second, the labels can be overridden. xControl applies them in a fixed order of precedence:

1. Extensions on the site's monitoring feature (highest)
2. Extensions on the Site
3. The default labels above (lowest)

Any extension whose key begins with `label.` becomes a metric label, with the prefix stripped — so an extension `label.region` with value `west` adds `region="west"` to everything that site reports. Overriding `customer` or `site` is a supported way to keep human-readable customer names out of a monitoring system that other parties can see.

> **Note**
>
> Scrapes are configured to honor labels already present in the scraped data. If a site's metrics already carry a label, that value wins over the one xView would attach. This is what lets each site's identity survive being collected through a single shared endpoint.

Suspending monitoring for a site

Nearly every Expeto alert expression carries the guard `site_state!~"decommissioned|maintenance"`. Setting the Site's state is therefore how you suppress a site's alerts for planned work — it is a property of the Site, not a silence that expires.

To suspend monitoring for a Site:

1. Open xControl, navigate to **Sites**, and click the name of the Site.
2. Click **Edit**.
3. Create or edit the extension `label.site_state`.
4. Set the value to `maintenance` (planned work, expected to return) or `decommissioned` (the site is being retired).
5. Click **Save**.

The extension appears with the Site's other key parameters. To resume monitoring, delete the extension or set it to `enabled`.

> **Warning**
>
> A suspended Site raises no alerts at all — including alerts that would tell you the maintenance itself has gone wrong. Clear the state as soon as the work is finished.

3.6.2 Traffic-metric conventions

Protocol counters are the metrics you reach for when answering "is this interface healthy?". They follow one pattern across the platform:

```
xcore_<nf>_<protocol>_total{direction, message, type, cause}
```

One metric per protocol, with the detail in labels rather than in the metric name. The four labels are:

Label	Answers	Values
`direction`	Which way did it go?	`inbound`, `outbound`, and the drop/retry variants below
`message`	Which protocol message was it?	The message name, lowercased, e.g. `session_establishment`

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Label	Answers	Values
`type`	Which part of the exchange?	`request`, `response`, and the protocol-specific variants below
`cause`	How did it end?	The protocol's own result code, by name, e.g. `request_accepted`

This shape is what makes cross-protocol queries possible. To find every rejected request a site handled, regardless of protocol, count the responses whose `cause` is neither success value:

```
sum by (site, job) (
  rate({__name__=~"xcore_.+_total", type="response", cause!="", cause!~"success|request_accepted"}[5m])
)
```

Both extra matchers are load-bearing. `type="response"` keeps requests out: they carry no `cause`, and a negative regex match against an absent label succeeds, so without it every request would be counted as a rejection. `cause!=""` then drops responses that carry no `cause` at all — which is the case for the MME's counters — since those would otherwise be counted as rejections too.

direction

Value	Meaning
`inbound`	Received by this network function
`outbound`	Sent by this network function
`inbound_drop`	Received and discarded without being processed
`outbound_retry`	Re-sent after no response arrived in time

Counting drops and retries separately is deliberate: `inbound_drop` isolates overload and malformed traffic from healthy receive volume, and `outbound_retry` exposes a peer that is failing to answer before the retransmission shows up as a timeout elsewhere.

> **Note**
>
> A few of the smaller MME interfaces use the abbreviated forms `in`, `out` and `in_drop` rather than the full words. When writing a query that must cover every interface, match with `direction=~"in.*"` and `direction=~"out.*"` rather than listing exact values.

type

`request` and `response` cover most traffic. Protocols with richer exchanges add their own values: S1AP uses `indication`, `command`, `complete`, `confirm`, `failure`, `notify`, `ack` and others; NAS uses `accept`, `reject`, `complete`, `fail` and `command`. Where a protocol has no request/response structure for a message, `type` is `msg`.

cause

`cause` carries the protocol's own result, converted to a lowercase name — `request_accepted`, `user_unknown`, `system_failure`. It is present only on responses, so a query that groups by `cause` should filter to `type="response"` to avoid counting requests into an empty bucket.

> **Note**
>
> On the service-based interface the `cause` label holds the **HTTP status code** as a string (`"200"`, `"404"`), because that is the result the protocol defines. Treat it as a name, not a number — PromQL will not order it numerically.

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Per-protocol reference

Labels carried by each protocol counter, as deployed:

Protocol	Metric	direction	message	type
PFCP (N4)	xcore_smf_pfcp_total	●	●	●
GTP-C v2 (S5/S8, S11)	xcore_smf_gtp_2_total	●	●	●
GTP-C v1 (Gn/Gp)	xcore_smf_gtp_1_total	●	●	●
SBI (N11)	xcore_smf_n11_total	●	●	●
S1AP	xcore_mme_s1ap_total	●	●	●
NAS	xcore_mme_nas_total	●	●	●
GTP-C v2 (MME)	xcore_mme_gtpv2_total	●	●	●
GTP-C v1 (MME)	xcore_mme_gtpv1_total	●	●	●
Diameter (MME)	xcore_mme_diameter_total	●	●	●
S6a/S6d	xcore_hss_s6_messages_total		●	●
Other Diameter interfaces	xcore_hss_<interface>_messages_total		●	●
MAP	xcore_hss_map_messages_total		●	●

The HSS family covers every Diameter reference point the platform implements — `s6`, `s6b`, `s6c`, `s6t`, `s6mn`, `s13`, `sh`, `slh`, `swm`, `swx`, `staswa`, `cxdx` and `zh` — plus `map` and `sip`. They share one shape, so a query written for one works for all of them by changing the interface.

Where a cell is blank, that dimension is not currently reported for that protocol: the MME's counters do not carry `cause`, and the HSS's do not carry `direction` (the message name and `type` together imply it on those interfaces).

MESSAGE AND CAUSE VOCABULARIES

The values are the protocol's own message and result names, lowercased with words separated by underscores. Representative sets:

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PFCP	GTP-C v2	S6a	S1AP	NAS	SBI (N11)

`message`: `association_setup`, `heartbeat`, `session_establishment`, `session_modification`, `session_deletion`, `session_report`

`cause`: `request_accepted`, `request_rejected`, `mandatory_ie_incorrect`, `session_context_not_found`, `system_failure`

`message`: `create_session`, `modify_bearer`, `modify_bearer_cmd`, `delete_session`, `create_bearer`, `update_bearer`, `delete_bearer`, `release_access_bearers`, `downlink_data_notif`, `downlink_data_notif_ack`, `echo`

`cause`: `request_accepted`, `request_rejected_(reason_not_specified)`, `context_not_found`, `imsi/imei_not_known`, `invalid_message_format`, `no_resources_available`, `unable_to_page_ue`, `system_failure`

`message`: `authentication_information`, `update_location`, `cancel_location`, `insert_subscriber_data`, `delete_subscriber_data`, `purge_ue`, `notification`, `reset`, `routing_info`

`cause`: `success`, `user_unknown`, `unknown_eps_subscription`, `rat_not_allowed`, `roaming_not_allowed`, `authentication_data_unavailable`, `authentication_rejected`, `authorization_rejected`, `diameter_too_busy`, `missing_avp`, `unable_to_comply`, `system_error`

`message`: `s1_setup`, `initial_uemsg`, `initial_ctxt_setup`, `uectxt_mod`, `uectxt_rel`, `e_rabsetup`, `e_rabmod`, `e_rabrel`, `handover`, `path_switch_req`, `paging`, `uplink_nastrnspt`, `downlink_nastrnspt`, `reset`, `error`

`type`: `request`, `response`, `command`, `complete`, `confirm`, `failure`, `indication`, `notify`, `ack`, `required`, `preparation_failure`

`message`: `att`, `det`, `tau`, `auth`, `auth_fail`, `ident`, `sec_mod`, `service`, `pdn_conn`, `pdn_disconn`, `act_def_eps_brr_ctx`, `act_ded_eps_brr_ctx`, `deact_eps_brr_ctx`, `mod_eps_brr_ctx`, `uplink_sms`, `downlink_sms`

`type`: `request`, `accept`, `reject`, `complete`, `fail`, `command`, `msg`

`message`: `smcontextcreate`, `smcontextupdate`, `smcontextrelease`

`cause`: the HTTP status code as a string — `200`, `201`, `404`, `500`

Additional labels on protocol metrics

`smf_id` appears on SMF counters, identifying which SMF instance within the site reported the metric. Aggregate over it unless you are specifically comparing instances:

```
sum without (smf_id) (rate(xcore_smf_pfcp_total{type="request"}[5m]))
```

Peer identity is carried by `nfnode` and `nfnodeip` rather than by a dedicated `peer` label, and the interface is part of the metric name rather than a label.

3.6.3 Writing queries against these labels

A few patterns cover most needs.

Per-site message rate for one interface:

```
sum by (site) (rate(xcore_smf_pfcp_total{message="session_establishment", type="request"}[5m]))
```

Failure ratio on an interface, as a proportion of responses:

```
sum by (site) (rate(xcore_hss_s6_messages_total{type="response", cause!="success"}[5m]))
 /
sum by (site) (rate(xcore_hss_s6_messages_total{type="response"}[5m]))
```

One customer's sites only, using the stable identifier:

```
sum by (site) (rate(xcore_mme_nas_total{customerId=~".*/v1/customers/20806", message="att"}[5m]))
```

Retransmissions, which usually indicate an unresponsive peer:

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```
sum by (site, nfnode) (rate(xcore_mme_diameter_total{direction="outbound_retry"}[5m]))
```

> **Tip**
>
> Always aggregate away `instance` and `nfnode` unless you need them. A site with several instances of a function reports one series per instance, and a query that keeps them produces a graph per instance rather than the per-site figure you probably wanted.

3.6.4 Conventions for new instrumentation

If you are adding a metric to an Expeto component, follow the pattern above rather than inventing a new one. In particular:

- **Put the varying part in a label, not in the metric name.** One `..._total` with a `message` label, not one metric per message. Metric names that encode the outcome cannot be aggregated, and every dashboard has to be rewritten when a new message type appears.
- **Use the vocabularies on this page.** `direction` is `inbound` / `outbound`, not `rx` / `tx` or `in` / `out`; `type` is `request` / `response`; success and failure belong in `cause`, not in the metric name.
- **Name the protocol's own values, don't renumber them.** A `cause` is the protocol's result name, lowercased — not an internal enum ordinal.
- **Keep cardinality bounded.** Labels take values from a fixed, protocol-defined set. An address, a session identifier or a subscriber identity must never become a label value.
- **Let the platform add identity.** Do not emit `site`, `customer` or their identifiers yourself; they are attached centrally, and a locally-emitted copy will win over the correct value and be wrong the moment a Site is renamed.

3.6.5 Related pages

- xView Architecture — where each label is attached along the collection path
- xCore Metrics — the metrics these labels appear on
- Custom Alerts and Rules — using these labels in your own alerts

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3.7 Metrics

3.7.1 xCore Metrics

This page is the reference for the metrics an xCore site reports. They are grouped by the network function that produces them, because that is how you will troubleshoot: something is wrong with attach, or with the user plane, or with subscriber data, and you want the counters for that part of the system.

Every metric here carries the site and customer identity labels described in Metric Labels and Conventions, and protocol counters carry the `direction`, `message`, `type` and `cause` labels specified there. That page is the one to read first — it explains the label pattern this page relies on, and without it the tables below look like far more metrics than they really are.

xRouter reports these same metric families for the network functions it runs, through the same Expeto Agent and under the same job name — so everything here applies to an xRouter site too, for the functions present there.

> **Note**
>
> Counter metrics end in `_total` and only ever increase. Query them with `rate()` or `increase()` over a window; the raw value is the count since the process started and is rarely what you want. Metrics without that suffix are gauges — a current value, meaningful as-is.

Mobility management (MME)

The MME handles attach, tracking-area update, paging and handover for 4G subscribers.

PROTOCOL COUNTERS

Metric	Interface
`xcore_mme_s1ap_total`	S1AP, to the eNodeBs
`xcore_mme_nas_total`	NAS, to the devices
`xcore_mme_diameter_total`	S6a, to the HSS
`xcore_mme_gtpv2_total`	GTP-C v2, to the SGW/PGW and peer MMEs
`xcore_mme_gtpv1_total`	GTP-C v1, for legacy interworking
`xcore_mme_sbcap_total`	SBc-AP, for public warning messages
`xcore_mme_dns_total`	DNS lookups for node selection
`xcore_mme_eir_total`	S13, to the equipment identity register
`xcore_mme_sgh_total`	SGs, to the MSC for circuit-switched fallback and SMS

Supporting counters: `xcore_mme_diameter_peer_connection_down` and `xcore_mme_diameter_timer_expiry` (labelled by `timer`) report Diameter peer health directly, rather than requiring you to infer it from message rates.

CURRENT STATE

These gauges describe what the MME is holding right now, and are the fastest way to size a site or confirm that load has actually moved:

Metric	Meaning
`xcore_mme_resource_imsi_attached`	Subscribers currently attached
`xcore_mme_resource_imsi_active`	Subscribers with an active connection

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Metric	Meaning
xcore_mme_resource_imsi_visited_attached	Attached subscribers from a visited network
xcore_mme_resource_imsi_neutralhost_attached	Attached subscribers in a neutral-host configuration
xcore_mme_resource_sessions	Active sessions
xcore_mme_resource_bearers	Active bearers
xcore_mme_resource_bearers_gbr	Active guaranteed-bit-rate bearers
xcore_mme_resource_enodeb_connected	Radios with an established S1 connection
xcore_mme_resource_paging_ongoing	Paging procedures in progress
xcore_mme_resource_warning_received	Public warning messages received

PROCEDURES AND FAILURES

`xcore_mme_procedure_*` counts individual procedures — handovers of each kind, operator-initiated resets, bearer modifications, dropped packets — and `xcore_mme_failure_*` counts the corresponding failure cases. They are the detail behind a raised failure rate seen in the NAS or S1AP counters.

SMS and circuit-switched fallback over SGs have their own counters: `xcore_mme_sgh_mo_sms_received_total`, `xcore_mme_sgh_mt_sms_received_total`, the matching `_dropped_` variants, and `xcore_mme_sgh_combined_attach_total` with `xcore_mme_sgh_successful_combined_attach_total`.

Emergency and closed-subscriber-group handling: `xcore_mme_emergency_call_total`, `xcore_mme_emergency_sessions_with_imei_total`, `xcore_mme_emergency_sessions_witout_auth_total`, `xcore_mme_csg_calls_with_subscription_expired_total` and `xcore_mme_csg_calls_failed_for_subscription_not_available_total`.

Session management (SMF)

The SMF establishes and maintains sessions, and controls the user plane over PFCP.

PROTOCOL COUNTERS

Metric	Interface
xcore_smf_pfcp_total	N4, to the UPF
xcore_smf_n11_total	N11, to the AMF (service-based)
xcore_smf_gtp_2_total	GTP-C v2, for 4G session management
xcore_smf_gtp_1_total	GTP-C v1, for legacy interworking

SESSIONS AND ASSOCIATIONS

Metric	Meaning
xcore_smf_pdusession	Current 5G PDU sessions
xcore_smf_pdusession_total	PDU session events, by `message` and `type`
xcore_smf_pdnsession	Current 4G PDN sessions
xcore_smf_pdnsession_total	PDN session events, by `message` and `type`
xcore_smf_upfsession	Sessions per user plane, labelled by `upf_ip`

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Metric	Meaning
xcore_smf_pfcpassociation	Current PFCP associations
xcore_smf_gtpassociation	GTP peer state
xcore_smf_gtpassociation_total	GTP path events, including echo timeouts and path failures

Session counts are the first thing to check against the configured capacity of a site: a session count that has flattened at a round number is a limit, not a traffic pattern.

IDENTIFIER AND ADDRESS ALLOCATION

xcore_smf_idallocated and xcore_smf_idavailable, with xcore_smf_ipallocated and xcore_smf_ipavailable, report the allocators that hand out session identifiers and UE addresses. xcore_smf_idallocator_queue reports pending allocation requests; a queue that is not draining means sessions will start failing shortly, which makes it a useful leading indicator. xcore_smf_idallocator_total and xcore_smf_ipallocator_total count allocation operations.

> **Tip**
>
> Exhausted addresses look like a session-establishment failure at the protocol level. When xcore_smf_pfcp_total{cause="no_resources_available"} rises, check xcore_smf_ipavailable before investigating the user plane.

User plane (UPF)

The UPF forwards subscriber traffic and enforces the rules the SMF installs.

THROUGHPUT AND VOLUME

Metric	Meaning
xcore_upf_uplink_volume_bytes, xcore_upf_downlink_volume_bytes	Bytes forwarded in each direction
xcore_upf_uplink_volume_packets, xcore_upf_downlink_volume_packets	Packets forwarded in each direction
xcore_upf_uplink_throughput_rate, xcore_upf_downlink_throughput_rate	Current throughput in each direction

SESSIONS AND PFCP

xcore_upf_active_pfcp_sessions and xcore_upf_active_pfcp_association report what the UPF is currently holding. Comparing the session count against the SMF's own view is the standard way to detect a user plane that has drifted out of step with the control plane.

PFCP procedures are counted per procedure and outcome — for association setup, and for session create, modification, release and report, each with _total, _success and _failed:

```
rate(xcore_upf_pfcp_session_create_failed[5m])
```

On an xCore installed with the operator, every user plane reports its own series: the Agent reads each UPF's statistics from NFCM and labels them with the UPF's nfnode (elm-nfcm-statistics-<user plane>) and with upf, role (sgwu, pgwu, upf, iupf), position (front or anchor), mode and, for an anchor, systemid. Three further series describe each user plane and join on nfnode: xcore_upf_info (value 1, with the labels above plus dnn, n9peers, serviceid, tenantid and site), xcore_upf_dataplanes (its dataplane pods) and xcore_upf_sessions_per_dataplane (the session table of each). Sessions held by the anchors of one System, for example:

```
sum by (systemid) (xcore_upf_active_pfcp_sessions{position="anchor"})
```

Path health is reported by xcore_upf_pfcp_peer_down, xcore_upf_pfcp_msg_retrans_timer_expiry, xcore_upf_echo_req_recv, xcore_upf_echo_resp_send, xcore_upf_gtp_error_ind_recv and xcore_upf_gtp_error_ind_send. A rising error-indication count usually means the peer has lost session state that this node still believes exists.

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Access and mobility (AMF)

The AMF handles registration, connection management and paging for 5G subscribers. Its counters name the procedure and outcome in the metric itself, so they are read directly rather than aggregated by label.

The families follow a predictable shape — `xcore_amf_registration_initial_*` for initial registration (accept, complete, identity request and response, authentication request and response, and the reject reasons), `xcore_amf_registration_periodic_*` and `xcore_amf_registration_mobility_*` for the other registration types, `xcore_amf_dereg_*` for deregistration, `xcore_amf_paging_*` for paging, and `xcore_amf_nas_connection_established` / `xcore_amf_nas_connection_terminated` for connection state.

Interactions with other network functions are counted per peer and outcome under `xcore_amf_*_consumer_stats` and the `xcore_amf_nas_transport_*` families, covering the AUSF, UDM, SMF, NSSF, NRF and UDSF.

> **Note**
>
> Because outcome is part of the metric name here rather than a `cause` label, a query across all 5G registration failures matches on the name: `sum(rate({__name__=~"xcore_amf_registration_.*_reject_.*"}[5m]))` .

Subscriber data (HSS)

The HSS authenticates subscribers and serves their subscription data. Every interface it implements reports through one family, `xcore_hss_<interface>_messages_total` , labelled by `message` , `type` and `cause` :

Interface	Metric	Used for
S6a/S6d	`xcore_hss_s6_messages_total`	4G authentication and location management
MAP	`xcore_hss_map_messages_total`	3G and 2G authentication and mobility
SWx	`xcore_hss_swx_messages_total`	Non-3GPP access authentication
S6b	`xcore_hss_s6b_messages_total`	Non-3GPP session authorization
STa/SWa	`xcore_hss_staswa_messages_total`	Trusted and untrusted non-3GPP access
SWm	`xcore_hss_swm_messages_total`	ePDG interworking
Cx/Dx	`xcore_hss_cxdx_messages_total`	IMS registration and authentication
Sh	`xcore_hss_sh_messages_total`	IMS subscriber data
S6c	`xcore_hss_s6c_messages_total`	SMS routing
S6t	`xcore_hss_s6t_messages_total`	Machine-type communication
S6m/S6n	`xcore_hss_s6mn_messages_total`	Device-trigger subscriber information
S13	`xcore_hss_s13_messages_total`	Equipment identity check
SLh	`xcore_hss_slh_messages_total`	Location services routing
Zh	`xcore_hss_zh_messages_total`	Generic bootstrapping
SIP	`xcore_hss_sip_messages_total`	SIP signalling

Because the shape is identical, one query covers any of them:

```
sum by (site, cause) (
  rate(xcore_hss_s6_messages_total{message="authentication_information", type="response"}[5m])
)
```


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Signalling link state is reported by `xcore_hss_link_total` — labelled by `type` (`diameter`, `map`, `smpp`) and `status` — against `xcore_hss_link_count`, the number of links expected to be open. A gap between the two is what the connection-down alerts detect. `xcore_hss_link_dropped_messages_total` counts messages lost on a link.

`xcore_hss_3g`, `xcore_hss_4g`, `xcore_hss_active` and `xcore_hss_vlr` report subscriber and register counts, and `xcore_hss_msrn_get_total` counts roaming-number allocations. The `xcore_hss_diameter_sum`, `xcore_hss_map_sum` and `xcore_hss_sip_sum` families carry latency aggregates per protocol.

Supporting functions

The network repository, configuration manager and unstructured data store report their API calls per operation and outcome:

- `xcore_nrf_nf_*` — network function registration, update, deregistration and discovery, on an xRouter; an xCore runs without a network repository
- `xcore_nfcm_*_api_*` — configuration management operations, per resource
- `xcore_udsf_udsf_req_*` — record store requests

Each family follows the `_total` / `_success` / `_failed` pattern.

Platform and site-wide metrics

These describe the site as a whole rather than a single network function, and most of the default alerts are built on them.

Metric	Meaning
`xcore_nf_node_up`	Whether the agent can reach each network function. Labelled by `status`, and by `vendor` for the implementation family, with the instance in `nfnode` / `nfnodeip`.
`xcore_uptime_minutes`	Time since the site came up. A reset means a restart.
`xcore_version`	Deployed software version, carried in a label
`xcore_clients`	Devices currently connected to the site
`xcore_privateradio_count`	Radios connected to the site
`xcore_epc_connections`	Established core connections
`xcore_sgw_count`, `xcore_pgw_count`, `xcore_ggsn_count`	Instance counts per function
`xcore_upload_bytes_total`, `xcore_download_bytes_total`	Site-wide traffic volume

PROVISIONING SYNCHRONIZATION

The agent continuously reconciles what xControl says a site should hold against what the site actually holds, and reports the difference:

Metric	Meaning
`xcore_sync_correct`	Records that match
`xcore_sync_mismatch`	Records present but differing
`xcore_sync_missing`	Records that should exist at the site but do not
`xcore_sync_extra`	Records at the site that should not be there
`xcore_sync_pending`	Changes queued but not yet applied

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All five are labelled by `component`, so they cover subscribers, keysets and radios separately. Non-zero mismatch, missing or extra counts drive the synchronization alerts in xCore Alerts.

CHARGING RECORDS

`xcore_cdr_count` and `xcore_cdr_buffer` report charging records produced and records waiting to be written. A buffer that grows steadily means records are being produced faster than they are being delivered, and will eventually be lost.

AGENT INTERNALS

The agent's own health: `xcore_queue_status`, `xcore_jms_event_time` and `xcore_jms_delay_time` with their `_count` companions, `xcore_threadpool_fast`, `xcore_threadpool_slow` and `xcore_threadpool_dedicated` with theirs, `xcore_unhandledevents_total`, and the REST response counters `xcore_rest_2xx_responses_total`, `xcore_rest_3xx_responses_total`, `xcore_rest_401_UNAUTHORIZED_responses_total`, `xcore_rest_404_NOT_FOUND_responses_total` and `xcore_rest_5xx_responses_total`.

Growing JMS delay is the signal that the agent is falling behind xControl, which is what AgentJmsMessagesDelayed detects.

SMS CENTRE

`xcore_smsc_stored_sms_total`, `xcore_smsc_mo_forward_ok_total` and `xcore_smsc_map_sent_ok_total` count stored and forwarded messages.

Related pages

- Metric Labels and Conventions — the label pattern these metrics follow
- xCore Alerts — the default alerts built on these metrics
- xControl Metrics — the central platform's own metrics
- Infrastructure Metrics — hosts, containers and Kubernetes

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3.7.2 xControl Metrics

This page is the reference for the metrics xControl reports about itself: the work queues that carry configuration out to the sites, the caches and thread pools that serve the API, the database behind it, and the Java runtime it runs on.

These metrics are scraped directly from xControl under the job name `xControl`. Unlike site metrics, they carry no `site` or `customer` labels — xControl is a single central service, not something that exists per site. The alerts built on them are documented in xControl Alerts.

Message queues

xControl communicates with each site's agent asynchronously. Configuration changes are placed on a queue and delivered when the site is reachable, which is what allows a site to be offline without losing changes.

Metric	Meaning
`xcontrol_queue_size`	Messages currently waiting on a queue
`xcontrol_queue_total`	Messages processed
`xcontrol_queue_health`	Health of the queue subsystem
`xcontrol_jms_event_time`, `xcontrol_jms_event_time_count`	Time taken to process an event, and the number processed
`xcontrol_jms_delay_time`, `xcontrol_jms_delay_time_count`	Time a message waited before being processed

Queue depth is the number to watch. A queue that is growing rather than draining means configuration changes are not reaching sites, and subscribers provisioned in the API will not work on the network until it clears. This is what JMSQueueNotDraining detects.

```
xcontrol_queue_size
```

Rising delay time with a steady queue size is a different problem — messages are being processed, but slowly. Check the database and thread pools before assuming a site is unreachable.

Delivery outcomes are counted by `expeto_jms_event_success_total` and `expeto_jms_event_failure_total`, which the Expeto Agent also reports for its own side of the same exchange.

Thread pools

xControl separates fast operations from slow ones so that a long-running request cannot starve the interactive API.

Metric	Meaning
`xcontrol_threadpool_fast`, `xcontrol_threadpool_fast_count`	The fast pool's utilization and task count
`xcontrol_threadpool_slow`, `xcontrol_threadpool_slow_count`	The slow pool's utilization and task count

A saturated fast pool shows up to users as a slow interface, and usually indicates work that belongs on the slow pool, or a downstream dependency that has become slow.

Caches

Metric	Meaning
`xcontrol_cache_count`	Entries currently cached
`xcontrol_cache_total`	Cache capacity

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Metric	Meaning
xcontrol_cache_utilization	Proportion of capacity in use

Sustained utilization at capacity means entries are being evicted and re-fetched, which turns cache reads into database reads.

External service credits

Some features call metered third-party services. These gauges report the balance remaining, so the service can be topped up before it stops working:

Metric	Service
xcontrol_imeilookup_credits	Device identity lookups
xcontrol_cpsapi_credits	Location lookups

Both drive alerts — ImeiLookupCreditsLow and LocationLookupApiCreditsLow — because the failure mode when they run out is a feature that silently stops returning results.

Subscribers and tokens

Metric	Meaning
xcontrol_subscribers_active30d	Subscribers active in the last 30 days
xcontrol_token_expiration	Time remaining before an API token expires

xcontrol_token_expiration is what SiteApiTokenExpiringSoon evaluates. An expired site token stops that site's agent from authenticating, which presents as the site going out of contact.

Database

xControl stores its data in PostgreSQL. Its own view of the database:

Metric	Meaning
xcontrol_postgres_preparedtransactionsage	Age of the oldest prepared transaction

An ageing prepared transaction blocks vacuum and will eventually degrade the whole database, which is why it is monitored separately from ordinary transaction duration.

Connection-pool health is reported by the pool itself, under the HikariPool_* family:

Metric	Meaning
HikariPool_1_pool_ActiveConnections	Connections currently in use
HikariPool_1_pool_IdleConnections	Connections available
HikariPool_1_pool_TotalConnections	Connections open
HikariPool_1_pool_MaxConnections, HikariPool_1_pool_MinConnections	Configured bounds
HikariPool_1_pool_PendingConnections	Threads waiting for a connection
HikariPool_1_pool_Wait, HikariPool_1_pool_Wait_count	Time spent waiting for a connection

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Metric	Meaning
`HikariPool_1_pool_Usage`, `HikariPool_1_pool_Usage_count`	How long connections are held
`HikariPool_1_pool_ConnectionTimeoutRate_total`	Requests that gave up waiting

Pending connections above zero for any sustained period means the pool is too small for the load, or queries are holding connections too long.

The database server itself is monitored separately by postgres_exporter under the `postgres` job, producing the standard `pg_*` metrics — see postgres_exporter for the full set, and xControl Alerts for the alerts built on them.

Java runtime

xControl is a JVM application and exports the standard runtime metrics defined by the Prometheus Java client:

Family	Covers
`jvm_memory_bytes_used`, `jvm_memory_bytes_committed`, `jvm_memory_bytes_max`	Heap and non-heap memory, by area
`jvm_memory_pool_bytes_*`	The same, per memory pool
`jvm_gc_collection_seconds_*`	Garbage collection count and time, by collector
`jvm_threads_current`, `jvm_threads_peak`, `jvm_threads_deadlocked`	Thread counts
`jvm_classes_currently_loaded`, `jvm_classes_loaded_total`	Class loading
`jvm_buffer_pool_*`	Direct and mapped buffer usage
`process_cpu_seconds_total`, `process_resident_memory_bytes`, `process_open_fds`	Process-level resources

Thread count is the one to watch: JVMThreadsTooHigh fires on it, because runaway thread creation usually precedes a failure rather than following one.

Logging

`log_error_total` and `log_fatal_total` count log events by level, labelled by `logger`, and drive ErrorLogs and FatalLogs. The `logger` label makes it possible to exclude a known-noisy source from an alert without losing the signal elsewhere.

Related pages

- xControl Alerts — the alerts built on these metrics
- Metric Labels and Conventions — label conventions across the platform
- xCore Metrics — the site-side equivalents

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3.7.3 Infrastructure Metrics

Alongside the platform's own metrics, xView collects the standard measurements of the machines and Kubernetes clusters everything runs on. These come from well-known open-source exporters, and this page is a guide to which exporter covers what, with the queries worth knowing — not a restatement of their reference documentation, which is linked and is authoritative.

The alerts built on these metrics are documented in Platform and Infrastructure Alerts and Kubernetes and Monitoring Stack Alerts.

Host metrics

Host-level measurements come from **node_exporter**, running on every cluster node, under the `node` job. The full metric set is large and documented upstream at prometheus/node_exporter.

The families that matter most in practice:

Family	Covers
`node_cpu_seconds_total`	CPU time, by core and mode. A counter — always use `rate()`.
`node_memory_MemTotal_bytes`, `node_memory_MemAvailable_bytes`	Memory. Prefer *available* over *free*: free excludes reclaimable cache and will look alarmingly low on a healthy machine.
`node_filesystem_size_bytes`, `node_filesystem_avail_bytes`	Filesystem capacity and free space, per mount
`node_filesystem_readonly`	Whether a filesystem has been remounted read-only, which the kernel does after storage errors
`node_disk_read_bytes_total`, `node_disk_write_bytes_total`, `node_disk_io_time_seconds_total`	Disk throughput and utilization
`node_network_receive_bytes_total`, `node_network_transmit_bytes_total`	Network throughput, per interface
`node_network_up`	Interface link state
`node_load1`, `node_load5`, `node_load15`	Load average
`node_time_seconds`, `node_timex_sync_status`	Clock and time synchronization
`node_boot_time_seconds`	Boot time, from which uptime is derived

QUERIES WORTH KNOWING

CPU utilization as a percentage, per node:

```
100 - (avg by (instance) (rate(node_cpu_seconds_total{mode="idle"}[5m])) * 100)
```

Memory utilization, using available rather than free:

```
100 * (1 - node_memory_MemAvailable_bytes / node_memory_MemTotal_bytes)
```

Filesystem usage, excluding the pseudo-filesystems that would otherwise dominate the result:

```
100 * (1 - node_filesystem_avail_bytes{fstype!~"tmpfs|squashfs|overlay"}
       / node_filesystem_size_bytes{fstype!~"tmpfs|squashfs|overlay"})
```


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Projected time until a filesystem fills, which is a far better alerting signal than a fixed threshold — it distinguishes a disk sitting steadily at 85 percent from one that will be full by morning:

```
predict_linear(node_filesystem_avail_bytes{fstype!~"tmpfs|squashfs|overlay"}[6h], 24 * 3600) < 0
```

> **Note**
>
> Clock synchronization is worth checking early when timestamps look wrong, metrics arrive out of order, or authentication fails intermittently. Time skew produces symptoms that look like unrelated faults — see HostClockNotSynchronising.

Container metrics

Per-container resource usage comes from **cAdvisor**, which is built into the kubelet, under the `kubelet` job. Reference documentation is at google/cadvisor.

Family	Covers
`container_cpu_usage_seconds_total`	CPU time consumed by a container
`container_memory_working_set_bytes`	Memory in use. This is the figure the kernel compares against the limit when deciding to kill a container.
`container_memory_rss`, `container_memory_cache`	Memory breakdown
`container_fs_usage_bytes`, `container_fs_limit_bytes`	Container filesystem usage
`container_network_receive_bytes_total`, `container_network_transmit_bytes_total`	Per-container network traffic, by `interface`

> **Important**
>
> Use `container_memory_working_set_bytes`, not `container_memory_usage_bytes`, when comparing against a memory limit. The latter includes reclaimable page cache, so it overstates real usage and will suggest a container is near its limit when it is not.

Memory headroom for a container, as a proportion of its limit:

```
container_memory_working_set_bytes{container!=""}
  / on (container, pod, namespace)
kube_pod_container_resource_limits{resource="memory"}
```

Kubernetes object state

kube-state-metrics reports the state of Kubernetes objects themselves — not their resource usage, but what the API server believes exists and whether it is healthy. It runs under the `k8s` job, and its metrics are documented per object type at kube-state-metrics.

Family	Covers
`kube_pod_status_phase`	Pod phase: pending, running, succeeded, failed
`kube_pod_container_status_restarts_total`	Container restarts, the signal for a crash loop
`kube_pod_container_status_waiting_reason`	Why a container is not running, including image-pull failures
`kube_deployment_status_replicas_available` vs `kube_deployment_spec_replicas`	Whether a workload is fully scheduled
`kube_node_status_condition`	Node readiness, memory and disk pressure

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Family	Covers
`kube_persistentvolumeclaim_status_phase`	Whether storage is bound
`kube_pod_container_resource_requests` , `..._limits`	Configured requests and limits, for comparison against actual usage

Workloads that are not fully available:

```
kube_deployment_spec_replicas - kube_deployment_status_replicas_available > 0
```

Containers restarting repeatedly:

```
increase(kube_pod_container_status_restarts_total[1h]) > 3
```

Kubernetes control plane

The API server, scheduler, controller manager, etcd and CoreDNS each expose their own metrics, and xView scrapes them where they are reachable. On a managed Kubernetes service the control plane is usually not exposed, and those targets will be absent — that is expected, not a fault.

The corresponding alerts are documented in Kubernetes and Monitoring Stack Alerts, which is generated from the alert definitions themselves and includes each alert's upstream runbook link.

A note on where to look first

When a site is in trouble, these metrics answer a different question from the platform metrics, and the order matters. Platform metrics tell you *what* is failing — attach is failing, sessions are not establishing. Infrastructure metrics tell you *why* it might be — the node is out of memory, the disk is full, the container is being restarted.

Start with the platform metrics to establish the symptom, then use these to explain it. Going the other way around tends to produce plausible-looking infrastructure findings that turn out to be unrelated.

Related pages

- Platform and Infrastructure Alerts — alerts on host and container health
- Kubernetes and Monitoring Stack Alerts — alerts from the Kubernetes and monitoring stack
- Data Sources and Exporters — where these metrics come from
- xCore Metrics — the platform metrics to correlate against

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3.8 Monitored Endpoints

This page is the reference for everything xView monitors: every scrape job in a standard deployment, what it collects and from which exporter. It follows the metrics along the path described in the xView architecture — from the exporters at a site, through the site collector and the xControl relay, into xView's metric database.

The alerts evaluated over these metrics are documented in Platform and Infrastructure Alerts, xCore Alerts, xControl Alerts and Kubernetes and Monitoring Stack Alerts. The labels every scrape attaches are described in Metric Labels and Conventions, and the exporters themselves in Data Sources and Exporters.

3.8.1 Two tiers of collection

Scraping happens in two places, and it is worth keeping them apart when you troubleshoot:

1. **The site collector** runs inside each site's cluster, xCore and xRouter alike. It scrapes the local exporters and network functions and keeps a short local history — it is a buffer, not the system of record. Everything it holds is relayed to xControl by the Expeto Agent.
2. **xView's vmagent** runs centrally, alongside xControl. It scrapes xControl (both xControl's own metrics and each site's relayed metrics), plus the Kubernetes infrastructure of the cluster it runs in. What it collects is what lands in the metric database and what alerts evaluate against.

A site therefore never needs an inbound connection: the collector is scraped locally, and the agent pushes outward to xControl.

3.8.2 Site collector scrape jobs

The site collector discovers most of its targets through the Kubernetes API, keeping only the endpoints that match a named service, so targets follow the cluster's actual inventory without configuration changes. The remaining jobs use the agent's service-discovery endpoint on port 9767, which publishes site-specific targets that Kubernetes cannot enumerate.

Intervals shown as *(global)* inherit the collector's default rather than setting their own.

Job	Monitors	Discovery	Metrics path	Interval
`prometheus`	The site collector itself (self-monitoring)	Static: `localhost:9090`	`/metrics`	15s
`xAgent`	The Expeto Agent: its own health, plus every network function metric it collects	Kubernetes SD (`service`), keeping `.*agent-prom`	`/metrics`	15s
`node`	Host health via node_exporter on each cluster node	Kubernetes SD (`endpoints`), keeping `.*node-exporter`	`/metrics`	15s
`k8s`	Kubernetes object state via kube-state-metrics	Kubernetes SD (`endpoints`), keeping `(.+-kube-state-metrics;8080)`	`/metrics`	15s
`mariadb-galera`	Site database health via the MariaDB Galera exporter	Kubernetes SD (`endpoints`), keeping `(.+-mariadb-galera-metrics;9104)`	`/metrics`	15s

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Job	Monitors	Discovery	Metrics path	Interval
`hss`	HSS application metrics from its native Prometheus endpoint	Kubernetes SD (`endpoints`), keeping `(.+-hss;8090)`	`/hss/prometheus`	15s
`udr`	UDR application metrics from its native Prometheus endpoint	Kubernetes SD (`endpoints`), keeping `(.+-udr;.+)`	`/prometheus`	15s
`udm`	UDM application metrics from its native Prometheus endpoint	Kubernetes SD (`endpoints`), keeping `(.+-udm;.+)`	`/prometheus`	15s
`ausf`	AUSF application metrics from its native Prometheus endpoint	Kubernetes SD (`endpoints`), keeping `(.+-ausf;.+)`	`/prometheus`	15s
`other`	Site-specific targets published by the agent's service-discovery endpoint	HTTP SD: `http://agent-prom.<namespace>.svc.cluster.local:9767/sd?job=other`	`/metrics`	15s
`SecGw`	Security gateway (IPsec concentrator) metrics	HTTP SD: `http://agent-prom.<namespace>.svc.cluster.local:9767/sd?job=SecGw`	`/metrics`	15s
`blackbox`	Synthetic availability probes via the blackbox exporter	HTTP SD: `http://agent-prom.<namespace>.svc.cluster.local:9767/sd?job=blackbox`	`/metrics`	15s (global)

`<namespace>` in a discovery URL is the namespace the xCore release is installed into.

The `other` job is the extension point for site-specific monitoring: targets returned by the agent's `/sd?job=other` endpoint are scraped without changing the managed configuration.

3.8.3 Central xView scrape jobs

xView's vmagent defines its scrape jobs as `VMScrapeConfig` objects rather than a Prometheus configuration file. Three matter:

Job	Monitors	Discovery	Metrics path	Interval
`site`	Every site's relayed metrics, one scrape per site	HTTP SD against xControl's `/sd?job=site` endpoint on port 9765	`/x-metrics`	10s

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Job	Monitors	Discovery	Metrics path	Interval
`xControl`	xControl's own application and JVM metrics	Static, xControl port 9765	`/metrics`	10s
federation	A collector scraped directly rather than through the relay	Static, collector port 9090	`/federate`	15s

The `site` job is the platform's most important scrape. Service discovery returns one entry per site; vmagent rewrites each discovered entry into a `site` query parameter and directs the request back at xControl, so a single host serves every site's metrics as `/x-metrics?site=<id>`. Each site's metrics arrive already carrying their own identity labels, which is what lets one alert rule cover every site.

> **Note**
>
> The federation job is not enabled by default. It scrapes a collector's `/federate` endpoint directly, which is only useful where xView can reach a collector over the network — the relay path through xControl is the norm. See xView architecture.

All three jobs scrape with honored labels, meaning labels already present in the scraped payload are kept in preference to the labels the scrape would otherwise attach.

3.8.4 Kubernetes and monitoring-stack jobs

In the cluster where it runs, xView also scrapes the standard Kubernetes control plane and node targets. These are provided by the monitoring stack rather than configured by Expeto:

Target	Collected from	Notes
kubelet, including cAdvisor	Each node's kubelet	Scraped every 30s, over HTTPS
Kubernetes API server	The `kubernetes` service	
controller-manager, scheduler, etcd	Control-plane endpoints	Unavailable on managed control planes
CoreDNS	The `kube-dns` service	
kube-state-metrics	The kube-state-metrics service	Kubernetes object state
node_exporter	The node-exporter DaemonSet	Host-level health
vmagent, vmalert, VMSingle, Alertmanager, Grafana	Each component's own metrics endpoint	Self-monitoring

Scraping of kube-proxy is disabled by default.

The self-monitoring jobs exist so that a failure of the monitoring stack itself raises an alert — see the vmagent and vmalert alert groups.

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3.8.5 Synthetic probes

Where scraping a metrics endpoint is not enough — "is this service actually reachable?" — the site collector probes through the blackbox exporter. The `blackbox` job passes each target to the exporter as a parameter; the exporter performs the check and reports the result as metrics, which the ProbeFailure and ProbeSuccessLow alerts evaluate.

3.8.6 Exporting metrics onward

xView does not forward metrics to an external system by default. Where a deployment needs one, a remote-write target is configured on vmagent, and the delivery itself is then monitored by the vmagent alerts — a failing remote write shows up as dropped or retried samples rather than as a silent gap.

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3.9 Alerts

3.9.1 Expeto xCore Alerts

This page is the reference for the default Prometheus alerts that monitor the Expeto xCore — site connectivity, provisioning synchronization, telecom signalling, and the site database. Each entry shows the alert's severity, how long its condition must hold before it fires, the exact PromQL trigger expression, and what to check when it fires.

Before using this page, read How to read these alerts for severity levels and the conventions shared by all alert expressions, and How alerts work for how alerts are defined and how tiers escalate. The metrics used in these expressions are described in xCore Metrics.

Alert	Severity	Fires after
xCoreAgentOutOfContact	Critical	5m
ExpetoNetworkFunctionDown	Critical	3m
xCoreDBNotSyncing	Critical	2m
AgentJmsMessagesDelayed	Critical	4m
HssSubscriberMismatch	Warning	2m
HssSubscriberMissing	Warning	2m
HssSubscriberExtra	Warning	2m
MmePrivateRadioMissing	Warning	2m
MmePrivateRadioMismatch	Warning	2m
MmePrivateRadiosExtra	Warning	2m
HssKeysetMissing	Critical	2m
HssKeysetMismatch	Critical	2m
HssKeysetExtra	Critical	2m
DiameterConnectionDown	Critical	2m
M3UAConnectionDown	Critical	31m
SmppConnectionDown	Critical	2m
PrivateRadioConnectionDown	Critical	1m
Low3gMapAuthRequests	Info	5m
Low4gS6aAuthRequests	Info	5m
MariadbDown	Critical	1m
MariadbTooManyConnections	Warning	2m
MariadbTooManyOpenFiles	Warning	2m
MariadbTooManyOpenInnodbFiles	Warning	2m

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Alert	Severity	Fires after
MariadbHighPreparedStatementsUtilization	Warning	2m
MariadbHighThreadsRunning	Warning	2m
MariadbSlowQueries	Warning	2m
MariadbInnodbLogWaits	Warning	Immediately
MariadbClusterOutOfSync	Critical	1m
MariadbInstanceOutOfSync	Critical	1m
xCoreCrashRestart	Info	2m
ProbeFailure	Critical	1m
ProbeSuccessLow	Warning	Immediately

xCore connectivity

These alerts cover the link between each site's Expeto Agent and xControl. They are the first alerts to look at when a site appears to be offline.

XCOREAGENTOUTOFCONTACT

Severity	Fires after
Critical	5m

Escalation: if the condition persists, `xCoreAgentOutOfContactTier2` after 1h and `xCoreAgentOutOfContactTier3` after 4h — see alert tiers.

Trigger condition

```
up{job="site",site_state!~"decommissioned|maintenance|poc",tier=~"1|"} == 0 or up{job="xAgent",site_state!~"decommissioned|maintenance|poc",tier=~"1|"} == 0
```

The Expeto Agent at the affected site has stopped reporting metrics. The agent may be down, or it may have lost its network connection to xControl. This is the primary "site out of contact" alert.

What to check: Confirm whether the site is reachable at all (VPN/IPsec tunnel, WAN link), then whether the agent process and its containers are running on the site host. If the agent is up but unreachable, investigate the network path between the site and xControl.

EXPETONETWORKFUNCTIONDOWN

Severity	Fires after
Critical	3m

Trigger condition

```
xcore_nf_node_up{status="unhealthy", site_state!~"decommissioned|maintenance"} == 0
```

The site's agent cannot communicate with one of the network functions it manages (the function and its address are reported in the alert's labels). The function may be down or in a bad state.

What to check: Look at the health and logs of the named network function, and verify it is reachable from the agent host. Restore or restart the function if it has failed.

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XCOREDBNOTSYNCING

Severity	Fires after
Critical	2m

Trigger condition

```
xcore_db_sync_delta_seconds{site_state!~"decommissioned|maintenance"} > 75
```

The site's local database has not synchronized with xControl for more than 75 seconds. Provisioning changes made in xControl are not reaching the site.

What to check: Verify the agent's connection to xControl and look for a message backlog (see JMSQueueNotDraining). If connectivity is healthy, check the agent logs for database errors at the reported path.

AGENTJMSMESSAGESDELAYED

Severity	Fires after
Critical	4m

Trigger condition

```
avg by (customer, site) (xcore_jms_delay_time{site_state!~"decommissioned|maintenance", quantile="0.95"} / 1000) > 150
```

The site's agent is not processing messages from xControl fast enough: the 95th-percentile message delay exceeds 150 seconds. Provisioning changes are applied late.

What to check: Check the agent host for resource exhaustion (CPU, memory, disk I/O) and the quality of the site's network link. A large provisioning burst can also cause a temporary backlog that clears on its own.

xCore synchronization

These alerts compare the intended state held by xControl with what is actually provisioned in the site's network functions. A **mismatch** means an object exists but its data differs, **missing** means an expected object is absent, and **extra** means an object exists that xControl does not expect. All three point to the same follow-up: inspect the affected site's synchronization status in xControl and re-synchronize.

HSSSUBSCRIBERMISMATCH

Severity	Fires after
Warning	2m

Trigger condition

```
xcore_sync_mismatch{site_state!~"decommissioned|maintenance",component="hss"} > 0
```

The site's HSS holds subscribers whose provisioned data does not match what xControl expects. Affected Mobile Assets may behave inconsistently.

What to check: Open the site's synchronization view in xControl to identify the affected subscribers and trigger a re-sync. If the mismatch recurs, look for an external system writing to the HSS directly.

HSSSUBSCRIBERMISSING

Severity	Fires after
Warning	2m

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Trigger condition

```
xcore_sync_missing{site_state!~"decommissioned|maintenance",component="hss"} > 0
```

Subscribers that should be provisioned in the site's HSS are absent. The affected Mobile Assets cannot attach to the network at this site.

What to check: Re-synchronize the site from xControl. If subscribers stay missing, check the agent logs for provisioning errors on the reported instance.

HSSSUBSCRIBEREXTRA

Severity	Fires after
Warning	2m

Trigger condition

```
xcore_sync_extra{site_state!~"decommissioned|maintenance",component="hss"} > 0
```

The site's HSS holds subscribers that xControl does not expect — typically left over from deletions that did not propagate, or from provisioning outside of xControl.

What to check: Review the extra entries in the site's synchronization view and remove them via a re-sync. Investigate how they were created if the alert recurs.

MMEPRIVATERADIOMISSING

Severity	Fires after
Warning	2m

Trigger condition

```
xcore_sync_missing{site_state!~"decommissioned|maintenance",component="privateradio"} > 0
```

One or more private radios that should be configured in the site's MME are absent.

What to check: Re-synchronize the site from xControl and confirm the radios reappear. The alert fires on a single missing radio once the condition has held for two minutes, so it clears on its own when a re-sync completes; if it persists, the radio is not being provisioned.

MMEPRIVATERADIOMISMATCH

Severity	Fires after
Warning	2m

Trigger condition

```
xcore_sync_mismatch{site_state!~"decommissioned|maintenance",component="privateradio"} > 0
```

The site's MME has private radios whose configuration does not match what xControl expects.

What to check: Identify the affected radios in the site's synchronization view and re-sync. Check for local configuration changes made outside of xControl.

MMEPRIVATERADIOSEXTRA

Severity	Fires after
Warning	2m

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Trigger condition

```
xcore_sync_extra{site_state!~"decommissioned|maintenance",component="privateradio"} > 0
```

The site's MME has private radios configured that xControl does not expect.

What to check: Review and remove the unexpected radios via a re-sync from xControl.

HSSKEYSETMISSING

Severity	Fires after
Critical	2m

Trigger condition

```
xcore_sync_missing{site_state!~"decommissioned|maintenance",component="site"} > 0
```

Authentication keysets that should be provisioned at the site are absent. Mobile Assets relying on those keysets cannot authenticate, which is why this is critical rather than a warning.

What to check: Re-synchronize the site from xControl immediately and confirm the keysets are restored. Check agent logs for provisioning errors if they stay missing.

HSSKEYSETMISMATCH

Severity	Fires after
Critical	2m

Trigger condition

```
xcore_sync_mismatch{site_state!~"decommissioned|maintenance",component="site"} > 0
```

Keysets at the site do not match the values xControl expects. Authentication for the affected Mobile Assets can fail.

What to check: Re-synchronize the site from xControl and verify the mismatch count returns to zero.

HSSKEYSETEXTRA

Severity	Fires after
Critical	2m

Trigger condition

```
xcore_sync_extra{site_state!~"decommissioned|maintenance",component="site"} > 0
```

The site holds keysets that xControl does not expect.

What to check: Review the unexpected keysets and remove them via a re-sync; investigate their origin, since unexpected credentials are a security concern.

DIAMETERCONNECTIONDOWN

Severity	Fires after
Critical	2m

Trigger condition

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```
((xcore_hss_link_total{site_state!~"decommissioned|maintenance", type="diameter", status="opened"} - on (customerId, siteId, instance, nfnode, nfnodeip, type) xcore_hss_link_count{site_state!~"decommissioned|maintenance"}) != 0) or ((xcore_hss_link_total{site_state!~"decommissioned|maintenance", type="diameter", status="opened"} unless on (customerId, siteId, instance, nfnode, nfnodeip, type) xcore_hss_link_count{site_state!~"decommissioned|maintenance"}) > 0)
```

The number of open Diameter links to a peer differs from the expected link count — one or more Diameter connections (4G/5G signalling, e.g. S6a) are down.

What to check: Check the reachability and status of the Diameter peer named in the alert labels, and the SCTP/TCP transport between the site and that peer. Signalling to and from the affected peer is impaired while the link is down.

M3UACONNECTIONDOWN

Severity	Fires after
Critical	31m

Trigger condition

```
((xcore_hss_link_total{site_state!~"decommissioned|maintenance", type="map", status="opened"} - on (customerId, siteId, instance, nfnode, nfnodeip, type) xcore_hss_link_count{site_state!~"decommissioned|maintenance"}) != 0) or ((xcore_hss_link_total{site_state!~"decommissioned|maintenance", type="map", status="opened"} unless on (customerId, siteId, instance, nfnode, nfnodeip, type) xcore_hss_link_count{site_state!~"decommissioned|maintenance"}) > 0)
```

The number of open M3UA links (3G MAP signalling over SS7) differs from the expected count — a 3G signalling connection is down. The long 31-minute hold time tolerates routine link flaps before alerting.

What to check: Check the M3UA/SCTP association to the peer named in the alert labels and the health of the SS7 signalling path. 3G authentication and mobility for the affected peer are impaired while the link is down.

SMPPCONNECTIONDOWN

Severity	Fires after
Critical	2m

Trigger condition

```
((xcore_hss_link_total{site_state!~"decommissioned|maintenance", type="smpp", status="opened"} - on (customerId, siteId, instance, nfnode, nfnodeip, type) xcore_hss_link_count{site_state!~"decommissioned|maintenance"}) != 0) or ((xcore_hss_link_total{site_state!~"decommissioned|maintenance", type="smpp", status="opened"} unless on (customerId, siteId, instance, nfnode, nfnodeip, type) xcore_hss_link_count{site_state!~"decommissioned|maintenance"}) > 0)
```

The number of open SMPP links differs from the expected count — an SMS signalling connection is down. SMS delivery through the affected peer is interrupted.

What to check: Check the SMPP peer named in the alert labels and the transport between the site and that peer.

PRIVATERADIOCONNECTIONDOWN

Severity	Fires after
Critical	1m

Trigger condition

```
abs( max by (customer, customerId, site, siteId, site_state) (xcore_sync_correct{component="privateradio",site_state!~"decommissioned|maintenance|poc"}) + max by (customer, customerId, site, siteId, site_state) (xcore_sync_missing{component="privateradio",site_state!~"decommissioned|maintenance|poc"}) - max by (customer, customerId, site, siteId, site_state) (xcore_privateradio_count{site_state!~"decommissioned|maintenance|poc"}) ) > 0
```

The number of private radios actually connected at the site differs from the number that should be connected.

What to check: Compare the site's expected radio inventory in xControl against what is connected, then check the disconnected radios' power and transport links.

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xCore telecom signalling

These are traffic-pattern alerts: they fire when a site that normally carries signalling traffic (more than 1000 requests over the past day) suddenly goes quiet. They are informational — silence may be a real upstream problem or an expected lull.

LOW3GMAPAUTHREQUESTS

Severity	Fires after
Info	5m

Trigger condition

```
(increase(xcore_hss_map_messages_total{message="send_authentication_info",type="request",site_state!~"decommissioned|maintenance"}[1d]) > 1000 and
increase(xcore_hss_map_messages_total{message="send_authentication_info",type="request",site_state!~"decommissioned|maintenance"}[15m]) == 0)
```

A site that normally handles 3G MAP authentication traffic has received none in the last 15 minutes.

What to check: Confirm whether the silence is expected (maintenance, traffic moved elsewhere). If not, check the 3G signalling path — see M3UAConnectionDown — and the upstream network feeding the site.

LOW4GS6AAUTHREQUESTS

Severity	Fires after
Info	5m

Trigger condition

```
(increase(xcore_hss_s6_messages_total{message=~"authentication_information",type=~"request",site_state!~"decommissioned|maintenance"}[1d]) > 1000 and
increase(xcore_hss_s6_messages_total{message=~"authentication_information",type=~"request",site_state!~"decommissioned|maintenance"}[15m]) == 0)
```

A site that normally handles 4G S6a authentication traffic has received none in the last 15 minutes.

What to check: Confirm whether the silence is expected. If not, check the Diameter signalling path — see DiameterConnectionDown — and the upstream 4G core.

Database health

These alerts monitor the MariaDB databases used by xCore sites, via the metrics of the `mariadb` scrape job (see Monitored Endpoints).

MARIADBDOWN

Severity	Fires after
Critical	1m

Trigger condition

```
mysql_up{site_state!~"decommissioned|maintenance"} != 1
```

A MariaDB instance is down or unreachable by its metrics exporter.

What to check: Check whether the database process/container is running on the reported instance and review its logs for the cause of the failure (crash, out of disk, restart loop).

MARIADBTOOMANYCONNECTIONS

Severity	Fires after
Warning	2m

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Trigger condition

```
max_over_time(mysql_global_status_threads_connected{site_state!~"decommissioned|maintenance"}[1m]) / mysql_global_variables_max_connections{site_state!~"decommissioned|maintenance"} * 100 > 80
```

The instance is using more than 80% of its configured `max_connections`. If the limit is reached, new connections are refused and dependent services fail.

What to check: Identify which clients hold the connections (`SHOW PROCESSLIST`) and look for connection leaks. Raise `max_connections` only if the demand is legitimate.

MARIADBTOOMANYOPENFILES

Severity	Fires after
Warning	2m

Trigger condition

```
(mysql_global_status_open_files{site_state!~"decommissioned|maintenance"} / mysql_global_variables_open_files_limit{site_state!~"decommissioned|maintenance"} * 100) > 2
```

The instance's open file count is above the expected share of its `open_files_limit`. The 2% threshold is deliberately low to act as an early warning of unusual file usage.

What to check: Compare the open file count against the instance's normal baseline. If it is climbing, look for table growth, missing cleanup, or a lowered `open_files_limit`.

MARIADBTOOMANYOPENINNODBFILES

Severity	Fires after
Warning	2m

Trigger condition

```
(mysql_global_status_innodb_num_open_files{site_state!~"decommissioned|maintenance"} / mysql_global_variables_open_files_limit{site_state!~"decommissioned|maintenance"} * 100) > 2
```

Same early-warning check as MariadbTooManyOpenFiles, but for files opened by the InnoDB storage engine specifically.

What to check: As for MariadbTooManyOpenFiles; additionally check for a large number of InnoDB tablespaces.

MARIADBHIGHPREPAREDSTATEMENTSUTILIZATION

Severity	Fires after
Warning	2m

Trigger condition

```
max_over_time(mysql_global_status_prepared_stmt_count{site_state!~"decommissioned|maintenance"}[1m]) / mysql_global_variables_max_prepared_stmt_count{site_state!~"decommissioned|maintenance"} * 100 > 80
```

The instance is using more than 80% of `max_prepared_stmt_count`. Hitting the limit causes application errors on statement preparation; a steadily climbing count usually indicates a statement leak in a client.

What to check: Identify the client application holding prepared statements and restart or fix it. Raise the limit only for legitimate sustained demand.

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MARIADBHIGHTHREADSRUNNING

Severity	Fires after
Warning	2m

Trigger condition

```
max_over_time(mysql_global_status_threads_running{site_state!~"decommissioned|maintenance"}[1m]) / mysql_global_variables_max_connections{site_state!~"decommissioned|maintenance"} * 100 > 60
```

An unusually high share of connections are actively executing at once. This usually means queries are running slowly and piling up rather than completing.

What to check: Look at the currently running queries (`SHOW PROCESSLIST`) for long-running or blocked statements, and at host CPU and disk I/O. Often accompanies MariadbSlowQueries.

MARIADBSLOWQUERIES

Severity	Fires after
Warning	2m

Trigger condition

```
increase(mysql_global_status_slow_queries{site_state!~"decommissioned|maintenance"}[1m]) > 40
```

The instance is logging more than 40 slow queries per minute.

What to check: Review the slow query log to identify the offending statements, then check for missing indexes, lock contention, or resource pressure on the host.

MARIADBINNODBLOGWAITS

Severity	Fires after
Warning	Immediately

Trigger condition

```
rate(mysql_global_status_innodb_log_waits{site_state!~"decommissioned|maintenance"}[15m]) > 10
```

Writes are waiting for InnoDB redo-log space at a sustained rate — the log is being written faster than it can be flushed.

What to check: Check disk write latency on the host (see DiskIOUnhealthy); if the disk is healthy, the InnoDB log buffer/file size may be too small for the write load.

MARIADBCLUSTEROUTOFSYNC

Severity	Fires after
Critical	1m

Trigger condition

```
abs(count by(customer,site) (sum by (customer,site,statefulset) (kube_statefulset_status_replicas{site_state!~"decommissioned|maintenance",job="k8s",statefulset=~".+-mariadb-galera"})) - on(customer, site) count by (customer,site) (count by(customer, site, wsrep_cluster_state_uuid) (mysql_galera_status_info{site_state!~"decommissioned|maintenance",job="mariadb-galera"}))) > 0
```

The MariaDB Galera cluster at a site has partitioned: its members no longer agree on a single cluster state. Writes may diverge between partitions.

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What to check: Inspect the Galera status (`wsrep_cluster_status` , `wsrep_cluster_size`) on each member and the network between them. Follow the standard Galera recovery procedure to rejoin or bootstrap members — do not restart members blindly.

MARIADBINSTANCEOUTOFSYNC

Severity	Fires after
Critical	1m

Trigger condition

```
label_replace(mysql_galera_status_info{site_state!~"decommissioned|maintenance"}, "__uuid__", "$1", "wsrep_cluster_state_uuid", "(.*)") != on (customer,site,instance,__uuid__)
label_replace(mysql_galera_status_info{site_state!~"decommissioned|maintenance"}, "__uuid__", "$1", "wsrep_local_state_uuid", "(.*)")
```

A single Galera member's local state no longer matches the cluster state — the instance has fallen out of sync while the rest of the cluster is healthy.

What to check: Check the desynchronized member's Galera logs and let it complete a state transfer (IST/SST) to rejoin. If it cannot rejoin, remove and re-add it to the cluster.

Experimental alerts

These alerts are under evaluation. They are enabled by default, but their thresholds and severities are still being tuned against real deployments, and any of them may change or be withdrawn in a future release. Treat them as signals worth investigating rather than as settled operational policy — and tell Expeto support if one proves noisy in your environment.

XCORECRASHRESTART

Severity	Fires after
Info	2m

Trigger condition

```
resets(xcore_uptime_minutes{site_state!~"decommissioned|maintenance"}[5m]) > 0
```

The site's uptime counter went backwards, which means the xCore restarted. The alert cannot tell a planned restart from a crash, which is why it is informational: during a maintenance window it is expected, and outside one it is not.

What to check: Establish whether the restart was planned. If it was not, look at the logs from before the restart for the cause, and check whether the process was killed for exceeding a memory limit. A site that restarts repeatedly will show this alert clearing and re-firing.

PROBEFAILURE

Severity	Fires after
Critical	1m

Trigger condition

```
probe_success == 0
```

A synthetic probe failed: the blackbox exporter could not reach the target it was asked to check. Unlike a scrape failure, this alert reports on a service the platform depends on rather than on a metrics endpoint, so it fires even when every Expeto component is healthy.

What to check: The failing target is in the alert's `instance` label. Verify the target is reachable from the site — by name as well as by address, since probe failures are often DNS — and confirm any firewall or proxy on the path still permits the check.

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PROBESUCCESSLOW

Severity	Fires after
Warning	Immediately

Trigger condition

```
avg_over_time((probe_success >bool 0)[5m:1m]) * 100 < 85
```

A synthetic probe is succeeding less than 85 percent of the time over five minutes. The target is reachable but unreliable, which ProbeFailure does not catch because the probe keeps recovering between checks.

What to check: The same path as for ProbeFailure, but look for intermittent causes rather than an outage: packet loss on the link, an overloaded target, or one unhealthy member behind a load balancer.

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3.9.2 Expeto xControl Alerts

This page is the reference for the default Prometheus alerts that monitor Expeto xControl — its messaging to sites, its external integrations, and its PostgreSQL database. Each entry shows the alert's severity, how long its condition must hold before it fires, the exact PromQL trigger expression, and what to check when it fires.

Before using this page, read How to read these alerts for severity levels and the conventions shared by all alert expressions, and How alerts work for how alerts are defined and how tiers escalate.

Alert	Severity	Fires after
JMSQueueNotDraining	Critical	5m
LocationLookupApiCreditsLow	Warning	Immediately
ImeiLookupCreditsLow	Warning	Immediately
IpsecTunnelDown	Critical	2m
SiteApiTokenExpiringSoon	Warning	Immediately
PostgresDeadlocks	Critical	1m
PostgresTxDurationTooLong	Warning	Immediately
PostgresClusterOutOfSync	Critical	2m
PostgresCollectorUnhealthy	Critical	1m

xControl health

JMSQUEUENOTDRAINING

Severity	Fires after
Critical	5m

Escalation: if the condition persists, `JMSQueueNotDrainingTier2` after 1h and `JMSQueueNotDrainingTier3` after 4h — see alert tiers.

Trigger condition

```
xcontrol_queue_health{site_state!~"decommissioned|maintenance",tier=~"1|",siteAlive="1"} == 100
```

The message queue from xControl to a site is not draining: xControl is producing messages for the site but the site's Expeto Agent is not consuming them. The agent may be down or may have lost its network connection to xControl. Note the `siteAlive="1"` filter — the alert only fires for sites that are otherwise considered alive, which points at a stuck queue rather than a dead site.

What to check: Check the site's agent first — if xCoreAgentOutOfContact is firing for the same site, chase that. If the agent is up, inspect its logs for message-processing errors and check the network path between the site and xControl.

xControl miscellaneous

LOCATIONLOOKUPAPICREDITSLOW

Severity	Fires after
Warning	Immediately

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Trigger condition

```
xcontrol_cpsapi_credits < 5000
```

xControl has fewer than 5000 credits left with the external location-lookup API provider. When the credits run out, location lookups fail.

What to check: Review recent lookup volume for anything unusual, and top up the credits with the provider before they are exhausted.

IMEILOOKUPCREDITSLOW

Severity	Fires after
Warning	Immediately

Trigger condition

```
xcontrol_imeilookup_credits < 2000
```

xControl has fewer than 2000 credits left with the external IMEI-lookup API provider. When the credits run out, IMEI lookups fail.

What to check: As for LocationLookupApiCreditsLow: review usage and top up before exhaustion.

IPSECTUNNELDOWN

Severity	Fires after
Critical	2m

Trigger condition

```
expeto_ipsec_tunnel_health == 0
```

An IPsec tunnel endpoint has been unpingable for 2 minutes and the tunnel is probably down. The alert's labels report the tunnel's configuration file and peer IP. All traffic routed through the tunnel — typically site-to-platform traffic — is affected.

What to check: Check the tunnel status on the IPsec concentrator, the reachability of the peer gateway, and whether the underlying network path between the two endpoints is up.

SITEAPITOKENEXPIRINGSOON

Severity	Fires after
Warning	Immediately

Trigger condition

```
(xcontrol_token_expiration{site_state!~"decommissioned|maintenance"} - time()) < (60 * 60 * 24 * 7)
```

An API token known to xControl expires within the next 7 days. If it expires, every integration that authenticates with it starts failing.

What to check: Identify the token from the alert's labels, renew or rotate it, and update the systems that use it before the expiry date.

Database health

These alerts monitor the PostgreSQL database behind xControl, via the metrics of the `postgres` scrape job (see Monitored Endpoints).

POSTGRESDEADLOCKS

Severity	Fires after
Critical	1m

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Trigger condition

```
increase(pg_stat_database_deadlocks{datname!~"template.*|postgres"}[1m]) > 5
```

A database is recording more than 5 deadlocks per minute — concurrent transactions are repeatedly blocking each other, and PostgreSQL is killing some of them to break the cycles.

What to check: Find the conflicting statements in the PostgreSQL log (deadlock reports name both queries) and address the access pattern that lets them collide.

POSTGRESTXDURATIONTOOLONG

Severity	Fires after
Warning	Immediately

Trigger condition

```
pg_stat_activity_max_tx_duration{application_name!="pg_dump"} > 800
```

A transaction (backups via `pg_dump` excluded) has been open for more than 800 seconds. Long-running transactions hold locks and prevent vacuum from cleaning up, degrading the whole database over time.

What to check: Find the transaction in `pg_stat_activity`, identify its client, and terminate it if it is stuck. Investigate why the client left it open.

POSTGRESCLUSTEROUTOFSYNC

Severity	Fires after
Critical	2m

Trigger condition

```
pg_replication_slots_pg_wal_lsn_diff > 500000000
```

A replica is lagging the primary by more than 500 MB of WAL. A failover while lagging this far would lose data, and unbounded lag can fill the primary's disk with retained WAL.

What to check: Check that the replica is running and applying WAL, and that the network between primary and replica is healthy. If the replica is permanently gone, drop its replication slot so the primary stops retaining WAL for it.

POSTGRESCOLLECTORUNHEALTHY

Severity	Fires after
Critical	1m

Trigger condition

```
up{job="postgres",site_state!~"decommissioned|maintenance"} == 0 or pg_exporter_last_scrape_error{job="postgres",site_state!~"decommissioned|maintenance"} == 1
```

The PostgreSQL metrics exporter is down or cannot probe the database. While it is unhealthy, all the database alerts above are blind.

What to check: Check the exporter container, then its connection to the database (credentials, reachability). If the database itself is down, that is the real incident.

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3.9.3 Platform and Infrastructure Alerts

This page is the reference for the default alerts that apply to every Expeto deployment regardless of component: the health of the Kubernetes nodes everything runs on, application log signals, liveness of nodes and of the monitoring pipeline itself, and the optional metric export integrations. Alerts specific to one component are on their own pages: xCore alerts and xControl alerts. The endpoints these alerts draw their metrics from are listed in Monitored Endpoints.

How to read these alerts

Each alert entry on this page — and on the xCore and xControl alert pages — shows the alert's severity, how long its trigger condition must hold before it fires ("Fires after"), the exact PromQL trigger expression as deployed, and a short guide to what the alert means and what to check. How alerts are defined, and how some alerts escalate through Tier2/Tier3 variants as a condition persists, is explained in How alerts work.

Severity reflects the intended response:

Severity	Meaning
Critical	Service is impacted or imminently at risk — act now.
Warning	Something is off and needs investigation soon, but service is not yet impacted.
Info	An awareness signal, such as an unusual traffic pattern. Review, but no immediate action is implied.

> **Note**
>
> Nearly every trigger expression carries the guard `site_state!~"decommissioned|maintenance"` : sites marked as decommissioned or in maintenance never fire these alerts. Put a site into maintenance before planned work to suppress its alerts — see suspending monitoring.

Firing alerts carry labels identifying the affected customer, site and node, which the notification templates use; filter by these labels in Grafana or the metric database to find all alerts for one site or customer.

Alert summary

Alert	Severity	Fires after
DiskInReadOnlyMode	Critical	1m
DiskIOUnhealthy	Warning	Immediately
DiskSpaceLow	Critical	1m
DiskSpaceFilling	Warning	1h
HostHighCpuLoad	Critical	5m
HostHighMemoryUsage	Critical	5m
HostClockNotSynchronising	Critical	2m
NetworkInterfaceDown	Critical	5m
ErrorLogs	Warning	Immediately
FatalLogs	Critical	Immediately

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Alert	Severity	Fires after
JVMThreadsTooHigh	Warning	Immediately
NodeDown	Critical	1m
PrometheusCollectorDown	Critical	3m
PrometheusFederationDown	Critical	2m
PrometheusScrapeDurationHigh	Critical	5m
KafkaRemoteWriteErrors	Critical	Immediately
SplunkRemoteWriteErrors	Critical	Immediately

Node health

These alerts come from node_exporter metrics collected on every Kubernetes node (the `node` scrape job). The checks below are run on the node itself — over SSH where the cluster allows it, or with `kubectl debug node/<name>` for a shell with access to the node.

DISKINREADONLYMODE

Severity	Fires after
Critical	1m

Trigger condition

```
node_filesystem_readonly{site_state!~"decommissioned|maintenance",fstype!="squashfs"} == 1
```

A filesystem on the affected node has been remounted read-only, which the kernel typically does after underlying storage errors. Every service writing to that filesystem is failing.

What to check: Inspect the kernel log (`dmesg`) on the node for the storage error that triggered the remount, and check the health of the underlying disk or storage backend. Repair or replace the storage before remounting read-write; a reboot alone usually only postpones the problem.

DISKIOUNHEALTHY

Severity	Fires after
Warning	Immediately

Trigger condition

```
increase(node_disk_write_time_seconds_total[1m])>500
```

Writes on a device are spending an excessive amount of time in flight — the disk is saturated or degrading.

What to check: Look at I/O statistics on the node (`iostat -x`) to see whether a workload is saturating the device or the device itself is slow. Databases on the node are usually the first services to suffer.

DISKSPACELOW

Severity	Fires after
Critical	1m

Trigger condition

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```
100 - ((node_filesystem_avail_bytes{site_state!~"decommissioned|maintenance",fstype!="squashfs"} * 100) / node_filesystem_size_bytes{site_state!~"decommissioned|maintenance",fstype!="squashfs"})
> 90
```

Disk usage on a filesystem has exceeded 90 percent on the affected node. A full disk halts databases, the site collector, and every pod scheduled on the node.

What to check: Identify what is consuming space on the reported device (`df -h` , then look for large log files, core dumps, or old images) and free space or expand the volume.

DISKSPACEFILLING

Severity	Fires after
Warning	1h

Trigger condition

```
(node_filesystem_avail_bytes{job="node",fstype!="",site_state!~"decommissioned|maintenance"} / node_filesystem_size_bytes{job="node",fstype!="",site_state!~"decommissioned|maintenance"} * 100 <
40 and  predict_linear(node_filesystem_avail_bytes{job="node",fstype!="",site_state!~"decommissioned|maintenance"}[6h], 24*60*60) < 0  and node_filesystem_readonly{job="node",fstype!="",site_state!
~"decommissioned|maintenance"} == 0 )
```

A filesystem is below 40 percent free and, at its current growth rate over the last 6 hours, is predicted to fill completely within 24 hours. This is the early warning before DiskSpaceLow.

What to check: Find what is growing (usually logs or database data) and address it before the disk actually fills. If the growth is legitimate, plan a volume expansion now.

HOSTHIGHCPULOAD

Severity	Fires after
Critical	5m

Trigger condition

```
100 - max without (cpu) ( max without (mode) (rate(node_cpu_seconds_total{mode="idle",site_state!~"decommissioned|maintenance"}[5m])) + max without (mode)
(rate(node_cpu_seconds_total{mode="nice",site_state!~"decommissioned|maintenance"}[5m])) ) * 100 > 85
```

CPU load on the affected node has averaged above 85 percent for 5 minutes.

What to check: Identify the busy pods (`kubectl top pods --all-namespaces --sort-by=cpu`) or processes on the node (`top`). A one-off spike may be a batch job; sustained saturation means the node is undersized for its workload or a process is misbehaving.

HOSTHIGHMEMORYUSAGE

Severity	Fires after
Critical	5m

Trigger condition

```
100-(node_memory_MemAvailable_bytes / node_memory_MemTotal_bytes{site_state!~"decommissioned|maintenance"} * 100 ) > 90
```

Memory usage on the affected node has been above 90 percent for 5 minutes. If it keeps climbing, the kubelet starts evicting pods and the kernel starts killing processes.

What to check: Identify the largest consumers (`kubectl top pods --all-namespaces --sort-by=memory`) and whether one of them is leaking. If usage is legitimately high, the node needs more memory.

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HOSTCLOCKNOTSYNCHRONISING

Severity	Fires after
Critical	2m

Trigger condition

```
min_over_time(node_timex_sync_status{site_state!~"decommissioned|maintenance"}[1h]) == 0 and node_timex_maxerror_seconds{site_state!~"decommissioned|maintenance"} >= 16
```

The node's clock has not synchronized with NTP for the past hour and its estimated error is at least 16 seconds. Clock drift breaks certificate validation, authentication, and log correlation.

What to check: Check the time service on the node (`chronyc tracking` or `timedatectl`) and whether the configured NTP servers are reachable from the site.

NETWORKINTERFACEDOWN

Severity	Fires after
Critical	5m

Trigger condition

```
node_network_up{site_state!~"decommissioned|maintenance",device=~"eth.*"} == 0
```

A physical network interface (`eth*`) on the affected node has been down for 5 minutes.

What to check: Check the interface state on the node (`ip link`), then the layer below it — cabling or switch port on bare metal, the virtual NIC on a hypervisor.

Error logs

These alerts are derived from log-level counters exposed by the Expeto Java applications, so they fire on what the applications themselves report rather than on resource metrics.

ERRORLOGS

Severity	Fires after
Warning	Immediately

Trigger condition

```
increase(log_error_total{site_state!~"decommissioned|maintenance",logger!~"io.expeto.thunder.rest.error.RestExceptionHandler"}[1m]) > 1
```

An Expeto component has logged more than one error-level message in the last minute. A few known-noisy loggers are excluded from the expression; the deployed rule also excludes loggers belonging to retired subsystems, which are omitted here because the code they name no longer exists.

What to check: Open the logs of the component named in the alert's labels around the time the alert fired and read the actual error. This alert is a pointer, not a diagnosis.

FATALLOGS

Severity	Fires after
Critical	Immediately

Trigger condition

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```
increase(log_fatal_total{site_state!~"decommissioned|maintenance"}[1m]) > 1
```

An Expeto component has logged fatal-level messages — it has most likely crashed or aborted an operation it could not recover from.

What to check: Go straight to the component's logs, then check whether its pod is still running and whether it has restarted (see KubePodCrashLooping). Treat the service as impaired until proven otherwise.

JVMTHREADSTOOHIGH

Severity	Fires after
Warning	Immediately

Trigger condition

```
jvm_threads_current > 500
```

An Expeto JVM is running more than 500 threads — usually a thread leak or a processing backlog rather than legitimate load.

What to check: Identify the component from the alert labels and take a thread dump to see what the threads are doing. A restart clears the symptom but the dump tells you the cause.

Basic up and down

Liveness alerts: nodes, the site collectors, and the monitoring pipeline itself.

NODEDOWN

Severity	Fires after
Critical	1m

Trigger condition

```
up{job="node",site_state!~"decommissioned|maintenance"} == 0
```

A node's node_exporter is no longer reachable — the node is down, or it is up but not reporting any metrics.

What to check: Determine whether the whole node is down or only its exporter: `kubectl get nodes` shows the node's readiness, and if its kubelet and cAdvisor targets are failing at the same time the node itself is gone. A dead node is an infrastructure incident; a dead exporter is a monitoring gap to fix promptly.

PROMETHEUSCOLLECTORDOWN

Severity	Fires after
Critical	3m

Trigger condition

```
up{job="prometheus",site_state!~"decommissioned|maintenance"} == 0
```

A Prometheus instance (typically a site collector) is down. Metrics from everything it scrapes are not being collected, and since collectors retain only a short history, an extended outage loses data permanently.

What to check: Check the collector's pod in the site's namespace — `kubectl get pods`, then its logs and events — and restore it promptly.

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PROMETHEUSFEDERATIONDOWN

Severity	Fires after
Critical	2m

Trigger condition

```
up{job=~".*federate.*",site_state!~"decommissioned|maintenance"} == 0
```

A federation scrape has failed: xView can no longer pull metrics directly from one of the collectors it federates from (see central xView scrape jobs). Alerting for everything behind that collector is degraded until federation is restored. This alert applies only where a federation scrape job is configured; the standard deployment relays every site through xControl and does not federate, so in that case there are no targets for it to evaluate.

What to check: Check network reachability from xView to the collector named in the failing job, then the collector's own health, and the credentials/TLS used by the federation job.

PROMETHEUSSCRAPEDURATIONHIGH

Severity	Fires after
Critical	5m

Trigger condition

```
scrape_duration_seconds{site_state!~"decommissioned|maintenance"} > 8
```

Scraping a target has been taking more than 8 seconds — dangerously close to the 10-second scrape timeout. If the timeout is hit, samples are dropped and gaps appear in the data.

What to check: Check the load on the target named in the alert and the network path to it. A target exposing an unusually large number of metrics can also push scrape time up.

Kafka remote write

Health of the Kafka export adapter, which forwards platform metrics to an external Kafka topic (see exporting metrics onward).

> **Note**
>
> This alert applies only to deployments running the Kafka export adapter. The standard Kubernetes deployment does not include it, and the metrics it evaluates are then absent, so it never fires.

KAFKAREMOTEWRITEERRORS

Severity	Fires after
Critical	Immediately

Trigger condition

```
increase(objects_failed_total[5m])>0 OR increase(serialized_failed_total[5m])>0
```

The Kafka remote-write adapter has failed to serialize or deliver metric objects in the last 5 minutes. The external consumer of these metrics is missing data.

What to check: Check the adapter's logs for the failure reason, and the availability of the downstream Kafka brokers and topic.

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Splunk remote write

Health of the Splunk export adapter (see exporting metrics onward).

> **Note**
>
> This alert applies only to deployments running the Splunk export adapter. The standard Kubernetes deployment does not include it, and the metric it evaluates is then absent, so it never fires.

SPLUNKREMOTEWRITEERRORS

Severity	Fires after
Critical	Immediately

Trigger condition

```
increase(ropee_splunk_events_wrote_failed_count[5m])>0
```

The Splunk remote-write adapter has failed to write events in the last 5 minutes. Metrics destined for Splunk are being lost.

What to check: Check the adapter's logs for the failure reason, and the availability of the downstream Splunk endpoint it writes to.

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3.9.4 Kubernetes and Monitoring Stack Alerts

xView runs its Kubernetes monitoring on the victoria-metrics-k8s-stack Helm chart, which ships a large body of alerting rules of its own: the Kubernetes and node_exporter mixins, the etcd mixin, and VictoriaMetrics' rules for its own components. This page is the reference for those alerts. They are evaluated and routed exactly like Expeto's own rules, which are documented separately on Platform and Infrastructure Alerts, xCore Alerts, and xControl Alerts.

> **Note**
>
> These rules are written and maintained upstream, not by Expeto. Their thresholds, wording, and severities change when the chart is upgraded. Everything below is generated from the chart version currently vendored in xView, so it describes what is actually deployed rather than what upstream publishes today.

How to read these alerts

Each entry gives the alert's severity, how long its condition must hold before it fires, the trigger expression as deployed, the upstream description, and — where upstream provides one — a link to its runbook. The `{{ ... }}` placeholders in a description are substituted with the firing series' own labels when the notification is delivered.

Severity means the same thing here as on the Expeto alert pages:

Severity	Meaning
Critical	Service is impacted or imminently at risk — act now.
Warning	Something is off and needs investigation soon, but service is not yet impacted.
Info	An awareness signal. Review, but no immediate action is implied.
None	Deliberately never routed to an operator. Only `Watchdog` and `InfoInhibitor` use it; both exist to drive Alertmanager itself.
—	The rule ships no severity label at all, so Alertmanager applies its default route. Every etcd alert is in this category.

Some alerts are defined more than once under a single name — usually as a warning and a critical variant of the same condition at different thresholds, and in one case as four error-budget burn rate windows. Those appear as one entry with a row per variant.

> **Important**
>
> Unlike Expeto's rules, none of these carry the `site_state` guard, so putting a Site into maintenance does **not** suppress them. Silence them in Alertmanager for the duration of planned work instead.

Alerts operators most often ask about

Operators integrating against the platform ask about the alerts below more than any others. It is a starting point for triage, not a statement of which alerts you should route or page on; the full reference follows.

Alert	Group	Severity
TargetDown	General	Warning
InfoInhibitor	General	None

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Alert	Group	Severity
KubePodCrashLooping	Kubernetes workloads	Warning
KubeStatefulSetReplicasMismatch	Kubernetes workloads	Warning
KubeDaemonSetRolloutStuck	Kubernetes workloads	Warning
KubeDaemonSetMisScheduled	Kubernetes workloads	Warning
CPUThrottlingHigh	Kubernetes resource usage	Info
KubeAggregatedAPIDown	Kubernetes API server	Warning
KubeControllerManagerInstanceUnreachable	Kubernetes controller manager	Warning
KubeSchedulerInstanceUnreachable	Kubernetes scheduler	Warning
KubeNodeNotReady	Kubelet and node readiness	Warning
KubeletInstanceUnreachable	Kubelet and node readiness	Warning
etcdMembersDown	etcd	—
etcdInsufficientMembers	etcd	—
NodeMemoryHighUtilization	Host and node health	Warning
NodeMemoryMajorPagesFaults	Host and node health	Warning
RemoteWriteConnectionIsSaturated	vmagent metric collection	Warning
TooHighSlowInsertsRate	VictoriaMetrics single-node storage	Warning
TooHighSlowInsertsRate	VictoriaMetrics cluster storage	Warning
TooManyLogs	VictoriaMetrics process health	Warning
TooHighCPUUsage	VictoriaMetrics process health	Critical

Alert summary

Alert	Group	Severity	Fires after
TargetDown	General	Warning	10m
Watchdog	General	None	Immediately
InfoInhibitor	General	None	Immediately
KubePodCrashLooping	Kubernetes workloads	Warning	15m
KubePodNotReady	Kubernetes workloads	Warning	15m
KubeDeploymentGenerationMismatch	Kubernetes workloads	Warning	15m
KubeDeploymentReplicasMismatch	Kubernetes workloads	Warning	15m
KubeDeploymentRolloutStuck	Kubernetes workloads	Warning	15m
KubeStatefulSetReplicasMismatch	Kubernetes workloads	Warning	15m

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Alert	Group	Severity	Fires after
KubeStatefulSetGenerationMismatch	Kubernetes workloads	Warning	15m
KubeStatefulSetUpdateNotRolledOut	Kubernetes workloads	Warning	15m
KubeDaemonSetRolloutStuck	Kubernetes workloads	Warning	15m
KubeContainerWaiting	Kubernetes workloads	Warning	1h
KubeDaemonSetNotScheduled	Kubernetes workloads	Warning	10m
KubeDaemonSetMisScheduled	Kubernetes workloads	Warning	15m
KubeJobNotCompleted	Kubernetes workloads	Warning	Immediately
KubeJobFailed	Kubernetes workloads	Warning	15m
KubeHpaReplicasMismatch	Kubernetes workloads	Warning	15m
KubeHpaMaxedOut	Kubernetes workloads	Warning	15m
KubePdbNotEnoughHealthyPods	Kubernetes workloads	Warning	15m
KubeCPUOvercommit	Kubernetes resource usage	Warning	10m
KubeMemoryOvercommit	Kubernetes resource usage	Warning	10m
KubeCPUQuotaOvercommit	Kubernetes resource usage	Warning	5m
KubeMemoryQuotaOvercommit	Kubernetes resource usage	Warning	5m
KubeQuotaAlmostFull	Kubernetes resource usage	Info	15m
KubeQuotaFullyUsed	Kubernetes resource usage	Info	15m
KubeQuotaExceeded	Kubernetes resource usage	Warning	15m
CPUThrottlingHigh	Kubernetes resource usage	Info	15m
KubePersistentVolumeFillingUp	Kubernetes storage	Critical / Warning	1m / 1h
KubePersistentVolumeInodesFillingUp	Kubernetes storage	Critical / Warning	1m / 1h
KubePersistentVolumeErrors	Kubernetes storage	Critical	5m
KubeVersionMismatch	Kubernetes system components	Warning	15m

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Alert	Group	Severity	Fires after
KubeClientErrors	Kubernetes system components	Warning	15m
KubeClientCertificateExpiration	Kubernetes API server	Warning / Critical	5m
KubeAggregatedAPIErrors	Kubernetes API server	Warning	10m
KubeAggregatedAPIDown	Kubernetes API server	Warning	5m
KubeAPIDown	Kubernetes API server	Critical	15m
KubeAPIInstanceUnreachable	Kubernetes API server	Warning	15m
KubeAPITerminatedRequests	Kubernetes API server	Warning	5m
KubeAPIErrorBudgetBurn	Kubernetes API server error budget	Critical / Warning	2m / 15m / 1h / 3h
KubeControllerManagerDown	Kubernetes controller manager	Critical	15m
KubeControllerManagerInstanceUnreachable	Kubernetes controller manager	Warning	15m
KubeSchedulerDown	Kubernetes scheduler	Critical	15m
KubeSchedulerInstanceUnreachable	Kubernetes scheduler	Warning	15m
KubeNodeNotReady	Kubelet and node readiness	Warning	15m
KubeNodePressure	Kubelet and node readiness	Info	10m
KubeNodeUnreachable	Kubelet and node readiness	Warning	15m
KubeletTooManyPods	Kubelet and node readiness	Info	15m
KubeNodeReadinessFlapping	Kubelet and node readiness	Warning	15m
KubeNodeEviction	Kubelet and node readiness	Info	Immediately
KubeletPlegDurationHigh	Kubelet and node readiness	Warning	5m
KubeletPodStartUpLatencyHigh	Kubelet and node readiness	Warning	15m
KubeletClientCertificateExpiration	Kubelet and node readiness	Warning / Critical	Immediately
KubeletServerCertificateExpiration	Kubelet and node readiness	Warning / Critical	Immediately

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Alert	Group	Severity	Fires after
KubeletClientCertificateRenewalErrors	Kubelet and node readiness	Warning	15m
KubeletServerCertificateRenewalErrors	Kubelet and node readiness	Warning	15m
KubeletInstanceUnreachable	Kubelet and node readiness	Warning	15m
KubeletDown	Kubelet and node readiness	Critical	15m
KubeStateMetricsListErrors	kube-state-metrics	Critical	15m
KubeStateMetricsWatchErrors	kube-state-metrics	Critical	15m
KubeStateMetricsShardingMismatch	kube-state-metrics	Critical	15m
KubeStateMetricsShardsMissing	kube-state-metrics	Critical	15m
etcdMembersDown	etcd	—	Immediately
etcdInsufficientMembers	etcd	—	Immediately
etcdNoLeader	etcd	—	Immediately
etcdHighNumberOfLeaderChanges	etcd	—	Immediately
etcdHighNumberOfFailedGRPCRequests	etcd	—	Immediately
etcdGRPCRequestsSlow	etcd	—	Immediately
etcdMemberCommunicationSlow	etcd	—	Immediately
etcdHighNumberOfFailedProposals	etcd	—	Immediately
etcdHighFsyncDurations	etcd	—	Immediately
etcdHighCommitDurations	etcd	—	Immediately
etcdDatabaseQuotaLowSpace	etcd	—	Immediately
etcdExcessiveDatabaseGrowth	etcd	—	Immediately
etcdDatabaseHighFragmentationRatio	etcd	—	Immediately
NodeFilesystemSpaceFillingUp	Host and node health	Warning / Critical	1h
NodeFilesystemAlmostOutOfSpace	Host and node health	Warning / Critical	30m
NodeFilesystemFilesFillingUp	Host and node health	Warning / Critical	1h
NodeFilesystemAlmostOutOfFiles	Host and node health	Warning / Critical	1h
NodeNetworkReceiveErrs	Host and node health	Warning	1h

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Alert	Group	Severity	Fires after
NodeNetworkTransmitErrs	Host and node health	Warning	1h
NodeHighNumberConntrackEntriesUsed	Host and node health	Warning	Immediately
NodeTextFileCollectorScrapeError	Host and node health	Warning	Immediately
NodeClockSkewDetected	Host and node health	Warning	10m
NodeClockNotSynchronising	Host and node health	Warning	10m
NodeRAIDDegraded	Host and node health	Critical	15m
NodeRAIDDiskFailure	Host and node health	Warning	Immediately
NodeFileDescriptorLimit	Host and node health	Warning / Critical	15m
NodeCPUHighUsage	Host and node health	Info	15m
NodeSystemSaturation	Host and node health	Warning	15m
NodeMemoryMajorPagesFaults	Host and node health	Warning	15m
NodeMemoryHighUtilization	Host and node health	Warning	15m
NodeDiskIOSaturation	Host and node health	Warning	30m
NodeSystemdServiceFailed	Host and node health	Warning	5m
NodeSystemdServiceCrashlooping	Host and node health	Warning	15m
NodeBondingDegraded	Host and node health	Warning	5m
NodeNetworkInterfaceFlapping	Host networking	Warning	2m
AlertmanagerFailedReload	Alertmanager	Critical	10m
AlertmanagerMembersInconsistent	Alertmanager	Critical	15m
AlertmanagerFailedToSendAlerts	Alertmanager	Warning	5m
AlertmanagerClusterFailedToSendAlerts	Alertmanager	Critical / Warning	5m
AlertmanagerConfigInconsistent	Alertmanager	Critical	20m
AlertmanagerClusterDown	Alertmanager	Critical	5m
AlertmanagerClusterCrashlooping	Alertmanager	Critical	5m
PersistentQueueIsDroppingData	vmagent metric collection	Critical	10m
RejectedRemoteWriteDataBlocksAreDropped	vmagent metric collection	Warning	15m
TooManyScrapeErrors	vmagent metric collection	Warning	15m

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Alert	Group	Severity	Fires after
ScrapePoolHasNoTargets	vmagent metric collection	Warning	30m
TooManyWriteErrors	vmagent metric collection	Warning	15m
TooManyRemoteWriteErrors	vmagent metric collection	Warning	15m
RemoteWriteConnectionIsSaturated	vmagent metric collection	Warning	15m
PersistentQueueForWritesIsSaturated	vmagent metric collection	Warning	15m
PersistentQueueForReadsIsSaturated	vmagent metric collection	Warning	15m
SeriesLimitHourReached	vmagent metric collection	Critical	Immediately
SeriesLimitDayReached	vmagent metric collection	Critical	Immediately
ConfigurationReloadFailure	vmagent metric collection	Warning	Immediately
StreamAggrFlushTimeout	vmagent metric collection	Warning	Immediately
StreamAggrDedupFlushTimeout	vmagent metric collection	Warning	Immediately
PersistentQueueRunsOutOfSpaceIn12Hours	vmagent metric collection	Warning	10m
PersistentQueueRunsOutOfSpaceIn4Hours	vmagent metric collection	Critical	10m
ConfigurationReloadFailure	vmalert rule evaluation	Warning	Immediately
AlertingRulesError	vmalert rule evaluation	Warning	5m
RecordingRulesError	vmalert rule evaluation	Warning	5m
RecordingRulesNoData	vmalert rule evaluation	Info	30m
TooManyMissedIterations	vmalert rule evaluation	Warning	15m
RemoteWriteErrors	vmalert rule evaluation	Warning	15m
RemoteWriteDroppingData	vmalert rule evaluation	Critical	5m
RemoteWriteQueueHighUsage	vmalert rule evaluation	Warning	15m
AlertmanagerErrors	vmalert rule evaluation	Warning	15m

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Alert	Group	Severity	Fires after
DiskRunsOutOfSpaceIn3Days	VictoriaMetrics single-node storage	Critical	30m
NodeBecomesReadonlyIn3Days	VictoriaMetrics single-node storage	Warning	30m
DiskRunsOutOfSpace	VictoriaMetrics single-node storage	Critical	30m
RequestErrorsToAPI	VictoriaMetrics single-node storage	Warning	15m
TooHighChurnRate	VictoriaMetrics single-node storage	Warning	15m
TooHighChurnRate24h	VictoriaMetrics single-node storage	Warning	15m
TooHighSlowInsertsRate	VictoriaMetrics single-node storage	Warning	15m
MetadataCacheUtilizationIsTooHigh	VictoriaMetrics single-node storage	Warning	15m
DiskRunsOutOfSpaceIn3Days	VictoriaMetrics cluster storage	Critical	30m
NodeBecomesReadonlyIn3Days	VictoriaMetrics cluster storage	Warning	30m
DiskRunsOutOfSpace	VictoriaMetrics cluster storage	Critical	30m
RequestErrorsToAPI	VictoriaMetrics cluster storage	Warning	15m
RPCErrors	VictoriaMetrics cluster storage	Warning	15m
TooHighChurnRate	VictoriaMetrics cluster storage	Warning	15m
TooHighChurnRate24h	VictoriaMetrics cluster storage	Warning	15m
TooHighSlowInsertsRate	VictoriaMetrics cluster storage	Warning	15m
VminsertVmstorageConnectionIsSaturated	VictoriaMetrics cluster storage	Warning	15m
MetadataCacheUtilizationIsTooHigh	VictoriaMetrics cluster storage	Warning	15m
MetricNameStatsCacheUtilizationIsTooHigh	VictoriaMetrics cluster storage	Warning	15m

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Alert	Group	Severity	Fires after
IndexDBRecordsDrop	VictoriaMetrics cluster storage	Critical	Immediately
TooManyTSIDMisses	VictoriaMetrics cluster storage	Critical	15m
TooManyRestarts	VictoriaMetrics process health	Critical	Immediately
ServiceDown	VictoriaMetrics process health	Critical	2m
ProcessNearFDLimits	VictoriaMetrics process health	Critical	5m
TooHighMemoryUsage	VictoriaMetrics process health	Critical	5m
TooHighCPUUsage	VictoriaMetrics process health	Critical	5m
TooHighGoroutineSchedulingLatency	VictoriaMetrics process health	Critical	15m
TooManyLogs	VictoriaMetrics process health	Warning	15m
ConcurrentInsertsHitTheLimit	VictoriaMetrics process health	Warning	15m
TooHighQueryLoad	VictoriaMetrics process health	Warning	15m
RowsRejectedOnIngestion	VictoriaMetrics process health	Warning	15m
LogErrors	VictoriaMetrics operator	Warning	15m
ReconcileErrors	VictoriaMetrics operator	Warning	10m
HighQueueDepth	VictoriaMetrics operator	Warning	15m

General

Chart-wide signals rather than alerts about any one component. `TargetDown` reports that a meaningful share of a scrape job's targets are unreachable. The other two never reach an operator: `Watchdog` fires permanently so that a dead alerting pipeline can be detected by its *absence*, and `InfoInhibitor` exists so Alertmanager can suppress info-level noise while a real alert is already firing for the same namespace.

TARGETDOWN

Severity	Fires after
Warning	10m

One or more targets are unreachable.

{{ printf "%.4g" $value }}% of the {{ $labels.job }}/{{ $labels.service }} targets in {{ $labels.namespace }} namespace are down.

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Trigger condition

```
(100 * (count(up == 0) by(cluster,job,namespace,service) / count(up) by(cluster,job,namespace,service))) > 10
```

Upstream runbook for TargetDown

WATCHDOG

Severity	Fires after
None	Immediately

An alert that should always be firing to certify that Alertmanager is working properly.

This is an alert meant to ensure that the entire alerting pipeline is functional. This alert is always firing, therefore it should always be firing in Alertmanager and always fire against a receiver. There are integrations with various notification mechanisms that send a notification when this alert is not firing. For example the "DeadMansSnitch" integration in PagerDuty.

Trigger condition

```
vector(1)
```

Upstream runbook for Watchdog

INFOINHIBITOR

Severity	Fires after
None	Immediately

Info-level alert inhibition.

This is an alert that is used to inhibit info alerts. By themselves, the info-level alerts are sometimes very noisy, but they are relevant when combined with other alerts. This alert fires whenever there's a severity="info" alert, and stops firing when another alert with a severity of 'warning' or 'critical' starts firing on the same namespace. This alert should be routed to a null receiver and configured to inhibit alerts with severity="info".

Trigger condition

```
group(ALERTS{severity="info"} == 1) by(namespace,cluster) unless on(namespace,cluster) group(ALERTS{alertname!="InfoInhibitor",alertstate="firing",severity=~"warning|critical"} == 1)
by(namespace,cluster)
```

Upstream runbook for InfoInhibitor

Kubernetes workloads

Workload-level alerts derived from kube-state-metrics: Deployments, StatefulSets, DaemonSets, Jobs, HorizontalPodAutoscalers, PodDisruptionBudgets, and individual Pods. Most wait 15 minutes before firing, which is long enough to ride out a normal rollout.

KUBEPODCRASHLOOPING

Severity	Fires after
Warning	15m

Pod is crash looping.

Pod {{ $labels.namespace }}/{{ $labels.pod }} ({{ $labels.container }}) is in waiting state (reason: "CrashLoopBackOff") on cluster {{ $labels.cluster }}.

Trigger condition

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```
max_over_time(kube_pod_container_status_waiting_reason{reason="CrashLoopBackOff",namespace=~".*",job="kube-state-metrics"}[5m]) >= 1
```

Upstream runbook for KubePodCrashLooping

KUBEPODNOTREADY

Severity	Fires after
Warning	15m

Pod has been in a non-ready state for more than 15 minutes.

Pod {{ $labels.namespace }}/{{ $labels.pod }} has been in a non-ready state for longer than 15 minutes on cluster {{ $labels.cluster }}.

Trigger condition

```
sum(max(kube_pod_status_phase{namespace=~".*",job="kube-state-metrics",phase=~"Pending|Unknown"}) by(namespace,pod,job,cluster) * on(namespace,pod,cluster) group_left() topk(1,
max(kube_pod_owner{owner_kind!="Job"}) by(namespace,pod,owner_kind,cluster)) by(namespace,pod,cluster)) by(namespace,pod,job,cluster) > 0
```

Upstream runbook for KubePodNotReady

KUBEDEPLOYMENTGENERATIONMISMATCH

Severity	Fires after
Warning	15m

Deployment generation mismatch due to possible roll-back

Deployment generation for {{ $labels.namespace }}/{{ $labels.deployment }} does not match, this indicates that the Deployment has failed but has not been rolled back on cluster {{ $labels.cluster }}.

Trigger condition

```
kube_deployment_status_observed_generation{namespace=~".*",job="kube-state-metrics"} != kube_deployment_metadata_generation{namespace=~".*",job="kube-state-metrics"}
```

Upstream runbook for KubeDeploymentGenerationMismatch

KUBEDEPLOYMENTREPLICASMISMATCH

Severity	Fires after
Warning	15m

Deployment has not matched the expected number of replicas.

Deployment {{ $labels.namespace }}/{{ $labels.deployment }} has not matched the expected number of replicas for longer than 15 minutes on cluster {{ $labels.cluster }}.

Trigger condition

```
(kube_deployment_spec_replicas{namespace=~".*",job="kube-state-metrics"} > kube_deployment_status_replicas_available{namespace=~".*",job="kube-state-metrics"}) and
(changes(kube_deployment_status_replicas_updated{namespace=~".*",job="kube-state-metrics"}[10m]) == 0)
```

Upstream runbook for KubeDeploymentReplicasMismatch

KUBEDEPLOYMENTROLLOUTSTUCK

Severity	Fires after
Warning	15m

Deployment rollout is not progressing.

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Rollout of deployment {{ $labels.namespace }}/{{ $labels.deployment }} is not progressing for longer than 15 minutes on cluster {{ $labels.cluster }}.

Trigger condition

```
kube_deployment_status_condition{condition="Progressing",status="false",namespace=~".*",job="kube-state-metrics"} != 0
```

Upstream runbook for KubeDeploymentRolloutStuck

KUBESTATEFULSETREPLICASMISMATCH

Severity	Fires after
Warning	15m

StatefulSet has not matched the expected number of replicas.

StatefulSet {{ $labels.namespace }}/{{ $labels.statefulset }} has not matched the expected number of replicas for longer than 15 minutes on cluster {{ $labels.cluster }}.

Trigger condition

```
(kube_statefulset_status_replicas_ready{namespace=~".*",job="kube-state-metrics"} != kube_statefulset_replicas{namespace=~".*",job="kube-state-metrics"}) and
(changes(kube_statefulset_status_replicas_updated{namespace=~".*",job="kube-state-metrics"}[10m]) == 0)
```

Upstream runbook for KubeStatefulSetReplicasMismatch

KUBESTATEFULSETGENERATIONMISMATCH

Severity	Fires after
Warning	15m

StatefulSet generation mismatch due to possible roll-back

StatefulSet generation for {{ $labels.namespace }}/{{ $labels.statefulset }} does not match, this indicates that the StatefulSet has failed but has not been rolled back on cluster {{ $labels.cluster }}.

Trigger condition

```
kube_statefulset_status_observed_generation{namespace=~".*",job="kube-state-metrics"} != kube_statefulset_metadata_generation{namespace=~".*",job="kube-state-metrics"}
```

Upstream runbook for KubeStatefulSetGenerationMismatch

KUBESTATEFULSETUPDATENOTROLLEDOUT

Severity	Fires after
Warning	15m

StatefulSet update has not been rolled out.

StatefulSet {{ $labels.namespace }}/{{ $labels.statefulset }} update has not been rolled out on cluster {{ $labels.cluster }}.

Trigger condition

```
(max(kube_statefulset_status_current_revision{namespace=~".*",job="kube-state-metrics"} unless kube_statefulset_status_update_revision{namespace=~".*",job="kube-state-metrics"})
by(namespace,statefulset,job,cluster) * on(namespace,statefulset,job,cluster) (kube_statefulset_replicas{namespace=~".*",job="kube-state-metrics"} !=
kube_statefulset_status_replicas_updated{namespace=~".*",job="kube-state-metrics"})) and on(namespace,statefulset,job,cluster)
(changes(kube_statefulset_status_replicas_updated{namespace=~".*",job="kube-state-metrics"}[5m]) == 0)
```

Upstream runbook for KubeStatefulSetUpdateNotRolledOut

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KUBEDAEMONSETROLLOUTSTUCK

Severity	Fires after
Warning	15m

DaemonSet rollout is stuck.

DaemonSet {{ $labels.namespace }}/{{ $labels.daemonset }} has not finished or progressed for at least 15m on cluster {{ $labels.cluster }}.

Trigger condition

```
((((kube_daemonset_status_current_number_scheduled{namespace=~".*",job="kube-state-metrics"} != kube_daemonset_status_desired_number_scheduled{namespace=~".*",job="kube-state-metrics"})
or (kube_daemonset_status_number_misscheduled{namespace=~".*",job="kube-state-metrics"} != 0)) or (kube_daemonset_status_updated_number_scheduled{namespace=~".*",job="kube-state-
metrics"} != kube_daemonset_status_desired_number_scheduled{namespace=~".*",job="kube-state-metrics"})) or (kube_daemonset_status_number_available{namespace=~".*",job="kube-state-
metrics"} != kube_daemonset_status_desired_number_scheduled{namespace=~".*",job="kube-state-metrics"})) and
(changes(kube_daemonset_status_updated_number_scheduled{namespace=~".*",job="kube-state-metrics"}[5m]) == 0)
```

Upstream runbook for KubeDaemonSetRolloutStuck

KUBECONTAINERWAITING

Severity	Fires after
Warning	1h

Pod container waiting longer than 1 hour

pod/{{ $labels.pod }} in namespace {{ $labels.namespace }} on container {{ $labels.container}} has been in waiting state for longer than 1 hour. (reason: "{{ $labels.reason }}") on cluster {{ $labels.cluster }}.

Trigger condition

```
kube_pod_container_status_waiting_reason{reason!="CrashLoopBackOff",namespace=~".*",job="kube-state-metrics"} > 0
```

Upstream runbook for KubeContainerWaiting

KUBEDAEMONSETNOTSCHEDULED

Severity	Fires after
Warning	10m

DaemonSet pods are not scheduled.

{{ $value }} Pods of DaemonSet {{ $labels.namespace }}/{{ $labels.daemonset }} are not scheduled on cluster {{ $labels.cluster }}.

Trigger condition

```
(kube_daemonset_status_desired_number_scheduled{namespace=~".*",job="kube-state-metrics"} - kube_daemonset_status_current_number_scheduled{namespace=~".*",job="kube-state-metrics"}) > 0
```

Upstream runbook for KubeDaemonSetNotScheduled

KUBEDAEMONSETMISSCHEDULED

Severity	Fires after
Warning	15m

DaemonSet pods are misscheduled.

{{ $value }} Pods of DaemonSet {{ $labels.namespace }}/{{ $labels.daemonset }} are running where they are not supposed to run on cluster {{ $labels.cluster }}.

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Trigger condition

```
kube_daemonset_status_number_misscheduled{namespace=~".*",job="kube-state-metrics"} > 0
```

Upstream runbook for KubeDaemonSetMisScheduled

KUBEJOBNOTCOMPLETED

Severity	Fires after
Warning	Immediately

Job did not complete in time

Job {{ $labels.namespace }}/{{ $labels.job_name }} is taking more than {{ "43200" | humanizeDuration }} to complete on cluster {{ $labels.cluster }}.

Trigger condition

```
(time() - max(kube_job_status_start_time{namespace=~".*",job="kube-state-metrics"} and (kube_job_status_active{namespace=~".*",job="kube-state-metrics"} > 0)) by(namespace,job_name,cluster)) > 43200
```

Upstream runbook for KubeJobNotCompleted

KUBEJOBFAILED

Severity	Fires after
Warning	15m

Job failed to complete.

Job {{ $labels.namespace }}/{{ $labels.job_name }} failed to complete. Removing failed job after investigation should clear this alert on cluster {{ $labels.cluster }}.

Trigger condition

```
kube_job_failed{namespace=~".*",job="kube-state-metrics"} > 0
```

Upstream runbook for KubeJobFailed

KUBEHPAREPLICASMISMATCH

Severity	Fires after
Warning	15m

HPA has not matched desired number of replicas.

HPA {{ $labels.namespace }}/{{ $labels.horizontalpodautoscaler }} has not matched the desired number of replicas for longer than 15 minutes on cluster {{ $labels.cluster }}.

Trigger condition

```
(((kube_horizontalpodautoscaler_status_desired_replicas{namespace=~".*",job="kube-state-metrics"} != kube_horizontalpodautoscaler_status_current_replicas{namespace=~".*",job="kube-state-metrics"}) and (kube_horizontalpodautoscaler_status_current_replicas{namespace=~".*",job="kube-state-metrics"} > kube_horizontalpodautoscaler_spec_min_replicas{namespace=~".*",job="kube-state-metrics"})) and (kube_horizontalpodautoscaler_status_current_replicas{namespace=~".*",job="kube-state-metrics"} < kube_horizontalpodautoscaler_spec_max_replicas{namespace=~".*",job="kube-state-metrics"})) and (changes(kube_horizontalpodautoscaler_status_current_replicas{namespace=~".*",job="kube-state-metrics"}[15m]) == 0)
```

Upstream runbook for KubeHpaReplicasMismatch

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KUBEHPAMAXEDOUT

Severity	Fires after
Warning	15m

HPA is running at max replicas

HPA {{ $labels.namespace }}/{{ $labels.horizontalpodautoscaler }} has been running at max replicas for longer than 15 minutes on cluster {{ $labels.cluster }}.

Trigger condition

```
(kube_horizontalpodautoscaler_status_current_replicas{namespace=~".*",job="kube-state-metrics"} == kube_horizontalpodautoscaler_spec_max_replicas{namespace=~".*",job="kube-state-metrics"})
and on(namespace,horizontalpodautoscaler,cluster) (kube_horizontalpodautoscaler_spec_max_replicas{namespace=~".*",job="kube-state-metrics"} !=
kube_horizontalpodautoscaler_spec_min_replicas{namespace=~".*",job="kube-state-metrics"})
```

Upstream runbook for KubeHpaMaxedOut

KUBEPDBNOTENOUGHHEALTHYPODS

Severity	Fires after
Warning	15m

PDB does not have enough healthy pods.

PDB {{ $labels.cluster }}/{{ $labels.namespace }}/{{ $labels.poddisruptionbudget }} expects {{ $value }} more healthy pods. The desired number of healthy pods has not been met for at least 15m.

Trigger condition

```
(kube_poddisruptionbudget_status_desired_healthy{namespace=~".*",job="kube-state-metrics"} - kube_poddisruptionbudget_status_current_healthy{namespace=~".*",job="kube-state-metrics"}) > 0
```

Upstream runbook for KubePdbNotEnoughHealthyPods

Kubernetes resource usage

Pod requests, limits, and namespace quotas measured against what the cluster can actually schedule. These describe capacity planning rather than a live outage — an overcommitted cluster runs fine until a node is lost.

KUBECPUOVERCOMMIT

Severity	Fires after
Warning	10m

Cluster has overcommitted CPU resource requests.

Cluster {{ $labels.cluster }} has overcommitted CPU resource requests for Pods by {{ printf "%.2f" $value }} CPU shares and cannot tolerate node failure.

Trigger condition

```
(((sum(namespace_cpu:kube_pod_container_resource_requests:sum) by(cluster) - sum(kube_node_status_allocatable{job="kube-state-metrics",resource="cpu"}) by(cluster)) > 0) and
(count(max(kube_node_role{job="kube-state-metrics",role="control-plane"}) by(cluster,node)) by(cluster) < 3)) or ((sum(namespace_cpu:kube_pod_container_resource_requests:sum) by(cluster) -
((sum(kube_node_status_allocatable{job="kube-state-metrics",resource="cpu"}) by(cluster) - max(kube_node_status_allocatable{job="kube-state-metrics",resource="cpu"}) by(cluster)) > 0)) > 0)
```

Upstream runbook for KubeCPUOvercommit

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KUBEMEMORYOVERCOMMIT

Severity	Fires after
Warning	10m

Cluster has overcommitted memory resource requests.

Cluster {{ $labels.cluster }} has overcommitted memory resource requests for Pods by {{ $value | humanize }} bytes and cannot tolerate node failure.

Trigger condition

```
(((sum(namespace_memory:kube_pod_container_resource_requests:sum) by(cluster) - sum(kube_node_status_allocatable{job="kube-state-metrics",resource="memory"}) by(cluster)) > 0) and
(count(max(kube_node_role{job="kube-state-metrics",role="control-plane"}) by(cluster,node)) by(cluster) < 3)) or ((sum(namespace_memory:kube_pod_container_resource_requests:sum) by(cluster) -
((sum(kube_node_status_allocatable{job="kube-state-metrics",resource="memory"}) by(cluster) - max(kube_node_status_allocatable{job="kube-state-metrics",resource="memory"}) by(cluster)) > 0)) > 0)
```

Upstream runbook for KubeMemoryOvercommit

KUBECPUQUOTAOVERCOMMIT

Severity	Fires after
Warning	5m

Cluster has overcommitted CPU resource requests.

Cluster {{ $labels.cluster }} has overcommitted CPU resource requests for Namespaces.

Trigger condition

```
(sum(min(kube_resourcequota{job="kube-state-metrics",type="hard",resource=~"(cpu|requests.cpu)"}) without(resource)) by(cluster) / sum(kube_node_status_allocatable{resource="cpu",job="kube-
state-metrics"}) by(cluster)) > 1.5
```

Upstream runbook for KubeCPUQuotaOvercommit

KUBEMEMORYQUOTAOVERCOMMIT

Severity	Fires after
Warning	5m

Cluster has overcommitted memory resource requests.

Cluster {{ $labels.cluster }} has overcommitted memory resource requests for Namespaces.

Trigger condition

```
(sum(min(kube_resourcequota{job="kube-state-metrics",type="hard",resource=~"(memory|requests.memory)"}) without(resource)) by(cluster) /
sum(kube_node_status_allocatable{resource="memory",job="kube-state-metrics"}) by(cluster)) > 1.5
```

Upstream runbook for KubeMemoryQuotaOvercommit

KUBEQUOTAALMOSTFULL

Severity	Fires after
Info	15m

Namespace quota is going to be full.

Namespace {{ $labels.namespace }} is using {{ $value | humanizePercentage }} of its {{ $labels.resource }} quota on cluster {{ $labels.cluster }}.

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Trigger condition

```
((max(kube_resourcequota{job="kube-state-metrics",type="used"}) without(instance,job,type) / on(cluster,namespace,resource,resourcequota) group_left() (max(kube_resourcequota{job="kube-state-metrics",type="hard"}) without(instance,job,type) > 0)) > 0.9) < 1
```

Upstream runbook for KubeQuotaAlmostFull

KUBEQUOTAFULLYUSED

Severity	Fires after
Info	15m

Namespace quota is fully used.

Namespace {{ $labels.namespace }} is using {{ $value | humanizePercentage }} of its {{ $labels.resource }} quota on cluster {{ $labels.cluster }}.

Trigger condition

```
(max(kube_resourcequota{job="kube-state-metrics",type="used"}) without(instance,job,type) / on(cluster,namespace,resource,resourcequota) group_left() (max(kube_resourcequota{job="kube-state-metrics",type="hard"}) without(instance,job,type) > 0)) == 1
```

Upstream runbook for KubeQuotaFullyUsed

KUBEQUOTAEXCEEDED

Severity	Fires after
Warning	15m

Namespace quota has exceeded the limits.

Namespace {{ $labels.namespace }} is using {{ $value | humanizePercentage }} of its {{ $labels.resource }} quota on cluster {{ $labels.cluster }}.

Trigger condition

```
(max(kube_resourcequota{job="kube-state-metrics",type="used"}) without(instance,job,type) / on(cluster,namespace,resource,resourcequota) group_left() (max(kube_resourcequota{job="kube-state-metrics",type="hard"}) without(instance,job,type) > 0)) > 1
```

Upstream runbook for KubeQuotaExceeded

CPUTHROTTLINGHIGH

Severity	Fires after
Info	15m

Processes experience elevated CPU throttling.

{{ $value | humanizePercentage }} throttling of CPU in namespace {{ $labels.namespace }} for container {{ $labels.container }} in pod {{ $labels.pod }} on cluster {{ $labels.cluster }}.

Trigger condition

```
(sum(topk(1, increase(container_cpu_cfs_throttled_periods_total{container!="",job="kubelet",metrics_path="/metrics/cadvisor"}[5m])) by(cluster,namespace,pod,container,instance)) without(id,metrics_path,name,image,endpoint,job,node) / on(cluster,namespace,pod,container,instance) group_left() sum(topk(1, increase(container_cpu_cfs_periods_total{job="kubelet",metrics_path="/metrics/cadvisor"}[5m])) by(cluster,namespace,pod,container,instance)) without(id,metrics_path,name,image,endpoint,job,node)) > 0.25
```

Upstream runbook for CPUThrottlingHigh

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Kubernetes storage

PersistentVolume capacity, inode exhaustion, and provisioning failures. The two filling-up alerts combine a current threshold with a `predict_linear` forecast, so they fire before the volume is actually full.

KUBEPERSISTENTVOLUMEFILLINGUP

Severity	Fires after
Critical	1m
Warning	1h

PersistentVolume is filling up.

This alert is defined in 2 variants:

Critical, fires after 1m

The PersistentVolume claimed by {{ $labels.persistentvolumeclaim }} in Namespace {{ $labels.namespace }} on Cluster {{ $labels.cluster }} is only {{ $value | humanizePercentage }} free.

```
((((kubelet_volume_stats_available_bytes{namespace=~".*",job="kubelet",metrics_path="/metrics"} / kubelet_volume_stats_capacity_bytes{namespace=~".*",job="kubelet",metrics_path="/metrics"}) < 0.03) and (kubelet_volume_stats_used_bytes{namespace=~".*",job="kubelet",metrics_path="/metrics"} > 0)) unless on(cluster,namespace,persistentvolumeclaim) (kube_persistentvolumeclaim_access_mode{access_mode="ReadOnlyMany"} == 1)) unless on(cluster,namespace,persistentvolumeclaim) (kube_persistentvolumeclaim_labels{label_excluded_from_alerts="true"} == 1)
```

Warning, fires after 1h

Based on recent sampling, the PersistentVolume claimed by {{ $labels.persistentvolumeclaim }} in Namespace {{ $labels.namespace }} on Cluster {{ $labels.cluster }} is expected to fill up within four days. Currently {{ $value | humanizePercentage }} is available.

```
(((((kubelet_volume_stats_available_bytes{namespace=~".*",job="kubelet",metrics_path="/metrics"} / kubelet_volume_stats_capacity_bytes{namespace=~".*",job="kubelet",metrics_path="/metrics"}) < 0.15) and (kubelet_volume_stats_used_bytes{namespace=~".*",job="kubelet",metrics_path="/metrics"} > 0)) and (predict_linear(kubelet_volume_stats_available_bytes{namespace=~".*",job="kubelet",metrics_path="/metrics"}[6h], 345600) < 0)) unless on(cluster,namespace,persistentvolumeclaim) (kube_persistentvolumeclaim_access_mode{access_mode="ReadOnlyMany"} == 1)) unless on(cluster,namespace,persistentvolumeclaim) (kube_persistentvolumeclaim_labels{label_excluded_from_alerts="true"} == 1)
```

Upstream runbook for KubePersistentVolumeFillingUp

KUBEPERSISTENTVOLUMEINODESFILLINGUP

Severity	Fires after
Critical	1m
Warning	1h

PersistentVolumeInodes are filling up.

This alert is defined in 2 variants:

Critical, fires after 1m

The PersistentVolume claimed by {{ $labels.persistentvolumeclaim }} in Namespace {{ $labels.namespace }} on Cluster {{ $labels.cluster }} only has {{ $value | humanizePercentage }} free inodes.

```
((((kubelet_volume_stats_inodes_free{namespace=~".*",job="kubelet",metrics_path="/metrics"} / kubelet_volume_stats_inodes{namespace=~".*",job="kubelet",metrics_path="/metrics"}) < 0.03) and (kubelet_volume_stats_inodes_used{namespace=~".*",job="kubelet",metrics_path="/metrics"} > 0)) unless on(cluster,namespace,persistentvolumeclaim) (kube_persistentvolumeclaim_access_mode{access_mode="ReadOnlyMany"} == 1)) unless on(cluster,namespace,persistentvolumeclaim) (kube_persistentvolumeclaim_labels{label_excluded_from_alerts="true"} == 1)
```

Warning, fires after 1h

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Based on recent sampling, the PersistentVolume claimed by {{ $labels.persistentvolumeclaim }} in Namespace {{ $labels.namespace }} on Cluster {{ $labels.cluster }} is expected to run out of inodes within four days. Currently {{ $value | humanizePercentage }} of its inodes are free.

```
(((((kubelet_volume_stats_inodes_free{namespace=~".*",job="kubelet",metrics_path="/metrics"} / kubelet_volume_stats_inodes{namespace=~".*",job="kubelet",metrics_path="/metrics"}) < 0.15) and (kubelet_volume_stats_inodes_used{namespace=~".*",job="kubelet",metrics_path="/metrics"} > 0)) and (predict_linear(kubelet_volume_stats_inodes_free{namespace=~".*",job="kubelet",metrics_path="/metrics"}[6h], 345600) < 0)) unless on(cluster,namespace,persistentvolumeclaim) (kube_persistentvolumeclaim_access_mode{access_mode="ReadOnlyMany"} == 1)) unless on(cluster,namespace,persistentvolumeclaim) (kube_persistentvolumeclaim_labels{label_excluded_from_alerts="true"} == 1)
```

Upstream runbook for KubePersistentVolumeInodesFillingUp

KUBEPERSISTENTVOLUMEERRORS

Severity	Fires after
Critical	5m

PersistentVolume is having issues with provisioning.

The persistent volume {{ $labels.persistentvolume }} on Cluster {{ $labels.cluster }} has status {{ $labels.phase }}.

Trigger condition

```
kube_persistentvolume_status_phase{phase=~"Failed|Pending",job="kube-state-metrics"} > 0
```

Upstream runbook for KubePersistentVolumeErrors

Kubernetes system components

Cross-component consistency: version skew between control-plane components, and Kubernetes API clients whose requests are failing.

KUBEVERSIONMISMATCH

Severity	Fires after
Warning	15m

Different semantic versions of Kubernetes components running.

There are {{ $value }} different semantic versions of Kubernetes components running on cluster {{ $labels.cluster }}.

Trigger condition

```
count(count(label_replace(kubernetes_build_info{job!~"kube-dns|coredns"}, "git_version", "$1", "git_version", "(v[0-9]*.[0-9]*).*")) by(git_version,cluster)) by(cluster) > 1
```

Upstream runbook for KubeVersionMismatch

KUBECLIENTERRORS

Severity	Fires after
Warning	15m

Kubernetes API server client is experiencing errors.

Kubernetes API server client '{{ $labels.job }}/{{ $labels.instance }}' is experiencing {{ $value | humanizePercentage }} errors on cluster {{ $labels.cluster }}.

Trigger condition

```
(sum(rate(rest_client_requests_total{job="apiserver",code=~"5.."}[5m])) by(cluster,instance,job,namespace) / sum(rate(rest_client_requests_total{job="apiserver"}[5m])) by(cluster,instance,job,namespace)) > 0.01
```


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Upstream runbook for KubeClientErrors

Kubernetes API server

Availability of the API server itself, certificate expiry for its clients, health of aggregated (extension) APIs, and requests the server is terminating under load. A failure here disables scheduling and rollouts even while running workloads keep serving traffic.

KUBECLIENTCERTIFICATEEXPIRATION

Severity	Fires after
Warning	5m
Critical	5m

Client certificate is about to expire.

This alert is defined in 2 variants:

Warning, fires after 5m

A client certificate used to authenticate to kubernetes apiserver is expiring in less than 7.0 days on cluster {{ $labels.cluster }}.

```
(histogram_quantile(0.01, sum(rate(apiserver_client_certificate_expiration_seconds_bucket{job="apiserver"}[5m])) without(namespace,service,endpoint)) < 604800) and on(job,cluster,instance)
(apiserver_client_certificate_expiration_seconds_count{job="apiserver"} > 0)
```

Critical, fires after 5m

A client certificate used to authenticate to kubernetes apiserver is expiring in less than 24.0 hours on cluster {{ $labels.cluster }}.

```
(histogram_quantile(0.01, sum(rate(apiserver_client_certificate_expiration_seconds_bucket{job="apiserver"}[5m])) without(namespace,service,endpoint)) < 86400) and on(job,cluster,instance)
(apiserver_client_certificate_expiration_seconds_count{job="apiserver"} > 0)
```

Upstream runbook for KubeClientCertificateExpiration

KUBEAGGREGATEDAPIERRORS

Severity	Fires after
Warning	10m

Kubernetes aggregated API has reported errors.

Kubernetes aggregated API {{ $labels.instance }}/{{ $labels.name }} has reported {{ $labels.reason }} errors on cluster {{ $labels.cluster }}.

Trigger condition

```
sum(increase(aggregator_unavailable_apiservice_total{job="apiserver"}[1m])) by(cluster,instance,name,reason) > 0
```

Upstream runbook for KubeAggregatedAPIErrors

KUBEAGGREGATEDAPIDOWN

Severity	Fires after
Warning	5m

Kubernetes aggregated API is down.

Kubernetes aggregated API {{ $labels.name }}/{{ $labels.namespace }} has been only {{ $value | humanize }}% available over the last 10m on cluster {{ $labels.cluster }}.

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Trigger condition

```
((1 - max(avg_over_time(aggregator_unavailable_apiservice{job="apiserver"}[10m])) by(name,namespace,cluster)) * 100) < 85
```

Upstream runbook for KubeAggregatedAPIDown

KUBEAPIDOWN

Severity	Fires after
Critical	15m

Target disappeared from Prometheus target discovery.

KubeAPI has disappeared from Prometheus target discovery.

Trigger condition

```
absent(up{job="apiserver"})
```

Upstream runbook for KubeAPIDown

KUBEAPIINSTANCEUNREACHABLE

Severity	Fires after
Warning	15m

KubeAPI instance is unreachable.

A KubeAPI instance has been unreachable for more than 15 minutes.

Trigger condition

```
up{job="apiserver"} == 0
```

Upstream runbook for KubeAPIInstanceUnreachable

KUBEAPITERMINATEDREQUESTS

Severity	Fires after
Warning	5m

The kubernetes apiserver has terminated {{ $value | humanizePercentage }} of its incoming requests.

The kubernetes apiserver has terminated {{ $value | humanizePercentage }} of its incoming requests on cluster {{ $labels.cluster }}.

Trigger condition

```
(sum(rate(apiserver_request_terminations_total{job="apiserver"}[10m])) by(cluster) / (sum(rate(apiserver_request_total{job="apiserver"}[10m])) by(cluster) +
sum(rate(apiserver_request_terminations_total{job="apiserver"}[10m])) by(cluster))) > 0.20
```

Upstream runbook for KubeAPITerminatedRequests

Kubernetes API server error budget

A single alert, defined as four multi-window burn rate variants of the API server's availability SLO. Each variant pairs a long and a short window so that a brief spike does not fire the slow burn rate, and a sustained failure escalates. Read the variants together: the 1h/5m pair means the error budget is being consumed fast enough to exhaust it within roughly two days.

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KUBEAPIERRORBUDGETBURN

Severity	Fires after
Critical	2m
Critical	15m
Warning	1h
Warning	3h

The API server is burning too much error budget.

This alert is defined in 4 variants:

Critical, fires after 2m

The API server is burning too much error budget on cluster {{ $labels.cluster }}.

```
(sum(apiserver_request:burnrate1h) by(cluster) > 0.14400000000000002) and on(cluster) (sum(apiserver_request:burnrate5m) by(cluster) > 0.14400000000000002)
```

Critical, fires after 15m

The API server is burning too much error budget on cluster {{ $labels.cluster }}.

```
(sum(apiserver_request:burnrate6h) by(cluster) > 0.06) and on(cluster) (sum(apiserver_request:burnrate30m) by(cluster) > 0.06)
```

Warning, fires after 1h

The API server is burning too much error budget on cluster {{ $labels.cluster }}.

```
(sum(apiserver_request:burnrate1d) by(cluster) > 0.03) and on(cluster) (sum(apiserver_request:burnrate2h) by(cluster) > 0.03)
```

Warning, fires after 3h

The API server is burning too much error budget on cluster {{ $labels.cluster }}.

```
(sum(apiserver_request:burnrate3d) by(cluster) > 0.01) and on(cluster) (sum(apiserver_request:burnrate6h) by(cluster) > 0.01)
```

Upstream runbook for KubeAPIErrorBudgetBurn

Kubernetes controller manager

Reachability of the controller manager. If it is down, controllers stop reconciling — Deployments do not scale, and failed Pods are not replaced.

KUBECONTROLLERMANAGERDOWN

Severity	Fires after
Critical	15m

Target disappeared from Prometheus target discovery.

KubeControllerManager has disappeared from Prometheus target discovery.

Trigger condition

```
absent(up{job="kube-controller-manager"})
```

Upstream runbook for KubeControllerManagerDown

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KUBECONTROLLERMANAGERINSTANCEUNREACHABLE

Severity	Fires after
Warning	15m

KubeControllerManager instance is unreachable.

A KubeControllerManager instance has been unreachable for more than 15 minutes.

Trigger condition

```
up{job="kube-controller-manager"} == 0
```

Upstream runbook for KubeControllerManagerInstanceUnreachable

Kubernetes scheduler

Reachability of the scheduler. If it is down, existing Pods keep running but nothing new is placed on a node.

KUBESCHEDULERDOWN

Severity	Fires after
Critical	15m

Target disappeared from Prometheus target discovery.

KubeScheduler has disappeared from Prometheus target discovery.

Trigger condition

```
absent(up{job="kube-scheduler"})
```

Upstream runbook for KubeSchedulerDown

KUBESCHEDULERINSTANCEUNREACHABLE

Severity	Fires after
Warning	15m

KubeScheduler instance is unreachable.

A KubeScheduler instance has been unreachable for more than 15 minutes.

Trigger condition

```
up{job="kube-scheduler"} == 0
```

Upstream runbook for KubeSchedulerInstanceUnreachable

Kubelet and node readiness

The largest group in the bundle: node conditions, evictions, pod capacity, container runtime and PLEG latency, and kubelet certificate expiry and renewal. This is where a failing node shows up first.

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KUBENODENOTREADY

Severity	Fires after
Warning	15m

Node is not ready.

{{ $labels.node }} has been unready for more than 15 minutes on cluster {{ $labels.cluster }}.

Trigger condition

```
(kube_node_status_condition{job="kube-state-metrics",condition="Ready",status="true"} == 0) and on(cluster,node) (kube_node_spec_unschedulable{job="kube-state-metrics"} == 0)
```

Upstream runbook for KubeNodeNotReady

KUBENODEPRESSURE

Severity	Fires after
Info	10m

Node has as active Condition.

{{ $labels.node }} on cluster {{ $labels.cluster }} has active Condition {{ $labels.condition }}. This is caused by resource usage exceeding eviction thresholds.

Trigger condition

```
(kube_node_status_condition{job="kube-state-metrics",condition=~"(MemoryPressure|DiskPressure|PIDPressure)",status="true"} == 1) and on(cluster,node) (kube_node_spec_unschedulable{job="kube-state-metrics"} == 0)
```

Upstream runbook for KubeNodePressure

KUBENODEUNREACHABLE

Severity	Fires after
Warning	15m

Node is unreachable.

{{ $labels.node }} is unreachable and some workloads may be rescheduled on cluster {{ $labels.cluster }}.

Trigger condition

```
(kube_node_spec_taint{job="kube-state-metrics",key="node.kubernetes.io/unreachable",effect="NoSchedule"} unless ignoring(key,value) kube_node_spec_taint{job="kube-state-metrics",key=~"ToBeDeletedByClusterAutoscaler|cloud.google.com/impending-node-termination|aws-node-termination-handler/spot-itn"}) == 1
```

Upstream runbook for KubeNodeUnreachable

KUBELETTOOMANYPODS

Severity	Fires after
Info	15m

Kubelet is running at capacity.

Kubelet '{{ $labels.node }}' is running at {{ $value | humanizePercentage }} of its Pod capacity on cluster {{ $labels.cluster }}.

Trigger condition

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```
((max(kubelet_running_pods{job="kubelet",metrics_path="/metrics"} > 1) by(cluster,instance) * on(cluster,instance) group_left(node) max(kubelet_node_name{job="kubelet",metrics_path="/metrics"})
by(cluster,instance,node)) / on(cluster,node) group_left() max(kube_node_status_capacity{job="kube-state-metrics",resource="pods"} != 1) by(cluster,node)) > 0.95
```

Upstream runbook for KubeletTooManyPods

KUBENODEREADINESSFLAPPING

Severity	Fires after
Warning	15m

Node readiness status is flapping.

The readiness status of node {{ $labels.node }} has changed {{ $value }} times in the last 15 minutes on cluster {{ $labels.cluster }}.

Trigger condition

```
(sum(changes(kube_node_status_condition{job="kube-state-metrics",status="true",condition="Ready"}[15m])) by(cluster,node) > 2) and on(cluster,node) (kube_node_spec_unschedulable{job="kube-
state-metrics"} == 0)
```

Upstream runbook for KubeNodeReadinessFlapping

KUBENODEEVICTION

Severity	Fires after
Info	Immediately

Node is evicting pods.

Node {{ $labels.node }} on {{ $labels.cluster }} is evicting Pods due to {{ $labels.eviction_signal }}. Eviction occurs when eviction thresholds are crossed, typically caused by Pods exceeding RAM/ephemeral-storage limits.

Trigger condition

```
(sum(rate(kubelet_evictions{job="kubelet",metrics_path="/metrics"}[15m])) by(cluster,eviction_signal,instance) * on(cluster,instance) group_left(node)
max(kubelet_node_name{job="kubelet",metrics_path="/metrics"}) by(cluster,instance,node)) > 0
```

Upstream runbook for KubeNodeEviction

KUBELETPLEGDURATIONHIGH

Severity	Fires after
Warning	5m

Kubelet Pod Lifecycle Event Generator is taking too long to relist.

The Kubelet Pod Lifecycle Event Generator has a 99th percentile duration of {{ $value }} seconds on node {{ $labels.node }} on cluster {{ $labels.cluster }}.

Trigger condition

```
node_quantile:kubelet_pleg_relist_duration_seconds:histogram_quantile{quantile="0.99"} >= 10
```

Upstream runbook for KubeletPlegDurationHigh

KUBELETPODSTARTUPLATENCYHIGH

Severity	Fires after
Warning	15m

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Kubelet Pod startup latency is too high.

Kubelet Pod startup 99th percentile latency is {{ $value }} seconds on node {{ $labels.node }} on cluster {{ $labels.cluster }}.

Trigger condition

```
(histogram_quantile(0.99, sum(topk(1, rate(kubelet_pod_worker_duration_seconds_bucket{job="kubelet",metrics_path="/metrics"}[5m])) by(cluster,instance,le,operation_type)) by(cluster,instance,le)) *
on(cluster,instance) group_left(node) topk(1, kubelet_node_name{job="kubelet",metrics_path="/metrics"}) by(cluster,instance,node)) > 60
```

Upstream runbook for KubeletPodStartUpLatencyHigh

KUBELETCLIENTCERTIFICATEEXPIRATION

Severity	Fires after
Warning	Immediately
Critical	Immediately

Kubelet client certificate is about to expire.

This alert is defined in 2 variants:

Warning, fires immediately

Client certificate for Kubelet on node {{ $labels.node }} expires in {{ $value | humanizeDuration }} on cluster {{ $labels.cluster }}.

```
kubelet_certificate_manager_client_ttl_seconds < 604800
```

Critical, fires immediately

Client certificate for Kubelet on node {{ $labels.node }} expires in {{ $value | humanizeDuration }} on cluster {{ $labels.cluster }}.

```
kubelet_certificate_manager_client_ttl_seconds < 86400
```

Upstream runbook for KubeletClientCertificateExpiration

KUBELETSERVERCERTIFICATEEXPIRATION

Severity	Fires after
Warning	Immediately
Critical	Immediately

Kubelet server certificate is about to expire.

This alert is defined in 2 variants:

Warning, fires immediately

Server certificate for Kubelet on node {{ $labels.node }} expires in {{ $value | humanizeDuration }} on cluster {{ $labels.cluster }}.

```
kubelet_certificate_manager_server_ttl_seconds < 604800
```

Critical, fires immediately

Server certificate for Kubelet on node {{ $labels.node }} expires in {{ $value | humanizeDuration }} on cluster {{ $labels.cluster }}.

```
kubelet_certificate_manager_server_ttl_seconds < 86400
```

Upstream runbook for KubeletServerCertificateExpiration

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KUBELETCLIENTCERTIFICATERENEWALERRORS

Severity	Fires after
Warning	15m

Kubelet has failed to renew its client certificate.

Kubelet on node {{ $labels.node }} has failed to renew its client certificate ({{ $value | humanize }} errors in the last 5 minutes) on cluster {{ $labels.cluster }}.

Trigger condition

```
increase(kubelet_certificate_manager_client_expiration_renew_errors[5m]) > 0
```

Upstream runbook for KubeletClientCertificateRenewalErrors

KUBELETSERVERCERTIFICATERENEWALERRORS

Severity	Fires after
Warning	15m

Kubelet has failed to renew its server certificate.

Kubelet on node {{ $labels.node }} has failed to renew its server certificate ({{ $value | humanize }} errors in the last 5 minutes) on cluster {{ $labels.cluster }}.

Trigger condition

```
increase(kubelet_server_expiration_renew_errors[5m]) > 0
```

Upstream runbook for KubeletServerCertificateRenewalErrors

KUBELETINSTANCEUNREACHABLE

Severity	Fires after
Warning	15m

Kubelet instance is unreachable.

A Kubelet instance has been unreachable for more than 15 minutes.

Trigger condition

```
up{job="kubelet",metrics_path="/metrics"} == 0
```

Upstream runbook for KubeletInstanceUnreachable

KUBELETDOWN

Severity	Fires after
Critical	15m

Target disappeared from Prometheus target discovery.

Kubelet has disappeared from Prometheus target discovery on cluster {{ $labels.cluster }}.

Trigger condition

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```
count(kube_node_info{job="kube-state-metrics"}) by(cluster) unless on(cluster) count(up{job="kubelet",metrics_path="/metrics"} == 1) by(cluster)
```

Upstream runbook for KubeletDown

kube-state-metrics

Health of the exporter that supplies the metrics behind most of the Kubernetes alerts above. Treat these as meta-alerts: while kube-state-metrics is degraded, the workload and resource alerts go quiet whether or not anything is wrong.

KUBESTATEMETRICSLISTERRORS

Severity	Fires after
Critical	15m

kube-state-metrics is experiencing errors in list operations.

kube-state-metrics is experiencing errors at an elevated rate in list operations. This is likely causing it to not be able to expose metrics about Kubernetes objects correctly or at all.

Trigger condition

```
(sum(rate(kube_state_metrics_list_total{job="kube-state-metrics",result="error"}[5m])) by(cluster) / sum(rate(kube_state_metrics_list_total{job="kube-state-metrics"}[5m])) by(cluster)) > 0.01
```

Upstream runbook for KubeStateMetricsListErrors

KUBESTATEMETRICSWATCHERRORS

Severity	Fires after
Critical	15m

kube-state-metrics is experiencing errors in watch operations.

kube-state-metrics is experiencing errors at an elevated rate in watch operations. This is likely causing it to not be able to expose metrics about Kubernetes objects correctly or at all.

Trigger condition

```
(sum(rate(kube_state_metrics_watch_total{job="kube-state-metrics",result="error"}[5m])) by(cluster) / sum(rate(kube_state_metrics_watch_total{job="kube-state-metrics"}[5m])) by(cluster)) > 0.01
```

Upstream runbook for KubeStateMetricsWatchErrors

KUBESTATEMETRICSSHARDINGMISMATCH

Severity	Fires after
Critical	15m

kube-state-metrics sharding is misconfigured.

kube-state-metrics pods are running with different --total-shards configuration, some Kubernetes objects may be exposed multiple times or not exposed at all.

Trigger condition

```
stdvar(kube_state_metrics_total_shards{job="kube-state-metrics"}) by(cluster) != 0
```

Upstream runbook for KubeStateMetricsShardingMismatch

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KUBESTATEMETRICSSHARDSMISSING

Severity	Fires after
Critical	15m

kube-state-metrics shards are missing.

kube-state-metrics shards are missing, some Kubernetes objects are not being exposed.

Trigger condition

```
(((2 ^ max(kube_state_metrics_total_shards{job="kube-state-metrics"}) by(cluster)) - 1) - sum(2 ^ max(kube_state_metrics_shard_ordinal{job="kube-state-metrics"}) by(cluster,shard_ordinal)) by(cluster)) != 0
```

Upstream runbook for KubeStateMetricsShardsMissing

etcd

Cluster membership, leader stability, request and fsync latency, and database growth against the storage quota. Losing quorum here takes the whole control plane with it.

> **Note**
>
> None of the etcd rules carry a `severity` label. They are routed by Alertmanager's default route, not by severity, so check that route before relying on them.

ETCDMEMBERSDOWN

Severity	Fires after
—	Immediately

etcd cluster members are down.

etcd cluster "{{ $labels.job }}": members are down ({{ $value }}).

Trigger condition

```
max(sum(up{job=~".*etcd.*"} ==bool 0) without(instance) or count(sum(rate(etcd_network_peer_sent_failures_total{job=~".*etcd.*"}[120s])) without(instance) > 0.01) without(To)) without(endpoint) > 0
```

ETCDINSUFFICIENTMEMBERS

Severity	Fires after
—	Immediately

etcd cluster has insufficient number of members.

etcd cluster "{{ $labels.job }}": insufficient members ({{ $value }}).

Trigger condition

```
sum(up{job=~".*etcd.*"} ==bool 1) without(instance) < ((count(up{job=~".*etcd.*"}) without(instance) + 1) / 2)
```

ETCDNOLEADER

Severity	Fires after
—	Immediately

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etcd cluster has no leader.

etcd cluster "{{ $labels.job }}": member {{ $labels.instance }} has no leader.

Trigger condition

```
etcd_server_has_leader{job=~".*etcd.*"} == 0
```

ETCDHIGHNUMBEROFLEADERCHANGES

Severity	Fires after
—	Immediately

etcd cluster has high number of leader changes.

etcd cluster "{{ $labels.job }}": {{ $value }} leader changes within the last 15 minutes. Frequent elections may be a sign of insufficient resources, high network latency, or disruptions by other components and should be investigated.

Trigger condition

```
increase((max(etcd_server_leader_changes_seen_total{job=~".*etcd.*"}) without(instance) or (0 * absent(etcd_server_leader_changes_seen_total{job=~".*etcd.*"})))[15m:1m]) >= 4
```

ETCDHIGHNUMBEROFFAILEDGRPCREQUESTS

Severity	Fires after
—	Immediately
—	Immediately

etcd cluster has high number of failed grpc requests.

This alert is defined in 2 variants:

—, fires immediately

etcd cluster "{{ $labels.job }}": {{ $value }}% of requests for {{ $labels.grpc_method }} failed on etcd instance {{ $labels.instance }}.

```
((100 * sum(rate(grpc_server_handled_total{job=~".*etcd.*",grpc_code=~"Unknown|FailedPrecondition|ResourceExhausted|Internal|Unavailable|DataLoss|DeadlineExceeded"}[5m]))
without(grpc_type,grpc_code)) / sum(rate(grpc_server_handled_total{job=~".*etcd.*"}[5m])) without(grpc_type,grpc_code)) > 1
```

—, fires immediately

etcd cluster "{{ $labels.job }}": {{ $value }}% of requests for {{ $labels.grpc_method }} failed on etcd instance {{ $labels.instance }}.

```
((100 * sum(rate(grpc_server_handled_total{job=~".*etcd.*",grpc_code=~"Unknown|FailedPrecondition|ResourceExhausted|Internal|Unavailable|DataLoss|DeadlineExceeded"}[5m]))
without(grpc_type,grpc_code)) / sum(rate(grpc_server_handled_total{job=~".*etcd.*"}[5m])) without(grpc_type,grpc_code)) > 5
```

ETCDGRPCREQUESTSSLOW

Severity	Fires after
—	Immediately

etcd grpc requests are slow

etcd cluster "{{ $labels.job }}": 99th percentile of gRPC requests is {{ $value }}s on etcd instance {{ $labels.instance }} for {{ $labels.grpc_method }} method.

Trigger condition

```
histogram_quantile(0.99, sum(rate(grpc_server_handling_seconds_bucket{job=~".*etcd.*",grpc_method!="Defragment",grpc_type="unary"}[5m])) without(grpc_type)) > 0.15
```


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ETCDMEMBERCOMMUNICATIONSLOW

Severity	Fires after
—	Immediately

etcd cluster member communication is slow.

etcd cluster "{{ $labels.job }}": member communication with {{ $labels.To }} is taking {{ $value }}s on etcd instance {{ $labels.instance }}.

Trigger condition

```
histogram_quantile(0.99, rate(etcd_network_peer_round_trip_time_seconds_bucket{job=~".*etcd.*"}[5m])) > 0.15
```

ETCDHIGHNUMBEROFFAILEDPROPOSALS

Severity	Fires after
—	Immediately

etcd cluster has high number of proposal failures.

etcd cluster "{{ $labels.job }}": {{ $value }} proposal failures within the last 30 minutes on etcd instance {{ $labels.instance }}.

Trigger condition

```
rate(etcd_server_proposals_failed_total{job=~".*etcd.*"}[15m]) > 5
```

ETCDHIGHFSYNCDURATIONS

Severity	Fires after
—	Immediately
—	Immediately

etcd cluster 99th percentile fsync durations are too high.

This alert is defined in 2 variants:

—, fires immediately

etcd cluster "{{ $labels.job }}": 99th percentile fsync durations are {{ $value }}s on etcd instance {{ $labels.instance }}.

```
histogram_quantile(0.99, rate(etcd_disk_wal_fsync_duration_seconds_bucket{job=~".*etcd.*"}[5m])) > 0.5
```

—, fires immediately

etcd cluster "{{ $labels.job }}": 99th percentile fsync durations are {{ $value }}s on etcd instance {{ $labels.instance }}.

```
histogram_quantile(0.99, rate(etcd_disk_wal_fsync_duration_seconds_bucket{job=~".*etcd.*"}[5m])) > 1
```

ETCDHIGHCOMMITDURATIONS

Severity	Fires after
—	Immediately

etcd cluster 99th percentile commit durations are too high.

etcd cluster "{{ $labels.job }}": 99th percentile commit durations {{ $value }}s on etcd instance {{ $labels.instance }}.

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Trigger condition

```
histogram_quantile(0.99, rate(etcd_disk_backend_commit_duration_seconds_bucket{job=~".*etcd.*"}[5m])) > 0.25
```

ETCDDATABASEQUOTALOWSPACE

Severity	Fires after
—	Immediately

etcd cluster database is running full.

etcd cluster "{{ $labels.job }}": database size exceeds the defined quota on etcd instance {{ $labels.instance }}, please defrag or increase the quota as the writes to etcd will be disabled when it is full.

Trigger condition

```
((last_over_time(etcd_mvcc_db_total_size_in_bytes{job=~".*etcd.*"}[5m]) / last_over_time(etcd_server_quota_backend_bytes{job=~".*etcd.*"}[5m])) * 100) > 95
```

ETCDEXCESSIVEDATABASEGROWTH

Severity	Fires after
—	Immediately

etcd cluster database growing very fast.

etcd cluster "{{ $labels.job }}": Predicting running out of disk space in the next four hours, based on write observations within the past four hours on etcd instance {{ $labels.instance }}, please check as it might be disruptive.

Trigger condition

```
predict_linear(etcd_mvcc_db_total_size_in_bytes{job=~".*etcd.*"}[4h], 14400) > etcd_server_quota_backend_bytes{job=~".*etcd.*"}
```

ETCDDATABASEHIGHFRAGMENTATIONRATIO

Severity	Fires after
—	Immediately

etcd database size in use is less than 50% of the actual allocated storage.

etcd cluster "{{ $labels.job }}": database size in use on instance {{ $labels.instance }} is {{ $value | humanizePercentage }} of the actual allocated disk space, please run defragmentation (e.g. etcdctl defrag) to retrieve the unused fragmented disk space.

Trigger condition

```
((last_over_time(etcd_mvcc_db_total_size_in_use_in_bytes{job=~".*etcd.*"}[5m]) / last_over_time(etcd_mvcc_db_total_size_in_bytes{job=~".*etcd.*"}[5m])) < 0.5) and
(etcd_mvcc_db_total_size_in_use_in_bytes{job=~".*etcd.*"} > 104857600)
```

Upstream runbook for etcdDatabaseHighFragmentationRatio

Host and node health

Host-level alerts from node_exporter, covering the same ground as the VM alerts on Platform and Infrastructure Alerts but for Kubernetes nodes: filesystem space and inodes, memory, CPU and I/O saturation, clock synchronization, file descriptors, RAID, bonding, and failed systemd units.

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NODEFILESYSTEMSPACEFILLINGUP

Severity	Fires after
Warning	1h
Critical	1h

Filesystem is predicted to run out of space within the next 24 hours.

This alert is defined in 2 variants:

Warning, fires after 1h

Filesystem on {{ $labels.device }}, mounted on {{ $labels.mountpoint }}, at {{ $labels.instance }} has only {{ printf "%.2f" $value }}% available space left and is filling up.

```
((((node_filesystem_avail_bytes{job="node-exporter",fstype!="",mountpoint!=""} / node_filesystem_size_bytes{job="node-exporter",fstype!="",mountpoint!=""}) * 100) < 15) and
(predict_linear(node_filesystem_avail_bytes{job="node-exporter",fstype!="",mountpoint!=""}[6h], 86400) < 0)) and (node_filesystem_readonly{job="node-exporter",fstype!="",mountpoint!=""} == 0)
```

Critical, fires after 1h

Filesystem on {{ $labels.device }}, mounted on {{ $labels.mountpoint }}, at {{ $labels.instance }} has only {{ printf "%.2f" $value }}% available space left and is filling up fast.

```
((((node_filesystem_avail_bytes{job="node-exporter",fstype!="",mountpoint!=""} / node_filesystem_size_bytes{job="node-exporter",fstype!="",mountpoint!=""}) * 100) < 10) and
(predict_linear(node_filesystem_avail_bytes{job="node-exporter",fstype!="",mountpoint!=""}[6h], 14400) < 0)) and (node_filesystem_readonly{job="node-exporter",fstype!="",mountpoint!=""} == 0)
```

Upstream runbook for NodeFilesystemSpaceFillingUp

NODEFILESYSTEMALMOSTOUTOFSPACE

Severity	Fires after
Warning	30m
Critical	30m

Filesystem has less than 5% space left.

This alert is defined in 2 variants:

Warning, fires after 30m

Filesystem on {{ $labels.device }}, mounted on {{ $labels.mountpoint }}, at {{ $labels.instance }} has only {{ printf "%.2f" $value }}% available space left.

```
(((node_filesystem_avail_bytes{job="node-exporter",fstype!="",mountpoint!=""} / node_filesystem_size_bytes{job="node-exporter",fstype!="",mountpoint!=""}) * 100) < 5) and
(node_filesystem_readonly{job="node-exporter",fstype!="",mountpoint!=""} == 0)
```

Critical, fires after 30m

Filesystem on {{ $labels.device }}, mounted on {{ $labels.mountpoint }}, at {{ $labels.instance }} has only {{ printf "%.2f" $value }}% available space left.

```
(((node_filesystem_avail_bytes{job="node-exporter",fstype!="",mountpoint!=""} / node_filesystem_size_bytes{job="node-exporter",fstype!="",mountpoint!=""}) * 100) < 3) and
(node_filesystem_readonly{job="node-exporter",fstype!="",mountpoint!=""} == 0)
```

Upstream runbook for NodeFilesystemAlmostOutOfSpace

Expeto Inc @ 2026

NODEFILESYSTEMFILESFILLINGUP

Severity	Fires after
Warning	1h
Critical	1h

Filesystem is predicted to run out of inodes within the next 24 hours.

This alert is defined in 2 variants:

Warning, fires after 1h

Filesystem on {{ $labels.device }}, mounted on {{ $labels.mountpoint }}, at {{ $labels.instance }} has only {{ printf "%.2f" $value }}% available inodes left and is filling up.

```
((((node_filesystem_files_free{job="node-exporter",fstype!="",mountpoint!=""} / node_filesystem_files{job="node-exporter",fstype!="",mountpoint!=""}) * 100) < 40) and
(predict_linear(node_filesystem_files_free{job="node-exporter",fstype!="",mountpoint!=""}[6h], 86400) < 0)) and (node_filesystem_readonly{job="node-exporter",fstype!="",mountpoint!=""} == 0)
```

Critical, fires after 1h

Filesystem on {{ $labels.device }}, mounted on {{ $labels.mountpoint }}, at {{ $labels.instance }} has only {{ printf "%.2f" $value }}% available inodes left and is filling up fast.

```
((((node_filesystem_files_free{job="node-exporter",fstype!="",mountpoint!=""} / node_filesystem_files{job="node-exporter",fstype!="",mountpoint!=""}) * 100) < 20) and
(predict_linear(node_filesystem_files_free{job="node-exporter",fstype!="",mountpoint!=""}[6h], 14400) < 0)) and (node_filesystem_readonly{job="node-exporter",fstype!="",mountpoint!=""} == 0)
```

Upstream runbook for NodeFilesystemFilesFillingUp

NODEFILESYSTEMALMOSTOUTOFFILES

Severity	Fires after
Warning	1h
Critical	1h

Filesystem has less than 5% inodes left.

This alert is defined in 2 variants:

Warning, fires after 1h

Filesystem on {{ $labels.device }}, mounted on {{ $labels.mountpoint }}, at {{ $labels.instance }} has only {{ printf "%.2f" $value }}% available inodes left.

```
(((node_filesystem_files_free{job="node-exporter",fstype!="",mountpoint!=""} / node_filesystem_files{job="node-exporter",fstype!="",mountpoint!=""}) * 100) < 5) and
(node_filesystem_readonly{job="node-exporter",fstype!="",mountpoint!=""} == 0)
```

Critical, fires after 1h

Filesystem on {{ $labels.device }}, mounted on {{ $labels.mountpoint }}, at {{ $labels.instance }} has only {{ printf "%.2f" $value }}% available inodes left.

```
(((node_filesystem_files_free{job="node-exporter",fstype!="",mountpoint!=""} / node_filesystem_files{job="node-exporter",fstype!="",mountpoint!=""}) * 100) < 3) and
(node_filesystem_readonly{job="node-exporter",fstype!="",mountpoint!=""} == 0)
```

Upstream runbook for NodeFilesystemAlmostOutOfFiles

Expeto Inc @ 2026

NODENETWORKRECEIVEERRS

Severity	Fires after
Warning	1h

Network interface is reporting many receive errors.

{{ $labels.instance }} interface {{ $labels.device }} has encountered {{ printf "%.0f" $value }} receive errors in the last two minutes.

Trigger condition

```
(rate(node_network_receive_errs_total{job="node-exporter"}[2m]) / rate(node_network_receive_packets_total{job="node-exporter"}[2m])) > 0.01
```

Upstream runbook for NodeNetworkReceiveErrs

NODENETWORKTRANSMITERRS

Severity	Fires after
Warning	1h

Network interface is reporting many transmit errors.

{{ $labels.instance }} interface {{ $labels.device }} has encountered {{ printf "%.0f" $value }} transmit errors in the last two minutes.

Trigger condition

```
(rate(node_network_transmit_errs_total{job="node-exporter"}[2m]) / rate(node_network_transmit_packets_total{job="node-exporter"}[2m])) > 0.01
```

Upstream runbook for NodeNetworkTransmitErrs

NODEHIGHNUMBERCONNTRACKENTRIESUSED

Severity	Fires after
Warning	Immediately

Number of conntrack are getting close to the limit.

{{ $labels.instance }} {{ $value | humanizePercentage }} of conntrack entries are used.

Trigger condition

```
(node_nf_conntrack_entries{job="node-exporter"} / node_nf_conntrack_entries_limit) > 0.75
```

Upstream runbook for NodeHighNumberConntrackEntriesUsed

NODETEXTFILECOLLECTORSCRAPEERROR

Severity	Fires after
Warning	Immediately

Node Exporter text file collector failed to scrape.

Node Exporter text file collector on {{ $labels.instance }} failed to scrape.

Trigger condition

```
node_textfile_scrape_error{job="node-exporter"} == 1
```

Upstream runbook for NodeTextFileCollectorScrapeError

Expeto Inc @ 2026

NODECLOCKSKEWDETECTED

Severity	Fires after
Warning	10m

Clock skew detected.

Clock at {{ $labels.instance }} is out of sync by more than 0.05s. Ensure NTP is configured correctly on this host.

Trigger condition

```
((node_timex_offset_seconds{job="node-exporter"} > 0.05) and (deriv(node_timex_offset_seconds{job="node-exporter"}[5m]) >= 0)) or ((node_timex_offset_seconds{job="node-exporter"} < -0.05) and (deriv(node_timex_offset_seconds{job="node-exporter"}[5m]) <= 0))
```

Upstream runbook for NodeClockSkewDetected

NODECLOCKNOTSYNCHRONISING

Severity	Fires after
Warning	10m

Clock not synchronising.

Clock at {{ $labels.instance }} is not synchronising. Ensure NTP is configured on this host.

Trigger condition

```
(min_over_time(node_timex_sync_status{job="node-exporter"}[5m]) == 0) and (node_timex_maxerror_seconds{job="node-exporter"} >= 16)
```

Upstream runbook for NodeClockNotSynchronising

NODERAIDDEGRADED

Severity	Fires after
Critical	15m

RAID Array is degraded.

RAID array '{{ $labels.device }}' at {{ $labels.instance }} is in degraded state due to one or more disks failures. Number of spare drives is insufficient to fix issue automatically.

Trigger condition

```
(node_md_disks_required{job="node-exporter",device=~"(/dev/)?(mmcblk.p.+|nvme.+|rbd.+|sd.+|vd.+|xvd.+|dm-.+|md.+|dasd.+)"} - ignoring(state) node_md_disks{state="active",job="node-exporter",device=~"(/dev/)?(mmcblk.p.+|nvme.+|rbd.+|sd.+|vd.+|xvd.+|dm-.+|md.+|dasd.+)"}) > 0
```

Upstream runbook for NodeRAIDDegraded

NODERAIDDISKFAILURE

Severity	Fires after
Warning	Immediately

Failed device in RAID array.

At least one device in RAID array at {{ $labels.instance }} failed. Array '{{ $labels.device }}' needs attention and possibly a disk swap.

Trigger condition

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```
node_md_disks{state="failed",job="node-exporter",device=~"(/dev/)?(mmcblk.p.+|nvme.+|rbd.+|sd.+|vd.+|xvd.+|dm-.+|md.+|dasd.+)"} > 0
```

Upstream runbook for NodeRAIDDiskFailure

NODEFILEDESCRIPTORLIMIT

Severity	Fires after
Warning	15m
Critical	15m

Kernel is predicted to exhaust file descriptors limit soon.

This alert is defined in 2 variants:

Warning, fires after 15m

File descriptors limit at {{ $labels.instance }} is currently at {{ printf "%.2f" $value }}%.

```
((node_filefd_allocated{job="node-exporter"} * 100) / node_filefd_maximum{job="node-exporter"}) > 70
```

Critical, fires after 15m

File descriptors limit at {{ $labels.instance }} is currently at {{ printf "%.2f" $value }}%.

```
((node_filefd_allocated{job="node-exporter"} * 100) / node_filefd_maximum{job="node-exporter"}) > 90
```

Upstream runbook for NodeFileDescriptorLimit

NODECPUHIGHUSAGE

Severity	Fires after
Info	15m

High CPU usage.

CPU usage at {{ $labels.instance }} has been above 90% for the last 15 minutes, is currently at {{ printf "%.2f" $value }}%.

Trigger condition

```
(sum(avg(rate(node_cpu_seconds_total{job="node-exporter",mode!~"idle|iowait"}[2m])) without(cpu)) without(mode) * 100) > 90
```

Upstream runbook for NodeCPUHighUsage

NODESYSTEMSATURATION

Severity	Fires after
Warning	15m

System saturated, load per core is very high.

System load per core at {{ $labels.instance }} has been above 2 for the last 15 minutes, is currently at {{ printf "%.2f" $value }}. This might indicate this instance resources saturation and can cause it becoming unresponsive.

Trigger condition

```
(node_load1{job="node-exporter"} / count(node_cpu_seconds_total{job="node-exporter",mode="idle"}) without(cpu,mode)) > 2
```

Upstream runbook for NodeSystemSaturation

Expeto Inc @ 2026

NODEMEMORYMAJORPAGESFAULTS

Severity	Fires after
Warning	15m

Memory major page faults are occurring at very high rate.

Memory major pages are occurring at very high rate at {{ $labels.instance }}, 500 major page faults per second for the last 15 minutes, is currently at {{ printf "%.2f" $value }}. Please check that there is enough memory available at this instance.

Trigger condition

```
rate(node_vmstat_pgmajfault{job="node-exporter"}[5m]) > 500
```

Upstream runbook for NodeMemoryMajorPagesFaults

NODEMEMORYHIGHUTILIZATION

Severity	Fires after
Warning	15m

Host is running out of memory.

Memory is filling up at {{ $labels.instance }}, has been above 90% for the last 15 minutes, is currently at {{ printf "%.2f" $value }}%.

Trigger condition

```
(100 - ((node_memory_MemAvailable_bytes{job="node-exporter"} / node_memory_MemTotal_bytes{job="node-exporter"}) * 100)) > 90
```

Upstream runbook for NodeMemoryHighUtilization

NODEDISKIOSATURATION

Severity	Fires after
Warning	30m

Disk IO queue is high.

Disk IO queue (aqu-sq) is high on {{ $labels.device }} at {{ $labels.instance }}, has been above 10 for the last 30 minutes, is currently at {{ printf "%.2f" $value }}. This symptom might indicate disk saturation.

Trigger condition

```
rate(node_disk_io_time_weighted_seconds_total{job="node-exporter",device=~"(/dev/)?(mmcblk.p.+|nvme.+|rbd.+|sd.+|vd.+|xvd.+|dm-.+|md.+|dasd.+)"}[5m]) > 10
```

Upstream runbook for NodeDiskIOSaturation

NODESYSTEMDSERVICEFAILED

Severity	Fires after
Warning	5m

Systemd service has entered failed state.

Systemd service {{ $labels.name }} has entered failed state at {{ $labels.instance }}

Trigger condition

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```
node_systemd_unit_state{job="node-exporter",state="failed"} == 1
```

Upstream runbook for NodeSystemdServiceFailed

NODESYSTEMDSERVICECRASHLOOPING

Severity	Fires after
Warning	15m

Systemd service keeps restaring, possibly crash looping.

Systemd service {{ $labels.name }} has being restarted too many times at {{ $labels.instance }} for the last 15 minutes. Please check if service is crash looping.

Trigger condition

```
increase(node_systemd_service_restart_total{job="node-exporter"}[5m]) > 2
```

Upstream runbook for NodeSystemdServiceCrashlooping

NODEBONDINGDEGRADED

Severity	Fires after
Warning	5m

Bonding interface is degraded.

Bonding interface {{ $labels.master }} on {{ $labels.instance }} is in degraded state due to one or more slave failures.

Trigger condition

```
(node_bonding_slaves{job="node-exporter"} - node_bonding_active{job="node-exporter"}) != 0
```

Upstream runbook for NodeBondingDegraded

Host networking

Physical and virtual interfaces changing state repeatedly, which usually points at the cable, switch port, or virtual NIC below the host rather than at Kubernetes.

NODENETWORKINTERFACEFLAPPING

Severity	Fires after
Warning	2m

Network interface is often changing its status

Network interface "{{ $labels.device }}" changing its up status often on node-exporter {{ $labels.namespace }}/{{ $labels.pod }}

Trigger condition

```
changes(node_network_up{job="node-exporter",device!~"veth.+"}[2m]) > 2
```

Upstream runbook for NodeNetworkInterfaceFlapping

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Alertmanager

The notification path itself: configuration reloads, cluster membership between Alertmanager replicas, and failures delivering to a receiver. An alert here means other alerts may not be reaching anyone.

ALERTMANAGERFAILEDRELOAD

Severity	Fires after
Critical	10m

Reloading an Alertmanager configuration has failed.

Configuration has failed to load for {{ $labels.namespace }}/{{ $labels.pod}}.

Trigger condition

```
max_over_time(alertmanager_config_last_reload_successful{job="vmalertmanager-xview-victoria-metrics-k8s-stack",container="alertmanager",namespace="default"}[5m]) == 0
```

Upstream runbook for AlertmanagerFailedReload

ALERTMANAGERMEMBERSINCONSISTENT

Severity	Fires after
Critical	15m

A member of an Alertmanager cluster has not found all other cluster members.

Alertmanager {{ $labels.namespace }}/{{ $labels.pod}} has only found {{ $value }} members of the {{$labels.job}} cluster.

Trigger condition

```
max_over_time(alertmanager_cluster_members{job="vmalertmanager-xview-victoria-metrics-k8s-stack",container="alertmanager",namespace="default"}[5m]) < on(namespace,service,cluster)
group_left() count(max_over_time(alertmanager_cluster_members{job="vmalertmanager-xview-victoria-metrics-k8s-stack",container="alertmanager",namespace="default"}[5m]))
by(namespace,service,cluster)
```

Upstream runbook for AlertmanagerMembersInconsistent

ALERTMANAGERFAILEDTOSENDALERTS

Severity	Fires after
Warning	5m

An Alertmanager instance failed to send notifications.

Alertmanager {{ $labels.namespace }}/{{ $labels.pod}} failed to send {{ $value | humanizePercentage }} of notifications to {{ $labels.integration }}.

Trigger condition

```
(rate(alertmanager_notifications_failed_total{job="vmalertmanager-xview-victoria-metrics-k8s-stack",container="alertmanager",namespace="default"}[15m]) / ignoring(reason) group_left()
rate(alertmanager_notifications_total{job="vmalertmanager-xview-victoria-metrics-k8s-stack",container="alertmanager",namespace="default"}[15m])) > 0.01
```

Upstream runbook for AlertmanagerFailedToSendAlerts

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ALERTMANAGERCLUSTERFAILEDTOSENDALERTS

Severity	Fires after
Critical	5m
Warning	5m

All Alertmanager instances in a cluster failed to send notifications to a critical integration.

This alert is defined in 2 variants:

Critical, fires after 5m

The minimum notification failure rate to {{ $labels.integration }} sent from any instance in the {{$labels.job}} cluster is {{ $value | humanizePercentage }}.

```
min((rate(alertmanager_notifications_failed_total{job="vmalertmanager-xview-victoria-metrics-k8s-stack",container="alertmanager",namespace="default",integration=~".*"}[15m]) / ignoring(reason)
group_left() rate(alertmanager_notifications_total{job="vmalertmanager-xview-victoria-metrics-k8s-stack",container="alertmanager",namespace="default",integration=~".*"}[15m])) > 0)
by(namespace,service,integration,cluster) > 0.01
```

Warning, fires after 5m

The minimum notification failure rate to {{ $labels.integration }} sent from any instance in the {{$labels.job}} cluster is {{ $value | humanizePercentage }}.

```
min((rate(alertmanager_notifications_failed_total{job="vmalertmanager-xview-victoria-metrics-k8s-stack",container="alertmanager",namespace="default",integration!~".*"}[15m]) / ignoring(reason)
group_left() rate(alertmanager_notifications_total{job="vmalertmanager-xview-victoria-metrics-k8s-stack",container="alertmanager",namespace="default",integration!~".*"}[15m])) > 0)
by(namespace,service,integration,cluster) > 0.01
```

Upstream runbook for AlertmanagerClusterFailedToSendAlerts

ALERTMANAGERCONFIGINCONSISTENT

Severity	Fires after
Critical	20m

Alertmanager instances within the same cluster have different configurations.

Alertmanager instances within the {{$labels.job}} cluster have different configurations.

Trigger condition

```
count(count_values("config_hash", alertmanager_config_hash{job="vmalertmanager-xview-victoria-metrics-k8s-stack",container="alertmanager",namespace="default"}) by(namespace,service,cluster))
by(namespace,service,cluster) != 1
```

Upstream runbook for AlertmanagerConfigInconsistent

ALERTMANAGERCLUSTERDOWN

Severity	Fires after
Critical	5m

Half or more of the Alertmanager instances within the same cluster are down.

{{ $value | humanizePercentage }} of Alertmanager instances within the {{$labels.job}} cluster have been up for less than half of the last 5m.

Trigger condition

```
(count(avg_over_time(up{job="vmalertmanager-xview-victoria-metrics-k8s-stack",container="alertmanager",namespace="default"}[5m]) < 0.5) by(namespace,service,cluster) /
count(up{job="vmalertmanager-xview-victoria-metrics-k8s-stack",container="alertmanager",namespace="default"}) by(namespace,service,cluster)) >= 0.5
```

Upstream runbook for AlertmanagerClusterDown

Expeto Inc @ 2026

ALERTMANAGERCLUSTERCRASHLOOPING

Severity	Fires after
Critical	5m

Half or more of the Alertmanager instances within the same cluster are crashlooping.

{{ $value | humanizePercentage }} of Alertmanager instances within the {{$labels.job}} cluster have restarted at least 5 times in the last 10m.

Trigger condition

```
(count(changes(process_start_time_seconds{job="vmalertmanager-xview-victoria-metrics-k8s-stack",container="alertmanager",namespace="default"}[10m]) > 4) by(namespace,service,cluster) /
count(up{job="vmalertmanager-xview-victoria-metrics-k8s-stack",container="alertmanager",namespace="default"}) by(namespace,service,cluster)) >= 0.5
```

Upstream runbook for AlertmanagerClusterCrashlooping

vmagent metric collection

vmagent scrapes every target and forwards the samples to storage. These alerts cover scrape failures, per-tenant series limits, and the persistent queue that buffers samples when the remote write destination is slow or unreachable. Sustained saturation here ends in dropped data.

PERSISTENTQUEUEISDROPPINGDATA

Severity	Fires after
Critical	10m

Instance {{ $labels.instance }} is dropping data from persistent queue

Vmagent dropped {{ $value | humanize1024 }} from persistent queue on instance {{ $labels.instance }} for the last 10m.

Trigger condition

```
sum(increase(vm_persistentqueue_bytes_dropped_total[5m])) without(path) > 0
```

REJECTEDREMOTEWRITEDATABLOCKSAREDROPPED

Severity	Fires after
Warning	15m

Vmagent is dropping data blocks that are rejected by remote storage

Job "{{ $labels.job }}" on instance {{ $labels.instance }} drops the rejected by remote-write server data blocks. Check the logs to find the reason for rejects.

Trigger condition

```
sum(increase(vmagent_remotewrite_packets_dropped_total[5m])) without(url) > 0
```

TOOMANYSCRAPEERRORS

Severity	Fires after
Warning	15m

Vmagent fails to scrape one or more targets

Job "{{ $labels.job }}" on instance {{ $labels.instance }} fails to scrape targets for last 15m

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Trigger condition

```
increase(vm_promscrape_scrapes_failed_total[5m]) > 0
```

SCRAPEPOOLHASNOTARGETS

Severity	Fires after
Warning	30m

Vmagent has scrape_pool with 0 configured/discovered targets

Vmagent "{{ $labels.job }}" has scrape_pool "{{ $labels.scrape_job }}" with 0 discovered targets. It is likely a misconfiguration. Please follow https://docs.victoriametrics.com/victoriametrics/vmagent/#debugging-scrape-targets to troubleshoot the scraping config.

Trigger condition

```
sum(vm_promscrape_scrape_pool_targets) without(status,instance,pod) == 0
```

TOOMANYWRITEERRORS

Severity	Fires after
Warning	15m

Vmagent responds with too many errors on data ingestion protocols

Job "{{ $labels.job }}" on instance {{ $labels.instance }} responds with errors to write requests for last 15m.

Trigger condition

```
(sum(increase(vm_ingestserver_request_errors_total[5m])) without(name,net,type) + sum(increase(vmagent_http_request_errors_total[5m])) without(path,protocol)) > 0
```

TOOMANYREMOTEWRITEERRORS

Severity	Fires after
Warning	15m

Job "{{ $labels.job }}" on instance {{ $labels.instance }} fails to push to remote storage

Vmagent fails to push data via remote write protocol to destination "{{ $labels.url }}" Ensure that destination is up and reachable.

Trigger condition

```
rate(vmagent_remotewrite_retries_count_total[5m]) > 0
```

REMOTEWRITECONNECTIONISSATURATED

Severity	Fires after
Warning	15m

Remote write connection from "{{ $labels.job }}" (instance {{ $labels.instance }}) to {{ $labels.url }} is saturated

The remote write connection between vmagent "{{ $labels.job }}" (instance {{ $labels.instance }}) and destination "{{ $labels.url }}" is saturated by more than 90% and vmagent won't be able to keep up. There could be the following reasons for this: * vmagent can't send data fast enough through the existing network connections. Increase `-remoteWrite.queues` cmd-line flag value to establish more connections per destination. * remote destination can't accept data fast enough. Check if remote destination has enough resources for processing.

Trigger condition

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```
(rate(vmagent_remotewrite_send_duration_seconds_total[5m]) / vmagent_remotewrite_queues) > 0.9
```

PERSISTENTQUEUEFORWRITESISSATURATED

Severity	Fires after
Warning	15m

Persistent queue writes for instance {{ $labels.instance }} are saturated

Persistent queue writes for vmagent "{{ $labels.job }}" (instance {{ $labels.instance }}) are saturated by more than 90% and vmagent won't be able to keep up with flushing data on disk. In this case, consider to decrease load on the vmagent or improve the disk throughput.

Trigger condition

```
rate(vm_persistentqueue_write_duration_seconds_total[5m]) > 0.9
```

PERSISTENTQUEUEFORREADSISSATURATED

Severity	Fires after
Warning	15m

Persistent queue reads for instance {{ $labels.instance }} are saturated

Persistent queue reads for vmagent "{{ $labels.job }}" (instance {{ $labels.instance }}) are saturated by more than 90% and vmagent won't be able to keep up with reading data from the disk. In this case, consider to decrease load on the vmagent or improve the disk throughput.

Trigger condition

```
rate(vm_persistentqueue_read_duration_seconds_total[5m]) > 0.9
```

SERIESLIMITHOURREACHED

Severity	Fires after
Critical	Immediately

Instance {{ $labels.instance }} reached 90% of the limit

Max series limit set via -remoteWrite.maxHourlySeries flag is close to reaching the max value. Then samples for new time series will be dropped instead of sending them to remote storage systems.

Trigger condition

```
(vmagent_hourly_series_limit_current_series / vmagent_hourly_series_limit_max_series) > 0.9
```

SERIESLIMITDAYREACHED

Severity	Fires after
Critical	Immediately

Instance {{ $labels.instance }} reached 90% of the limit

Max series limit set via -remoteWrite.maxDailySeries flag is close to reaching the max value. Then samples for new time series will be dropped instead of sending them to remote storage systems.

Trigger condition

```
(vmagent_daily_series_limit_current_series / vmagent_daily_series_limit_max_series) > 0.9
```


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CONFIGURATIONRELOADFAILURE

Severity	Fires after
Warning	Immediately

Configuration reload failed for vmagent instance {{ $labels.instance }}

Configuration hot-reload failed for vmagent on instance {{ $labels.instance }}. Check vmagent's logs for detailed error message.

Trigger condition

```
(vm_promscrape_config_last_reload_successful != 1) or (vmagent_relabel_config_last_reload_successful != 1)
```

STREAMAGGRFLUSHTIMEOUT

Severity	Fires after
Warning	Immediately

Streaming aggregation at "{{ $labels.job }}" (instance {{ $labels.instance }}) can't be finished within the configured aggregation interval.

Stream aggregation process can't keep up with the load and might produce incorrect aggregation results. Check logs for more details. Possible solutions: increase aggregation interval; aggregate smaller number of series; reduce samples' ingestion rate to stream aggregation.

Trigger condition

```
increase(vm_streamaggr_flush_timeouts_total[5m]) > 0
```

STREAMAGGRDEDUPFLUSHTIMEOUT

Severity	Fires after
Warning	Immediately

Deduplication "{{ $labels.job }}" (instance {{ $labels.instance }}) can't be finished within configured deduplication interval.

Deduplication process can't keep up with the load and might produce incorrect results. Check docs https://docs.victoriametrics.com/victoriametrics/stream-aggregation/#deduplication and logs for more details. Possible solutions: increase deduplication interval; deduplicate smaller number of series; reduce samples' ingestion rate.

Trigger condition

```
increase(vm_streamaggr_dedup_flush_timeouts_total[5m]) > 0
```

PERSISTENTQUEUERUNSOUTOFSPACEIN12HOURS

Severity	Fires after
Warning	10m

Persistent Queue (url {{ $labels.url }}) of {{ $labels.instance }} (job:{{ $labels.job }}) will run out of space in 12 hours.

RemoteWrite destination ({{ $labels.url }}) is unavailable or unable to receive data in a timely manner, so the persistent queue size is growing. Once the available space is exhausted, some samples will be discarded and cause incident. Please check the health of remoteWrite destination ({{ $labels.url }}).

Trigger condition

```
(((sum(vm_persistentqueue_free_disk_space_bytes) by(job,instance,path,cluster) / (sum(deriv(vm_persistentqueue_bytes_pending[1m])) by(job,instance,path,cluster) > 0)) * on(job,instance,path,cluster) group_left(url) ((vmagent_remotewrite_pending_data_bytes * 0) + 1)) < 43200) > 0
```


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PERSISTENTQUEUERUNSOUTOFSPACEIN4HOURS

Severity	Fires after
Critical	10m

Persistent Queue (url {{ $labels.url }}) of {{ $labels.instance }} (job:{{ $labels.job }}) will run out of space in 4 hours.

RemoteWrite destination ({{ $labels.url }}) is unavailable or unable to receive data in a timely manner, so the persistent queue size is growing. Once the available space is exhausted, some samples will be discarded and cause incident. Please check the health of remoteWrite destination ({{ $labels.url }}).

Trigger condition

```
(((sum(vm_persistentqueue_free_disk_space_bytes) by(job,instance,path,cluster) / (sum(deriv(vm_persistentqueue_bytes_pending[1m])) by(job,instance,path,cluster) > 0)) * on(job,instance,path,cluster) group_left(url) ((vmagent_remotewrite_pending_data_bytes * 0) + 1)) < 14400) > 0
```

vmalert rule evaluation

vmalert evaluates the recording and alerting rules — including everything documented on this page and on the Expeto alert pages — and delivers the results to Alertmanager. A failure here is silent from the operator's point of view, which is why it is worth routing.

CONFIGURATIONRELOADFAILURE

Severity	Fires after
Warning	Immediately

Configuration reload failed for vmalert instance {{ $labels.instance }}

Configuration hot-reload failed for vmalert on instance {{ $labels.instance }}. Check vmalert's logs for detailed error message.

Trigger condition

```
vmalert_config_last_reload_successful != 1
```

ALERTINGRULESERROR

Severity	Fires after
Warning	5m

Alerting rules are failing for vmalert instance {{ $labels.instance }}

Alerting rules execution is failing for "{{ $labels.alertname }}" from group "{{ $labels.group }}" in file "{{ $labels.file }}". Check vmalert's logs for detailed error message.

Trigger condition

```
sum(increase(vmalert_alerting_rules_errors_total[5m])) without(id) > 0
```

RECORDINGRULESERROR

Severity	Fires after
Warning	5m

Recording rules are failing for vmalert instance {{ $labels.instance }}

Recording rules execution is failing for "{{ $labels.recording }}" from group "{{ $labels.group }}" in file "{{ $labels.file }}". Check vmalert's logs for detailed error message.

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Trigger condition

```
sum(increase(vmalert_recording_rules_errors_total[5m])) without(id) > 0
```

RECORDINGRULESNODATA

Severity	Fires after
Info	30m

Recording rule {{ $labels.recording }} ({{ $labels.group }}) produces no data

Recording rule "{{ $labels.recording }}" from group "{{ $labels.group }} in file "{{ $labels.file }}" produces 0 samples over the last 30min. It might be caused by a misconfiguration or incorrect query expression.

Trigger condition

```
sum(vmalert_recording_rules_last_evaluation_samples) without(id) < 1
```

TOOMANYMISSEDITERATIONS

Severity	Fires after
Warning	15m

vmalert instance {{ $labels.instance }} is missing rules evaluations

vmalert instance {{ $labels.instance }} is missing rules evaluations for group "{{ $labels.group }}" in file "{{ $labels.file }}". The group evaluation time takes longer than the configured evaluation interval. This may result in missed alerting notifications or recording rules samples. Try increasing evaluation interval or concurrency of group "{{ $labels.group }}". See https://docs.victoriametrics.com/victoriametrics/vmalert/#groups. If rule expressions are taking longer than expected, please see https://docs.victoriametrics.com/victoriametrics/troubleshooting/#slow-queries.

Trigger condition

```
increase(vmalert_iteration_missed_total[5m]) > 0
```

REMOTEWRITEERRORS

Severity	Fires after
Warning	15m

vmalert instance {{ $labels.instance }} is failing to push metrics to remote write URL

vmalert instance {{ $labels.instance }} is failing to push metrics generated via alerting or recording rules to the configured remote write URL. Check vmalert's logs for detailed error message.

Trigger condition

```
increase(vmalert_remotewrite_errors_total[5m]) > 0
```

REMOTEWRITEDROPPINGDATA

Severity	Fires after
Critical	5m

vmalert instance {{ $labels.instance }} is dropping data sent to remote write URL

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vmalert instance {{ $labels.instance }} is failing to send results of alerting or recording rules to the configured remote write URL. This may result into gaps in recording rules or alerts state. Check vmalert's logs for detailed error message.

Trigger condition

```
increase(vmalert_remotewrite_dropped_rows_total[5m]) > 0
```

REMOTEWRITEQUEUEHIGHUSAGE

Severity	Fires after
Warning	15m

Remote write queue capacity on the vmalert instance {{ $labels.instance }} has exceeded 80% utilization

The remote write queue on vmalert instance {{ $labels.instance }} has consistently high utilization. The queue acts as a buffer between rules generating series and remote-write client consuming and pushing these series. When queue overflows, vmalert will start dropping newly generated series. Queue may overflow due to multiple reasons: 1. Some bad rules produce too many series at once. This can be limited using the global `-rule.resultsLimit` flag or `limit` param at the rule group level. 2. Remote write connection is slow. Increase `-remoteWrite.concurrency`, so vmalert could establish more concurrent connections. 3. The queue size is too small. Increase `-remoteWrite.maxQueueSize` to extend the buffer size. Note that a larger queue will result in higher memory consumption when the queue is full.

Trigger condition

```
(histogram_quantile(0.99, sum(increase(vmalert_remotewrite_queue_size_bucket[5m])) by(job,instance,vmrange,cluster)) / vmalert_remotewrite_queue_capacity) > 0.8
```

ALERTMANAGERERRORS

Severity	Fires after
Warning	15m

vmalert instance {{ $labels.instance }} is failing to send notifications to Alertmanager

vmalert instance {{ $labels.instance }} is failing to send alert notifications to "{{ $labels.addr }}". Check vmalert's logs for detailed error message.

Trigger condition

```
increase(vmalert_alerts_send_errors_total[5m]) > 0
```

VictoriaMetrics single-node storage

Storage alerts for vmsingle: disk headroom, ingestion churn, and cache utilization.

> **Note**
>
> The rules for both storage modes are installed regardless of which one is deployed. If your xView instance runs vmsingle, the cluster-storage group below never fires, and vice versa.

DISKRUNSOUTOFSPACEIN3DAYS

Severity	Fires after
Critical	30m

Instance {{ $labels.instance }} will run out of disk space soon

Expeto Inc @ 2026

Taking into account current ingestion rate, free disk space will be enough only for {{ $value | humanizeDuration }} on instance {{ $labels.instance }}. Consider to limit the ingestion rate, decrease retention or scale the disk space if possible.

Trigger condition

```
((sum(vm_free_disk_space_bytes) without(path) / (((rate(vm_rows_added_to_storage_total[1d]) - sum(rate(vm_deduplicated_samples_total[1d])) without(type)) * (sum(vm_data_size_bytes{type!~"indexdb.*"}) without(type) / sum(vm_rows{type!~"indexdb.*"}) without(type))) + (rate(vm_new_timeseries_created_total[1d]) * (sum(vm_data_size_bytes{type="indexdb/file"}) without(type) / sum(vm_rows{type="indexdb/file"}) without(type))))) < 259200) > 0
```

NODEBECOMESREADONLYIN3DAYS

Severity	Fires after
Warning	30m

Instance {{ $labels.instance }} will become read-only in 3 days

Taking into account current ingestion rate and free disk space instance {{ $labels.instance }} is writable for {{ $value | humanizeDuration }}. Consider to limit the ingestion rate, decrease retention or scale the disk space up if possible.

Trigger condition

```
((sum(vm_free_disk_space_bytes - vm_free_disk_space_limit_bytes) without(path) / (((rate(vm_rows_added_to_storage_total[1d]) - sum(rate(vm_deduplicated_samples_total[1d])) without(type)) * (sum(vm_data_size_bytes{type!~"indexdb.*"}) without(type) / sum(vm_rows{type!~"indexdb.*"}) without(type))) + (rate(vm_new_timeseries_created_total[1d]) * (sum(vm_data_size_bytes{type="indexdb/file"}) without(type) / sum(vm_rows{type="indexdb/file"}) without(type))))) < 259200) > 0
```

DISKRUNSOUTOFSPACE

Severity	Fires after
Critical	30m

Instance {{ $labels.instance }} (job={{ $labels.job }}) will run out of disk space soon

Disk utilisation on instance {{ $labels.instance }} is more than 80%. Having less than 20% of free disk space could cripple merge processes and overall performance. Consider to limit the ingestion rate, decrease retention or scale the disk space if possible.

Trigger condition

```
(sum(vm_data_size_bytes) by(job,instance,cluster) / (sum(vm_free_disk_space_bytes) by(job,instance,cluster) + sum(vm_data_size_bytes) by(job,instance,cluster))) > 0.8
```

REQUESTERRORSTOAPI

Severity	Fires after
Warning	15m

Too many errors served for path {{ $labels.path }} (instance {{ $labels.instance }})

Requests to path {{ $labels.path }} are receiving errors. Please verify if clients are sending correct requests.

Trigger condition

```
increase(vm_http_request_errors_total[5m]) > 0
```

TOOHIGHCHURNRATE

Severity	Fires after
Warning	15m

Churn rate is more than 10% on "{{ $labels.instance }}" for the last 15m

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VM constantly creates new time series on "{{ $labels.instance }}". This effect is known as Churn Rate. High Churn Rate is tightly connected with database performance and may result in unexpected OOM's or slow queries.

Trigger condition

```
(sum(rate(vm_new_timeseries_created_total[5m])) by(instance,cluster) / sum(rate(vm_rows_inserted_total[5m])) by(instance,cluster)) > 0.1
```

TOOHIGHCHURNRATE24H

Severity	Fires after
Warning	15m

Too high number of new series on "{{ $labels.instance }}" created over last 24h

The number of created new time series over last 24h is 3x times higher than current number of active series on "{{ $labels.instance }}". This effect is known as Churn Rate. High Churn Rate is tightly connected with database performance and may result in unexpected OOM's or slow queries.

Trigger condition

```
sum(increase(vm_new_timeseries_created_total[24h])) by(instance,cluster) > (sum(vm_cache_entries{type="storage/hour_metric_ids"}) by(instance,cluster) * 3)
```

TOOHIGHSLOWINSERTSRATE

Severity	Fires after
Warning	15m

Percentage of slow inserts is more than 5% on "{{ $labels.instance }}" for the last 15m

High rate of slow inserts on "{{ $labels.instance }}" may be a sign of resource exhaustion for the current load. It is likely more RAM is needed for optimal handling of the current number of active time series. See also https://github.com/VictoriaMetrics/VictoriaMetrics/issues/3976#issuecomment-1476883183

Trigger condition

```
(sum(rate(vm_slow_row_inserts_total[5m])) by(instance,cluster) / sum(rate(vm_rows_inserted_total[5m])) by(instance,cluster)) > 0.05
```

METADATACACHEUTILIZATIONISTOOHIGH

Severity	Fires after
Warning	15m

Metadata cache capacity on {{ $labels.instance }} (job={{ $labels.job }}) is utilized for more than 95% for the last 15min

Metadata cache stores meta information about ingested time series - see https://docs.victoriametrics.com/victoriametrics/#metrics-metadata. When cache is overutilized, the oldest entries will be dropped out automatically. It may result into incomplete response for /api/v1/metadata API calls. It doesn't impact regular queries or alerts. Cache size is controlled via -storage.maxMetadataStorageSize cmd-line flag.

Trigger condition

```
(vm_metrics_metadata_storage_size_bytes / vm_metrics_metadata_storage_max_size_bytes) > 0.95
```

VictoriaMetrics cluster storage

The vmcluster equivalents of the single-node storage alerts, plus alerts for the vminsert to vmstorage connection and for index-level problems that only arise in the clustered topology.

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DISKRUNSOUTOFSPACEIN3DAYS

Severity	Fires after
Critical	30m

Instance {{ $labels.instance }} will run out of disk space in 3 days

Taking into account current ingestion rate, free disk space will be enough only for {{ $value | humanizeDuration }} on instance {{ $labels.instance }}. Consider to limit the ingestion rate, decrease retention or scale the disk space up if possible.

Trigger condition

```
((sum(vm_free_disk_space_bytes) without(path) / (((rate(vm_rows_added_to_storage_total[1d]) - sum(rate(vm_deduplicated_samples_total[1d])) without(type)) * (sum(vm_data_size_bytes{type!~"indexdb.*"}) without(type) / sum(vm_rows{type!~"indexdb.*"}) without(type))) + (rate(vm_new_timeseries_created_total[1d]) * (sum(vm_data_size_bytes{type="indexdb/file"}) without(type) / sum(vm_rows{type="indexdb/file"}) without(type))))) < 259200) > 0
```

NODEBECOMESREADONLYIN3DAYS

Severity	Fires after
Warning	30m

Instance {{ $labels.instance }} will become read-only in 3 days

Taking into account current ingestion rate, free disk space and -storage.minFreeDiskSpaceBytes instance {{ $labels.instance }} will remain writable for {{ $value | humanizeDuration }}. Consider to limit the ingestion rate, decrease retention or scale the disk space up if possible.

Trigger condition

```
((sum(vm_free_disk_space_bytes - vm_free_disk_space_limit_bytes) without(path) / (((rate(vm_rows_added_to_storage_total[1d]) - sum(rate(vm_deduplicated_samples_total[1d])) without(type)) * (sum(vm_data_size_bytes{type!~"indexdb.*"}) without(type) / sum(vm_rows{type!~"indexdb.*"}) without(type))) + (rate(vm_new_timeseries_created_total[1d]) * (sum(vm_data_size_bytes{type="indexdb/file"}) without(type) / sum(vm_rows{type="indexdb/file"}) without(type))))) < 259200) > 0
```

DISKRUNSOUTOFSPACE

Severity	Fires after
Critical	30m

Instance {{ $labels.instance }} (job={{ $labels.job }}) will run out of disk space soon

Disk utilisation on instance {{ $labels.instance }} is more than 80%. Having less than 20% of free disk space could cripple merges processes and overall performance. Consider to limit the ingestion rate, decrease retention or scale the disk space if possible.

Trigger condition

```
(sum(vm_data_size_bytes) by(job,instance,cluster) / (sum(vm_free_disk_space_bytes) by(job,instance,cluster) + sum(vm_data_size_bytes) by(job,instance,cluster))) > 0.8
```

REQUESTERRORSTOAPI

Severity	Fires after
Warning	15m

Too many errors served for {{ $labels.job }} path {{ $labels.path }} (instance {{ $labels.instance }})

Requests to path {{ $labels.path }} are receiving errors. Please verify if clients are sending correct requests.

Trigger condition

```
increase(vm_http_request_errors_total[5m]) > 0
```


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RPCERRORS

Severity	Fires after
Warning	15m

Too many RPC errors for {{ $labels.job }} (instance {{ $labels.instance }})

RPC errors are interconnection errors between cluster components. Possible reasons for errors are misconfiguration, overload, network blips or unreachable components.

Trigger condition

```
((sum(increase(vm_rpc_connection_errors_total[5m])) by(job,instance,cluster) + sum(increase(vm_rpc_dial_errors_total[5m])) by(job,instance,cluster)) + sum(increase(vm_rpc_handshake_errors_total[5m])) by(job,instance,cluster)) > 0
```

TOOHIGHCHURNRATE

Severity	Fires after
Warning	15m

Churn rate is more than 10% for the last 15m

VM constantly creates new time series. This effect is known as Churn Rate. High Churn Rate tightly connected with database performance and may result in unexpected OOM's or slow queries.

Trigger condition

```
(sum(rate(vm_new_timeseries_created_total[5m])) by(job,cluster) / sum(rate(vm_rows_inserted_total[5m])) by(job,cluster)) > 0.1
```

TOOHIGHCHURNRATE24H

Severity	Fires after
Warning	15m

Too high number of new series created over last 24h

The number of created new time series over last 24h is 3x times higher than current number of active series. This effect is known as Churn Rate. High Churn Rate tightly connected with database performance and may result in unexpected OOM's or slow queries.

Trigger condition

```
sum(increase(vm_new_timeseries_created_total[24h])) by(job,cluster) > (sum(vm_cache_entries{type="storage/hour_metric_ids"}) by(job,cluster) * 3)
```

TOOHIGHSLOWINSERTSRATE

Severity	Fires after
Warning	15m

Percentage of slow inserts is more than 5% for the last 15m

High rate of slow inserts may be a sign of resource exhaustion for the current load. It is likely more RAM is needed for optimal handling of the current number of active time series. See also https://github.com/VictoriaMetrics/VictoriaMetrics/issues/3976#issuecomment-1476883183

Trigger condition

```
(sum(rate(vm_slow_row_inserts_total[5m])) by(job,cluster) / sum(rate(vm_rows_inserted_total[5m])) by(job,cluster)) > 0.05
```


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VMINSERTVMSTORAGECONNECTIONISSATURATED

Severity	Fires after
Warning	15m

Connection between vminsert on {{ $labels.instance }} and vmstorage on {{ $labels.addr }} is saturated

The connection between vminsert (instance {{ $labels.instance }}) and vmstorage (instance {{ $labels.addr }}) is saturated by more than 90% and vminsert won't be able to keep up. This usually means that more vminsert or vmstorage nodes must be added to the cluster in order to increase the total number of vminsert -> vmstorage links.

Trigger condition

```
rate(vm_rpc_send_duration_seconds_total[5m]) > 0.9
```

METADATACACHEUTILIZATIONISTOOHIGH

Severity	Fires after
Warning	15m

Metadata cache capacity on {{ $labels.instance }} (job={{ $labels.job }}) is utilized for more than 95% for the last 15min

Metadata cache stores meta information about ingested time series - see https://docs.victoriametrics.com/victoriametrics/#metrics-metadata. When cache is overutilized, the oldest entries will be dropped out automatically. It may result into incomplete response for /api/v1/metadata API calls. It doesn't impact regular queries or alerts. Cache size is controlled via -storage.maxMetadataStorageSize cmd-line flag.

Trigger condition

```
(vm_metrics_metadata_storage_size_bytes / vm_metrics_metadata_storage_max_size_bytes) > 0.95
```

METRICNAMESTATSCACHEUTILIZATIONISTOOHIGH

Severity	Fires after
Warning	15m

Cache capacity for tracking metric names usage on {{ $labels.instance }} (job={{ $labels.job }}) is utilized for more than 95% during the last 15min

Metric names usage cache stores information about unique metric names and how frequently they are queried - see https://docs.victoriametrics.com/victoriametrics/#track-ingested-metrics-usage. When cache is overutilized, it will stop tracking the new metric names. It has no other negative impact. Usually, the number of unique metric names is very limited (thousands). The cache can be overutilized only if metric names are changing too frequently or if the cache size is too low. There are following ways to mitigate cache overutilization: - disable cache via `--storage.trackMetricNamesStats=false` flag, so metric names usage will stop tracking - increase the cache size via `--storage.cacheSizeMetricNamesStats` flag - reset the cache (see docs for details)

Trigger condition

```
(vm_cache_size_bytes{type="storage/metricNamesStatsTracker"} / vm_cache_size_max_bytes{type="storage/metricNamesStatsTracker"}) > 0.95
```

INDEXDBRECORDSDROP

Severity	Fires after
Critical	Immediately

IndexDB skipped registering items during data ingestion with reason={{ $labels.reason }}.

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VictoriaMetrics could skip registering new timeseries during ingestion if they fail the validation process. For example, `reason=too_long_item` means that time series cannot exceed 64KB. Please, reduce the number of labels or label values for such series. Or enforce these limits via `-maxLabelsPerTimeseries` and `-maxLabelValueLen` command-line flags.

Trigger condition

```
increase(vm_indexdb_items_dropped_total[5m]) > 0
```

TOOMANYTSIDMISSES

Severity	Fires after
Critical	15m

Unexpected TSID misses for job "{{ $labels.job }}" ({{ $labels.instance }}) for the last 15 minutes

Unexpected TSID misses for "{{ $labels.job }}" ({{ $labels.instance }}) for the last 15 minutes. If this happens after unclean shutdown of VictoriaMetrics process (via "kill -9", OOM or power off), then this is OK - the alert must go away in a few minutes after the restart. Otherwise this may point to the corruption of index data.

Trigger condition

```
increase(vm_missing_tsids_for_metric_id_total[5m]) > 0
```

VictoriaMetrics process health

Generic process-level alerts that apply to every VictoriaMetrics component — vmagent, vmalert, vmsingle, vmstorage, and the rest. The instance and job labels on a firing alert identify which component is affected.

TOOMANYRESTARTS

Severity	Fires after
Critical	Immediately

{{ $labels.job }} too many restarts (instance {{ $labels.instance }})

Job {{ $labels.job }} (instance {{ $labels.instance }}) has restarted more than twice in the last 15 minutes. It might be crashlooping.

Trigger condition

```
changes(process_start_time_seconds{job=~".*(victoriametrics|vmselect|vminsert|vmstorage|vmagent|vmalert|vmsingle|vmalertmanager|vmauth).*"}[15m]) > 2
```

SERVICEDOWN

Severity	Fires after
Critical	2m

Service {{ $labels.job }} is down on {{ $labels.instance }}

{{ $labels.instance }} of job {{ $labels.job }} has been down for more than 2 minutes.

Trigger condition

```
up{job=~".*(victoriametrics|vmselect|vminsert|vmstorage|vmagent|vmalert|vmsingle|vmalertmanager|vmauth).*"} == 0
```


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PROCESSNEARFDLIMITS

Severity	Fires after
Critical	5m

Number of free file descriptors is less than 100 for "{{ $labels.job }}"("{{ $labels.instance }}") for the last 5m

Exhausting OS file descriptors limit can cause severe degradation of the process. Consider to increase the limit as fast as possible.

Trigger condition

```
(process_max_fds - process_open_fds) < 100
```

TOOHIGHMEMORYUSAGE

Severity	Fires after
Critical	5m

It is more than 80% of memory used by "{{ $labels.job }}"("{{ $labels.instance }}")

Too high memory usage may result into multiple issues such as OOMs or degraded performance. Consider to either increase available memory or decrease the load on the process.

Trigger condition

```
(min_over_time(process_resident_memory_anon_bytes[10m]) / vm_available_memory_bytes) > 0.8
```

TOOHIGHCPUUSAGE

Severity	Fires after
Critical	5m

More than 90% of CPU is used by "{{ $labels.job }}"("{{ $labels.instance }}") during the last 5m

Too high CPU usage may be a sign of insufficient resources and make process unstable. Consider to either increase available CPU resources or decrease the load on the process.

Trigger condition

```
(rate(process_cpu_seconds_total[5m]) / process_cpu_cores_available) > 0.9
```

TOOHIGHGOROUTINESCHEDULINGLATENCY

Severity	Fires after
Critical	15m

"{{ $labels.job }}"("{{ $labels.instance }}") has insufficient CPU resources for >15m

Go runtime is unable to schedule goroutines execution in acceptable time. This is usually a sign of insufficient CPU resources or CPU throttling. Verify that service has enough CPU resources. Otherwise, the service could work unreliably with delays in processing.

Trigger condition

```
histogram_quantile(0.99, sum(rate(go_sched_latencies_seconds_bucket{job=~".*(victoriametrics|vmselect|vminsert|vmstorage|vmagent|vmalert|vmsingle|vmalertmanager|vmauth).*"}[5m])) by(le,job,instance,cluster)) > 0.1
```


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TOOMANYLOGS

Severity	Fires after
Warning	15m

Too many logs are generated for job "{{ $labels.job }}" ({{ $labels.instance }})

The job "{{ $labels.job }}" ({{ $labels.instance }}) generated {{ $value }} log messages with the level higher than info for the last 5 minutes. Check the logs for the given target. Check also the "location" label at the vm_log_messages_total metric if -loggerLevel command-line flag is set to value other than INFO. This label contains code locations responsible for generating log messages suppressed by -loggerLevel.

Trigger condition

```
sum(increase(vm_log_messages_total{level!="info"}[5m])) without(app_version,location,is_printed) > 0
```

CONCURRENTINSERTSHITTHELIMIT

Severity	Fires after
Warning	15m

{{ $labels.job }} on instance {{ $labels.instance }} is constantly hitting concurrent inserts limit

The limit of concurrent inserts on instance {{ $labels.instance }} depends on the number of CPUs. Usually, when component constantly hits the limit it is likely the component is overloaded and requires more CPU. In some cases for components like vmagent or vminsert the alert might trigger if there are too many clients making write attempts. If vmagent's or vminsert's CPU usage and network saturation are at normal level, then it might be worth adjusting `-maxConcurrentInserts` cmd-line flag.

Trigger condition

```
avg_over_time(vm_concurrent_insert_current[1m]) >= vm_concurrent_insert_capacity
```

TOOHIGHQUERYLOAD

Severity	Fires after
Warning	15m

Read queries fail with timeout for {{ $labels.job }} on instance {{ $labels.instance }}

Instance {{ $labels.instance }} ({{ $labels.job }}) is failing to serve read queries during last 15m. Concurrency limit `-search.maxConcurrentRequests` was reached on this instance and extra queries were put into the queue for `-search.maxQueueDuration` interval. But even after waiting in the queue these queries weren't served. This happens if instance is overloaded with the current workload, or datasource is too slow to respond. Possible solutions are the following: * reduce the query load; * increase compute resources or number of replicas; * adjust limits `-search.maxConcurrentRequests` and `-search.maxQueueDuration`. See more at https://docs.victoriametrics.com/victoriametrics/troubleshooting/#slow-queries.

Trigger condition

```
increase(vm_concurrent_select_limit_timeout_total[5m]) > 0
```

ROWSREJECTEDONINGESTION

Severity	Fires after
Warning	15m

Some rows are rejected on "{{ $labels.instance }}" on ingestion attempt

Ingested rows on instance "{{ $labels.instance }}" are rejected due to the following reason: "{{ $labels.reason }}"

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Trigger condition

```
rate(vm_rows_ignored_total[5m]) > 0
```

VictoriaMetrics operator

Health of the operator that turns the `VMRule`, `VMAgent`, and related custom resources into running configuration. While it is failing to reconcile, changes to alert rules or scrape configs are accepted but never applied.

LOGERRORS

Severity	Fires after
Warning	15m

Too many errors at logs of operator: {{ $value}}

Operator has too many errors at logs: {{ $value}}, check operator logs

Trigger condition

```
sum(rate(operator_log_messages_total{level="error",job=~".*((victoria.*)|vm)-?operator"}[5m])) by(cluster) > 0
```

RECONCILEERRORS

Severity	Fires after
Warning	10m

Too many errors at reconcile loop of operator: {{ $value}}

Operator cannot parse response from k8s api server, possible bug: {{ $value }}, check operator logs

Trigger condition

```
sum(rate(controller_runtime_reconcile_errors_total{job=~".*((victoria.*)|vm)-?operator"}[5m])) by(cluster) > 0
```

HIGHQUEUEDEPTH

Severity	Fires after
Warning	15m

Too many `{{- $labels.name }}` in queue: {{ $value }}

Operator cannot handle reconciliation load for controller: `{{- $labels.name }}`, current depth: {{ $value }}

Trigger condition

```
sum(workqueue_depth{job=~".*((victoria.*)|vm)-?operator",name=~"(vmagent|vmalert|vmalertmanager|vmauth|vmcluster|vmnodescrape|vmpodscrape|vmprobe|vmrule|vmservicescrape|
vmsingle|vmstaticscrape)"}) by(name,cluster) > 10
```


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4. xCore

4.1 Expeto xCore

xCore is the Expeto 4G and 5G mobile core. It is delivered as a Kubernetes operator: you install the operator with Helm, describe the core you want in a single `Site` custom resource, and the operator brings up and maintains the network functions, their databases and their network attachments in that namespace. One xCore installation is one Site in xControl, and the Expeto Agent that ships with it keeps the two in sync.

This guide covers xCore 4.0.6, installed from the `xfabric` chart, which is the release that brings the combined 4G and 5G core. Every new xCore, public or private, is installed this way. The xCore Helm chart of the 3.3 releases is deprecated and no longer documented; the 3.3 releases continue to deliver xControl and xRouter. xCore 4.0.6 registers with xControl 3.3.22 or later.

4.1.1 Deployment shapes

The same operator and the same `Site` resource describe every xCore deployment. What changes is which control-plane blocks the Site declares.

Shape	Where it runs	What the Site declares
Public core	A data centre or cloud region, behind an xRouter that receives the traffic of private SIMs roaming on public networks over IPX.	User planes only: an SGW-U that terminates the tunnels from xRouter and one PGW-U anchor per network segment, with the SMF acting as combined SGW-C and PGW-C. No radio-facing functions.
Private 5G core	On the enterprise premises, or hosted for the enterprise, connected to private gNodeBs.	An AMF, the 5G subscriber store (UDR, UDM, AUSF), the SMF and one or more UPFs.
Private 4G core	On the enterprise premises, connected to private eNodeBs.	An MME, the HSS, the SMF as SGW-C and PGW-C, and an SGW-U in front of one or more PGW-Us.
Combined private core	One installation serving both 4G and 5G private radios.	Both the AMF and the MME, the subscriber store in dual mode (UDR, UDM, AUSF and HSS), a front user plane for both radio types and an anchor per System that serves both, so a session follows a device between 4G and 5G. There is no N26 interface between the two mobility functions. See Install a combined core.

A private core can also serve the public path at the same time: point an xRouter at one of its user planes and the same subscribers reach the enterprise network from anywhere.

4.1.2 Network functions

Function	3GPP role	Present in
SMF	Session management; also the SGW-C and PGW-C for 4G sessions. Routes each subscriber to the user plane of its System.	every shape
UPF	User plane. In 5G a session anchor (PSA) or intermediate UPF; in 4G an SGW-U or a PGW-U, never both.	every shape

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Function	3GPP role	Present in
AMF	Access and mobility management for gNodeBs over N2.	5G, combined
MME	Mobility management for eNodeBs over S1-MME, with its S1 transport controller.	4G, combined
UDR, UDM, AUSF	5G subscriber data, subscriber management and authentication.	5G, combined
HSS	4G subscriber data and authentication over S6a.	4G, combined
NFCM	Network function configuration management, monitoring and statistics.	every shape
UDSF	Unstructured data storage for session state, with the identifier allocator and timer services.	every shape
Expeto Agent	Connects the Site to xControl: subscriber synchronisation, configuration, session records and metrics.	every shape

Supporting them are an Apache Ignite cluster for session state, MariaDB for subscriber and session-management persistence, and Dragonfly as the in-memory cache. All three are created by the operator inside the Site's namespace.

4.1.3 How a Site is managed

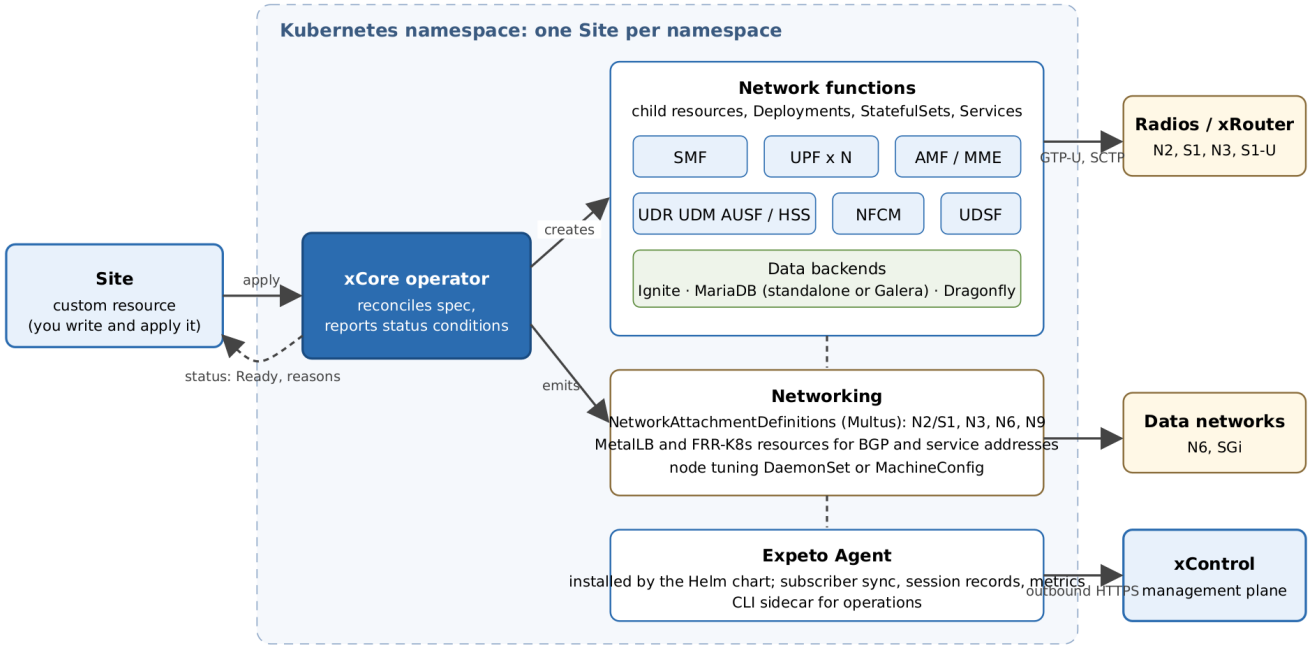
- **xControl provisions, the Site executes.** Mobile Assets, Systems and policies are created in xControl. The Agent receives them over its outbound connection and writes them into the Site's subscriber store. A Site keeps serving traffic when that connection is down.
- **The Site resource is the deployment contract.** Every network attachment, address range, PLMN and user plane is declared in one document, written with Expeto Support during the design phase and applied as agreed. The operator reports the outcome as conditions on the same resource, so `kubectl describe site` tells you whether the core is ready and, if not, why. Today you edit the Site yourself; Expeto intends the Agent to write it from the configuration held in xControl, so the resource is changing and may not stay directly editable. See Who writes the Site.
- **The operator owns its objects.** Everything it creates is labelled and guarded by an admission webhook; configuration changes go through the Site resource, never through `kubectl edit` on a generated ConfigMap or Deployment.

The Architecture page explains the operator model and the network model in detail. The Installation section takes you from an empty cluster to a Site that reports `Ready`, and Install a combined core walks through a complete combined core, from xControl preparation and key loading to the first attached devices.

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4.2 Architecture

xCore is a Kubernetes operator with a single custom resource. This page explains what the operator creates from a `Site`, how the network model maps 3GPP interfaces onto cluster networking, and how the operator reports state. Read it before writing your first Site definition; the field-level detail is on the Site definition page.



4.2.1 The operator model

An xCore installation is one Helm release in one namespace. The release contains the operator, the Expeto Agent and, unless the cluster already has them, the MariaDB and Dragonfly operators and the netcfg node-configuration operator, which is shared by every Expeto product on the cluster. The cluster-scoped CustomResourceDefinitions are applied by the chart before the rest of the release on every install and upgrade, and shared by every release on the cluster.

The operator reconciles exactly one `Site` in its namespace. From that document it creates and owns:

- a child resource per network function, each reconciled into Deployments or StatefulSets, Services and ConfigMaps: `Smf`, one `Upf` per user plane, `Mm` (the AMF), `Mme` (the MME and its S1 transport controller), `Sdm` (the subscriber store), `Nfcm` and `Udsf`;
- the data backends: an Apache Ignite cluster for session state, a MariaDB instance or Galera cluster for the SMF and the subscriber store, a Dragonfly cache for identifier allocation and timers, and separate Dragonfly session stores for the MME and the subscriber store;
- one `NetworkAttachmentDefinition` per declared attachment, plus MetalLB and FRR-K8s resources when the Site uses BGP or service addresses;
- optionally a node-tuning DaemonSet (or a MachineConfig on OpenShift) from the Site's `nodeConfig`.

The Agent is the one component the Helm chart installs directly rather than the operator: its identity (Site ID and token) is installation configuration, not topology. The operator watches the Agent's readiness and folds it into the Site's status.

Every object the operator creates carries the label `expeto.io/managed-by=taiga` and is guarded by a validating admission webhook that rejects edits from anyone but the operator. Configuration changes are made on the `Site`; `kubectl edit` on a generated ConfigMap or Deployment is refused with a message pointing back at the field that owns it.

Multiple cores on one cluster are separate installations in separate namespaces. A second `Site` applied into a namespace that already has one is rejected with the reason `RejectedExtraSite`.

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4.2.2 Network model

The Site describes networking in two layers.

Attachments (`spec.network.attachments`) are the identity carrier. Each one becomes a `NetworkAttachmentDefinition` whose CNI plugin chain is rendered verbatim, so any plugin the nodes support works: macvlan or ipvlan on a VLAN interface, SR-IOV, a route-override chain, with static, host-local or whereabouts address management. An attachment is a segment: "the radio VLAN", "the corporate breakout".

Interfaces in the topology reference attachments by name and pin the address a pod uses on that segment as a host address with prefix length (`transitIpRange: 10.0.3.10/24`). The mapping to 3GPP interfaces:

Site field	5G	4G	Carried by
`controlPlane.amf.n2[]`	N2 (NGAP over SCTP)		AMF
`controlPlane.mme.s1[]`		S1-MME (S1AP over SCTP)	MME transport controller
`userPlanes[].n3[]`	N3	S1-U	UPF, radio side
`userPlanes[].n6[]`	N6	SGi	UPF, data-network side; carries the UE pools
`userPlanes[].n9[]`	N9	S5-U	UPF to UPF; an attachment or the pod network
`controlPlane.n16[]`	N16	S5-C / S8 (GTP-C)	SMF, roaming or upstream control plane

Interfaces that face other clusters or cloud networks can be realized as LoadBalancer addresses drawn from a **service range** (`spec.network.serviceRanges`) instead of an attachment, for N2, S1, N3 and N16. The address is allocated by MetalLB and advertised over BGP or layer 2. On a cluster with neither MetalLB nor a suitable network interface, N2 and S1 can also be served on a node port of every node.

UE address pools live on the N6 interface that serves them. Each pool declares how its traffic reaches the outside: source NAT on the UPF (the default), static routes that the network team installs (the operator lists the required routes in the Site's status), or BGP advertisement over a named peering with the UPF's N6 transit address as next hop.

BGP routers are declared in `spec.network.bgp` , each with a local ASN and named peerings that ride an attachment. A Site has at most one MetalLB router: the operator emits its FRR-K8s configuration and MetalLB peers into MetalLB's namespace and cleans them up through a finalizer when the Site is deleted. A GoBGP router instead runs as a sidecar in the dataplane pods of the user planes whose UE pools name its peerings, and announces those pools from the user plane itself; see BGP.

4.2.3 User planes and routing

Each entry in `spec.topology.userPlanes` is one UPF, and its `mode` and the interfaces it declares determine its 3GPP role. A user plane with N6 is an anchor: it carries the `systemId` of an xControl System, and the SMF routes a subscriber to the anchor whose `systemId` matches the System the Mobile Asset was provisioned into. A user plane without N6 is a front: it serves every System on the Site, carries no `systemId` , and hands traffic over N9 to the anchors named in its `peerUpfs` .

Interfaces	Mode `5G`	Mode `4G`	Mode `Dual`
N3 and N9, no N6 (front)	intermediate UPF	SGW-U	SGW-U and intermediate UPF
N9 and N6 (anchor)	session anchor behind an intermediate UPF	PGW-U	PGW-U and 5G session anchor, behind a front

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Interfaces	Mode `5G`	Mode `4G`	Mode `Dual`
N3 and N6 (anchor)	session anchor (PSA-UPF)	none: 4G sessions are refused	5G session anchor; 4G sessions are refused

No user plane is both the SGW-U and the PGW-U of a 4G session: the SMF refuses a session that would use one user plane for both. 4G radios therefore always connect to a front, which forwards over N9 (S5-U) to the anchors.

A public core declares one SGW-U with N3 and N9 and one PGW-U per network segment with N9 and N6. A private 4G core declares an SGW-U in front of one or more PGW-Us; a private 5G core can be a single PSA-UPF with N3 and N6. A combined core declares a front in mode `Dual` and one anchor in mode `Dual` per System, so that each System serves both radio technologies from one address pool. `numberOfSessions` sizes each user plane's session table and is fixed once the user plane exists.

4.2.4 Control plane

`spec.topology.controlPlane` declares the PLMN and the mobility and subscriber functions:

- `plmnId` is the PLMN the mobility functions serve and the home PLMN the subscriber store keys Mobile Assets under. A Site with an MME needs a 3-digit MNC.
- `amf` deploys the AMF (three microservices) with its N2 endpoint, its tracking areas and, optionally, its identity and NAS security preferences. `slices` sets the S-NSSAIs it advertises.
- `mme` deploys the MME and its S1 transport controller with the same vocabulary, plus its NAS and mobility timers, the S-GW and P-GW lists (default: the co-located SMF) and the Diameter realm (default: derived from the PLMN). The Agent registers the MME, so xControl shows its eNodeBs and the Expeto CLI reads its sessions; the MME's configuration stays with the operator.
- `subscriberManagement` deploys the subscriber store: UDR, UDM and AUSF in mode `5G`, the HSS in mode `4G`, all four in mode `Dual`. The AMF needs mode `5G` or `Dual`, the MME `4G` or `Dual`. The Agent provisions Mobile Assets into whichever store is present.
- `dataNetworks` lists the DNNs or APNs the core serves; the first is the AMF's default DNN and each one becomes a P-GW association on the MME.
- `usageReporting` sets how often the SMF collects session usage from the user planes for xControl.

Declaring both `amf` and `mme` gives a combined core, and the two identities must not collide. There is no N26 interface between the AMF and the MME. When every anchor is in mode `Dual`, so that one anchor serves both radio technologies for its System, the operator configures both mobility functions for interworking without N26 and they tell dual-mode UEs so; a session then follows the UE between 4G and 5G and keeps its address. Otherwise a UE that changes radio technology attaches or registers afresh. In both cases the HSS and the UDM of the dual-mode store cancel each other's registration of a UE that has moved.

4.2.5 Status model

The Site carries standard Kubernetes conditions. `Ready` rolls up the Agent, every user plane and every control-plane function, and is the condition every validation failure is reported on; the subsystem conditions `GatewaysReady`, `ControlPlaneReady` and `PeeringReady` say which part is waiting, and `InfrastructureReady` is always `True`. Each `False` condition names its cause in `reason` (`TopologyMissingNADs`, `NetworkSpecInvalid`, `MariaDbOperatorMissing`, `GatewayNotReady`, ...), and `status.lastReconcileError` carries the last error verbatim, so `kubectl describe site` is the first and usually last place to look. The child resources (`smf`, `upf`, `mm`, `mme`, `sdm`) carry their own `NetworkConfigured` and `DatabaseReady`. The troubleshooting page lists every reason.

The operator also publishes the gauge `taiga_site_condition{namespace,site,type}` (`1` true, `0` false, `-1` unknown) on its metrics endpoint, which is what an alert on `type="Ready"` watches.

4.2.6 Change management

The Site definition is agreed with Expeto Support during design, and later changes are reviewed with them too: its data model moves between releases, and Expeto intends the Agent to write the Site from the configuration held in xControl. See Who writes the Site. Edits to the Site fall into two classes. Live-reload fields (routes, MTU, BGP peers, pool reachability) are applied by the running pods. Restart-required fields (image tags, topology bindings, storage shape, sysctls) roll the affected pods. Setting `spec.maintenanceMode: false` makes the webhook reject restart-required edits until you flip it back, so a change window can be enforced on the resource itself.

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Two decisions are fixed at creation: the MariaDB topology (standalone or Galera; changing between them on an existing database is refused) and each user plane's `numberOfSessions`.

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4.3 Installation

4.3.1 Planning and Prerequisites

xCore runs on a Kubernetes cluster that you provide. This page lists what that cluster must have before the operator is installed, what to obtain from Expeto and from xControl, and the addressing and identity decisions the Site definition will ask for. Work through it once per Site; the operator install and Site definition pages assume it is done.

Cluster requirements

Requirement	Detail
Kubernetes	Version 1.25 or later, with `kubectl` access that can create namespaces and CustomResourceDefinitions. The operator itself is namespaced; the CRDs it installs are cluster-scoped and shared by every xCore on the cluster.
Nodes	Worker nodes with a network interface on every VLAN or segment the core attaches to (radio, data network, inter-site). The operator's user planes attach to those interfaces with macvlan or ipvlan through Multus. Node sizes are in the sizing guide; each Ignite replica reserves 11 GiB of memory by default and each MariaDB replica needs its own node when Galera is used.
Multus CNI	Required. Every N2, S1, N3, N6 and N9 interface is a `NetworkAttachmentDefinition`; the install fails fast when the Multus CRD is absent. The containernetworking reference plugins (`macvlan`, `ipvlan`, `static`) must be present in the nodes' CNI plugin directory; some distributions ship Multus without them.
whereabouts IPAM	Optional. Needed only when an attachment uses `ipam.type: whereabouts` for cluster-wide address assignment; static IPAM needs nothing extra.
cert-manager	Required. The operator's admission webhook is served with a cert-manager issued certificate. Install cert-manager once per cluster; the chart cannot bundle it.
MariaDB and Dragonfly operators	Bundled with the chart and enabled by default. Disable the bundled copy on a cluster that already runs the same operator; two controllers reconciling the same resources is undefined behaviour.
netcfg operator	Required. Expeto's node-configuration operator, a cluster singleton shared by xControl, xCore and xRouter. The chart bundles it and enables it by default; on a cluster where another Expeto release already runs it, install with `netcfg.enabled=false`, and the install checks that the running one is present.
MetalLB with FRR-K8s	Optional. Required when the Site has a BGP router with `impl: metallb`, the default, which every service-address announcement uses, or exposes an N2 or S1 endpoint as a LoadBalancer address. A router with `impl: gobgp` runs in the user-plane pods and needs no MetalLB. MetalLB can be bundled by the chart on clusters that have no load balancer.
Storage	A default StorageClass providing `ReadWriteOnce` volumes. Ignite claims 25 GiB per replica by default, MariaDB and the Agent claim their own volumes.
Kernel	SCTP support on the nodes that run the AMF or MME (the N2 and S1 transports), the `tun` module on user-plane nodes, and the network buffer sizes the user plane expects. The Site's `nodeConfig` block applies these through a privileged DaemonSet, or a MachineConfig on OpenShift; omit it if you manage node tuning yourself.

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Requirement	Detail
Outbound access	Nodes pull images from `docker.expeto.io`; the machine running Helm pulls charts from `repo.expeto.io`. The Agent connects to xControl over HTTPS. No inbound connection from xControl is needed.
xControl	Release 3.3.22 or later. The Agent of xCore 4.0.6 must not be newer than the xControl it registers with. xControl must present a certificate the Agent trusts: one issued by a public certificate authority.

The platform notes describe how each of these is met on MicroK8s, OpenShift, Tanzu Kubernetes Grid and Amazon EKS.

Tools

- `kubectl` (or `oc`) configured for the cluster.
- Helm 3.
- `helm test` uses no extra tooling; the preflight check runs inside the cluster.
- For a core with a subscriber store, OpenSSL on the offline machine the key custodians use; see Load the subscriber-store keys.

What to obtain

Item	Source	Used as
Registry credentials	Expeto Support. One username and password for the Helm repository and the container registry.	`global.imageCredentials.username` and `.password` on the chart.
Site identifier	xControl: the numeric ID of the Site you create for this core; see Connect the first Site.	`agent.connections.siteId` on the chart.
Site API token	xControl: the API Tokens tab of that Site.	`agent.apiToken` on the chart.
xControl URL	The hostname of your xControl installation, or Expeto's hosted service.	`agent.connections.serverUri` and `.brokerUri` on the chart.
System identifiers	xControl: each System under the Site has a numeric ID. Mobile Assets are provisioned with the System they belong to.	`systemId` on each anchor user plane (one with N6) in the Site definition.
Customer identifier	xControl: the numeric ID of the Customer that owns the Site.	`customerId` in the Site definition.
HSS Identifiers	xControl: the Keyset Mapping of each SIM batch on the Site.	The name each transport key is loaded under in the subscriber store.
Transport keys and SUCI keys	Your SIM vendor and your key custodians: the transport key of each SIM batch, and the home network's SUCI private key with its key identifier.	Loaded into the subscriber store after installation, never into xControl or the Site definition.

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Network plan

The Site definition declares every network the core touches. Expeto Support writes it with you from the plan below during the design phase, so have the following agreed with the network team before that conversation.

Item	Needed for	Notes
Parent interface per segment	every attachment	The node interface (for example `ens192` or `bond0.2001`) that carries each VLAN. Confirm the name on the worker nodes; it differs between platforms.
N2 (5G) or S1-MME (4G) transit address	AMF, MME	One address per mobility function in the radio control-plane subnet, written as a host address with prefix length (`10.0.2.10/24`). The radios point their control-plane connection at it.
N3 or S1-U transit address	every user plane that faces the radios	One per such user plane in the radio user-plane subnet. The radios send GTP-U to it.
N6 or SGi transit address and gateway	every user plane with a data network	One per data network per user plane, with the gateway that routes traffic onward.
N9 or S5-U transit addresses	user-plane chains (SGW-U to PGW-U, intermediate UPF to anchors)	Either an attachment with one address per user plane, or the pod network.
UE address pools	every data network	The CIDR blocks Mobile Assets get their addresses from, one or more per user plane, and how each pool reaches the outside: source NAT on the UPF (default), static routes installed by the network team, or BGP advertisement.
DNS servers	every data network	Handed to Mobile Assets at session setup.
BGP peers	pools or service addresses advertised over BGP	Local ASN, peer address and ASN, and which segment the session rides. The peer must be adjacent on the N6 segment for advertised pools.
MTU	attachments with jumbo or reduced frames	Set on the attachment or per interface; the default is 1500.

Reserve addresses so that no two pods on the same attachment share one; every transit address is pinned by the Site.

Identity plan

Item	Needed for	Notes
PLMN	AMF, MME, subscriber store	MCC and MNC as one string (`310410`); the MNC length is part of the identity and must match the SIMs and the radios. A core with an MME needs a 3-digit MNC: with a 2-digit MNC, 4G attach fails.

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Item	Needed for	Notes
Tracking area codes	AMF, MME	The TACs the radios broadcast; 1 to 65535 for the MME. The AMF accepts an N2 connection from any gNodeB that reaches it with the PLMN and a served TAC; there is no gNodeB allow-list.
Data network names	SMF, AMF, MME	The DNNs or APNs the core serves; the first one is the default. They must match the APNs of the Mobile Assets' System Profiles.
Slices	AMF	The S-NSSAIs the core serves, when Mobile Assets are provisioned for slices other than SST 1.
NAS security algorithms	AMF, MME	Integrity and ciphering preference order. Agree them explicitly for every AMF and MME; the defaults are listed in the Site resource reference.
AMF and MME identities	combined core	Region, set and pointer for the AMF; MME group and code for the MME. They must not collide in a combined core.

One Site per namespace

The operator manages exactly one Site in its own namespace. To run a second core on the same cluster, install the chart again in another namespace; the CRDs are shared. The examples in this section use `xcore` as the namespace and the release name.

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4.3.2 Install a Combined Core

A combined core is one xCore that serves 4G and 5G private radios at the same time: the AMF and the MME side by side, a subscriber store holding both the 4G HSS and the 5G UDR, UDM and AUSF, and user planes that anchor both radio technologies. This page takes you through the whole installation, from an empty cluster to a 4G and a 5G device attached, including loading the keys the subscriber store needs. Each step links to the page that covers it in depth.

What you build

The core in this walk-through is the combined core example of the Site definition page:

Part	What it does
AMF	Serves the gNodeBs over N2.
MME with its S1 transport controller	Serves the eNodeBs over S1-MME.
Subscriber store in mode `Dual`	The HSS authenticates 4G devices, the UDR, UDM and AUSF 5G devices. When a device changes radio technology, each side cancels the other's registration.
SMF	Session management for both radio technologies: the SGW-C and PGW-C for 4G.
Front user plane `upf-front`	Terminates GTP-U from every radio: the SGW-U for 4G and the intermediate UPF for 5G. It serves every System.
One anchor user plane per System	The PGW-U and the 5G session anchor of that System, with its UE address pool and its data network.
Expeto Agent	Connects the core to xControl and provisions every Mobile Asset into the HSS and the UDR.

Every anchor is in mode `Dual`, so the core interworks without N26 (TS 23.501 §5.17.2.3): when a device moves between 4G and 5G, its session moves with it and keeps its address, instead of the device attaching afresh. There is no N26 interface between the AMF and the MME.

The installation involves these roles; one person may hold several:

- the **platform team**, who owns the Kubernetes cluster;
- the **network team**, who owns the radio, transit and data-network segments and the addressing;
- an **xControl administrator** with permission to create Sites, Systems and Keysets;
- two **key custodians**, who hold the SIM batch's transport key and the home network's SUCI private key and enter them into the core.

Before you start

Have the following ready. The planning and prerequisites page explains each item.

- A Kubernetes cluster that meets the cluster requirements, with SCTP on the nodes that will run the AMF and the MME.
- An xControl installation of release 3.3.22 or later, reachable from the cluster over HTTPS, and presenting a certificate issued by a public certificate authority.
- The registry credentials from Expeto Support.
- The network plan: segments and addresses for N2, S1-MME, N3 and S1-U, N9 and each data network, and the UE address pool of each System.
- The identity plan: the PLMN, with a 3-digit MNC, the tracking area codes, and the AMF and MME identities.
- The SIMs: a batch whose IMSIs belong to the PLMN, and the SIM vendor's output file (`.out`) for the batch, with each SIM's K, and usually its OPc, encrypted under the batch's transport key.

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- For 5G, the SIMs personalized for SUCI concealment with the home network's public key, its key identifier and protection scheme Profile B; see Generate a SUCI key pair.
- The radios: eNodeBs and gNodeBs configured with the PLMN, the tracking area codes, and the core's S1-MME and N2 addresses.
- The key material, held by the key custodians and never sent by email or chat: the transport key of each SIM batch, and the SUCI private key of each key identifier. To generate a SUCI key pair, see Generate a SUCI key pair.

Step 1: prepare the cluster

Install the cluster prerequisites the platform team owns: Multus CNI with the reference CNI plugins, cert-manager, a default StorageClass and, for BGP or load-balanced radio endpoints, MetalLB with FRR-K8s. The platform notes give the commands for MicroK8s, OpenShift, Tanzu and EKS. The xCore chart installs the netcfg node-configuration operator itself, unless another Expeto product on the cluster already runs it; see Install the operator.

Step 2: prepare xControl

Create the objects the core registers under and provisions from. Note each numeric identifier as you go; the Site definition and the chart values use them.

1. **Customer.** Use the Customer that owns the private network, or create it. Note its numeric ID: it becomes `customerId` in the Site.
2. **Site.** Create the Site under the Customer, with **Site type xCore**, enable API tokens on it and create a token, as described in Connect the first Site. Note the Site's numeric ID and keep the token secret: they become `agent.connections.siteId` and `agent.apiToken`.
3. **Systems.** Create one System per anchor user plane, under the Customer, on the Site, with the anchor's UE address pool as its network. Note each System's numeric ID: it becomes the anchor's `systemId`.
4. **APN and System Profile.** Make sure the APN the Mobile Assets use exists and matches a data network of the Site (`enterprise` in the example), and that a System Profile uses it.
5. **Keyset.** Create a Keyset for the SIM batch. Set **K4 Field Type** to what the SIM vendor encrypted under the transport key: **K Only**, or **K And OPC** when the OPc is encrypted too.
6. **Keyset Mapping.** Open the Site, click **Edit** and select the **Keyset Mappings** tab. Switch **Enable** on, click **Add Keyset Mapping**, select the Keyset and enter an **HSS Identifier**: a whole number, `1` for the first batch. The HSS Identifier is the name the core's subscriber store will know the batch's transport key by in step 6. Identifier `0` is reserved for Mobile Assets whose K is not encrypted; do not map a Keyset to it.

Step 3: install the operator

Install the xCore chart into its own namespace with the Site ID, xControl's address and the API token, as described in Install the operator:

```
helm install xcore expeto/xfabric -n xcore --create-namespace -f values.yaml \
  --set global.imageCredentials.username='<username>' \
  --set global.imageCredentials.password='<password>' \
  --set agent.apiToken='<site API token>'
kubectl -n xcore rollout status deployment/xcore-xfabric
helm test xcore -n xcore --filter name=xcore-xfabric-test-preflight --logs
```

The preflight test must report every required prerequisite as satisfied before you continue.

Step 4: apply the Site

Write the Site from the combined core example with your addresses, PLMN, identities, `customerId` and `systemId` values, agree it with Expeto Support, then apply it:

```
kubectl -n xcore create secret generic ignite-credentials --from-literal=password='<password>'
kubectl -n xcore apply -f site.yaml
kubectl -n xcore wait --for=condition=Ready --timeout=15m sites.expeto.io/acmecorp-hq
```

`Ready` turns `True` once the Agent, every user plane and every control-plane function (the SMF, the AMF, the MME and the subscriber store) report ready. If it does not, `kubectl describe site` names the cause; see Troubleshooting.

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Step 5: verify the installation

Work through Verify the installation: the Site's conditions, the workloads, the preflight check, and the Site showing **Connected** in xControl. A combined core runs, in addition to the shared functions, the AMF's three `mm-*` Deployments, the `mme-mme` and `mme-stc` Deployments with the `mme-cache` store, and the `sdm-hss`, `sdm-udr`, `sdm-udm` and `sdm-ausf` subscriber store with its `sdm-cache`.

Step 6: load the subscriber-store keys

The subscriber store needs two kinds of key that xControl never holds, and they are loaded on the Site itself, once per Site, through the Expeto CLI. Treat the loading as a small key ceremony.

Transport key. The SIM vendor encrypts each SIM's K, and usually its OPc, under the batch's transport key before delivering the batch. xControl stores the encrypted values as delivered, and the Agent provisions them into the HSS and the UDR with the HSS Identifier of the Keyset Mapping. The HSS and the UDR decrypt them with the transport key stored under that identifier. A combined core needs the transport key in both: the HSS authenticates the SIMs on 4G and the UDR on 5G. The operator variant (OP) is not loaded: Mobile Assets carry their OPc.

SUCI private key. A 5G device conceals its identity in a Subscription Concealed Identifier (SUCI), encrypted with the home network's public key. The UDM de-conceals it with the matching private key, which the UDR stores per PLMN under the key identifier the SIMs carry. Without it, a 5G device whose SIM conceals its identity cannot register.

PREPARE THE CEREMONY

- Two people take part: a key custodian who enters each key, and a second person who witnesses and checks every step.
- Use a workstation the platform team approves, with `kubectl` access to the core's namespace. Do not share or record the screen.
- Bring the keys on the medium your security policy prescribes, as hexadecimal strings: 32 digits for an AES-128 transport key, 64 digits for a SUCI private key.
- Have the HSS Identifier of each Keyset Mapping and the key identifier of each SUCI key at hand.
- For each SUCI key, the custodian computes its fingerprint on the offline machine before the ceremony, without displaying the key, and brings the fingerprint. The fingerprint is taken over the key exactly as it is entered, in lowercase hexadecimal, which is how this pipeline prints it:

```
openssl pkey -in hn-key-1.pem -noout -text \
  | awk '/^priv:/{f=1;next} /^pub:/{f=0} f' | tr -d ' :\n' | sha1sum
```

The CLI never takes a key on its command line. It prompts for every key and masks the input, so a key does not reach the shell history or the screen. The confirmation it prints after an `add`, and the detail view of a single keyset (`read keyset name=<n>`, `read udr-keyset name=<n>`), can show the stored values; verify with the list views shown below instead, and clear the terminal when you finish.

LOAD THE TRANSPORT KEY INTO THE HSS

Open the CLI in the Agent pod:

```
kubectl -n xcore exec -it xcore-xfabric-agent-0 -c agent-cli -- cli
```

Move to the 4G folder and list the keysets the HSS holds. The record `0`, without a transport key, is created by the Agent for Mobile Assets without a Keyset.

```
expeto_shell>cd /lte
expeto_shell>lte>read keyset
```

Add the transport key under the HSS Identifier, here `1`. The CLI prompts for the transport key and for an OP; enter the transport key, and press Enter at the OP prompt to leave it empty:

```
expeto_shell>lte>add keyset name=1 encryption=AES_128
please input transport key: ********************************
please input OP:
```

`encryption` names the algorithm the transport key is used with. `AES_128`, the default, matches a 32-digit key. For a SIM batch encrypted with another algorithm, ask Expeto Support.

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LOAD THE TRANSPORT KEY INTO THE UDR

Move to the 5G folder and add the same transport key under the same identifier, again leaving the OP empty:

```
expeto_shell>lte>cd /nr
expeto_shell>nr>add udr-keyset name=1 encryption=AES_128
please input transport key: ********************************
please input OP:
```

LOAD THE SUCI PRIVATE KEY INTO THE UDR

Add the private key under the key identifier the SIMs carry, here `1`. Without `plmn`, the key is stored for every home PLMN the store serves, which on a Site is its `plmnId`; `plmn=<MCC and MNC>` stores it for one PLMN only.

```
expeto_shell>nr>add suci pkId=1
SUCI key ('openssl ec -in <pem file> -text -noout' and then take 'priv:' hex value without colon and new-lines): ************************************************************************
```

VERIFY AND CLOSE

List what each store holds:

```
expeto_shell>nr>read udr-keyset
expeto_shell>nr>read suci
expeto_shell>nr>cd /lte
expeto_shell>lte>read keyset
```

- `read udr-keyset` lists each keyset with **Transport Key** `Yes` and **OP** `No`.
- `read suci` lists each key identifier with its PLMN and the SHA-1 fingerprint of the private key. The witness compares the fingerprint with the one the custodian brought.
- `read keyset` lists the HSS keysets by name: `0` and each HSS Identifier you added.

Type `exit`, then clear the terminal and its scrollback.

To replace a key later, for example when a new SIM batch arrives, use `update keyset`, `update udr-keyset` or `update suci` with the same arguments; `delete keyset name=<n>`, `delete udr-keyset name=<n>` and `delete suci pkId=<n>` remove one. Every Site of the Customer that serves the batch needs the same transport key under the HSS Identifier its own Keyset Mapping uses.

GENERATE A SUCI KEY PAIR

The home network key pair is generated once, on an offline machine, by the key custodians. This guide uses protection scheme Profile B of TS 33.501 (NIST P-256), the scheme the CLI's `add suci` is written for; ask Expeto Support before personalizing SIMs with Profile A.

```
openssl genpkey -algorithm EC -pkeyopt ec_paramgen_curve:P-256 -out hn-key-1.pem
openssl ec -in hn-key-1.pem -pubout -outform DER -conv_form compressed 2>/dev/null \
  | tail -c 33 | xxd -p -c 66
```

The second command prints the public key in its compressed form, 33 bytes: give it to the SIM vendor together with the key identifier (`1` here, 1 to 255) and the protection scheme. The private key stays with the key custodians; the hexadecimal string the CLI asks for is the `priv:` value of `openssl ec -in hn-key-1.pem -noout -text`, without colons and line breaks (the pipeline in Prepare the ceremony produces it).

Step 7: provision the Mobile Assets

Import the SIM batch into xControl with a bulk import of the vendor's `.out` file: select the Customer, one of the Systems, the System Profile and the Keyset you mapped in step 2. Mobile Assets added one at a time on the Mobile Assets page take the encrypted K and OPc as delivered, with the same Keyset.

The Agent provisions each Mobile Asset into the HSS and the UDR. Check one in the CLI:

```
expeto_shell>cd /lte
expeto_shell>lte>read hss <imsi>
expeto_shell>lte>cd /nr
expeto_shell>nr>read udr <imsi>
```

A Mobile Asset that does not appear in either store is reported by the Agent's synchronisation check; in the CLI, `cd /debug/ops` and `read sync-sub-error` list the failures.

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Step 8: connect the radios and attach

Point the eNodeBs at the MME's S1-MME address (SCTP port 36412) and the gNodeBs at the AMF's N2 address (SCTP port 38412). Both send GTP-U to the front user plane's N3 address. In the CLI, `cd /lte` and `read enodeb` list the connected eNodeBs, and `cd /nr` and `read ran` the gNodeBs.

Then attach one device on each radio technology:

1. Attach a device on 4G. In the CLI, `cd /lte` and `read mme -f imsi=<imsi>` show its attach, and `cd /nr` and `read smf -f imsi=<imsi>` its data session with the address from the System's pool. The Mobile Asset shows the session in xControl.
2. Register a device on 5G. `cd /nr`, `read amf <imsi>` shows its registration and `read smf -f imsi=<imsi>` its PDU session.
3. Move the 4G device to 5G coverage. It registers on 5G and keeps its address.

A device rejected at authentication usually points at the keys: a transport key that differs from the SIM vendor's, a Keyset Mapping whose HSS Identifier differs from the keyset name you loaded, or, on 5G only, a missing SUCI key or a key identifier that differs from the SIMs'.

Step 9: hand over

Run the installation and upgrade verification set before the core is handed over, and keep the Site definition and the chart values under version control for the upgrades to come.

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4.3.3 Install the Operator

The xCore operator ships as the `xfabric` Helm chart. Installing it puts the operator, the Expeto Agent and the bundled data-backend operators into one namespace, applies the CustomResourceDefinitions, and installs the netcfg node-configuration operator unless the cluster already runs it. The core itself is created afterwards by applying a Site definition.

Add the Helm repository

```
helm repo add expeto https://repo.expeto.io/repository/ngc \
  --username '<username>' --password '<password>'
helm repo update
helm search repo expeto/xfabric
```

Write the values file

Keep the installation's settings in a `values.yaml` under version control. A minimal file:

```
agent:
  connections:
    siteId: "3051"                  # numeric Site ID from xControl
    serverUri: https://xcontrol.example.com
    brokerUri: https://xcontrol.example.com
```

- `agent.connections.siteId` is the Site the Agent registers as. The install is refused unless it is set to an all-digit value.
- `agent.connections.serverUri` and `brokerUri` point at your xControl installation. Both default to Expeto's hosted service.
- The API token and the registry credentials are secrets; pass them on the command line as shown below, or pre-create the Secrets and reference them (`agent.existingCredsSecret` , `global.imageCredentials.create: false`).

Other values you may need at install time:

Value	Default	Purpose
`mariadb-operator.enabled` , `dragonfly-operator.enabled`	`true`	Bundled data-backend operators. Set `false` for the one the cluster already runs.
`netcfg.enabled`	`true`	Bundled netcfg operator. Set `false` when another Expeto release on the cluster (xRouter, xControl with netcfg, or a second xCore) already runs it; the install fails its singleton check otherwise.
`crds.install`	`true`	Apply the CustomResourceDefinitions before every install and upgrade. With `false` , apply them yourself first.
`metallb.enabled`	`false`	Bundle MetalLB with FRR-K8s on a cluster that has no load balancer.
`bgp.enabled`	`false`	Let the operator emit BGP resources into MetalLB's namespace. Required when the Site has a BGP router with `impl: metallb` , the default; MetalLB must already be installed. A `gobgp` router does not need it.
`metallbNamespace`	detected	Namespace of the MetalLB controller, when detection fails.
`kube-prometheus-stack.enabled`	`false`	Bundle a Prometheus stack on a cluster without one. Keep `false` on OpenShift.
`metrics.serviceMonitor.enabled`	`false`	Create a `ServiceMonitor` for the operator's own metrics when prometheus-operator is present.

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Value	Default	Purpose
`nfMonitoring.enabled`	`false`	Render scrape configurations for the network functions when prometheus-operator is present.
`image.tag`	chart `appVersion`	Pin the operator to a specific build.
`agent.image.tag`	the Agent build the chart pins	The Agent build; the chart of xCore 4.0.6 pins a 3.3.22 Agent. It must not be newer than the xControl it registers with, and an Agent older than 3.3.22-beta8 cannot manage the Site's MME.
`agent.hostAliases`	`[]`	Extra `/etc/hosts` entries (`ip` , `hostnames`) for the Agent pod, for example to reach xControl through an in-cluster ingress under its public name.
`imageOverrides.<key>`	unset	Replace one network-function image with a full `repository:tag` ; the keys are listed in the chart's `files/operator/versions.yaml` . The operator replaces the override's registry host with `global.imageRegistry` , so the image must be in that registry.
`global.imageRegistry`	`docker.expeto.io`	Mirror registry for air-gapped clusters. The uninstall hook's image does not follow it; on a mirror, also set `imageOverrides.helm_kubectl` .
`preDeleteDrain.mode`	`abort`	What `helm uninstall` does while a Site exists: `abort` refuses, `drain` deletes the Sites first (test clusters only), `disabled` installs no check. See Uninstall.
`preDeleteDrain.timeoutSeconds`	`180`	How long `drain` waits for the Sites to be deleted.
`agent.smfRulesConfigMapRef`	unset	Customer-managed SMF routing rules; see Upgrade, change and uninstall.

Run `helm show values expeto/xfabric` for the complete file with its inline comments. Helm checks the values against the chart's schema on every install and upgrade: an unknown key in the chart's own sections (`agent` , `bgp` , `preDeleteDrain` and others), or a value outside an allowed set, stops the command with an error that names it.

Install

```
helm install xcore expeto/xfabric -n xcore --create-namespace -f values.yaml \
  --set global.imageCredentials.username='<username>' \
  --set global.imageCredentials.password='<password>' \
  --set agent.apiToken='<site API token>'
kubectl -n xcore rollout status deployment/xcore-xfabric
```

The chart's install-time guards check for the Multus and cert-manager CustomResourceDefinitions, and for a running netcfg operator when the bundled one is disabled, and stop with a hint when one is missing. On success the namespace holds the operator Deployment, the Agent StatefulSet with its CLI sidecar, the bundled MariaDB and Dragonfly operators, and the netcfg operator with its node agent.

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OpenShift **Pre-created pull Secret**

The operator detects OpenShift; no profile file is needed. The chart never bundles cert-manager, and MetalLB and the Prometheus stack are off by default, which is what OpenShift requires: the platform owns those CustomResourceDefinitions and provides the operators through OperatorHub. The operator's `ServiceMonitor` is enabled automatically when user-workload monitoring serves its CustomResourceDefinition; the command below sets it explicitly. Decide per cluster whether the bundled MariaDB and Dragonfly operators are wanted:

```
helm install xcore expeto/xfabric -n xcore --create-namespace -f values.yaml \
  --set metrics.serviceMonitor.enabled=true \
  --set global.imageCredentials.username='<username>' \
  --set global.imageCredentials.password='<password>' \
  --set agent.apiToken='<site API token>'
```

Install the cert-manager Operator and, for BGP, the MetalLB Operator from OperatorHub first, then add `--set bgp.enabled=true`. A cluster that already runs the MariaDB or Dragonfly operator takes `--set mariadb-operator.enabled=false` or `--set dragonfly-operator.enabled=false` so that two controllers never reconcile the same resources.

When the registry credential is managed outside Helm (a secret store, External Secrets), create the Secret first and tell the chart not to:

```
kubectl create namespace xcore
kubectl -n xcore create secret docker-registry expeto \
  --docker-server=docker.expeto.io \
  --docker-username='<username>' --docker-password='<password>'
helm install xcore expeto/xfabric -n xcore -f values.yaml \
  --set global.imageCredentials.create=false \
  --set agent.apiToken='<site API token>'
```

The same applies to the Agent's token: create a Secret whose `.creds` key holds `SECRET=<token>` and set `agent.existingCredsSecret` to its name.

Run the preflight check

The chart's Helm tests run the operator's preflight inside the cluster and report every dependency, required and optional, with a fix hint for anything missing:

```
helm test xcore -n xcore --filter name=xcore-xfabric-test-preflight --logs
```

Required checks are Multus, cert-manager and the netcfg operator. Optional ones cover whereabouts, MetalLB, FRR-K8s, prometheus-operator and duplicate MariaDB or Dragonfly operators elsewhere on the cluster. The same report is available at any time from the operator pod:

```
kubectl -n xcore exec deployment/xcore-xfabric -- /opt/taiga/app preflight
```

> **Note**
>
> Run the test with the `--filter` shown. A bare `helm test` also runs the bundled Dragonfly operator's connection test, which addresses a Service name that chart does not create and fails regardless of the installation's health.

Next step

Apply the Site definition agreed with Expeto Support during the design phase. Until a Site exists the operator runs idle and the Agent waits for its network functions.

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4.3.4 Define and Apply a Site

A `Site` is the single document that describes an xCore: its network attachments, the mobility and subscriber functions it runs, its user planes with their address pools, and its data backends. This page explains how the document is put together so that you can read the Site agreed for your deployment, gives four complete examples of the deployment shapes, and shows how to apply one. The Site resource reference lists every field.

Who writes the Site

The Site for your deployment is written together with Expeto Support during the design phase, from your network and identity plan, and applied during installation. Today you hold the document: keep it under version control, apply it with `kubectl`, and review every later change with Expeto Support before you apply it.

That is going to change. Expeto intends the Expeto Agent to write the Site from configuration held in xControl, so that the Site, its Systems and its radios are configured in one place and the core follows. As that work lands, fields move from the Site into xControl, the schema changes from one release to the next, and the Site may stop being a document you edit directly: the Agent will own it. A release that changes the schema ships with the steps to migrate an existing Site; see Upgrade, change and uninstall.

The examples on this page illustrate the deployment shapes for the design conversation. They are starting points for that conversation, not templates to adapt on your own.

Anatomy of a Site

```yaml
apiVersion: expeto.io/v1
kind: Site
metadata:
  name: acmecorp-campus          # one Site per namespace
spec:
  network:                       # attachments, service ranges, BGP
  topology:
    controlPlane: {}             # PLMN, AMF, MME, subscriber store, SMF interfaces
    userPlanes: []               # one entry per UPF
  elm: {}                        # service map, tenant identity, Ignite credentials
  ignite: {}                     # session-state cluster
  dragonfly: {}                  # cache
  mariaDb: {}                    # relational store
  nodeConfig: {}                 # optional node tuning
```

NETWORK ATTACHMENTS

`spec.network.attachments` declares one `NetworkAttachmentDefinition` per segment the core touches. The `plugins` list is a CNI plugin chain rendered as-is, so use whatever the nodes support; the common shape is macvlan on a VLAN interface with static addressing, where every pod's address is pinned from the topology:

```yaml
network:
  attachments:
    - name: n3-radio
      plugins:
        - type: macvlan
          master: ens192         # node interface carrying the segment
          mtu: 1500
          ipam:
            type: static
```

Attachment names are how the topology refers to segments; a topology entry that names an undeclared attachment leaves the Site `Ready=False` with reason `TopologyMissingNADs`.

Add `serviceRanges` when an endpoint must be a load-balanced address rather than a pod on a segment (radios that cannot be adjacent to a Multus attachment, cloud networks), and `bgp` when pools or service addresses are advertised to a peer router. Both are described in Architecture; a BGP router with `impl: metallb`, the default, needs the chart installed with `bgp.enabled=true`.

CONTROL PLANE

`spec.topology.controlPlane` declares the identity of the network and the functions that serve it:

- `plmnId`, the PLMN as MCC and MNC in one string. It is required whenever a mobility function or the subscriber store is declared, and the MNC length is part of the identity. A Site with an MME needs a 3-digit MNC.

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- `subscriberManagement`, the subscriber store: mode `5G` deploys the UDR, UDM and AUSF, `4G` the HSS, `Dual` all four.
- `amf`, the AMF with its N2 endpoint and tracking areas, and `mme`, the MME with its S1 endpoint, tracking areas and timers. Each needs the subscriber store it authenticates through: `5G` or `Dual` for the AMF, `4G` or `Dual` for the MME.
- `dataNetworks`, the DNNs or APNs the core serves, and `slices`, the S-NSSAIs the AMF advertises.
- `n16`, the SMF's GTP-C endpoint towards an upstream control plane, such as the xRouter of a public core.

Declaring both `amf` and `mme` gives a combined core. The two identities must not map onto each other. There is no N26 interface between them; see Architecture for how a combined core interworks.

USER PLANES

Each entry in `spec.topology.userPlanes` is one UPF, and its `mode` and interfaces define its role; see Architecture. An anchor, a user plane with `n6`, carries the `systemId` that ties it to a System in xControl and holds the UE address pools of that System. A front, without `n6`, serves every System and carries no `systemId`. 4G radios always connect to a front (the SGW-U), which forwards over N9 to the anchors (the PGW-Us).

Each pool under `ueIpPools` is a CIDR and, optionally, how it reaches the outside:

```
ueIpPools:
  - cidr: 10.100.0.0/16            # source NAT on the UPF (default)
  - cidr: 10.101.0.0/16
    reachability:
      static: {}                   # the network team routes the pool to the N6 address
  - cidr: 10.102.0.0/16
    reachability:
      bgp:
        peering: southbound        # advertised over a declared peering
```

All pools on one user plane must use the same mode.

SERVICE MAP AND IGNITE CREDENTIALS

`spec.elm` is required. `operatorIdentifier` names the tenant and service the network functions report under; pick two stable identifiers. `services` is the map the network functions use to locate each other; the entries are the Services the operator creates in the namespace, so copy the block from the examples unchanged. Sites with an AMF carry four additional entries (the identifier allocator, the SMF, the AUSF and the UDM) that the AMF resolves by network-function type. `dbInfo` holds the Ignite credentials; reference the password from a Secret rather than writing it into the Site.

DATA BACKENDS AND NODE TUNING

`ignite`, `mariaDb` and `dragonfly` size the data backends. The defaults suit a production cluster: three Ignite replicas with 11 GiB of memory and a 25 GiB volume each, and a standalone MariaDB. `mariaDb.replicas: 3` runs a Galera cluster and is fixed at creation; see MariaDB topology. `nodeConfig` applies node tuning through the operator; leave it out when the netcfg operator the chart installs, or the platform team, prepares the nodes.

CHANGE CONTROL

`spec.maintenanceMode` (default `true`) allows every edit. Set it to `false` to have the admission webhook reject edits that would restart pods until a change window; see Change a Site.

Examples

Each example is a complete Site for one deployment shape, with placeholder addressing (`10.0.x.0/24` segments, `10.100.0.0/16` and `10.101.0.0/16` pools, `ens192` as the parent interface, PLMN `001001`). Pick transit segments and pools that do not overlap the cluster's pod and Service networks; the operator refuses a Site whose ranges do.

PUBLIC CORE

Terminates the tunnels an xRouter forwards over IPX and breaks subscriber traffic out to two data networks. The xRouter's user plane sends GTP-U to the SGW-U's N3 address and its control plane reaches the SMF over the `signalling` attachment. No radio-facing functions. Download.

```
# Public xCore: terminates the tunnels an xRouter forwards over IPX and
# breaks subscriber traffic out to two data networks. No radio-facing
# functions; the SMF acts as SGW-C and PGW-C.
# Illustrative deployment shape with placeholder addressing. The Site for a real
# deployment is agreed with Expeto Support during design; do not adapt this on your own.
apiVersion: expeto.io/v1
kind: Site
metadata:
```


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```
  name: acmecorp-public
spec:
  network:
    attachments:
      - name: n3-xrouter          # GTP-U from the xRouter user plane
        plugins:
          - type: macvlan
            master: ens192
            mtu: 1500
            ipam:
              type: static
      - name: signalling          # GTP-C from the xRouter control plane
        plugins:
          - type: macvlan
            master: ens192
            mtu: 1500
            ipam:
              type: static
      - name: n9-transit          # SGW-U to PGW-U
        plugins:
          - type: macvlan
            master: ens192
            mtu: 1500
            ipam:
              type: static
      - name: n6-internet
        plugins:
          - type: macvlan
            master: ens192
            mtu: 1500
            ipam:
              type: static
      - name: n6-corporate
        plugins:
          - type: macvlan
            master: ens192
            mtu: 1500
            ipam:
              type: static
  topology:
    ipProtocolMode: ipv4
    customerId: 2851              # the Customer's numeric ID in xControl
    controlPlane:
      n16:
        - name: signalling
          transitIpRange: 10.0.16.10/24
          gatewayIp: 10.0.16.1
    userPlanes:
      # SGW-U: receives GTP-U from the xRouter and forwards to the anchors.
      # It serves every System, so it has no systemId.
      - name: sgw-u
        mode: "4G"
        numberOfSessions: 50000
        n3:
          - name: n3-xrouter
            transitIpRange: 10.0.3.10/24
            gatewayIp: 10.0.3.1
        n9:
          - name: n9-transit
            transitIpRange: 10.0.9.10/24
            peerUpfs: [pgw-u-internet, pgw-u-corporate]
      # PGW-U for the "internet" System: source NAT on the UPF.
      - name: pgw-u-internet
        mode: "4G"
        systemId: 2               # System ID in xControl
        numberOfSessions: 50000
        n9:
          - name: n9-transit
            transitIpRange: 10.0.9.20/24
            peerUpfs: [sgw-u]
        n6:
          - name: n6-internet
            dataNetworkName: internet
            transitIpRange: 10.0.6.10/24
            gatewayIp: 10.0.6.1
            ueIpPools:
              - cidr: 10.100.0.0/16
            dnsServers: [10.0.6.53]
      # PGW-U for the "corporate" System: the corporate router carries a
      # static route for the pool; the Site status lists it.
      - name: pgw-u-corporate
        mode: "4G"
        systemId: 3
        numberOfSessions: 50000
        n9:
          - name: n9-transit
            transitIpRange: 10.0.9.30/24
            peerUpfs: [sgw-u]
        n6:
          - name: n6-corporate
            dataNetworkName: corporate
            transitIpRange: 10.0.7.10/24
            gatewayIp: 10.0.7.1
            ueIpPools:
```


Expeto Inc @ 2026

```
          - cidr: 10.101.0.0/16
            reachability:
              static: {}
        dnsServers: [10.0.7.53]
  elm:
    operatorIdentifier:
      serviceId: slice1
      tenantId: acmecorp
    services:
      - componentName: NFCM
        value:
          - serviceName: MONITORING
            serviceDomain: nfcm-monitoring:8080
          - serviceName: STATISTICS
            serviceDomain: nfcm-statistics:8080
      - componentName: TIMER
        value:
          - serviceName: TIMER
            serviceDomain: udsf-timer:8080
      - componentName: UDSF
        value:
          - serviceName: UDSF
            serviceDomain: udsf:8080
      - componentName: UPF
        value:
          - serviceName: UPFIDALLOCATOR
            serviceDomain: udsf-idallocator:8080
    dbInfo:
      dbType: ignite
      hostname: ignite-proxy
      username: ignite
      passwordSecret:
        name: ignite-credentials
        key: password
  ignite:
    enabled: true
    replicas: 3
  dragonfly:
    enabled: true
  mariaDb:
    enabled: true
    replicas: 3
```

PRIVATE 5G CORE

An AMF, the 5G subscriber store and one session-anchor UPF serving a campus of gNodeBs. Download.

```
# Private 5G core: AMF, 5G subscriber store and one session-anchor UPF
# serving a campus of gNodeBs.
# Illustrative deployment shape with placeholder addressing. The Site for a real
# deployment is agreed with Expeto Support during design; do not adapt this on your own.
apiVersion: expeto.io/v1
kind: Site
metadata:
  name: acmecorp-campus
spec:
  network:
    attachments:
      - name: n2-radio              # gNodeB control plane (NGAP over SCTP)
        plugins:
          - type: macvlan
            master: ens192
            mtu: 1500
            ipam:
              type: static
      - name: n3-radio              # gNodeB user plane (GTP-U)
        plugins:
          - type: macvlan
            master: ens192
            mtu: 1500
            ipam:
              type: static
      - name: n6-enterprise         # data network
        plugins:
          - type: macvlan
            master: ens192
            mtu: 1500
            ipam:
              type: static
  topology:
    ipProtocolMode: ipv4
    customerId: 2851
    controlPlane:
      plmnId: "001001"              # MCC 001, MNC 001; must match SIMs and radios
      dataNetworks: [enterprise]
      subscriberManagement:
        enabled: true
        mode: "5G"                  # UDR, UDM and AUSF on the Site
      amf:
        n2:
          - name: n2-radio
            transitIpRange: 10.0.2.10/24
```


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```
        gatewayIp: 10.0.2.1
      trackingAreas: [1]
  userPlanes:
    # One session-anchor UPF: N3 from the radios, N6 to the enterprise.
    - name: psa-upf
      mode: "5G"
      systemId: 2               # System ID in xControl
      numberOfSessions: 10000
      n3:
        - name: n3-radio
          transitIpRange: 10.0.3.10/24
      n6:
        - name: n6-enterprise
          dataNetworkName: enterprise
          transitIpRange: 10.0.6.10/24
          gatewayIp: 10.0.6.1
          ueIpPools:
            - cidr: 10.100.0.0/16
          dnsServers: [10.0.6.53]
elm:
  operatorIdentifier:
    serviceId: slice1
    tenantId: acmecorp
  services:
    - componentName: NFCM
      value:
        - serviceName: MONITORING
          serviceDomain: nfcm-monitoring:8080
        - serviceName: STATISTICS
          serviceDomain: nfcm-statistics:8080
    - componentName: TIMER
      value:
        - serviceName: TIMER
          serviceDomain: udsf-timer:8080
    - componentName: UDSF
      value:
        - serviceName: UDSF
          serviceDomain: udsf:8080
    - componentName: UPF
      value:
        - serviceName: UPFIDALLOCATOR
          serviceDomain: udsf-idallocator:8080
    # Peers the AMF resolves by network-function type.
    - componentName: IDALLOCATOR
      value:
        - serviceName: IDALLOCATOR
          serviceDomain: udsf-idallocator:8080
    - componentName: SMF
      value:
        - serviceName: PDUSESSION
          serviceDomain: smf:8080
    - componentName: AUSF
      value:
        - serviceName: UEAUTHENTICATION
          serviceDomain: sdm-ausf:8080
    - componentName: UDM
      value:
        - serviceName: SDM
          serviceDomain: sdm-udm:8080
        - serviceName: UECM
          serviceDomain: sdm-udm:8080
  dbInfo:
    dbType: ignite
    hostname: ignite-proxy
    username: ignite
    passwordSecret:
      name: ignite-credentials
      key: password
ignite:
  enabled: true
  replicas: 3
dragonfly:
  enabled: true
mariaDb:
  enabled: true
  replicas: 3
```

PRIVATE 4G CORE

An MME with its S1 transport controller, the HSS, and an SGW-U in front of a PGW-U, serving eNodeBs. Download.

```
# Private 4G core: MME with its S1 transport controller, HSS, and an
# SGW-U / PGW-U pair serving a site of eNodeBs.
# Illustrative deployment shape with placeholder addressing. The Site for a real
# deployment is agreed with Expeto Support during design; do not adapt this on your own.
apiVersion: expeto.io/v1
kind: Site
metadata:
  name: acmecorp-plant
spec:
  network:
    attachments:
```


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```
    - name: s1-radio              # eNodeB control plane (S1AP over SCTP)
      plugins:
        - type: macvlan
          master: ens192
          mtu: 1500
          ipam:
            type: static
    - name: s1u-radio             # eNodeB user plane (GTP-U)
      plugins:
        - type: macvlan
          master: ens192
          mtu: 1500
          ipam:
            type: static
    - name: s5u-transit           # SGW-U to PGW-U
      plugins:
        - type: macvlan
          master: ens192
          mtu: 1500
          ipam:
            type: static
    - name: sgi-enterprise        # data network
      plugins:
        - type: macvlan
          master: ens192
          mtu: 1500
          ipam:
            type: static
topology:
  ipProtocolMode: ipv4
  customerId: 2851
  controlPlane:
    plmnId: "001001"
    dataNetworks: [enterprise]     # the APN; also the MME's P-GW association
    subscriberManagement:
      enabled: true
      mode: "4G"                   # HSS on the Site
    mme:
      s1:
        - name: s1-radio
          transitIpRange: 10.0.2.11/24
          gatewayIp: 10.0.2.1
      identity:
        mmegi: 2
        mmec: 1
      trackingAreas: [1]
      nasSecurity:
        integrity: [AES, SNOW3G]   # EIA2 preferred, EIA1 fallback
  userPlanes:
    # SGW-U: S1-U from the eNodeBs, S5-U to the PGW-U. It serves every
    # System, so it has no systemId.
    - name: sgw-u
      mode: "4G"
      numberOfSessions: 10000
      n3:
        - name: s1u-radio
          transitIpRange: 10.0.3.20/24
      n9:
        - name: s5u-transit
          transitIpRange: 10.0.9.10/24
          peerUpfs: [pgw-u]
    # PGW-U: anchors the UE addresses and egresses on SGi.
    - name: pgw-u
      mode: "4G"
      systemId: 3                  # System ID in xControl
      numberOfSessions: 10000
      n9:
        - name: s5u-transit
          transitIpRange: 10.0.9.20/24
          peerUpfs: [sgw-u]
      n6:
        - name: sgi-enterprise
          dataNetworkName: enterprise
          transitIpRange: 10.0.6.20/24
          gatewayIp: 10.0.6.1
          ueIpPools:
            - cidr: 10.101.0.0/16
          dnsServers: [10.0.6.53]
elm:
  operatorIdentifier:
    serviceId: slice1
    tenantId: acmecorp
  services:
    - componentName: NFCM
      value:
        - serviceName: MONITORING
          serviceDomain: nfcm-monitoring:8080
        - serviceName: STATISTICS
          serviceDomain: nfcm-statistics:8080
    - componentName: TIMER
      value:
        - serviceName: TIMER
          serviceDomain: udsf-timer:8080
    - componentName: UDSF
```


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```
      value:
        - serviceName: UDSF
          serviceDomain: udsf:8080
      - componentName: UPF
        value:
          - serviceName: UPFIDALLOCATOR
            serviceDomain: udsf-idallocator:8080
    dbInfo:
      dbType: ignite
      hostname: ignite-proxy
      username: ignite
      passwordSecret:
        name: ignite-credentials
        key: password
  ignite:
    enabled: true
    replicas: 3
  dragonfly:
    enabled: true
  mariaDb:
    enabled: true
    replicas: 3
```

COMBINED 4G AND 5G CORE

The AMF and the MME side by side, the subscriber store in dual mode, one front user plane for both radio types and one anchor per System that serves both. Because every anchor is in mode `Dual`, a UE that moves between 4G and 5G keeps its address. This is the shape the combined core installation walks through. Download.

```
# Combined 4G and 5G private core: the AMF and the MME side by side, the
# subscriber store in dual mode, one front user plane for both radio types
# and one anchor per System that serves both. Every anchor is mode Dual, so
# the core interworks without N26: a UE that changes radio keeps its
# address. There is no N26 interface between the AMF and the MME.
# Illustrative deployment shape with placeholder addressing. The Site for a real
# deployment is agreed with Expeto Support during design; do not adapt this on your own.
apiVersion: expeto.io/v1
kind: Site
metadata:
  name: acmecorp-hq
spec:
  network:
    attachments:
      - name: n2-radio            # gNodeB control plane (NGAP over SCTP)
        plugins:
          - type: macvlan
            master: ens192
            mtu: 1500
            ipam:
              type: static
      - name: s1-radio            # eNodeB control plane (S1AP over SCTP)
        plugins:
          - type: macvlan
            master: ens192
            mtu: 1500
            ipam:
              type: static
      - name: n3-radio            # GTP-U from both radio types
        plugins:
          - type: macvlan
            master: ens192
            mtu: 1500
            ipam:
              type: static
      - name: n9-transit          # front to anchors
        plugins:
          - type: macvlan
            master: ens192
            mtu: 1500
            ipam:
              type: static
      - name: n6-office           # data network of the "office" System
        plugins:
          - type: macvlan
            master: ens192
            mtu: 1500
            ipam:
              type: static
      - name: n6-plant            # data network of the "plant" System
        plugins:
          - type: macvlan
            master: ens192
            mtu: 1500
            ipam:
              type: static
  topology:
    ipProtocolMode: ipv4
    customerId: 2851              # the Customer's numeric ID in xControl
    controlPlane:
      plmnId: "001001"            # 3-digit MNC: the MME needs one for 4G attach
      dataNetworks: [enterprise]
```


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```
    subscriberManagement:
      enabled: true
      mode: "Dual"              # UDR, UDM, AUSF and HSS
    amf:
      n2:
        - name: n2-radio
          transitIpRange: 10.0.2.10/24
          gatewayIp: 10.0.2.1
      identity:
        region: 1
        set: 1
        pointer: 1
      trackingAreas: [1]
    mme:
      s1:
        - name: s1-radio
          transitIpRange: 10.0.4.10/24
          gatewayIp: 10.0.4.1
      identity:
        mmegi: 2
        mmec: 1
      trackingAreas: [1]
      nasSecurity:
        integrity: [AES, SNOW3G]    # EIA2 preferred, EIA1 fallback
  userPlanes:
    # Front for both radio types: the SGW-U for 4G and the intermediate
    # UPF for 5G. It serves every System, so it has no systemId.
    - name: upf-front
      mode: "Dual"
      numberOfSessions: 20000
      n3:
        - name: n3-radio
          transitIpRange: 10.0.3.10/24
      n9:
        - name: n9-transit
          transitIpRange: 10.0.9.10/24
          peerUpfs: [upf-office, upf-plant]
    # Anchor of the "office" System: PGW-U for 4G and session anchor for
    # 5G, one address pool for both.
    - name: upf-office
      mode: "Dual"
      systemId: 2               # System ID in xControl
      numberOfSessions: 10000
      n9:
        - name: n9-transit
          transitIpRange: 10.0.9.20/24
          peerUpfs: [upf-front]
      n6:
        - name: n6-office
          dataNetworkName: enterprise
          transitIpRange: 10.0.6.10/24
          gatewayIp: 10.0.6.1
          ueIpPools:
            - cidr: 10.100.0.0/16
          dnsServers: [10.0.6.53]
    # Anchor of the "plant" System. The plant network routes its pool to
    # the N6 address; the Site status lists the route it needs.
    - name: upf-plant
      mode: "Dual"
      systemId: 3
      numberOfSessions: 10000
      n9:
        - name: n9-transit
          transitIpRange: 10.0.9.30/24
          peerUpfs: [upf-front]
      n6:
        - name: n6-plant
          dataNetworkName: enterprise
          transitIpRange: 10.0.7.10/24
          gatewayIp: 10.0.7.1
          ueIpPools:
            - cidr: 10.101.0.0/16
              reachability:
                static: {}
          dnsServers: [10.0.7.53]
elm:
  operatorIdentifier:
    serviceId: slice1
    tenantId: acmecorp
  services:
    - componentName: NFCM
      value:
        - serviceName: MONITORING
          serviceDomain: nfcm-monitoring:8080
        - serviceName: STATISTICS
          serviceDomain: nfcm-statistics:8080
    - componentName: TIMER
      value:
        - serviceName: TIMER
          serviceDomain: udsf-timer:8080
    - componentName: UDSF
      value:
        - serviceName: UDSF
          serviceDomain: udsf:8080
```


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```
    - componentName: UPF
      value:
        - serviceName: UPFIDALLOCATOR
          serviceDomain: udsf-idallocator:8080
    # Peers the AMF resolves by network-function type.
    - componentName: IDALLOCATOR
      value:
        - serviceName: IDALLOCATOR
          serviceDomain: udsf-idallocator:8080
    - componentName: SMF
      value:
        - serviceName: PDUSESSION
          serviceDomain: smf:8080
    - componentName: AUSF
      value:
        - serviceName: UEAUTHENTICATION
          serviceDomain: sdm-ausf:8080
    - componentName: UDM
      value:
        - serviceName: SDM
          serviceDomain: sdm-udm:8080
        - serviceName: UECM
          serviceDomain: sdm-udm:8080
  dbInfo:
    dbType: ignite
    hostname: ignite-proxy
    username: ignite
    passwordSecret:
      name: ignite-credentials
      key: password
ignite:
  enabled: true
  replicas: 3
dragonfly:
  enabled: true
mariaDb:
  enabled: true
  replicas: 3
```

Apply the Site

Create the Ignite credential the Site references, then apply the Site agreed with Expeto Support:

```
kubectl -n xcore create secret generic ignite-credentials --from-literal=password='<password>'
kubectl -n xcore apply -f site.yaml
kubectl -n xcore get sites.expeto.io -w
```

The API server validates the document against the CustomResourceDefinition schema and rejects malformed addresses, unknown enum values and missing required fields immediately. The operator then validates the cross-references (attachment names, peer user planes, service ranges, identities) and reports any problem as a condition on the Site within seconds. Bring-up of a healthy Site takes a few minutes: the Ignite cluster initialises first, then the databases, then the network functions, and `Ready` turns `True` when the Agent, every user plane and every control-plane function report ready.

```
kubectl -n xcore wait --for=condition=Ready --timeout=15m sites.expeto.io/acmecorp-campus
```

Continue with Verify the installation.

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4.3.5 Site Resource Reference

The `Site` custom resource (`sites.expeto.io` , API version `expeto.io/v1`) is the deployment contract of an xCore: one document that declares every network attachment, mobility and subscriber function, user plane and data backend of the core. The operator reconciles the core from it and reports the outcome in its `status` . This page lists the fields of the Site in xCore 4.0.6. For how the sections fit together, and for complete examples, see Define and apply a Site.

> **The Site resource is changing**
>
> Today you write the Site yourself, from the design agreed with Expeto Support, and change it with `kubectl` . Expeto intends the Expeto Agent to write the Site instead, from the configuration held in xControl (the Site, its Systems, radios and subscriber settings). As that work lands, fields move from this resource into xControl, the schema changes between releases, and editing the Site directly may no longer be possible: the Agent will own it, and changes will be made in xControl. Keep your Site under version control, review every change with Expeto Support, and treat this page as a description of the current release rather than a stable interface.

Conventions

- **Required** fields are marked in the tables. Everything else is optional and takes the default shown, or is absent when no default is shown.
- **On change** says what happens when the field is edited on a running Site. *Live* changes are applied by the running pods. *Restart* changes roll the affected pods and are rejected while `spec.maintenanceMode` is `false` . *Fixed* fields cannot be changed once the object they shape exists. See Change a Site.
- The API server checks types, enumerations, patterns and ranges when the Site is applied. The operator then checks cross-references (attachment names, peer user planes, service ranges, identities) and reports a violation as `Ready=False` with a reason; see Troubleshooting.
- Fields the operator reads but this page does not list are reserved for Expeto Support or for test tooling. Leave them unset.

Top level

Field	Type	Default	On change	Description
`spec.network`	object		see below	Network attachments, service address ranges and BGP.
`spec.topology`	object, **required**		see below	The control plane and the user planes.
`spec.elm`	object, **required**		Restart	Service map, tenant identity and Ignite credentials of the network functions.
`spec.ignite`	object		see below	The Apache Ignite cluster that holds session state.
`spec.dragonfly`	object		Restart	The Dragonfly cache for identifier allocation and timers.
`spec.mariaDb`	object		see below	The MariaDB database of the SMF and the subscriber store.
`spec.storage`	object	`size: 1Gi`	Fixed	The Site's data volume: `size` and `className` .

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Field	Type	Default	On change	Description
`spec.nodeConfig`	object		Restart	Node tuning applied to the worker nodes.
`spec.maintenanceMode`	boolean	`true`	Live	`false` makes the admission webhook reject every Restart edit until it is set back to `true`.
`spec.namePrefix`	string	`""`	Fixed	Prefix for every resource the operator creates. Set it at installation or not at all.
`spec.pullPolicy`	`Always`, `IfNotPresent`, `Never`	`Always`	Live	Image pull policy of every network-function pod. Use `IfNotPresent` with release images.
`spec.nfcm.enabled`	boolean	`true`	Restart	Deploys NFCM, the monitoring and statistics function.
`spec.udsf.enabled`	boolean	`true`	Restart	Deploys the UDSF with its identifier allocator and timer services.
`spec.description`	string		Live	Free text.

Network

`spec.network.attachments[]`

Each entry becomes one `NetworkAttachmentDefinition` in the Site's namespace. Topology interfaces refer to attachments by name.

Field	Type	Default	Description
`name`	string, **required**		Name of the attachment and of the `NetworkAttachmentDefinition`.
`plugins`	list of CNI plugin objects, **required**		The CNI plugin chain, rendered verbatim: macvlan or ipvlan on a VLAN interface, SR-IOV, a route-override chain, with static, host-local or whereabouts address management. Use `ipam.type: static` when the topology pins every address.
`cniVersion`	string	`0.3.1`	CNI specification version stamped into the configuration.

A change to an attachment restarts the pods that use it.

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spec.network.serviceRanges[]

Address ranges MetalLB allocates to LoadBalancer Services, for endpoints realized as an `ingress` address rather than a pod on an attachment. Changes are live.

Field	Type	Default	Description
`name`	string, **required**		Unique name; `ingress` entries refer to it.
`addresses`	list, **required**		CIDRs (`192.0.2.0/28`) or inclusive ranges (`192.0.2.50-192.0.2.62`).
`advertise[]`	list of 1 to 8, **required**		How the range is announced. Each entry is either BGP (`peering` , a peering of the `metallb` router; optional `aggregationLength` , `aggregationLengthV6` , `localPref` , `communities` , `prefixes`) or layer 2 (`l2: {}` , optionally limited by `l2.interfaces` and `l2.nodeSelectors`).
`autoAssign`	boolean	`true`	Lets MetalLB assign addresses from the range automatically.
`avoidBuggyIps`	boolean	`false`	Excludes `.0` and `.255` addresses.

spec.network.bgp

BGP routers with named peerings. Each router runs in one of two places, set by its `impl` :

- `metallb` , the default: FRR-K8s on the nodes, configured through MetalLB. It needs MetalLB with FRR-K8s and the chart's `bgp.enabled=true` , and announces service ranges and UE pools. A Site has at most one `metallb` router.
- `gobgp` : a GoBGP sidecar in the dataplane pod of each user plane whose UE pools name one of the router's peerings. It needs neither MetalLB nor `bgp.enabled` , and announces those UE pools from the user plane itself. Agree its use with Expeto Support; BGP lists its constraints.

Changes are live, with one exception: giving a user plane its first `gobgp` pool, or removing its last, restarts that user plane's dataplane pod, even while `spec.maintenanceMode` is `false` .

Field	Type	Default	Description
`routers[]`	list, **required**		The Site's BGP routers: at most one with `impl: metallb` , and any number with `impl: gobgp` .
`routers[].name`	string, **required**		Router name.
`routers[].asn`	integer, **required**		Local AS number.
`routers[].impl`	`metallb` or `gobgp`	`metallb`	Where the router runs; see above.
`routers[].routerId`	string	FRR's choice (`metallb`); the user plane's N6 transit address (`gobgp`)	BGP router identifier.

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Field	Type	Default	Description
routers[].peerings[]	list, **required**		Named groups of BGP sessions. Peering names are unique across the Site; service ranges and UE pools refer to them.
routers[].peerings[].attachment	string		The attachment whose segment the sessions ride. For a gobgp router, the first peering's attachment must be the name of an n6 entry with a transitIpRange on every user plane that uses the router.
routers[].peerings[].peers[]	list, **required**		name, address (IPv4 or IPv6), peerAsn (required); port (179), holdTime (45s), keepaliveTime (15s), gracefulRestart (true), ebgpMultiHop, sourceAddress (required when the session rides an attachment), receiveMode (all or filtered with receivePrefixes), and bfd: {} to enable Bidirectional Forwarding Detection. A gobgp router uses only address (IPv4), peerAsn, holdTime, keepaliveTime and gracefulRestart, and ignores the others.
nodeSelector	label selector	all nodes	Nodes that run the BGP sessions.
rawConfig	string		FRR configuration appended verbatim, for options the Site does not model. Agree it with Expeto Support.

spec.network.podCidr

The cluster's pod network CIDR, as a string. Needed only when a user plane source-NATs GTP-U out of its N3 interface, so that GTP-U to peers inside the cluster is not diverted. Live.

Topology

Field	Type	Default	On change	Description
spec.topology.controlPlane	object		see below	The PLMN, the mobility and subscriber functions and the SMF's interfaces.
spec.topology.userPlanes[]	list of up to 32		see below	One entry per UPF.
spec.topology.customerId	integer ≥ 1	1	Restart	The numeric ID of the Customer in xControl that owns the Site.
spec.topology.ipProtocolMode	string		Restart	IP stack of the user planes. Set ipv4.

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spec.topology.controlPlane

Field	Type	Default	On change	Description
plmnId	5 or 6 digits		Restart	MCC followed by a 2- or 3-digit MNC (001001 , 00101). It is the PLMN the AMF and MME serve and the home PLMN the HSS, UDM and UDR key subscribers under. Required when amf , mme or subscriberManagement.enabled is set. A Site with mme needs a 3-digit MNC.
dataNetworks	list of up to 16 names	[internet]	Restart	DNNs (5G) or APNs (4G) the core serves. The AMF takes the first as its default; the MME gets a P-GW association for each.
slices[]	list of up to 8	AMF built-in: SST 1, SD 000001	Restart	S-NSSAIs the AMF advertises on every TAC: sst (0 to 255, required) and sd (6 hex digits). The listed slices replace the built-in one; list {sst: 1} as well when Mobile Assets are provisioned without an SD.
subscriberManagement	object		Restart	The subscriber store; see below.
amf	object		Restart	The AMF; see below.
mme	object		Restart, except timers	The MME; see below.
n16[]	list of up to 8 endpoints	the SMF's Service address	Restart	GTP-C endpoints of the SMF towards an upstream or roaming control plane, such as the xRouter of a public core. See Endpoints; canonicalIp selects the advertised address when an entry has several.
usageReporting	object		Restart	intervalMinutes (1 to 1440, default 59): how long after scheduling a session's usage query the SMF sends it. thresholdMegabytes (default 10): the volume after which a UPF reports usage on its own; applies to sessions set up after the change.

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Field	Type	Default	On change	Description
overrideApn	string		Restart	The SMF replaces the APN or DNN the UE requests with this one.

amf and amfN11Host are mutually exclusive. amfN11Host names an AMF the Site does not host and exists for test setups only; connecting an external AMF is not a supported integration.

subscriberManagement

Field	Type	Default	Description
enabled	boolean, **required**		Deploys the subscriber store.
mode	5G, 4G, Dual	5G	5G deploys the UDR, UDM and AUSF; 4G the HSS; Dual all four, with the HSS and UDM cancelling each other's registrations when a UE changes radio technology. amf needs 5G or Dual; mme needs 4G or Dual.
globalTitles	list of up to 16 digit strings	a placeholder	SS7 Global Title prefixes of the HSS home PLMN; the first is the HLR Global Title.

The Agent provisions Mobile Assets into whichever stores the mode deploys. The keys those stores need, transport keys and the SUCI private key, are loaded once per Site; see Load the subscriber-store keys.

amf

Field	Type	Default	Description
n2[]	exactly one endpoint, **required**		The gNodeB-facing NGAP endpoint. See Endpoints.
trackingAreas	list of up to 64 integers, 1 to 16777215	[1]	TACs the AMF serves, rendered as 24-bit TACs.
nasSecurity	integrity, ciphering: lists of up to 4 of NULL, SNOW3G, AES, ZUC	integrity NIA0, NIA1; ciphering NEA0, NEA1	NAS algorithm preference, most preferred first. AES renders as NIA2/NEA2, SNOW3G as NIA1/NEA1, ZUC as NIA3/NEA3, NULL as NIA0/NEA0. The defaults put the null algorithms first; set both lists on a production Site, AES first.
identity	region (0 to 255), set (0 to 1023), pointer (0 to 63)	1, 1, 1	The AMF Identifier within the PLMN.

mme

Field	Type	Default	Description
s1[]	exactly one endpoint, **required**		The eNodeB-facing S1AP endpoint, served by the S1 transport controller (STC). See Endpoints.

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Field	Type	Default	Description
trackingAreas	list of up to 64 integers, 1 to 65535	[1]	TACs the MME serves, rendered as 16-bit TACs.
nasSecurity	as for amf	integrity EIA2, EIA1; ciphering EEA0 only	NAS algorithm preference, rendered as EIA and EEA names. With ciphering unset the MME keeps its built-in default, null ciphering only; set it on a production Site, AES first.
identity	mmegi (0 to 65535), mmec (0 to 255)	2, 1	MME group ID and MME code. In a combined core it must not map (TS 23.003) onto the AMF identity.
timers	object	the MME's defaults	NAS and mobility timers in milliseconds; see below. Live: applied without a restart.
sgwList[] , pgwList[]	up to 16 of name , address	the Site's SMF	S-GW and P-GW nodes the MME selects from.
realm	domain name	epc.mnc<MNC>.mcc<MCC>.3gppnetwork.org	Diameter origin realm.
instanceId	integer ≥ 1	1	Key prefix of the MME in its session store.

mme.timers fields, with their ranges and the defaults used when unset:

Field	Range	Default	Timer
t3402Ms	6000 to 1440000	720000	Attach and tracking area update retry back-off given to the UE.
t3412Ms	6000 to 6960000	3240000	Periodic tracking area update.
t3413Ms	1000 to 60000	3000	Paging retransmission.
t3422Ms	1000 to 60000	6000	DETACH REQUEST retransmission.
t3423Ms	6000 to 6960000	3240000	Deactivate ISR timer given to the UE.
t3442Ms	1000 to 60000	6000	SERVICE REJECT back-off given to the UE.
t3450Ms	1000 to 60000	6000	ATTACH ACCEPT, TRACKING AREA UPDATE ACCEPT and GUTI REALLOCATION retransmission.
t3460Ms	1000 to 60000	6000	AUTHENTICATION REQUEST and SECURITY MODE COMMAND retransmission.
t3470Ms	1000 to 60000	6000	IDENTITY REQUEST retransmission.

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Field	Range	Default	Timer
t3485Ms	1000 to 60000	8000	ACTIVATE EPS BEARER CONTEXT REQUEST retransmission.
t3486Ms	1000 to 60000	8000	MODIFY EPS BEARER CONTEXT REQUEST retransmission.
t3489Ms	1000 to 60000	4000	ESM INFORMATION REQUEST retransmission.
t3495Ms	1000 to 60000	8000	DEACTIVATE EPS BEARER CONTEXT REQUEST retransmission.
mobileReachableMs	6000 to 7200000	3480000, or T3412 plus 4 minutes when only t3412Ms is set	Mobile reachable timer. Must be longer than the effective T3412.
implicitDetachMs	6000 to 3600000	3480000	Implicit detach timer.

A timer removed from the Site reverts to its default.

ENDPOINTS

amf.n2[], mme.s1[], controlPlane.n16[] and userPlanes[].n3[] share one model. Each entry is realized in exactly one of two ways:

- **On an attachment:** name names an entry of spec.network.attachments and transitIpRange pins the pod's address as a host address with prefix length (10.0.2.10/24). gatewayIp optionally names the next hop on that segment.
- **As an ingress address:** ingress[] holds a LoadBalancer address, either range (a serviceRanges name) with ip pinned inside it, or, on amf.n2 and mme.s1 only, a nodePort served on every node. The 3GPP ports (38412 for NGAP, 36412 for S1AP) are outside the API server's default node-port range, so a node port needs that range widened. An N3 ingress address needs replicas of at most 1 on its user plane.

amf.n2 and mme.s1 take one entry, and that entry at most one ingress address.

spec.topology.userPlanes[]

Each entry is one UPF: a controller and one or more dataplane pods.

Field	Type	Default	On change	Description
name	string of up to 50 characters, **required**		Fixed	Unique within the Site; names every resource of the user plane.
mode	4G, 5G, Dual, **required**		Restart	The radio generation it serves. With the interfaces it declares, the mode decides its role; see the table below.
systemId	integer ≥ 1		Restart	The numeric ID of the xControl System whose Mobile Assets the user plane anchors. Required on every anchor (a user plane with n6), unique within the Site, and refused on a front (a user plane without n6).

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Field	Type	Default	On change	Description
`numberOfSessions`	integer	3000	Fixed	Size of the session table. A full table rejects new sessions.
`replicas`	integer	1	Restart	Active dataplane pods.
`n3[]`	up to 8 endpoints		Restart, except `routes`, `mtu`	Radio-facing GTP-U interface (N3, S1-U). See Endpoints. Also takes `routes[]` (`destination`, `gateway` inside the transit subnet), `mtu` (≥ 576) and `canonicalIp`.
`n6[]`	up to 8		Restart, except `routes`, `mtu`, `dnsServers`, pool `reachability`	Data-network interface (N6, SGi); see below.
`n9[]`	up to 8		Restart	Interface to other user planes (N9, S5-U): `name` and `transitIpRange` on an attachment, or both omitted for the pod network; `peerUpfs` (required) names the user planes at the far end.
`udpMem`, `tcpMem`	integer ≥ 4096	32000000, 16000000	Restart	Kernel socket buffer sizes in the dataplane pods.

The role of a user plane follows from its mode and interfaces:

Interfaces	Mode `5G`	Mode `4G`	Mode `Dual`
N3 and N9, no N6 (a front)	intermediate UPF	SGW-U	SGW-U and intermediate UPF
N9 and N6 (an anchor)	session anchor behind an intermediate UPF	PGW-U	PGW-U and 5G session anchor, behind a front
N3 and N6 (an anchor)	session anchor (PSA)	none: 4G sessions are refused	5G session anchor; 4G sessions are refused

The SMF never uses one user plane as both the SGW-U and the PGW-U of a 4G session. A user plane in mode `4G` or `Dual` with both N3 and N6 is selected for both roles, so every 4G session through it is refused. Serve 4G radios from a front with N3 and N9, chained to anchors with N9 and N6.

`n6[]`

Field	Type	Default	Description
`name`	string		The attachment. Omit it, together with `transitIpRange` and `gatewayIp`, to egress on the pod network.

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Field	Type	Default	Description
`dataNetworkName`	string, **required**		The DNN or APN this interface serves.
`transitIpRange`	host address with prefix		Required with `name`.
`gatewayIp`	address		Next hop on the data network.
`ueIpPools[]`	list of up to 16, **required**		`cidr` (required), `allocationType` (`dynamic` or `static`, default `dynamic`) and `reachability`, one of `sourceNat: {}` (the default), `static: {}` (the network team routes the pool to the N6 address, and the Site status lists the routes) or `bgp: {peering: <name>}`. All pools of one user plane use the same reachability. A pool on a peering of a `gobgp` router is announced by the user plane's own GoBGP sidecar; see `spec.network.bgp`.
`dnsServers`	list of addresses		DNS servers handed to Mobile Assets. Live.
`routes[]`, `mtu`			As for `n3`. Live.

Service map and Ignite credentials: `spec.elm`

Field	Type	Description
`operatorIdentifier`	`tenantId`, `serviceId`, both **required**	The tenant and service the network functions report and store state under. Pick two stable identifiers; no user plane name may derive the same service ID.
`services[]`	list of `componentName` with `value[]` of `serviceName` and `serviceDomain`, **required**	How the network functions find each other: the Services the operator creates in the namespace. The operator passes the list to every network function as written and adds nothing to it, so copy it from the examples. A Site with an AMF also lists the identifier allocator, SMF, AUSF and UDM entries the AMF resolves by network-function type.
`dbInfo`	`dbType: ignite`, `hostname`, `username`, `password` or `passwordSecret`	Ignite credentials. Reference a Secret with `passwordSecret: {name, key}` rather than writing the password into the Site. The operator rewrites `hostname` to its Ignite proxy.
`logging`, `http`	objects	Log rotation and HTTP client timeouts of the network functions. Leave the defaults.

Every `spec.elm` change is Restart.

Data backends

`spec.ignite`

Field	Type	Default	Description
`enabled`	boolean, **required**		Deploys Ignite.
`replicas`	integer, **required**	3	Ignite nodes.

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Field	Type	Default	Description
storageEngine	aipersist , aimem	aipersist	aipersist keeps the data on each node's volume and survives restarts; aimem keeps it in memory only.
storage	size , className	size: 25Gi	Per-node work volume. Fixed once created.
resources	Kubernetes resource requirements	11 GiB memory request and limit	Ignite container resources.
jvm	minHeap , maxHeap	2g , 4g	JVM heap.
dataRegion	maxSize , initSize	maxSize: 1Gi	Page cache (aipersist) or in-memory region (aimem).
inMemoryWorkDir	boolean	false	Keeps Ignite's work directory in memory. Volatile: a restarted node loses its cluster state.

Every spec.ignite change is Restart. The operator refuses a memory limit that cannot hold the heap plus the data region.

spec.mariaDb

Field	Type	Default	On change	Description
enabled	boolean, **required**	true	Restart	MariaDB is deployed whenever the SMF, the MME or the subscriber store needs it, whatever this says.
replicas	1, or an odd number ≥ 3	1	Fixed between 1 and Galera	1 runs a standalone server; 3 or more runs a Galera cluster. Moving between the two shapes is refused; growing or shrinking between odd sizes is supported.
antiAffinity	boolean	true	Fixed	One Galera replica per node. Set false only on test clusters.

spec.dragonfly

Field	Type	Default	Description
enabled	boolean, **required**		Deploys the cache.
snapshot	enabled , cron , storage	disabled; */5 * * * * ; size: 1Gi	Persists the cache to a volume on the schedule and at shutdown, so identifier allocations survive a restart.

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Node tuning: `spec.nodeConfig`

Applies host tuning to the worker nodes, through a privileged DaemonSet or, on OpenShift, a MachineConfig. Leave it out when the nodes are prepared another way, such as by the netcfg operator the chart installs. Every change is Restart and can interrupt the data plane: the DaemonSet re-runs on every node, and a MachineConfig drains and reboots the pool.

Field	Description
`backend`	`auto` (default: MachineConfig on OpenShift, DaemonSet elsewhere), `daemonset` or `machineconfig`.
`sysctls[]`	Kernel parameters, by dotted name.
`extraKernelModules[]`	Modules to load in addition to `sctp` and `tun`.
`extraRoutes[]`, `extraIPTables[]`, `extraIpAddresses[]`	Routes, iptables rules and interface addresses to install before the dataplane starts.
`txInterfaces[]`, `txQueueLength`	Transmit queue length of the named interfaces.
`workerRoleName`	OpenShift MachineConfigPool the MachineConfig targets; `worker` when that pool has machines.

Status

Field	Description
`status.conditions[]`	`Ready` and the subsystem conditions `GatewaysReady`, `ControlPlaneReady`, `PeeringReady` and `InfrastructureReady`. A `False` condition names its cause in `reason`; see Troubleshooting. The child resources carry `NetworkConfigured` and `DatabaseReady`.
`status.lastReconcileTime`	Time of the last reconcile pass. It advances on every pass; a stale value means the operator is not running.
`status.lastReconcileError`	The error of the last failed pass, verbatim.
`status.requiredUpstreamRoutes[]`	For pools with `reachability.static`: the routes the network team must install, with the next hop and a ready-to-use command.

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4.3.6 Verify the Installation

When the Site reports `Ready`, confirm each layer before connecting radios or handing the core over: the operator's view of the Site, the workloads it created, the Agent's registration in xControl, and the monitoring path. The commands below use the `xcore` namespace and release name.

The Site

```
kubectl -n xcore get sites.expeto.io
kubectl -n xcore describe site acmecorp-campus
```

All conditions must be `True`. For the combined core example:

```
Status:
  Conditions:
    Type:    InfrastructureReady   Status: True   Reason: InfrastructureReady
    Type:    GatewaysReady         Status: True   Reason: AllGatewaysReady    Message: 3 child UPF(s) ready
    Type:    ControlPlaneReady     Status: True   Reason: ControlPlaneReady   Message: Control-plane children ready: smf, mm, mme, sdm
    Type:    Ready                 Status: True   Reason: Ready               Message: Site agent and all 3 child UPF(s) are ready
  Last Reconcile Time:  2026-10-26T16:29:11Z
```

`Last Reconcile Time` advances on every pass. If it stops moving the operator is not running:

```
kubectl -n xcore rollout status deployment/xcore-xfabric
```

Workloads

```
kubectl -n xcore get pods
kubectl -n xcore get smf,upf,udsf,nfcm,mm,mme,sdm,mariadb,dragonfly
```

Every pod must be `Running` (the Ignite initialisation Job ends `Completed`). The set depends on the Site; a public core produces these, with one controller Deployment and one dataplane StatefulSet per user plane:

Workload	Kind
`smf`	Deployment
`upf-<user plane>-controller`, `upf-<user plane>-dataplane`	Deployment, StatefulSet
`udsf`, `udsf-idallocator`, `udsf-timer`	Deployment, Deployment, StatefulSet
`nfcm-monitoring`, `nfcm-statistics`	Deployment
`ignite`, `ignite-proxy`, `ignite-init`	StatefulSet, Deployment, Job
`mariadb`	StatefulSet, managed by the MariaDB operator
`cache`	StatefulSet, managed by the Dragonfly operator
`xcore-xfabric`, `xcore-xfabric-agent`	Deployment, StatefulSet (the operator and the Agent)

The control-plane blocks of a private or combined core add their own workloads:

Workload	Kind	Present with
`mm-ranhandler`, `mm-communication`, `mm-uehandler`	Deployment	`amf`
`mme-mme`, `mme-stc`	Deployment	`mme`: the MME and its S1 transport controller

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Workload	Kind	Present with
`mme-cache`	StatefulSet, managed by the Dragonfly operator	`mme` : the MME's session store
`sdm-hss`	Deployment	subscriber store in mode `4G` or `Dual`
`sdm-udr` , `sdm-udm` , `sdm-ausf`	Deployment	subscriber store in mode `5G` or `Dual`
`sdm-cache`	StatefulSet, managed by the Dragonfly operator	subscriber store

The user planes' radio-facing and data-network addresses live on Multus attachments, not on Services. Confirm each dataplane pod holds the addresses the Site pins:

```
kubectl -n xcore exec upf-psa-upf-dataplane-0 -- ip -br addr
```

Prerequisite check

The operator's preflight lists every dependency it found, with a fix hint for anything missing. Run it as the chart's Helm test or directly on the operator pod:

```
helm test xcore -n xcore --filter name=xcore-xfabric-test-preflight --logs
kubectl -n xcore exec deployment/xcore-xfabric -- /opt/taiga/app preflight
```

```
Taiga preflight check

  ✓ Multus CNI                installed
  ✓ cert-manager              installed
  ! MetalLB (optional)        NOT INSTALLED
    → Optional — BGP fabric (Site.Spec.Network.Bgp) is not supported without MetalLB.
  ...
2 of 2 required prerequisites satisfied.
```

Registration in xControl

Open **Sites** in xControl. The Site whose ID you gave the chart shows **Connected**, with the Agent version and the address it connects from on its detail page. It turns **Disconnected** after five minutes without contact.

If it stays **Disconnected**, check the Agent:

```
kubectl -n xcore logs statefulset/xcore-xfabric-agent -c agent --tail=100
```

The usual causes are a `siteId` that does not match the Site in xControl, a token that was issued for another Site, or an xControl hostname the pod cannot resolve or reach on port 443.

Operations CLI

The Agent pod carries a CLI sidecar that reads live state from every network function on the Site:

```
kubectl -n xcore exec -it xcore-xfabric-agent-0 -c agent-cli -- cli
```

At the `expeto_shell>` prompt, `ls` lists the command folders (`lte` , `nr` , `nf` , `ops`), and `cd nr` followed by `read smf` shows the SMF's sessions. The CLI Guide covers the grammar.

Monitoring path

The operator publishes each Site's conditions as a metric on its metrics Service:

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```
kubectl -n xcore port-forward service/xcore-xfabric-metrics 8080:8080 &
curl -s http://127.0.0.1:8080/metrics | grep taiga_site_condition
```

```
taiga_site_condition{namespace="xcore",site="acmecorp-campus",type="ControlPlaneReady"} 1
taiga_site_condition{namespace="xcore",site="acmecorp-campus",type="GatewaysReady"} 1
taiga_site_condition{namespace="xcore",site="acmecorp-campus",type="InfrastructureReady"} 1
taiga_site_condition{namespace="xcore",site="acmecorp-campus",type="Ready"} 1
```

The Agent exposes the Site's network-function metrics on the `agent-prom` Service (port 9767); the xCore metrics page lists the families. They reach xView the way every site's metrics do: a Prometheus in the Site's namespace scrapes them, and the Agent uploads that Prometheus's federation endpoint to xControl for each Monitoring Endpoint configured on the Site in xControl; see xView architecture. The `xfabric` chart does not install that Prometheus by default. Use the platform's prometheus-operator, or bundle one with `kube-prometheus-stack.enabled=true`, set `nfMonitoring.enabled=true` so that the chart renders the scrape configuration of the network functions, and add the Monitoring Endpoint to the Site in xControl, as agreed with Expeto Support.

Acceptance tests

With radios connected and Mobile Assets provisioned, run the installation and upgrade verification set: attach, detach, idle mode, throughput and the other checks an installation must pass before it is handed over.

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4.3.7 Upgrade, Change and Uninstall

Once a Site is `Ready`, day-two work falls into three kinds: upgrading the Helm release (the operator, the Agent and the bundled operators), changing the Site definition, and removing a core. This page covers each, plus the topology decisions that are fixed at creation and the customer-owned overrides the operator supports.

Upgrade the release

```
helm repo update
helm upgrade xcore expeto/xfabric -n xcore -f values.yaml --server-side --force-conflicts \
  --set global.imageCredentials.username='<username>' \
  --set global.imageCredentials.password='<password>' \
  --set agent.apiToken='<site API token>'
```

The values file is yours: it holds every setting of the installation, lives in version control, and is passed on every upgrade together with the secrets, exactly as at install time. Anything it does not mention takes the chart's default for the new release. If no values file is kept, `--reuse-values` carries the current release's values forward, secrets included:

```
helm upgrade xcore expeto/xfabric -n xcore --reuse-values --server-side --force-conflicts
```

Use `--server-side --force-conflicts` on every upgrade. Some dependency CustomResourceDefinitions exceed the size that client-side apply can annotate, and server-side apply lets Helm take ownership of fields another manager (a `kubectl apply` of the CRDs, for instance) touched earlier. The flags are safe on `helm install` too.

> **Warning**
>
> Never pass `--force-replace`. It deletes and recreates every resource, which for the MariaDB and Dragonfly CustomResourceDefinitions means deleting every database and cache on the cluster. Helm refuses the combination with server-side apply, but do not reach for it with client-side apply either.

The chart applies the release's CustomResourceDefinitions before anything else in the upgrade, so the Site schema of the new release is in place when the new operator starts; an older release never downgrades them. The upgrade then rolls the operator, which reconciles the Site with the new network-function images. Restart-required changes roll the affected pods one workload at a time; the data backends keep their volumes.

Upgrade xControl first: the Agent that an xCore release pins must not be newer than the xControl it registers with. A release whose Site schema changes lists the edits an existing Site needs; plan them with Expeto Support before the upgrade window.

UPGRADE FROM 4.0.5 TO 4.0.6

xCore 4.0.6 needs xControl 3.3.22 or later. Its Site schema changes, so review the Site against the list below with Expeto Support, and apply the edited Site right after `helm upgrade`, in the same window. Until it is applied, the operator reports the Site `Ready=False` with a validation reason and does not reconcile it.

- **Front user planes lose `systemId`.** A user plane without `n6` (an SGW-U or an intermediate UPF) serves every System and must not set `systemId`; remove it, typically from the SGW-U of a public core. Anchors keep theirs.
- **`subscriberManagement.plmnId` becomes `controlPlane.plmnId`**, with the same value. It is required whenever `amf`, `mme` or the subscriber store is declared.
- **`controlPlane.mm` becomes `controlPlane.amf`**: rename the block, rename `ranInterfaces` to `n2` and remove `mode`.
- **`amf.exposure` is gone.** `exposure.loadBalancer: {range, ip}` becomes `n2: [{ingress: [{range, ip}]}]`.
- **`amf.servedTrackingAreas` becomes `trackingAreas`**, a list of integers: `[{tac: "000001"}]` becomes `[1]`. Tracking area 0 is refused.
- **`amf.allowedRanNodeIds` is removed**; nothing ever read it.
- **`amf.n2` and `mme.s1` take one entry.** Keep the first and remove the rest.
- **`amf` and `mme` need their subscriber store:** `subscriberManagement` enabled in mode `5G` or `Dual` for the AMF, `4G` or `Dual` for the MME.
- **`subscriberManagement.adminPass`, `adminPassSecret` and `dbInterfaces` are removed**, and **`spec.hickory` is removed**. Delete the keys.

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- **Control-plane validation failures report** `ControlPlaneSpecInvalid` instead of `NetworkSpecInvalid`. Update alerts that match on the reason.
- **The SMF collects session usage every 59 minutes** instead of every minute, and a user plane still reports every 10 MiB. Session usage in xControl therefore updates less often for light sessions. `controlPlane.usageReporting` sets both values.
- A Site with a 5G subscriber store provisioned under 4.0.5 needs its UDR records migrated to the new UDR's identifier format before 5G devices can register again; Expeto Support runs the migration.

Change a Site

> **Important**
>
> Review every change to the Site with Expeto Support before you apply it. Its data model changes between releases, and Expeto intends the Expeto Agent to write the Site from the configuration held in xControl, after which the Site may not be directly editable. See Who writes the Site.

Apply a change by editing the Site definition in version control and applying it again. The Site resource reference says how each field behaves; they fall into two classes:

Class	Examples	Effect
Live reload	routes and MTU on an interface, BGP peers and advertisements, service ranges, pool reachability, `dnsServers`, the MME's `timers`	Applied by the running pods; no restart.
Restart required	the PLMN, the AMF, MME and subscriber-store blocks other than the MME's timers, slices, data networks, usage reporting, attachments an interface binds to, `udpMem` and `tcpMem`, storage shape, node tuning	The affected pods roll.

To enforce a change window, set `spec.maintenanceMode: false` on the Site. The admission webhook then rejects any edit that would require a restart until you set it back to `true`; live-reload edits still go through. Toggling the flag itself is never gated.

Two settings are fixed once created and cannot be changed by editing the Site:

- **User-plane session table**: `numberOfSessions` on a user plane is immutable after the user plane exists. Size it for the peak; the dataplane rejects new sessions with PFCP cause 75 when the table is full.
- **MariaDB topology**: see below.

`namePrefix` renames every resource on the next reconcile but deletes none of the old ones; treat it as set at install time.

A changed `plmnId` or `mme.identity` reaches the MME only once its session store is recreated: the MME restores its PLMN and identity from the store at start-up. After applying such a change, delete the `mme-cache` pod, wait until it is ready again, then delete the MME pod (`kubectl -n xcore delete pod -l app=mme-mme`). Attached 4G devices attach again.

MARIADB TOPOLOGY

`spec.mariaDb.replicas: 1` runs a standalone MariaDB; `3` or another odd number runs a Galera cluster managed by the MariaDB operator, with one replica per node and automatic primary failover. The SMF and the subscriber store always write through the primary Service.

Moving an existing database between the two shapes is refused in both directions with the reason `MariaDbReplicasLocked`: the operator relocates the data directory when converting to Galera and would not carry the data over, and a cluster bootstrapped down to one node may pick a stale replica. Choose the topology at first install. Growing or shrinking a Galera cluster between odd sizes (3 to 5) is supported; the new members state-transfer from the existing ones.

For a Galera cluster:

- one schedulable node per replica, or set `spec.mariaDb.antiAffinity: false` on test clusters (colocated replicas defeat the purpose);
- one data volume and one small configuration volume per replica;
- a PodDisruptionBudget keeps `replicas - 1` pods available, so node drains proceed one at a time.

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IGNITE SIZING

Each Ignite replica requests and is limited to 11 GiB of memory by default, with a 25 GiB work volume, a 2 GiB to 4 GiB heap and a 1 GiB data region. The default engine (`aipersist`) keeps the dataset on the volume and survives restarts. On small clusters shrink `resources` , `jvm` and `dataRegion` together; the operator refuses a combination whose memory limit cannot hold the heap plus the data region.

Custom SMF rules

The SMF routes sessions with a bundled rule set: it selects the Site's SGW-U and intermediate UPF by type, and the anchor by the System of the Mobile Asset (`systemId`). That covers public, private and combined cores with one front. A Site with more than one SGW-U or intermediate UPF, Mobile Assets provisioned without a System, or special routing (an external P-GW, APN-based steering) needs its own Drools rules instead:

```
apiVersion: v1
kind: ConfigMap
metadata:
  name: acmecorp-smf-rules
  namespace: xcore
data:
  rules.txt: |
    package com.expeto.smf;
    // your rules
```

```
helm upgrade xcore expeto/xfabric -n xcore --reuse-values --set agent.smfRulesConfigMapRef=acmecorp-smf-rules
```

The ConfigMap is yours: the operator only mounts it. It must live in the install namespace with a `rules.txt` key, or the Agent pod stays `Pending` on `FailedMount` . Nothing validates the rules before the Agent's rule engine loads them at start-up; a bad rule set shows as an Agent crash loop. The Agent reads the file once, so restart it after editing:

```
kubectl -n xcore rollout restart statefulset/xcore-xfabric-agent
```

BGP

A Site announces UE pools and service addresses through the BGP routers in `spec.network.bgp` . Each router's `impl` says where it runs: `metallb` , the default, or `gobgp` . The fields are in the Site resource reference.

METALLB ROUTERS

A `metallb` router runs on FRR-K8s. The operator emits the BGP resources into MetalLB's namespace, which needs cross-namespace permissions the chart provisions only when asked:

```
helm upgrade xcore expeto/xfabric -n xcore --reuse-values --set bgp.enabled=true
```

MetalLB must already be installed (the chart can bundle it with `metallb.enabled=true` on clusters that have none). Its namespace is detected; set `metallbNamespace` when detection fails. Emitted resources carry the labels `expeto.io/site` and `expeto.io/site-namespace` , and a finalizer on the Site removes them on deletion. A Site has at most one `metallb` router, and only that router announces service ranges.

GOBGP ROUTERS

A `gobgp` router runs as a GoBGP sidecar in the dataplane pod of each user plane whose UE pools name one of its peerings. The user plane's netcfg sidecar configures it, so it needs neither MetalLB nor `bgp.enabled` . Agree its use with Expeto Support. In this example, user plane `anchor` announces `10.45.0.0/16` to the border router at `192.0.2.1` :

```
spec:
  network:
    bgp:
      routers:
        - name: upf-uplink
          asn: 64512
          impl: gobgp
          peerings:
            - name: n6-upstream
              attachment: n6-internet
              peers:
                - name: border
                  address: 192.0.2.1
                  peerAsn: 64500
  topology:
    userPlanes:
      - name: anchor
```


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```
    mode: Dual
    systemId: 2
    n6:
     - name: n6-internet
       transitIpRange: 192.0.2.10/24
       dataNetworkName: internet
       ueIpPools:
        - cidr: 10.45.0.0/16
          reachability:
            bgp:
              peering: n6-upstream
```

The sidecar announces the pool with `192.0.2.10` as next hop, and uses it as router-id unless the router sets `routerId`. Plan a GoBGP router within these constraints:

- **Local address.** The user plane's address on the router is the `transitIpRange` address of its `n6` entry whose `name` is the attachment of the router's **first** peering. Without such an entry the Site goes `Ready=False` with reason `NetworkSpecInvalid` and a message containing `cannot derive localAddr`.
- **Sessions.** The user plane opens every session and accepts none, so the peer must accept a session opened from the user plane. The peer must be directly reachable on that N6 segment; there is no multihop.
- **Announcements.** The router announces IPv4 UE pools only. Routes the peer sends are not installed. Service ranges on a GoBGP peering are accepted but never announced; put them on the `metallb` router.
- **Peer fields.** Only `address`, `peerAsn`, `holdTime`, `keepaliveTime` and `gracefulRestart` are used; the other peer fields are ignored.
- **One router per user plane.** When a user plane's pools name the peerings of two GoBGP routers, every pool is announced through the first one. Keep each user plane on one GoBGP router.
- **One replica.** Every replica of the user plane announces from the same address, so run a user plane with a GoBGP router at `replicas: 1`.
- **Restarts.** Giving a user plane its first GoBGP pool, or removing its last, restarts its dataplane pod, even outside maintenance mode; make that change in a maintenance window. Other changes, to peers or pools, are applied live.
- **Control API.** GoBGP's API listens without authentication on TCP port 50051 on every interface of the dataplane pod. Restrict that port on the pod network with a NetworkPolicy. A NetworkPolicy does not cover the N6 attachment, so keep untrusted hosts off that segment.

Each sidecar logs to its own container:

```
kubectl -n xcore logs upf-anchor-dataplane-0 -c gobgp
kubectl -n xcore logs upf-anchor-dataplane-0 -c netcfg
```

Pin images

A release normally runs the images its chart version names. To pin the operator, the Agent or a single network function:

```
image:
  tag: "<operator build>"
agent:
  image:
    tag: "<agent build>"
imageOverrides:
  oak_smf: docker.expeto.io/oak/smf:<build>
```

The override keys are listed in the chart's `files/operator/versions.yaml` (`helm show values expeto/xfabric` prints them). The operator replaces an override's registry host with `global.imageRegistry`, so the image must be in that registry. The Agent must never be newer than the xControl it registers with; xControl stays compatible with older Agents, not the reverse. An Agent older than 3.3.22-beta8 cannot manage the MME, so only a Site without an MME may pin an older Agent, and no older than 3.3.20.

Uninstall

Delete the Site first, then the release. The operator must be running to remove what it created in other namespaces (the BGP resources) and to let the Site's finalizers complete; an uninstall with Sites present is refused by the chart's pre-delete hook.

```
kubectl -n xcore delete sites.expeto.io --all
kubectl -n xcore wait --for=delete sites.expeto.io --all --timeout=10m
helm uninstall xcore -n xcore
```

When the uninstall goes ahead, the hook also deletes the operator's `taiga-gateways` and `taiga-nf-config` ConfigMaps and, when the chart created it, the image pull Secret.

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IF THE UNINSTALL IS REFUSED

With a Site present, the pre-delete hook fails and `helm uninstall` fails with it. Nothing is deleted, but the release stays in the `uninstalling` state (`helm list -n xcore -a`), in which `helm upgrade` is refused. The hook's log lists the Sites and the ways out:

```
kubectl -n xcore logs job/xcore-xfabric-pre-delete-drain
```

- **Delete the Sites, then uninstall again.** This is the normal path:

  ```
  kubectl -n xcore delete sites.expeto.io --all --wait
  helm uninstall xcore -n xcore
  ```

- **Delete the Sites and the release in one step.** Create the hook's mode ConfigMap, then uninstall again. The hook deletes every Site, waits up to `preDeleteDrain.timeoutSeconds` (180 seconds by default) for them to go, and lets the uninstall proceed:

  ```
  kubectl -n xcore create configmap xcore-xfabric-pre-delete-mode --from-literal=mode=drain
  helm uninstall xcore -n xcore
  ```

  The ConfigMap is named `<release>-xfabric-pre-delete-mode`, or `<release>-pre-delete-mode` when the release name contains `xfabric`. The hook deletes it once the uninstall proceeds.

- **Skip the hook** with `helm uninstall xcore -n xcore --no-hooks`. Avoid this: the Sites keep running without an operator, and deleting one later hangs on its finalizer (see stuck deletion).

The chart value `preDeleteDrain.mode` sets the hook's behaviour for every uninstall: `abort`, the default, refuses as described; `drain` always deletes the Sites first and suits test clusters only; `disabled` installs no hook.

> **Note**
>
> The hook's image does not follow `global.imageRegistry`. On an air-gapped cluster, set `imageOverrides.helm_kubectl` to the mirrored image at install time, or the hook cannot start and every uninstall fails. If one already has, delete the Sites, then run `helm uninstall xcore -n xcore --no-hooks`.

VOLUMES AND CUSTOMRESOURCEDEFINITIONS

Helm does not delete the PersistentVolumeClaims of MariaDB, Ignite and the Agent, nor the CustomResourceDefinitions, which other releases on the cluster may use. A leftover Ignite volume stops the Ignite cluster of a new Site in the same namespace from starting, so remove the claims when the data is no longer needed:

```
kubectl -n xcore get pvc
kubectl -n xcore delete pvc --all
kubectl delete namespace xcore
```

To remove the CustomResourceDefinitions after the last release on the cluster is gone:

```
helm pull expeto/xfabric --untar
kubectl delete -f xfabric/charts/xfabric-crds/files/
```

If a Site is stuck in `Terminating` because the operator was removed first, see Troubleshooting.

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4.3.8 Troubleshooting

The operator reports everything it knows about a Site on the Site itself. Start every investigation with `kubectl describe site`, read the conditions and the last reconcile error, and only then move to pods and logs. This page lists what each condition and reason means and where to look next.

First look

```
kubectl -n xcore get sites.expeto.io
kubectl -n xcore describe site <name>
```

The `Status` section shows the conditions, `Last Reconcile Time` (updated on every pass, so a stale value means the operator is not running) and, when the last pass failed, `Last Reconcile Error` with the wrapped error verbatim. The `Events` section below it records every condition transition.

```
Status:
  Conditions:
    Type:    InfrastructureReady   Status: True   Reason: InfrastructureReady
    Type:    GatewaysReady         Status: True   Reason: AllGatewaysReady    Message: 3 child UPF(s) ready
    Type:    ControlPlaneReady     Status: True   Reason: ControlPlaneReady   Message: Control-plane children ready: smf, mm, mme, sdm
    Type:    Ready                 Status: True   Reason: Ready              Message: Site agent and all 3 child UPF(s) are ready
  Last Reconcile Time:  2026-10-26T16:29:11Z
```

Conditions

Condition	Meaning
`Ready`	Rollup of the Agent, every user plane and every control-plane function, and the condition every validation failure is reported on. The one to alert on.
`GatewaysReady`	Every child user plane reports ready.
`ControlPlaneReady`	Every control-plane child the topology needs reports ready: `smf`, `mm` (the AMF), `mme` and `sdm` (the subscriber store). Absent on a Site without them.
`PeeringReady`	The operator can manage BGP resources in MetalLB's namespace. Informational; never part of `Ready`.
`InfrastructureReady`	Always `True`; kept so that existing dashboards and alerts keep working.

The child resources (`kubectl -n xcore get smf,upf,mm,mme,sdm`) carry their own conditions: `NetworkConfigured` says whether the pods' network attachments exist, and the `mme` and `sdm` resources' `DatabaseReady` whether their session store is up. `kubectl describe` on a child that is not ready shows which.

Reasons

A `False` condition names its cause in `reason`. The catalogue:

Reason	Condition	What it means	What to c
`ProvisioningAgent`, `ProvisioningGateways`, `ProvisioningControlPlane`	`Ready`	Normal start-up: the Site is converging and waits for the Agent, the user planes or the control-plane functions.	Nothing ye takes a few Ignite initi first. If it d matching s condition a `pods` show

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Reason	Condition	What it means	What to c
`TopologyMissingNADs`	`Ready`	A topology interface references an attachment name that `spec.network.attachments` does not declare.	Compare t `n2` , `s1` , `n` the attach are match
`TopologyInvalidUpfName`	`Ready`	Duplicate user-plane names or `systemId` values, an anchor without a `systemId` , a front with one, a missing `mode` , or a user-plane name that derives the Site's own service identifier.	Every user unique na and every plane with `systemId` ; sets none.
`NetworkSpecInvalid`	`Ready`	`spec.network` or the topology addressing failed validation: a bad peer address, a peering or range referenced but not declared, more than one `metallb` BGP router, a `gobgp` router whose first peering's attachment is not an `n6` entry with a `transitIpRange` on a user plane that uses it (`cannot derive localAddr`), an advertisement mixing BGP and layer 2 fields, a transit address that is the subnet's network or broadcast address, or a range that overlaps the cluster's pod or Service network.	The messa field.
`ControlPlaneSpecInvalid`	`Ready`	`spec.topology.controlPlane` failed validation: no `plmnId` beside a mobility function or subscriber store, an `amf` or `mme` without the subscriber store it authenticates through, AMF and MME identities that map onto each other, an MME TAC above 65535, a mobile reachable timer not longer than T3412, or a duplicate slice.	The messa field.

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Reason	Condition	What it means	What to cl
`InterfaceRealizationInvalid`	`Ready`	An N2, S1, N3 or N16 entry has neither an attachment nor an ingress address, references an unknown service range, pins an address outside the range, or declares several addresses without `canonicalIp`.	The messa entry.
`ReachabilityModeConflict`	`Ready`	Pools on one user plane declare different reachability modes.	A user plar mode acro split the po planes.
`IgniteConfigInvalid`	`Ready`	Ignite heap, data region or resource settings are inconsistent (minimum above maximum, or a memory limit that cannot hold the heap plus the data region).	Adjust `spe` `dataRegion` together.
`DragonflySnapshotInvalid`	`Ready`	The Dragonfly snapshot schedule is not a valid cron expression.	Fix `spec.dragon`
`MariaDbOperatorMissing`, `DragonflyOperatorMissing`	`Ready`	The CustomResourceDefinition of a data-backend operator is not installed.	Re-enable bundled op it. The cha these CustomRe so on a cha missing op instead as Dragonfly never beco
`MariaDbStaleStorage`	`Ready`	A MariaDB volume from an earlier database is present and does not match the current topology.	Remove th if its data i
`MariaDbReplicasLocked`	`Ready`	`spec.mariaDb.replicas` would move an existing database between standalone and Galera.	That transi both direct Upgrade, uninstall.

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Reason	Condition	What it means	What to cl
`GatewayNotReady`	`GatewaysReady`	A user plane's dataplane StatefulSet or controller Deployment is not ready.	`kubectl get app.kubern component` `Pending` da usually car Multus att node (pare name, mis binary).
`ControlPlaneNotReady`	`ControlPlaneReady`	A control-plane child is not ready; the message names it.	`kubectl -n x` the child th names, an function.
`MetalLBRBACMissing`	`PeeringReady`	MetalLB CustomResourceDefinitions exist but the release was installed without `bgp.enabled=true`.	`helm upgra bgp.enable`
`RejectedExtraSite`	`Ready`	An older Site already exists in this namespace.	One Site p delete the install a se elsewhere.
`DrainingWorkloads`	`Ready`	The Site is being deleted and its workloads are draining.	Wait; if it n see stuck c

Pods

```
kubectl -n xcore get pods
kubectl -n xcore get pods --field-selector=status.phase!=Running,status.phase!=Succeeded
```

Symptom	Likely cause
Dataplane pod `Pending` or `ContainerCreating` with a Multus event	The attachment's `master` interface does not exist on the scheduled node, or the CNI plugin binary (`macvlan`, `static`) is missing from the node's CNI directory. `kubectl describe pod` shows the CNI error.
`ImagePullBackOff`	Wrong registry credentials, or an air-gapped cluster without `global.imageRegistry` pointing at the mirror.
Ignite pod `Pending`	No node has 11 GiB free for the default request; shrink `spec.ignite.resources` and `jvm` on small clusters.
Ignite initialisation job never completes	The Ignite pods cannot reach each other on the discovery Service, or a previous cluster's work directory is on the volume.

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Symptom	Likely cause
Ignite of a new Site fails with `Cluster names do not match`	The volumes of an earlier Site in the namespace are still there. Deleting that Site recorded a `Warning` event with reason `IgniteStorageRetained` that names the claims (`kubectl -n xcore get events --field-selector reason=IgniteStorageRetained` , while the cluster keeps the event); delete them, as described under Uninstall.
A GoBGP router's session does not come up	Read `kubectl -n xcore logs upf-<user plane>-dataplane-0 -c gobgp` and `-c netcfg` . The peer must accept a session opened by the user plane from its N6 transit address; see GoBGP routers.
Agent pod `Pending` on `FailedMount`	`agent.smfRulesConfigMapRef` names a ConfigMap that does not exist or has no `rules.txt` key.
A Deployment keeps restarting after a Site edit	Restart-required fields rolled it; check `kubectl rollout status` and the container log.

Radios and devices

Symptom	Likely cause
An eNodeB's S1 Setup or a gNodeB's NG Setup is rejected	The radio broadcasts a PLMN or a TAC the Site does not serve. Compare the radio's configuration with `plmnId` and the `trackingAreas` of the `mme` or `amf` block. In the CLI, `cd /lte` and `read enodeb` , or `cd /nr` and `read ran` , list the radios that are connected.
Every 4G attach fails although S1 Setup succeeds	A 2-digit MNC: the MME needs a 3-digit MNC to read a home IMSI.
The MME keeps an old PLMN or MME identity after the Site changed it	The MME restores its identity from its session store at start-up. Delete the `mme-cache` pod, wait until it is ready again, then delete the MME pod (`kubectl -n xcore delete pod -l app=mme-mme`); attached devices attach again.
Every 4G attach fails when the default bearer is set up, while 5G sessions work	The 4G path has no front: a user plane in mode `4G` or `Dual` with both `n3` and `n6` would be the SGW-U and the PGW-U of the session, which the SMF refuses. Serve the eNodeBs from a front with `n3` and `n9` .

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Symptom	Likely cause
A device is rejected at authentication	The subscriber-store keys: a transport key that differs from the SIM vendor's, a Keyset Mapping whose HSS Identifier differs from the name the key was loaded under, or, on 5G only, a missing SUCI key or a key identifier that differs from the SIM's. See Load the subscriber-store keys.
A Mobile Asset exists in xControl but not in the subscriber store	In the CLI, `cd /debug/ops` and `read sync-sub-error` list the Agent's provisioning failures; `cd /lte` and `read hss <imsi>`, or `cd /nr` and `read udr <imsi>`, show what the store holds.

Preflight

The chart's Helm tests re-run the operator's preflight, which reports each dependency:

```
helm test xcore -n xcore --filter name=xcore-xfabric-test-preflight --logs
```

`Multus CNI`, `cert-manager` and the `netcfg operator` are required; the others (whereabouts, MetalLB, FRR-K8s, prometheus-operator, duplicate operators) are warnings with a fix hint.

Admission webhook denials

A `kubectl edit` or `kubectl patch` on an object the operator created is refused:

```
admission webhook "vmanaged.expeto.io" denied the request: ... managed by the Site; edit the Site instead
```

This is intended: change the Site field that renders the object. If the webhook is unreachable (`failurePolicy: Fail`) because the operator pod is down, restore the operator first.

Uninstall refused

`helm uninstall` fails while a Site exists in the release namespace: the chart's pre-delete hook refuses to remove the operator, deletes nothing, and leaves the release in the `uninstalling` state. Delete the Sites and run the uninstall again, or let the hook delete them; see If the uninstall is refused.

Stuck deletion

A Site whose operator was removed before the Site was deleted stays in `Terminating`, held by the `expeto.io/bgp-cleanup` finalizer that only the operator can process. Reinstall the operator and let it finish. Only if that is impossible, and together with Expeto Support, remove the finalizer and delete any BGP resources the Site created in MetalLB's namespace by hand:

```
kubectl -n xcore patch site <name> --type=merge -p '{"metadata":{"finalizers":[]}}'
kubectl -n metallb-system get bgppeers,frrconfigurations,bfdprofiles,ipaddresspools,bgpadvertisements \
  -l expeto.io/site=<name>
```

Operator logs

```
kubectl -n xcore logs deployment/xcore-xfabric --tail=200
```

Every reconcile step wraps its error with the step name, so the log line that matches `Last Reconcile Error` on the Site says which phase failed.

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4.3.9 Platform Notes

The operator installs the same way on every conformant Kubernetes distribution. What differs is how the prerequisites are met: Multus, the CNI plugin binaries, cert-manager, storage, node tuning and the monitoring stack. This page records the platform-specific steps.

MicroK8s

- **Multus** comes from the community add-ons. The add-on installs the Multus DaemonSet but not the reference CNI plugins the attachments need; confirm `macvlan` and `static` are present and copy a containernetworking plugins release into the directory if they are not.

```
sudo microk8s enable community
sudo microk8s enable multus
ls /var/snap/microk8s/current/opt/cni/bin | grep -E 'macvlan|static'
```

- **cert-manager**: `sudo microk8s enable cert-manager`.
- **Storage**: `hostpath-storage` works on a single node only. Multi-node clusters need a storage class that follows pods between nodes; in the absence of a built-in or otherwise preferred option, Longhorn is the suggested choice.
- **Node tuning**: the Site's `nodeConfig` DaemonSet applies sysctls and loads the `sctp` module. If you manage nodes yourself, raise the open-file limit for containerd as well:

```
echo 'ulimit -n 1048576 || true' | sudo tee -a /var/snap/microk8s/current/args/containerd-env
```

- **NodePort exposure** of N2 or S1 needs the API server's `--service-node-port-range` widened to include 38412 and 36412; Multus-attached endpoints need no such change.
- **Firewall**: with `ufw` active, allow the MicroK8s control ports between nodes (25000, 16443, 10250, 10255, 12379, 10257, 10259, 19001) or pods cannot reach the API server.

OpenShift

- The operator detects OpenShift; install with the standard command. The chart never bundles cert-manager, and MetalLB and the Prometheus stack are off by default, as OpenShift needs. Enable the operator's `ServiceMonitor` and switch off any bundled operator the cluster already provides:

```
helm install xcore expeto/xfabric -n xcore --create-namespace -f values.yaml \
  --set metrics.serviceMonitor.enabled=true \
  --set global.imageCredentials.username='<username>' \
  --set global.imageCredentials.password='<password>' \
  --set agent.apiToken='<site API token>'
```

- **cert-manager**: install the cert-manager Operator from OperatorHub. The chart's install-time guard checks that the CustomResourceDefinition exists.
- **Multus** is part of the OpenShift networking stack; declare attachments as usual. The parent interface for macvlan must exist on the worker nodes' host network.
- **MetalLB**: install the MetalLB Operator from OperatorHub, then `--set bgp.enabled=true`.
- **Monitoring**: enable user-workload monitoring (`enableUserWorkload: true` in the `cluster-monitoring-config` ConfigMap); its Prometheus discovers the operator's `ServiceMonitor`. Never bundle `kube-prometheus-stack` on OpenShift; the cluster version operator owns those CustomResourceDefinitions and the install loses the ownership conflict.
- **Node tuning** is rendered as a `MachineConfig` for the pool named in `spec.nodeConfig.workerRoleName`. The operator references an existing MachineConfigPool; it does not create one.
- **SCTP** is enabled through the same MachineConfig; without `nodeConfig`, load the module with your own MachineConfig before deploying an AMF or MME.
- Use `oc` where this guide says `kubectl`, and a project instead of a namespace.

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Tanzu Kubernetes Grid

TKG ships Antrea but not Multus, cert-manager or the data-backend operators. Install the prerequisites once per cluster:

```
helm repo add jetstack https://charts.jetstack.io
helm install cert-manager jetstack/cert-manager -n cert-manager --create-namespace --set installCRDs=true

kubectl apply -f https://raw.githubusercontent.com/k8snetworkplumbingwg/multus-cni/master/deployments/multus-daemonset.yml

kubectl apply \
  -f https://raw.githubusercontent.com/k8snetworkplumbingwg/whereabouts/master/doc/crds/daemonset-install.yaml \
  -f https://raw.githubusercontent.com/k8snetworkplumbingwg/whereabouts/master/doc/crds/whereabouts.cni.cncf.io_ippools.yaml \
  -f https://raw.githubusercontent.com/k8snetworkplumbingwg/whereabouts/master/doc/crds/whereabouts.cni.cncf.io_overlappingrangeipreservations.yaml
```

The chart's bundled MariaDB and Dragonfly operators cover the rest.

- **Parent NIC**: worker VMs usually have a single vNIC. Either add a second vSphere port group to the worker template through the ClusterClass, or reuse the pod-network NIC when the LAN carries the extra subnets. Confirm the interface name before writing the attachments:

  ```
  kubectl debug node/<worker> -it --image=busybox -- ip -br link
  ```

- **Pod Security Admission**: TKG enforces `baseline` on workload namespaces. The operator's pods are `restricted`-grade and need no exemption; the user-plane pods run privileged and need a namespace labelled for the `privileged` profile.
- **Storage**: the vSphere CSI default class is used unless `spec.storage.className` or `spec.ignite.storage.className` says otherwise.
- **NSX-T Container Plugin** clusters bundle Multus and expose port groups as VIFs; skip the Multus step and reference the VIF as the macvlan parent.

Amazon EKS

- **Multus**: install the AWS-maintained Multus release for your cluster version. Each attachment maps to an additional Elastic Network Interface on the node, so pick instance types with enough interfaces (two are reserved for the cluster itself) and trunking support.
- **Source/destination check** must be disabled on every instance that runs a user plane, or the VPC drops the forwarded UE traffic.
- **Load balancing**: MetalLB is not used on EKS. Serve N2 or S1 on a node port (`ingress[].nodePort` in the Site), or attach the radios' segment directly through Multus.
- **Autoscaling**: Karpenter provisions nodes with the right interface capacity; size its requirements for the user-plane instance types.
- **Storage**: the EBS CSI driver's `gp3` class as default.

Kind and other development clusters

Kind ships neither Multus nor the reference plugins. Install the Multus thick DaemonSet and copy the containernetworking plugins into `/opt/cni/bin` on the node, then use the node's `eth0` as the macvlan parent. Shrink Ignite (`spec.ignite.replicas: 1`, smaller `resources` and `jvm`) and set `spec.mariaDb.antiAffinity: false` on single-node clusters.

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4.4 Expeto CLI Guide for Operations

The Expeto CLI is an interactive shell for operations staff. It reads live state from the network functions of an xCore or xRouter Site and runs operational commands against them: querying a subscriber's session, listing radio connections, forcing a synchronisation with xControl. It runs as a sidecar of the Expeto Agent pod, so it needs no network access beyond `kubectl exec`.

4.4.1 Accessing the CLI

Open an interactive session in the CLI container of the Agent pod. The pod and container names depend on how the core was installed:

xCore (operator)

```
kubectl -n xcore exec -it xcore-xfabric-agent-0 -c agent-cli -- cli
```

xRouter (Helm chart)

```
kubectl -n xrouter exec -it xrouter-agent-0 -c cli -- cli
```

Replace the namespace and the release-name prefix with your own. The shell fetches the command sets of the connected functions at start-up and shows the `expeto_shell>` prompt.

4.4.2 Navigation and help

The CLI features a hierarchical, folder-like structure categorized by network types and functions (e.g., `lte` for 4G Core, `nr` for 5G Core, `debug` for operational commands).

- **List Directory (`ls`)**: Displays sub-directories, connected instances, and available commands (nouns and verbs) in the current context.
- **Change Directory (`cd`)**: Navigates through the command hierarchy. For example, `cd lte` moves into the 4G Core command set, and `cd ../nr` moves back and into the 5G Core command set.
- **Auto-complete (Tab)**: Press `Tab` at any time to auto-complete commands, noun names, or see available options. This is highly recommended to explore available parameters.
- **Help (`help` or `?`)**: Type `help` to see descriptions of commands in the current folder. You can also append `help` to a specific command to view its usage and options (e.g., `cmd sync-sub help`).

4.4.3 Command structure

Commands in the Expeto CLI generally follow a **Verb + Noun + [Options]** pattern.

Verbs

Verbs define the action to be taken on a resource. The available verbs depend on the noun: - **`read`** : Lists available records (e.g., a list of subscribers) or retrieves the detailed state of a specific record. - **`add`** : Adds a new record. - **`update`** : Modifies an existing record. - **`delete`** : Deletes a record. - **`show`** : Displays the current operational state of a component. - **`set`** : Changes the operational state of a component. - **`cmd`** : Executes a specific operational command or action.

Nouns

Nouns represent the network components or data entities you are interacting with. To see available nouns for your current context, use the `ls` command. - **4G (LTE) Examples**: `hss` , `mme` , `sgw` , `pgw` , `enodeb` . - **5G (NR) Examples**: `amf` , `smf` , `upf` , `udr` , `udsf` .

4.4.4 Examples

Exploring available commands

After login, `ls` shows the top-level folders:

```
expeto_shell>ls
Sub-directories:
-debug
```


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```
-lte     4G Core
-nr      5G Core
```

Listing components and supported actions

Enter a core (here 5G) and list its resources:

```
expeto_shell>cd nr
expeto_shell>nr>ls

Instances:
- name: birch-udr1
 description: HttpEndpoint(url=http://local-udr.default.svc.cluster.local:8080)

┌──────────────┬──────────────────┐
| Noun         | Verb(s)          |
├──────────────┼──────────────────┤
| amf          | read, delete     |
| associations | read             |
| smf          | delete, read     |
| udsf         | read, delete     |
| ...          | ...              |
└──────────────┴──────────────────┘
```

Reading and paginating records

To list the records of a function, for example the Unstructured Data Storage Function (UDSF):

```
expeto_shell>nr>read udsf
```

With many records, page through them with the `-o` (offset) option:

```
expeto_shell>nr>read udsf -o 10
```

Viewing a record

To see the full state of one record, append its identifier to `read`:

```
expeto_shell>nr>read udsf UPF:Controller:enterprise1:slice1:SmfInitHbInfoKey
```

Running operational actions

Operational actions, such as forcing a subscriber synchronisation with xControl, live in the `debug` folder. Run `help` on a command before executing it:

```
expeto_shell>nr>cd ../debug/ops/
expeto_shell>debug>ops>cmd sync-sub help
```

The help output lists the options: a single `imsi`, `siteWide` for the whole Site, and the `type` of synchronisation (`UPDATE` or `RECREATE`).

Loading subscriber-store keys

The keys the subscriber store needs are loaded through the CLI: the transport key of a SIM batch into the HSS (`cd /lte`, `add keyset name=<HSS Identifier>`) and the UDR (`cd /nr`, `add udr-keyset name=<HSS Identifier>`), and the home network's SUCI private key into the UDR (`cd /nr`, `add suci pkId=<key identifier>`). The CLI prompts for every key with masked input and never takes one on the command line. Follow the procedure in Load the subscriber-store keys.

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5. xRouter

5.1 Expeto xRouter

xRouter is the Expeto core that faces the public mobile networks. Deployed by the Mobile Network Operator (MNO) or in a data centre with IPX connectivity, it is the home network for Expeto SIMs roaming on public radio: it authenticates them, applies the subscriber's policy and forwards their traffic to the xCore that serves their enterprise.

5.1.1 What xRouter does

- **Home subscriber server.** The HSS answers Diameter S6a from the visited networks' MMEs and MAP from 3G networks over the IPX, holds the subscriber records synchronised from xControl, and hosts the SMS centre with SMPP delivery for messaging over the public networks.
- **Gateway towards the visited network.** The SMF, acting as SGW-C and PGW-C, terminates the GTP-C sessions the visited networks set up over S8, and the UPF forwards the GTP-U traffic on to the public xCore of the subscriber's enterprise.
- **Policy and routing.** Each session is routed to a downstream xCore user plane by the subscriber's System; the policy engine keeps the routing data in step with xControl.
- **BGP.** Address ranges are exchanged with the IPX side and with the downstream xCores over BGP, through MetalLB with FRR-K8s.

5.1.2 Network functions

The chart deploys these network functions:

Function	Role in xRouter
HSS	Subscriber authentication and data over Diameter (S6a and related applications) and MAP; SMS centre with SMPP.
SMF	SGW-C and PGW-C towards the visited networks; selects the downstream xCore user plane per subscriber.
UPF	GTP-U forwarding between the visited network and the downstream xCores.
NRF	Service discovery between the functions.
NFCM	Configuration, monitoring and statistics.
UDSF	Session state with the identifier allocator and timer services.
Fault manager	Alarm and event handling.
Expeto Agent	Connection to xControl: subscriber synchronisation, session records, metrics.

MariaDB Galera and Redis back the functions; both are installed by the chart.

5.1.3 Deployment model

xRouter is installed with Helm as one release per Site. Geo-redundant deployments run one installation per region with the HSS databases replicated between them, so a region can fail or be taken down for maintenance while subscribers stay authenticated. Every installation registers with xControl as a Site of type xRouter, and the same xControl manages the public xCores behind it.

The Installation section covers the cluster requirements, the IPX-facing configuration and the install itself.

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5.2 Installation

5.2.1 Planning and Prerequisites

xRouter runs on a Kubernetes cluster with connectivity to the IPX (or directly to the roaming partners) on one side and to the public xCores on the other. This page lists what the cluster needs, what to obtain from Expeto and xControl, and the interconnect data to gather before writing the `values.yaml`.

Cluster requirements

Requirement	Detail
Kubernetes	Version 1.29 or later, with `kubectl` (or `oc`) access that can create namespaces, CustomResourceDefinitions and cluster-scoped RBAC.
Helm	3.17 or later: upgrades of release 3.3.22 and later adopt the Prometheus Operator's CustomResourceDefinitions with `--take-ownership`.
Nodes	Three or more worker nodes for redundancy, sized per the sizing guide; user-plane nodes need the interfaces the IPX and downstream segments arrive on.
Kernel	SCTP support on every node that may run the HSS: Diameter and M3UA towards the IPX run over SCTP. The netcfg node-configuration operator loads the module and sets the network buffer sizes from the chart's `nodeNetworkConfig`; keep `global.manualNodeConfig` at `false` unless the platform team tunes nodes itself.
netcfg operator	Bundled with the chart and enabled by default. It is a cluster singleton shared by xControl, xCore and xRouter: on a cluster where another Expeto release already runs it, install with `netcfg.enabled=false`; the chart's `nodeNetworkConfig` is then applied by that operator.
DNS and cert-manager	A cluster DNS and cert-manager. cert-manager issues the internal certificates the functions use.
Storage	A default StorageClass providing `ReadWriteOnce` volumes for MariaDB Galera and Redis.
Service exposure	Either NodePorts, with the API server's `--service-node-port-range` widened to `1024-38413` so the Diameter (3868), MAP (2905), SMPP (2775), GTP-C (2123) and GTP-U (2152) ports can be published on the nodes, or Multus attachments and MetalLB LoadBalancer addresses on the IPX-facing segment.
Multus CNI	Recommended for production: the user plane and the HSS attach directly to the interconnect VLANs with fixed addresses. The chart can install Multus and whereabouts where the platform has none.
MetalLB with FRR-K8s	Required for BGP route exchange with the IPX and the downstream xCores, and for LoadBalancer addresses on bare-metal clusters. Not for managed clouds, which bring their own load balancers.
Outbound access	Nodes pull images from `docker.expeto.io`; the Helm client pulls charts from `repo.expeto.io`. The Agent reaches xControl over HTTPS.

The xCore platform notes describe how MicroK8s, OpenShift, Tanzu and EKS meet the Multus, SCTP and node-tuning requirements; they apply to xRouter unchanged.

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What to obtain

Item	Source	Used as
Registry credentials	Expeto Support. One username and password for the Helm repository and the container registry.	`imageCredentials.*`
Customer, Site and System identifiers	xControl. Create a Site of type xRouter under the Customer and at least one System under it.	`agent.connections.customerId` , `.siteId` , `.s`
Site API token	xControl, on the Site's API Tokens tab; see Connect the first Site.	`agent.connections.apiToken`
xControl URL	Your xControl installation, or Expeto's hosted service.	`agent.connections.serverUri` , `.brokerUri`

Interconnect data

Agree the following with the roaming partners, the IPX carrier and the network team. It maps directly onto the HSS and networking values described on the HSS configuration page.

Item	Needed for
Home PLMNs with their Diameter realms	Subscriber identity; one realm per PLMN in the form `epc.mnc<MNC>.mcc<MCC>.3gppnetwork.org` .
Diameter identity	The HSS host name and realm the partners' Diameter Routing Agents expect.
Diameter transport	SCTP or TCP, listen addresses (primary and secondary for multi-homing), port.
Diameter peers	For each DRA the HSS connects to or accepts: address, port, realm, host, protocol.
Diameter routing rules	Which peer hosts serve which realms.
MAP and SS7	SCCP variant (ITU or ANSI), the HSS's HLR point code and global title, the SMS centre's point code and global title, and for each STP link: point codes, network indicator, routing contexts, addresses and ports, SCCP address patterns.
Global title routing	Prefixes and the STPs they route to.
SMPP	System IDs and passwords of the SMPP clients, routing rules by destination address.
PLMN and UE addressing	MCC and MNC of the home network, the default UE address range and DNS servers, and the address ranges to advertise over BGP north (IPX) and south (xCores).
Interfaces	Which node interfaces and VLANs carry the IPX-facing and xCore-facing segments, and the addresses for the user plane on each.

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Namespace

Install xRouter into its own namespace; if xCore shares the cluster, keep the two in separate namespaces, and let only one of the two releases run the netcfg operator. The examples use `xrouter` as namespace and release name.

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5.2.2 Install with Helm

xRouter is installed as one Helm release from Expeto's chart repository. This page covers adding the repository, writing the values file, installing MetalLB where BGP or LoadBalancer addresses are needed, and the install itself. The IPX-facing HSS settings have their own configuration page.

Add the Helm repository

```
helm repo add expeto https://repo.expeto.io/repository/ngc \
  --username '<username>' --password '<password>'
helm repo update
helm search repo expeto/xrouter
```

Write the values file

> **Important**
>
> The values file for a deployment is agreed with Expeto Support during the design phase and applied as agreed. Route later changes through Expeto Support as well: interconnect and routing settings changed on your own are unsupported and can block a future upgrade.

The chart validates its values against a schema: an install without the required keys is refused before anything is created. A minimal `values.yaml`:

```
global:
  plmn:
    mcc: "001"
    mnc: "001"
  ueConfig:
    defaultIpRanges:
      ipv4Cidr: 100.64.0.0/20       # default UE address range
    defaultDnsServers:
      ipv4: [192.0.2.53]
    apn: internet

agent:
  connections:
    customerId: "2851"              # from xControl
    siteId: "3051"
    systemId: "3351"
    serverUri: https://xcontrol.example.com
    brokerUri: https://xcontrol.example.com

hss:
  diameter:
    tcp: false                      # SCTP towards the IPX
    host: hss01
    realm: epc.mnc001.mcc001.3gppnetwork.org
  map:
    enabled: true
  smsc:
    enabled: true
```

- `global.plmn` and `global.ueConfig` set the home network identity and the defaults for UE address assignment.
- `agent.connections` identifies the installation to xControl. The token is a secret and is passed on the command line.
- The `hss` block is where the interconnect configuration lives; the HSS configuration page walks through it.

The chart's `examples/` directory holds complete values files for typical deployments, including BGP towards both sides and a geo-redundant HSS:

```
helm pull expeto/xrouter --untar
ls xrouter/examples
```

The values reference lists the top-level sections.

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Install MetalLB

Skip this step on a managed cloud or when the cluster already runs MetalLB. Otherwise install MetalLB with FRR-K8s before the core, from Expeto's repository:

```
helm install metallb expeto/metallb -n metallb-system --create-namespace \
  --set metallb.frrk8s.nodeSelector.'node-role\.kubernetes\.io/worker'='' \
  --set imageCredentials.username='<username>' \
  --set imageCredentials.password='<password>' \
  --set imageCredentials.email='user@example.com'
```

The chart can also bundle MetalLB (`metallb.enabled=true`); because MetalLB's CustomResourceDefinitions must exist before the core's address pools are rendered, that route takes an install followed by an upgrade.

Install xRouter

```
kubectl create namespace xrouter
helm install xrouter expeto/xrouter -n xrouter -f values.yaml \
  --set imageCredentials.username='<username>' \
  --set imageCredentials.password='<password>' \
  --set imageCredentials.email='user@example.com' \
  --set agent.connections.apiToken='<site API token>'
```

Quote every `--set` value in single quotes so the shell and Helm's type coercion leave it alone. The release installs MariaDB Galera and Redis, then the network functions; expect several minutes on a fresh cluster.

```
kubectl -n xrouter get pods -w
```

The first install creates a Secret named `expeto-seed` in the namespace. Every generated password is derived from it, so the release can be reinstalled with the same credentials as long as the Secret is kept. Back it up with the values file.

OpenShift

Create a project instead of a namespace and use `oc` where this guide says `kubectl` . The chart detects OpenShift, renders Routes instead of Ingress objects and ships the security context constraints the user plane needs. Set the node port range with the cluster network operator:

```
oc patch network.config.openshift.io cluster --type=merge \
  -p '{"spec":{"serviceNodePortRange":"1024-38413"}}'
```

Next steps

Continue with Verify the installation.

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5.2.3 HSS Configuration

The HSS is the part of xRouter that the roaming partners talk to. Its configuration has two halves: the transport and peer settings of the HSS itself (Diameter, MAP over SS7, SMPP), which live under `hss` in `values.yaml`, and the home-network identity the Expeto Agent provisions into it (home PLMNs, HLR and SMS centre addressing), which lives under `agent.hss.nodeConfig`. This page maps the decisions from the interconnect data onto both.

All values shown are placeholders: replace the PLMN, realm, addresses, global titles and point codes with the ones agreed with your partners.

Home network identity

The Agent configures the HSS with the home PLMNs it serves and the SS7 identity it answers under. Everything under `agent.hss.nodeConfig` is passed to the Agent's HSS configuration unchanged.

```yaml
agent:
  hss:
    nodeConfig:
      hssConfig:
        homePlmns:
          - plmn:
              mcc: "001"
              mncs: ["001"]
              realm: epc.mnc001.mcc001.3gppnetwork.org
            gts: ["882600000001", "882600000002"]   # global titles serving this PLMN
        hostUri: hss01                      # Diameter host name of this HSS
        originHost: hss01.epc.mnc001.mcc001.3gppnetwork.org
        originRealm: epc.mnc001.mcc001.3gppnetwork.org
        hlrGt: "882600000001"                   # HLR global title
        pointCode: 2010                     # HLR point code
        hlrTt: 0                          # translation type
        hlrGti: GLOBAL_TITLE_INCLUDES_TRANSLATION_TYPE_NUMBERING_PLAN_ENCODING_SCHEME_AND_NATURE_OF_ADDRESS
        hlrEncoding: BCD_ODD
        allowRoaming: true
        smsInMme: false                     # S6a "SMS in MME" for the home PLMN
      smscConfig:
        gt: "882600000002"                  # SMS centre global title
        pointCode: 2010
```

Field	Purpose
`homePlmns[].plmn`	One entry per home PLMN: `mcc`, the list of `mncs` (two or three digits, as encoded on the SIMs) and the Diameter `realm`, normally `epc.mnc<MNC>.mcc<MCC>.3gppnetwork.org` with the MNC padded to three digits.
`homePlmns[].gts`	Global titles registered for the PLMN; the first is used as the HLR global title.
`hostUri`, `originHost`, `originRealm`	The Diameter identity this HSS presents to the partners' Diameter Routing Agents.
`hlrGt`, `pointCode`, `hlrTt`, `hlrGti`, `hlrEncoding`, `hlrNp`, `hlrNoai`	The HLR's SS7 addressing: global title, point code and the SCCP address indicators.
`allowRoaming`	Whether subscribers may attach from visited networks.
`smsInMme`	Enable delivery of SMS through the MME over S6a for this home network.
`smscConfig`	Global title and point code of the SMS centre.

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Diameter

Diameter is the S6a path from the visited networks' MMEs. The HSS listens on one or two addresses and either accepts connections from the partners' Diameter Routing Agents (DRAs) or initiates them.

```
hss:
  diameter:
    tcp: false                  # SCTP; set true for TCP
    host: hss01                 # Diameter host name
    realm: epc.mnc001.mcc001.3gppnetwork.org
    primaryIp: 192.0.2.10       # listen address; default 0.0.0.0
    secondaryIp: 192.0.2.11     # second address for SCTP multi-homing; omit for single-homed
    port: 3868
    capabilitiesIntersectionOnly: true
    applications:
      s6a: true
      s6b: true
      s13: true
      cxdx: true
      sh: true
      swx: false
    routingRules:
      - peerRealm: "*"
        peerHosts: [dra1.ipx.example.com, dra2.ipx.example.com]
    peers:                      # only for connections this HSS initiates
      - ip: 192.0.2.50
        port: 3868
        diameterRealm: ipx.example.com
        diameterHost: dra1.ipx.example.com
        protocol: SCTP
        hssIp: 192.0.2.10
        hssPort: 3868
```

Field	Purpose
`tcp`	Transport: SCTP (the IPX default) when `false`, TCP when `true`.
`host`, `realm`	Diameter identity; keep them consistent with `originHost` and `originRealm` above.
`primaryIp`, `secondaryIp`, `port`	Listen addresses and port. With Multus the addresses are the HSS pod's fixed addresses on the interconnect segment; with NodePorts leave the default.
`capabilitiesIntersectionOnly`	Advertise only the applications both sides support in the capabilities exchange.
`applications`	Which Diameter applications are enabled; extra keys are rendered as given.
`routingRules`	Which peer hosts serve which realms (`*` for any).
`peers`	DRAs this HSS connects to, with the local address and port to use. Omit when the partners initiate the connection.

MAP over SS7

MAP serves 3G partners and SMS. The HSS runs an M3UA stack over SCTP towards the partners' signalling transfer points (STPs), acting as server or client per link.

```
hss:
  map:
    enabled: true
    sccpVersion: ITU            # or ANSI
    hlr:
      pointCode: 2010
      globalTitle: "882600000001"
      sccp:
        - addressIndicator: "11"
          globalTitleType: GT0010
    smsc:
      pointCode: 2010
      globalTitle: "882600000002"
      sccp:
        - addressIndicator: "11"
          globalTitleType: GT0010
    servers:                    # local M3UA endpoints partners connect to
      - name: sctp1
        ip: 0.0.0.0
        port: 2905
    stps:
      - pointCodes: ["4444", "4445"]  # primary and backup point code of the STP
```


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```
    networkIndicator: "2"
    routingContexts: []        # only if the STP requires them
    trafficMode: 2             # 2 = load share, 1 = override
    sccp:
      - name: stp1-sccp
        addressIndicator: "19"
        globalTitleType: GT0100
        translationType: "0"
        encodingScheme: "1"
        numberingPlan: "0"
        natureOfAddress: "0"
    ips:
      - ip: 192.0.2.60         # the STP's address
        port: 2905
        name: stp1-link1
        linkTo: sctp1          # accept from this STP on our server "sctp1"
      - ip: 192.0.2.61
        port: 2906
        hlrIp: 192.0.2.10      # connect out from this address instead
        hlrPort: 2906
  routingRules:
    - addressIndicator: "19"
      globalTitleType: GT0100
      translationType: "0"
      encodingScheme: "1"
      numberingPlan: "0"
      natureOfAddress: "0"
      globalTitlePrefixes: ["8826*"]
      routeTo:
        - pointCode: 4444
          sccp: stp1-sccp
```

Field	Purpose
`sccpVersion`	`ITU` or `ANSI`, as the STPs use.
`hlr`, `smsc`	Point code, global title and SCCP address pattern of the HLR and the SMS centre. Keep them consistent with `agent.hss.nodeConfig`.
`servers`	Local SCTP endpoints on which STPs connect to the HSS.
`stps[]`	One entry per STP link: its point codes, network indicator, routing contexts, traffic mode, SCCP patterns and the addresses. An `ips[]` entry with `linkTo` accepts the STP's connection on the named server; one with `hlrIp` and `hlrPort` connects out to the STP.
`routingRules`	Global title prefixes and the STPs and SCCP patterns they are routed to.

The default SCCP address indicators (`11`, `GT0010`, translation type `10`, numbering plan ISDN, international nature of address) suit most ITU interconnects; the STP operator confirms the values.

SMS centre and SMPP

The SMS centre delivers messages over MAP to the partners and accepts SMPP clients for application-originated traffic:

```
hss:
  smsc:
    enabled: true
    smpp:
      clients:
        - systemId: acmecorp-app
          password: <SMPP password>
    routingRules:
      - destinationAddress: "1555*"
        destinationRoute: SMPP
        sourceRoute: ANY
        systemId: acmecorp-app
```

The SMPP port (2775) is published with the other HSS ports; see Verify the installation.

Exposed ports

The HSS chart publishes Diameter (3868), M3UA (2905) and SMPP (2775) as Services and, by default, as NodePorts on the same numbers, which is why the API server's node port range must include them. On a Multus deployment, attach the HSS to the interconnect segment through `hss.deployments.hss.networks` and give the partners the fixed address instead.

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Applying changes

The HSS reads its configuration at start-up. After changing any of the values above:

```
helm upgrade xrouter expeto/xrouter -n xrouter -f values.yaml \
    --set imageCredentials.username='<username>' \
    --set imageCredentials.password='<password>' \
    --set imageCredentials.email='user@example.com' \
    --set agent.connections.apiToken='<site API token>'
kubectl -n xrouter rollout status deployment/xrouter-hss
```

Peer state after a restart is visible in the HSS log; a partner link that does not come up is almost always an address, port or firewall mismatch on the interconnect.

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5.2.4 Verify the Installation

After `helm install` reports success, confirm that the release is healthy, that the Agent has registered with xControl, and that the IPX-facing endpoints are listening where the partners expect them. The commands use the `xrouter` namespace and release name.

Workloads

Every pod labelled as part of xRouter must be `Running`:

```
kubectl -n xrouter get pods -l app.kubernetes.io/part-of=xRouter
kubectl -n xrouter get pods -l app.kubernetes.io/part-of=xRouter \
  --field-selector=status.phase!=Running,status.phase!=Succeeded
```

The second command should print nothing. Pods are labelled with their function in `app.kubernetes.io/component`; the set for a default install is:

Component labels	Function
`agent`	Expeto Agent (StatefulSet, with the `cli` sidecar)
`hss`	HSS with SMS centre
`smf`	SGW-C and PGW-C
`controller`, `dataplane`, `idallocator`, `nrfproxy`	UPF
`nfdiscovery`, `nfmanagement`, `accesstoken`	NRF
`configuration`, `nfconfiguration`, `monitoring`, `statistics`	NFCM
`udsf`, `timer`	UDSF
`alarmhandler`, `eventhandler`	Fault manager

MariaDB Galera and Redis run as StatefulSets alongside them.

```
kubectl -n xrouter get pods -l app.kubernetes.io/component=hss
kubectl -n xrouter logs -l app.kubernetes.io/component=hss --tail=100
```

Endpoints

List the Services and confirm the IPX-facing ports are published the way the partners were told:

```
kubectl -n xrouter get services
```

Port	Protocol	Function
3868	SCTP or TCP	Diameter (HSS)
2905	SCTP	M3UA for MAP (HSS)
2775	TCP	SMPP (SMS centre)
2123	UDP	GTP-C (SMF)
2152	UDP	GTP-U (UPF)

With NodePorts, the node address plus the port is what the partners connect to. With MetalLB, the `EXTERNAL-IP` of the LoadBalancer Services is the advertised address; check that the routes reach the peer:

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```
kubectl -n metallb-system get bgppeers,ipaddresspools,bgpadvertisements
kubectl -n metallb-system logs -l component=frr-k8s --tail=50
```

For Multus attachments, the dataplane and HSS pods hold the fixed addresses:

```
kubectl -n xrouter exec statefulset/xrouter-upf-dataplane -- ip -br addr
```

Registration in xControl

Open **Sites** in xControl. The Site whose identifier you gave the chart shows **Connected**, with the Agent version and its address on the detail page. If it stays **Disconnected**, read the Agent log and check the identifiers, the token and that the pod resolves and reaches the xControl hostname on port 443:

```
kubectl -n xrouter logs xrouter-agent-0 -c agent --tail=100
```

Diameter and MAP peers

Once a partner's Diameter Routing Agent or STP is configured, the HSS log records the capability exchange and the M3UA association coming up; a peer that never appears there has a transport, address or firewall problem on the interconnect. The Operations CLI on the Agent pod gives a live view of the HSS and the sessions it serves:

```
kubectl -n xrouter exec -it xrouter-agent-0 -c cli -- cli
```

At the prompt, `cd lte` and `ls` list the HSS commands; `read hss <IMSI>` shows a subscriber as the HSS holds it. The CLI Guide covers the grammar.

End to end

With a subscriber provisioned in xControl on a System of this Site and its public xCore installed, an attach from the public network must authenticate through this HSS and its traffic must arrive at the enterprise. The installation and upgrade verification set covers that path under "Enterprise access through the public radio network".

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5.2.5 Upgrade, Scaling and Geo-Redundant HSS

This page covers the day-two operation of an xRouter installation: upgrading the release, scaling the functions, running the HSS database across regions, and uninstalling.

Upgrade

```
helm repo update
helm upgrade xrouter expeto/xrouter -n xrouter -f values.yaml \
  --set imageCredentials.username='<username>' \
  --set imageCredentials.password='<password>' \
  --set imageCredentials.email='user@example.com' \
  --set agent.connections.apiToken='<site API token>'
```

The values file is yours: it holds every setting of the installation, lives in version control, and is passed on every upgrade together with the secrets, exactly as at install time. Anything it does not mention takes the chart's default for the new release. If no values file is kept, `helm upgrade xrouter expeto/xrouter -n xrouter --reuse-values` carries the current release's values forward, secrets included.

The release rolls each function's pods one at a time. Database migrations for the HSS and the SMF run before the new pods start. Pin a chart version with `--version` when you need to control exactly what is installed, and render with `helm template` first on a production installation.

> **Important**
>
> Keep every setting in `values.yaml`. A change made with `kubectl edit` or `kubectl scale` is reverted by the next `helm upgrade`.

From release 3.3.22 the monitoring subchart installs and upgrades the Prometheus Operator's CustomResourceDefinitions. The first upgrade after an installation of 3.3.22 or later, and the upgrade from an earlier release to 3.3.22, stops before changing anything and prints the command that lets Helm adopt them: run that one upgrade with `--take-ownership` and `--set global.crds.ignoreOwnershipCheck=true` added to the command above. It needs Helm 3.17 or later; later upgrades need neither.

Scaling

Every function accepts a replica count or a Horizontal Pod Autoscaler, globally or per function:

```
replicaSet: 2              # default for every function
upf:
  statefulsets:
    dataplane:
      replicaSet: 4        # user plane throughput
smf:
  autoscaling:
    enabled: true
    minReplicas: 2
    maxReplicas: 6
```

When autoscaling is enabled for a function its `replicaSet` is ignored. The user plane scales linearly with dataplane replicas; the control plane and the HSS are sized for subscribers and transaction rate. The sizing guide gives the node figures.

The session table of the user plane is set with `nfcm.dataNetwork.numSessions`; size it for the expected concurrent sessions before go-live.

Geo-redundant HSS

The HSS stores subscribers in MariaDB Galera. Two or more installations in different regions can share one Galera cluster spanning all of them, so every HSS answers from the same subscriber data and a region can be lost without losing authentication.

The chart's `examples/geo-redundant-hss.yaml` is the reference. In outline, each installation:

- runs its own MariaDB Galera StatefulSet for the HSS (`hss.galeracluster`), with TLS between the nodes;
- publishes the Galera replication ports (group communication, incremental and full state transfer) as NodePorts, three per node;
- lists every other installation's database node under `replication.clusterNodes` with those ports, and resolves their names through `hostAliases`;
- carries a `replication.segment` number per region so Galera prefers local replication.

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A two-region cluster needs a third voter to avoid a split brain: run a Galera arbitrator at a third location. Agree the segment layout, addresses and certificates with Expeto Support before the first install; the topology is set when the databases are created.

Uninstall

```
helm uninstall xrouter -n xrouter
kubectl -n xrouter get pvc
```

Helm leaves the PersistentVolumeClaims of MariaDB and Redis and the `expeto-seed` Secret in place. Delete the claims only when the subscriber data is no longer needed; keep the seed Secret if the release is to be reinstalled with the same credentials.

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5.2.6 values.yaml Reference

The xRouter chart is configured entirely through Helm values. This page maps the top-level sections of `values.yaml`; run `helm show values expeto/xrouter` for the complete file with its inline comments. Values are checked against the chart's schema at install time. The values file for a deployment is agreed with Expeto Support during design; use this page to read it, and route changes through Expeto Support.

Required values

Value	Purpose
`imageCredentials.username`, `.password`, `.email`	Registry credentials, written into the `expeto` pull Secret. Pass them with `--set`.
`agent.connections.customerId`, `.siteId`, `.systemId`	The xControl Customer, Site and System this installation belongs to.
`agent.connections.serverUri`, `.brokerUri`	The xControl installation the Agent connects to.
`agent.connections.apiToken`	The Site's API token. Pass it with `--set`.
`global.plmn.mcc`, `.mnc`	The home PLMN.
`global.ueConfig.defaultIpRanges.ipv4Cidr`	Default UE address range.

Global settings

Section	Purpose
`global.productName`, `global.imageRegistry`	Labels and the registry every image is pulled from; point the registry at a mirror for air-gapped clusters.
`global.k8sPlatform`	Force a platform profile (`openshift`, `eks`, `aks`, `microk8s`, `tanzu`) when rendering without a cluster.
`global.manualNodeConfig`	`true` renders no node configuration at all: neither the netcfg operator nor the `nodeNetworkConfig` resource. The platform team then prepares kernel modules, sysctls and NIC queues itself.
`global.metallb.namespace`, `global.frrk8s.namespace`	Namespaces of an existing MetalLB and FRR-K8s. MetalLB resources default to `metallb-system`; FRR configurations default to `openshift-frr-k8s` on OpenShift and to the MetalLB namespace elsewhere. Not used with the bundled MetalLB, whose resources stay in the release namespace.
`global.tls`	Enable TLS between the functions with certificates from cert-manager.
`global.plmn`, `global.ambr`, `global.ueConfig`	Home PLMN, default bit-rate limits, default UE address ranges, DNS servers and APN.
`global.frr`	BGP routers and neighbours: typically a `north` router towards the IPX and a `south` router (in its own VRF) towards the xCores, each with the prefixes to advertise and accept.
`global.networks`	Network attachments and MetalLB address pools shared by the functions.
`global.database`, `global.store`	MariaDB Galera and Redis settings shared by the functions.
`global.eks`	Karpenter and ENI settings for EKS.

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Network functions

Section	Purpose
`agent`	The Expeto Agent: connection to xControl, the `gateways` it reports (the SMF and UPF roles of this installation), the HSS functions it drives (provisioning, integrity check, metrics).
`hss`	The HSS: Diameter (`hss.diameter`), MAP over M3UA (`hss.map`), SMS centre and SMPP (`hss.smsc`), SIP interworking (`hss.sip`), its database (`hss.galeracluster`), exposed ports and Java heap. See HSS configuration.
`smf`	SGW-C and PGW-C.
`upf`	The user plane: dataplane StatefulSet, controller, replicas and autoscaling.
`nfcm`	Configuration management, monitoring and statistics; `nfcm.dataNetwork.numSessions` sizes the session table.
`nrf` , `udsf` , `faultmanager`	Service discovery, session state and fault handling. Enabled by default.
`pcef`	Policy and charging enforcement towards a PCRF over Gx. Disabled by default.

Each function accepts `enabled` , `replicaSet` , `autoscaling` , `resources` , `nodeSelector` , `tolerations` and `affinity` , and per-workload overrides under `deployments.<name>` or `statefulsets.<name>` .

Networking

Section	Purpose
`createNetworks`	Render the `NetworkAttachmentDefinition` and MetalLB objects declared under `global.networks` .
`metallb`	Bundle MetalLB with FRR-K8s.
`multus-cni` , `whereabouts` , `cni-route-override`	Bundle Multus and its companions where the platform has none.
`netcfg`	The bundled netcfg node-configuration operator, a cluster singleton. Set `netcfg.enabled=false` when another Expeto release on the cluster already runs it.
`nodeNetworkConfig`	xRouter's node requirements, rendered as a `NodeNetworkConfig` resource the netcfg operator applies to every node: kernel modules, sysctls and, per named interface, transmit queue lengths, addresses, routes and iptables rules.
`securityContextConstraints`	OpenShift security context constraints for the privileged user plane.
`tls`	Certificate issuer for the internal certificates.

Infrastructure and monitoring

Section	Purpose
`galeracluster` , `redis`	The shared MariaDB Galera cluster and Redis.
`couchbase`	Optional document store for NFCM.
`kubemonitoring`	Namespace-scoped Prometheus scraping the functions; the Agent relays the metrics to xControl for xView.

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Section	Purpose
`teleport-kube-agent`	Optional Teleport agent for Expeto Support access.
`karpenter`	Node autoscaling on EKS.
`serviceAccount` , `role`	The service account and RBAC the functions run with.

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Sizing Guide

This page gives the compute and storage figures for running the Expeto Platform components on Kubernetes: how many nodes, how large, and how much disk for a given throughput or subscriber count. Use it with the sizing calculator when planning a deployment.

Platform components

The Expeto platform consists of several key components that work together to deliver network services:

xCore / xRouter

- Built to scale horizontally based on data throughput capacity needs
- Configurable redundancy from none to full geographic redundancy
- xRouter deployment:
  - Typically hosted centrally by the network operator
  - Geo-redundant deployments available for High Availability, Data Sovereignty, or low latency localization
- xCore deployment:
  - Typically hosted by the end customer
  - Flexible deployment model with one to many xCores to match specific use cases

xControl / xView

- Deployment model:
  - Typically deployed centrally by the network operator
  - Geo-redundant deployments available for High Availability
- Scaling:
  - Built to scale vertically depending on node specifications
  - Sized according to required active subscribers
- Redundancy options:
  - Single site with failover capability
  - Full geographic redundancy

All platform components are deployed in Kubernetes Clusters for consistent management and orchestration.

Kubernetes infrastructure Key definitions

Node: A physical or virtual machine with defined capacity to run Kubernetes workloads

Cluster: A group of nodes working together to run an Expeto Component in a single geographic location

Redundancy: Each cluster contains two or more nodes to provide service continuity, ideally three or more depending on the Kubernetes environment.

Geographic redundancy: Two or more cluster locations, each with two or more nodes, for multi-site resilience.

Assumptions

- The underlying infrastructure is composed of Kubernetes nodes running either on bare metal or on virtual machines with a modern Linux kernel (5.13 or later), or on a hosted Kubernetes offering such as AKS, GKE, EKS or DigitalOcean Kubernetes.
- The same nodes can be used for both the control plane and the worker nodes though for production systems it is strongly recommended to use separate nodes. At minimum, 3 nodes are always needed to guarantee redundancy and availability for both control-plane and worker nodes.
- Expeto is not recommending the size, specification, or number of the underlying physical servers, only the resources allocated to the Kubernetes nodes required to run the Expeto components. A compute partner may recommend the physical server and network switch designs.

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- This design is for a single cluster deployment at a co-location or cloud provider running on x86_64 (amd64) based processors and does not take into consideration geographic or other types of 'failover'. It is not recommended to have clusters spanning multiple geographically separated co-locations or geographic regions.
- High Availability (HA) is achieved using multiple clusters in an active-active setup.
- The choice of hypervisors/operating systems for nodes, and their maintenance and support, is left to the discretion of the operations team as per best practices.

Node selectors, tolerations and affinity

Workloads can be associated and restricted to specific nodes but special care must be taken to prevent single points of failure or compromise performance or load balancing.

The simplest way to associate a workload with a specific node is to use node-selectors in combination with labels. This allows pods from a specific workload to be assigned to dedicated nodes which can be either VMs or bare metal. This is generally only recommended when physical constraints are in place because of network interface cards or other infrastructure components.

Affinities are more powerful and flexible than node-selectors and allow "soft" preferences. These soft preferences allow failover to other nodes and the ability to choose if pods should move back when a node does come back. Anti-affinities are also supported and can be used to achieve redundancy without restricting load-balancing.

Taints and tolerations are the most powerful but also the most complex. They allow advanced scheduling logic to be written to the exact specifications and requirements of the hardware and customer.

These topics should be familiar to most experienced Kubernetes administrators and as such will not be covered in more detail here but for more information see: - Assign Pods to Nodes - Taint and Toleration

Node configuration and performance

For best performance and resource utilization, configuration changes should be made to the underlying hardware and host operating systems. This includes but is not limited to changing kernel settings and parameters, network interface settings and queue lengths, NIC drivers, and settings.

These settings and modules are configured automatically by MachineConfigs or DaemonSets but can be configured manually if desired.

Supported Kubernetes platforms

- VMware Tanzu
- RedHat OpenShift/MicroShift
- MicroK8s
- EKS
- AKS*
- GKE*
- DigitalOcean Kubernetes*

* Some hosted Kubernetes platforms have limitations on performance and networking configurations that should be considered.

xCore and xRouter scaling Key assumptions

- Default size descriptions are for production deployments using built-in Kubernetes networking.
- VPP/DPDK/SR-IOV networking functionality can be enabled for substantially better networking performance.
- Capacity limits are estimated based on typical deployments. Actual limits depend on traffic model of end customers
- A k8s node can be deployed bare metal or on a VM. For redundancy, multiple VMs should always be distributed on as many physical servers as specified.
- HA Sizing recommendations assume an active-active configuration.
- Unless otherwise specified, CPU/Core count refers to physical cores and not hyperthreaded vCPUs.
- All disks should be enterprise SSD storage in a redundant setup, made available as PersistentVolumes via PersistentVolumeClaims from any node in the cluster with ReadWriteOnce access.

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Sizing methodology

1. **Determine redundancy requirements (cluster size)**
   - 1 node – no redundancy (total capacity = 1 node)
   - 2 nodes – failover redundancy (total capacity = 1 node, MicroK8s only)
   - 3+ nodes – horizontal scalable redundancy (total capacity = n nodes - 1)
   - Geographic requires 2+ clusters (total capacity = n clusters - 1)
2. **Select scale per node**
   - 4 CPU / 32 GB – up to 2 Gbps or 50,000 subscribers
   - 4 CPU / 64 GB with VPP/DPDK/SR-IOV – up to 10 Gbps or 250,000 subscribers
   - 8 CPU / 64 GB – up to 4 Gbps or 100,000 subscribers
   - 8 CPU / 96 GB with VPP/DPDK/SR-IOV – up to 20 Gbps or 500,000 subscribers
3. **Build clusters based on capacity requirements**

Storage requirements

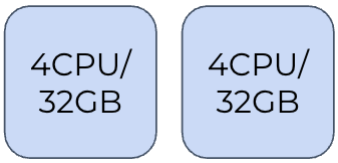
Disk per cluster: 100GB per 2 Gbps capacity

Example configurations 2 Gbps, no redundancy



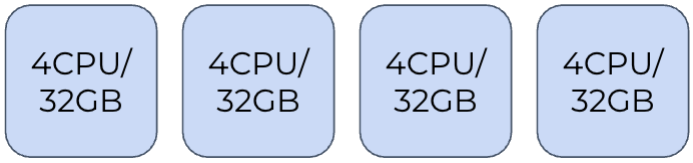
- Single node: 4 CPU / 32 GB
- 100 GB Disk Storage

2 Gbps, with redundancy



- Two nodes: 4 CPU / 32 GB each
- 200 GB Disk Storage

6 Gbps, scalable and redundant



- Four nodes: 4 CPU / 32 GB each
- 300 GB Disk Storage

12 Gbps, scalable and redundant

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- Four nodes: 8 CPU / 64 GB each
- 600 GB Disk Storage
- Higher capacity per node for increased throughput

xControl and xView scaling Key assumptions

- Capacity limits are estimated based on typical deployments. Actual limits depend on traffic model of end customers
- A k8s node can be deployed bare metal or on a VM. For redundancy, multiple VMs should always be distributed on as many physical servers as specified.
- HA Sizing recommendations assume the use of an active-active configuration.
- Unless otherwise specified, CPU/Core count refers to physical cores and not hyperthreaded vCPUs.
- All disks should be enterprise SSD storage in a redundant setup, made available as PersistentVolumes via PersistentVolumeClaims from any node in the cluster with ReadWriteOnce access.

Sizing methodology

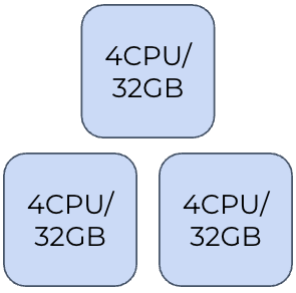
1. **Determine redundancy requirements (cluster size)**
   - Single Location (2+ nodes)
   - Geographic failover (2 clusters)
2. **Scale per node**
   - 4 CPU / 32 GB – up to 100,000 subscribers
   - 8 CPU / 64 GB – up to 500,000 subscribers
   - 16 CPU / 128 GB – up to 1,000,000 subscribers
3. **Build clusters based on capacity requirements**

Storage requirements

Disk requirements per cluster:

- 100K subscribers = 1 TB
- 500K subscribers = 4 TB
- 1M subscribers = 8 TB

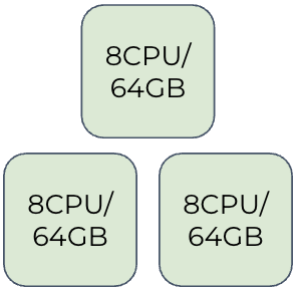
Example configurations 100,000 subscribers



- Three nodes: 4 CPU / 32 GB each
- 1 TB Disk Storage

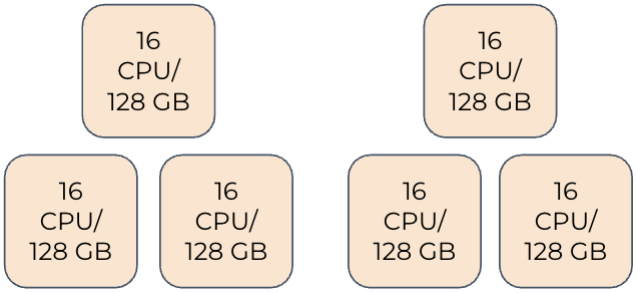
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500,000 subscribers



- Three nodes: 8 CPU / 64 GB each
- 4 TB Disk Storage

1,000,000 subscribers with geographic failover



- Location A: Three nodes of 16 CPU / 128 GB each
- Location B: Three nodes of 16 CPU / 128 GB each
- Provides complete geographic redundancy
- 8 TB Disk Storage

For sizing recommendations tailored to a specific deployment, consult Expeto technical specialists.

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6. Testing

6.1 Testing at Expeto

This section describes how the Expeto Platform is verified before a release reaches a mobile operator, publishes the acceptance test catalog an MNO uses to plan its own verification, and states the platform's conformance to the 3GPP specifications it implements.

Expeto's approach is deliberately compact and deliberately transparent. The platform is a focused private-wireless core, not a national core, and the published tests reflect that: a catalog of end-to-end procedures that exercise the platform the way an MNO's enterprise customers use it, executed on real devices against a complete deployment, with signalling evidence captured where it matters. Behind the catalog sits a continuous verification pipeline that installs real cores on Kubernetes and drives them with 3GPP peer simulators on every code change.

6.1.1 Four layers of verification

Layer	What runs	Against	When
Component tests	Unit and component suites in every repository	The component in isolation, with real databases where the component needs one	Every merge request
Continuous end-to-end verification	Six platform suites that install xControl, xView and the cores from published charts, and browser tests of xControl	Real deployments on Kubernetes, 3GPP peer simulators for radio and core signalling, real Chromium browsers	Every merge request, plus a weekly deep soak
Release certification	Declarative core configurations driven end to end with subscriber lifecycle scenarios	A real cluster	Before a release is published
Acceptance testing	The published acceptance test catalog	A complete deployment with real devices and radios	Every release candidate in Expeto's lab, and the installation and upgrade verification set in the MNO's environment

6.1.2 What is published here

Page	What it covers
How Expeto tests	Test levels, cadence, environments, release gating, evidence, and how the catalog is maintained as code.
Test environment and tooling	The reference topology, where to capture signalling, the tools each procedure assumes, and how evidence is named and kept.
How to read and run a procedure	The anatomy of a test card, how procedures chain, how results are recorded, and the glossary of xControl and 3GPP states.

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Page	What it covers
Continuous verification	What runs automatically on every change: the platform suites, the xControl browser suite, release certification, component tests and supply-chain checks.
Acceptance test catalog	End-to-end tests of Expeto Edge (xCore), Expeto Gateway (xRouter) and Expeto Management (xControl and xView), by domain, with full procedures.
Installation and upgrade verification	The minimal set an MNO runs after every installation or upgrade, with its execution order and results sheet.
Standards coverage	The 3GPP procedure each test exercises, and which tests cover each cited clause.
Campaign planning and results	Effort and resources per domain, a suggested sequence, and the results template.
Standards conformance	The item-level conformance statements against the 3GPP and IETF specifications the network functions implement, generated from a structured source, with the capabilities the platform does not exercise marked as such.

6.1.3 Principles

Tests are code. Every acceptance test is a version-controlled source file in the same repository as this documentation. A test changes the same way the software does: through a reviewed merge request. The catalog pages are generated from those sources, and the documentation pipeline refuses to publish a page that differs from its source.

End to end, on real devices. Acceptance tests are executed with commercial UEs against a complete deployment of xCore, xRouter and xControl, not against mocks. Where a procedure has a defined 3GPP flow, the signalling capture is part of the evidence.

Stable identifiers. Each test has a permanent public identifier. Release notes cite test identifiers when a release adds, changes or retires a test, so an MNO can trace a release to the tests that gated it.

Nothing is published half-finished. Every procedure in the catalog is complete and reviewed before it is released; the result of executing it on a platform release is recorded per release in the acceptance test report. The continuous verification pages state the real cadence of every automated suite, including the ones that run on demand.

MNOs run the same tests. The installation and upgrade verification set is written to be executed by an operator's own test team in its own environment, and Expeto reviews the results with the MNO before sign-off.

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6.2 How Expeto Tests

This page describes the levels at which the Expeto Platform is tested, how often each level runs, what gates a release, what evidence is kept, and how the acceptance test catalog is maintained. It is the reference an MNO's test or assurance team uses to understand what Expeto has already verified before a release arrives.

6.2.1 Test levels

Level	Scope	Executed by	When
Component tests	Individual services and network functions inside xCore, xRouter and xControl, with real databases where a component needs one	Automated, in each repository's pipeline	Every merge request
Platform end-to-end suites	Complete platform installs from published Helm charts on Kubernetes, driven by 3GPP peer simulators: provisioning, session flows, soaks, capacity ramps, fault injection, monitoring, browser checks of xControl	Automated, six suites per pipeline	Every merge request; weekly deep soak
xControl browser suite	The management portal's create, edit, search, filter and report flows in a real Chromium browser against a real backend	Automated, on demand	Before an xControl release
Release certification	Declarative core configurations applied to a real cluster and driven with subscriber lifecycle scenarios; a single go or no-go verdict per configuration	Automated harness, run by Engineering	Before a release is published
Acceptance tests	End-to-end behaviour of a complete deployment with real devices and radios, per the acceptance test catalog	QA, manual and scripted	Every release candidate

The first four levels are described in Continuous verification, including the cadence of each suite and the checks that run on demand rather than on every change. The acceptance tests are the subject of the rest of this section.

6.2.2 Environments

Acceptance testing is performed in Expeto's lab against a complete platform: Expeto Edge (xCore) on Kubernetes, Expeto Gateway (xRouter), and Expeto Management (xControl and xView), with private radios and commercial UEs. A test that depends on topology (a Kubernetes node failure, a geo-redundant failover, a public-radio path through xRouter) states that topology in its **Applies to** facets and preconditions and is executed on that topology.

MNOs execute the installation and upgrade verification set in their own environment after installing an xCore and before promoting an upgrade to production. Expeto does not host pre-production or production infrastructure; every procedure in the catalog is written to run in the MNO's environment with the MNO's own devices.

6.2.3 Release gating

A platform release is published to MNOs only when:

1. every component test and every platform end-to-end suite is green on the release commit;

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2. the release certification harness passes for the reference configurations;
3. every test in the acceptance test catalog that applies to the changed components has been executed on the release candidate, with a passing result or an agreed, documented deviation;
4. any test added or modified for the release has been reviewed and accepted in the test repository;
5. the release notes cite the test identifiers affected by the release.

Results are recorded per release in an acceptance test report that lists each test identifier, its result, the tester, the date and the evidence reference. MNOs receive the report for each release they deploy on request.

6.2.4 Evidence

Each acceptance test names the evidence collected when it is executed. Typical evidence is a 3GPP signalling capture (pcap) showing the expected procedure, the Mobile Asset's session event log in xControl, a device-side connectivity or throughput result, and, for resilience tests, the Kubernetes or service status before and after the fault. Test environment and tooling defines where each capture is taken and how evidence files are named. Evidence is retained with the acceptance test report for the release.

6.2.5 Test status

Status	Meaning
Accepted	The procedure is complete, has been reviewed by QA and by the engineering owner of the component it exercises, and is released in the catalog.
Retired	No longer executed. Keeps its identifier for the record; not shown in the catalog.

Every procedure in the catalog is accepted; a procedure that is still being written stays on a branch and is not published. The result of executing a procedure on a given platform release is not a property of the procedure: it is recorded, per release, in the acceptance test report described under Release gating.

6.2.6 How the catalog is maintained

The catalog is a set of structured source files, one per domain, in the same repository as this documentation. Each test is a record with a permanent identifier, its applicability facets, preconditions, single-action steps with expected results, the 3GPP clauses it exercises, the evidence it produces and the automated checks that mirror it. Any Expeto engineer can propose a new test or a change through a merge request; every change is reviewed by QA and, for platform behaviour, by the engineering owner of the affected component, and is published only once accepted.

The pages in this section are generated from those sources. The generator validates every identifier, cross-reference and vocabulary, and the documentation pipeline fails if a published page differs from its source, so what an MNO reads is what Expeto executes.

New tests most often come from three places: a feature or behaviour change in a release, a defect found in the field that had no covering test, and a scenario raised by an MNO during onboarding. MNOs are welcome to propose scenarios through their Expeto account team; an accepted scenario becomes a test with a public identifier.

6.2.7 Scope and limitations

The catalog covers the Expeto Platform. It does not cover the mobile operator's radio access network, transport, or core network beyond the interfaces xRouter and xCore present to them; those remain the mobile operator's responsibility and are covered by the operator's own test programs. Device interoperability is tested with a representative set of commercial UEs; an MNO with specific device requirements includes them when it runs the installation and upgrade verification set.

The following are not provided by the Expeto Platform. No acceptance test covers them, and the standards conformance statements mark the related items **Not applicable**:

- voice services (VoLTE, VoNR, IMS);
- emergency services;

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- network slice-specific authentication and authorization (NSSAA);
- SMS on the private radio path (SMS is tested on the public radio path, where the Expeto SMSC in xRouter serves it);
- mobility between the 4G and 5G cores of a site over the N26 interface (a combined core interworks without N26);
- non-3GPP access to the 4G and 5G cores;
- power-saving modes (eDRX, PSM);
- dynamic policy control through a PCF (N7, N15), policy being applied from the subscription profile instead;
- a Network Slice Selection Function, the AMF granting the subscribed S-NSSAIs instead;
- the visited-network side of a roaming split (V-SMF, I-SMF, V-PCF, N32), roaming subscribers being served from the home side over S6a, S8 and Gp.

The following are implemented by the network function software but are not configured in an Expeto deployment by default, so no acceptance test covers them. Their statements are published under Additional network function capabilities; enabling one is configuration work agreed with Expeto Product Support:

- circuit-switched fallback and the SGs interface;
- cell broadcast (SBc);
- location services (SLs, SLg, 5G LCS);
- lawful interception;
- subscriber and equipment trace;
- EPS AAA interfaces for non-3GPP access (SWx, STa, SWm, SWa, S6b).

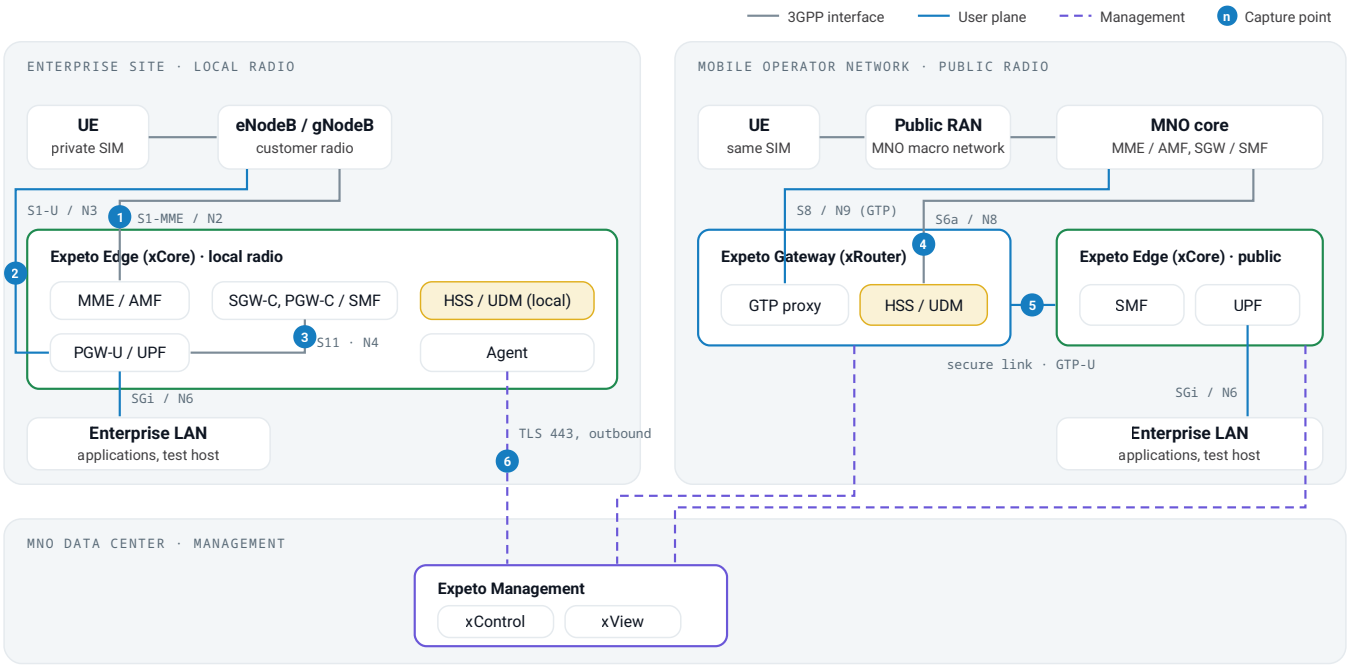
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6.3 Test Environment and Tooling

This page defines the environment every procedure in the acceptance test catalog assumes: the reference topology and its capture points, the tools a tester needs, what the devices and SIMs must be able to do, and how evidence is named and kept. Read it once before planning a campaign; the procedures refer to it rather than repeating it.

6.3.1 Reference topology

The platform is exercised on two access paths that share one Mobile Asset, one xControl and one enterprise network. On the **local-radio path**, customer-controlled radios attach directly to an Expeto Edge (xCore) instance at the site; authentication is performed by the subscriber database inside that xCore and nothing leaves the site. On the **public-radio path**, the same SIM attaches to the mobile operator's macro network; the operator's core reaches Expeto Gateway (xRouter), which authenticates the subscriber and forwards user-plane traffic over a secure link to the xCore instance dedicated to that customer in its public configuration. Both xCores and the xRouter are managed by Expeto Management (xControl and xView) through an agent that connects outbound from each site.



Reference test topology. Both paths end on the same enterprise network; the yellow chips are the functions that hold subscriber credentials, and the numbered badges are the capture points listed below.

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6.3.2 Capture points

Every procedure that ends with "inspect the signalling capture" expects a capture at one or more of these points. Capture on the host interface that carries the traffic (with `tcpdump` on the node, or a port mirror on the switch) or on the radio itself.

#	Interface	Where	Wireshark display filter	What to look for
1	S1-MME (4G) / N2 (5G)	Between the radio and the MME or AMF, on the node interface facing the radio	`s1ap || nas-eps` / `ngap || nas-5gs`	Attach or Registration, Authentication, Security Mode, Initial Context Setup, Detach or Deregistration, Paging, UE Context Release
2	S1-U (4G) / N3 (5G)	Between the radio and the user plane (PGW-U / UPF)	`gtp`	GTP-U tunnels carrying the UE's traffic; TEIDs match the session setup
3	S11 (4G) / N4 (PFCP)	Inside the xCore, between control-plane and user-plane pods	`gtpv2` / `pfcp`	Create Session, Modify Bearer, Delete Session; PFCP Session Establishment, Modification, Deletion
4	S6a (4G) / N8 and N12 (5G)	Between the mobile operator's core and the HSS or UDM inside xRouter (public radio); inside the xCore on the local-radio path	`diameter` / `http2`	Authentication Information and Update Location; Cancel Location on a network-initiated detach; Capabilities-Exchange (CER/CEA) and Device-Watchdog (DWR/DWA) with each Diameter peer
5	Secure link	Between xRouter and the public-configuration xCore	`gtp`	User-plane traffic only; no signalling traverses the link
6	Management path	From the xCore agent to xControl	`tls && tcp.port == 443`	The connection is initiated from the xCore; no inbound connection is required
7	SMS over MAP	Between the operator's signalling network and the SMSC in xRouter (SIGTRAN)	`gsm_map || tcap`	MO-ForwardSM, SendRoutingInfoForSM, MT-ForwardSM, ReportSMDeliveryStatus, ReadyForSM, AlertServiceCentre

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#	Interface	Where	Wireshark display filter	What to look for
8	SMS over SGd	Between the operator's MME (or SMS router) and the SMSC in xRouter	`diameter.applicationId == 16777313`	MO-Forward-Short-Message (OFR/OFA), MT-Forward-Short-Message (TFR/TFA), Alert-Service-Centre (ALR/ALA)
9	SMPP	Between an application server and the SMSC in xRouter (port 2775)	`smpp`	bind, submit_sm, deliver_sm, delivery receipts
10	Gp (3G)	Between the operator's SGSN and the GTP proxy in xRouter (GTPv1-C on port 2123, GTPv1-U on 2152)	`gtp && gtp.flags.version == 1`	Create PDP Context, Update PDP Context, Delete PDP Context; the GTPv1-U tunnel that follows
11	MAP (HLR)	Between the operator's SGSN or VLR and the HLR in xRouter (SIGTRAN, M3UA)	`gsm_map || tcap`	SendAuthenticationInfo, UpdateGprsLocation, UpdateLocation, InsertSubscriberData, CancelLocation

6.3.3 Tools

Tool	Used for	Notes
Signalling capture	Evidence for every procedure with a 3GPP flow	`tcpdump` or an equivalent at the capture points above; save as `.pcapng`
xControl	Mobile Asset status, session **Event Log**, Sites, Systems, Reports	Log in with the role the procedure names. Bulk actions, **Cancel Session** and CSV export require **ADMIN**
xControl API	Scripted provisioning and verification	The REST API documented under **API** in this guide; use an API token for the Customer under test
Expeto CLI	Reading the state of a network function (MME/AMF context, HSS/UDR record, sessions) and forcing a subscriber synchronization	`kubectl exec -it <release>-xfabric-agent-0 -c agent-cli -- cli` on xCore, `kubectl exec -it <release>-agent-0 -c cli -- cli` on xRouter and xControl; the commands the procedures use are listed below, and the CLI guide under **xCore** explains navigation
`kubectl`	Node, pod and service status for resilience tests; log collection	Read-only access to the xCore, xRouter and xControl namespaces is sufficient

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Tool	Used for	Notes
Throughput measurement	AMBR, throughput and failover tests	An iperf3 or OpenSpeedTest server on the enterprise LAN, which gives a measurement inside the enterprise network with no internet dependency
Network-side test host	Paging and reachability tests	A host on the enterprise LAN (SGi / N6 side) that can send ICMP or TCP traffic toward a UE address
xView	Metrics and alerts as evidence for operations tests	Prometheus metrics such as `xcore_clients`, `xcore_upload_bytes_total`, `xcore_download_bytes_total` and `xcore_sync_*`, filtered by the `site` and `customer` labels
3GPP peer simulator	Capacity, stability and signalling-storm tests that exceed what devices can produce	Expeto's simulator plays the radio and peer-core side of the protocols (eNodeB over S1AP with UE lifecycles, the S11 peer, gNodeB and UE). Tests that offer a simulator variant say so in their resources
SMPP test client	SMS tests	An external short message entity (ESME) that binds to the SMSC in xRouter with a system id from the SMSC configuration, sends `submit_sm` and receives `deliver_sm`, including delivery receipts

6.3.4 CLI commands used by the procedures

Open the CLI with `kubectl exec -it <release>-xfabric-agent-0 -c agent-cli -- cli` on xCore, or `kubectl exec -it <release>-agent-0 -c cli -- cli` on xRouter and xControl. Commands are folder-scoped: `cd` to the folder first. Options are `key=value`; list filters are `-f key=value`; `-s <n>` sets the page size. A one-shot form for scripts is `cli "cd /debug/ops && cmd sync-sub-check mode=FULL"`.

Need	Command	What the output shows
Subscriber record	`cd /lte`, `read hss <imsi>`; 5G: `cd /nr`, `read udr <imsi>`	The subscriber's record on the Site, or "not found"
MME or AMF context, idle or connected, serving cell	`read mme -f imsi=<imsi>` (4G list), `read mme <imsi>` (full context); `read amf <imsi>` (5G)	Columns imsi, enodeb, state, bearers; 5G Status (CM-IDLE or CM-CONNECTED), PLMN-CellId, TAC, gNodeB
Sessions with the UE address	`read pgw -f imsi=<imsi>`, `read sgw -f imsi=<imsi>` (4G); `read smf -f imsi=<imsi>` (5G)	Instance, IMSI, Bearer/PDU ID, Ip Address, SessionState, last download and upload bytes, Uptime
Connected radios	`cd /lte`, `read enodeb`; 5G: `cd /nr`, `read ran`	id, address, plmn, tais; 5G RanNode ID, IP:PORT, PLMN(s), TAC(s)

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Need	Command	What the output shows
PFCP associations	`read associations -f type=pfcp`	Instance, type, nodeId, peerIp, heartbeatSeqNum
Full subscriber synchronization check	`cd /debug/ops`, then `cmd cache-clear type=SUBSCRIBER_CHECK_ERRORS`, `cmd sync-sub-check mode=FULL` (repeat the command until it no longer answers "already running"), then `read sync-sub-error`	One row per discrepancy (IMSI, Error, Node); an empty table means the Site matches xControl
Repair a discrepancy	`cmd sync-sub siteWide=true type=RECREATE`, or `cmd sync-sub id=<imsi> type=UPDATE`	Confirmation
Cancel Location, detach	`cd /lte`, `cmd hss-cancel imsi=<imsi>`; `delete mme <imsi>`; 5G: `cd /nr`, `delete amf <imsi>`	Confirmation
MME timers	`cd /lte/debug/ashmme`, `show timer`; `update timer t3412=<s> mobileReachableTimer=<s> valimplicitDetachTimerval=<s>`	The periodic update, mobile reachable and implicit detach timers
SUCI home-network keys (5G)	`cd /nr`, `add suci pkId=<1..255> plmn=<mccmnc>` (prompts for the private key), `read suci`, `delete suci pkId=<n>`	Private-Key-Id, PLMN, key fingerprint
Stored short messages	`cd /lte`, `read smsc`; `show smsc`	Sender, Receiver, Retries, Route, SMPP
Versions and network-function health	`read agent-versions` at the root; `cd /debug/nf`, `read node`	Site, Agent Version, Last Seen; Name, Vendor, Health

`show pgw` and `show sgw` are not implemented and are never cited.

6.3.5 Devices and SIMs

- At least two UEs with SIMs provisioned as Mobile Assets on a System of the Site under test. Capacity tests state their own counts.
- Each UE supports the radio access technology under test (LTE, and 5G Standalone where 5G is tested), has the APN of its System Profile configured, and can browse the web or run a terminal application that sends ICMP echo requests.
- A UE application that shows the registration and radio connection state (for example the phone's field-test menu) is needed for the idle-mode procedures.
- For transitions between the public and the private radio, the UE must be able to select the private network's PLMN: either automatically, because the SIM's MNO-controlled PLMN list or the MNO's steering configuration lists it, or manually through the device's network selection menu. State which method the campaign uses in the results sheet.
- Speed and byte-count procedures assume the UE generates no background traffic during the measurement; disable automatic updates and cloud synchronization on the test devices, or use a data-only device.

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6.3.6 Evidence

Name every evidence file `<test ID>_<YYYYMMDD>_<item>.<ext>`, for example `EXP-SES-001_20260917_s1mme.pcapng` or `EXP-POL-001_20260917_speedtest-after.png`. Keep the files with the completed results sheet for the campaign. Expeto keeps the evidence of its own release-candidate runs with the acceptance test report for that release.

Evidence type	Capture as
3GPP signalling capture	`.pcapng` from the capture point the procedure names, trimmed to the procedure
xControl session event log, Mobile Asset status, Site status	Screenshot showing the IMSI, the timestamp and the field the expected result names
UE connectivity	Screenshot of the browser page or terminal output, with the device clock visible
Throughput	Screenshot or export of the speed test or iperf3 result, before and after where the procedure compares them
Kubernetes or service status	Output of `kubectl get pods -o wide` (and `kubectl get nodes`) before, during and after the fault, as text
CLI output	Terminal output of the command, as text

The results template has one row per published test with columns for the result, tester, date, evidence reference and deviation.

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6.4 How to Read and Run a Procedure

Every test in the acceptance test catalog is published in the same shape, so a test engineer who has executed one can execute any other. This page explains that shape, how procedures build on each other, how a result is recorded, and what the platform and 3GPP state names used in the expected results mean.

6.4.1 Anatomy of a test

Each test opens with a card of attributes, followed by the same sections in the same order.

Element	What it tells you
Identifier and title	`EXP-<DOMAIN>-<nnn>`. The identifier is permanent; release notes and results sheets cite it.
Status	Accepted: complete, reviewed and released. Every test in the catalog is accepted; the result of running it on a given release is recorded in the acceptance test report, not in the status.
Category	Functional, Security, Resilience, Capacity or Operations.
Components	The platform components the procedure exercises or observes: xCore, xRouter, xControl, xView.
Applies to	Three facets: radio access technology (4G, 5G; 3G on the public radio path only), access model (local radio, public radio) and deployment (single node, HA cluster, geo-redundant). Run the test on every combination your deployment uses; skip a facet your deployment does not have and record it as **Not run**.
Duration	A planning figure for one engineer executing the published steps once, excluding environment preparation.
Prerequisite procedures	Tests executed before this one, either as a precondition or as a step.
Included in	The execution sets the test belongs to, such as installation and upgrade verification.
Automated by	The continuous verification checks that exercise the same behaviour on every code change.
Objective	What the test proves, in one paragraph. A **Service impact** warning follows it when the procedure interrupts service; run such tests in a maintenance window or in a pre-production environment.
Preconditions	Grouped as Platform (deployment state), Mobile Asset (state in xControl), Device and Tooling.
Procedure	One observable action per row. **Where** names the surface you act on or observe: the UE, xControl, the xControl API, the CLI, Kubernetes, the signalling capture, the radio, a test host or the infrastructure. **Expected result** is what you verify before moving to the next row.
Expected signalling	Where the procedure has a defined 3GPP flow, the capture points and the message sequence per radio access technology.
Pass criteria	The conditions that must all hold for a **Pass**, including any timing limits.
Postconditions	The state the procedure leaves behind, and any cleanup.
Evidence collected	What you attach to the result.
References	The 3GPP clauses the procedure exercises.

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6.4.2 Chaining procedures

Procedures reuse one another instead of repeating steps. A row that reads "Execute EXP-SES-001 as a prerequisite procedure" means: run that test in full, confirm its expected results, and continue. When a campaign runs several tests in sequence on the same device, a prerequisite that is already satisfied (the UE is attached from the previous test) does not need to be repeated; record the identifier of the run that satisfied it in the evidence reference.

6.4.3 Recording a result

Result	Meaning
Pass	Every expected result was observed and every pass criterion holds.
Fail	An expected result was not observed, or a pass criterion does not hold, and no agreed explanation exists.
Deviation	The observed behaviour differs from the published expectation in a way that has been analyzed and agreed with Expeto; the deviation record states the difference and the agreement.
Not run	The test was not executed, and the reason is recorded (for example, the facet does not apply).

Record one row per test in the results template. Where a procedure is run on more than one facet combination, record one row per combination and say which in the evidence reference.

6.4.4 State glossary

The expected results use xControl's own status names for the Mobile Asset and 3GPP state names for the UE. They describe different things and change at different times.

xControl status	Meaning in xControl	3GPP state it usually corresponds to
Provisioned	The Mobile Asset exists in the database and has never had a session.	Not registered (EMM-DEREGISTERED / 5GMM-DEREGISTERED).
Registered	Authenticated, with no current data session. Also the steady state of a device that uses only the control plane, such as an SMS-only device.	Registered, no active PDN connection or PDU session, or a session in idle state that xControl has aged out of **Disconnected**.
Connected	An active data session; the IP address and radio access technology are shown.	Registered with an active default bearer or PDU session (ECM-CONNECTED or ECM-IDLE / CM-CONNECTED or CM-IDLE).

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xControl status	Meaning in xControl	3GPP state it usually corresponds to
Disconnected	The session on the network was closed. After a while the status becomes **Registered**.	Detached, or the PDN connection or PDU session released.
Active / **Inactive**	The administrative state you set: whether the Mobile Asset may have a session at all.	Not a 3GPP state. An **Inactive** Mobile Asset is rejected at attach or registration.
Connected PGW, **Unregistered**, **Error PGW**, **Error HSS**, **Unknown**	Warning statuses: the network and the database disagree about the Mobile Asset.	Investigate before continuing; they are never an expected result.

The session **Event Log** records two entry types. **HSS** entries (control plane) move between **Provisioned**, **Attached** and **Deleted**; **PGW** entries (user plane) are **Open** while a data session is active and **Closed** when it ends. A session with a start time and no end time is still open.

Other statuses the procedures use:

Object	Statuses
Private Radio	**Enabled** (configured, waiting for the radio), **Connected**, **Disconnected**, **Disabled** (configured, refusing connections).
Site	Online when the agent has reported within the last five minutes; otherwise offline.
UE radio connection	Connected (a radio connection exists) or idle (released for inactivity while the UE stays registered).

6.4.5 4G and 5G names side by side

The procedures name both radio access technologies. The pairs below are equivalent for the purpose of the expected results.

4G (EPS)	5G (5GS)
Attach / Detach	Registration / Deregistration
Tracking Area Update	Registration Update
S1 Release; Service Request	AN Release; Service Request
eNodeB	gNodeB
MME	AMF
SGW-C and PGW-C	SMF
PGW-U	UPF
HSS	UDM, AUSF and UDR
S1-MME, S1-U	N2, N3

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4G (EPS)	5G (5GS)
S11; S5/S8	N4 (PFCP); N9
S6a	N8, N12, N13
APN	DNN
Default EPS bearer; dedicated bearer	PDU session; QoS flow
QCI, APN-AMBR	5QI, Session-AMBR
EMM cause	5GMM cause

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6.5 Continuous verification

6.5.1 Continuous Verification

Before any procedure in the acceptance test catalog is run by a person, the platform has already been installed, provisioned, driven with subscriber traffic, broken and repaired by automation. This section publishes what that automation is, what it asserts and how often it runs, so that an MNO can weigh the manual catalog against the verification that precedes it.

What runs, and when

Check	What it is	Cadence
Component tests	Unit and component suites in each repository: the xControl services against a real PostgreSQL 17 database, the session-management function, the Kubernetes operator for the core, the xControl front end	Every merge request in the owning repository
Platform end-to-end suites	Six suites that install xControl, xView and the cores from the published Helm charts into a fresh namespace on a Kubernetes cluster, provision a tenant through the xControl API, drive sessions with 3GPP peer simulators, inject faults and verify the cluster is left clean	Every merge request to the platform verification repository; a weekly deep soak of every session flow and the capacity ramps
xControl browser suite	Real Chromium browsers driving the xControl portal against a real backend and front end	On demand from the front-end pipeline, before an xControl release
Release certification	A harness that applies a declarative core configuration to a real cluster, waits for it to converge, and drives subscriber lifecycle scenarios through the simulator, producing one JUnit verdict per configuration	Before a release is published
Supply-chain checks	Image provenance and pull-policy validation and vulnerability scanning in the platform suites; software bills of materials on every release tag	Every platform suite run; every release tag

What a failure does

A failing component test or platform suite blocks the merge request that caused it. A failing weekly soak is reported to Engineering with the soak's full report and the captured diagnostics. A failing certification run is a no-go for the release. Every finding fails the run that produced it; findings are tracked as work items in the verification repository until they are fixed, so none is silently ignored.

Diagnostics on failure

When any platform-suite test fails, the framework captures the state of every managed namespace (pods, container logs, events) into the run's report before teardown, so a failure can be analyzed without reproducing it. Soak and capacity runs write their full report and a memory summary before any verdict is asserted, and a run that detects a wedged component can be configured to leave the cluster in place for diagnosis instead of tearing it down.

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Where the results are

Results are GitLab pipeline artifacts: JUnit reports per suite, the soak and capacity reports, Trivy scan reports, browser traces and videos. They are not public. An MNO evaluating a release can request the pipeline summary and the certification verdict for that release through its Expeto account team.

Names used in this section

The platform verification framework is Expeto's own and is referred to by its internal name, Canopy, where the distinction from the browser suite matters. The xControl browser suite lives in the front-end repository (internal name Spruce). The 3GPP peer simulator that plays the radio and the peer core in both the platform suites and release certification is referred to as the simulator (internal name hickory). No other internal names appear in this documentation.

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6.5.2 Platform End-to-End Suites

The platform end-to-end suites install the Expeto Platform from its published Helm charts onto a real Kubernetes cluster, provision a tenant through the xControl API, drive subscriber sessions through 3GPP peer simulators, inject faults, measure capacity and stability, and verify that the cluster is left clean. They run on every merge request to the platform verification repository, and a weekly deep soak runs every session flow at full size for long enough to judge memory behaviour.

How a suite runs

1. **Preflight.** The cluster identity is checked against an allow-list and the cluster is confirmed clean of earlier runs.
2. **Install.** xControl is installed first; the suite's cores follow, each into its own namespace labelled with the run's identity. A tenant (Customer, Site, tokens) is provisioned through the xControl API and the resulting parameters are injected into the core installs, exactly as an MNO would wire a new site.
3. **Wait.** Every workload, database cluster and, for the Kubernetes-operator managed core, every Site resource must report ready before the first test runs.
4. **Test.** The suite's test classes run in a fixed order in one JVM. Session flows are single runs with hard assertions; soaks and capacity ramps count every outcome and fail on any that is not a success.
5. **Tear down and verify.** Charts are uninstalled, namespaces removed, and the cluster is checked clean again. On any failure the state of every managed namespace is captured first.

The framework is written in Kotlin on the Citrus integration-test framework and JUnit 5. Radio and peer-core signalling comes from Expeto's 3GPP peer simulator: for the 4G split core it plays two eNodeBs over SCTP and S1AP with a fleet of UEs; for the Kubernetes-operator managed core it plays the S11 peer. Echo services on the N6 side answer the UEs' traffic so that byte counts are exact. Browser checks of xControl use Playwright driving Chromium against the deployed portal.

The suites

Suite	Installs on top of xControl	Radio or load generator	Test classes	Cadence	Wall cloc
`XControlSuite`	Nothing more; a placeholder Site gives site tests a target	—	7	Every merge request	10 to 25 r
`XControlAndXViewSuite`	xView	—	8	Every merge request	10 to 25 r
`FullSuite`	xView and the 5G core at chart defaults (AMF, UDM, UDR, AUSF, one SMF, one UPF)	—	11	Every merge request	Under 1 h

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Suite	Installs on top of xControl	Radio or load generator	Test classes	Cadence	Wall cloc
TaigaSuite	The Kubernetes-operator managed core: one 4G user plane, a UE pool of 65 000 addresses, 12 000 sessions, exact usage-record checks	Two simulator instances as S11 peers, one N6 echo service	12	Every merge request; weekly deep soak	About 50
TaigaSplitSuite	The Kubernetes-operator managed core with a split user plane: an SGW-U and two PGW-U instances, one serving a dynamically addressed System and one a statically addressed System	Same fleet, one echo service per user plane	15	Every merge request; weekly deep soak	About 65
PrivateLteSuite	The 4G split core: MME and HSS, SGW-C and PGW-C as two session-management instances, SGW-U and PGW-U as two user planes, 11 000 sessions	One simulator instance playing two eNodeBs over S1AP	14	Every merge request; weekly deep soak	About 2 h

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Suite	Installs on top of xControl	Radio or load generator	Test classes	Cadence	Wall cloc
`XCoreSuite` , `PrivateLteHandoverSuite`	The 5G core alone; the 4G split core without its three long-running tests	— / two eNodeBs	8 / 12	Engineering workstations	—

The per-merge-request leg runs every suite on the default Kubernetes version. Legs for an older and a newer Kubernetes version are present in every pipeline as manual, non-blocking jobs and are run before a release.

Shared checks

Run in every suite.

Check	Asserts
Container image validation	Every container and init container in every managed namespace runs an image from the Expeto registry, tagged with the chart version, with `imagePullPolicy: IfNotPresent` ; third-party images are on an allow-list.
Helm template invariance	Rendering the installed chart twice with the same arguments and the live cluster capabilities gives the same output.
Provisioning	The persisted run state exists, the xControl release is deployed with the expected chart, the administrator credentials exist, and every Site resolves by identifier to its provisioned name through the ingress.
Vulnerability scan	Trivy scans every managed namespace for HIGH and CRITICAL findings and produces JSON, table, HTML and JUnit reports on every run; the findings are reviewed with the software bill of materials before a release.
Documentation sites	A browser opens the public and administrator documentation served by the deployment: HTTP 200, the right sections present and absent per audience, a sample of links resolving.
Single sign-on	A user that exists only in the identity provider logs in; an xControl account is created on first login and the redirect chain passes through the identity provider and ends in the authenticated application.
Device data	No device lookup is ever purchased from an external service during a run: the device data shipped in the xControl image resolves every handset the simulators present.

Stack checks

Check	Suite	Asserts
xView dashboards	xView suites	Grafana holds exactly the expected production dashboards; every dashboard renders and every dashboard link is followed and must resolve.
Site status in xControl	5G core	A browser opens the Site's detail page: the status is not **Offline** and the agent version matches the chart version.

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Check	Suite	Asserts
Mobile Asset provisioning	5G core	A Mobile Asset provisioned through the API (APN, System Profile, APN Profile, System, Mobile Asset) is listed by the UDR and by the SMF within 120 seconds, and the agent's full synchronization check reports no discrepancy for it.
Metrics federation	5G core	The core's Prometheus federation endpoint serves at least 40 000 samples and 200 `xcore_*` series, every one of which is fresh in xView within 10 minutes and carries the `customer`, `customerId`, `site` and `siteId` labels of the provisioned tenant.
Site resources	Kubernetes-operator managed core	Every Site resource is **Ready** with an observed generation at least its generation, the agent is ready, and the Site resolves in xControl. In the split configuration, exactly three user-plane resources (the SGW-U and two PGW-U instances) and exactly two Systems exist.

Session flows

A flow is a named sequence of operations that a single-run test plays once with hard assertions and that the soak engine replays at volume. Every flow first provisions its Mobile Asset through xControl and waits for **Provisioned**; on the 4G split core it also takes a settled census of MME contexts, session-management sessions and user-plane sessions, and ends by asserting that every gauge is exactly back to that baseline within 2 minutes.

Core	Flow	Sequence	Asserts
4G split core	`attach-detach`	attach, five pings of exact size, detach	The simulator reports an established session with a UE address and the MME attach counter moves within 2 minutes; xControl usage is exactly 185 bytes down and 185 bytes up (five pings of 37 bytes), fed from usage records within 3 minutes; the detach is accepted, active sessions decrease and the detach counter moves within 30 seconds.
4G split core	`idle-reactivate`	attach, pings, idle, reactivate, census unchanged, ping, detach	The idle counter moves; a Service Request reactivates the UE and the active counter moves; the census is identical to the post-attach census (no context minted or dropped); the session is still held.
4G split core	`idle-detach`	attach, pings, idle, detach	The terminal detach is issued against an idle UE; this is the coverage of the wake-then-detach path.

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Core	Flow	Sequence	Asserts
4G split core	`s1-handover`	attach, pings, S1 handover, census unchanged, ping, detach	The handover is accepted, the serving eNodeB reported by the simulator differs from the one at attach, the census is identical, the session survives.
4G split core	`x2-handover`	attach, pings, X2 handover (the MME sees only the Path Switch Request), census unchanged, ping, detach	As for the S1 handover.
Kubernetes-operator managed core	`attach-detach`	attach, UE address from the System's pool, session in the SMF, three pings, **Connected**, detach, **Disconnected**, usage, record fields	The UE address is inside the System's pool (or equals the static IP address); the SMF holds the subscriber within 120 seconds; three of three ICMP replies arrive over GTP-U from the System's N6 echo; xControl shows **Connected** and the SMF session is active, then **Disconnected** and the SMF row is gone; usage is exactly 111 bytes each way; the session record carries IMSI, MSISDN, bearer, UE address and APN; the history carries the visited MCC, MNC and tracking area.
Kubernetes-operator managed core	`reattach`	the sequence above, twice	Both sessions come up on the same Mobile Asset; at least two closed session-history records exist; no residual SMF session.

Each flow runs once per user plane on the split configuration, so every assertion is made for the dynamically addressed and the statically addressed System.

Fault injection and semantics

Test	Does	Asserts
System reassignment	A Mobile Asset with a live session on the dynamically addressed System is moved to the statically addressed System, with a static IP address, while **Connected**; then detached and re-attached	An explicit detach clears the SMF session within 60 seconds; the re-attach lands exactly on the new static address with three of three pings on the new user plane, **Connected** then **Disconnected**; no residual SMF session.

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Test	Does	Asserts
Static IP semantics	A static-IP session is held while a second Mobile Asset attaches with the same pinned address and a third with an address outside the pool	No two active sessions ever hold the same UE address; an out-of-pool address is never assigned; the baseline session still pings after both attempts.
User-plane failure isolation	Two static-IP sessions are held on user plane B while user plane A's pod is deleted; a Mobile Asset then re-attaches on A	Every held B session keeps receiving ping replies during A's outage; A's pod is ready again within 5 minutes and accepts an attach within 3 minutes with an in-pool address that pings; no residual sessions and no half-open legs on the SGW-U.
Radio capability sweep	Attach with ascending S1AP UE radio capability sizes from 512 to 11 000 bytes on three paths: attach, S1 handover container, post-X2	Each path tolerates at least 1 024 bytes; the first break per path is reported.

Soaks and capacity

Soaks judge stability; single runs judge correctness. A soak plays flows at volume and then applies, in order, the verdicts below. Baselines are taken after warm-up and before load: the claim is "back to where we started". The report and the memory summary are written before any verdict is asserted, and any verdict that does not hold fails the run.

#	Verdict	Holds when
1	No crash	No watched container restarted (4G split core: MME, HSS, SGW-C, PGW-C, SGW-U, PGW-U, agent, database, simulator; Kubernetes-operator managed core: every running pod in the core namespace and the simulator fleet).
2	Did churn	The run produced the number of attaches its duration and concurrency imply; a stalled load generator is a failure, not a pass.
3	Load generator drained	Every session the simulator opened was released, and its live-session count is back to the pre-run value.
4	Every session succeeded	Every attach, every idle, reactivation and handover procedure, and every detach completed; the simulator lost no session.
5	No session leak	Every census gauge (MME contexts, session-management sessions, user-plane sessions; SMF session table and per-System residual by UE pool on the Kubernetes-operator managed core) is exactly back to its baseline.
6	No memory growth	The memory of every core container is flat after warm-up: no upward trend over the second half of the run.

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#	Verdict	Holds when
7	Core-specific hooks	Kubernetes-operator managed core: the simulator's attach and detach ledger equals the engine's counts; no Mobile Asset is left **Connected**; usage-record byte totals equal pings times 37 bytes.

Run	Load	Verdict
Mixed-flow soak, 4G split core	100 live sessions, 10-second lifetime, a random registered flow per session, 200 IMSIs	The verdict set above.
Mixed-flow soak, Kubernetes-operator managed core	300 Mobile Assets, 300 live sessions, lifetimes of 0.5 to 2 seconds, at least 6 000 sessions, 64 calls in flight, keep-alive pings	The verdict set above with the core-specific hooks.
Weekly deep soak	Every registered flow in isolation for one hour at full size: private LTE 100 live sessions on 200 subscribers across its 5 flows; Kubernetes-operator managed core 300 live sessions on 300 subscribers across its 2 flows, once per user plane. Every merge request runs the same soaks as a 60-second smoke.	The verdict set above; the memory verdict is decisive at this length.
Unknown-IMSI signalling storm, 4G split core	250 IMSIs on an unserved PLMN hammer the MME for 5 to 10 minutes, concurrency ramping from 2 to 32 while MME CPU stays under 4 cores	No MME, HSS or simulator restart; at least 100 attempts, every one rejected, **zero** accepted; an unknown IMSI is still refused without timing out afterwards; MME memory returns to its baseline; attached, active and bearer gauges are back to baseline.

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Run	Load	Verdict
Maximum concurrent sessions, 4G split core	10 800 Mobile Assets provisioned, then a ramp to **10 000 held sessions** with 32 in flight, held 3 minutes, released	Every Mobile Asset is reconciled into the HSS; no watched container restarted; the simulator drained; every release answered; MME, both session-management and both user-plane instances back to baseline; the exact target reached.
Session capacity ramp, Kubernetes-operator managed core	5 000 Mobile Assets with two sessions each (10 000 sessions, 5 000 held), up to 50 attaches per second, 128 in flight	No watched container restarted while holding; the simulator back to its pre-run live count; every release answered; the target reached, otherwise the run fails naming the peak, the ceiling reason and per-component peak memory and CPU.

A run on the Kubernetes-operator managed core that detects a wedge (a crashed container or a stalled throughput) freezes instead of cleaning up, leaving Mobile Assets, sessions and echo services in place for diagnosis. A stall dominated by transport errors is reported as a load-generator fault, never as a platform defect.

Acceptance tests mirrored by automation

The acceptance test catalog cites, on each test card, the automated checks that exercise the same behaviour. The table below is the reverse view.

Automated check	Acceptance tests it mirrors
Platform suite, 4G split core: session flow `attach-detach` (single run, mixed soak and weekly deep soak)	EXP-SES-001, EXP-SES-002, EXP-SES-008
Platform suite, 4G split core: session flow `idle-reactivate`	EXP-SES-004, EXP-SES-005
Platform suite, 4G split core: session flow `idle-detach`	EXP-SES-004
Platform suite, 4G split core: session flow `s1-handover`	EXP-MOB-002
Platform suite, 4G split core: session flow `x2-handover`	EXP-MOB-001
Platform suite, 4G split core: mixed-flow soak (100 live sessions, random flow per session) and weekly deep soak	EXP-CAP-004, EXP-SES-007

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Automated check	Acceptance tests it mirrors
Platform suite, 4G split core: unknown-IMSI signalling soak (250 unserved IMSIs)	EXP-PRV-005, EXP-SEC-008
Platform suite, 4G split core: 10 000 concurrently held sessions	EXP-CAP-001
Platform suite, Kubernetes-operator managed core: session flow `attach-detach`, once per user plane	EXP-SES-001, EXP-SES-002
Platform suite, Kubernetes-operator managed core: session flow `reattach`	EXP-SES-008
Platform suite, Kubernetes-operator managed core: 10 000-session capacity ramp	EXP-CAP-001
Platform suite, split user plane: System reassignment of a connected Mobile Asset (Cancel Location with re-attach)	EXP-PRV-007
Platform suite, split user plane: static IP semantics (duplicate and out-of-pool addresses)	EXP-PRV-009
Platform suite, split user plane: one user-plane instance deleted while sessions are held on the other	EXP-HA-001, EXP-HA-011, EXP-HA-015
Platform suite, 5G core: Mobile Asset provisioned through the xControl API appears in UDR and SMF within 120 s	EXP-INS-002, EXP-PRV-001
Release certification: subscriber lifecycle scenarios on the reference 5G configuration	EXP-SES-001

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6.5.3 xControl UI

xControl, the Expeto Management portal, is verified at three levels: unit tests of the front-end code on every change, a browser suite that drives the portal in a real Chromium browser against a real xControl backend and front end, and the browser checks that the platform end-to-end suites make against the deployed portal. This page lists what the browser suite covers, test by test, and the wider UI regression scope it is drawn from.

The browser suite

The suite is written in TypeScript on Playwright and runs in Chromium. It does not use mocks or network stubs. Before a run, the pipeline starts a real xControl backend with a seeded in-memory database and generated data, a front end built from the commit under test, and the browser container that drives them; every test acts on the portal the way an administrator does, through the rendered pages. Traces are retained for failed tests, video is recorded for every test, and an HTML report is published as a pipeline artifact.

Tests carry the TestRail case identifiers of the manual regression cases they cover, either in the test title or in the titles of the steps inside the test. The suite authenticates with the **ADMIN** role; Customer-Admin and Read-Only behaviour is in the manual scope.

The browser suite holds **74 tests** in 11 specification files. **70** run in the default selection, 17 of them as the end-to-end sanity chain; the other 5 seed data or authenticate before a run. The tests carry **53 distinct TestRail case identifiers**. Of the **137 cases** in the UI regression scope below, **56** are covered by a browser test; the remainder stay in the manual regression scope.

The browser suite is a manual, non-blocking job in the front-end pipeline, started before an xControl release. The gates that run on every merge request to the front end are the type check, the linter and the unit tests.

Specification file	Area	Test	TestRail cases	Default run
`account.spec.ts`	Accounts	C256 - Filter Columns by IP Origin and Email Address	C256	Yes
		C257 - Filter Columns by First Attempt and Email Address	C257	Yes
		C258 - Filter Columns by IP Origin and Last Attempt	C258	Yes
		Create, search, edit, delete new account	C252, C255, C254, C253	Yes
		C263 - Display default columns	C263	Yes
		C264 - None selected in the table columns	C264	Yes
		C259 - Display Only List of Accounts	C259	Yes
		C260 - Display Only Audit	C260	Yes
`customer.spec.ts`	Customers	Create, edit, delete new customer as SuperAdmin	C6, C50, C200, C209	Yes
		Create, edit, delete new customer with extensions as SuperAdmin	C6, C207, C208, C209	Yes

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Specification file	Area	Test	TestRail cases	Default run
keysets.spec.ts	Keysets	Create, edit, delete keysets	C265, C267, C266	Yes
		C273 - Verify "Reset List" Button Functionality	C273	Yes
		C274 - Verify Behavior with no columns selected	C274	Yes
		Filter columns	C275, C276	Yes
mobile.assets.spec.ts	Mobile Assets	Create a new Mobile Asset	C269	Yes
		Search, filter mobile asset	C272, C270, C271	Yes
		Delete created Mobile Asset	—	Yes
		Verify columns track	—	Yes
		Regression check - Spruce Issue #1255 - Unable to search mobile assets by ICCID	—	Yes
		C284 - Verify "Reset List" Button Functionality	C284	Yes
		C279 - Reset Tiles to Default	C279	Yes
		C278 - Display Only Data Usage Tile	C278	Yes
private.radio.spec.ts	Private Radios	Create New Private Radio	—	Yes
		Delete Private Radio	—	Yes
reports.spec.ts	Reports	C320 - Generate Detailed usage report with Valid Parameters	C320	Yes
		C321 - Generate Summary usage report - By IMSI with Valid Parameters	C321	Yes
		C322 - Generate Summary usage report - By System with Valid Parameters	C322	Yes
		C323 - Generate Summary usage report with Valid Parameters	C323	Yes
		C324 - Generate Active devices by site report with Valid Parameters	C324	Yes

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Specification file	Area	Test	TestRail cases	Default run
		C325 - Generate Active devices report with Valid Parameters	C325	Yes
		C328 - Filter Columns by ID and Report Name	C328	Yes
		C329 - Filter Columns by ID and Generated by	C329	Yes
		C330 - Filter Columns by Report Name and Initiated	C330	Yes
		C331 - Filter Columns by Report Config and Completed	C331	Yes
		C332 - Filter Columns by Status and Owned by	C332	Yes
		C333 - Filter Columns by ID and Status	C333	Yes
		C334 - Filter Columns by Generated by and Owned by	C334	Yes
		C335 - Filter Columns by Report Config and Initiated	C335	Yes
		C336 - Verify "Reset List" Button Functionality	C336	Yes
`sanity.spec.ts`	End-to-end sanity chain	Create Customer	—	Yes
		Create Account	—	Yes
		Create Keyset	—	Yes
		Create Site & Private Radio	—	Yes
		Create APN Global	—	Yes
		Create System Profile & APN Profile	—	Yes
		Create System	—	Yes
		Create Mobile Asset	—	Yes
		Delete Mobile Asset	—	Yes
		Delete APN Profile	—	Yes
		Delete System Profile	—	Yes
		Delete APN Global	—	Yes

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Specification file	Area	Test	TestRail cases	Default run
		Delete System	—	Yes
		Delete Site	—	Yes
		Delete Keyset	—	Yes
		Delete Account	—	Yes
		Delete Customer	—	Yes
sites.spec.ts	Sites	Search sites	—	Yes
		C293 - Display only Name and Customer Columns in the sites details table	C293	Yes
		C294 - Display only Status and Systems Columns in the sites details table	C294	Yes
		C295 - Display only Private Radios and Type Columns in the sites details table	C295	Yes
		C296 - Display only Name and Status Columns in the sites details table	C296	Yes
system-profiles.spec.ts	System Profiles and APNs	Add a new global APN	—	Yes
		Add a new System Profile	—	Yes
		Add a new APN Profile to the System Profile	—	Yes
		Delete APNProfile from System Profile	—	Yes
		Delete System Profile	—	Yes
		Delete global APN	—	Yes
systems.spec.ts	Systems	C299 - Display Name and State Columns in the Systems Details table	C299	Yes
		C302 - Verify "Reset list" Button Functionality	C302	Yes
		C301 - Verify Default columns in the Systems Details table	C301	Yes
setup.spec.ts	Seed data (setup only)	Create Customer	—	No

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Specification file	Area	Test	TestRail cases	Default run
		Create Keyset	—	No
		Create Site	—	No
		Create System	—	No
auth.setup.ts	Login (setup project)	Authenticate admin user	—	No

Checks made by the platform suites

The platform end-to-end suites also open the deployed portal in a browser. They sign in through the identity provider and confirm that a first login creates the account, open a Site's detail page and confirm that its status is not **Offline** and its agent version matches the deployed chart, open the documentation sites served by the deployment and check their navigation, and confirm that no device lookup is purchased from an external service while sessions are generated.

UI regression scope

The following is the full UI regression scope for xControl, by functional area. It is included for reference: it shows the breadth of behaviour the portal is checked against, from every create, edit and delete flow to list filtering, pagination, column selection, reporting and export. The **Automated by** column names the browser tests that cover a case; the mapping is kept in the documentation sources from the case identifiers and test titles in the suite's code, and is updated when the suite changes.

APNs (11 cases, 2 automated)

Case	Automated by
APNs page - Create APN Global	system-profiles.spec.ts : Add a new global APN sanity.spec.ts : Create APN Global
APNs page - Delete apn	system-profiles.spec.ts : Delete global APN sanity.spec.ts : Delete APN Global
APNs page - Edit APN	—
APNs page - Filter by Customer and Max Upload (Mbps) with Max Download (Mbps)	—
APNs page - Filter by Customer with Max Download (Mbps) only	—
APNs page - Filter by Max Upload (Mbps) and Max Download (Mbps) only	—
APNs page - Filter by Name and Customer with Max Download (Mbps) only	—
APNs page - Filter by Name and Customer with Max Upload (Mbps) only	—
APNs page - Filter by Name and Max Upload (Mbps) with Max Download (Mbps) only	—
APNs page - Filter by Name with Max Download (Mbps) only	—
APNs page - Filter by Name, Customer, Max Upload (Mbps), and Max Download (Mbps)	—

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Accounts (24 cases, 11 automated)

Case	Automated by
Account - Verify Records Per Page Limit	—
Account - Verify Records Per Page Limit in the Accounts Table	—
Account - Verify Specific Page Navigation in the Accounts Table	—
Accounts - Verify Failed to login	—
Accounts - Verify Specific Page Navigation	—
Accounts - Verify audit log of the current user's last login	—
Accounts Page - Accounts list pagination	—
Accounts page - Display Only Audit Tile	`account.spec.ts` : C260 - Display Only Audit
Accounts page - Display Only List of Accounts Tile	`account.spec.ts` : C259 - Display Only List of Accounts
Accounts page - Display default columns	`account.spec.ts` : C263 - Display default columns
Accounts page - Filter Columns by Email Address and First Attempt	`account.spec.ts` : C257 - Filter Columns by First Attempt and Email Address
Accounts page - Filter Columns by Email Address and IP Origin	`account.spec.ts` : C256 - Filter Columns by IP Origin and Email Address
Accounts page - Filter Columns by IP Origin and Last Attempt	`account.spec.ts` : C258 - Filter Columns by IP Origin and Last Attempt
Accounts page - None selected in the table columns	`account.spec.ts` : C264 - None selected in the table columns
Accounts page - Show all tiles in Accounts page	—
Accounts page - Verify "Reset List" Button Functionality	—
Accounts page - Verify Functionality of Next and Previous Buttons	—
Create new Account as Admin	`account.spec.ts` : Create, search, edit, delete new account `sanity.spec.ts` : Create Account
Create new Account as Customer	—
Create new Account as Read-Only Customer	—
Delete Account	`account.spec.ts` : Create, search, edit, delete new account `sanity.spec.ts` : Delete Account
Edit account as Admin	`account.spec.ts` : Create, search, edit, delete new account
Search account	`account.spec.ts` : Create, search, edit, delete new account
Search by customer	—

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Customers (16 cases, 5 automated)

Case	Automated by
Create new Customer as Admin	customer.spec.ts : Create, edit, delete new customer as SuperAdmin sanity.spec.ts : Create Customer
Create new Customer as Customer-Admin	—
Customers - Display Only Mobile Assets Column	—
Customers - Display Only Sites Column	—
Customers - Display Only Systems Column	—
Delete Customer Extensions as Admin	customer.spec.ts : Create, edit, delete new customer with extensions as SuperAdmin
Delete Customer Extensions as Customer-Admin	—
Delete existing customer as Admin	customer.spec.ts : Create, edit, delete new customer as SuperAdmin sanity.spec.ts : Delete Customer
Delete existing customer as Customer-Admin	—
Delete existing customer as Read-Only	—
Edit Customer Extensions as Admin	customer.spec.ts : Create, edit, delete new customer with extensions as SuperAdmin
Edit existing customer as Admin	customer.spec.ts : Create, edit, delete new customer as SuperAdmin
Edit existing customer as Customer-Admin	—
Edit existing customer as Read-Only	—
Filter Customers by status	—
Filter by customer	—

Home (1 case, 0 automated)

Case	Automated by
Home - Overview metrics	—

Keysets (7 cases, 7 automated)

Case	Automated by
Add New Keyset	keysets.spec.ts : Create, edit, delete keysets sanity.spec.ts : Create Keyset
Delete Keyset	keysets.spec.ts : Create, edit, delete keysets sanity.spec.ts : Delete Keyset
Edit Keyset	keysets.spec.ts : Create, edit, delete keysets
Keysets page - Filter by Customer	keysets.spec.ts : Filter columns

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Case	Automated by
Keysets page - Filter by Name	keysets.spec.ts : Filter columns
Keysets page - Verify "Reset List" Button Functionality	keysets.spec.ts : C273 - Verify "Reset List" Button Functionality
Keysets page - Verify Behavior with no columns selected	keysets.spec.ts : C274 - Verify Behavior with no columns selected

Login (2 cases, 1 automated)

Case	Automated by
Login to xControl with Admin role	auth.setup.ts : Authenticate admin user
Logout from xControl	—

Mobile Assets (18 cases, 6 automated)

Case	Automated by
Create New Mobile Assets	mobile.assets.spec.ts : Create a new Mobile Asset sanity.spec.ts : Create Mobile Asset
Display All Columns in the Mobile Assets Details Table	—
Display Only Connected or Disconnected Since Column in the Mobile Assets Details Table	—
Display Only IMSI and IMEI Columns in the Mobile Assets Details Table	—
Download Mobile Assets as .CSV File	—
Filter Mobile Assets by system	mobile.assets.spec.ts : Search, filter mobile asset
Mobile Assets - Delete bulk	—
Mobile Assets - Display All Tiles	—
Mobile Assets - Display Only Data Usage Tile	mobile.assets.spec.ts : C278 - Display Only Data Usage Tile
Mobile Assets - Display Only Mobile Assets Details Tile	—
Mobile Assets - Display Only Overview Tile	—
Mobile Assets - Display deafult columns on the table	—
Mobile Assets - Edit bulk	—
Mobile Assets - Edit bulk as Customer Admin	—
Mobile Assets - Reset Tiles to Default	mobile.assets.spec.ts : C279 - Reset Tiles to Default

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Case	Automated by
Mobile Assets - Verify "Reset List" Button Functionality	mobile.assets.spec.ts : C284 - Verify "Reset List" Button Functionality
Mobile Assets Page - Overview metrics	—
Search mobile assets	mobile.assets.spec.ts : Search, filter mobile asset

Private Radios (5 cases, 1 automated)

Case	Automated by
Create New Private Radio	private.radio.spec.ts : Create New Private Radio sanity.spec.ts : Create Site & Private Radio
Deselect All Columns in the Private Radios Details table	—
Display Private Radio ID and Site Columns	—
Private Radios - Verify "Reset Tiles" Button Functionality	—
Verify Default columns in the Private Radios Details table	—

Profiles (7 cases, 0 automated)

Case	Automated by
Create New Profile	—
Create New Profile with extensions	—
Delete profile	—
Edit profile	—
Profiles - Display Only System Column	—
Profiles - Display Only Customer Column	—
Search profile	—

Reports (16 cases, 14 automated)

Case	Automated by
Download Report from the "Generated Reports" table as Admin	—
Download Report from the "Generated Reports" table as Customer-Admin	—
Generate a Detailed Usage Report with Valid Parameters	reports.spec.ts : C320 - Generate Detailed usage report with Valid Parameters
Generate a Summary Usage Report - By IMSI with Valid Parameters	reports.spec.ts : C321 - Generate Summary usage report - By IMSI with Valid Parameters

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Case	Automated by
Generate a Summary Usage Report - By System with Valid Parameters	reports.spec.ts : C322 - Generate Summary usage report - By System with Valid Parameters
Generate a Summary Usage Report with Valid Parameters	reports.spec.ts : C323 - Generate Summary usage report with Valid Parameters
Generate an Active Devices Report with Valid Parameters	reports.spec.ts : C325 - Generate Active devices report with Valid Parameters
Generate an Active Devices by Site Report with Valid Parameters	reports.spec.ts : C324 - Generate Active devices by site report with Valid Parameters
Reports page - Filter Columns by Generated by and Owned by	reports.spec.ts : C334 - Filter Columns by Generated by and Owned by
Reports page - Filter Columns by ID and Generated by	reports.spec.ts : C329 - Filter Columns by ID and Generated by
Reports page - Filter Columns by ID and Report Name	reports.spec.ts : C328 - Filter Columns by ID and Report Name
Reports page - Filter Columns by ID and Status	reports.spec.ts : C333 - Filter Columns by ID and Status
Reports page - Filter Columns by Report Config and Completed	reports.spec.ts : C331 - Filter Columns by Report Config and Completed
Reports page - Filter Columns by Report Config and Initiated	reports.spec.ts : C335 - Filter Columns by Report Config and Initiated
Reports page - Filter Columns by Report Name and Initiated	reports.spec.ts : C330 - Filter Columns by Report Name and Initiated
Reports page - Verify "Reset List" Button Functionality	reports.spec.ts : C336 - Verify "Reset List" Button Functionality

Sites (9 cases, 2 automated)

Case	Automated by
Add custom extensions to a Site	—
Create Sites as SuperUser	sanity.spec.ts : Create Site & Private Radio
Deselect All Columns in the Sites Details List on the Sites Page	—
Search sites	sites.spec.ts : Search sites
Sites Page - Overview metrics	—
Verify Associated System(s)	—
Verify Default columns in the Sites Details list on Sites page	—
Verify General Information of a Site	—

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Case	Automated by
Verify Name columns in the Sites Details list on Sites page	—

System Profile (8 cases, 3 automated)

Case	Automated by
Systems profile page - Filter by "Customer" Column	—
Systems profile page - Filter by "Name" Column	—
Systems profile page - Filter by "System" Column	—
Systems profile page - Create systems profile	`system-profiles.spec.ts` : Add a new System Profile `sanity.spec.ts` : Create System Profile & APN Profile
Systems profile page - Delete systems profile	`system-profiles.spec.ts` : Delete System Profile `sanity.spec.ts` : Delete System Profile
Systems profile page - Reset Column Selection to Default	—
Systems profile page - Search by name profile	—
Systems profile page.- Edit system profile	`system-profiles.spec.ts` : Add a new APN Profile to the System Profile

Systems (13 cases, 4 automated)

Case	Automated by
Create systems	`sanity.spec.ts` : Create System
Delete a System	`sanity.spec.ts` : Delete System
Deselect All Columns in the Systems Details table	—
Display Name and State Columns in the Systems Details table	`systems.spec.ts` : C299 - Display Name and State Columns in the Systems Details table
Edit systems extensions	—
Export System Details as .JPEG File	—
Export System Details as .PNG File	—
Export System Details as .SVG File	—
Systems - Edit system name	—
Systems - Enable/disable status	—
Systems - Verify "Reset Tiles" Button Functionality	—
Systems - Verify Default columns in the Systems Details table	`systems.spec.ts` : C301 - Verify Default columns in the Systems Details table
Systems Page - Overview metrics	—

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6.5.4 Release Certification

Release certification is the go or no-go signal for a platform release: for a given declarative core configuration, does the whole product loop work end to end? A harness applies the configuration to a real Kubernetes cluster, waits until the Kubernetes operator that manages the core reports it ready, verifies that the management agent is present and correctly configured, and then drives subscriber lifecycle scenarios through the 3GPP peer simulator. Each scenario produces a pass or fail; the harness aggregates them into one JUnit report per configuration.

What a certification run does

#	Phase	What is verified
1	Discover configurations	Every configuration directory holding a Site definition is certified in turn.
2	Apply overrides	Where the configuration ships an image catalog override, the images under test are substituted; where it ships session-management rules, they are installed as the rule set the agent mounts.
3	Apply the Site definition	The declarative description of the core is applied to the cluster.
4	Wait for readiness	The Site reports **Ready** and its observed generation is at least the applied generation, so a stale readiness from an earlier configuration cannot satisfy the wait.
5	Verify the agent	The management agent exists, is ready, and mounts the expected rule set; a core with no agent, or with a drifted component label, fails here even though the core itself is ready.
6	Wait for the simulator	The simulator reports ready on its own condition, kept separate from the core's readiness so that test scaffolding can never mask a core that is not ready.
7	Confirm images in use	When images were overridden, every pod in the namespace is polled until it runs the overridden references; the run certifies what it was asked to certify.
8	Optional readiness soak	Absorbs cold-start effects such as PFCP association and identifier-pool registration before traffic starts.
9	Run scenarios	Subscriber lifecycle scenarios are executed against the simulator's API; each scenario's assertions are evaluated against the core's own state endpoints.
10	Aggregate and tear down	Scenario results are collected into JUnit; the Site, rule set and image overrides are removed. A configuration that fails before scenarios run gets a synthetic failed test case carrying the full phase log, so the report covers the whole run.

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Certified configurations

Configuration	Shape	What its scenarios prove
Reference 5G core	One session-management function, one intermediate user-plane function and two user-plane functions, one per System, selected by session-management rules	Two subscribers attach repeatedly and land on different user planes; the assertion is on the UE address block each receives, so a subscriber placed on the wrong user plane fails. The active PFCP session count on that user plane is read from the network function's own statistics as ground truth.
Reference 5G core with a replicated database	The same shape with one change: the database runs as a three-node synchronous cluster	Any behavioural difference is attributable to the database change alone. Certifies schema migration and event persistence against the replicated database. Manual drills for database failover, the refusal to convert a running database between standalone and clustered mode, and rescaling are documented alongside it.

Exit codes and reports

The harness exits 0 when every configuration passes, 1 when configurations ran and at least one failed, and 2 when it could not proceed (cluster unreachable, configuration directory unreadable, required tools absent). The JUnit report has one test suite per configuration and one test case per scenario; a failure carries the phase log, including the last readiness status observed, so the cause is in the report rather than in a lost terminal.

When it runs

Certification is run by Engineering against a managed test cluster before a release is published. It is not part of the per-change pipeline: it needs a real cluster with the network attachments the core requires, and it takes minutes per configuration. The configurations themselves are checked on every change: a unit test decodes every checked-in Site definition strictly, so a malformed configuration fails the ordinary pipeline even though the harness itself did not run.

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6.5.5 Component Tests and Supply Chain

Every component of the Expeto Platform is tested in isolation in its own repository before it reaches the platform end-to-end suites, and every image and chart that ships is checked for provenance and known vulnerabilities. This page summarizes those layers.

Component tests

Component	Test suite	Runs
xControl services (API, agent protocol, data model, reporting)	More than 400 JUnit test classes across the service modules. The database suite runs against a real PostgreSQL 17 instance in the pipeline, so schema migrations and queries are exercised against the database the platform ships with.	Every me request; reports publishe
xControl front end	Unit tests (Vitest) of the portal's components and state, a TypeScript type check and a lint pass	Every me request
Session management function (SMF, SGW-C and PGW-C)	About 90 test classes covering session establishment, modification and release, rule evaluation, PFCP handling and persistence	Every me request

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Component	Test suite	Runs
Kubernetes operator for the core (the controller that reconciles a declarative Site into a running core)	More than 600 Go test functions in 83 files: reconciler tests that drive a full reconcile against a fake API server, admission validation, network configuration rendering, BGP resources, preflight checks and the certification harness itself. The suite is deterministic by rule: a flake is treated as a defect.	Every me request
Network functions (AMF, MME, HSS, UDM, UDR, AUSF, UPF and the supporting services)	Built and packaged by the shared pipelines, then exercised end to end by the platform suites and release certification.	Every me request i owning reposito

Supply chain

Check	What it verifies	When
Image provenance	Every container in every managed namespace of a platform-suite run comes from the Expeto registry, is tagged with the chart version, and uses `imagePullPolicy: IfNotPresent`; third-party images are on an explicit allow-list	Every platform suite run
Vulnerability scanning	Trivy scans every managed namespace for HIGH and CRITICAL findings and publishes JSON, table, HTML and JUnit reports	Every platform suite run on the default Kubernetes version

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Check	What it verifies	When
Software bill of materials	A CycloneDX bill of materials is produced for the Java components, for every image the rendered charts reference, and for the charts themselves, and uploaded to Expeto's Dependency-Track instance where it is tracked against vulnerability feeds	Every release tag
Chart rendering	The charts are rendered with `helm template` against the supported Kubernetes API versions as part of the bill-of-materials pipeline, and rendered twice with identical arguments in the platform suites to detect non-deterministic templates	Every release tag; every platform suite run
Image availability	Every image in the operator's image catalog is confirmed to exist in the registry with a manifest inspection before certification	Before a release

MNOs who require the bill of materials or the vulnerability report for a release can request them through their Expeto account team.

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6.6 Acceptance test catalog

6.6.1 Acceptance Test Catalog

The acceptance test catalog holds **97 accepted end-to-end tests** across 12 domains. Every test is executed against a complete deployment of Expeto Edge (xCore), Expeto Gateway (xRouter) and Expeto Management (xControl) with real devices and, where the procedure calls for it, a 3GPP signalling capture.

Tests marked ★ form the **Installation and Upgrade Verification** set, the subset an operator runs after every installation or upgrade.

Domains

Domain	Tests	What it proves
Installation checks	5	The checks that confirm a fresh installation or an upgraded platform is ready for service: every workload running at the release version, the management path to xControl established and synchronized, the radio connected, monitoring receiving the site, and, after an upgrade, the existing configuration and subscribers intact.
Session lifecycle	13	Standard 3GPP session procedures on Expeto Edge (xCore): attach and registration, detach, idle-mode transitions, service request and paging, periodic updates, repeated sessions, the loss of a device without a detach, session release while registered and multiple simultaneous sessions. These tests confirm that a Mobile Asset provisioned in xControl behaves on the private network exactly as it would on a public mobile network.
Provisioning	11	Changes made in xControl (Expeto Management) take effect in the network: creating, importing, activating, deactivating, moving and deleting Mobile Assets, assigning static addresses and device locks, rejecting unknown or inactive SIMs, and applying changes queued while the site was out of contact.
Policy and traffic	8	Policy configured in xControl is enforced on the user plane and applied to live sessions without a re-attach: bandwidth limits and quality of service from the System Profile, egress through the System's subnet, roaming restrictions from Roaming Profiles and Carrier Groups, per-network APN overrides for Mobile Assets on the mobile operator's public radio network, network slice selection on 5G, and correct handling of large packets.
Public network access	3	Enterprise access through the mobile operator's public radio network and the IPX beyond the basic 4G and 5G case of EXP-POL-002: 5G non-standalone (EN-DC) service on the 4G core path, 3G access through the operator's SGSN over Gp with MAP authentication and location management, and a device that changes between 4G and 3G on the public network.

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Domain	Tests	What it proves
Mobility and access transitions	7	Handover between radios of one site, reselection in idle mode, roaming between two private Sites through a Shared System, and the transitions a device makes between the mobile operator's public radio network and the private radio network with the same SIM.
Security and isolation	12	Mobile Asset traffic is contained, subscribers are authenticated with the configured algorithms and re-synchronized when needed, the 5G permanent identity is never sent in clear, the management path is outbound only, access to xControl follows the role model, changes are audited, and the core withstands a flood of unknown subscribers.
Messaging (SMS)	6	Short messages for Mobile Assets on the mobile operator's public radio network, served by the Expeto SMSC in Expeto Gateway (xRouter): mobile-originated and mobile-terminated messages over MAP and over SGd, exchange with application servers over SMPP, concatenated and binary messages, delivery reports, store-and-forward for absent devices, and routing rules.
Session records and usage	6	Session history and usage records in xControl are complete, accurate to the byte, attributed to the right Site and System, produced for sessions that end abnormally, and delivered even when the site was out of contact while the session ran.
Resilience and high availability	16	Node, pod, database, radio, link and site failures on Expeto Edge (xCore), Expeto Gateway (xRouter) and xControl, including loss of the management path. Tests cover Kubernetes node failover, single-site restart recovery, geo-redundant failover and the isolation of faults between user planes.
Capacity and stability	4	The platform sustains the Mobile Asset counts, attach rates and throughput each tier is rated for, and stays stable under sustained churn: no restarts, no failed procedure, no leaked session, no memory growth, and complete records.
Operations and maintenance	6	Alarms, metrics, diagnostics and maintenance procedures an MNO relies on to run the platform: faults are alarmed and cleared, metrics agree with the platform's own state, a support case can be documented completely, and time is consistent across the platform.

Coverage by category and component

	Functional	Security	Resilience	Capacity	Operations	Total
xCore	43	11	13	4	11	82
xRouter	14	2	6	–	–	22
xControl	42	7	4	1	8	62
xView	–	–	2	–	4	6

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A test that exercises more than one component is counted under each.

Full index

ID	Test	Domain	Category	Applies to	Set
EXP-INS-001	Platform readiness after installation	Installation checks	Operations	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant	★
EXP-INS-002	Management path and subscriber synchronization	Installation checks	Operations	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant	★
EXP-INS-003	Radio access node connection	Installation checks	Operations	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant	★
EXP-INS-004	Monitoring path	Installation checks	Operations	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant	★
EXP-INS-005	Upgrade and post-upgrade regression	Installation checks	Operations	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant	
EXP-SES-001	UE-initiated attach	Session lifecycle	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant	★
EXP-SES-002	UE-initiated detach	Session lifecycle	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant	★

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ID	Test	Domain	Category	Applies to	Set
EXP-SES-003	Network-initiated detach	Session lifecycle	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant	
EXP-SES-004	UE idle mode	Session lifecycle	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant	★
EXP-SES-005	UE-triggered service request	Session lifecycle	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant	★
EXP-SES-006	UE paging	Session lifecycle	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant	
EXP-SES-007	Multiple UE attach	Session lifecycle	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant	★
EXP-SES-008	Repeated attach and detach cycles	Session lifecycle	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant	
EXP-SES-009	Periodic tracking area or registration update	Session lifecycle	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant	

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ID	Test	Domain	Category	Applies to	Set
EXP-SES-010	Implicit detach after loss of the device	Session lifecycle	Functional	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant	
EXP-SES-011	Attach with an APN outside the System Profile	Session lifecycle	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant	
EXP-SES-012	Session release and re-establishment while registered	Session lifecycle	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant	
EXP-SES-013	Multiple PDN connections	Session lifecycle	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant	
EXP-PRV-001	Provision a Mobile Asset	Provisioning	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant	★
EXP-PRV-002	Deactivate a Mobile Asset	Provisioning	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant	★
EXP-PRV-003	Reactivate a Mobile Asset	Provisioning	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant	

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ID	Test	Domain	Category	Applies to	Set
EXP-PRV-004	Inactive Mobile Asset attach rejected	Provisioning	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant	
EXP-PRV-005	Unknown UE attach rejected	Provisioning	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant	★
EXP-PRV-006	Bulk import of Mobile Assets	Provisioning	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant	
EXP-PRV-007	Move a connected Mobile Asset to another System	Provisioning	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant	
EXP-PRV-008	Delete a Mobile Asset with an active session	Provisioning	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant	
EXP-PRV-009	Static IP address assignment	Provisioning	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant	
EXP-PRV-010	IMEI lock	Provisioning	Security	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant	

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ID	Test	Domain	Category	Applies to	Set
EXP-PRV-011	Provisioning changes made while the site is out of contact	Provisioning	Functional	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant	
EXP-POL-001	Limit bandwidth (AMBR)	Policy and traffic	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant	★
EXP-POL-002	Enterprise access through the public radio network	Policy and traffic	Functional	4G, 5G · Public radio · Single node, HA cluster, Geo-redundant	★
EXP-POL-003	System egress mapping	Policy and traffic	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant	
EXP-POL-004	Quality of service profile applied to the session	Policy and traffic	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant	
EXP-POL-005	Per-network APN override on the public radio network	Policy and traffic	Functional	4G, 5G · Public radio · Single node, HA cluster, Geo-redundant	
EXP-POL-006	Roaming Profile restriction on the public radio network	Policy and traffic	Security	4G, 5G · Public radio · Single node, HA cluster, Geo-redundant	
EXP-POL-007	Large packets and MTU	Policy and traffic	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant	

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ID	Test	Domain	Category	Applies to	Set
EXP-POL-008	Network slice selection (5G)	Policy and traffic	Functional	5G · Local radio · Single node, HA cluster, Geo-redundant	
EXP-PUB-001	5G non-standalone (EN-DC) access through the public radio network	Public network access	Functional	4G, 5G · Public radio · Single node, HA cluster, Geo-redundant	
EXP-PUB-002	3G access through the public radio network (Gp)	Public network access	Functional	3G · Public radio · Single node, HA cluster, Geo-redundant	
EXP-PUB-003	Change between 4G and 3G on the public radio network	Public network access	Functional	3G, 4G · Public radio · Single node, HA cluster, Geo-redundant	
EXP-MOB-001	X2 (Xn) handover between two radios	Mobility and access transitions	Functional	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant	
EXP-MOB-002	S1 (N2) handover between two radios	Mobility and access transitions	Functional	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant	
EXP-MOB-003	Idle-mode reselection with tracking area update	Mobility and access transitions	Functional	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant	
EXP-MOB-004	Roaming between two private Sites through a Shared System	Mobility and access transitions	Functional	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant	

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ID	Test	Domain	Category	Applies to	Set
EXP-MOB-005	Transition from the public radio network to the private radio	Mobility and access transitions	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant	
EXP-MOB-006	Transition from the private radio to the public radio network	Mobility and access transitions	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant	
EXP-MOB-007	Repeated transitions between public and private radio	Mobility and access transitions	Resilience	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant	
EXP-SEC-001	UE-to-UE communication prevented	Security and isolation	Security	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant	★
EXP-SEC-002	UE-to-platform communication prevented	Security and isolation	Security	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant	★
EXP-SEC-003	Authentication failure with wrong key material	Security and isolation	Security	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant	
EXP-SEC-004	Signalling security algorithms	Security and isolation	Security	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant	

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ID	Test	Domain	Category	Applies to	Set
EXP-SEC-005	Management path is outbound only and encrypted	Security and isolation	Security	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant	
EXP-SEC-006	Role-based access control in xControl	Security and isolation	Security	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant	
EXP-SEC-007	Audit trail of provisioning and access	Security and isolation	Security	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant	
EXP-SEC-008	Unknown-subscriber signalling storm	Security and isolation	Security	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant	
EXP-SEC-009	Subscriber identity concealment (SUCI)	Security and isolation	Security	5G · Local radio · Single node, HA cluster, Geo-redundant	
EXP-SEC-010	Authentication re-synchronisation	Security and isolation	Security	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant	
EXP-SEC-011	Illegal UE reject (cause #3) after a failed authentication	Security and isolation	Security	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant	
EXP-SEC-012	PLMN not allowed (cause #11) for a UE of a PLMN the Site does not serve	Security and isolation	Security	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant	

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ID	Test	Domain	Category	Applies to	Set
EXP-MSG-001	UE to UE SMS over MAP	Messaging (SMS)	Functional	4G · Public radio · Single node, HA cluster, Geo-redundant	
EXP-MSG-002	UE to application SMS over MAP and SMPP	Messaging (SMS)	Functional	4G · Public radio · Single node, HA cluster, Geo-redundant	
EXP-MSG-003	Application to UE SMS over SMPP and MAP, concatenated, binary and receipted	Messaging (SMS)	Functional	4G · Public radio · Single node, HA cluster, Geo-redundant	
EXP-MSG-004	MO and MT SMS over SGd	Messaging (SMS)	Functional	4G · Public radio · Single node, HA cluster, Geo-redundant	
EXP-MSG-005	Store-and-forward for an absent UE	Messaging (SMS)	Functional	4G · Public radio · Single node, HA cluster, Geo-redundant	
EXP-MSG-006	Message routing rules	Messaging (SMS)	Functional	4G · Public radio · Single node, HA cluster, Geo-redundant	
EXP-REC-001	Session record completeness	Session records and usage	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant	★
EXP-REC-002	Usage accounting accuracy	Session records and usage	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant	

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ID	Test	Domain	Category	Applies to	Set
EXP-REC-003	Record of a session that ended abnormally	Session records and usage	Functional	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant	
EXP-REC-004	Records delivered after a management-path outage	Session records and usage	Functional	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant	
EXP-REC-005	Usage report generation and export	Session records and usage	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant	
EXP-REC-006	Record attribution across public and private transitions	Session records and usage	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant	
EXP-HA-001	xCore user-plane node failure	Resilience and high availability	Resilience	4G, 5G · Local radio, Public radio · HA cluster	★
EXP-HA-002	xCore session-management node failure	Resilience and high availability	Resilience	4G, 5G · Local radio, Public radio · HA cluster	
EXP-HA-003	xCore subscriber-data node failure	Resilience and high availability	Resilience	4G, 5G · Local radio · HA cluster	
EXP-HA-004	xCore restart recovery	Resilience and high availability	Resilience	4G, 5G · Local radio, Public radio · Single node, HA cluster	★
EXP-HA-005	xCore geographic redundancy	Resilience and high availability	Resilience	4G, 5G · Local radio, Public radio · Geo-redundant	
EXP-HA-006	xRouter geographic redundancy	Resilience and high availability	Resilience	4G, 5G · Public radio · Geo-redundant	

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ID	Test	Domain	Category	Applies to	Set
EXP-HA-007	xRouter subscriber-management node failure	Resilience and high availability	Resilience	4G, 5G · Public radio · HA cluster	
EXP-HA-008	xRouter restart recovery	Resilience and high availability	Resilience	4G, 5G · Public radio · Single node, HA cluster	
EXP-HA-009	xControl restart recovery	Resilience and high availability	Resilience	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant	
EXP-HA-010	xControl unreachable from the xCore	Resilience and high availability	Resilience	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant	
EXP-HA-011	Single network function restart	Resilience and high availability	Resilience	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant	
EXP-HA-012	Radio link loss and recovery	Resilience and high availability	Resilience	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant	
EXP-HA-013	Secure link interruption between xRouter and xCore	Resilience and high availability	Resilience	4G, 5G · Public radio · Single node, HA cluster, Geo-redundant	
EXP-HA-014	Database node failure	Resilience and high availability	Resilience	4G, 5G · Local radio, Public radio · HA cluster	
EXP-HA-015	User-plane isolation between Systems	Resilience and high availability	Resilience	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant	

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ID	Test	Domain	Category	Applies to	Set
EXP-HA-018	Diameter peer failure and failover toward the operator's network	Resilience and high availability	Resilience	4G · Public radio · Single node, HA cluster, Geo-redundant	
EXP-CAP-001	xCore maximum concurrent Mobile Assets	Capacity and stability	Capacity	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant	
EXP-CAP-002	Attach rate	Capacity and stability	Capacity	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant	
EXP-CAP-003	Throughput at the rated tier	Capacity and stability	Capacity	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant	
EXP-CAP-004	Stability soak	Capacity and stability	Capacity	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant	
EXP-OAM-001	Alarm raised and cleared for an induced fault	Operations and maintenance	Operations	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant	
EXP-OAM-002	Metrics for capacity and usage	Operations and maintenance	Operations	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant	
EXP-OAM-003	Diagnostic collection for a support case	Operations and maintenance	Operations	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant	

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ID	Test	Domain	Category	Applies to	Set
EXP-OAM-004	xControl backup and restore	Operations and maintenance	Operations	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant	
EXP-OAM-005	API token expiry warning	Operations and maintenance	Operations	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant	
EXP-OAM-006	Time synchronization and timestamp consistency	Operations and maintenance	Operations	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant	

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6.6.2 Installation Checks

The checks that confirm a fresh installation or an upgraded platform is ready for service: every workload running at the release version, the management path to xControl established and synchronized, the radio connected, monitoring receiving the site, and, after an upgrade, the existing configuration and subscribers intact.

ID	Test	Category	Applies to
EXP-INS-001	Platform readiness after installation	Operations	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
EXP-INS-002	Management path and subscriber synchronization	Operations	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
EXP-INS-003	Radio access node connection	Operations	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant
EXP-INS-004	Monitoring path	Operations	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
EXP-INS-005	Upgrade and post-upgrade regression	Operations	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant

EXP-INS-001 — Platform readiness after installation

Status	✅ Accepted
Category	Operations
Components	xCore, xControl
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 30 min
Included in	Installation and Upgrade Verification

Objective. Every workload of a newly installed xCore is running at the release version, no container is restarting, every network function reports healthy, and the Site is registered with xControl at that version.

Preconditions

- Platform
  - The xCore is installed per the installation guide and the installer reports success.
  - You know the release version that was installed and the Kubernetes namespace of the xCore.
- Tooling and access
  - Read access to the cluster with `kubectl`.
  - Access to the CLI.
  - Log in to xControl with an account that can view the Mobile Asset under test.

Procedure

#	Where	Action	Expected result
1	Kubernetes	Run `kubectl get nodes`.	Every node is **Ready**.

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#	Where	Action	Expected result
2	Kubernetes	Run `kubectl get pods -n <namespace>` once the installer reports success.	Every pod is **Running** (or **Completed** for one-time jobs) with all containers ready. Note the **RESTARTS** count of every pod.
3	Kubernetes	Run `helm list -n <namespace>`.	The release is **deployed** and its chart version is the release version.
4	Kubernetes	Run `kubectl get pods -n <namespace> -o jsonpath='{range .items[*].spec.containers[*]}{.image}{"\n"}{end}' | sort -u`.	Every image under the Expeto registry paths is tagged with the release version; third-party images (databases, Kubernetes operators, exporters) carry the versions the release notes list.
5	CLI	Open the CLI, run `cd /debug/nf`, then `read node`.	Every network function of the deployment is listed with **Health** reported as healthy.
6	xControl	Open **Sites** and select the Site.	The Site is online, **Agent Version** equals the release version, and **Last Seen** is within the last five minutes.
7	Kubernetes	Fifteen minutes after the installer reported success, run `kubectl get pods -n <namespace>` again.	No **RESTARTS** count has increased.

Pass criteria

- Every pod is ready, and no pod restarts during the fifteen minutes that follow the installer's completion.
- Every Expeto image tag and the chart version equal the release version, and third-party images match the release notes.
- Every network function reports healthy.
- The Site is online in xControl with the release's agent version.

Deployment notes

- **Kubernetes-operator managed core:** The core is described by a Site resource rather than a Helm release. Replace the `helm list` step with `kubectl get site <name> -n <namespace> -o jsonpath='{.status.conditions[?(@.type=="Ready")].status}'` and expect `True`, and check that `{.status.observedGeneration}` equals `{.metadata.generation}`. The CLI sidecar is named `agent-cli`, and `read node` lists the SMF only; check the other network functions through their pod status.

Evidence collected: Kubernetes pod and node status; CLI output; xControl screenshot.

EXP-INS-002 — Management path and subscriber synchronization

Status	✅ Accepted
Category	Operations

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Components	xCore, xControl
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 30 min
Prerequisite procedures	EXP-INS-001 — Platform readiness after installation
Included in	Installation and Upgrade Verification
Automated by	Platform suite, 5G core: Mobile Asset provisioned through the xControl API appears in UDR and SMF within 120 s

Objective. The xCore agent holds an outbound connection to xControl, the Site reports online, and the subscriber data held by the xCore matches what xControl has provisioned for it.

Preconditions

- Mobile Asset
  - At least one Mobile Asset is provisioned on a System of the Site.
- Tooling and access
  - Log in to xControl with an account that holds the **ADMIN** role.
  - Access to the CLI.
  - A signalling capture on the xCore's egress interface, filtered to TCP port 443 (capture point 6).
- Procedures executed first
  - EXP-INS-001 — Platform readiness after installation

Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-INS-001 — Platform readiness after installation** as a prerequisite procedure.	As defined in EXP-INS-001.
2	Capture	Start the capture and restart the agent pod (`kubectl delete pod <release>-agent-0 -n <namespace>`), then inspect the capture.	The TLS connection to xControl is initiated by the xCore. No connection is initiated toward the xCore.
3	xControl	Open **Sites**, select the Site and watch its status while the agent pod restarts.	The Site returns to online and **Last Seen** updates within five minutes.
4	CLI	Run `cd /debug/ops` , then `cmd cache-clear type=SUBSCRIBER_CHECK_ERRORS` , then `cmd sync-sub-check mode=FULL` . Repeat `cmd sync-sub-check mode=FULL` until it no longer answers that a check is already running.	The full check completes.
5	CLI	Run `read sync-sub-error` .	The table is empty; no Mobile Asset is missing, mismatched or extra on the Site.

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#	Where	Action	Expected result
6	CLI	Run `cd /lte`, then `read hss` (or `cd /nr`, then `read udr` on a 5G-only Site) and read the total in the table footer.	The total equals the number of Mobile Assets xControl lists for the Site's Systems.

Pass criteria

- The agent connection is outbound only.
- The Site is online within five minutes of an agent restart.
- The full synchronization check reports zero discrepancies and the record counts match.

Evidence collected: 3GPP signalling capture (pcap); CLI output; xControl screenshot.

EXP-INS-003 — Radio access node connection

Status	✅ Accepted
Category	Operations
Components	xCore, xControl
Applies to	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant
Duration	About 20 min
Prerequisite procedures	EXP-INS-001 — Platform readiness after installation
Included in	Installation and Upgrade Verification

Objective. The customer's eNodeB or gNodeB establishes its control-plane association with the xCore, the xCore accepts the radio's PLMN and tracking area, and xControl shows the Private Radio as connected.

Preconditions

- Platform
  - The radio is configured with the xCore's MME or AMF address, the PLMN and the tracking area code agreed for the Site, and is powered off.
  - A Private Radio with the identifier `<PLMN>-<Cell ID>` of the radio exists on the Site in xControl with status **Enabled**.
- Tooling and access
  - Log in to xControl with an account that holds the **ADMIN** role.
  - A signalling capture on the xCore interface facing the radio (capture point 1).
  - Access to the CLI.
- Procedures executed first
  - EXP-INS-001 — Platform readiness after installation

Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-INS-001 — Platform readiness after installation** as a prerequisite procedure.	As defined in EXP-INS-001.

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#	Where	Action	Expected result
2	Radio	Power on the radio and wait for it to complete its start-up. Note the time.	The radio reports its cell as on air.
3	Capture	Inspect the capture.	An SCTP association is established, followed by S1 Setup Request and S1 Setup Response (4G) or NG Setup Request and NG Setup Response (5G). The response lists the served PLMN; there is no Setup Failure.
4	xControl	Open **Private Radios** and select the radio.	The status is **Connected** within two minutes of the radio reporting on air.
5	CLI	Run `cd /lte`, then `read enodeb` (4G), or `cd /nr`, then `read ran` (5G).	The radio is listed with its identifier, address, PLMN and tracking area.

Pass criteria

- The setup exchange completes with a Response, not a Failure, and the served PLMN and tracking area are the agreed ones.
- The Private Radio shows **Connected** within two minutes of the radio reporting on air.

Evidence collected: 3GPP signalling capture (pcap); xControl screenshot; CLI output.
References: 3GPP TS 36.413 §8.7.3 (S1 Setup); 3GPP TS 38.413 §8.7.3 (NG Setup).

EXP-INS-004 — Monitoring path

Status	✅ Accepted
Category	Operations
Components	xCore, xView
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 15 min
Prerequisite procedures	EXP-INS-001 — Platform readiness after installation
Included in	Installation and Upgrade Verification

Objective. The new Site's metrics reach xView with the Site's labels, its scrape targets are up, and no critical alert is firing for it.

Preconditions

- Tooling and access
  - Access to the xView Prometheus query interface and Grafana.
- Procedures executed first
  - EXP-INS-001 — Platform readiness after installation

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Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-INS-001 — Platform readiness after installation** as a prerequisite procedure.	As defined in EXP-INS-001.
2	Tester	In Prometheus, run `up{job="site", site="<site name>"}`.	The result is 1 for every instance of the Site.
3	Tester	Run `xcore_version{site="<site name>"}`.	The series exist and carry the `customer`, `customerId`, `site` and `siteId` labels of the Site.
4	Tester	Run `ALERTS{alertstate="firing", site="<site name>", severity="critical"}`.	The result is empty.
5	Tester	Open the Site dashboard in Grafana and select the Site.	The panels show data for the Site.

Pass criteria

- Every scrape target of the Site is up within ten minutes of the install completing.
- The Site's series carry its Customer and Site labels.
- No critical alert is firing for the Site.

Evidence collected: xControl screenshot.

EXP-INS-005 — Upgrade and post-upgrade regression

Status	✅ Accepted
Category	Operations
Components	xCore, xControl
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 2 h
Prerequisite procedures	EXP-INS-001 — Platform readiness after installation EXP-INS-002 — Management path and subscriber synchronization

Objective. A platform upgrade completes with every workload at the new version, leaves the configuration and the provisioned Mobile Assets intact, restores service to connected devices without manual intervention, and passes the installation and upgrade verification set.

> ⚠ **Service impact**
>
> This procedure interrupts service. Run it in a maintenance window or in a pre-production environment.

Preconditions

- Platform
  - The upgrade package or chart version is available and the upgrade procedure of the installation guide is at hand.
  - A maintenance window is agreed; the upgrade interrupts service.

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    - The results of the installation and upgrade verification set on the current version are at hand as the baseline.
- Mobile Asset
    - One Mobile Asset is connected and passing data (execute the UE-initiated attach procedure first if it is not).
- Tooling and access
    - Read access to the cluster with `kubectl`.
    - Log in to xControl with an account that holds the **ADMIN** role.
- Procedures executed first
    - EXP-INS-001 — Platform readiness after installation
    - EXP-INS-002 — Management path and subscriber synchronization

Procedure

#	Where	Action	Expected result
1	xControl	Record the Site status, the number of Systems, Private Radios and Mobile Assets on the Site, and the **Agent Version**.	The baseline is recorded.
2	UE	Start a continuous ping from the UE to a host on the enterprise LAN and note the time.	Replies arrive.
3	Infrastructure	Perform the upgrade as documented in the installation guide.	The upgrade command completes without error.
4	Kubernetes	Run `kubectl get pods -n <namespace>` until the rollout is complete.	Every pod is ready, with images tagged with the new version.
5	UE	Stop the ping and note when replies stopped and resumed. If the UE dropped its connection, wait for it to reconnect on its own.	Replies resume without any action on the UE or the platform; the service interruption is recorded.
6	xControl	Open **Sites** and select the Site.	The Site is online and **Agent Version** equals the new version.
7	xControl	Compare the number of Systems, Private Radios and Mobile Assets with the baseline.	The counts are unchanged.
8	Tester	Execute the installation and upgrade verification set.	Every test passes.

Pass criteria

- Every workload runs the new version and the Site reports the new agent version.
- Systems, Private Radios and Mobile Assets are unchanged.
- Connected devices regain service without manual intervention, and the measured interruption is recorded in the results sheet.
- The installation and upgrade verification set passes on the upgraded platform.

Postconditions

- Record the measured service interruption in the results sheet.

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Deployment notes

- **Kubernetes-operator managed core:** Fields of the Site definition that require a restart are rejected by the platform's admission check unless the Site is first placed in maintenance mode; the installation guide's upgrade procedure includes that step.

Evidence collected: Kubernetes pod and node status; xControl screenshot; UE connectivity check.

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6.6.3 Session Lifecycle

Standard 3GPP session procedures on Expeto Edge (xCore): attach and registration, detach, idle-mode transitions, service request and paging, periodic updates, repeated sessions, the loss of a device without a detach, session release while registered and multiple simultaneous sessions. These tests confirm that a Mobile Asset provisioned in xControl behaves on the private network exactly as it would on a public mobile network.

ID	Test	Category	Applies to
EXP-SES-001	UE-initiated attach	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
EXP-SES-002	UE-initiated detach	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
EXP-SES-003	Network-initiated detach	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
EXP-SES-004	UE idle mode	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
EXP-SES-005	UE-triggered service request	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
EXP-SES-006	UE paging	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
EXP-SES-007	Multiple UE attach	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
EXP-SES-008	Repeated attach and detach cycles	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
EXP-SES-009	Periodic tracking area or registration update	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
EXP-SES-010	Implicit detach after loss of the device	Functional	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant
EXP-SES-011	Attach with an APN outside the System Profile	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
EXP-SES-012	Session release and re-establishment while registered	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
EXP-SES-013	Multiple PDN connections	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant

EXP-SES-001 — UE-initiated attach

Status	✔ Accepted
Category	Functional
Components	xCore, xControl
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 15 min

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Included in	Installation and Upgrade Verification
Automated by	Platform suite, 4G split core: session flow `attach-detach` (single run, mixed soak and weekly deep soak) Platform suite, Kubernetes-operator managed core: session flow `attach-detach`, once per user plane Release certification: subscriber lifecycle scenarios on the reference 5G configuration

Objective. A UE initiates an attach request to the network and is authenticated. After authentication the network obtains the UE's subscription data from the subscriber database and, based on the default APN and PDN/PDU context in that data, creates the default session. The UE is then attached to the network and passes data.

Preconditions

- Mobile Asset
  - The UE's Mobile Asset is provisioned in xControl on the System under test, with state **Active** and status **Provisioned** or **Disconnected**.
- Device
  - The UE is powered off or in airplane mode.
  - The UE has the APN of its System Profile configured.
  - The UE has a web browser or a terminal application that can send ICMP echo requests (ping).
- Tooling and access
  - Log in to xControl with an account that can view the Mobile Asset under test.
  - Start a 3GPP signalling capture (pcap) with your preferred tool on the interfaces the procedure exercises.

Procedure

#	Where	Action	Expected result
1	UE	Power on the UE, or take it out of airplane mode, and wait for it to connect to the cellular network.	The UE shows a cellular data connection.
2	UE	Open a web page, or ping a known reachable host.	The page loads, or the ping is answered.
3	xControl	Open **Mobile Assets** and select the UE's IMSI.	The Mobile Asset status is **Connected** and an IP address inside the System's range is shown.
4	xControl	Scroll down to the **Sessions** section and select **Session History**.	On 4G, an HSS entry **Attached** and a PGW entry **Open** with a start time and no end time are present; on 5G the same two entries appear, named after the subscriber database and the SMF.
5	Capture	Inspect the signalling capture.	The messages match the sequence under *Expected signalling*, with no reject or failure message.

Expected signalling

Capture points: S1-MME / N2 (point 1), S11 / N4 (point 3), S6a / N8 (point 4).

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4G 5G

4G (EPS) sequence

1. Attach Request, carrying a PDN Connectivity Request (S1AP Initial UE Message)
2. Identity Request / Identity Response, when the network does not hold the UE's identity
3. Authentication Information Request / Answer on S6a, then Authentication Request / Authentication Response
4. Security Mode Command / Security Mode Complete
5. Update Location Request / Answer on S6a
6. Create Session Request / Create Session Response on S11
7. Initial Context Setup Request, carrying Attach Accept and Activate Default EPS Bearer Context Request
8. Initial Context Setup Response
9. Attach Complete, carrying Activate Default EPS Bearer Context Accept
10. Modify Bearer Request / Modify Bearer Response on S11

5G (5GS) sequence

1. Registration Request (NGAP Initial UE Message)
2. Identity Request / Identity Response, when the network does not hold the UE's identity
3. Authentication Request / Authentication Response, with the AUSF and UDM exchanges on the service-based interfaces
4. Security Mode Command / Security Mode Complete
5. Initial Context Setup Request, carrying Registration Accept
6. Initial Context Setup Response, then Registration Complete
7. PDU Session Establishment Request (UL NAS Transport)
8. PFCP Session Establishment Request / Response on N4
9. PDU Session Resource Setup Request, carrying PDU Session Establishment Accept
10. PDU Session Resource Setup Response

Pass criteria

- The UE obtains a data connection and passes traffic without manual intervention.
- The IP address shown in xControl is inside the address range of the Mobile Asset's System.
- The capture contains the complete sequence and no reject or failure message.

Evidence collected: 3GPP signalling capture (pcap); xControl session event log; UE connectivity check.
References: 3GPP TS 23.401 §5.3.2.1 (E-UTRAN Initial Attach); 3GPP TS 24.301 §5.5.1.2 (Attach procedure for EPS services); 3GPP TS 23.502 §4.2.2.2.2 (General Registration); 3GPP TS 23.502 §4.3.2.2.1 (UE Requested PDU Session Establishment).

EXP-SES-002 — UE-initiated detach

Status	✔ Accepted
Category	Functional
Components	xCore, xControl
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 10 min
Prerequisite procedures	EXP-SES-001 — UE-initiated attach

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Included in	Installation and Upgrade Verification
Automated by	Platform suite, 4G split core: session flow `attach-detach` (single run, mixed soak and weekly deep soak) Platform suite, Kubernetes-operator managed core: session flow `attach-detach`, once per user plane

Objective. The UE initiates a detach procedure and the network releases the session, the user-plane resources and the UE context, and xControl records the end of the session.

Preconditions

- Tooling and access
  - Log in to xControl with an account that holds the **ADMIN** role.
  - Start a 3GPP signalling capture (pcap) with your preferred tool on the interfaces the procedure exercises.
- Procedures executed first
  - EXP-SES-001 — UE-initiated attach

Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-SES-001 — UE-initiated attach** as a prerequisite procedure.	As defined in EXP-SES-001.
2	UE	Power off the UE, or put it in airplane mode, and wait for it to disconnect from the network.	The UE no longer shows a cellular connection.
3	xControl	Open the Mobile Asset.	The status changes to **Disconnected** within a reasonable time (nominally within 30 seconds).
4	xControl	Scroll down to the **Sessions** section and select **Session History**.	The PGW entry of the session is **Closed** with an end time.
5	CLI	Run `cd /lte`, then `read pgw -f imsi=<imsi>` (4G), or `cd /nr`, then `read smf -f imsi=<imsi>` (5G).	No session is listed for the IMSI.
6	Capture	Inspect the signalling capture.	The messages match the sequence under *Expected signalling*.

Expected signalling

Capture points: S1-MME / N2 (point 1), S11 / N4 (point 3).

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4G 5G

4G (EPS) sequence

1. Detach Request (UE originating; the switch-off indication is set when the UE powers off)
2. Delete Session Request / Delete Session Response on S11
3. Detach Accept (absent when the UE indicated switch-off)
4. UE Context Release Command / UE Context Release Complete

5G (5GS) sequence

1. Deregistration Request (UE originating)
2. PFCP Session Deletion Request / Response on N4
3. Deregistration Accept (absent when the UE indicated switch-off)
4. UE Context Release Command / UE Context Release Complete

Pass criteria

- xControl shows **Disconnected** within 30 seconds of the detach.
- The session record is closed with an end time.
- No session context remains for the IMSI on the session-management function.

Evidence collected: 3GPP signalling capture (pcap); xControl session event log; CLI output.
References: 3GPP TS 23.401 §5.3.8.2 (UE-initiated Detach procedure); 3GPP TS 23.502 §4.2.2.3.2 (UE-initiated Deregistration).

EXP-SES-003 — Network-initiated detach

Status	Accepted
Category	Functional
Components	xCore, xControl
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 10 min
Prerequisite procedures	EXP-SES-001 — UE-initiated attach

Objective. An administrator cancels a Mobile Asset's session from xControl. The subscriber database instructs the mobility function to detach the UE with re-attach required, the session and its resources are released, and the UE attaches again on its own with a new session.

Preconditions

- Tooling and access
  - Log in to xControl with an account that holds the **ADMIN** role.
  - Start a 3GPP signalling capture (pcap) with your preferred tool on the interfaces the procedure exercises.
- Procedures executed first
  - EXP-SES-001 — UE-initiated attach

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Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-SES-001 — UE-initiated attach** as a prerequisite procedure.	As defined in EXP-SES-001.
2	xControl	On the Mobile Asset's detail page, click the more button (**...**) and then **Cancel Session**.	The action is accepted.
3	xControl	Watch the Mobile Asset status.	The status changes to **Disconnected**, then back to **Connected** within one minute as the UE re-attaches on its own.
4	xControl	Scroll down to the **Sessions** section and select **Session History**.	The PGW entry of the cancelled session is **Closed**; an HSS entry records the deregistration; a new PGW entry is **Open**.
5	Capture	Inspect the signalling capture.	The messages match the sequence under *Expected signalling*; the Cancel Location Request carries the Reattach-Required flag and the Detach Request has detach type re-attach required.

Expected signalling

Capture points: S6a / N8 (point 4), S1-MME / N2 (point 1), S11 / N4 (point 3).

4G 5G

4G (EPS) sequence

1. Cancel Location Request on S6a from the HSS to the MME, with the Reattach-Required flag set, and Cancel Location Answer
2. Detach Request (network originating), detach type re-attach required
3. Detach Accept
4. Delete Session Request / Delete Session Response on S11
5. UE Context Release Command / UE Context Release Complete
6. Attach Request from the UE and the attach sequence of EXP-SES-001

5G (5GS) sequence

1. Deregistration notification from the UDM to the AMF (Nudm_UECM_DeregistrationNotification), re-registration required
2. Deregistration Request (UE terminated), re-registration required
3. Deregistration Accept
4. PFCP Session Deletion Request / Response on N4
5. UE Context Release Command / UE Context Release Complete
6. Registration Request from the UE and the registration sequence of EXP-SES-001

Pass criteria

• The session is released without any action on the UE.

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- The Cancel Location Request carries the Reattach-Required flag and the UE re-attaches on its own within one minute.
- A new session is open in xControl after the re-attach.

Postconditions

- Leave the UE attached for the next procedure or detach it with EXP-SES-002.

Evidence collected: 3GPP signalling capture (pcap); xControl session event log.
References: 3GPP TS 23.401 §5.3.8.3 (MME-initiated Detach procedure); 3GPP TS 23.401 §5.3.8.4 (HSS-initiated Detach procedure); 3GPP TS 29.272 §5.2.2.2 (Cancel Location (CLR-Flags); 3GPP TS 23.502 §4.2.2.3.3 (Network-initiated Deregistration).

EXP-SES-004 — UE idle mode

Status	✅ Accepted
Category	Functional
Components	xCore
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 20 min
Prerequisite procedures	EXP-SES-001 — UE-initiated attach
Included in	Installation and Upgrade Verification
Automated by	Platform suite, 4G split core: session flow `idle-reactivate` Platform suite, 4G split core: session flow `idle-detach`

Objective. A connected UE that stops generating traffic has its radio connection released after the radio's inactivity timer expires. The UE enters the idle state (ECM-IDLE in 4G, CM-IDLE in 5G) while it stays registered and keeps its session and IP address.

Preconditions

- Device
  - The UE has a web browser or a terminal application that can send ICMP echo requests (ping).
  - A UE application that shows the radio connection state, or knowledge of the radio's inactivity timer.
- Tooling and access
  - Start a 3GPP signalling capture (pcap) with your preferred tool on the interfaces the procedure exercises.
  - Log in to xControl with an account that can view the Mobile Asset under test.
- Procedures executed first
  - EXP-SES-001 — UE-initiated attach

Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-SES-001 — UE-initiated attach** as a prerequisite procedure.	As defined in EXP-SES-001.
2	UE	Make sure the UE generates no data traffic and wait for the inactivity time defined by the radio configuration.	The UE's radio connection is released while the UE remains registered.

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#	Where	Action	Expected result
3	CLI	For a private radio, run `cd /lte`, then `read mme -f imsi=<imsi>` (4G), or `cd / nr`, then `read amf <imsi>` (5G).	The context exists and its **state** (4G) or **Status** (5G) shows the UE as idle (ECM-IDLE or CM-IDLE).
4	xControl	Open the Mobile Asset.	The status is still **Connected** and the IP address is unchanged; the idle transition does not end the session.
5	Capture	Inspect the signalling capture.	The messages match the sequence under *Expected signalling*.

Expected signalling

Capture points: S1-MME / N2 (point 1), S11 / N4 (point 3).

4G 5G

4G (EPS) sequence

1. UE Context Release Request from the eNodeB, cause user inactivity
2. Release Access Bearers Request / Response on S11
3. UE Context Release Command / UE Context Release Complete

5G (5GS) sequence

1. UE Context Release Request from the gNodeB, cause user inactivity
2. PFCP Session Modification Request / Response on N4, deactivating the N3 tunnel and enabling downlink buffering or notification
3. UE Context Release Command / UE Context Release Complete

Pass criteria

- The radio connection is released within the radio's configured inactivity time and the UE stays registered.
- The session and IP address survive the idle transition.

Evidence collected: 3GPP signalling capture (pcap); CLI output.
References: 3GPP TS 23.401 §5.3.5 (S1 release procedure); 3GPP TS 23.502 §4.2.6 (AN release).

EXP-SES-005 — UE-triggered service request

Status	✅ Accepted
Category	Functional
Components	xCore, xControl
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 15 min
Prerequisite procedures	EXP-SES-001 — UE-initiated attach EXP-SES-004 — UE idle mode
Included in	Installation and Upgrade Verification

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Automated by	Platform suite, 4G split core: session flow `idle-reactivate`

Objective. A registered UE in idle state generates new uplink traffic. The network re-establishes the radio connection and the user-plane path with a service request, without a new attach, and the UE keeps its IP address.

Preconditions

- Device
  - The UE has a web browser or a terminal application that can send ICMP echo requests (ping).
- Tooling and access
  - Start a 3GPP signalling capture (pcap) with your preferred tool on the interfaces the procedure exercises.
  - Log in to xControl with an account that holds the **ADMIN** role.
- Procedures executed first
  - EXP-SES-001 — UE-initiated attach
  - EXP-SES-004 — UE idle mode

Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-SES-001 — UE-initiated attach** as a prerequisite procedure.	As defined in EXP-SES-001.
2	—	Execute **EXP-SES-004 — UE idle mode** as a prerequisite procedure.	As defined in EXP-SES-004.
3	UE	Open a web page, or ping a known reachable host.	The UE regains its radio connection and the page loads, or the ping is answered.
4	xControl	Open the Mobile Asset.	The status is **Connected** with the same IP address as before the idle period, and no new session was created in the **Event Log**.
5	Capture	Inspect the signalling capture.	The messages match the sequence under *Expected signalling*; there is no Attach Request or Registration Request.

Expected signalling

Capture points: S1-MME / N2 (point 1), S11 / N4 (point 3).

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4G 5G

4G (EPS) sequence

1. Service Request (S1AP Initial UE Message)
2. Initial Context Setup Request / Initial Context Setup Response
3. Modify Bearer Request / Modify Bearer Response on S11

5G (5GS) sequence

1. Service Request (NGAP Initial UE Message)
2. Initial Context Setup Request, carrying Service Accept, and Initial Context Setup Response
3. PFCP Session Modification Request / Response on N4, re-activating the N3 tunnel

Pass criteria

- Traffic resumes without a new attach or registration and with the same IP address.

Evidence collected: 3GPP signalling capture (pcap); xControl session event log.
References: 3GPP TS 23.401 §5.3.4.1 (UE triggered Service Request); 3GPP TS 23.502 §4.2.3.2 (UE Triggered Service Request).

EXP-SES-006 — UE paging

Status	✅ Accepted
Category	Functional
Components	xCore
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 20 min
Prerequisite procedures	EXP-SES-001 — UE-initiated attach EXP-SES-004 — UE idle mode

Objective. Downlink traffic arrives for a UE in idle state. The user plane reports the data, the network pages the UE, the UE responds with a service request and the traffic is delivered.

Preconditions

- Tooling and access
  - A host on the enterprise LAN (SGi / N6 side) that can send ping or other traffic to the UE's IP address.
  - Start a 3GPP signalling capture (pcap) with your preferred tool on the interfaces the procedure exercises.
  - Log in to xControl with an account that holds the **ADMIN** role.
- Procedures executed first
  - EXP-SES-001 — UE-initiated attach
  - EXP-SES-004 — UE idle mode

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Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-SES-001 — UE-initiated attach** as a prerequisite procedure.	As defined in EXP-SES-001.
2	—	Execute **EXP-SES-004 — UE idle mode** as a prerequisite procedure.	As defined in EXP-SES-004.
3	Test host	Send a ping (or other traffic the UE answers) from the LAN host toward the IP address of the UE.	After a short delay the ping is answered. If the UE does not respond to ICMP, use a protocol it answers.
4	Capture	Inspect the signalling capture.	The messages match the sequence under *Expected signalling*.

Expected signalling

Capture points: S11 / N4 (point 3), S1-MME / N2 (point 1).

4G 5G

4G (EPS) sequence

1. Downlink Data Notification / Downlink Data Notification Acknowledge on S11
2. Paging (S1AP) on every eNodeB of the tracking area list
3. Service Request from the UE
4. Initial Context Setup Request / Response
5. Modify Bearer Request / Modify Bearer Response on S11, then the buffered downlink data is delivered

5G (5GS) sequence

1. PFCP Session Report Request / Response on N4, reporting downlink data
2. Paging (NGAP) on every gNodeB of the registration area
3. Service Request from the UE
4. Initial Context Setup Request, carrying Service Accept, and Initial Context Setup Response
5. PFCP Session Modification Request / Response on N4, then the buffered downlink data is delivered

Pass criteria

- The UE is paged and answers; the first or one of the first downlink packets is delivered after the service request.

Evidence collected: 3GPP signalling capture (pcap).
References: 3GPP TS 23.401 §5.3.4.3 (Network Triggered Service Request); 3GPP TS 23.502 §4.2.3.3 (Network Triggered Service Request).

EXP-SES-007 — Multiple UE attach

Status	✅ Accepted
Category	Functional
Components	xCore, xControl

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Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 30 min
Prerequisite procedures	EXP-SES-001 — UE-initiated attach
Included in	Installation and Upgrade Verification
Automated by	Platform suite, 4G split core: mixed-flow soak (100 live sessions, random flow per session) and weekly deep soak

Objective. Several UEs connect to the network at the same time, each obtains its own address and service, and xControl shows all of them connected.

Preconditions

- Mobile Asset
  - Several Mobile Assets are provisioned in xControl on the System under test, one per UE, each with state **Active**.
- Device
  - The UE is powered off or in airplane mode.
  - The UE has the APN of its System Profile configured.
  - The UE has a web browser or a terminal application that can send ICMP echo requests (ping).
- Tooling and access
  - Log in to xControl with an account that can view the Mobile Asset under test.
- Procedures executed first
  - EXP-SES-001 — UE-initiated attach

Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-SES-001 — UE-initiated attach** as a prerequisite procedure.	As defined in EXP-SES-001.
2	UE	Repeat the previous procedure for each remaining provisioned UE, without detaching the ones already attached.	Every UE shows the results of EXP-SES-001.
3	xControl	Open **Mobile Assets** filtered by the System.	All the UEs are **Connected** at the same time, each with a distinct IP address.

Pass criteria

- Every UE is connected and passing traffic simultaneously, with no two UEs sharing an address.

Evidence collected: xControl Mobile Asset status; UE connectivity check.

EXP-SES-008 — Repeated attach and detach cycles

Status	✅ Accepted
Category	Functional
Components	xCore, xControl

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Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 30 min
Prerequisite procedures	EXP-SES-001 — UE-initiated attach EXP-SES-002 — UE-initiated detach
Automated by	Platform suite, Kubernetes-operator managed core: session flow `reattach` Platform suite, 4G split core: session flow `attach-detach` (single run, mixed soak and weekly deep soak)

Objective. A UE attaches and detaches repeatedly. Every cycle produces a complete session, every session is recorded and closed, and no context is left behind in the core after the last detach.

Preconditions

- Tooling and access
  - Log in to xControl with an account that holds the **ADMIN** role.
  - Access to the CLI.
- Procedures executed first
  - EXP-SES-001 — UE-initiated attach
  - EXP-SES-002 — UE-initiated detach

Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-SES-001 — UE-initiated attach** as a prerequisite procedure.	As defined in EXP-SES-001.
2	—	Execute **EXP-SES-002 — UE-initiated detach** as a prerequisite procedure.	As defined in EXP-SES-002.
3	UE	Repeat the attach and detach four more times, waiting for **Connected** and **Disconnected** in xControl on each cycle.	Every cycle reaches **Connected** and then **Disconnected**.
4	xControl	Scroll down to the **Sessions** section and select **Session History**.	Five PGW entries exist, each **Closed** with a start and an end time, and no entry remains **Open**.
5	CLI	Run `read mme -f imsi=<imsi>` (or `read amf <imsi>`) and `read pgw -f imsi=<imsi>` (or `read smf -f imsi=<imsi>`).	No context and no session is listed for the IMSI.
6	xControl	Compare the IP addresses of the five sessions.	Each address is inside the System's range. A dynamically addressed Mobile Asset may receive the same or a different address on each cycle; a statically addressed one receives its pinned address every time.

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#	Where	Action	Expected result
7	Capture	Inspect the five Attach Requests (or Registration Requests) in the capture.	The first carries the IMSI (or SUCI); every later one carries the GUTI (or 5G-GUTI) assigned by the previous cycle, and the IMSI does not appear in clear again.

Pass criteria

- Five of five cycles complete.
- Five closed session records and no open record exist for the IMSI.
- No residual context remains in the core after the last detach.
- The permanent identity is sent in clear at most once; every later attach uses the temporary identity.

Evidence collected: xControl session event log; CLI output; 3GPP signalling capture (pcap).
References: 3GPP TS 23.401 §5.3.10.3 (User Identity Confidentiality (GUTI reallocation)); 3GPP TS 24.501 §5.4.4 (Generic UE configuration update (5G-GUTI reallocation)).

EXP-SES-009 — Periodic tracking area or registration update

Status	✅ Accepted
Category	Functional
Components	xCore
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 1 h 30 min
Prerequisite procedures	EXP-SES-001 — UE-initiated attach EXP-SES-004 — UE idle mode

Objective. A UE that stays idle beyond the periodic update timer performs a periodic tracking area update (4G) or periodic registration update (5G), the network accepts it, and the UE stays registered with its session intact.

Preconditions

- Platform
  - You know the periodic update timer (T3412 in 4G, T3512 in 5G) that the xCore assigns to the UE. Read it with `cd /lte/debug/ashmme`, then `show timer` (4G), or from the Attach Accept or Registration Accept in the capture of EXP-SES-001. To shorten the wait, set it for the test with `update timer t3412=<seconds>` and restore it afterwards.
- Tooling and access
  - Start a 3GPP signalling capture (pcap) with your preferred tool on the interfaces the procedure exercises.
  - Log in to xControl with an account that can view the Mobile Asset under test.
- Procedures executed first
  - EXP-SES-001 — UE-initiated attach
  - EXP-SES-004 — UE idle mode

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Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-SES-001 — UE-initiated attach** as a prerequisite procedure.	As defined in EXP-SES-001.
2	—	Execute **EXP-SES-004 — UE idle mode** as a prerequisite procedure.	As defined in EXP-SES-004.
3	UE	Leave the UE idle, with no traffic, for longer than the periodic update timer.	The UE stays registered.
4	Capture	Inspect the signalling capture after the timer has expired.	The messages match the sequence under *Expected signalling*; the update type is periodic.
5	xControl	Open the Mobile Asset.	The status is unchanged (**Connected**) and no new session was created.
6	UE	Open a web page, or ping a known reachable host.	Traffic resumes with a service request, as in EXP-SES-005.

Expected signalling

Capture points: S1-MME / N2 (point 1).

4G 5G

4G (EPS) sequence

1. Tracking Area Update Request, update type periodic updating
2. Tracking Area Update Accept (with a new GUTI when the network reallocates it)
3. Tracking Area Update Complete, when a new GUTI was allocated
4. UE Context Release Command / UE Context Release Complete

5G (5GS) sequence

1. Registration Request, registration type periodic registration updating
2. Registration Accept (with a new 5G-GUTI when the network reallocates it)
3. Registration Complete, when a new 5G-GUTI was allocated
4. UE Context Release Command / UE Context Release Complete

Pass criteria

- The periodic update is accepted and the UE stays registered with its session and address.
- The update occurs no later than the periodic timer value signalled in the Attach Accept or Registration Accept plus 60 seconds.

Postconditions

- Restore the periodic timer if it was shortened for the test.

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Evidence collected: 3GPP signalling capture (pcap); xControl session event log.
References: 3GPP TS 23.401 §5.3.3.0 (Triggers for tracking area update); 3GPP TS 24.301 §5.5.3.2 (Normal and periodic tracking area updating procedure); 3GPP TS 24.501 §5.5.1.3 (Registration procedure for mobility and periodic registration update).

EXP-SES-010 — Implicit detach after loss of the device

Status	✅ Accepted
Category	Functional
Components	xCore, xControl
Applies to	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant
Duration	About 2 h
Prerequisite procedures	EXP-SES-001 — UE-initiated attach

Objective. A UE disappears from coverage without detaching. The network keeps its context until the reachability and implicit detach timers expire, then detaches it implicitly, closes the session with a cause, and leaves no context behind.

Preconditions

- Platform
  - You know the periodic update, mobile reachable and implicit detach timers the xCore applies (`cd /lte/debug/ashmme` , then `show timer`); the time to implicit detach is their sum. To shorten the wait, set them for the test with `update timer t3412=<s> mobileReachableTimer=<s> valimplicitDetachTimerval=<s>` and restore them afterwards.
- Device
  - A way to remove the UE from coverage abruptly (an RF-shielded box, or moving the UE out of coverage) without it sending a detach.
- Tooling and access
  - Log in to xControl with an account that holds the **ADMIN** role.
  - Access to the CLI.
- Procedures executed first
  - EXP-SES-001 — UE-initiated attach

Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-SES-001 — UE-initiated attach** as a prerequisite procedure.	As defined in EXP-SES-001.
2	UE	Place the UE in the shielded box, or move it out of coverage, without powering it off or enabling airplane mode. Note the time.	The UE loses coverage; no Detach Request or Deregistration Request appears in the capture.
3	xControl	Open the Mobile Asset immediately after.	The status is still **Connected**; the network has not yet detected the loss.
4	CLI	Run `read mme -f imsi=<imsi>` (or `read amf <imsi>`) at intervals until the implicit detach timer has expired.	The context exists until the timers expire, then disappears.

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#	Where	Action	Expected result
5	xControl	Open the **Event Log** section and select **Session** after the timers have expired.	The PGW entry is **Closed** with an end time, and the record carries a cause code for the implicit detach.
6	UE	Take the UE out of the box, or back into coverage.	The UE attaches again as in EXP-SES-001 and a new session opens.

Pass criteria

- The session is closed with a cause no later than the sum of the configured periodic, mobile reachable and implicit detach timers plus 60 seconds.
- No context remains for the IMSI once the session is closed.
- The UE regains service without manual intervention when coverage returns.

Postconditions

- Restore the timers if they were shortened for the test.

Evidence collected: xControl session event log; CLI output.
References: 3GPP TS 23.401 §5.3.8.3 (MME-initiated Detach procedure (implicit detach)); 3GPP TS 24.301 §5.3.7 (Handling of the periodic tracking area update timer and mobile reachable timer); 3GPP TS 24.501 §5.3.7 (Handling of the periodic registration update timer and mobile reachable timer).

EXP-SES-011 — Attach with an APN outside the System Profile

Status	✅ Accepted
Category	Functional
Components	xCore
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 20 min
Prerequisite procedures	EXP-SES-001 — UE-initiated attach

Objective. A UE requests a PDN connection or PDU session for an APN (DNN) that is not in its Mobile Asset's System Profile. The network rejects the request with a cause the UE understands, and correcting the APN on the UE restores service.

Preconditions

- Mobile Asset
  - The UE's Mobile Asset is provisioned in xControl on the System under test, with state **Active** and status **Provisioned** or **Disconnected**.
- Device
  - The UE's data APN is set to a name that is not in the Mobile Asset's System Profile (for example `wrong.example.com`).
  - The UE is powered off or in airplane mode.
- Tooling and access
  - Log in to xControl with an account that can view the Mobile Asset under test.
  - Start a 3GPP signalling capture (pcap) with your preferred tool on the interfaces the procedure exercises.

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- Procedures executed first
  - EXP-SES-001 — UE-initiated attach

Procedure

#	Where	Action	Expected result
1	UE	Power on the UE, or take it out of airplane mode, and wait for it to attempt to connect.	The UE registers but obtains no data connection, or fails to attach, depending on the radio access technology and device.
2	Capture	Inspect the signalling capture.	The messages match the sequence under *Expected signalling*; the reject cause identifies the APN or DNN as unknown.
3	xControl	Open the Mobile Asset.	The status is not **Connected**; no PGW entry is **Open**.
4	UE	Correct the APN to the one in the System Profile and toggle airplane mode.	The UE connects as in EXP-SES-001.

Expected signalling

Capture points: S1-MME / N2 (point 1).

4G 5G

4G (EPS) sequence

1. Attach Request, carrying a PDN Connectivity Request with the unknown APN
2. Authentication and Security Mode exchanges complete
3. Attach Reject, or Attach Accept followed by PDN Connectivity Reject, with an ESM cause that names the APN as missing or unknown

5G (5GS) sequence

1. Registration Request, Authentication, Security Mode; Registration Accept
2. PDU Session Establishment Request with the unknown DNN
3. PDU Session Establishment Reject with a 5GSM cause that names the DNN as missing or unknown

Pass criteria

- No data session is established for the unknown APN.
- The reject carries ESM cause #27 (4G) or 5GSM cause #27 (5G), missing or unknown APN or DNN.
- Service is restored by correcting the APN on the UE, with no change on the platform.

Evidence collected: 3GPP signalling capture (pcap); xControl Mobile Asset status.
References: 3GPP TS 24.301 §6.5.1.4 (UE requested PDN connectivity procedure not accepted by the network); 3GPP TS 24.501 §6.4.1.4 (UE-requested PDU session establishment procedure not accepted by the network).

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EXP-SES-012 — Session release and re-establishment while registered

Status	✅ Accepted
Category	Functional
Components	xCore, xControl
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 20 min
Prerequisite procedures	EXP-SES-001 — UE-initiated attach EXP-SES-013 — Multiple PDN connections

Objective. A registered UE releases one data session without deregistering, the network tears down that session's user-plane resources and closes its record, and the UE establishes a new session afterwards, still without a new attach or registration.

Preconditions

- Device
  - 5G, a UE whose mobile-data switch releases the PDU session. 4G, the UE has two PDN connections (EXP-SES-013), so that releasing one leaves the UE attached.
  - The UE has a web browser or a terminal application that can send ICMP echo requests (ping).
- Tooling and access
  - Log in to xControl with an account that holds the **ADMIN** role.
  - Start a 3GPP signalling capture (pcap) with your preferred tool on the interfaces the procedure exercises.
  - Access to the CLI.
- Procedures executed first
  - EXP-SES-001 — UE-initiated attach
  - EXP-SES-013 — Multiple PDN connections

Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-SES-001 — UE-initiated attach** as a prerequisite procedure.	As defined in EXP-SES-001.
2	UE	Release the session. 5G, switch mobile data off. 4G, disable the second APN so the UE disconnects that PDN.	The UE stays registered on the network.
3	Capture	Inspect the signalling capture.	The messages match the sequence under *Expected signalling*; there is no Detach Request or Deregistration Request.
4	CLI	Run `read amf <imsi>` (5G) or `read mme -f imsi=<imsi>` (4G), then `read smf -f imsi=<imsi>` or `read pgw -f imsi=<imsi>`.	The mobility context still exists; the released session is no longer listed.

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#	Where	Action	Expected result
5	xControl	Open the Mobile Asset and its **Event Log**.	The released session's PGW entry is **Closed**; 5G, the status is **Disconnected** while no session exists.
6	UE	Re-establish the session. 5G, switch mobile data on. 4G, enable the second APN again.	The UE obtains a data connection and passes traffic.
7	Capture	Inspect the signalling capture.	A new PDU Session Establishment (or PDN Connectivity Request) completes; there is no Registration Request or Attach Request.
8	xControl	Open the Mobile Asset.	The status is **Connected** with a new **Open** session record.

Expected signalling

Capture points: S1-MME / N2 (point 1), S11 / N4 (point 3).

4G 5G

4G (EPS) sequence

1. PDN Disconnect Request from the UE for the second PDN
2. Delete Session Request / Delete Session Response on S11
3. Deactivate EPS Bearer Context Request / Accept, and E-RAB Release Command / Response
4. Later, PDN Connectivity Request, Create Session Request / Response, Activate Default EPS Bearer Context Request / Accept, E-RAB Setup Request / Response

5G (5GS) sequence

1. PDU Session Release Request from the UE (UL NAS Transport)
2. PFCP Session Deletion Request / Response on N4
3. PDU Session Resource Release Command / Response, carrying PDU Session Release Command
4. PDU Session Release Complete
5. Later, PDU Session Establishment Request, PFCP Session Establishment, PDU Session Resource Setup Request / Response carrying PDU Session Establishment Accept

Pass criteria

- The session is released and re-established with no detach, deregistration, attach or registration.
- The released session's record is closed and the new session's record is open, each with its own start time.
- No user-plane resource remains for the released session.

Evidence collected: 3GPP signalling capture (pcap); CLI output; xControl session event log.
References: 3GPP TS 23.502 §4.3.4.2 (UE or network requested PDU Session Release); 3GPP TS 24.501 §6.4.3 (UE-requested PDU session release procedure); 3GPP TS 23.401 §5.10.3 (UE requested PDN disconnection); 3GPP TS 24.301 §6.5.2 (UE requested PDN disconnect procedure).

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EXP-SES-013 — Multiple PDN connections

Status	✅ Accepted
Category	Functional
Components	xCore, xControl
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 30 min
Prerequisite procedures	EXP-SES-001 — UE-initiated attach

Objective. A UE whose System Profile holds two APN Profiles establishes two PDN connections (4G) or two PDU sessions (5G) at the same time, each with its own address and record, passes traffic on both, and can release one without affecting the other.

Preconditions

- Platform
  - The Mobile Asset's System Profile contains two APN Profiles, A and B, each with its own address range and egress on the enterprise network.
- Device
  - The UE has both APNs configured and set to connect (for example APN A as the default data APN and APN B as a second data APN).
  - The UE has a web browser or a terminal application that can send ICMP echo requests (ping).
- Tooling and access
  - Log in to xControl with an account that holds the **ADMIN** role.
  - Start a 3GPP signalling capture (pcap) with your preferred tool on the interfaces the procedure exercises.
  - Access to the CLI.
  - A host reachable through each APN's egress.
- Procedures executed first
  - EXP-SES-001 — UE-initiated attach

Procedure

#	Where	Action	Expected result
1	UE	Power on the UE, or take it out of airplane mode, and wait for both APNs to connect.	The UE shows two active data connections.
2	Capture	Inspect the signalling capture.	The messages match the sequence under *Expected signalling*; two default bearers (4G) or two PDU sessions (5G) are set up with distinct identifiers.
3	CLI	Run `read pgw -f imsi=<imsi>` (4G) or `read smf -f imsi=<imsi>` (5G).	Two sessions are listed for the IMSI, with different bearer or PDU session identifiers and different addresses.
4	xControl	Open the Mobile Asset and its **Event Log**.	Two PGW entries are **Open**, one per APN name, each with its address.
5	UE	Ping the host behind APN A and the host behind APN B.	Both pings are answered.

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#	Where	Action	Expected result
6	UE	Disable APN B on the UE.	The APN B session is released (EXP-SES-012) and the APN A connection is unaffected.
7	UE	Ping the host behind APN A again.	The ping is answered without interruption.

Expected signalling

Capture points: S1-MME / N2 (point 1), S11 / N4 (point 3).

4G 5G

4G (EPS) sequence

1. Attach with the first PDN as in EXP-SES-001
2. PDN Connectivity Request for the second APN
3. Create Session Request / Create Session Response on S11 for the second PDN
4. E-RAB Setup Request carrying Activate Default EPS Bearer Context Request, E-RAB Setup Response, Activate Default EPS Bearer Context Accept

5G (5GS) sequence

1. Registration as in EXP-SES-001
2. Two PDU Session Establishment Requests with different PDU session identifiers and DNNs
3. Two PFCP Session Establishment Request / Response exchanges on N4
4. Two PDU Session Resource Setup Request / Response exchanges carrying PDU Session Establishment Accept

Pass criteria

- Two sessions with distinct identifiers and addresses exist for the UE at the same time and both pass traffic.
- Each session has its own open record in xControl, attributed to its APN.
- Releasing one session leaves the other passing traffic without interruption.

Evidence collected: 3GPP signalling capture (pcap); CLI output; xControl session event log; ICMP result from the UE.
References: 3GPP TS 23.401 §5.10.2 (UE requested PDN connectivity); 3GPP TS 24.301 §6.5.1 (UE requested PDN connectivity procedure); 3GPP TS 23.502 §4.3.2.2.1 (UE Requested PDU Session Establishment).

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6.6.4 Provisioning

Changes made in xControl (Expeto Management) take effect in the network: creating, importing, activating, deactivating, moving and deleting Mobile Assets, assigning static addresses and device locks, rejecting unknown or inactive SIMs, and applying changes queued while the site was out of contact.

ID	Test	Category	Applies to
EXP-PRV-001	Provision a Mobile Asset	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
EXP-PRV-002	Deactivate a Mobile Asset	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
EXP-PRV-003	Reactivate a Mobile Asset	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
EXP-PRV-004	Inactive Mobile Asset attach rejected	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
EXP-PRV-005	Unknown UE attach rejected	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
EXP-PRV-006	Bulk import of Mobile Assets	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
EXP-PRV-007	Move a connected Mobile Asset to another System	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
EXP-PRV-008	Delete a Mobile Asset with an active session	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
EXP-PRV-009	Static IP address assignment	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
EXP-PRV-010	IMEI lock	Security	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
EXP-PRV-011	Provisioning changes made while the site is out of contact	Functional	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant

EXP-PRV-001 — Provision a Mobile Asset

Status	✅ Accepted
Category	Functional
Components	xControl, xCore
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 20 min
Prerequisite procedures	EXP-SES-001 — UE-initiated attach
Included in	Installation and Upgrade Verification
Automated by	Platform suite, 5G core: Mobile Asset provisioned through the xControl API appears in UDR and SMF within 120 s

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Objective. A Mobile Asset created in xControl, through the portal or the API, is written to the subscriber database of the Site within a bounded time, is reported consistent by the synchronization check, and can attach.

Preconditions

- Platform
  - The Site has a System with a System Profile, and a Keyset mapped to the Site.
- Mobile Asset
  - A SIM whose IMSI is not yet provisioned, with its key material available for the Keyset in use.
- Device
  - The UE is powered off or in airplane mode.
  - The UE has the APN of its System Profile configured.
- Tooling and access
  - Log in to xControl with an account that holds the **ADMIN** role.
  - An API token for the Customer, for the API variant.
  - Access to the CLI.
- Procedures executed first
  - EXP-SES-001 — UE-initiated attach

Procedure

#	Where	Action	Expected result
1	xControl	Open **Mobile Assets**, click **New**, enter the IMSI and the SIM details, select the **System**, the **System Profile** and the **Keyset**, set **Status** to **Active**, and click **Submit**. Note the time.	The Mobile Asset appears in the list with status **Provisioned**.
2	xControl API	For the API variant, create the Mobile Asset with a POST to the subscribers endpoint using the same values, then GET it back.	The response returns the Mobile Asset with the status field set to Active.
3	CLI	Run `cd /lte`, then `read hss <imsi>` (or `cd /nr`, then `read udr <imsi>` on a 5G Site), repeating until the record appears.	The record exists within 120 seconds of the submit.
4	CLI	Run `cd /debug/ops`, then `cmd sync-sub-check id=<imsi>`.	The check reports the IMSI as consistent between xControl and the Site on every node.
5	—	Execute **EXP-SES-001 — UE-initiated attach** as a prerequisite procedure.	As defined in EXP-SES-001.

Pass criteria

- The subscriber record is present on the Site within 120 seconds of creation.
- The synchronization check reports no discrepancy for the IMSI.
- The UE attaches and passes traffic.

Evidence collected: xControl screenshot; CLI output; xControl session event log.

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EXP-PRV-002 — Deactivate a Mobile Asset

Status	✅ Accepted
Category	Functional
Components	xCore, xControl
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 15 min
Prerequisite procedures	EXP-SES-001 — UE-initiated attach
Included in	Installation and Upgrade Verification

Objective. A connected Mobile Asset is set to **Inactive** in xControl. The subscriber database cancels its location without requesting a re-attach, the network releases its session, and every new attach attempt is rejected while it stays inactive.

Preconditions

- Tooling and access
  - Log in to xControl with an account that holds the **ADMIN** role.
  - Start a 3GPP signalling capture (pcap) with your preferred tool on the interfaces the procedure exercises.
- Procedures executed first
  - EXP-SES-001 — UE-initiated attach

Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-SES-001 — UE-initiated attach** as a prerequisite procedure.	As defined in EXP-SES-001.
2	xControl	On the Mobile Asset's detail page click **Edit**, set **Status** to **Inactive**, and click **Submit**.	The change is saved.
3	xControl	Watch the Mobile Asset status.	The status changes to **Disconnected**.
4	UE	Observe the UE.	The UE loses its cellular connection, and any reconnection attempt fails.
5	Capture	Inspect the signalling capture.	The messages match the sequence under *Expected signalling*; the Cancel Location Request does not carry the Reattach-Required flag and the Detach Request has detach type re-attach not required.

Expected signalling

Capture points: S6a / N8 (point 4), S1-MME / N2 (point 1).

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4G 5G

4G (EPS) sequence

1. Cancel Location Request on S6a without the Reattach-Required flag, and Cancel Location Answer
2. Detach Request (network originating), detach type re-attach not required, and Detach Accept
3. Delete Session Request / Response on S11 and the release of the UE context
4. On each reconnection attempt, Attach Request followed by Attach Reject

5G (5GS) sequence

1. Deregistration notification from the UDM without re-registration required
2. Deregistration Request (UE terminated) and Deregistration Accept, then the release of the session and the UE context
3. On each reconnection attempt, Registration Request followed by Registration Reject

Pass criteria

- The session is released without any action on the UE, and the UE is not told to re-attach.
- Every reconnection attempt while the Mobile Asset is **Inactive** is rejected.

Evidence collected: xControl session event log; 3GPP signalling capture (pcap).
References: 3GPP TS 23.401 §5.3.8.4 (HSS-initiated Detach procedure); 3GPP TS 29.272 §5.2.2.2 (Cancel Location (CLR-Flags)).

EXP-PRV-003 — Reactivate a Mobile Asset

Status	✅ Accepted
Category	Functional
Components	xCore, xControl
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 15 min
Prerequisite procedures	EXP-PRV-002 — Deactivate a Mobile Asset

Objective. A deactivated Mobile Asset is set back to **Active** in xControl, and the UE regains service without any change on the device.

Preconditions

- Device
  - The UE is powered on and not in airplane mode.
  - The UE has the APN of its System Profile configured.
  - The UE has a web browser or a terminal application that can send ICMP echo requests (ping).
- Tooling and access
  - Start a 3GPP signalling capture (pcap) with your preferred tool on the interfaces the procedure exercises.
  - Log in to xControl with an account that holds the **ADMIN** role.
- Procedures executed first
  - EXP-PRV-002 — Deactivate a Mobile Asset

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Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-PRV-002 — Deactivate a Mobile Asset** as a prerequisite procedure.	As defined in EXP-PRV-002.
2	xControl	On the Mobile Asset's detail page click **Edit**, set **Status** to **Active**, and click **Submit**.	The change is saved.
3	UE	Wait for the UE to reconnect. If it does not retry on its own, toggle airplane mode.	The UE shows a cellular data connection.
4	UE	Open a web page, or ping a known reachable host.	The page loads, or the ping is answered.
5	xControl	Open the Mobile Asset.	The status is **Connected**.
6	Capture	Inspect the signalling capture.	The attach or registration completes as in EXP-SES-001.

Pass criteria

- The UE regains service with no change on the device other than, at most, toggling airplane mode.

Evidence collected: xControl session event log; 3GPP signalling capture (pcap).

EXP-PRV-004 — Inactive Mobile Asset attach rejected

Status	✅ Accepted
Category	Functional
Components	xCore
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 15 min
Prerequisite procedures	EXP-PRV-002 — Deactivate a Mobile Asset

Objective. A UE whose Mobile Asset is **Inactive** in xControl attempts to attach, and the network rejects the attempt.

Preconditions

- Mobile Asset
  - The UE's Mobile Asset is provisioned in xControl with state **Inactive**.
- Device
  - The UE is powered off or in airplane mode.
- Tooling and access
  - Log in to xControl with an account that can view the Mobile Asset under test.
  - Start a 3GPP signalling capture (pcap) with your preferred tool on the interfaces the procedure exercises.
- Procedures executed first
  - EXP-PRV-002 — Deactivate a Mobile Asset

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Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-PRV-002 — Deactivate a Mobile Asset** as a prerequisite procedure.	As defined in EXP-PRV-002.
2	UE	Power off the UE, or put it in airplane mode.	The UE is detached.
3	UE	Power on the UE, or take it out of airplane mode, and wait for it to attempt to connect.	The UE fails to connect to the network.
4	Capture	Inspect the signalling capture.	The attach (4G) or registration (5G) attempt is rejected.

Pass criteria

- The UE obtains no service while the Mobile Asset is **Inactive**.

Evidence collected: 3GPP signalling capture (pcap).

EXP-PRV-005 — Unknown UE attach rejected

Status	✅ Accepted
Category	Functional
Components	xCore
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 15 min
Included in	Installation and Upgrade Verification
Automated by	Platform suite, 4G split core: unknown-IMSI signalling soak (250 unserved IMSIs)

Objective. A UE whose IMSI is not provisioned in xControl attempts to attach, and the network rejects the attempt.

Preconditions

- Mobile Asset
  - The UE's IMSI is **not** provisioned as a Mobile Asset in xControl.
- Device
  - The UE is powered off or in airplane mode.
- Tooling and access
  - Log in to xControl with an account that can view the Mobile Asset under test.
  - Start a 3GPP signalling capture (pcap) with your preferred tool on the interfaces the procedure exercises.

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Procedure

#	Where	Action	Expected result
1	UE	Power on the UE, or take it out of airplane mode, and wait for it to attempt to connect.	The UE fails to connect to the network.
2	Capture	Inspect the signalling capture.	The messages match the sequence under *Expected signalling*.

Expected signalling

Capture points: S1-MME / N2 (point 1), S6a / N8 (point 4).

4G 5G

4G (EPS) sequence

1. Attach Request, then Identity Request / Identity Response for the IMSI when the UE presented a GUTI
2. Authentication Information Request on S6a answered with an error result for an unknown user
3. Attach Reject with an EMM cause

5G (5GS) sequence

1. Registration Request, then Identity Request / Identity Response when needed
2. The authentication request to the UDM fails for an unknown subscriber
3. Registration Reject with a 5GMM cause

Pass criteria

• The UE obtains no service and no context or session is created for the IMSI.

Evidence collected: 3GPP signalling capture (pcap).
References: 3GPP TS 24.301 §5.5.1.2.5 (Attach not accepted by the network); 3GPP TS 24.501 §5.5.1.2.5 (Initial registration not accepted by the network).

EXP-PRV-006 — Bulk import of Mobile Assets

Status	✅ Accepted
Category	Functional
Components	xControl, xCore
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 30 min
Prerequisite procedures	EXP-SES-001 — UE-initiated attach

Objective. A batch of SIMs is imported into xControl from the SIM vendor's output file. Every Mobile Asset is created with the chosen System, System Profile, Keyset and initial state, is written to the Site, and one of them attaches.

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Preconditions

- Platform
  - The Site has a System with a System Profile, and a Keyset mapped to the Site.
- Mobile Asset
  - A SIM vendor output file (`.out`) with at least ten records whose IMSIs are not yet provisioned, and the corresponding 128-bit K encryption key.
- Tooling and access
  - Log in to xControl with an account that holds the **ADMIN** role.
  - Access to the CLI.
- Procedures executed first
  - EXP-SES-001 — UE-initiated attach

Procedure

#	Where	Action	Expected result
1	xControl	Open **Mobile Assets**, click **Import**, then **Bulk Import**, click **Choose File** and select the `.out` file.	The file passes validation and the column mapping interface appears.
2	xControl	Select the **Customer**, **System**, **System Profile** and **Keyset**, paste the **K encryption key**, set **Initial Status** to **Active**, leave **Overwrite if Existing** unchecked, and click **Submit**. Note the time.	The import completes and the Mobile Assets appear in the list with status **Provisioned**.
3	xControl	Filter **Mobile Assets** by the System and count the new records.	The count equals the number of records in the file.
4	CLI	Run `cd /debug/ops`, then `cmd cache-clear type=SUBSCRIBER_CHECK_ERRORS`, `cmd sync-sub-check mode=FULL` (repeat until it no longer answers that a check is already running), then `read sync-sub-error`.	The error table is empty; no record is missing, mismatched or extra.
5	xControl	Repeat the import with the same file and **Overwrite if Existing** unchecked.	The import is refused because the IMSIs already exist; no duplicate is created.
6	—	Execute **EXP-SES-001 — UE-initiated attach** as a prerequisite procedure.	As defined in EXP-SES-001.

Pass criteria

- Every record in the file becomes a Mobile Asset with the selected System, System Profile, Keyset and state.
- The synchronization check reports no discrepancy within five minutes of the import.
- A repeated import without overwrite creates no duplicates.
- A UE from the batch attaches and passes traffic.

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Postconditions

- Delete the imported Mobile Assets that are not needed for later tests with **Bulk Delete**.

Evidence collected: xControl screenshot; CLI output.

EXP-PRV-007 — Move a connected Mobile Asset to another System

Status	✅ Accepted
Category	Functional
Components	xControl, xCore
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 30 min
Prerequisite procedures	EXP-SES-001 — UE-initiated attach
Automated by	Platform suite, split user plane: System reassignment of a connected Mobile Asset (Cancel Location with re-attach)

Objective. A Mobile Asset with an active session is moved from one System to another in xControl. The subscriber database cancels its location with re-attach required, the UE re-attaches on its own, every bearer is re-established on the new System with an address from its range and egress to its network, and no session is left behind on the old System.

Preconditions

- Platform
  - The Site has two Systems, A and B, with different address ranges and egress networks, each with a System Profile.
- Mobile Asset
  - The Mobile Asset is on System A and connected (EXP-SES-001).
- Tooling and access
  - Log in to xControl with an account that holds the **ADMIN** role.
  - Access to the CLI.
  - A host on System B's egress network that answers ping.
  - Start a 3GPP signalling capture (pcap) with your preferred tool on the interfaces the procedure exercises.
- Procedures executed first
  - EXP-SES-001 — UE-initiated attach

Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-SES-001 — UE-initiated attach** as a prerequisite procedure.	As defined in EXP-SES-001.
2	xControl	On the Mobile Asset's detail page click **Edit**, select System B and a System Profile of System B, and click **Submit**. Note the time.	The change is saved.

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#	Where	Action	Expected result
3	xControl	Watch the Mobile Asset status.	The status changes to **Disconnected** within 60 seconds and back to **Connected** within one further minute, with no action on the UE.
4	Capture	Inspect the signalling capture.	The messages match the sequence under *Expected signalling*; the Cancel Location Request carries the Reattach-Required flag.
5	xControl	Open the Mobile Asset and its **Event Log**.	The status is **Connected**, the IP address is inside System B's range, and the new session record names System B.
6	UE	Ping the host on System B's egress network.	The ping is answered.
7	CLI	Run `read pgw -f imsi=<imsi>` (or `read smf -f imsi=<imsi>`).	Exactly one session is listed, on System B's user plane; none remains on System A.
8	xControl	Repeat the move for several Mobile Assets at once with **Bulk Update**, choosing **Move Mobile Assets to a New System**.	Every selected Mobile Asset re-attaches on its own and shows the new System.

Expected signalling

Capture points: S6a / N8 (point 4), S1-MME / N2 (point 1), S11 / N4 (point 3).

4G 5G

4G (EPS) sequence

1. Cancel Location Request on S6a with the Reattach-Required flag, and Cancel Location Answer
2. Detach Request (network originating), detach type re-attach required, and Detach Accept
3. Delete Session Request / Response on S11
4. Attach Request from the UE and the full attach sequence of EXP-SES-001, with the Create Session Request selecting System B's user plane

5G (5GS) sequence

1. Deregistration notification from the UDM, re-registration required
2. Deregistration Request (UE terminated), re-registration required, and Deregistration Accept
3. PFCP Session Deletion Request / Response on N4
4. Registration Request from the UE and the registration and PDU session sequence of EXP-SES-001 on System B

Pass criteria

- The platform releases the existing session within 60 seconds of the move with a Cancel Location that requires re-attach.
- The UE re-attaches on its own; the address is inside the target System's range and the session record names the target System.
- No session remains on the source System.

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Postconditions

- Move the Mobile Asset back to System A if later tests assume it.

Evidence collected: xControl session event log; CLI output; ICMP result from the UE; 3GPP signalling capture (pcap).
References: 3GPP TS 29.272 §5.2.2.2 (Cancel Location (CLR-Flags); 3GPP TS 24.301 §5.5.2.3 (Network initiated detach procedure (re-attach required)).

EXP-PRV-008 — Delete a Mobile Asset with an active session

Status	✅ Accepted
Category	Functional
Components	xControl, xCore
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 20 min
Prerequisite procedures	EXP-SES-001 — UE-initiated attach

Objective. A connected Mobile Asset is deleted from xControl. Its session is terminated, its record is removed from the Site's subscriber database, and any later attach attempt is rejected as an unknown subscriber.

Preconditions

- Tooling and access
  - Log in to xControl with an account that holds the **ADMIN** role.
  - Access to the CLI.
  - Start a 3GPP signalling capture (pcap) with your preferred tool on the interfaces the procedure exercises.
- Procedures executed first
  - EXP-SES-001 — UE-initiated attach

Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-SES-001 — UE-initiated attach** as a prerequisite procedure.	As defined in EXP-SES-001.
2	xControl	On **Mobile Assets**, select the Mobile Asset's checkbox, click **Delete**, and confirm with **OK**. Note the time.	The Mobile Asset disappears from the list.
3	xControl	Search for the IMSI.	No Mobile Asset is found.
4	CLI	Run `cd /lte`, then `read hss <imsi>` (or `cd /nr`, then `read udr <imsi>`), repeating until the record is gone.	The record is removed within 120 seconds.
5	UE	Observe the UE, then toggle airplane mode.	The UE loses service (immediately, or at its next attach) and every attach attempt is rejected as in EXP-PRV-005.

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#	Where	Action	Expected result
6	Capture	Inspect the signalling capture.	The attach attempt after deletion is rejected with the sequence of EXP-PRV-005.

Pass criteria

- The subscriber record is gone from the Site within 120 seconds.
- Every attach attempt after the deletion is rejected.

Postconditions

- Re-create the Mobile Asset with EXP-PRV-001 if later tests need it.

Evidence collected: xControl screenshot; CLI output; 3GPP signalling capture (pcap).

EXP-PRV-009 — Static IP address assignment

Status	✅ Accepted
Category	Functional
Components	xControl, xCore
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 30 min
Prerequisite procedures	EXP-SES-001 — UE-initiated attach EXP-SES-007 — Multiple UE attach
Automated by	Platform suite, split user plane: static IP semantics (duplicate and out-of-pool addresses)

Objective. A Mobile Asset given a static IP address through the `ip` extension receives exactly that address on every session, the address is reachable from the enterprise network, and the platform never gives the same address to two active sessions.

Preconditions

- Platform
  - The System's address range has addresses reserved for static assignment, outside the dynamic pool.
- Mobile Asset
  - Two Mobile Assets on the System, A and B, both connected (EXP-SES-007).
- Tooling and access
  - Log in to xControl with an account that holds the **ADMIN** role.
  - A host on the System's egress network that can ping the UE's address.
- Procedures executed first
  - EXP-SES-001 — UE-initiated attach
  - EXP-SES-007 — Multiple UE attach

Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-SES-007 — Multiple UE attach** as a prerequisite procedure.	As defined in EXP-SES-007.

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#	Where	Action	Expected result
2	xControl	On Mobile Asset A's detail page click **Edit**, add the extension `ip` with a reserved address from the System's range, and click **Submit**.	The extension is saved.
3	UE	Toggle airplane mode on UE A so that it attaches again.	UE A connects.
4	xControl	Open Mobile Asset A.	The IP address equals the pinned address exactly.
5	Test host	Ping the pinned address from the host on the egress network.	The ping is answered.
6	UE	Repeat the attach cycle on UE A twice more.	UE A receives the pinned address on every cycle.
7	xControl	Add the same `ip` extension to Mobile Asset B and toggle airplane mode on UE B while UE A stays connected.	UE B does not receive A's address while A holds it; it is rejected or receives a dynamic address. Record which.
8	xControl	Set Mobile Asset B's `ip` extension to an address outside the System's range, then toggle airplane mode on UE B.	UE B never receives the out-of-range address; it is rejected or receives a dynamic address. Record which.

Pass criteria

- The pinned address is assigned on every session of Mobile Asset A.
- No two active sessions ever hold the same address.
- An address outside the System's range is never assigned.

Postconditions

- Remove the `ip` extension from Mobile Asset B.

Evidence collected: xControl screenshot; ICMP result from the UE; xControl session event log.

EXP-PRV-010 — IMEI lock

Status	✅ Accepted
Category	Security
Components	xControl, xCore
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 20 min
Prerequisite procedures	EXP-SES-001 — UE-initiated attach

Objective. A Mobile Asset locked to a device through the `imei` extension obtains service only in that device; the same SIM in another device is refused.

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Preconditions

- Device
  - Two UEs; the IMEI of each is known (dial `*#06#`).
- Tooling and access
  - Log in to xControl with an account that holds the **ADMIN** role.
  - Start a 3GPP signalling capture (pcap) with your preferred tool on the interfaces the procedure exercises.
- Procedures executed first
  - EXP-SES-001 — UE-initiated attach

Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-SES-001 — UE-initiated attach** as a prerequisite procedure.	As defined in EXP-SES-001.
2	xControl	On the Mobile Asset's detail page click **Edit**, add the extension `imei` with the 15-digit IMEI of the first UE, and click **Submit**.	The extension is saved.
3	UE	Toggle airplane mode on the first UE.	The UE connects as before.
4	UE	Move the SIM to the second UE and power it on.	The second UE fails to obtain service.
5	Capture	Inspect the signalling capture for the second UE's attempt.	The attach or registration is rejected after the network has obtained the IMEI (Identity Request for IMEI or the equipment identity in the attach), or the session is refused.
6	xControl	Open the Mobile Asset and its **Event Log**.	The failed attempt is visible, and the IMEI recorded for the Mobile Asset is that of the first UE.

Pass criteria

- The locked SIM obtains service in the locked device and in no other device.
- The refusal is signalled with EMM cause #6 (4G) or 5GMM cause #6 (5G), illegal ME.

Postconditions

- Move the SIM back to the first UE, or remove the `imei` extension.

Evidence collected: 3GPP signalling capture (pcap); xControl session event log.

EXP-PRV-011 — Provisioning changes made while the site is out of contact

Status	✅ Accepted

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Category	Functional
Components	xControl, xCore
Applies to	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant
Duration	About 45 min
Prerequisite procedures	EXP-INS-002 — Management path and subscriber synchronization

Objective. Provisioning changes made in xControl while the xCore cannot reach it are queued and applied to the Site when the connection returns, and the Site's subscriber database is consistent afterwards.

Preconditions

- Platform
  - You can block outbound traffic from the xCore to xControl (a firewall rule on the node's egress, or a network policy) and remove the block again.
- Mobile Asset
  - One Mobile Asset connected (EXP-SES-001) and one further SIM not yet provisioned.
- Tooling and access
  - Log in to xControl with an account that holds the **ADMIN** role.
  - Access to the CLI.
- Procedures executed first
  - EXP-INS-002 — Management path and subscriber synchronization

Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-INS-002 — Management path and subscriber synchronization** as a prerequisite procedure.	As defined in EXP-INS-002.
2	Infrastructure	Block traffic from the xCore to xControl on TCP port 443. Note the time.	The block is in place.
3	xControl	Open **Sites** and watch the Site.	The Site is shown offline within about five minutes.
4	xControl	Create a new Mobile Asset for the unprovisioned SIM (EXP-PRV-001, first step only) and set the connected Mobile Asset to **Inactive**.	Both changes are saved in xControl.
5	UE	Observe the connected UE.	It stays connected; the deactivation cannot reach the Site yet.
6	CLI	Run `read hss <new imsi>` (or `read udr <new imsi>`).	The record does not exist yet.
7	Infrastructure	Remove the block. Note the time.	Connectivity is restored.
8	xControl	Watch the Site.	The Site returns to online.

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#	Where	Action	Expected result
9	CLI	Run `read hss <new imsi>` repeatedly until the record appears, then `read hss <imsi>` for the deactivated Mobile Asset.	The new record exists within 60 seconds of the Site returning online, and the deactivated one is inactive.
10	UE	Observe the previously connected UE.	Its session is released and its reconnection attempts are rejected, as in EXP-PRV-002.
11	CLI	Run `cd /debug/ops`, then `cmd cache-clear type=SUBSCRIBER_CHECK_ERRORS`, `cmd sync-sub-check mode=FULL` (repeat until it no longer answers that a check is already running), then `read sync-sub-error`.	The error table is empty.

Pass criteria

- Every change made during the outage is applied to the Site within 60 seconds of the connection returning.
- The synchronization check reports no discrepancy after the changes are applied.

Postconditions

- Reactivate the deactivated Mobile Asset.

Evidence collected: xControl screenshot; CLI output.

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6.6.5 Policy and Traffic

Policy configured in xControl is enforced on the user plane and applied to live sessions without a re-attach: bandwidth limits and quality of service from the System Profile, egress through the System's subnet, roaming restrictions from Roaming Profiles and Carrier Groups, per-network APN overrides for Mobile Assets on the mobile operator's public radio network, network slice selection on 5G, and correct handling of large packets.

ID	Test	Category	Applies to
EXP-POL-001	Limit bandwidth (AMBR)	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
EXP-POL-002	Enterprise access through the public radio network	Functional	4G, 5G · Public radio · Single node, HA cluster, Geo-redundant
EXP-POL-003	System egress mapping	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
EXP-POL-004	Quality of service profile applied to the session	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
EXP-POL-005	Per-network APN override on the public radio network	Functional	4G, 5G · Public radio · Single node, HA cluster, Geo-redundant
EXP-POL-006	Roaming Profile restriction on the public radio network	Security	4G, 5G · Public radio · Single node, HA cluster, Geo-redundant
EXP-POL-007	Large packets and MTU	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
EXP-POL-008	Network slice selection (5G)	Functional	5G · Local radio · Single node, HA cluster, Geo-redundant

EXP-POL-001 — Limit bandwidth (AMBR)

Status	✅ Accepted
Category	Functional
Components	xCore, xControl
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 30 min
Prerequisite procedures	EXP-SES-001 — UE-initiated attach
Included in	Installation and Upgrade Verification

Objective. When the Mobile Asset is moved to a System Profile with lower uplink and downlink bitrates (AMBR) in xControl, the subscriber database pushes the change into the live session: the bearer is modified without a detach, the UE keeps its address, and the measured upload and download throughput drops to the new limits.

Preconditions

- Device
  - The UE has a web browser application.

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- Tooling and access
  - Log in to xControl with an account that holds the **ADMIN** role.
  - A tool that measures upload and download throughput from the UE against a server on the enterprise network, such as iperf3 or OpenSpeedTest.
  - Start a 3GPP signalling capture (pcap) with your preferred tool on the interfaces the procedure exercises.
- Procedures executed first
  - EXP-SES-001 — UE-initiated attach

Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-SES-001 — UE-initiated attach** as a prerequisite procedure.	As defined in EXP-SES-001.
2	UE	Run a speed test and record the upload and download results as the baseline.	Baseline upload and download figures are recorded.
3	xControl	Create, or select, a System Profile whose APN Profile has a significantly lower **Upload Bitrate** and **Download Bitrate** than the current one (for example one quarter).	The System Profile is available on the Mobile Asset's System.
4	xControl	On the Mobile Asset's detail page click **Edit**, select the new System Profile, and click **Submit**.	The change is saved.
5	xControl	Open the Mobile Asset and its **Event Log**.	The status stays **Connected** with the same IP address; the session record stays **Open**; no detach and no new session.
6	Capture	Inspect the signalling capture.	The messages match the sequence under *Expected signalling*; the modified bearer or session carries the new bitrate limits, and there is no Detach Request or Deregistration Request.
7	UE	Run the speed test again and record the upload and download results.	Both figures are below the baseline and do not exceed the new limits.

Expected signalling

Capture points: S6a / N8 (point 4), S11 / N4 (point 3), S1-MME / N2 (point 1).

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4G 5G

4G (EPS) sequence

1. Insert Subscriber Data Request on S6a from the HSS with the new APN-AMBR, and Insert Subscriber Data Answer
2. Modify Bearer Command on S11 from the MME, then Update Bearer Request from the PGW and Update Bearer Response
3. E-RAB Modify Request / Response and Modify EPS Bearer Context Request / Accept carrying the new APN-AMBR

5G (5GS) sequence

1. Nudm_SDM_Notification from the UDM with the new subscribed Session-AMBR
2. PFCP Session Modification Request / Response on N4
3. PDU Session Resource Modify Request / Response carrying PDU Session Modification Command with the new Session-AMBR, and PDU Session Modification Complete

Pass criteria

- The change takes effect with no detach and no new session; the UE keeps its address.
- The signalled AMBR values equal the bitrates configured in the APN Profile.
- Measured upload and download after the change do not exceed the new limits.

Postconditions

- Restore the original System Profile if later tests assume it.

Evidence collected: Speed test result; xControl session event log; 3GPP signalling capture (pcap).
References: 3GPP TS 23.401 §4.7.3 (Bearer level QoS parameters (APN-AMBR)); 3GPP TS 23.401 §5.3.9.2 (Insert Subscriber Data procedure); 3GPP TS 23.401 §5.4.2.1 (HSS Initiated Subscribed QoS Modification); 3GPP TS 23.501 §5.7.2.6 (Session-AMBR); 3GPP TS 23.502 §4.3.3.2 (UE or network requested PDU Session Modification).

EXP-POL-002 — Enterprise access through the public radio network

Status	✅ Accepted
Category	Functional
Components	xRouter, xCore
Applies to	4G, 5G · Public radio · Single node, HA cluster, Geo-redundant
Duration	About 20 min
Included in	Installation and Upgrade Verification

Objective. A Mobile Asset attached through the mobile operator's public radio network is authenticated by Expeto Gateway (xRouter), reaches the enterprise private LAN through the customer-dedicated xCore, and passes upload and download traffic.

Preconditions

- Platform
  - An xCore in the public configuration is installed and operational.
  - An xRouter is installed, configured, and integrated with that xCore.
- Mobile Asset
  - The Mobile Asset is imported into xControl and authorized (state **Active**).

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- Tooling and access
  - Log in to xControl with an account that can view the Mobile Asset under test.
  - A signalling capture at the xRouter (capture point 4) and on the secure link (capture point 5).

Procedure

#	Where	Action	Expected result
1	UE	Connect the UE to the mobile operator's public network.	The UE shows a connection to the public network.
2	UE	Access a resource on the enterprise private LAN.	The resource is reachable from the UE.
3	UE	Transfer data in both directions (for example, upload and download a file).	Upload and download traffic is sent and received.
4	xControl	Open the Mobile Asset.	The status is **Connected** and the session is attributed to the xRouter site.
5	Capture	Inspect the captures.	The authentication and session setup arrive at xRouter from the operator's core, and only GTP-U user-plane traffic crosses the secure link.

Expected signalling

Capture points: S6a / N8 at xRouter (point 4), secure link (point 5).

4G 5G

4G (EPS) sequence

1. Authentication Information Request / Answer and Update Location Request / Answer from the operator's MME to the HSS in xRouter
2. Create Session Request / Response from the operator's SGW to the GTP proxy in xRouter (S8)
3. GTP-U on the secure link between xRouter and the xCore

5G (5GS) sequence

1. Authentication and subscription exchanges from the operator's core to the UDM in xRouter
2. N9 session setup toward the GTP proxy in xRouter
3. GTP-U on the secure link between xRouter and the xCore

Pass criteria

- The UE reaches the enterprise LAN and passes traffic in both directions.
- No signalling crosses the secure link; only user-plane traffic does.

Evidence collected: UE connectivity check; xControl Mobile Asset status; 3GPP signalling capture (pcap).

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EXP-POL-003 — System egress mapping

Status	✅ Accepted
Category	Functional
Components	xCore, xControl
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 30 min
Prerequisite procedures	EXP-SES-001 — UE-initiated attach EXP-SES-007 — Multiple UE attach

Objective. Each System's Mobile Assets receive addresses from that System's range and their traffic leaves the xCore on that System's egress network, so that the enterprise can segment its network by System.

Preconditions

- Platform
  - The Site has two Systems, A and B, with different address ranges and different egress networks (for example two VLANs), each with a host that answers ping.
- Mobile Asset
  - One Mobile Asset on System A and one on System B, both connected (EXP-SES-007).
- Tooling and access
  - Log in to xControl with an account that can view the Mobile Asset under test.
  - A capture on each egress network (capture point SGi / N6).
- Procedures executed first
  - EXP-SES-001 — UE-initiated attach
  - EXP-SES-007 — Multiple UE attach

Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-SES-007 — Multiple UE attach** as a prerequisite procedure.	As defined in EXP-SES-007.
2	xControl	Open each Mobile Asset and note its IP address.	Each address is inside its own System's range.
3	UE	From UE A, ping the host on System A's egress network; from UE B, ping the host on System B's.	Both pings are answered.
4	Capture	Inspect the egress captures during the pings.	UE A's packets appear only on System A's egress network and UE B's only on System B's, each with the UE's address as source (or the System's translated address where source address translation is configured).

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#	Where	Action	Expected result
5	UE	From UE A, ping the host on System B's egress network.	The ping is answered only if the enterprise network routes between the two egress networks; record the result.

Pass criteria

- Every Mobile Asset's address is inside its System's range.
- Every Mobile Asset's traffic leaves on its own System's egress network and on no other.

Deployment notes

- **Source address translation:** Where a System's address pool is configured for source address translation on egress, the packets on the egress network carry the translated address; otherwise they carry the UE's address unchanged.

Evidence collected: xControl screenshot; ICMP result from the UE; 3GPP signalling capture (pcap).

EXP-POL-004 — Quality of service profile applied to the session

Status	✅ Accepted
Category	Functional
Components	xCore, xControl
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 25 min
Prerequisite procedures	EXP-SES-001 — UE-initiated attach

Objective. The quality-of-service class configured in the Mobile Asset's APN Profile is signalled to the radio and the UE at session setup, and a change of profile is pushed into the live session by the subscriber database without a detach.

Preconditions

- Platform
  - Two System Profiles exist on the System whose APN Profiles differ in **QoS** (for example QCI 9 and QCI 6).
- Tooling and access
  - Log in to xControl with an account that holds the **ADMIN** role.
  - Start a 3GPP signalling capture (pcap) with your preferred tool on the interfaces the procedure exercises.
- Procedures executed first
  - EXP-SES-001 — UE-initiated attach

Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-SES-001 — UE-initiated attach** as a prerequisite procedure.	As defined in EXP-SES-001.
2	Capture	Inspect the session setup in the capture.	The QoS class and priority match the APN Profile of the Mobile Asset's current System Profile.

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#	Where	Action	Expected result
3	xControl	On the Mobile Asset's detail page click **Edit**, select the other System Profile, and click **Submit**.	The change is saved.
4	Capture	Inspect the signalling capture.	The messages match the sequence under *Expected signalling*; the modified bearer or QoS flow carries the new class and priority; there is no Detach Request or Deregistration Request.
5	xControl	Open the Mobile Asset.	The status stays **Connected** with the same IP address and the same open session.

Expected signalling

Capture points: S6a / N8 (point 4), S11 / N4 (point 3), S1-MME / N2 (point 1).

4G 5G

4G (EPS) sequence

1. At setup, Create Session Response on S11 carrying the bearer QoS (QCI, ARP); Initial Context Setup Request carrying the E-RAB level QoS parameters and Activate Default EPS Bearer Context Request carrying the EPS QoS
2. On the change, Insert Subscriber Data Request / Answer on S6a, Modify Bearer Command, Update Bearer Request / Response, E-RAB Modify Request / Response and Modify EPS Bearer Context Request / Accept carrying the new QCI and ARP

5G (5GS) sequence

1. At setup, PDU Session Establishment Accept carrying the authorized QoS rules and QoS flow descriptions (5QI); PDU Session Resource Setup Request carrying the QoS flow level parameters
2. On the change, Nudm_SDM_Notification, PFCP Session Modification Request / Response, PDU Session Resource Modify Request / Response carrying PDU Session Modification Command with the new 5QI and ARP, PDU Session Modification Complete

Pass criteria

- The signalled QoS class and priority equal the configured values at setup and after the change.
- The change is applied to the live session with no detach and the same address.

Postconditions

- Restore the original System Profile if later tests assume it.

Evidence collected: 3GPP signalling capture (pcap); xControl session event log.
References: 3GPP TS 23.401 §4.7.3 (Bearer level QoS parameters); 3GPP TS 23.401 §5.4.2.1 (HSS Initiated Subscribed QoS Modification); 3GPP TS 23.501 §5.7.1 (QoS model); 3GPP TS 23.502 §4.3.3.2 (UE or network requested PDU Session Modification).

EXP-POL-005 — Per-network APN override on the public radio network

Status	✅ Accepted
Category	Functional
Components	xRouter, xControl

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Applies to	4G, 5G · Public radio · Single node, HA cluster, Geo-redundant
Duration	About 30 min
Prerequisite procedures	EXP-POL-002 — Enterprise access through the public radio network

Objective. An APN override configured for a specific Carrier in the Mobile Asset's System Profile is applied when the UE is served by that network, taking precedence over the APN Profile's own bitrates.

Preconditions

- Platform
  - The public network the UE uses exists as a **Carrier** in xControl.
- Tooling and access
  - Log in to xControl with an account that holds the **ADMIN** role.
  - A tool that measures upload and download throughput from the UE against a server on the enterprise network, such as iperf3 or OpenSpeedTest.
  - A signalling capture at xRouter (capture point 4).
- Procedures executed first
  - EXP-POL-002 — Enterprise access through the public radio network

Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-POL-002 — Enterprise access through the public radio network** as a prerequisite procedure.	As defined in EXP-POL-002.
2	UE	Run a speed test and record the baseline.	Baseline figures are recorded.
3	xControl	Open **System Profiles**, edit the Mobile Asset's System Profile, open the **APN Profiles** tab, click **Add Carrier Override** for the Carrier of the public network, set significantly lower bitrates, and click **Submit**.	The override is saved.
4	Capture	Inspect the capture at xRouter.	The HSS pushes the change to the operator's MME with an Insert Subscriber Data Request carrying the override's APN-AMBR; the bearer is updated without a detach.
5	UE	Run the speed test again.	Upload and download are below the baseline and do not exceed the override.

Pass criteria

- The override's bitrates are applied to the live session when the UE is on the named network, without a detach.

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Postconditions

- Remove the override.

Evidence collected: Speed test result; 3GPP signalling capture (pcap).

EXP-POL-006 — Roaming Profile restriction on the public radio network

Status	✅ Accepted
Category	Security
Components	xRouter, xControl
Applies to	4G, 5G · Public radio · Single node, HA cluster, Geo-redundant
Duration	About 30 min
Prerequisite procedures	EXP-POL-002 — Enterprise access through the public radio network

Objective. A Roaming Profile whose Allowed Carrier Groups exclude the public network the UE is on causes the attach to be refused, and adding the network's Carrier Group restores service.

Preconditions

- Platform
  - The public network the UE uses exists as a **Carrier** in a **Carrier Group** in xControl.
  - A Roaming Profile exists whose **Allowed Carrier Groups** do not include that Carrier Group.
- Tooling and access
  - Log in to xControl with an account that holds the **ADMIN** role.
  - A signalling capture at xRouter (capture point 4).
- Procedures executed first
  - EXP-POL-002 — Enterprise access through the public radio network

Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-POL-002 — Enterprise access through the public radio network** as a prerequisite procedure.	As defined in EXP-POL-002.
2	xControl	On the Mobile Asset's detail page click **Edit**, select the restrictive **Roaming Profile**, and click **Submit**.	The change is saved.
3	UE	Toggle airplane mode so that the UE attaches again through the public network.	The UE fails to obtain service.
4	Capture	Inspect the capture at xRouter.	The location update from the operator's core is answered with a roaming-not-allowed error, and the UE receives a reject.

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#	Where	Action	Expected result
5	xControl	Edit the Roaming Profile, add the network's Carrier Group to **Allowed Carrier Groups**, and click **Submit**.	The change is saved.
6	UE	Toggle airplane mode again.	The UE connects as in EXP-POL-002.

Expected signalling

Capture points: S6a / N8 at xRouter (point 4).

4G 5G

4G (EPS) sequence

1. Update Location Request from the operator's MME answered with an error result for roaming not allowed
2. Attach Reject to the UE from the operator's MME

5G (5GS) sequence

1. The subscription retrieval from the operator's AMF is refused for the serving PLMN
2. Registration Reject to the UE from the operator's AMF

Pass criteria

- The UE obtains no service while its Roaming Profile excludes the serving network.
- The Update Location Answer carries the roaming-not-allowed error and the UE receives EMM cause #11, PLMN not allowed (4G), or 5GMM cause #11 (5G), so it stops retrying this network and continues PLMN selection on others.
- Service returns once the Carrier Group is allowed.

Postconditions

- Restore the Mobile Asset's original Roaming Profile.

Evidence collected: 3GPP signalling capture (pcap); xControl session event log.
References: 3GPP TS 29.272 §5.2.1.1 (Update Location procedure (roaming not allowed)); 3GPP TS 24.301 §5.5.1.2.5 (Attach not accepted by the network).

EXP-POL-007 — Large packets and MTU

Status	✅ Accepted
Category	Functional
Components	xCore
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 25 min
Prerequisite procedures	EXP-SES-001 — UE-initiated attach

Objective. Packets up to the link MTU the network signals to the UE pass end to end without fragmentation, larger packets are handled per the configuration, and bulk TCP transfers do not stall.

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Preconditions

- Device
  - The UE has a terminal application that can send pings of a chosen size with the do-not-fragment flag set.
- Tooling and access
  - Start a 3GPP signalling capture (pcap) with your preferred tool on the interfaces the procedure exercises.
  - A host on the enterprise LAN that answers ping and runs an iperf3 server.
- Procedures executed first
  - EXP-SES-001 — UE-initiated attach

Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-SES-001 — UE-initiated attach** as a prerequisite procedure.	As defined in EXP-SES-001.
2	Capture	In the capture of the attach, read the IPv4 link MTU the network provides to the UE (protocol configuration options in the Attach Accept, or the PDU Session Establishment Accept).	The signalled MTU is recorded; if none is signalled, record that.
3	UE	Ping the LAN host with a payload that produces an IP packet of the signalled MTU (or 1400 bytes if none was signalled), with the do-not-fragment flag set.	The ping is answered.
4	UE	Ping the LAN host with an IP packet of 1500 bytes, do-not-fragment set.	The ping is answered, or the UE reports that fragmentation is needed; record which.
5	Capture	Inspect the user-plane capture on the egress network during the pings.	Packets at the signalled MTU arrive unfragmented.
6	UE	Run an iperf3 test toward the LAN host for 60 seconds in each direction.	Throughput is stable and the transfer does not stall.

Pass criteria

- The network signals a link MTU of at least 1400 bytes to the UE.
- Packets at the signalled MTU pass unfragmented in both directions.
- The 60-second TCP transfers complete without stall in either direction.

Evidence collected: 3GPP signalling capture (pcap); UE connectivity check; Speed test result.
References: 3GPP TS 24.301 §6.5.1.3 (UE requested PDN connectivity procedure accepted by the network (protocol configuration options)).

EXP-POL-008 — Network slice selection (5G)

Status	✅ Accepted
Category	Functional

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Components	xCore, xControl
Applies to	5G · Local radio · Single node, HA cluster, Geo-redundant
Duration	About 30 min

Objective. A 5G UE requests network slices at registration. The AMF grants exactly the slices the Mobile Asset is subscribed to, the PDU session is established on an allowed slice and carries its S-NSSAI to the radio and the user plane, and a request for a slice the Mobile Asset is not subscribed to is refused.

Preconditions

- Platform
  - The Site's AMF advertises the S-NSSAIs supported for the Site's PLMN and tracking areas (in the access-mobility configuration of the core, `plmnTacSliceList` with `supportedSnssais`), and the user plane maps each S-NSSAI to the System's DNN.
  - You know the S-NSSAIs written into the Mobile Asset's subscription by xControl (its default single NSSAIs, for example SST 1 and SST 1 with SD 000001).
- Mobile Asset
  - The UE's Mobile Asset is provisioned in xControl on the System under test, with state **Active** and status **Provisioned** or **Disconnected**.
- Device
  - A 5G SA UE whose Requested NSSAI can be set (or a UE that requests the network's default slice) and, for the negative step, a UE or simulator that can request an S-NSSAI not in the subscription.
  - The UE has the APN of its System Profile configured.
- Tooling and access
  - Log in to xControl with an account that can view the Mobile Asset under test.
  - Start a 3GPP signalling capture (pcap) with your preferred tool on the interfaces the procedure exercises.
  - Access to the CLI.

Procedure

#	Where	Action	Expected result
1	UE	Power on the UE, or take it out of airplane mode, and wait for it to register and establish its data session.	The UE shows a data connection.
2	Capture	Open the Registration Request.	The Requested NSSAI lists the slice or slices the UE asked for.
3	Capture	Open the Registration Accept.	The Allowed NSSAI equals the S-NSSAIs of the Mobile Asset's subscription; a requested S-NSSAI outside the subscription appears in the Rejected NSSAI with cause "S-NSSAI not available in the current PLMN".
4	Capture	Open the PDU Session Establishment Request and Accept, and the PDU Session Resource Setup Request on N2.	The request carries an allowed S-NSSAI and the System's DNN; the Accept and the N2 message carry the same S-NSSAI; the PFCP session on N4 is established on the user plane serving that DNN.

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#	Where	Action	Expected result
5	CLI	Run `cd /nr` , then `read amf <imsi>` .	The context lists the allowed NSSAI and the PDU session with its S-NSSAI and DNN.
6	UE	Pass traffic to a host on the enterprise network.	The traffic is answered.
7	xControl	Open the Mobile Asset.	The status is **Connected** with an address from the System's range.
8	UE	Request a PDU session on an S-NSSAI that is not in the Allowed NSSAI (with a UE that allows it, or the simulator).	The request is refused; no session is created for it and the existing session is unaffected.
9	Capture	Inspect the refusal.	The network rejects the PDU Session Establishment Request for the non-allowed S-NSSAI, and no PFCP session is established for it.

Expected signalling

Capture points: N2 (point 1), N4 (point 3).

5G

5G (5GS) sequence

1. Registration Request with Requested NSSAI
2. Registration Accept with Allowed NSSAI equal to the subscribed S-NSSAIs, and Rejected NSSAI for any non-subscribed S-NSSAI requested
3. Registration Complete; UE Configuration Update Command with Configured NSSAI when the network sends one
4. PDU Session Establishment Request with S-NSSAI and DNN
5. PFCP Session Establishment Request / Response on N4 toward the user plane serving the DNN
6. PDU Session Resource Setup Request carrying the S-NSSAI and PDU Session Establishment Accept with the S-NSSAI
7. For a non-allowed S-NSSAI, the establishment is rejected and no N4 session is created

Pass criteria

- The Allowed NSSAI in the Registration Accept equals the Mobile Asset's subscribed S-NSSAIs; every other requested S-NSSAI is rejected.
- The PDU session carries an allowed S-NSSAI end to end (NAS, N2, AMF context) and passes traffic.
- A PDU session on a non-allowed S-NSSAI is refused without affecting the established session.

Evidence collected: 3GPP signalling capture (pcap); CLI output; xControl Mobile Asset status.
References: 3GPP TS 23.501 §5.15.5.2.1 (Network slice selection at registration); 3GPP TS 23.502 §4.2.2.2.2 (General Registration (Allowed NSSAI)); 3GPP TS 24.501 §5.5.1.2.4 (Initial registration accepted by the network (Allowed and Rejected NSSAI)); 3GPP TS 24.501 §6.4.1.2 (UE-requested PDU session establishment procedure initiation (S-NSSAI); 3GPP TS 29.503 §5.2.2.2 (Subscription data retrieval (NSSAI)).

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6.6.6 Public Network Access

Enterprise access through the mobile operator's public radio network and the IPX beyond the basic 4G and 5G case of EXP-POL-002: 5G non-standalone (EN-DC) service on the 4G core path, 3G access through the operator's SGSN over Gp with MAP authentication and location management, and a device that changes between 4G and 3G on the public network.

ID	Test	Category	Applies to
EXP-PUB-001	5G non-standalone (EN-DC) access through the public radio network	Functional	4G, 5G · Public radio · Single node, HA cluster, Geo-redundant
EXP-PUB-002	3G access through the public radio network (Gp)	Functional	3G · Public radio · Single node, HA cluster, Geo-redundant
EXP-PUB-003	Change between 4G and 3G on the public radio network	Functional	3G, 4G · Public radio · Single node, HA cluster, Geo-redundant

EXP-PUB-001 — 5G non-standalone (EN-DC) access through the public radio network

Status	✅ Accepted
Category	Functional
Components	xRouter, xCore, xControl
Applies to	4G, 5G · Public radio · Single node, HA cluster, Geo-redundant
Duration	About 30 min
Prerequisite procedures	EXP-POL-002 — Enterprise access through the public radio network

Objective. A 5G-capable Mobile Asset on the mobile operator's network uses NR as a secondary radio (EN-DC) while its session stays on the 4G core path through Expeto Gateway (xRouter): the subscriber database permits NR as a secondary RAT, the operator's MME adds the NR leg, the UE shows 5G service, and traffic carried over NR reaches the enterprise LAN and is counted in the session record like any other traffic.

Preconditions

- Platform
  - The operator's network offers EN-DC (NR non-standalone) at the test location and its MME supports the NR-as-secondary-RAT feature on S6a.
  - An xCore in the public configuration and an xRouter are installed and integrated (EXP-POL-002 passed).
- Mobile Asset
  - The Mobile Asset is **Active** with a System Profile whose APN the UE uses for data.
- Device
  - A UE that supports EN-DC, with 5G (NSA) enabled in its settings and a network-type indicator.
  - The UE has the APN of its System Profile configured.
- Tooling and access
  - Log in to xControl with an account that can view the Mobile Asset under test.
  - A tool that measures upload and download throughput from the UE against a server on the enterprise network, such as iperf3 or OpenSpeedTest.
  - A signalling capture at the xRouter (capture point 4) covering S6a and S8.
- Procedures executed first
  - EXP-POL-002 — Enterprise access through the public radio network

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Procedure

#	Where	Action	Expected result
1	UE	Enable 5G (NSA) in the UE settings and connect through the operator's network with the enterprise APN.	The UE shows 5G service (the mobile operator's non-standalone indicator) while attached.
2	Capture	Inspect the S6a exchange at xRouter.	The Update Location Request from the operator's MME advertises the NR-as-secondary-RAT feature, and the Update Location Answer grants it and carries subscription data whose Access-Restriction-Data does not set "NR as Secondary RAT in E-UTRAN Not Allowed".
3	UE	Access a resource on the enterprise LAN and run the throughput measurement while the UE shows 5G.	The resource is reachable and the measurement completes.
4	xControl	Open the Mobile Asset.	The status is **Connected** and the network type is 4G. The session belongs to the 4G core, NR is a secondary radio, and the reported RAT type is E-UTRAN.
5	UE	Disable 5G on the UE (LTE only) and access the enterprise resource again; then re-enable 5G.	The UE shows 4G, then 5G again; the resource stays reachable and the UE keeps its address.
6	xControl	Disable mobile data on the UE, then open the closed session record.	The record's byte counts cover the traffic transferred while NR was active, and its radio access technology is E-UTRAN.

Expected signalling

Capture points: S6a and S8 at xRouter (point 4), secure link (point 5).

4G

4G (EPS) sequence

1. Update Location Request from the operator's MME with Supported-Features (Feature-List-ID 2) indicating NR as Secondary RAT
2. Update Location Answer with Supported-Features granting NR as Secondary RAT, and Subscription-Data whose Access-Restriction-Data does not forbid NR as a secondary RAT in E-UTRAN
3. Create Session Request from the operator's SGW on S8 with RAT Type E-UTRAN; Create Session Response with the UE address
4. Modify Bearer Request, Change Notification Request or Delete Session Request from the operator's SGW may carry Secondary RAT Usage Data Report IEs; the GTP proxy accepts them without effect on the session
5. GTP-U on the secure link carrying the traffic transferred over both radios

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Pass criteria

- The Update Location Answer grants NR as a secondary RAT and the UE obtains 5G (NSA) service with the enterprise APN.
- Traffic reaches the enterprise LAN while the UE is on NR, and the closed record counts it; the record's radio access technology is E-UTRAN.
- Disabling and re-enabling 5G on the UE leaves the session and the UE address in place.

Evidence collected: UE connectivity check; 3GPP signalling capture (pcap); xControl Mobile Asset status; Speed test result.
References: 3GPP TS 29.272 §7.3.10 (Supported-Features and Feature-List (NR as Secondary RAT)); 3GPP TS 29.272 §7.3.31 (Access-Restriction-Data); 3GPP TS 37.340 §4.1 (Multi-RAT Dual Connectivity overview (EN-DC)); 3GPP TS 29.274 §8.132 (Secondary RAT Usage Data Report).

EXP-PUB-002 — 3G access through the public radio network (Gp)

Status	✅ Accepted
Category	Functional
Components	xRouter, xCore, xControl
Applies to	3G · Public radio · Single node, HA cluster, Geo-redundant
Duration	About 30 min
Prerequisite procedures	EXP-POL-002 — Enterprise access through the public radio network

Objective. A Mobile Asset on a 3G (UMTS) cell of the mobile operator's network is authenticated by the HLR function of Expeto Gateway (xRouter) over MAP, registered from the operator's SGSN (and, on a combined attach, from its VLR), and given a PDP context terminated at the GTP proxy in xRouter over Gp with GTPv1, so that it reaches the enterprise LAN exactly as it does on 4G.

Preconditions

- Platform
  - The operator's network has 3G (UTRAN) coverage at the test location, and its SGSN reaches the GTP proxy in xRouter over Gp through the IPX.
  - The MAP signalling of xRouter toward the operator's signalling transfer point (SIGTRAN, M3UA) is configured and up; no `M3UAConnectionDown` alert is active.
  - The HLR in xRouter allows UTRAN access for the Mobile Asset (the RAT types are allowed by default).
- Mobile Asset
  - The Mobile Asset is **Active** with a System Profile whose APN the UE uses for data.
- Device
  - A UE whose network mode can be locked to 3G ("3G only" or "WCDMA only").
  - The UE has the APN of its System Profile configured.
  - The UE has a web browser or a terminal application that can send ICMP echo requests (ping).
- Tooling and access
  - Log in to xControl with an account that can view the Mobile Asset under test.
  - A signalling capture at xRouter on the MAP side (capture point 11) and the Gp side (capture point 10).
- Procedures executed first
  - EXP-POL-002 — Enterprise access through the public radio network

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Procedure

#	Where	Action	Expected result
1	UE	Set the network mode to 3G only and connect to the mobile operator's network with the enterprise APN.	The UE shows a 3G (UMTS or HSPA) connection.
2	Capture	Inspect the MAP capture.	SendAuthenticationInfo from the operator's SGSN is answered with UMTS authentication vectors; UpdateGprsLocation from the SGSN is answered after InsertSubscriberData carried the subscription with the APN; on a combined attach, UpdateLocation from the operator's VLR is answered as well.
3	Capture	Inspect the Gp capture.	Create PDP Context Request from the SGSN carries the enterprise APN and the IMSI; the Create PDP Context Response carries cause Request accepted and the UE's address; GTPv1-U follows.
4	UE	Access a resource on the enterprise LAN and transfer data in both directions.	The resource is reachable and traffic flows in both directions.
5	xControl	Open the Mobile Asset.	The status is **Connected** with network type 3G, and the session is attributed to the xRouter site.
6	UE	Disable mobile data on the UE.	The PDP context is deleted; xControl shows **Disconnected** and the closed record carries radio access technology UTRAN and the byte counts.

Expected signalling

Capture points: MAP at xRouter (point 11), Gp at xRouter (point 10), secure link (point 5).

3G

3G (UMTS, GPRS core) sequence

1. SendAuthenticationInfo from the operator's SGSN to the HLR in xRouter, answered with UMTS authentication vectors
2. UpdateGprsLocation from the SGSN; InsertSubscriberData from the HLR carrying the GPRS subscription with the APN; UpdateGprsLocation result
3. On a combined GPRS and IMSI attach, UpdateLocation from the operator's VLR, InsertSubscriberData and its result
4. Create PDP Context Request from the SGSN over Gp with the APN, the IMSI, the MSISDN and the requested QoS; Create PDP Context Response with cause Request accepted, the end-user address and the GTP-U tunnel endpoints
5. GTPv1-U between the SGSN and the GTP proxy in xRouter, then GTP-U on the secure link to the xCore
6. Delete PDP Context Request / Response when the UE disables data or detaches

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Pass criteria

- The UE is authenticated over MAP and registered by the SGSN in the HLR, and the PDP context is accepted at the first attempt with an address from the Mobile Asset's System.
- The UE reaches the enterprise LAN in both directions over 3G.
- xControl shows the session as **Connected** with network type 3G, and the closed record carries radio access technology UTRAN and byte counts equal to the traffic sent.

Postconditions

- Set the UE's network mode back to automatic.

Evidence collected: 3GPP signalling capture (pcap); UE connectivity check; xControl Mobile Asset status; xControl session event log.
References: 3GPP TS 23.060 §6.5 (Attach function (GPRS attach); 3GPP TS 23.060 §9.2.2.1 (PDP Context Activation Procedure); 3GPP TS 24.008 §4.7.3 (GPRS attach procedure); 3GPP TS 29.002 §8.1 (Location management services (UpdateLocation); 3GPP TS 29.002 §8.5 (Authentication management services (SendAuthenticationInfo)); 3GPP TS 29.002 §8.8 (Subscriber management services (InsertSubscriberData)); 3GPP TS 29.060 §7.3.1 (Create PDP Context Request); 3GPP TS 29.060 §7.3.2 (Create PDP Context Response); 3GPP TS 29.060 §7.3.5 (Delete PDP Context Request).

EXP-PUB-003 — Change between 4G and 3G on the public radio network

Status	✅ Accepted
Category	Functional
Components	xRouter, xCore, xControl
Applies to	3G, 4G · Public radio · Single node, HA cluster, Geo-redundant
Duration	About 45 min
Prerequisite procedures	EXP-POL-002 — Enterprise access through the public radio network EXP-PUB-002 — 3G access through the public radio network (Gp)

Objective. A dual-mode Mobile Asset that leaves 4G coverage for 3G on the mobile operator's network, and returns, keeps enterprise access with no user action: each serving node registers the UE with the subscriber database in xRouter over its own protocol (S6a from the MME, MAP from the SGSN), the PDN connection is either handed to the new node or re-established at the GTP proxy in xRouter, and the records show each radio access technology used. The 4G attach of a phone is a combined EPS and IMSI attach, so the operator's VLR registers with the HLR as well.

Preconditions

- Platform
  - The operator's network offers both 4G and 3G coverage at the test location, and you can force the change (a place where 4G coverage ends, or the UE's network mode setting).
  - EXP-PUB-002 passed, so the Gp and MAP integration is in place.
- Mobile Asset
  - The Mobile Asset is **Active** with a System Profile whose APN the UE uses for data.
- Device
  - A dual-mode 4G and 3G UE in automatic network mode (LTE preferred).
  - The UE has the APN of its System Profile configured.
  - The UE has a web browser or a terminal application that can send ICMP echo requests (ping).
- Tooling and access
  - Log in to xControl with an account that can view the Mobile Asset under test.
  - Signalling captures at xRouter on S6a and S8 (capture point 4), Gp (capture point 10) and MAP (capture point 11).

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- Procedures executed first
  - EXP-POL-002 — Enterprise access through the public radio network
  - EXP-PUB-002 — 3G access through the public radio network (Gp)

Procedure

#	Where	Action	Expected result
1	UE	Connect on 4G through the operator's network with the enterprise APN and start a continuous ping to a host on the enterprise LAN.	The UE shows 4G and replies arrive, as in EXP-POL-002.
2	Capture	Inspect the S6a and MAP captures for the attach.	Update Location Request / Answer on S6a from the operator's MME; where the UE performed a combined EPS and IMSI attach, an UpdateLocation from the operator's VLR arrives over MAP and is answered.
3	UE	Move to 3G-only coverage, or set the network mode to 3G only. Note the time.	The UE shows 3G within a minute and the ping recovers within 60 seconds of the change, either without interruption or after a short gap.
4	Capture	Inspect the MAP and Gp captures.	UpdateGprsLocation from the SGSN over MAP, and over Gp either an Update PDP Context Request for the existing context (the connection was handed over) or a Create PDP Context Request for a new one (re-established). Record which.
5	xControl	Open the Mobile Asset.	The status is **Connected** with network type 3G, and the **Event Log** shows the change.
6	UE	Return to 4G (automatic mode, or move back into 4G coverage). Note the time.	The UE shows 4G within a minute and the ping recovers within 60 seconds.
7	Capture	Inspect the S6a and S8 captures.	Update Location Request / Answer on S6a from the MME, and on S8 either a Modify Bearer Request for the existing connection or a Create Session Request for a new one. Record which.
8	xControl API	Stop the ping, disable mobile data, and list the Mobile Asset's session records for the period.	The records cover the whole period with no gap longer than 60 seconds; each record's radio access technology matches the access used (E-UTRAN, UTRAN), and the byte totals sum to the traffic sent.

Expected signalling

Capture points: S6a and S8 at xRouter (point 4), Gp at xRouter (point 10), MAP at xRouter (point 11).

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3G 4G

3G (UMTS, GPRS core) sequence

1. UpdateGprsLocation from the operator's SGSN, InsertSubscriberData and the result, when the UE arrives on 3G
2. Update PDP Context Request / Response over Gp for a handed-over connection, or Create PDP Context Request / Response for a re-established one

4G (EPS) sequence

1. Update Location Request / Answer on S6a from the operator's MME, and UpdateLocation over MAP from the operator's VLR on a combined attach
2. Modify Bearer Request / Response on S8 for a handed-over connection, or Create Session Request / Response for a re-established one, when the UE returns to 4G

Pass criteria

- Enterprise connectivity returns within 60 seconds of each change with no user action, and the UE keeps its address whenever the operator's network hands the connection over rather than re-establishing it.
- Each serving node's registration is answered by the subscriber database in xRouter (Update Location Answer on S6a, UpdateGprsLocation result over MAP), and a combined attach also produces an answered UpdateLocation from the VLR.
- The records for the period have no gap longer than 60 seconds, the radio access technology of each matches the access used, and the totals equal the traffic sent.

Postconditions

- Set the UE's network mode back to automatic.

Deployment notes

- **Continuity mechanism:** Whether the operator's network hands the PDN connection to the new serving node (Update PDP Context or Modify Bearer at the GTP proxy) or re-establishes it depends on the operator's core configuration; record the mechanism observed with the result.

Evidence collected: 3GPP signalling capture (pcap); UE connectivity check; xControl Mobile Asset status; xControl session event log.
References: 3GPP TS 23.401 §D.3 (Interoperation with Gn/Gp SGSNs); 3GPP TS 24.301 §5.5.1.3 (Combined attach procedure for EPS services and non-EPS services); 3GPP TS 29.060 §7.3.3 (Update PDP Context Request); 3GPP TS 29.274 §7.2.7 (Modify Bearer Request).

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6.6.7 Mobility and Access Transitions

Handover between radios of one site, reselection in idle mode, roaming between two private Sites through a Shared System, and the transitions a device makes between the mobile operator's public radio network and the private radio network with the same SIM.

ID	Test	Category	Applies to
EXP-MOB-001	X2 (Xn) handover between two radios	Functional	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant
EXP-MOB-002	S1 (N2) handover between two radios	Functional	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant
EXP-MOB-003	Idle-mode reselection with tracking area update	Functional	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant
EXP-MOB-004	Roaming between two private Sites through a Shared System	Functional	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant
EXP-MOB-005	Transition from the public radio network to the private radio	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
EXP-MOB-006	Transition from the private radio to the public radio network	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
EXP-MOB-007	Repeated transitions between public and private radio	Resilience	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant

EXP-MOB-001 — X2 (Xn) handover between two radios

Status	✅ Accepted
Category	Functional
Components	xCore, xControl
Applies to	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant
Duration	About 30 min
Prerequisite procedures	EXP-SES-001 — UE-initiated attach
Automated by	Platform suite, 4G split core: session flow `x2-handover`

Objective. A UE with an active data session moves from one radio to another of the same site. The radios hand the UE over directly, the core switches the user-plane path, and the session, its address and its traffic continue with no re-attach.

Preconditions

- Platform
  - Two radios are connected to the xCore (EXP-INS-003 for each), with the X2 (4G) or Xn (5G) interface configured between them, in the same tracking area.
  - Both radios appear as **Connected** Private Radios on the Site.
- Device
  - The UE has a web browser or a terminal application that can send ICMP echo requests (ping).
  - A way to move the UE between the coverage of the two radios (walking between them, or attenuating the serving radio).

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- Tooling and access
  - Start a 3GPP signalling capture (pcap) with your preferred tool on the interfaces the procedure exercises.
  - Log in to xControl with an account that can view the Mobile Asset under test.
  - Access to the CLI.
- Procedures executed first
  - EXP-SES-001 — UE-initiated attach

Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-SES-001 — UE-initiated attach** as a prerequisite procedure.	As defined in EXP-SES-001.
2	UE	Start a continuous ping (one per second) to a host on the enterprise LAN and note the serving cell in the UE's field-test menu.	Replies arrive; the serving cell is the first radio.
3	UE	Move the UE into the coverage of the second radio until it hands over.	The serving cell changes to the second radio; the ping continues with no lost reply.
4	Capture	Inspect the signalling capture.	The messages match the sequence under *Expected signalling*; there is no Attach Request or Registration Request.
5	xControl	Open the Mobile Asset and its **Event Log**.	The status is **Connected** with the same IP address; no new session was created; the session record now names the second radio.
6	CLI	Run `read mme -f imsi=<imsi>` (or `read amf <imsi>`).	The context names the second radio as serving and the state is connected.
7	UE	Move the UE back into the first radio's coverage.	The UE hands back with the same behaviour.

Expected signalling

Capture points: S1-MME / N2 (point 1), S11 / N4 (point 3).

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4G 5G

4G (EPS) sequence

1. Path Switch Request from the target eNodeB (the X2 handover preparation itself is between the eNodeBs and not visible on S1)
2. Modify Bearer Request / Modify Bearer Response on S11 with the target eNodeB's user-plane address
3. Path Switch Request Acknowledge

5G (5GS) sequence

1. Path Switch Request from the target gNodeB
2. PFCP Session Modification Request / Response on N4 with the target gNodeB's N3 tunnel
3. Path Switch Request Acknowledge

Pass criteria

- The session continues with the same IP address and no re-attach.
- No ping reply is lost during the handover.
- The core's context and the xControl session record name the new serving radio after the handover.

Evidence collected: 3GPP signalling capture (pcap); UE connectivity check; xControl session event log; CLI output.
References: 3GPP TS 23.401 §5.5.1.1.2 (X2-based handover without Serving GW relocation); 3GPP TS 23.502 §4.9.1.2 (Xn based inter NG-RAN handover).

EXP-MOB-002 — S1 (N2) handover between two radios

Status	✅ Accepted
Category	Functional
Components	xCore, xControl
Applies to	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant
Duration	About 30 min
Prerequisite procedures	EXP-SES-001 — UE-initiated attach
Automated by	Platform suite, 4G split core: session flow `s1-handover`

Objective. A UE with an active data session moves between two radios that have no direct interface. The core coordinates the handover, and the session, its address and its traffic continue with no re-attach.

Preconditions

- Platform
  - Two radios are connected to the xCore (EXP-INS-003 for each) with no X2 (4G) or Xn (5G) interface between them.
- Device
  - The UE has a web browser or a terminal application that can send ICMP echo requests (ping).
  - A way to move the UE between the coverage of the two radios.
- Tooling and access
  - Start a 3GPP signalling capture (pcap) with your preferred tool on the interfaces the procedure exercises.
  - Log in to xControl with an account that can view the Mobile Asset under test.
  - Access to the CLI.

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- Procedures executed first
  - EXP-SES-001 — UE-initiated attach

Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-SES-001 — UE-initiated attach** as a prerequisite procedure.	As defined in EXP-SES-001.
2	UE	Start a continuous ping to a host on the enterprise LAN and note the serving cell.	Replies arrive; the serving cell is the first radio.
3	UE	Move the UE into the coverage of the second radio until it hands over.	The serving cell changes; the ping continues with no lost reply.
4	Capture	Inspect the signalling capture.	The messages match the sequence under *Expected signalling*.
5	xControl	Open the Mobile Asset and its **Event Log**.	The status is **Connected** with the same IP address and no new session.
6	CLI	Run `read mme -f imsi=<imsi>` (or `read amf <imsi>`).	The context names the second radio and exactly one context exists for the IMSI.

Expected signalling

Capture points: S1-MME / N2 (point 1), S11 / N4 (point 3).

4G 5G

4G (EPS) sequence

1. Handover Required from the source eNodeB
2. Handover Request / Handover Request Acknowledge with the target eNodeB
3. Handover Command to the source eNodeB
4. eNB Status Transfer / MME Status Transfer
5. Handover Notify from the target eNodeB
6. Modify Bearer Request / Modify Bearer Response on S11
7. UE Context Release Command / Complete toward the source eNodeB

5G (5GS) sequence

1. Handover Required from the source gNodeB
2. Handover Request / Handover Request Acknowledge with the target gNodeB
3. Handover Command to the source gNodeB
4. Uplink RAN Status Transfer / Downlink RAN Status Transfer
5. Handover Notify from the target gNodeB
6. PFCP Session Modification Request / Response on N4
7. UE Context Release Command / Complete toward the source gNodeB

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Pass criteria

- The session continues with the same IP address and no re-attach.
- No ping reply is lost during the handover.
- Exactly one context exists for the IMSI after the handover.

Evidence collected: 3GPP signalling capture (pcap); UE connectivity check; xControl session event log; CLI output.
References: 3GPP TS 23.401 §5.5.1.2.2 (S1-based handover); 3GPP TS 23.502 §4.9.1.3 (Inter NG-RAN node N2 based handover).

EXP-MOB-003 — Idle-mode reselection with tracking area update

Status	✅ Accepted
Category	Functional
Components	xCore
Applies to	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant
Duration	About 30 min
Prerequisite procedures	EXP-SES-001 — UE-initiated attach EXP-SES-004 — UE idle mode

Objective. A UE in idle state moves into a radio of a different tracking area of the same site, performs a tracking area update (4G) or mobility registration update (5G), stays registered with its session, and can be paged and served in the new area.

Preconditions

- Platform
  - Two radios are connected to the xCore with different tracking area codes, and the second area is not in the tracking area list the UE received at attach.
- Tooling and access
  - Start a 3GPP signalling capture (pcap) with your preferred tool on the interfaces the procedure exercises.
  - Log in to xControl with an account that can view the Mobile Asset under test.
  - A host on the enterprise LAN that can ping the UE.
- Procedures executed first
  - EXP-SES-001 — UE-initiated attach
  - EXP-SES-004 — UE idle mode

Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-SES-001 — UE-initiated attach** as a prerequisite procedure.	As defined in EXP-SES-001.
2	—	Execute **EXP-SES-004 — UE idle mode** as a prerequisite procedure.	As defined in EXP-SES-004.
3	UE	While idle, move the UE into the coverage of the second radio.	The UE reselects the second radio and stays registered.

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#	Where	Action	Expected result
4	Capture	Inspect the signalling capture.	The messages match the sequence under *Expected signalling*; there is no Attach Request or Registration Request.
5	xControl	Open the Mobile Asset.	The status is unchanged and the IP address is the same.
6	Test host	Ping the UE's address from the LAN host.	The UE is paged in the new area and answers, as in EXP-SES-006.

Expected signalling

Capture points: S1-MME / N2 (point 1).

4G 5G

4G (EPS) sequence

1. Tracking Area Update Request from the second eNodeB, update type TA updating
2. Tracking Area Update Accept with the new tracking area list
3. Tracking Area Update Complete, when a new GUTI was allocated

5G (5GS) sequence

1. Registration Request, registration type mobility registration updating
2. Registration Accept with the new registration area
3. Registration Complete, when a new 5G-GUTI was allocated

Pass criteria

- The update is accepted; the UE stays registered with its session and address.
- Paging in the new area succeeds.

Evidence collected: 3GPP signalling capture (pcap); xControl session event log.
References: 3GPP TS 23.401 §5.3.3.2 (E-UTRAN Tracking Area Update without Serving GW change); 3GPP TS 23.502 §4.2.2.2.2 (General Registration (mobility registration update)).

EXP-MOB-004 — Roaming between two private Sites through a Shared System

Status	✅ Accepted
Category	Functional
Components	xCore, xControl
Applies to	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant
Duration	About 1 h
Prerequisite procedures	EXP-SES-001 — UE-initiated attach

Objective. A Mobile Asset on a System assigned to two Sites (a Shared System) obtains service at either Site. Arriving at the second Site, the UE registers with that Site's xCore, receives an address from the System's range, and reaches the enterprise network; the first Site's session is closed.

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Preconditions

- Platform
  - Two Sites, A and B, of the same Customer, each an operational xCore with a connected radio.
  - One System is assigned to both Sites (**Systems**, **Edit**, **Sites**), with a System Profile available at both.
- Mobile Asset
  - The Mobile Asset is on the Shared System and connected at Site A.
- Tooling and access
  - Log in to xControl with an account that holds the **ADMIN** role.
  - A signalling capture at Site B (capture point 1).
  - Access to the CLI of both Sites.
- Procedures executed first
  - EXP-SES-001 — UE-initiated attach

Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-SES-001 — UE-initiated attach** as a prerequisite procedure.	As defined in EXP-SES-001.
2	UE	Move the UE from Site A's coverage into Site B's coverage (or attenuate Site A and power on at Site B). Note the time.	The UE registers at Site B and shows a data connection.
3	Capture	Inspect the capture at Site B.	The UE's first message at Site B is a tracking area update or registration update that Site B cannot serve, followed by identification, authentication and a full attach or registration (see *Expected signalling*).
4	xControl	Open the Mobile Asset and its **Event Log**.	The status is **Connected**; the new session record names Site B; the IP address is inside the System's range.
5	UE	Ping a host on the enterprise network reachable from Site B.	The ping is answered.
6	xControl	Watch the Site A session record.	The Site A record closes no later than Site A's implicit detach time (the sum of its periodic, mobile reachable and implicit detach timers, `show timer` at Site A) plus 60 seconds after the move.
7	CLI	At Site A, run `read mme -f imsi=<imsi>` (or `read amf <imsi>`) after the Site A record has closed.	No context remains at Site A.

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Expected signalling

Capture points: S1-MME / N2 at Site B (point 1).

4G 5G

4G (EPS) sequence

1. Tracking Area Update Request with the GUTI issued by Site A, or Attach Request
2. Identity Request / Identity Response (IMSI), because Site B does not hold the context
3. Tracking Area Update Reject (implicitly detached), followed by Attach Request, when the UE started with a TAU
4. The attach sequence of EXP-SES-001 at Site B

5G (5GS) sequence

1. Registration Request (mobility registration updating) with the 5G-GUTI issued by Site A
2. Identity Request / Identity Response (SUCI)
3. Registration Reject or a full initial registration, then the registration and PDU session sequence of EXP-SES-001 at Site B

Pass criteria

- The UE obtains service at Site B without any change in xControl.
- The session record at Site B names Site B and carries an address from the System's range; a Mobile Asset with a static IP address keeps it, a dynamically addressed one may receive a different address.
- The Site A session is closed no later than Site A's implicit detach time plus 60 seconds, and no context remains at Site A.

Evidence collected: 3GPP signalling capture (pcap); xControl session event log; CLI output.
References: 3GPP TS 23.401 §5.3.3.1 (Tracking Area Update procedure with Serving GW change (inter-MME)); 3GPP TS 24.301 §5.5.3.2.5 (Normal and periodic tracking area updating procedure not accepted by the network).

EXP-MOB-005 — Transition from the public radio network to the private radio

Status	✅ Accepted
Category	Functional
Components	xCore, xRouter, xControl
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 1 h
Prerequisite procedures	EXP-POL-002 — Enterprise access through the public radio network EXP-SES-001 — UE-initiated attach

Objective. A UE served through the mobile operator's public radio network (EXP-POL-002) enters the coverage of the enterprise's private radio, selects the private network, registers with the private xCore and reaches the enterprise network there, while the public session ends. The same SIM and the same Mobile Asset are used throughout.

Preconditions

- Platform
  - A public-configuration xCore with xRouter (the public Site) and a private-radio xCore (the private Site), both of the same Customer, and a System assigned to both Sites.
  - The UE is able to select the private network's PLMN (see Devices and SIMs in Test environment and tooling); record whether selection is automatic or manual in the results sheet.

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- Mobile Asset
  - The Mobile Asset is on the shared System and connected through the public network (EXP-POL-002).
- Tooling and access
  - Log in to xControl with an account that holds the **ADMIN** role.
  - A signalling capture at the private Site (capture point 1) and at xRouter (capture point 4).
  - A host on the enterprise LAN that answers ping.
- Procedures executed first
  - EXP-POL-002 — Enterprise access through the public radio network
  - EXP-SES-001 — UE-initiated attach

Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-POL-002 — Enterprise access through the public radio network** as a prerequisite procedure.	As defined in EXP-POL-002.
2	UE	Start a continuous ping to the LAN host, then move the UE into the private radio's coverage and let it select the private network (or select it manually). Note the time.	The UE registers on the private network; the ping resumes after the transition.
3	Capture	Inspect the capture at the private Site.	The UE performs a full attach or registration at the private xCore, including identification and authentication against the private Site's subscriber database (sequence of EXP-SES-001).
4	xControl	Open the Mobile Asset and its **Event Log**.	The status is **Connected**; the newest session record names the private Site; the earlier record names the xRouter site.
5	xControl	Compare the IP addresses of the two sessions.	The private session's address is inside the System's range; it equals the public session's address only when the Mobile Asset has a static address.
6	UE	Stop the ping and count the lost replies.	The interruption is recorded.
7	xControl	Watch the public session record.	The record closes when the operator's core releases the session (at the latest at the operator's implicit detach time); record after how long.
8	Capture	Inspect the capture at xRouter after the public record has closed.	The release of the public session is visible (Cancel Location, or the mobile operator core's Delete Session toward the GTP proxy).

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Pass criteria

- The UE obtains service on the private network with no change in xControl and the same SIM.
- The private session is attributed to the private Site in xControl, and the service interruption is recorded.
- The public session record is closed, and no session for the IMSI remains on the public xCore, no later than the operator's implicit detach time plus 60 seconds.

Postconditions

- Leave the UE on the private network for EXP-MOB-006.

Evidence collected: 3GPP signalling capture (pcap); xControl session event log; UE connectivity check.
References: 3GPP TS 23.122 §4.4 (PLMN selection).

EXP-MOB-006 — Transition from the private radio to the public radio network

Status	✅ Accepted
Category	Functional
Components	xCore, xRouter, xControl
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 1 h
Prerequisite procedures	EXP-MOB-005 — Transition from the public radio network to the private radio

Objective. A UE served by the private radio leaves its coverage, selects the mobile operator's public network, is authenticated by xRouter and reaches the enterprise network through the public xCore, while the private session ends. The same SIM and Mobile Asset are used throughout.

Preconditions

- Platform
  - As for EXP-MOB-005.
- Mobile Asset
  - The Mobile Asset is connected at the private Site (end state of EXP-MOB-005 or EXP-SES-001).
- Tooling and access
  - Log in to xControl with an account that holds the **ADMIN** role.
  - A signalling capture at the private Site (capture point 1) and at xRouter (capture point 4).
  - A host on the enterprise LAN that answers ping.
- Procedures executed first
  - EXP-MOB-005 — Transition from the public radio network to the private radio

Procedure

#	Where	Action	Expected result
1	UE	Start a continuous ping to the LAN host, then move the UE out of the private radio's coverage (or attenuate the private radio) and let it select the public network. Note the time.	The UE registers on the public network; the ping resumes after the transition.

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#	Where	Action	Expected result
2	Capture	Inspect the capture at xRouter.	The operator's core authenticates the UE against xRouter and sets up the session toward the GTP proxy (sequence of EXP-POL-002).
3	xControl	Open the Mobile Asset and its **Event Log**.	The status is **Connected**; the newest session record names the xRouter site; the earlier record names the private Site.
4	UE	Stop the ping and count the lost replies.	The interruption is recorded.
5	xControl	Watch the private Site's session record.	The record closes no later than the private Site's implicit detach time (`show timer` at the private Site) plus 60 seconds; record after how long.
6	CLI	At the private Site, run `read mme -f imsi=<imsi>` (or `read amf <imsi>`) after the record has closed.	No context remains.

Pass criteria

- The UE obtains service on the public network with no change in xControl and the same SIM.
- The public session is attributed to the xRouter site in xControl, and the service interruption is recorded.
- The private session record is closed and no context remains at the private Site no later than its implicit detach time plus 60 seconds.

Evidence collected: 3GPP signalling capture (pcap); xControl session event log; UE connectivity check; CLI output.
References: 3GPP TS 23.122 §4.4 (PLMN selection).

EXP-MOB-007 — Repeated transitions between public and private radio

Status	✅ Accepted
Category	Resilience
Components	xCore, xRouter, xControl
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 3 h
Prerequisite procedures	EXP-MOB-005 — Transition from the public radio network to the private radio EXP-MOB-006 — Transition from the private radio to the public radio network

Objective. A UE crosses the boundary between the public radio network and the private radio repeatedly. Every transition results in exactly one new session on the destination Site, every earlier session is closed, and no session or context accumulates on either Site.

Preconditions

- Tooling and access
  - Log in to xControl with an account that holds the **ADMIN** role.
  - Access to the CLI of the private Site and to the public xCore.

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- Procedures executed first
  - EXP-MOB-005 — Transition from the public radio network to the private radio
  - EXP-MOB-006 — Transition from the private radio to the public radio network

Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-MOB-005 — Transition from the public radio network to the private radio** as a prerequisite procedure.	As defined in EXP-MOB-005.
2	—	Execute **EXP-MOB-006 — Transition from the private radio to the public radio network** as a prerequisite procedure.	As defined in EXP-MOB-006.
3	UE	Repeat the two transitions four more times (ten transitions in total), waiting for **Connected** on the destination Site each time.	Every transition ends with the UE **Connected** on the destination Site.
4	xControl	Open the **Event Log** section and select **Session** after the last transition, and wait for the implicit detach times of both Sites to elapse.	Exactly ten session records exist for the transitions, alternating between the two Sites, and only the last one is **Open**.
5	CLI	At both Sites, run `read mme -f imsi=<imsi>` (or `read amf <imsi>`) and `read pgw -f imsi=<imsi>` (or `read smf -f imsi=<imsi>`).	Exactly one context and one session exist, at the Site the UE is currently on.

Pass criteria

- Ten of ten transitions end with service on the destination Site.
- After the implicit detach times, exactly one session is open and exactly one context exists for the IMSI across both Sites.

Evidence collected: xControl session event log; CLI output.
References: 3GPP TS 23.122 §4.4 (PLMN selection).

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6.6.8 Security and Isolation

Mobile Asset traffic is contained, subscribers are authenticated with the configured algorithms and re-synchronized when needed, the 5G permanent identity is never sent in clear, the management path is outbound only, access to xControl follows the role model, changes are audited, and the core withstands a flood of unknown subscribers.

ID	Test	Category	Applies to
EXP-SEC-001	UE-to-UE communication prevented	Security	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
EXP-SEC-002	UE-to-platform communication prevented	Security	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
EXP-SEC-003	Authentication failure with wrong key material	Security	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
EXP-SEC-004	Signalling security algorithms	Security	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant
EXP-SEC-005	Management path is outbound only and encrypted	Security	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
EXP-SEC-006	Role-based access control in xControl	Security	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
EXP-SEC-007	Audit trail of provisioning and access	Security	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
EXP-SEC-008	Unknown-subscriber signalling storm	Security	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant
EXP-SEC-009	Subscriber identity concealment (SUCI)	Security	5G · Local radio · Single node, HA cluster, Geo-redundant
EXP-SEC-010	Authentication re-synchronisation	Security	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
EXP-SEC-011	Illegal UE reject (cause #3) after a failed authentication	Security	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant
EXP-SEC-012	PLMN not allowed (cause #11) for a UE of a PLMN the Site does not serve	Security	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant

EXP-SEC-001 — UE-to-UE communication prevented

Status	✔ Accepted
Category	Security

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Components	xCore
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 15 min
Prerequisite procedures	EXP-SES-007 — Multiple UE attach
Included in	Installation and Upgrade Verification

Objective. The network blocks direct communication between two Mobile Assets served by the platform.

Preconditions

- Platform
  - An xCore is deployed and operational, and its Site shows as online in xControl.
  - The xCore is configured to prevent UE-to-UE communication (the default configuration).
  - The xCore has a System.
- Mobile Asset
  - Two Mobile Assets are provisioned on the System.
- Tooling and access
  - Log in to xControl with an account that can view the Mobile Asset under test.
- Procedures executed first
  - EXP-SES-007 — Multiple UE attach

Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-SES-007 — Multiple UE attach** as a prerequisite procedure.	As defined in EXP-SES-007.
2	xControl	Open **Mobile Assets**, select the target UE, and note its IP address.	The target UE's IP address is recorded.
3	UE	From the source UE, ping the target UE's IP address, then attempt a TCP connection to a port the target UE listens on (for example a local web server or file-sharing application).	The ping receives no reply and the connection attempt fails.
4	UE	Repeat from the target UE toward the source UE.	No reply and no connection in the other direction either.

Pass criteria

- No packet from one UE reaches the other in either direction.

Evidence collected: ICMP result from the UE.

EXP-SEC-002 — UE-to-platform communication prevented

Status	✔ Accepted
Category	Security

Expeto Inc @ 2026

Components	xCore
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 20 min
Prerequisite procedures	EXP-SES-001 — UE-initiated attach
Included in	Installation and Upgrade Verification

Objective. The network blocks communication from a UE to the software components of the Expeto Platform: the xCore's own addresses, its monitoring endpoints and the cluster's node addresses.

Preconditions

- Platform
  - An xCore is deployed and operational, and its Site shows as online in xControl.
  - The xCore is configured to prevent UE-to-UE communication (the default configuration).
  - The xCore has a System on which the UE is provisioned.
- Tooling and access
  - Log in to xControl with an account that can view the Mobile Asset under test.
  - The node addresses of the cluster hosting the xCore (`kubectl get nodes -o wide`).
- Procedures executed first
  - EXP-SES-001 — UE-initiated attach

Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-SES-001 — UE-initiated attach** as a prerequisite procedure.	As defined in EXP-SES-001.
2	xControl	Open **Mobile Assets**, select the UE, and open the details page of its Site. Note the IP addresses of the Site and of its monitoring endpoints.	The platform IP addresses are recorded.
3	UE	From the UE, ping each recorded address and each cluster node address.	No ping receives a reply.
4	UE	From the UE, attempt TCP connections to the Kubernetes API port (6443), the metrics ports and the CLI pod's service ports on those addresses.	Every connection attempt fails.

Pass criteria

- No platform or node address answers the UE on any protocol tried.

Evidence collected: ICMP result from the UE.

EXP-SEC-003 — Authentication failure with wrong key material

Status	✅ Accepted
Category	Security
Components	xCore, xControl

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Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 25 min

Objective. A SIM whose secret key does not match the key stored for its Mobile Asset fails authentication and obtains no service, and the failure is visible in xControl.

Preconditions

- Platform
  - The Site has a System with a System Profile and a Keyset.
- Mobile Asset
  - A Mobile Asset provisioned for the UE's IMSI with a deliberately wrong secret key (K) or operator key (OPc), state **Active**.
- Device
  - The UE is powered off or in airplane mode.
- Tooling and access
  - Log in to xControl with an account that holds the **ADMIN** role.
  - Start a 3GPP signalling capture (pcap) with your preferred tool on the interfaces the procedure exercises.

Procedure

#	Where	Action	Expected result
1	UE	Power on the UE, or take it out of airplane mode, and wait for it to attempt to connect.	The UE fails to obtain service.
2	Capture	Inspect the signalling capture.	The messages match the sequence under *Expected signalling*; no Security Mode Command follows.
3	xControl	Open the Mobile Asset and its **Event Log**.	The status is not **Connected**; the failed authentication is recorded.
4	xControl	Correct the key material (or re-provision the Mobile Asset with the right values) and toggle airplane mode on the UE.	The UE connects as in EXP-SES-001.

Expected signalling

Capture points: S1-MME / N2 (point 1), S6a / N8 (point 4).

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4G 5G

4G (EPS) sequence

1. Attach Request, then Authentication Information Request / Answer on S6a
2. Authentication Request to the UE
3. Authentication Failure from the UE (MAC failure) when the operator key is wrong, or Authentication Response with a response the network rejects when the secret key is wrong
4. Authentication Reject from the network

5G (5GS) sequence

1. Registration Request, then the authentication vector retrieval on the service-based interfaces
2. Authentication Request to the UE
3. Authentication Failure from the UE, or Authentication Response rejected by the AUSF
4. Authentication Reject, or Registration Reject

Pass criteria

- No session is created and the UE obtains no service until the key material is corrected.
- The failed authentication is visible in xControl within 60 seconds.

Evidence collected: 3GPP signalling capture (pcap); xControl session event log.
References: 3GPP TS 33.401 §6.1.1 (AKA procedure); 3GPP TS 24.301 §5.4.2.5 (Authentication not accepted by the network); 3GPP TS 33.501 §6.1.3 (Authentication procedures).

EXP-SEC-004 — Signalling security algorithms

Status	Accepted
Category	Security
Components	xCore
Applies to	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant
Duration	About 20 min
Prerequisite procedures	EXP-SES-001 — UE-initiated attach

Objective. The network selects the configured ciphering and integrity algorithms for NAS and access stratum signalling, and every NAS message after the security mode procedure is integrity protected.

Preconditions

- Platform
  - You know the ciphering and integrity algorithms configured on the xCore (by default 128-EEA1 / 128-EIA1 for 4G and 128-NEA1 / 128-NIA1 for 5G).
- Tooling and access
  - Start a 3GPP signalling capture (pcap) with your preferred tool on the interfaces the procedure exercises.
- Procedures executed first
  - EXP-SES-001 — UE-initiated attach

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Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-SES-001 — UE-initiated attach** as a prerequisite procedure.	As defined in EXP-SES-001.
2	Capture	Open the Attach Request or Registration Request and read the UE's security capabilities.	The UE supports the configured algorithms.
3	Capture	Open the Security Mode Command.	The selected NAS ciphering and integrity algorithms equal the configured ones.
4	Capture	Open the Initial Context Setup Request.	It carries the UE security capabilities and the security key for the access stratum; the radio's subsequent Security Mode Command (on the air interface, not captured here) uses algorithms from that set.
5	Capture	Inspect every NAS message after the Security Mode Complete.	Each is marked integrity protected (and ciphered where ciphering is configured); no plain NAS message follows.

Pass criteria

- The selected algorithms equal the configured ones.
- Every NAS message after Security Mode Complete is integrity protected.

Evidence collected: 3GPP signalling capture (pcap).
References: 3GPP TS 33.401 §7.2.4 (NAS security mode command procedure); 3GPP TS 33.501 §6.7.2 (NAS security mode command procedure).

EXP-SEC-005 — Management path is outbound only and encrypted

Status	Accepted
Category	Security
Components	xCore, xControl
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 30 min
Prerequisite procedures	EXP-INS-002 — Management path and subscriber synchronization

Objective. The connection between an xCore and xControl is initiated by the xCore, uses TLS at an accepted protocol version, and requires no inbound connection to the xCore from the management network.

Preconditions

- Tooling and access
  - A signalling capture on the xCore's egress (capture point 6).
  - A host on the management network (where xControl runs) with a port scanner.

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- Procedures executed first
  - EXP-INS-002 — Management path and subscriber synchronization

Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-INS-002 — Management path and subscriber synchronization** as a prerequisite procedure.	As defined in EXP-INS-002.
2	Capture	Restart the agent pod and inspect the capture.	The TCP connection and the TLS Client Hello originate from the xCore toward xControl's address on port 443.
3	Capture	Open the TLS handshake.	The negotiated protocol version is TLS 1.2 or later, and the server certificate is xControl's.
4	Test host	From the management network, scan the xCore's external addresses for open TCP ports.	No port used by the management path is open toward the xCore; only the ports documented for the deployment (for example the radio-facing SCTP port on the radio network) are listening.
5	Infrastructure	Block all inbound connections from the management network to the xCore for ten minutes, keeping the outbound path open.	The Site stays online in xControl and provisioning changes still reach the Site (EXP-PRV-001, first steps).

Pass criteria

- Every management connection is initiated by the xCore.
- TLS 1.2 or later is negotiated, with a cipher suite from the list in the platform's security documentation.
- Blocking inbound traffic to the xCore has no effect on management.

Evidence collected: 3GPP signalling capture (pcap); CLI output.

EXP-SEC-006 — Role-based access control in xControl

Status	✅ Accepted
Category	Security
Components	xControl
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 40 min

Objective. Each xControl role can perform exactly the actions the permission model grants it, in the portal and through the API, and a Customer-scoped role sees only its own Customer's objects.

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Preconditions

- Platform
  - Two Customers exist, each with at least one Mobile Asset.
- Tooling and access
  - Accounts with the **ADMIN**, **CUSTOMER_ADMIN** and **READ_ONLY** roles; the last two scoped to the first Customer.
  - An API token for each account.

Procedure

#	Where	Action	Expected result
1	xControl	Log in as **READ_ONLY** and open **Mobile Assets**, **Systems** and **Sites**.	The objects of the first Customer are listed; there is no **New**, **Edit**, **Delete**, **Import** or **Bulk Actions** control.
2	xControl API	With the **READ_ONLY** token, attempt to create a Mobile Asset and to change an existing one.	Both requests are refused with an authorization error.
3	xControl	Log in as **CUSTOMER_ADMIN**, open a Mobile Asset, click **Edit**, change **Status**, and click **Submit**.	The change is saved.
4	xControl	As **CUSTOMER_ADMIN**, look for **New** on **Mobile Assets**, **Cancel Session** on a Mobile Asset, and **Import**.	None of these controls is available.
5	xControl	As **CUSTOMER_ADMIN**, search for a Mobile Asset of the second Customer by IMSI.	Nothing is found.
6	xControl	As **CUSTOMER_ADMIN**, open **Accounts** and try to create an account with the **ADMIN** role.	The **ADMIN** role is not offered.
7	xControl	Log in as **ADMIN** and repeat the actions refused above.	Every action is available and succeeds.

Pass criteria

- Every action tried matches the permission model for the role, in the portal and through the API.
- A Customer-scoped role never sees another Customer's objects.

Postconditions

- Revert the status change made as **CUSTOMER_ADMIN**.

Evidence collected: xControl screenshot.

EXP-SEC-007 — Audit trail of provisioning and access

Status	✅ Accepted
Category	Security

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Components	xControl
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 25 min
Prerequisite procedures	EXP-PRV-001 — Provision a Mobile Asset

Objective. Provisioning changes and portal logins are recorded with the account, the time and, for logins, the origin address, so that an administrator can reconstruct who changed what.

Preconditions

- Tooling and access
  - Log in to xControl with an account that holds the **ADMIN** role.
  - A superuser account, for the revision history.
- Procedures executed first
  - EXP-PRV-001 — Provision a Mobile Asset

Procedure

#	Where	Action	Expected result
1	xControl	Log in as **ADMIN**, then log out and attempt a login with a wrong password, then log in again correctly.	The correct logins succeed and the wrong one is refused.
2	xControl	Open **Accounts** and the **Audit** tile for your account.	The successful and the failed attempts are listed with their times and origin addresses.
3	—	Execute **EXP-PRV-001 — Provision a Mobile Asset** as a prerequisite procedure.	As defined in EXP-PRV-001.
4	xControl	Edit the new Mobile Asset (change its System Profile), then delete it.	Both changes are saved.
5	xControl	Log in as a superuser and open the revision history of the Mobile Asset.	Create, update and delete entries exist, each with the account that made the change and the time.

Pass criteria

- Every login attempt and every provisioning change tried is recorded with account and time.

Evidence collected: xControl screenshot.

EXP-SEC-008 — Unknown-subscriber signalling storm

Status	✅ Accepted
Category	Security
Components	xCore

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Applies to	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant
Duration	About 45 min
Prerequisite procedures	EXP-SES-001 — UE-initiated attach
Automated by	Platform suite, 4G split core: unknown-IMSI signalling soak (250 unserved IMSIs)

Objective. A sustained flood of attach attempts from subscribers the platform does not know is rejected in full, without a restart of any network function, without unbounded memory growth, and without degrading service for known subscribers.

> ⚠ **Service impact**
>
> This procedure interrupts service. Run it in a maintenance window or in a pre-production environment.

Preconditions

- Platform
  - The 3GPP peer simulator is connected to the xCore as a radio and configured with 250 IMSIs that are not provisioned (for example on an unserved PLMN).
  - Container CPU and memory of the MME or AMF and the subscriber database can be read (`kubectl top pod` , or the container metrics in xView).
- Mobile Asset
  - One Mobile Asset is connected and passing data (execute the UE-initiated attach procedure first if it is not).
- Tooling and access
  - Access to the CLI.
- Procedures executed first
  - EXP-SES-001 — UE-initiated attach

Procedure

#	Where	Action	Expected result
1	Tester	Record the restart count and the memory of every core pod (`kubectl top pod -n <namespace>`), and the MME or AMF context count (`read mme` or `read amf` , table footer total).	The baseline is recorded.
2	Tester	Start the simulator's attach flood for ten minutes, ramping the number of concurrent attempts from 2 to 32 while the MME or AMF stays below its CPU limit.	Attempts are answered continuously.
3	UE	During the flood, open a web page or ping from the connected UE, and detach and re-attach it once.	The known UE keeps service and re-attaches normally.
4	Tester	Stop the flood and read the simulator's counters.	At least 100 attempts were made, every one was rejected, and none was accepted.

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#	Where	Action	Expected result
5	Kubernetes	Five minutes after the flood ended, compare pod restart counts and memory with the baseline.	No pod restarted; the MME or AMF memory is back at the baseline.
6	UE	Power on a UE with an unknown IMSI.	It is rejected promptly, as in EXP-PRV-005.
7	CLI	Run `read mme` (or `read amf`) again and read the table footer total.	The context count is back to the baseline (the known UE only).

Pass criteria

- Zero unknown subscribers accepted; no network function restarted.
- The known UE keeps service and re-attaches during the flood.
- MME or AMF memory is back at its pre-flood baseline within five minutes of the flood ending, and no context remains for any unknown IMSI.

Evidence collected: Kubernetes pod and node status; CLI output; UE connectivity check.

EXP-SEC-009 — Subscriber identity concealment (SUCI)

Status	Accepted
Category	Security
Components	xCore
Applies to	5G · Local radio · Single node, HA cluster, Geo-redundant
Duration	About 30 min

Objective. A 5G UE never sends its permanent identity in clear. The Registration Request and every identity response carry a SUCI protected with the home network's public key, the UDM de-conceals it with the private key provisioned on the Site, and registration fails when that key is absent.

Preconditions

- Platform
  - The home network private key for the Site's PLMN is provisioned on the Site's subscriber database (`cd /nr`, then `add suci pkId=<key id> plmn=<mccmnc>`, entering the private key when prompted) and `read suci` lists it.
- Mobile Asset
  - The UE's Mobile Asset is provisioned in xControl on the System under test, with state **Active** and status **Provisioned** or **Disconnected**.
  - The SIM has SUCI concealment enabled with protection scheme Profile A or Profile B, the same key identifier, and the matching home network public key.
- Device
  - The UE is powered off or in airplane mode.
- Tooling and access
  - Log in to xControl with an account that can view the Mobile Asset under test.
  - A signalling capture on N2 (capture point 1).
  - Access to the CLI.

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Procedure

#	Where	Action	Expected result
1	UE	Power on the UE, or take it out of airplane mode, and wait for it to register.	The UE registers and obtains a data connection.
2	Capture	Open the Registration Request and read the 5GS mobile identity.	The identity type is SUCI, the protection scheme is Profile A or Profile B (not null), the home network public key identifier equals the provisioned key identifier, and the scheme output is present.
3	Capture	Search the whole capture for the IMSI digits and for a 5GS mobile identity of type SUPI.	The IMSI does not appear in clear anywhere on N2.
4	Capture	Follow the registration.	Authentication and Security Mode complete and the Registration Accept assigns a 5G-GUTI.
5	CLI	Run `cd /nr`, then `delete amf <imsi>`, so that the network forgets the UE's context, then toggle airplane mode on the UE.	The UE registers again with its 5G-GUTI; because the context is unknown, the network sends an Identity Request for the SUCI and the UE answers with a SUCI, again without the IMSI in clear.
6	CLI	Run `delete suci pkId=<key id>` (record the key first), then toggle airplane mode on the UE.	Registration fails at authentication because the SUCI cannot be de-concealed; the UE obtains no service.
7	CLI	Run `add suci pkId=<key id> plmn=<mccmnc>` with the recorded key, then toggle airplane mode on the UE.	The UE registers as in the first step.

Expected signalling

Capture points: N2 (point 1).

5G

5G (5GS) sequence

1. Registration Request with 5GS mobile identity of type SUCI (protection scheme Profile A or B, home network public key identifier, scheme output)
2. Authentication Request / Authentication Response, Security Mode Command / Security Mode Complete
3. Registration Accept with 5G-GUTI, Registration Complete
4. After the context is deleted, Registration Request with 5G-GUTI, Identity Request (identity type SUCI), Identity Response with a SUCI, then authentication and registration
5. Without the private key, Authentication Reject or Registration Reject after the Registration Request

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Pass criteria

- Every identity the UE sends on N2 is a SUCI with a non-null protection scheme and the provisioned key identifier; the IMSI never appears in clear.
- Registration succeeds with the private key present and fails without it.

Postconditions

- Confirm with `read suci` that the key is present again.

Evidence collected: 3GPP signalling capture (pcap); CLI output.
References: 3GPP TS 33.501 §6.12 (Subscription identifier privacy); 3GPP TS 24.501 §9.11.3.4 (5GS mobile identity (SUCI)); 3GPP TS 24.501 §5.4.3 (Identification procedure); 3GPP TS 23.003 §2.2B (Subscription Concealed Identifier (SUCI)).

EXP-SEC-010 — Authentication re-synchronisation

Status	✅ Accepted
Category	Security
Components	xCore, xRouter
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 45 min
Prerequisite procedures	EXP-SES-001 — UE-initiated attach

Objective. A SIM that has been authenticated by one subscriber database (for example the private Site's) and then attaches through another (the xRouter's, or a second private Site's) reports a sequence-number mismatch. The network re-synchronises with the SIM and completes the authentication without any action on the device.

Preconditions

- Platform
  - Two Sites of the same Customer with independent subscriber databases that both hold the Mobile Asset, A and B (a private Site and the xRouter, or two private Sites with a Shared System), each with a capture point on its S1-MME / N2 and S6a / N8 interfaces.
- Mobile Asset
  - The Mobile Asset is provisioned on a System available at both Sites.
- Tooling and access
  - Start a 3GPP signalling capture (pcap) with your preferred tool on the interfaces the procedure exercises.
  - Log in to xControl with an account that can view the Mobile Asset under test.
- Procedures executed first
  - EXP-SES-001 — UE-initiated attach

Procedure

#	Where	Action	Expected result
1	UE	At Site A, attach and detach the UE five times (EXP-SES-008), so that Site A's database advances the SIM's sequence number.	Every cycle completes.

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#	Where	Action	Expected result
2	UE	Move the UE to Site B's coverage (EXP-MOB-004 or EXP-MOB-006) and let it attach.	The UE attaches and obtains service without any action on the device.
3	Capture	Inspect the capture at Site B.	The messages match the sequence under *Expected signalling*; exactly one re-synchronisation round occurs.
4	UE	Detach and attach again at Site B.	The attach completes without a re-synchronisation.
5	UE	Return to Site A and attach.	At most one re-synchronisation round occurs and the attach completes.

Expected signalling

Capture points: S1-MME / N2 at Site B (point 1), S6a / N8 at Site B (point 4).

4G 5G

4G (EPS) sequence

1. Attach Request, Authentication Information Request / Answer, Authentication Request
2. Authentication Failure from the UE with EMM cause #21, synch failure, carrying the AUTS parameter
3. Authentication Information Request on S6a carrying Re-Synchronization-Info, and Authentication Information Answer with new vectors
4. Authentication Request / Authentication Response, then the attach completes

5G (5GS) sequence

1. Registration Request, authentication vector retrieval, Authentication Request
2. Authentication Failure from the UE with 5GMM cause #21, synch failure, carrying AUTS
3. Re-synchronisation between the AUSF and the UDM, then Authentication Request / Authentication Response and the registration completes

Pass criteria

- The attach at the second Site completes without any action on the device.
- Exactly one re-synchronisation round is needed on arrival, none on the following attach at the same Site.

Evidence collected: 3GPP signalling capture (pcap); xControl session event log.
References: 3GPP TS 33.102 §6.3.5 (Re-synchronisation procedure); 3GPP TS 24.301 §5.4.2.7 (Abnormal cases in the UE (synch failure)); 3GPP TS 29.272 §5.2.3.1 (Authentication Information Retrieval (Re-Synchronization-Info)); 3GPP TS 33.501 §6.1.3.3 (Synchronisation failure or MAC failure); 3GPP TS 24.501 §5.4.1.3.7 (Abnormal cases in the UE (5G AKA synch failure)).

EXP-SEC-011 — Illegal UE reject (cause #3) after a failed authentication

Status	✔ Accepted
Category	Security

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Components	xCore, xControl
Applies to	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant
Duration	About 25 min
Prerequisite procedures	EXP-SEC-003 — Authentication failure with wrong key material

Objective. A UE the network cannot authenticate is refused with cause 3, Illegal UE: the network abandons the attach or registration with that cause, releases the radio connection and keeps no context, and the UE treats its SIM as invalid for the network until it is power-cycled instead of retrying. EXP-SEC-003 covers the failure itself and its visibility; this test covers the exact cause and what follows it.

Preconditions

- Platform
  - The Site has a System with a System Profile and a Keyset.
- Mobile Asset
  - A Mobile Asset provisioned for the UE's IMSI with a deliberately wrong secret key (K), state **Active**, as in EXP-SEC-003.
- Device
  - The UE is powered off or in airplane mode.
- Tooling and access
  - Log in to xControl with an account that holds the **ADMIN** role.
  - Start a 3GPP signalling capture (pcap) with your preferred tool on the interfaces the procedure exercises.
- Procedures executed first
  - EXP-SEC-003 — Authentication failure with wrong key material

Procedure

#	Where	Action	Expected result
1	UE	Power on the UE, or take it out of airplane mode, and note the time.	The UE fails to obtain service on the private network.
2	Capture	Inspect the radio-side capture (point 1).	The attach or registration ends with a reject carrying cause #3, Illegal UE, as listed under *Expected signalling*, followed by the release of the UE's radio connection.
3	UE	Leave the UE on for five minutes and watch the capture.	No further Attach Request or Registration Request from the UE on this network: the UE treats its SIM as invalid for the network until it is switched off.
4	CLI	In the CLI on the Site: `cd /lte` then `read mme -f imsi=<imsi>` (4G), or `cd /nr` then `read amf <imsi>` (5G).	No context exists for the IMSI.
5	xControl	Open the Mobile Asset and its **Event Log**.	The status is not **Connected**; the failed authentication is recorded.

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#	Where	Action	Expected result
6	xControl	Correct the secret key, then power the UE off and on.	The UE attaches as in EXP-SES-001. The power cycle is needed because the UE had marked its SIM invalid.

Expected signalling

Capture points: S1-MME / N2 (point 1), S6a / N8 (point 4).

4G 5G

4G (EPS) sequence

1. Attach Request, then Authentication Information Request / Answer on S6a and Authentication Request to the UE
2. Authentication Failure from the UE (EMM cause #20, MAC failure), optionally followed by Identity Request / Response for the IMSI and a second Authentication Request / Failure; or, with a simulator, an Authentication Response whose RES the MME rejects
3. Authentication Reject when a response was received, then Attach Reject with EMM cause #3, Illegal UE
4. UE Context Release Command / Complete

5G (5GS) sequence

1. Registration Request, then the authentication vector retrieval through the AUSF and UDM and Authentication Request to the UE
2. Authentication Failure from the UE (5GMM cause #20, MAC failure), or an Authentication Response the AUSF rejects
3. Authentication Reject, or Registration Reject with 5GMM cause #3, Illegal UE
4. UE Context Release Command / Complete

Pass criteria

- The reject carries cause #3, Illegal UE (EMM on 4G, 5GMM on 5G), the radio connection is released, and no MME or AMF context remains.
- The UE makes no further attach or registration attempt on the network for five minutes after the reject.
- The failed authentication is visible in the xControl **Event Log** within 60 seconds, and service returns once the key is corrected and the UE power-cycled.

Postconditions

- Restore the correct key material on the Mobile Asset.

Deployment notes

- **Simulator:** With the 3GPP peer simulator, send an Authentication Response with a wrong RES instead of using a mis-keyed SIM: the network rejects the response and the same cause follows.

Evidence collected: 3GPP signalling capture (pcap); xControl session event log; CLI output.
References: 3GPP TS 24.301 §5.4.2.7 (Authentication procedure, abnormal cases on the network side); 3GPP TS 24.301 §5.5.1.2.5 (Attach not accepted by the network); 3GPP TS 24.501 §5.4.1.3.5 (Authentication not accepted by the network); 3GPP TS 24.501 §5.5.1.2.5 (Initial registration not accepted by the network); 3GPP TS 33.401 §6.1.1 (AKA procedure).

EXP-SEC-012 — PLMN not allowed (cause #11) for a UE of a PLMN the Site does not serve

Status	✅ Accepted
Category	Security
Components	xCore

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Applies to	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant
Duration	About 25 min

Objective. A UE whose IMSI belongs to a PLMN the Site does not serve selects the private network and is refused with cause 11, PLMN not allowed, before any authentication: the UE places the private PLMN on its forbidden list and returns to its own network instead of retrying, and the private core spends no subscriber-database exchange on it. This is the behaviour a private radio owes the mobile operator's other subscribers and any third-party device in its coverage.

Preconditions

- Platform
  - The private radio broadcasts a PLMN of its own, different from the home PLMN of the UE under test.
  - The Site's served PLMN list holds only the PLMNs of the Mobile Assets it hosts; the UE's home PLMN is not among them.
- Mobile Asset
  - A UE with a SIM of another network (a consumer SIM of the mobile operator, or a third party's) that is **not** provisioned in xControl.
- Device
  - The UE is powered off or in airplane mode.
- Tooling and access
  - Start a 3GPP signalling capture (pcap) with your preferred tool on the interfaces the procedure exercises.

Procedure

#	Where	Action	Expected result
1	UE	Power on the UE and select the private network's PLMN manually in its network selection menu, or power it on where only the private radio has coverage. Note the time.	The UE is refused and shows no service on the private network.
2	Capture	Inspect the radio-side capture (point 1).	The attach or registration is answered with a reject carrying cause #11, PLMN not allowed, with no Authentication Request before it, as listed under *Expected signalling*.
3	Capture	Inspect the subscriber-database capture (point 4).	No Authentication Information Request (4G) and no authentication request to the AUSF or UDM (5G) is sent for the UE's IMSI.
4	UE	Set network selection back to automatic and watch the UE and the capture for five minutes.	The UE selects its home network where it has coverage and sends no further Attach Request or Registration Request to the private network.
5	CLI	In the CLI on the Site: `cd /lte` then `read mme -f imsi=<imsi>` (4G), or `cd /nr` then `read amf <imsi>` (5G).	No context exists for the IMSI.

Expected signalling

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Capture points: S1-MME / N2 (point 1), S6a / N8 (point 4).

4G 5G

4G (EPS) sequence

1. Attach Request with the IMSI, or with a GUTI followed by Identity Request / Identity Response for the IMSI
2. Attach Reject with EMM cause #11, PLMN not allowed; no Authentication Request to the UE and no Authentication Information Request on S6a
3. UE Context Release Command / Complete

5G (5GS) sequence

1. Registration Request with a SUCI, or with a 5G-GUTI followed by Identity Request / Identity Response for the SUCI
2. Registration Reject with 5GMM cause #11, PLMN not allowed; no Authentication Request to the UE and no request to the AUSF or UDM
3. UE Context Release Command / Complete

Pass criteria

- The reject carries cause #11, PLMN not allowed, and is sent without an authentication attempt; no request for the UE's identity reaches the subscriber database.
- The UE makes no further attempt on the private PLMN in automatic selection for five minutes and returns to its home network where it has coverage.
- No MME or AMF context remains for the IMSI.

Postconditions

- Power-cycle the UE to clear the private PLMN from its forbidden list before using it in other tests.

Deployment notes

- **MNO PLMN broadcast:** Where the private radio broadcasts the mobile operator's own PLMN, cause #11 would forbid the UE's home network; such a deployment refuses unserved subscribers through the subscriber database instead (EXP-PRV-005) and this test does not apply.

Evidence collected: 3GPP signalling capture (pcap); CLI output.
References: 3GPP TS 24.301 §5.5.1.2.5 (Attach not accepted by the network); 3GPP TS 24.501 §5.5.1.2.5 (Initial registration not accepted by the network); 3GPP TS 23.122 §3.1 (Forbidden PLMN list (definition)).

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6.6.9 Messaging (SMS)

Short messages for Mobile Assets on the mobile operator's public radio network, served by the Expeto SMSC in Expeto Gateway (xRouter): mobile-originated and mobile-terminated messages over MAP and over SGd, exchange with application servers over SMPP, concatenated and binary messages, delivery reports, store-and-forward for absent devices, and routing rules.

ID	Test	Category	Applies to
EXP-MSG-001	UE to UE SMS over MAP	Functional	4G · Public radio · Single node, HA cluster, Geo-redundant
EXP-MSG-002	UE to application SMS over MAP and SMPP	Functional	4G · Public radio · Single node, HA cluster, Geo-redundant
EXP-MSG-003	Application to UE SMS over SMPP and MAP, concatenated, binary and receipted	Functional	4G · Public radio · Single node, HA cluster, Geo-redundant
EXP-MSG-004	MO and MT SMS over SGd	Functional	4G · Public radio · Single node, HA cluster, Geo-redundant
EXP-MSG-005	Store-and-forward for an absent UE	Functional	4G · Public radio · Single node, HA cluster, Geo-redundant
EXP-MSG-006	Message routing rules	Functional	4G · Public radio · Single node, HA cluster, Geo-redundant

EXP-MSG-001 — UE to UE SMS over MAP

Status	✅ Accepted
Category	Functional
Components	xRouter, xControl
Applies to	4G · Public radio · Single node, HA cluster, Geo-redundant
Duration	About 20 min

Objective. A Mobile Asset on the mobile operator's public radio network sends a text message to another Mobile Asset. The operator's core relays it over MAP to the Expeto SMSC, which locates the recipient through the HSS and delivers it over MAP to the recipient's serving node, and both legs are recorded in xControl.

Preconditions

- Platform
  - The Expeto SMSC in xRouter is enabled with MAP over SIGTRAN toward the operator's signalling network, and the mobile operator routes short messages for the Expeto SMSC global title to it.
- Mobile Asset
  - Two Mobile Assets, A and B, each with an MSISDN, both attached through the public radio network (EXP-POL-002).
- Tooling and access
  - Log in to xControl with an account that holds the **ADMIN** role.
  - A signalling capture at xRouter's SIGTRAN interface (capture point 7).
  - Access to the CLI.

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Procedure

#	Where	Action	Expected result
1	UE	On UE A, send a text message to UE B's MSISDN. Note the time.	UE A reports the message as sent.
2	Capture	Inspect the capture.	The messages match the sequence under *Expected signalling*.
3	UE	Observe UE B.	The message arrives within 30 seconds with the text sent.
4	xControl	Open Mobile Asset A's **Event Log** and select **SMS**, then Mobile Asset B's.	A's log shows the outgoing message with source MAP; B's log shows the delivered message with a delivery success and no failure cause.
5	CLI	Run `cd /lte`, then `read smsc`.	No message for A or B remains stored.

Expected signalling

Capture points: SIGTRAN at xRouter (point 7), S6c between the SMSC and the HSS.

4G

4G (EPS) sequence

1. MO-ForwardSM (mo-forwardSM invoke) from the operator's serving node to the Expeto SMSC, and its result
2. SendRoutingInfoForSM from the SMSC to the HSS for B's MSISDN, returning B's IMSI and serving node
3. MT-ForwardSM (mt-forwardSM invoke) from the SMSC to B's serving node, and its result

Pass criteria

- The message is delivered within 30 seconds with its content intact.
- Both legs appear in the capture and in the SMS event logs of the two Mobile Assets, with no failure cause.
- No message remains stored in the SMSC after delivery.

Evidence collected: 3GPP signalling capture (pcap); xControl session event log; CLI output.
References: 3GPP TS 23.040 §10 (Short message procedures); 3GPP TS 29.002 §12.2 (MO-ForwardSM); 3GPP TS 29.002 §12.9 (MT-ForwardSM); 3GPP TS 29.002 §12.1 (SendRoutingInfoForSM).

EXP-MSG-002 — UE to application SMS over MAP and SMPP

Status	✅ Accepted
Category	Functional
Components	xRouter, xControl
Applies to	4G · Public radio · Single node, HA cluster, Geo-redundant
Duration	About 20 min
Prerequisite procedures	EXP-MSG-001 — UE to UE SMS over MAP

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Objective. A Mobile Asset sends a text message to an application's short code or number. The Expeto SMSC receives it over MAP, matches a routing rule for the destination, and delivers it to the application server bound over SMPP.

Preconditions

- Platform
  - An SMSC routing rule maps the application's destination address to `destinationRoute: SMPP` for the application's system id.
- Mobile Asset
  - Mobile Asset A attached through the public radio network (EXP-POL-002).
- Tooling and access
  - Log in to xControl with an account that holds the **ADMIN** role.
  - An SMPP test client bound to the SMSC as a receiver with the application's system id.
  - A signalling capture at xRouter (capture points 7 and 9).
- Procedures executed first
  - EXP-MSG-001 — UE to UE SMS over MAP

Procedure

#	Where	Action	Expected result
1	UE	On UE A, send a text message to the application's destination address. Note the time.	UE A reports the message as sent.
2	Test host	Observe the SMPP test client.	A `deliver_sm` arrives within 30 seconds with A's MSISDN as source, the application's address as destination and the text sent; the client answers `deliver_sm_resp`.
3	Capture	Inspect the capture.	MO-ForwardSM arrives over MAP and the same message leaves over SMPP; no MT-ForwardSM is attempted.
4	xControl	Open Mobile Asset A's **Event Log** and select **SMS**.	The message is recorded with source MAP and route SMPP, delivered, with no failure cause.

Expected signalling

Capture points: SIGTRAN at xRouter (point 7), SMPP (point 9).

4G

4G (EPS) sequence

1. MO-ForwardSM from the operator's serving node to the Expeto SMSC, and its result
2. SMPP deliver_sm from the SMSC to the bound application, and deliver_sm_resp

Pass criteria

- The application receives the message within 30 seconds with source, destination and text intact.
- The event log records the message with source MAP and route SMPP and no failure cause.

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Evidence collected: 3GPP signalling capture (pcap); xControl session event log.
References: 3GPP TS 29.002 §12.2 (MO-ForwardSM); SMPP Protocol Specification v3.4 §4.6 (deliver_sm).

EXP-MSG-003 — Application to UE SMS over SMPP and MAP, concatenated, binary and receipted

Status	✅ Accepted
Category	Functional
Components	xRouter, xControl
Applies to	4G · Public radio · Single node, HA cluster, Geo-redundant
Duration	About 30 min
Prerequisite procedures	EXP-MSG-001 — UE to UE SMS over MAP

Objective. An application server submits messages to a Mobile Asset over SMPP: a plain text, a concatenated text longer than one segment, and a binary message. The Expeto SMSC delivers each over MAP to the recipient's serving node, the UE reassembles the concatenated text, and the application receives a delivery receipt for each message.

Preconditions

- Mobile Asset
  - Mobile Asset B attached through the public radio network (EXP-POL-002).
- Tooling and access
  - Log in to xControl with an account that holds the **ADMIN** role.
  - An SMPP test client bound to the SMSC as a transmitter and receiver, able to request delivery receipts.
  - A signalling capture at xRouter (capture points 7 and 9).
- Procedures executed first
  - EXP-MSG-001 — UE to UE SMS over MAP

Procedure

#	Where	Action	Expected result
1	Test host	Submit a plain text message (under 160 characters) to B's MSISDN with a delivery receipt requested (`registered_delivery`).	The SMSC answers `submit_sm_resp` with a message identifier.
2	UE	Observe UE B.	The message arrives within 30 seconds with the text intact.
3	Test host	Observe the SMPP test client.	A `deliver_sm` delivery receipt arrives for the message identifier with the delivered state.
4	Test host	Submit a 200-character text message with a delivery receipt requested.	The SMSC accepts it.

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#	Where	Action	Expected result
5	Capture	Inspect the capture.	The message is delivered as two MT-ForwardSM segments with a user data header (concatenation reference, total 2, sequence 1 and 2).
6	UE	Observe UE B.	The full 200-character text is shown as one message.
7	Test host	Submit an 8-bit binary message (for example 100 bytes of a known pattern, data coding 8-bit) to B's MSISDN.	The SMSC accepts it and the UE (or a data-SMS capable application on it) receives the exact bytes.
8	xControl	Open Mobile Asset B's **Event Log** and select **SMS**.	Three delivered messages are recorded with source SMPP and route MAP and no failure cause.

Expected signalling

Capture points: SMPP (point 9), SIGTRAN at xRouter (point 7).

4G

4G (EPS) sequence

1. SMPP submit_sm / submit_sm_resp for each message
2. SendRoutingInfoForSM from the SMSC to the HSS, then MT-ForwardSM to B's serving node, one per segment, each with its result
3. SMPP deliver_sm carrying the delivery receipt, and deliver_sm_resp

Pass criteria

- Each message is delivered within 30 seconds with content intact; the concatenated message is shown as one message; the binary payload is received byte for byte.
- The application receives a delivery receipt in the delivered state for each message.
- The event log records the three messages with source SMPP and route MAP and no failure cause.

Evidence collected: 3GPP signalling capture (pcap); xControl session event log.
References: SMPP Protocol Specification v3.4 §4.4 (submit_sm); 3GPP TS 23.040 §9.2.3.24 (TP-User-Data (concatenated short messages)); 3GPP TS 29.002 §12.9 (MT-ForwardSM).

EXP-MSG-004 — MO and MT SMS over SGd

Status	✅ Accepted
Category	Functional
Components	xRouter, xControl
Applies to	4G · Public radio · Single node, HA cluster, Geo-redundant
Duration	About 30 min

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Objective. Where the mobile operator's MME delivers short messages over Diameter, a Mobile Asset's mobile-originated message reaches the Expeto SMSC over SGd and a mobile-terminated message is delivered to the UE over SGd, without the circuit-switched network.

Preconditions

- Platform
  - The Expeto SMSC in xRouter has the SGd application enabled (`hss.diameter.applications.sgdGdd: true`) and a Diameter peer to the operator's MME or SMS router.
  - The HSS advertises SMS in MME to the operator's MME (`agent.hss.nodeConfig.hssConfig.smsInMme: true`), so that the MME registers for SMS over SGd.
  - The operator's MME supports SGd toward the Expeto SMSC.
- Mobile Asset
  - Two Mobile Assets, A and B, each with an MSISDN, attached through the public radio network (EXP-POL-002).
- Tooling and access
  - Log in to xControl with an account that holds the **ADMIN** role.
  - A signalling capture at xRouter's Diameter interface (capture point 8) and at S6a (capture point 4).
  - An SMPP test client bound to the SMSC.

Procedure

#	Where	Action	Expected result
1	Capture	Inspect the Update Location Answer for Mobile Asset A on S6a.	The answer advertises SMS in MME, so the MME handles A's short messages over SGd.
2	UE	On UE A, send a text message to UE B's MSISDN.	UE A reports the message as sent.
3	Capture	Inspect the Diameter capture.	The operator's MME sends MO-Forward-Short-Message-Request (OFR) to the Expeto SMSC and receives the answer (OFA); the SMSC then sends MT-Forward-Short-Message-Request (TFR) toward B's MME and receives the answer (TFA).
4	UE	Observe UE B.	The message arrives within 30 seconds with the text intact.
5	Test host	Submit a text message from the SMPP test client to UE A's MSISDN.	The SMSC accepts it and delivers it with TFR / TFA; UE A receives it within 30 seconds.
6	xControl	Open the **Event Log** of A and B and select **SMS**.	The messages are recorded with source or route DIAMETER and no failure cause.

Expected signalling

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Capture points: Diameter SGd at xRouter (point 8), S6a (point 4).

4G

4G (EPS) sequence

1. Update Location Answer with the SMS-in-MME indication
2. MO-Forward-Short-Message-Request / Answer (OFR / OFA) from the MME to the SMSC
3. SendRoutingInfoForSM to the HSS, then MT-Forward-Short-Message-Request / Answer (TFR / TFA) from the SMSC to the recipient's MME

Pass criteria

- Both messages are delivered within 30 seconds with their content intact, entirely over Diameter.
- The event logs record the messages with the Diameter source or route and no failure cause.

Evidence collected: 3GPP signalling capture (pcap); xControl session event log.
References: 3GPP TS 29.338 §5.3 (SGd interface procedures); 3GPP TS 29.338 §6.3 (MO-Forward-Short-Message and MT-Forward-Short-Message); 3GPP TS 23.040 §10 (Short message procedures).

EXP-MSG-005 — Store-and-forward for an absent UE

Status	✅ Accepted
Category	Functional
Components	xRouter, xControl
Applies to	4G · Public radio · Single node, HA cluster, Geo-redundant
Duration	About 30 min
Prerequisite procedures	EXP-MSG-003 — Application to UE SMS over SMPP and MAP, concatenated, binary and receipted

Objective. A message to a Mobile Asset that is switched off is held by the Expeto SMSC, the HSS is told the message is waiting, and the message is delivered when the device returns, with a delivery receipt to the sender.

Preconditions

- Mobile Asset
  - Mobile Asset B provisioned and its UE powered off.
- Tooling and access
  - Log in to xControl with an account that holds the **ADMIN** role.
  - An SMPP test client bound to the SMSC with delivery receipts requested.
  - A signalling capture at xRouter (capture points 7 and 9).
  - Access to the CLI.
- Procedures executed first
  - EXP-MSG-003 — Application to UE SMS over SMPP and MAP, concatenated, binary and receipted

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Procedure

#	Where	Action	Expected result
1	Test host	Submit a text message to B's MSISDN with a delivery receipt requested. Note the time.	The SMSC answers `submit_sm_resp`.
2	Capture	Inspect the capture.	The delivery attempt fails with an absent-subscriber indication, and the SMSC sends ReportSMDeliveryStatus to the HSS, which sets the message-waiting indication.
3	CLI	Run `cd /lte`, then `read smsc`.	The message is listed as stored, with B as receiver, its retry count and its route.
4	xControl	Open Mobile Asset B's **Event Log** and select **SMS**.	The failed attempt is recorded with the absent-subscriber cause and the message is pending.
5	UE	Power on UE B and let it attach.	The UE attaches; the message arrives within one minute of the attach.
6	Capture	Inspect the capture.	On the attach, the HSS alerts the SMSC (ReadyForSM or AlertServiceCentre) and the SMSC delivers the stored message with MT-ForwardSM.
7	Test host	Observe the SMPP test client.	A delivery receipt in the delivered state arrives for the message identifier.
8	CLI	Run `read smsc` again.	The message is no longer stored.

Expected signalling

Capture points: SIGTRAN at xRouter (point 7), SMPP (point 9).

4G

4G (EPS) sequence

1. SMPP submit_sm / submit_sm_resp
2. SendRoutingInfoForSM, then MT-ForwardSM failing with absent subscriber, then ReportSMDeliveryStatus to the HSS
3. On the UE's attach, ReadyForSM or AlertServiceCentre from the HSS to the SMSC
4. MT-ForwardSM to the serving node, then SMPP deliver_sm carrying the delivery receipt

Pass criteria

- The message is held while the UE is off and delivered within one minute of the UE attaching, with content intact.
- The sender receives a delivery receipt in the delivered state.
- The SMSC holds no copy after delivery.

Evidence collected: 3GPP signalling capture (pcap); xControl session event log; CLI output.
References: 3GPP TS 23.040 §3.2.7 (Alert-SC (message waiting)); 3GPP TS 23.040 §10.3 (Short message mobile terminated); 3GPP TS 29.002 §12.8 (ReadyForSM); 3GPP TS 29.002 §12.4 (AlertServiceCentre).

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EXP-MSG-006 — Message routing rules

Status	✅ Accepted
Category	Functional
Components	xRouter, xControl
Applies to	4G · Public radio · Single node, HA cluster, Geo-redundant
Duration	About 20 min
Prerequisite procedures	EXP-MSG-001 — UE to UE SMS over MAP

Objective. The Expeto SMSC applies its routing rules: a destination configured to be rejected returns a failure to the sender, a destination configured to be discarded is dropped silently, and the rules can be removed to restore delivery.

Preconditions

- Platform
  - Two SMSC routing rules exist, one with `destinationRoute: REJECT` for destination address R and one with `destinationRoute: DISCARD` for destination address D, and you can change the rules.
- Mobile Asset
  - Mobile Asset A attached through the public radio network (EXP-POL-002).
- Tooling and access
  - Log in to xControl with an account that holds the **ADMIN** role.
  - A signalling capture at xRouter (capture point 7).
- Procedures executed first
  - EXP-MSG-001 — UE to UE SMS over MAP

Procedure

#	Where	Action	Expected result
1	UE	On UE A, send a text message to address R.	UE A reports a delivery failure.
2	Capture	Inspect the capture.	The MO-ForwardSM is answered with an error; no MT-ForwardSM follows.
3	UE	On UE A, send a text message to address D.	UE A reports the message as sent; nothing is delivered anywhere.
4	Capture	Inspect the capture.	The MO-ForwardSM is answered with success; no further message follows.
5	xControl	Open Mobile Asset A's **Event Log** and select **SMS**.	The first message is recorded as Rejected and the second as Discarded.
6	Tester	Remove both rules and send a message to R again.	The message is delivered as in EXP-MSG-001.

Pass criteria

- A rejected destination returns a failure to the sender and nothing is forwarded.
- A discarded destination is accepted from the sender and nothing is forwarded.

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- The event log records Rejected and Discarded; removing the rules restores delivery.

Postconditions

- Restore the routing rules the deployment had before the test.

Evidence collected: 3GPP signalling capture (pcap); xControl session event log.

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6.6.10 Session Records and Usage

Session history and usage records in xControl are complete, accurate to the byte, attributed to the right Site and System, produced for sessions that end abnormally, and delivered even when the site was out of contact while the session ran.

ID	Test	Category	Applies to
EXP-REC-001	Session record completeness	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
EXP-REC-002	Usage accounting accuracy	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
EXP-REC-003	Record of a session that ended abnormally	Functional	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant
EXP-REC-004	Records delivered after a management-path outage	Functional	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant
EXP-REC-005	Usage report generation and export	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
EXP-REC-006	Record attribution across public and private transitions	Functional	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant

EXP-REC-001 — Session record completeness

Status	✅ Accepted
Category	Functional
Components	xControl, xCore
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 20 min
Prerequisite procedures	EXP-SES-001 — UE-initiated attach EXP-SES-002 — UE-initiated detach
Included in	Installation and Upgrade Verification

Objective. The record of a completed session carries every field an MNO needs to account for it, and the values agree with the signalling capture of the same session.

Preconditions

- Tooling and access
  - Log in to xControl with an account that holds the **ADMIN** role.
  - An API token for the Customer.
- Procedures executed first
  - EXP-SES-001 — UE-initiated attach
  - EXP-SES-002 — UE-initiated detach

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Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-SES-001 — UE-initiated attach** as a prerequisite procedure.	As defined in EXP-SES-001.
2	—	Execute **EXP-SES-002 — UE-initiated detach** as a prerequisite procedure.	As defined in EXP-SES-002.
3	xControl	Open the Mobile Asset's **Event Log**, select **Session**, and use the **Column Chooser** to show every column.	The closed session shows the Site and System names, the IMSI and IMEI, start and end time, the IP address and state **Closed**.
4	xControl API	Retrieve the session report for the IMSI through the API.	The record carries the IMEI, start and stop time, MCC, MNC, tracking area, radio identifier, bearer identifier, IP address, APN name, radio access technology, state, cause code, upload and download bytes, and links to the Site, System and subscriber.
5	Capture	Compare the record with the capture of EXP-SES-001 and EXP-SES-002.	The IP address equals the PDN or PDU address assigned; MCC, MNC and tracking area equal the tracking area identity in the attach; the radio identifier equals the cell identity in the attach; the start time is within one minute of the Attach Complete and the end time within one minute of the detach.

Pass criteria

- Every field listed is present and consistent with the capture.
- Start and end times are within 5 seconds of the corresponding signalling messages.

Evidence collected: xControl screenshot; 3GPP signalling capture (pcap).
References: 3GPP TS 32.251 §5.2 (PS domain charging principles).

EXP-REC-002 — Usage accounting accuracy

Status	✔ Accepted
Category	Functional
Components	xControl, xCore
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 30 min
Prerequisite procedures	EXP-SES-001 — UE-initiated attach EXP-SES-002 — UE-initiated detach

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Objective. The upload and download byte counts recorded for a session equal the bytes the UE actually sent and received, as counted on the enterprise side of the user plane.

Preconditions

- Device
  - Background traffic on the UE is disabled (see Devices and SIMs in Test environment and tooling).
- Tooling and access
  - A host on the enterprise LAN serving a file of known size over HTTP and running an iperf3 server.
  - A capture on the enterprise side of the user plane (SGi / N6) filtered to the UE's address.
  - Log in to xControl with an account that holds the **ADMIN** role.
- Procedures executed first
  - EXP-SES-001 — UE-initiated attach
  - EXP-SES-002 — UE-initiated detach

Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-SES-001 — UE-initiated attach** as a prerequisite procedure.	As defined in EXP-SES-001.
2	Capture	Start the SGi / N6 capture filtered to the UE's address.	The capture is running.
3	UE	Download the known-size file from the LAN host, then upload a fixed amount with iperf3 (for example 20 MB).	Both transfers complete.
4	—	Execute **EXP-SES-002 — UE-initiated detach** as a prerequisite procedure.	As defined in EXP-SES-002.
5	Capture	Stop the capture and read the byte totals of the UE's conversation in each direction (IP layer).	Upload and download totals are recorded.
6	xControl	Open the closed session's record.	Upload and download bytes are shown.
7	Tester	Compare the record with the capture totals.	The record equals the capture totals.

Pass criteria

- Recorded upload and download bytes equal the IP-layer bytes counted on the enterprise side of the user plane for the session.

Evidence collected: 3GPP signalling capture (pcap); xControl screenshot.
References: 3GPP TS 32.251 §5.2 (PS domain charging principles).

EXP-REC-003 — Record of a session that ended abnormally

Status	✅ Accepted
Category	Functional
Components	xControl, xCore

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Applies to	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant
Duration	About 30 min
Prerequisite procedures	EXP-SES-010 — Implicit detach after loss of the device

Objective. A session that ends without a detach, because the device disappeared, is closed with a cause that says so, and its byte counts reflect the traffic exchanged before the loss.

Preconditions

- Tooling and access
  - Log in to xControl with an account that holds the **ADMIN** role.
- Procedures executed first
  - EXP-SES-010 — Implicit detach after loss of the device

Procedure

#	Where	Action	Expected result
1	UE	Before the loss step of EXP-SES-010, download a known-size file from the LAN host.	The transfer completes.
2	—	Execute **EXP-SES-010 — Implicit detach after loss of the device** as a prerequisite procedure.	As defined in EXP-SES-010.
3	xControl	Open the closed session's record.	The end time corresponds to the implicit detach, the cause code differs from a normal detach, and the download bytes cover the file transferred before the loss.

Pass criteria

- The record is closed with a cause that identifies the abnormal end.
- The byte counts include the traffic exchanged before the loss.

Evidence collected: xControl screenshot.

EXP-REC-004 — Records delivered after a management-path outage

Status	✅ Accepted
Category	Functional
Components	xControl, xCore
Applies to	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant
Duration	About 40 min
Prerequisite procedures	EXP-SES-001 — UE-initiated attach EXP-PRV-011 — Provisioning changes made while the site is out of contact

Objective. Sessions that start, run and end while the xCore cannot reach xControl are recorded on the Site and delivered to xControl when the connection returns, with correct times and byte counts and without gaps.

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Preconditions

- Platform
  - You can block outbound traffic from the xCore to xControl and remove the block again.
- Tooling and access
  - Log in to xControl with an account that holds the **ADMIN** role.
  - A host on the enterprise LAN serving a file of known size.
- Procedures executed first
  - EXP-SES-001 — UE-initiated attach
  - EXP-PRV-011 — Provisioning changes made while the site is out of contact

Procedure

#	Where	Action	Expected result
1	Infrastructure	Block traffic from the xCore to xControl on TCP port 443. Note the time.	The Site is shown offline within about five minutes.
2	—	Execute **EXP-SES-001 — UE-initiated attach** as a prerequisite procedure.	As defined in EXP-SES-001.
3	UE	Download the known-size file, then detach (EXP-SES-002).	The session completes while the Site is out of contact.
4	xControl	Open the Mobile Asset's **Event Log**.	The session run during the outage is not yet visible.
5	Infrastructure	Remove the block. Note the time.	The Site returns to online.
6	xControl	Watch the **Event Log**.	The session appears, **Closed**, with start and end times inside the outage window and byte counts covering the file.

Pass criteria

- The session record is delivered within 60 seconds of the Site returning online.
- Its times and byte counts are correct.

Evidence collected: xControl screenshot.

EXP-REC-005 — Usage report generation and export

Status	✅ Accepted
Category	Functional
Components	xControl
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 20 min
Prerequisite procedures	EXP-REC-001 — Session record completeness

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Objective. Detailed and summary usage reports generated in xControl contain the sessions of the period, their totals agree with the session records, and a configured SFTP delivery receives the file.

Preconditions

- Platform
  - Optionally, an SFTP connection is configured for the Customer.
- Tooling and access
  - Log in to xControl with an account that holds the **ADMIN** role.
- Procedures executed first
  - EXP-REC-001 — Session record completeness

Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-REC-001 — Session record completeness** as a prerequisite procedure.	As defined in EXP-REC-001.
2	xControl	Open **Reports**, generate a **Detailed Usage Report** for the Customer and a period covering the session, and wait for its status.	The status changes from **Pending** to **Success**.
3	xControl	Download the report and open it.	A row for the session exists with Site, System, IMSI, MCC, MNC, IP address, start and end time and bytes equal to the session record.
4	xControl	Generate a **Summary Usage Report** by IMSI for the same period and download it.	The IMSI's totals equal the sum of its session records in the period.
5	Test host	If SFTP delivery is configured, list the SFTP destination.	The report file is present.

Pass criteria

- Both reports are generated and their contents agree with the session records.

Evidence collected: xControl screenshot.

EXP-REC-006 — Record attribution across public and private transitions

Status	✅ Accepted
Category	Functional
Components	xControl, xCore, xRouter
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 20 min
Prerequisite procedures	EXP-MOB-005 — Transition from the public radio network to the private radio EXP-MOB-006 — Transition from the private radio to the public radio network

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Objective. Each session a Mobile Asset had while moving between the public radio network and the private radio is recorded against the Site that served it, with that network's identifiers, and no record spans the transition.

Preconditions

- Tooling and access
  - Log in to xControl with an account that holds the **ADMIN** role.
- Procedures executed first
  - EXP-MOB-005 — Transition from the public radio network to the private radio
  - EXP-MOB-006 — Transition from the private radio to the public radio network

Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-MOB-005 — Transition from the public radio network to the private radio** as a prerequisite procedure.	As defined in EXP-MOB-005.
2	—	Execute **EXP-MOB-006 — Transition from the private radio to the public radio network** as a prerequisite procedure.	As defined in EXP-MOB-006.
3	xControl	Open the Mobile Asset's **Event Log** after the implicit detach times of both Sites have elapsed.	Two closed records and one open record exist for the three sessions.
4	xControl	Compare the records.	The public sessions name the xRouter site and carry the operator's MCC and MNC; the private session names the private Site and carries the private network's MCC and MNC and its radio identifier. No record has a start time before, and an end time after, a transition.

Pass criteria

- Every record names the Site and network that served it.
- No record spans a transition.

Evidence collected: xControl screenshot.

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6.6.11 Resilience and High Availability

Node, pod, database, radio, link and site failures on Expeto Edge (xCore), Expeto Gateway (xRouter) and xControl, including loss of the management path. Tests cover Kubernetes node failover, single-site restart recovery, geo-redundant failover and the isolation of faults between user planes.

ID	Test	Category	Applies to
EXP-HA-001	xCore user-plane node failure	Resilience	4G, 5G · Local radio, Public radio · HA cluster
EXP-HA-002	xCore session-management node failure	Resilience	4G, 5G · Local radio, Public radio · HA cluster
EXP-HA-003	xCore subscriber-data node failure	Resilience	4G, 5G · Local radio · HA cluster
EXP-HA-004	xCore restart recovery	Resilience	4G, 5G · Local radio, Public radio · Single node, HA cluster
EXP-HA-005	xCore geographic redundancy	Resilience	4G, 5G · Local radio, Public radio · Geo-redundant
EXP-HA-006	xRouter geographic redundancy	Resilience	4G, 5G · Public radio · Geo-redundant
EXP-HA-007	xRouter subscriber-management node failure	Resilience	4G, 5G · Public radio · HA cluster
EXP-HA-008	xRouter restart recovery	Resilience	4G, 5G · Public radio · Single node, HA cluster
EXP-HA-009	xControl restart recovery	Resilience	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
EXP-HA-010	xControl unreachable from the xCore	Resilience	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant
EXP-HA-011	Single network function restart	Resilience	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
EXP-HA-012	Radio link loss and recovery	Resilience	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant
EXP-HA-013	Secure link interruption between xRouter and xCore	Resilience	4G, 5G · Public radio · Single node, HA cluster, Geo-redundant
EXP-HA-014	Database node failure	Resilience	4G, 5G · Local radio, Public radio · HA cluster
EXP-HA-015	User-plane isolation between Systems	Resilience	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
EXP-HA-018	Diameter peer failure and failover toward the operator's network	Resilience	4G · Public radio · Single node, HA cluster, Geo-redundant

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EXP-HA-001 — xCore user-plane node failure

Status	Accepted
Category	Resilience
Components	xCore
Applies to	4G, 5G · Local radio, Public radio · HA cluster
Duration	About 45 min
Included in	Installation and Upgrade Verification
Automated by	Platform suite, split user plane: one user-plane instance deleted while sessions are held on the other

Objective. Expeto Edge (xCore) on a Kubernetes HA cluster continues to serve Mobile Assets when the node hosting the user-plane services (UPF / PGW-U) fails: the pods restart on the remaining nodes and the device regains service.

> **Service impact**
>
> This procedure interrupts service. Run it in a maintenance window or in a pre-production environment.

Preconditions

- Platform
  - An xCore is deployed on a Kubernetes HA cluster and operational.
  - You have identified the node (VM) hosting the user-plane pods (UPF / PGW-U).
  - Enough nodes remain available to host the user plane after the failure.
- Mobile Asset
  - One Mobile Asset is connected and passing data (execute the UE-initiated attach procedure first if it is not).
- Tooling and access
  - A tool that measures upload and download throughput from the UE against a server on the enterprise network, such as iperf3 or OpenSpeedTest.

Procedure

#	Where	Action	Expected result
1	UE	Start a continuous ping to a host on the enterprise LAN. Note the time.	Replies arrive.
2	Infrastructure	Shut down the node hosting the user-plane pods.	The node is reported as not ready by Kubernetes.
3	Kubernetes	Watch the pods that were running on that node.	All of them start successfully on the remaining nodes.
4	UE	Put the UE in airplane mode, then take it out again.	The UE authenticates and connects to the network.
5	UE	Run a speed test, then stop the ping and count the lost replies.	The UE uploads and downloads data; the interruption is recorded.
6	Infrastructure	Start the node again.	The node returns to ready and the cluster is back to its full size.

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Pass criteria

- Every pod of the failed node is running on another node without manual intervention.
- The UE regains service and passes traffic after the failover.

Postconditions

- Record the measured service interruption in the results sheet.

Evidence collected: Kubernetes pod and node status; Speed test result; UE connectivity check.

EXP-HA-002 — xCore session-management node failure

Status	✅ Accepted
Category	Resilience
Components	xCore
Applies to	4G, 5G · Local radio, Public radio · HA cluster
Duration	About 45 min

Objective. Expeto Edge (xCore) on a Kubernetes HA cluster continues to serve Mobile Assets when the node hosting the session-management services (SMF / PGW-C) fails.

> ⚠ **Service impact**
>
> This procedure interrupts service. Run it in a maintenance window or in a pre-production environment.

Preconditions

- Platform
  - An xCore is deployed on a Kubernetes HA cluster and operational.
  - You have identified the node (VM) hosting the session-management pods (SMF / PGW-C).
  - Enough nodes remain available to host session management after the failure.
- Mobile Asset
  - One Mobile Asset is connected and passing data (execute the UE-initiated attach procedure first if it is not).
- Tooling and access
  - A tool that measures upload and download throughput from the UE against a server on the enterprise network, such as iperf3 or OpenSpeedTest.

Procedure

#	Where	Action	Expected result
1	UE	Start a continuous ping to a host on the enterprise LAN. Note the time.	Replies arrive.
2	Infrastructure	Shut down the node hosting the session-management pods.	The node is reported as not ready by Kubernetes.
3	Kubernetes	Watch the pods that were running on that node.	All of them start successfully on the remaining nodes.

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#	Where	Action	Expected result
4	UE	Put the UE in airplane mode, then take it out again.	The UE authenticates and connects to the network.
5	UE	Run a speed test, then stop the ping and count the lost replies.	The UE uploads and downloads data; the interruption is recorded.
6	Infrastructure	Start the node again.	The node returns to ready.

Pass criteria

- Every pod of the failed node is running on another node without manual intervention.
- The UE regains service and passes traffic after the failover.

Postconditions

- Record the measured service interruption in the results sheet.

Evidence collected: Kubernetes pod and node status; UE connectivity check.

EXP-HA-003 — xCore subscriber-data node failure

Status	✅ Accepted
Category	Resilience
Components	xCore
Applies to	4G, 5G · Local radio · HA cluster
Duration	About 45 min

Objective. Expeto Edge (xCore) on a Kubernetes HA cluster continues to authenticate Mobile Assets when the node hosting the local subscriber database (HSS, or UDM, UDR and AUSF) fails: existing sessions continue and new attaches succeed once the pods have restarted.

> ⚠ **Service impact**
>
> This procedure interrupts service. Run it in a maintenance window or in a pre-production environment.

Preconditions

- Platform
  - An xCore is deployed on a Kubernetes HA cluster and operational.
  - You have identified the node (VM) hosting the subscriber-database pods.
  - Enough nodes remain available to host them after the failure.
- Mobile Asset
  - One Mobile Asset is connected and passing data (execute the UE-initiated attach procedure first if it is not).
  - A second Mobile Asset, provisioned and its UE powered off.

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Procedure

#	Where	Action	Expected result
1	UE	Start a continuous ping from the connected UE to a host on the enterprise LAN.	Replies arrive.
2	Infrastructure	Shut down the node hosting the subscriber-database pods. Note the time.	The node is reported as not ready by Kubernetes.
3	UE	Observe the ping.	The existing session keeps passing traffic; authentication is not needed for an established session.
4	Kubernetes	Watch the subscriber-database pods.	They start on the remaining nodes and become ready.
5	UE	Power on the second UE once the pods are ready.	The UE authenticates and connects as in EXP-SES-001.
6	CLI	Run `cd /debug/ops`, then `cmd cache-clear type=SUBSCRIBER_CHECK_ERRORS`, `cmd sync-sub-check mode=FULL` (repeat until it no longer answers that a check is already running), then `read sync-sub-error`.	The error table is empty; the subscriber data survived the failover.
7	Infrastructure	Start the node again.	The node returns to ready.

Pass criteria

- Established sessions are unaffected by the failure.
- The subscriber-database pods are ready on another node within five minutes, new attaches succeed once they are, and the subscriber data is complete.

Evidence collected: Kubernetes pod and node status; UE connectivity check; CLI output.

EXP-HA-004 — xCore restart recovery

Status	Accepted
Category	Resilience
Components	xCore
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster
Duration	About 45 min
Included in	Installation and Upgrade Verification

Objective. A non-redundant Expeto Edge (xCore) recovers after every resource hosting it is power-cycled (turned off and back on), and devices regain service without manual intervention.

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> **Service impact**
>
> This procedure interrupts service. Run it in a maintenance window or in a pre-production environment.

Preconditions

- Platform
  - An xCore is deployed and operational, and its Site shows as online in xControl.
- Mobile Asset
  - One Mobile Asset is connected and passing data (execute the UE-initiated attach procedure first if it is not).
- Tooling and access
  - A tool that measures upload and download throughput from the UE against a server on the enterprise network, such as iperf3 or OpenSpeedTest.

Procedure

#	Where	Action	Expected result
1	Infrastructure	Shut down all nodes (VMs) hosting the xCore site. Note the time.	The site is down.
2	Infrastructure	Start all the nodes that were shut down.	The nodes boot.
3	Kubernetes	Check the xCore workloads.	All services of the xCore are running; every pod is ready.
4	UE	Observe the UE.	The UE reconnects to the network on its own.
5	UE	Run a speed test.	The UE uploads and downloads data.
6	xControl	Open **Sites** and select the Site.	The Site is online.

Pass criteria

- Every service is running after the power cycle without manual intervention.
- The UE reconnects on its own and passes traffic.

Postconditions

- Record the time from power-on to the UE regaining service in the results sheet.

Evidence collected: Service status after recovery; UE connectivity check.

EXP-HA-005 — xCore geographic redundancy

Status	✅ Accepted
Category	Resilience
Components	xCore
Applies to	4G, 5G · Local radio, Public radio · Geo-redundant

Expeto Inc @ 2026

Duration	About 1 h

Objective. When one xCore of a geo-redundant pair fails, the Mobile Assets it served reconnect to the redundant xCore and continue to receive service.

> ⚠ **Service impact**
>
> This procedure interrupts service. Run it in a maintenance window or in a pre-production environment.

Preconditions

- Platform
  - Geo-redundant xCores are deployed in an active-active configuration.
- Mobile Asset
  - Mobile Assets are connected to both xCores and passing traffic.
- Tooling and access
  - A tool that measures upload and download throughput from the UE against a server on the enterprise network, such as iperf3 or OpenSpeedTest.

Procedure

#	Where	Action	Expected result
1	UE	Run a speed test on a UE connected to one of the xCore sites, and record the speed and the latency.	Baseline speed and latency are recorded.
2	Infrastructure	Shut down that xCore site. Note the time.	The site is down.
3	UE	Observe the UE.	The UE disconnects from the failed site and reconnects to the redundant site within a reasonable time.
4	UE	Run the speed test again.	Speed and latency are acceptable.
5	xControl	Open the Mobile Asset's **Event Log**.	The session on the failed site is closed and a new session names the redundant site.

Pass criteria

- Every UE of the failed site regains service on the redundant site without manual intervention.

Postconditions

- Record the reconnect time in the results sheet; start the failed site again.

Evidence collected: Speed test result; Measured reconnect time; xControl session event log.

EXP-HA-006 — xRouter geographic redundancy

Status	✔ Accepted
Category	Resilience

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Components	xRouter
Applies to	4G, 5G · Public radio · Geo-redundant
Duration	About 1 h

Objective. When one xRouter of a geo-redundant pair fails, the Mobile Assets connected through it reconnect through the redundant xRouter and continue to receive service.

> ⚠ **Service impact**
>
> This procedure interrupts service. Run it in a maintenance window or in a pre-production environment.

Preconditions

- Platform
  - Geo-redundant xRouters are deployed and operational.
  - Both xRouters are integrated with an xCore.
- Mobile Asset
  - Mobile Assets are connected through both xRouters to the xCore and passing traffic.
- Tooling and access
  - A tool that measures upload and download throughput from the UE against a server on the enterprise network, such as iperf3 or OpenSpeedTest.

Procedure

#	Where	Action	Expected result
1	UE	Run a speed test on a UE connected through one of the xRouter sites, and record the speed and the latency.	Baseline speed and latency are recorded.
2	Infrastructure	Shut down that xRouter site. Note the time.	The site is down.
3	UE	Observe the UE.	The UE disconnects from the failed xRouter and reconnects to the xCore through the redundant xRouter.
4	UE	Run the speed test again.	Speed and latency are acceptable.

Pass criteria

- Every UE of the failed xRouter regains service through the redundant one without manual intervention.

Postconditions

- Record the reconnect time in the results sheet; start the failed site again.

Evidence collected: Speed test result; Measured reconnect time.

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EXP-HA-007 — xRouter subscriber-management node failure

Status	✅ Accepted
Category	Resilience
Components	xRouter
Applies to	4G, 5G · Public radio · HA cluster
Duration	About 45 min

Objective. Expeto Gateway (xRouter) on a Kubernetes HA cluster continues to operate when the node hosting its subscriber-management services fails.

> ⚠ **Service impact**
>
> This procedure interrupts service. Run it in a maintenance window or in a pre-production environment.

Preconditions

- Platform
  - An xRouter is deployed on a Kubernetes HA cluster and operational.
  - You have identified the node (VM) hosting the subscriber-management pods (AUSF, UDR and UDM for 5G; HSS for 4G).
  - Enough nodes remain available to host subscriber management after the failure.
- Mobile Asset
  - One Mobile Asset is connected and passing data (execute the UE-initiated attach procedure first if it is not).

Procedure

#	Where	Action	Expected result
1	Infrastructure	Shut down the node hosting the subscriber-management pods.	The node is reported as not ready by Kubernetes.
2	Kubernetes	Watch the pods that were running on that node.	All of them start successfully on the remaining nodes.
3	UE	Put the UE in airplane mode, then take it out again. Repeat if needed: some visited networks cache authentication data fetched before the node failure, so an authentication or update-location exchange may only occur on a later attempt.	The UE authenticates and connects to the network.
4	Infrastructure	Start the node again.	The node returns to ready.

Pass criteria

- Every pod of the failed node is running on another node without manual intervention.
- The UE authenticates and connects after the failover.

Evidence collected: Kubernetes pod and node status; UE connectivity check.

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EXP-HA-008 — xRouter restart recovery

Status	✅ Accepted
Category	Resilience
Components	xRouter
Applies to	4G, 5G · Public radio · Single node, HA cluster
Duration	About 45 min

Objective. A non-redundant Expeto Gateway (xRouter) recovers after every resource hosting it is power-cycled (turned off and back on), and devices regain service through it.

> ⚠ **Service impact**
>
> This procedure interrupts service. Run it in a maintenance window or in a pre-production environment.

Preconditions

- Platform
  - An xRouter is deployed and operational.
  - The xRouter is integrated with an xCore.
- Mobile Asset
  - A Mobile Asset is connected to the xCore through the xRouter and passing data.
- Tooling and access
  - A tool that measures upload and download throughput from the UE against a server on the enterprise network, such as iperf3 or OpenSpeedTest.

Procedure

#	Where	Action	Expected result
1	Infrastructure	Shut down all nodes (VMs) hosting the xRouter site. Note the time.	The site is down.
2	Infrastructure	Start all the nodes that were shut down.	The nodes boot.
3	Kubernetes	Check the xRouter workloads.	All services of the xRouter are running; every pod is ready.
4	UE	Observe the UE.	The UE reconnects to the network through the xRouter.
5	UE	Run a speed test.	The UE uploads and downloads data.

Pass criteria

- Every service is running after the power cycle without manual intervention.
- The UE reconnects through the xRouter and passes traffic.

Postconditions

- Record the time from power-on to the UE regaining service in the results sheet.

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Evidence collected: Service status after recovery; UE connectivity check.

EXP-HA-009 — xControl restart recovery

Status	✅ Accepted
Category	Resilience
Components	xControl, xCore
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 45 min

Objective. A non-redundant xControl recovers after every resource hosting it is power-cycled, the xCore sites it manages reconnect to it, and devices on those sites are unaffected throughout.

> ⚠ **Service impact**
>
> This procedure interrupts service. Run it in a maintenance window or in a pre-production environment.

Preconditions

- Platform
  - An xControl is deployed and operational.
  - An xCore site is deployed and managed by that xControl.
- Mobile Asset
  - One Mobile Asset is connected and passing data (execute the UE-initiated attach procedure first if it is not).
- Tooling and access
  - You have an xControl account.

Procedure

#	Where	Action	Expected result
1	xControl	Log in to xControl and note the status of the xCore Site.	The Site status is recorded.
2	UE	Start a continuous ping from the UE to a host on the enterprise LAN.	Replies arrive.
3	Infrastructure	Shut down all nodes (VMs) hosting xControl. Note the time.	xControl is unreachable.
4	UE	Observe the ping.	Replies continue; the device is unaffected by the loss of xControl.
5	Infrastructure	Start all the nodes that were shut down.	The nodes boot.
6	xControl	Open xControl and log in.	xControl starts without errors and the login succeeds.

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#	Where	Action	Expected result
7	xControl	Open **Sites** and check the xCore Site.	The Site status matches the status recorded before the restart and **Last Seen** is current.

Pass criteria

- xControl returns to service after the power cycle without manual intervention beyond starting the nodes.
- Devices on the managed sites keep service throughout.
- The Site reconnects and shows online after the restart.

Evidence collected: xControl availability check; Agent reconnect and reconciliation; UE connectivity check.

EXP-HA-010 — xControl unreachable from the xCore

Status	✅ Accepted
Category	Resilience
Components	xCore, xControl, xView
Applies to	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant
Duration	About 45 min
Prerequisite procedures	EXP-INS-002 — Management path and subscriber synchronization

Objective. While the xCore cannot reach xControl, existing sessions continue, new devices attach and are authenticated locally, the loss of contact is alarmed, and when the connection returns the Site reconciles without manual action.

> ⚠ **Service impact**
>
> This procedure interrupts service. Run it in a maintenance window or in a pre-production environment.

Preconditions

- Platform
  - You can block outbound traffic from the xCore to xControl and remove the block again.
- Mobile Asset
  - One Mobile Asset is connected and passing data (execute the UE-initiated attach procedure first if it is not).
  - A second Mobile Asset, provisioned and its UE powered off.
- Tooling and access
  - Log in to xControl with an account that holds the **ADMIN** role.
  - Access to the xView alert view.
- Procedures executed first
  - EXP-INS-002 — Management path and subscriber synchronization

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Procedure

#	Where	Action	Expected result
1	UE	Start a continuous ping from the connected UE to a host on the enterprise LAN.	Replies arrive.
2	Infrastructure	Block traffic from the xCore to xControl on TCP port 443. Note the time.	The block is in place.
3	UE	Observe the ping for ten minutes.	Replies continue without interruption.
4	UE	Power on the second UE.	It attaches and passes traffic as in EXP-SES-001; authentication is local to the Site.
5	xControl	Open **Sites** and watch the Site.	The Site is shown offline within about five minutes of the block.
6	Tester	Open the alert view in xView.	The agent-out-of-contact alert for the Site is firing.
7	Infrastructure	Remove the block after at least fifteen minutes. Note the time.	Connectivity is restored.
8	xControl	Watch the Site and the second Mobile Asset.	The Site returns to online; the second Mobile Asset shows **Connected** with the session that started during the outage.
9	Tester	Watch the alert view.	The alert clears.

Pass criteria

- No impact on existing sessions or on new attaches while xControl is unreachable.
- The loss of contact is alarmed within six minutes.
- The Site is back online within 60 seconds of the connection returning, and the alert clears within five minutes.

Evidence collected: UE connectivity check; xControl screenshot; Agent reconnect and reconciliation.

EXP-HA-011 — Single network function restart

Status	✔ Accepted
Category	Resilience
Components	xCore
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 1 h 30 min
Prerequisite procedures	EXP-SES-001 — UE-initiated attach
Automated by	Platform suite, split user plane: one user-plane instance deleted while sessions are held on the other

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Objective. Each network function of the xCore, restarted on its own, recovers within a bounded time, causes no other function to restart, and leaves the core with exactly the sessions it had, with a recorded impact on a device passing traffic.

> ⚠ **Service impact**
>
> This procedure interrupts service. Run it in a maintenance window or in a pre-production environment.

Preconditions

- Mobile Asset
  - One Mobile Asset is connected and passing data (execute the UE-initiated attach procedure first if it is not).
- Tooling and access
  - Access to the cluster with `kubectl`.
  - Access to the CLI.
- Procedures executed first
  - EXP-SES-001 — UE-initiated attach

Procedure

#	Where	Action	Expected result
1	CLI	Record the MME or AMF context count (`read mme` or `read amf`, table footer total) and the session count (`read pgw` or `read smf`, table footer total) as the baseline.	The baseline is recorded.
2	UE	Start a continuous ping to a host on the enterprise LAN.	Replies arrive.
3	Kubernetes	Delete the pod of the first network function in the table below (`kubectl delete pod <pod> -n <namespace>`). Note the time.	A replacement pod is created.
4	Kubernetes	Watch the pods of the namespace.	The replacement pod becomes ready; no other pod restarts.
5	UE	Observe the ping and, if it does not resume on its own within three minutes, toggle airplane mode.	Traffic resumes; record the loss and whether a re-attach was needed.
6	CLI	Read the two totals again.	Both equal the baseline once the UE has recovered.
7	Tester	Repeat the previous four steps for each remaining network function; MME or AMF; SMF, SGW-C or PGW-C; UPF or PGW-U; HSS, UDM, UDR or AUSF; the agent.	Every function recovers with the impact recorded in the results sheet.

Pass criteria

- Every replacement pod is ready within five minutes; no other pod restarts.
- The device regains service within three minutes of each restart without action on the platform.

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- The context and session counts return to the baseline after each restart.

Postconditions

- Record the impact per network function (ping loss, re-attach needed or not) in the results sheet.

Evidence collected: Kubernetes pod and node status; UE connectivity check; CLI output.
References: 3GPP TS 29.244 §6.2 (PFCP association and heartbeat procedures); 3GPP TS 23.007 §19 (Restoration of PFCP entities).

EXP-HA-012 — Radio link loss and recovery

Status	✅ Accepted
Category	Resilience
Components	xCore, xControl, xView
Applies to	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant
Duration	About 45 min
Prerequisite procedures	EXP-INS-003 — Radio access node connection EXP-SES-007 — Multiple UE attach

Objective. When the radio loses its connection to the xCore and later reconnects, the loss is alarmed, the radio re-establishes its association, devices regain service, and no stale context remains.

> ⚠ **Service impact**
>
> This procedure interrupts service. Run it in a maintenance window or in a pre-production environment.

Preconditions

- Tooling and access
  - Log in to xControl with an account that holds the **ADMIN** role.
  - Start a 3GPP signalling capture (pcap) with your preferred tool on the interfaces the procedure exercises.
  - Access to the CLI and the xView alert view.
- Procedures executed first
  - EXP-INS-003 — Radio access node connection
  - EXP-SES-007 — Multiple UE attach

Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-SES-007 — Multiple UE attach** as a prerequisite procedure.	As defined in EXP-SES-007.
2	Infrastructure	Disconnect the radio's transport to the xCore (or power the radio off). Note the time.	The radio is unreachable.
3	xControl	Open **Private Radios**.	The radio's status changes to **Disconnected**.

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#	Where	Action	Expected result
4	Tester	Open the alert view in xView.	The private-radio-connection alert for the radio is firing.
5	Infrastructure	Reconnect the radio (or power it on) after at least ten minutes. Note the time.	The radio starts.
6	Capture	Inspect the capture.	A new SCTP association and S1 Setup or NG Setup complete, as in EXP-INS-003.
7	xControl	Open **Private Radios** and **Mobile Assets**.	The radio is **Connected**; every UE returns to **Connected** as it re-attaches.
8	CLI	Run `read mme -f imsi=<imsi>` (or `read amf <imsi>`) for each test IMSI after all UEs are back.	Exactly one context per UE; none from before the outage remains.
9	Tester	Watch the alert view.	The alert clears.

Pass criteria

- The loss is alarmed and the radio reconnects without manual intervention on the platform.
- Every UE regains service after the radio returns.
- No stale context remains for any UE.

Evidence collected: 3GPP signalling capture (pcap); xControl screenshot; CLI output.
References: 3GPP TS 36.413 §8.7.1 (Reset); 3GPP TS 36.413 §8.7.3 (S1 Setup); 3GPP TS 38.413 §8.7.1 (NG Reset).

EXP-HA-013 — Secure link interruption between xRouter and xCore

Status	✅ Accepted
Category	Resilience
Components	xRouter, xCore
Applies to	4G, 5G · Public radio · Single node, HA cluster, Geo-redundant
Duration	About 45 min
Prerequisite procedures	EXP-POL-002 — Enterprise access through the public radio network

Objective. A short interruption of the secure link between Expeto Gateway (xRouter) and the public xCore stops user traffic without affecting the device's registration, and traffic resumes when the link returns; a long interruption is detected and sessions are cleaned up.

> ⚠ **Service impact**
>
> This procedure interrupts service. Run it in a maintenance window or in a pre-production environment.

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Preconditions

- Platform
  - You can block traffic on the secure link between the xRouter and the xCore and remove the block again.
- Tooling and access
  - Log in to xControl with an account that holds the **ADMIN** role.
  - A capture on the secure link (capture point 5).
- Procedures executed first
  - EXP-POL-002 — Enterprise access through the public radio network

Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-POL-002 — Enterprise access through the public radio network** as a prerequisite procedure.	As defined in EXP-POL-002.
2	UE	Start a continuous ping to a host on the enterprise LAN.	Replies arrive.
3	Infrastructure	Block the secure link for 30 seconds, then remove the block.	Replies stop during the block.
4	UE	Observe the ping.	Replies resume within a few seconds of the link returning, with no re-attach.
5	xControl	Open the Mobile Asset.	The status stayed **Connected** and no new session was created.
6	Infrastructure	Block the secure link again for fifteen minutes, then remove the block. Note the times.	Replies stop during the block.
7	Capture	Inspect the capture on the link.	Path-management (echo) messages go unanswered during the long block; record whether the sessions were released as a result.
8	UE	Observe the UE after the block is removed; toggle airplane mode if service does not return on its own.	Service returns; record whether a re-attach was needed.

Pass criteria

- After a 30-second interruption, traffic resumes without a re-attach.
- After a fifteen-minute interruption, service returns within three minutes of the link returning; whether a re-attach was needed is recorded.

Evidence collected: UE connectivity check; 3GPP signalling capture (pcap); xControl session event log.
References: 3GPP TS 23.007 §20 (Path failure handling); 3GPP TS 29.274 §7.1 (Path Management Messages (Echo Request and Response)).

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EXP-HA-014 — Database node failure

Status	✅ Accepted
Category	Resilience
Components	xCore
Applies to	4G, 5G · Local radio, Public radio · HA cluster
Duration	About 1 h
Prerequisite procedures	EXP-SES-001 — UE-initiated attach

Objective. The loss of one node of the xCore's replicated database does not interrupt service or provisioning, no data is lost, and the database returns to full replication when the node is back.

> ⚠ **Service impact**
>
> This procedure interrupts service. Run it in a maintenance window or in a pre-production environment.

Preconditions

- Platform
  - The xCore runs its database as a replicated cluster (three members).
- Mobile Asset
  - One Mobile Asset is connected and passing data (execute the UE-initiated attach procedure first if it is not).
- Tooling and access
  - Log in to xControl with an account that holds the **ADMIN** role.
  - Access to the cluster with `kubectl`.
- Procedures executed first
  - EXP-SES-001 — UE-initiated attach

Procedure

#	Where	Action	Expected result
1	Kubernetes	List the database pods and note which node each runs on.	Three members are ready.
2	UE	Start a continuous ping to a host on the enterprise LAN.	Replies arrive.
3	Infrastructure	Shut down the node hosting one database member. Note the time.	The node is not ready.
4	UE	Observe the ping.	Replies continue.
5	xControl	Create a new Mobile Asset (EXP-PRV-001, first step) while the member is down.	The Mobile Asset is created and reaches the Site.
6	UE	Detach and re-attach the connected UE.	The UE connects; session management and records work with two members.

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#	Where	Action	Expected result
7	Infrastructure	Start the node again.	The database member rejoins and becomes ready.
8	Kubernetes	Check the database cluster's size and state.	Three members are synchronized.
9	CLI	Run `read hss <imsi>` (or `read udr <imsi>`) for the Mobile Asset created during the outage.	The record exists.

Pass criteria

- No service or provisioning interruption with one member down.
- No data created during the outage is lost.
- The cluster is back to three synchronized members within ten minutes of the node returning.

Evidence collected: Kubernetes pod and node status; UE connectivity check; CLI output.

EXP-HA-015 — User-plane isolation between Systems

Status	Accepted
Category	Resilience
Components	xCore
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 30 min
Prerequisite procedures	EXP-POL-003 — System egress mapping
Automated by	Platform suite, split user plane: one user-plane instance deleted while sessions are held on the other

Objective. On a site whose Systems have separate user planes, the failure of one System's user plane leaves the other System's sessions untouched, and the failed user plane accepts new sessions once it is back.

> **Service impact**
>
> This procedure interrupts service. Run it in a maintenance window or in a pre-production environment.

Preconditions

- Platform
  - The Site has two Systems, A and B, each served by its own user-plane instance.
- Mobile Asset
  - One Mobile Asset on each System, both connected and passing traffic (EXP-POL-003).
- Tooling and access
  - Access to the cluster with `kubectl`.
  - Access to the CLI.
- Procedures executed first
  - EXP-POL-003 — System egress mapping

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Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-POL-003 — System egress mapping** as a prerequisite procedure.	As defined in EXP-POL-003.
2	UE	Start a continuous ping from UE B to a host on System B's egress network.	Replies arrive.
3	Kubernetes	Delete the user-plane pod of System A. Note the time.	A replacement pod is created.
4	UE	Observe UE B's ping throughout.	No reply is lost.
5	Kubernetes	Watch System A's user-plane pod.	It becomes ready again.
6	UE	Toggle airplane mode on UE A once the pod is ready.	UE A attaches with an address in System A's range and pings a host on System A's egress network.
7	CLI	Run `read pgw -f imsi=<imsi>` (or `read smf -f imsi=<imsi>`) for both IMSIs.	Exactly one session each; nothing half-open remains from before the failure.

Pass criteria

- Zero ping loss on System B while System A's user plane is down.
- System A's user plane is ready within five minutes and accepts an attach within three minutes of being ready.
- No residual session remains.

Evidence collected: Kubernetes pod and node status; UE connectivity check; CLI output.

EXP-HA-018 — Diameter peer failure and failover toward the operator's network

Status	✅ Accepted
Category	Resilience
Components	xRouter
Applies to	4G · Public radio · Single node, HA cluster, Geo-redundant
Duration	About 45 min
Prerequisite procedures	EXP-POL-002 — Enterprise access through the public radio network

Objective. The HSS in Expeto Gateway (xRouter) keeps serving S6a when one of its Diameter connections to the operator's network (DRA links or IPX peers) fails: the Device-Watchdog exchange detects the failure, requests continue over the remaining connection, the failed connection is re-established on its own when transport returns, and the outage raises an alert.

> ⚠ **Service impact**
>
> This procedure interrupts service. Run it in a maintenance window or in a pre-production environment.

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Preconditions

- Platform
  - The HSS in xRouter has at least two Diameter connections toward the operator's network (two entries under `diameter.peers`, or one DRA reached over two transport paths) and a routing rule under `diameter.routingRules` that lets requests for the operator's realm use either.
  - You can block the transport of one connection at a time (firewall rule or interface) and remove the block again.
  - Alerting is in place; the `DiameterConnectionDown` alert exists for the site.
- Mobile Asset
  - The Mobile Asset is **Active** and attaches through the public network (EXP-POL-002).
- Tooling and access
  - Log in to xControl with an account that holds the **ADMIN** role.
  - A signalling capture at xRouter (capture point 4) with the display filter `diameter`.
  - Access to the alert view and to the metric `xcore_hss_link_total`.
- Procedures executed first
  - EXP-POL-002 — Enterprise access through the public radio network

Procedure

#	Where	Action	Expected result
1	Capture	Watch the Diameter capture for two minutes with no subscriber traffic.	Device-Watchdog-Request / Answer pairs are exchanged on every connection at a regular interval, each answer with Result-Code DIAMETER_SUCCESS.
2	—	Execute **EXP-POL-002 — Enterprise access through the public radio network** as a prerequisite procedure.	As defined in EXP-POL-002.
3	Capture	Note which connection carried the Authentication-Information and Update-Location exchanges of the attach.	One connection (call it A) carried them.
4	Infrastructure	Block the transport of connection A. Note the time.	Device-Watchdog-Requests on A go unanswered, and within a few watchdog intervals no further traffic is sent on A.
5	Tester	Watch the metric and the alert view.	`xcore_hss_link_total{type="diameter",status="opened"}` drops by one for the peer, and `DiameterConnectionDown` fires after its two-minute hold time.

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#	Where	Action	Expected result
6	UE	Toggle airplane mode so that the UE attaches again.	The UE attaches; the Authentication-Information and Update-Location exchanges are on connection B.
7	Infrastructure	Remove the block on A. Note the time.	Capabilities-Exchange re-establishes A without manual intervention, watchdog exchanges resume, and the alert clears.
8	Infrastructure	Block the transport of connection B, toggle airplane mode on the UE, then remove the block.	The UE attaches over A; B is re-established after the block is removed.

Expected signalling

Capture points: S6a at xRouter (point 4).

4G

4G (EPS) sequence

1. Device-Watchdog-Request / Device-Watchdog-Answer on each connection at the configured interval
2. Unanswered Device-Watchdog-Requests on the blocked connection, then no further requests on it
3. Authentication-Information-Request / Answer and Update-Location-Request / Answer on the remaining connection
4. Capabilities-Exchange-Request / Answer when the blocked connection's transport returns, then Device-Watchdog exchanges resume on it

Pass criteria

- Watchdog exchanges are observed on every connection, and an unanswered watchdog takes its connection out of service without affecting the other.
- Every attach attempted during the outage of either connection succeeds over the remaining one; no S6a request is lost or left unanswered.
- The failed connection is re-established without manual intervention when its transport returns, and `DiameterConnectionDown` fires during the outage and clears afterwards.

Postconditions

- Both connections are up and the alert has cleared.

Deployment notes

- **Transport multi-homing:** Where a connection uses SCTP with a primary and a secondary address (`diameter.primaryIp` , `diameter.secondaryIp`), blocking one address exercises SCTP path failover instead: the association stays up, no Diameter-level failover occurs, and requests continue without interruption.
- **Single DRA:** Where the mobile operator provides one DRA over one transport path, the test is limited to the watchdog detection, the alert and the re-establishment; attaches during the outage fail and are recorded as such.

Evidence collected: 3GPP signalling capture (pcap); UE connectivity check; Service status after recovery.
References: IETF RFC 6733 §5.5 (Transport failure detection (Device-Watchdog)); IETF RFC 6733 §5.6 (Peer state machine); IETF RFC 6733 §6.1 (Diameter request routing overview); 3GPP TS 29.272 §7.1.1 (Use of Diameter base protocol).

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6.6.12 Capacity and Stability

The platform sustains the Mobile Asset counts, attach rates and throughput each tier is rated for, and stays stable under sustained churn: no restarts, no failed procedure, no leaked session, no memory growth, and complete records.

ID	Test	Category	Applies to
EXP-CAP-001	xCore maximum concurrent Mobile Assets	Capacity	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
EXP-CAP-002	Attach rate	Capacity	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant
EXP-CAP-003	Throughput at the rated tier	Capacity	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant
EXP-CAP-004	Stability soak	Capacity	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant

EXP-CAP-001 — xCore maximum concurrent Mobile Assets

Status	✅ Accepted
Category	Capacity
Components	xCore
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 4 h
Prerequisite procedures	EXP-SES-001 — UE-initiated attach
Automated by	Platform suite, 4G split core: 10 000 concurrently held sessions Platform suite, Kubernetes-operator managed core: 10 000-session capacity ramp

Objective. A non-redundant Expeto Edge (xCore) supports the maximum number of active Mobile Assets it is designed for, with every one of them connected and able to pass traffic.

> ⚠ **Service impact**
>
> This procedure interrupts service. Run it in a maintenance window or in a pre-production environment.

Preconditions

- Platform
  - An xCore is deployed and operational, and its Site shows as online in xControl.
  - The xCore has a System.
- Mobile Asset
  - As many Mobile Assets as the xCore's designed maximum are provisioned on the System.
- Tooling and access
  - With real devices, enough UEs to reach the maximum; otherwise the 3GPP peer simulator configured with the provisioned IMSIs.
- Procedures executed first
  - EXP-SES-001 — UE-initiated attach

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Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-SES-001 — UE-initiated attach** as a prerequisite procedure.	As defined in EXP-SES-001.
2	Tester	Repeat the previous procedure for further UEs (or start the simulator's attach ramp) until the number of connected Mobile Assets reaches the designed maximum of the xCore.	Every attach succeeds.
3	xControl	Open **Mobile Assets** filtered by the System and by status **Connected**.	The count equals the designed maximum.
4	UE	Pass traffic from a sample of the connected UEs.	The sampled UEs upload and download data.
5	Kubernetes	Check the pods of the xCore.	No pod has restarted during the ramp.
6	Tester	Detach all the UEs (or stop the simulator) and run `read mme` (or `read amf`) in the CLI, reading the table footer total.	The count returns to the pre-test baseline.

Pass criteria

- Every Mobile Asset up to the designed maximum is connected at the same time.
- Sampled UEs pass traffic at the maximum.
- No pod restarted, and the context count returns to the baseline after release.

Evidence collected: xControl connected Mobile Asset count; UE connectivity check; Kubernetes pod and node status.

EXP-CAP-002 — Attach rate

Status	✔ Accepted
Category	Capacity
Components	xCore
Applies to	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant
Duration	About 45 min
Prerequisite procedures	EXP-SES-001 — UE-initiated attach

Objective. The xCore sustains the attach rate agreed for the deployment, accepting every attach of a sustained burst with no failure and no restart.

> ⚠ **Service impact**
>
> This procedure interrupts service. Run it in a maintenance window or in a pre-production environment.

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Preconditions

- Platform
  - The 3GPP peer simulator is connected to the xCore as a radio and configured with at least 1 000 provisioned IMSIs.
  - Container CPU and memory of the core pods can be read.
- Tooling and access
  - Access to the CLI.
- Procedures executed first
  - EXP-SES-001 — UE-initiated attach

Procedure

#	Where	Action	Expected result
1	CLI	Run `read mme` (or `read amf`) and record the table footer total as the baseline.	The baseline is recorded.
2	Tester	Start the simulator attaching at the agreed rate (for example 20 attaches per second) with sessions held, for five minutes.	Attaches are accepted continuously.
3	Tester	Read the simulator's counters at the end of the ramp.	Every attempt succeeded; the number of attempts is recorded.
4	Kubernetes	Check the pods and their CPU use during the ramp.	No pod restarted; CPU stayed below the container limits.
5	Tester	Release all sessions and read the MME or AMF context total again.	The count returns to the baseline.

Pass criteria

- Every attach at the agreed rate succeeds.
- No pod restarted; the context count returns to the baseline after release.

Evidence collected: CLI output; Kubernetes pod and node status.

EXP-CAP-003 — Throughput at the rated tier

Status	✅ Accepted
Category	Capacity
Components	xCore
Applies to	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant
Duration	About 1 h
Prerequisite procedures	EXP-SES-007 — Multiple UE attach

Objective. The xCore forwards user traffic at the aggregate throughput its tier is rated for, in both directions, for a sustained period, without loss attributable to the core.

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> **Service impact**
>
> This procedure interrupts service. Run it in a maintenance window or in a pre-production environment.

Preconditions

- Platform
  - The radio capacity, or the simulator's user-plane injection, is sufficient to offer the tier's rated throughput.
- Tooling and access
  - A tool that measures upload and download throughput from the UE against a server on the enterprise network, such as iperf3 or OpenSpeedTest.
  - An iperf3 server on the enterprise LAN with enough network capacity.
- Procedures executed first
  - EXP-SES-007 — Multiple UE attach

Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-SES-007 — Multiple UE attach** as a prerequisite procedure.	As defined in EXP-SES-007.
2	UE	Start iperf3 clients on every UE toward the LAN server, downlink, for fifteen minutes, with enough parallel streams to reach the rated throughput.	The aggregate throughput reported by the server is recorded.
3	UE	Repeat uplink for fifteen minutes.	The aggregate throughput is recorded.
4	Kubernetes	Read the user-plane pods' CPU and memory during the runs.	Resource use stays within limits; no pod restarts.
5	Capture	Compare the packet counts on the radio side and the enterprise side of the user plane for a one-minute window.	Every packet that entered the core left it; no loss is attributable to the core.

Pass criteria

- Aggregate throughput reaches the tier's rated figure in each direction for fifteen minutes.
- No packet loss is attributable to the core.
- No pod restarts.

Evidence collected: Speed test result; Kubernetes pod and node status; 3GPP signalling capture (pcap).

EXP-CAP-004 — Stability soak

Status	Accepted
Category	Capacity
Components	xCore, xControl
Applies to	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant

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Duration	About 24 h
Prerequisite procedures	EXP-SES-001 — UE-initiated attach EXP-SES-002 — UE-initiated detach EXP-SES-004 — UE idle mode EXP-SES-005 — UE-triggered service request
Automated by	Platform suite, 4G split core: mixed-flow soak (100 live sessions, random flow per session) and weekly deep soak

Objective. Under sustained session churn for at least 24 hours (72 hours as the target), no network function restarts, no procedure fails, no session leaks, memory does not grow after warm-up, and every session is recorded.

> ⚠ **Service impact**
>
> This procedure interrupts service. Run it in a maintenance window or in a pre-production environment.

Preconditions

- Platform
  - The 3GPP peer simulator is connected to the xCore as a radio and configured with at least 200 provisioned IMSIs and a scenario mixing attach, data, idle, reactivation and detach.
  - Container restart counts and memory of every core pod can be read over the period (xView container metrics).
- Tooling and access
  - Access to the CLI.
  - Log in to xControl with an account that holds the **ADMIN** role.
- Procedures executed first
  - EXP-SES-001 — UE-initiated attach
  - EXP-SES-002 — UE-initiated detach
  - EXP-SES-004 — UE idle mode
  - EXP-SES-005 — UE-triggered service request

Procedure

#	Where	Action	Expected result
1	CLI	After a fifteen-minute warm-up of the scenario, record the MME or AMF context total (`read mme` or `read amf`), the session total (`read pgw` or `read smf`) and the PFCP association state (`read associations -f type=pfcp`) as the baseline, and record every pod's restart count and memory.	The baseline is recorded.
2	Tester	Run the scenario with about 100 live sessions and a ten-second session lifetime for the soak period.	The simulator reports attempts and outcomes continuously.
3	Tester	At the end, stop the scenario, wait for the simulator to release every session, and read its counters.	Every attach, every procedure and every detach succeeded; the simulator holds no session.

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#	Where	Action	Expected result
4	CLI	Read the totals again.	Each equals the baseline exactly.
5	Kubernetes	Read every pod's restart count and memory.	No restart; the memory of every core container is flat after warm-up, with no upward trend over the second half of the period.
6	xControl	Generate a **Summary Usage Report** for the period.	The number of sessions recorded equals the number the simulator completed.

Pass criteria

- No pod restarted during the soak.
- Every attach, every procedure and every detach succeeded.
- Context and session counts return exactly to the baseline.
- The memory of every core container is flat after warm-up.
- Every completed session has a record.

Evidence collected: CLI output; Kubernetes pod and node status; xControl screenshot.

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6.6.13 Operations and Maintenance

Alarms, metrics, diagnostics and maintenance procedures an MNO relies on to run the platform: faults are alarmed and cleared, metrics agree with the platform's own state, a support case can be documented completely, and time is consistent across the platform.

ID	Test	Category	Applies to
EXP-OAM-001	Alarm raised and cleared for an induced fault	Operations	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant
EXP-OAM-002	Metrics for capacity and usage	Operations	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
EXP-OAM-003	Diagnostic collection for a support case	Operations	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
EXP-OAM-004	xControl backup and restore	Operations	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
EXP-OAM-005	API token expiry warning	Operations	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
EXP-OAM-006	Time synchronization and timestamp consistency	Operations	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant

EXP-OAM-001 — Alarm raised and cleared for an induced fault

Status	✅ Accepted
Category	Operations
Components	xCore, xView
Applies to	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant
Duration	About 45 min
Prerequisite procedures	EXP-INS-004 — Monitoring path

Objective. An induced fault raises the corresponding alert in xView within the evaluation window, with the Site and Customer labels, is delivered to the configured notification channel, and clears once the fault is removed.

> ⚠ **Service impact**
>
> This procedure interrupts service. Run it in a maintenance window or in a pre-production environment.

Preconditions

- Platform
  - A notification channel (for example e-mail or a webhook) is configured for xView alerts, or the alert view alone is used.
- Tooling and access
  - Access to the xView alert view.
  - Log in to xControl with an account that holds the **ADMIN** role.
- Procedures executed first
  - EXP-INS-004 — Monitoring path

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Procedure

#	Where	Action	Expected result
1	Infrastructure	Power off the private radio, or disconnect its transport. Note the time.	The radio is unreachable.
2	Tester	Watch the alert view.	The private-radio-connection alert appears with the Site and Customer labels.
3	Tester	Check the notification channel.	The notification for the alert arrived.
4	Infrastructure	Power the radio on again. Note the time.	The radio reconnects (EXP-INS-003).
5	Tester	Watch the alert view.	The alert clears; a resolved notification arrives where the channel supports it.
6	Infrastructure	Repeat with a second fault. Block the xCore's outbound path to xControl for ten minutes, then restore it.	The agent-out-of-contact alert fires and clears in the same way.

Pass criteria

- Each alert fires within six minutes of the fault, with correct labels, and is delivered.
- Each alert clears within five minutes of the fault being removed.

Evidence collected: xControl screenshot.

EXP-OAM-002 — Metrics for capacity and usage

Status	✅ Accepted
Category	Operations
Components	xCore, xView
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 30 min
Prerequisite procedures	EXP-SES-007 — Multiple UE attach EXP-REC-002 — Usage accounting accuracy

Objective. The connected-device and traffic metrics of a Site agree with xControl and with the traffic actually passed, carry the Site's labels, and are retained.

Preconditions

- Tooling and access
  - Access to the xView Prometheus query interface.
  - Log in to xControl with an account that can view the Mobile Asset under test.
- Procedures executed first
  - EXP-SES-007 — Multiple UE attach

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- EXP-REC-002 — Usage accounting accuracy

Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-SES-007 — Multiple UE attach** as a prerequisite procedure.	As defined in EXP-SES-007.
2	Tester	Query `xcore_clients{site="<site name>"}`.	The value equals the number of Mobile Assets shown as **Connected** for the Site in xControl.
3	Tester	Note `xcore_download_bytes_total{site="<site name>"}` and `xcore_upload_bytes_total{site="<site name>"}`, then run the transfers of EXP-REC-002 and query again.	Each counter increased by exactly the IP-layer bytes transferred.
4	Tester	Query the same series over the past 24 hours.	Data points exist across the whole period; nothing is missing.
5	Tester	Inspect the labels of the series.	`customer`, `customerId`, `site` and `siteId` are present and correct.

Pass criteria

- The connected-device metric equals xControl's count.
- The byte counters increase by exactly the transferred IP-layer bytes, as in EXP-REC-002.
- The series are labelled with the Site and Customer and retained for at least 24 hours.

Evidence collected: xControl screenshot.

EXP-OAM-003 — Diagnostic collection for a support case

Status	✅ Accepted
Category	Operations
Components	xCore, xControl
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 45 min
Prerequisite procedures	EXP-SES-001 — UE-initiated attach EXP-SES-002 — UE-initiated detach

Objective. An operations engineer can collect, for one Mobile Asset and one time window, every artifact Expeto support needs, and the artifacts correlate with one another by IMSI and time.

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Preconditions

- Tooling and access
  - Access to the cluster with `kubectl`, the CLI, xControl and a capture point.
- Procedures executed first
  - EXP-SES-001 — UE-initiated attach
  - EXP-SES-002 — UE-initiated detach

Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-SES-001 — UE-initiated attach** as a prerequisite procedure.	As defined in EXP-SES-001.
2	—	Execute **EXP-SES-002 — UE-initiated detach** as a prerequisite procedure.	As defined in EXP-SES-002.
3	Kubernetes	Collect the logs of every core pod for the window of the two procedures (`kubectl logs --since-time=... -n <namespace> <pod>`), and `kubectl get pods -o wide` and `kubectl describe pod` output.	The files are saved with the naming convention in Test environment and tooling.
4	CLI	Run and save `read hss <imsi>` (or `read udr <imsi>`), `read mme -f imsi=<imsi>` (or `read amf <imsi>`) and `read pgw -f imsi=<imsi>` (or `read smf -f imsi=<imsi>`).	The output is saved.
5	xControl	Export the Mobile Asset's **Event Log** (screenshot or report) and note the Site's **Agent Version**.	The export is saved.
6	Capture	Save the signalling capture of the window.	The capture is saved.
7	Tester	Correlate the artifacts: find the attach in the capture, the same event in the MME or AMF log and in the xControl Event Log.	The IMSI appears in each artifact and the timestamps agree within one second, as in EXP-OAM-006.

Pass criteria

- Every artifact in the list is collected.
- The same event is identifiable in the capture, the logs and xControl with consistent timestamps.

Evidence collected: CLI output; xControl screenshot; 3GPP signalling capture (pcap).

EXP-OAM-004 — xControl backup and restore

Status	✅ Accepted
Category	Operations
Components	xControl, xCore
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant

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Duration	About 2 h
Prerequisite procedures	EXP-INS-002 — Management path and subscriber synchronization EXP-SES-001 — UE-initiated attach

Objective. A backup of the xControl database is restored onto a rebuilt xControl instance. The provisioning state and the accounts are those of the backup, every Site reconnects, and the synchronization check shows exactly the differences that arose after the backup, which a re-synchronization resolves.

> ⚠ **Service impact**
>
> This procedure interrupts service. Run it in a maintenance window or in a pre-production environment.

Preconditions

- Platform
  - The backup and restore procedure of the xControl installation guide is at hand, and you can run `pg_dump` against the xControl database (PostgreSQL 17) and rebuild the xControl instance from the chart.
  - A maintenance window is agreed; xControl is unavailable during the restore.
- Mobile Asset
  - At least one Mobile Asset is provisioned on the Site.
- Tooling and access
  - Log in to xControl with an account that holds the **ADMIN** role.
  - Access to the cluster with `kubectl` and to the CLI.
- Procedures executed first
  - EXP-INS-002 — Management path and subscriber synchronization
  - EXP-SES-001 — UE-initiated attach

Procedure

#	Where	Action	Expected result
1	xControl	Record the number of Customers, Sites, Systems, Mobile Assets and Accounts.	The baseline is recorded.
2	Infrastructure	Take the backup with the documented procedure (`pg_dump` of the xControl database, plus the configuration the guide names). Note the time.	The backup completes and its file is stored off the cluster.
3	xControl	Create a new Mobile Asset X (EXP-PRV-001, first step) and a new Account Y.	Both exist in xControl; X reaches the Site (`read hss <imsi>`).
4	Infrastructure	Rebuild the xControl instance from the chart and restore the backup with the documented procedure. Note the time.	xControl starts and the login page is served.
5	xControl	Log in with an account from the baseline and compare the counts with the baseline.	The counts equal the baseline; Mobile Asset X and Account Y do not exist.

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#	Where	Action	Expected result
6	xControl	Open **Sites**.	Every Site returns to online within five minutes of xControl starting.
7	CLI	Run `cd /debug/ops`, then `cmd cache-clear type=SUBSCRIBER_CHECK_ERRORS`, `cmd sync-sub-check mode=FULL` (repeat until it no longer answers that a check is already running), then `read sync-sub-error`.	Exactly one discrepancy is reported, Mobile Asset X present on the Site but unknown to xControl.
8	CLI	Run `cmd sync-sub siteWide=true type=RECREATE`, wait for it to finish, then repeat the check.	The error table is empty; `read hss <imsi of X>` reports the record as not found.
9	—	Execute **EXP-SES-001 — UE-initiated attach** as a prerequisite procedure.	As defined in EXP-SES-001.

Pass criteria

- The restored xControl holds exactly the state of the backup and every account of the backup can log in.
- Every Site reconnects within five minutes of xControl starting.
- The synchronization check reports exactly the changes made after the backup, and a re-synchronization aligns the Sites to xControl.
- A UE attaches and passes traffic after the restore.

Postconditions

- Re-create any Mobile Asset or Account that was intentionally lost with the restore.

Evidence collected: xControl screenshot; CLI output; Kubernetes pod and node status.

EXP-OAM-005 — API token expiry warning

Status	✅ Accepted
Category	Operations
Components	xCore, xControl, xView
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 20 min
Prerequisite procedures	EXP-INS-004 — Monitoring path

Objective. An API token that is about to expire raises a warning in xView seven days ahead, and the warning clears once the token is renewed or removed.

Preconditions

- Tooling and access
  - Access to the xView Prometheus query interface and alert view.
  - Log in to xControl with an account that holds the **ADMIN** role.

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- Procedures executed first
  - EXP-INS-004 — Monitoring path

Procedure

#	Where	Action	Expected result
1	xControl	Create an API token for the Customer with an expiry date less than seven days away (API, **Getting Started**, generating an API token).	The token is created and its expiry is shown.
2	Tester	Run `xcontrol_token_expiration - time() < 60*60*24*7` in Prometheus and open the alert view.	The token appears in the result and the API-token-expiring alert fires for it at the next evaluation.
3	xControl	Delete the short-lived token (or extend it).	The token is gone or its expiry is more than seven days away.
4	Tester	Watch the alert view.	The alert clears within five minutes.

Pass criteria

- A token expiring within seven days raises the warning at the next evaluation, and the warning clears within five minutes of the token being renewed or removed.

Evidence collected: xControl screenshot.

EXP-OAM-006 — Time synchronization and timestamp consistency

Status	✔ Accepted
Category	Operations
Components	xCore, xControl
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 20 min
Prerequisite procedures	EXP-SES-001 — UE-initiated attach

Objective. Every node of the platform is synchronized to a time source, and the timestamps of the same event in the signalling capture, the network function logs and xControl agree.

Preconditions

- Tooling and access
  - Shell access to the cluster nodes, or `kubectl debug` on them.
  - Start a 3GPP signalling capture (pcap) with your preferred tool on the interfaces the procedure exercises.
  - Log in to xControl with an account that can view the Mobile Asset under test.
- Procedures executed first
  - EXP-SES-001 — UE-initiated attach

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Procedure

#	Where	Action	Expected result
1	Infrastructure	On every node, read the time synchronization status (`chronyc tracking` or `timedatectl`).	Each node is synchronized to a source with an offset below 100 milliseconds.
2	—	Execute **EXP-SES-001 — UE-initiated attach** as a prerequisite procedure.	As defined in EXP-SES-001.
3	Capture	Note the timestamp of the Attach Complete or Registration Complete in the capture.	The timestamp is recorded.
4	Kubernetes	Find the same event in the MME or AMF log.	The log timestamp is recorded.
5	xControl	Open the session record and note its start time.	The start time is recorded.
6	Tester	Compare the three timestamps.	They agree within one second.

Pass criteria

- Every node is synchronized with an offset below 100 milliseconds.
- The capture, log and xControl timestamps of the same event agree within one second.

Evidence collected: CLI output; 3GPP signalling capture (pcap); xControl screenshot.

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Installation and Upgrade Verification

The minimal mandatory set an MNO runs after installing an xCore, or after upgrading any platform component, before the deployment is handed over or returned to service. It is sized to be completed by one test engineer in one to two days with two or three provisioned devices, and it doubles as the exit criteria for the evaluation phase of onboarding.

The set contains **19 tests** with a planned duration of about **7 h 10 min**. Each test is reproduced in full below so that this page can be executed on its own; the same procedures are published in the acceptance test catalog.

ENTRY CRITERIA

- The deployment (xCore, and xRouter and xControl where they are part of the change) is installed or upgraded and reported healthy by the installer.
- At least two Mobile Assets are provisioned in xControl on a System of the Site under test, with SIMs in devices available to the tester.
- A signalling capture point and, for throughput tests, an iperf3 or OpenSpeedTest server on the enterprise network are available.

EXECUTION ORDER

Order	ID	Test	Domain	Duration	Evidence
1	EXP-INS-001	Platform readiness after installation	Installation checks	30 min	Kubernetes pod and node status; CLI output; xControl screenshot
2	EXP-INS-002	Management path and subscriber synchronization	Installation checks	30 min	3GPP signalling capture (pcap); CLI output; xControl screenshot
3	EXP-INS-003	Radio access node connection	Installation checks	20 min	3GPP signalling capture (pcap); xControl screenshot; CLI output
4	EXP-INS-004	Monitoring path	Installation checks	15 min	xControl screenshot
5	EXP-PRV-001	Provision a Mobile Asset	Provisioning	20 min	xControl screenshot; CLI output; xControl session event log

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Order	ID	Test	Domain	Duration	Evidence
6	EXP-SES-001	UE-initiated attach	Session lifecycle	15 min	3GPP signalling capture (pcap); xControl session event log; UE connectivity check
7	EXP-SES-002	UE-initiated detach	Session lifecycle	10 min	3GPP signalling capture (pcap); xControl session event log; CLI output
8	EXP-SES-004	UE idle mode	Session lifecycle	20 min	3GPP signalling capture (pcap); CLI output
9	EXP-SES-005	UE-triggered service request	Session lifecycle	15 min	3GPP signalling capture (pcap); xControl session event log
10	EXP-SES-007	Multiple UE attach	Session lifecycle	30 min	xControl Mobile Asset status; UE connectivity check
11	EXP-PRV-002	Deactivate a Mobile Asset	Provisioning	15 min	xControl session event log; 3GPP signalling capture (pcap)
12	EXP-PRV-005	Unknown UE attach rejected	Provisioning	15 min	3GPP signalling capture (pcap)

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Order	ID	Test	Domain	Duration	Evidence
13	EXP-POL-001	Limit bandwidth (AMBR)	Policy and traffic	30 min	Speed test result; xControl session event log; 3GPP signalling capture (pcap)
14	EXP-POL-002	Enterprise access through the public radio network	Policy and traffic	20 min	UE connectivity check; xControl Mobile Asset status; 3GPP signalling capture (pcap)
15	EXP-SEC-001	UE-to-UE communication prevented	Security and isolation	15 min	ICMP result from the UE
16	EXP-SEC-002	UE-to-platform communication prevented	Security and isolation	20 min	ICMP result from the UE
17	EXP-REC-001	Session record completeness	Session records and usage	20 min	xControl screenshot; 3GPP signalling capture (pcap)
18	EXP-HA-001	xCore user-plane node failure	Resilience and high availability	45 min	Kubernetes pod and node status; Speed test result; UE connectivity check
19	EXP-HA-004	xCore restart recovery	Resilience and high availability	45 min	Service status after recovery; UE connectivity check

RESULTS SHEET

Record one row per test. A blank template with the same columns is available as results-template.csv.

ID	Test	Result	Tester	Date	Evidence reference	Devi
EXP-INS-001	Platform readiness after installation					

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ID	Test	Result	Tester	Date	Evidence reference	Devi
EXP-INS-002	Management path and subscriber synchronization					
EXP-INS-003	Radio access node connection					
EXP-INS-004	Monitoring path					
EXP-PRV-001	Provision a Mobile Asset					
EXP-SES-001	UE-initiated attach					
EXP-SES-002	UE-initiated detach					
EXP-SES-004	UE idle mode					
EXP-SES-005	UE-triggered service request					
EXP-SES-007	Multiple UE attach					
EXP-PRV-002	Deactivate a Mobile Asset					
EXP-PRV-005	Unknown UE attach rejected					
EXP-POL-001	Limit bandwidth (AMBR)					
EXP-POL-002	Enterprise access through the public radio network					
EXP-SEC-001	UE-to-UE communication prevented					
EXP-SEC-002	UE-to-platform communication prevented					
EXP-REC-001	Session record completeness					

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ID	Test	Result	Tester	Date	Evidence reference	Devi
EXP-HA-001	xCore user-plane node failure					
EXP-HA-004	xCore restart recovery					

EXIT CRITERIA

- Every test in the set has a result recorded in the results sheet.
- Every result is **Pass**, or a **Deviation** is recorded, agreed with Expeto and referenced from the sheet.

PROCEDURES

EXP-INS-001 — Platform readiness after installation

Status	Accepted
Category	Operations
Components	xCore, xControl
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 30 min
Included in	Installation and Upgrade Verification

Objective. Every workload of a newly installed xCore is running at the release version, no container is restarting, every network function reports healthy, and the Site is registered with xControl at that version.

Preconditions

- Platform
  - The xCore is installed per the installation guide and the installer reports success.
  - You know the release version that was installed and the Kubernetes namespace of the xCore.
- Tooling and access
  - Read access to the cluster with `kubectl`.
  - Access to the CLI.
  - Log in to xControl with an account that can view the Mobile Asset under test.

Procedure

#	Where	Action	Expected result
1	Kubernetes	Run `kubectl get nodes`.	Every node is **Ready**.
2	Kubernetes	Run `kubectl get pods -n <namespace>` once the installer reports success.	Every pod is **Running** (or **Completed** for one-time jobs) with all containers ready. Note the **RESTARTS** count of every pod.

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#	Where	Action	Expected result
3	Kubernetes	Run `helm list -n <namespace>`.	The release is **deployed** and its chart version is the release version.
4	Kubernetes	Run `kubectl get pods -n <namespace> -o jsonpath='{range .items[*].spec.containers[*]}{.image}{"\n"}{end}' | sort -u`.	Every image under the Expeto registry paths is tagged with the release version; third-party images (databases, Kubernetes operators, exporters) carry the versions the release notes list.
5	CLI	Open the CLI, run `cd /debug/nf`, then `read node`.	Every network function of the deployment is listed with **Health** reported as healthy.
6	xControl	Open **Sites** and select the Site.	The Site is online, **Agent Version** equals the release version, and **Last Seen** is within the last five minutes.
7	Kubernetes	Fifteen minutes after the installer reported success, run `kubectl get pods -n <namespace>` again.	No **RESTARTS** count has increased.

Pass criteria

- Every pod is ready, and no pod restarts during the fifteen minutes that follow the installer's completion.
- Every Expeto image tag and the chart version equal the release version, and third-party images match the release notes.
- Every network function reports healthy.
- The Site is online in xControl with the release's agent version.

Deployment notes

- **Kubernetes-operator managed core:** The core is described by a Site resource rather than a Helm release. Replace the `helm list` step with `kubectl get site <name> -n <namespace> -o jsonpath='{.status.conditions[?(@.type=="Ready")].status}'` and expect `True`, and check that `{.status.observedGeneration}` equals `{.metadata.generation}`. The CLI sidecar is named `agent-cli`, and `read node` lists the SMF only; check the other network functions through their pod status.

Evidence collected: Kubernetes pod and node status; CLI output; xControl screenshot.

EXP-INS-002 — Management path and subscriber synchronization

Status	✅ Accepted
Category	Operations
Components	xCore, xControl
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 30 min
Prerequisite procedures	EXP-INS-001 — Platform readiness after installation

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Included in	Installation and Upgrade Verification
Automated by	Platform suite, 5G core: Mobile Asset provisioned through the xControl API appears in UDR and SMF within 120 s

Objective. The xCore agent holds an outbound connection to xControl, the Site reports online, and the subscriber data held by the xCore matches what xControl has provisioned for it.

Preconditions

- Mobile Asset
  - At least one Mobile Asset is provisioned on a System of the Site.
- Tooling and access
  - Log in to xControl with an account that holds the **ADMIN** role.
  - Access to the CLI.
  - A signalling capture on the xCore's egress interface, filtered to TCP port 443 (capture point 6).
- Procedures executed first
  - EXP-INS-001 — Platform readiness after installation

Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-INS-001 — Platform readiness after installation** as a prerequisite procedure.	As defined in EXP-INS-001.
2	Capture	Start the capture and restart the agent pod (`kubectl delete pod <release>-agent-0 -n <namespace>`), then inspect the capture.	The TLS connection to xControl is initiated by the xCore. No connection is initiated toward the xCore.
3	xControl	Open **Sites**, select the Site and watch its status while the agent pod restarts.	The Site returns to online and **Last Seen** updates within five minutes.
4	CLI	Run `cd /debug/ops` , then `cmd cache-clear type=SUBSCRIBER_CHECK_ERRORS` , then `cmd sync-sub-check mode=FULL` . Repeat `cmd sync-sub-check mode=FULL` until it no longer answers that a check is already running.	The full check completes.
5	CLI	Run `read sync-sub-error` .	The table is empty; no Mobile Asset is missing, mismatched or extra on the Site.
6	CLI	Run `cd /lte` , then `read hss` (or `cd /nr` , then `read udr` on a 5G-only Site) and read the total in the table footer.	The total equals the number of Mobile Assets xControl lists for the Site's Systems.

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Pass criteria

- The agent connection is outbound only.
- The Site is online within five minutes of an agent restart.
- The full synchronization check reports zero discrepancies and the record counts match.

Evidence collected: 3GPP signalling capture (pcap); CLI output; xControl screenshot.

EXP-INS-003 — Radio access node connection

Status	✅ Accepted
Category	Operations
Components	xCore, xControl
Applies to	4G, 5G · Local radio · Single node, HA cluster, Geo-redundant
Duration	About 20 min
Prerequisite procedures	EXP-INS-001 — Platform readiness after installation
Included in	Installation and Upgrade Verification

Objective. The customer's eNodeB or gNodeB establishes its control-plane association with the xCore, the xCore accepts the radio's PLMN and tracking area, and xControl shows the Private Radio as connected.

Preconditions

- Platform
  - The radio is configured with the xCore's MME or AMF address, the PLMN and the tracking area code agreed for the Site, and is powered off.
  - A Private Radio with the identifier `<PLMN>-<Cell ID>` of the radio exists on the Site in xControl with status **Enabled**.
- Tooling and access
  - Log in to xControl with an account that holds the **ADMIN** role.
  - A signalling capture on the xCore interface facing the radio (capture point 1).
  - Access to the CLI.
- Procedures executed first
  - EXP-INS-001 — Platform readiness after installation

Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-INS-001 — Platform readiness after installation** as a prerequisite procedure.	As defined in EXP-INS-001.
2	Radio	Power on the radio and wait for it to complete its start-up. Note the time.	The radio reports its cell as on air.

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#	Where	Action	Expected result
3	Capture	Inspect the capture.	An SCTP association is established, followed by S1 Setup Request and S1 Setup Response (4G) or NG Setup Request and NG Setup Response (5G). The response lists the served PLMN; there is no Setup Failure.
4	xControl	Open **Private Radios** and select the radio.	The status is **Connected** within two minutes of the radio reporting on air.
5	CLI	Run `cd /lte`, then `read enodeb` (4G), or `cd /nr`, then `read ran` (5G).	The radio is listed with its identifier, address, PLMN and tracking area.

Pass criteria

- The setup exchange completes with a Response, not a Failure, and the served PLMN and tracking area are the agreed ones.
- The Private Radio shows **Connected** within two minutes of the radio reporting on air.

Evidence collected: 3GPP signalling capture (pcap); xControl screenshot; CLI output.
References: 3GPP TS 36.413 §8.7.3 (S1 Setup); 3GPP TS 38.413 §8.7.3 (NG Setup).

EXP-INS-004 — Monitoring path

Status	✅ Accepted
Category	Operations
Components	xCore, xView
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 15 min
Prerequisite procedures	EXP-INS-001 — Platform readiness after installation
Included in	Installation and Upgrade Verification

Objective. The new Site's metrics reach xView with the Site's labels, its scrape targets are up, and no critical alert is firing for it.

Preconditions

- Tooling and access
  - Access to the xView Prometheus query interface and Grafana.
- Procedures executed first
  - EXP-INS-001 — Platform readiness after installation

Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-INS-001 — Platform readiness after installation** as a prerequisite procedure.	As defined in EXP-INS-001.
2	Tester	In Prometheus, run `up{job="site", site="<site name>"}`.	The result is 1 for every instance of the Site.

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#	Where	Action	Expected result
3	Tester	Run `xcore_version{site="<site name>"}`.	The series exist and carry the `customer`, `customerId`, `site` and `siteId` labels of the Site.
4	Tester	Run `ALERTS{alertstate="firing", site="<site name>", severity="critical"}`.	The result is empty.
5	Tester	Open the Site dashboard in Grafana and select the Site.	The panels show data for the Site.

Pass criteria

- Every scrape target of the Site is up within ten minutes of the install completing.
- The Site's series carry its Customer and Site labels.
- No critical alert is firing for the Site.

Evidence collected: xControl screenshot.

EXP-PRV-001 — Provision a Mobile Asset

Status	✅ Accepted
Category	Functional
Components	xControl, xCore
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 20 min
Prerequisite procedures	EXP-SES-001 — UE-initiated attach
Included in	Installation and Upgrade Verification
Automated by	Platform suite, 5G core: Mobile Asset provisioned through the xControl API appears in UDR and SMF within 120 s

Objective. A Mobile Asset created in xControl, through the portal or the API, is written to the subscriber database of the Site within a bounded time, is reported consistent by the synchronization check, and can attach.

Preconditions

- Platform
  - The Site has a System with a System Profile, and a Keyset mapped to the Site.
- Mobile Asset
  - A SIM whose IMSI is not yet provisioned, with its key material available for the Keyset in use.
- Device
  - The UE is powered off or in airplane mode.
  - The UE has the APN of its System Profile configured.
- Tooling and access
  - Log in to xControl with an account that holds the **ADMIN** role.
  - An API token for the Customer, for the API variant.
  - Access to the CLI.

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- Procedures executed first
  - EXP-SES-001 — UE-initiated attach

Procedure

#	Where	Action	Expected result
1	xControl	Open **Mobile Assets**, click **New**, enter the IMSI and the SIM details, select the **System**, the **System Profile** and the **Keyset**, set **Status** to **Active**, and click **Submit**. Note the time.	The Mobile Asset appears in the list with status **Provisioned**.
2	xControl API	For the API variant, create the Mobile Asset with a POST to the subscribers endpoint using the same values, then GET it back.	The response returns the Mobile Asset with the status field set to Active.
3	CLI	Run `cd /lte`, then `read hss <imsi>` (or `cd /nr`, then `read udr <imsi>` on a 5G Site), repeating until the record appears.	The record exists within 120 seconds of the submit.
4	CLI	Run `cd /debug/ops`, then `cmd sync-sub-check id=<imsi>`.	The check reports the IMSI as consistent between xControl and the Site on every node.
5	—	Execute **EXP-SES-001 — UE-initiated attach** as a prerequisite procedure.	As defined in EXP-SES-001.

Pass criteria

- The subscriber record is present on the Site within 120 seconds of creation.
- The synchronization check reports no discrepancy for the IMSI.
- The UE attaches and passes traffic.

Evidence collected: xControl screenshot; CLI output; xControl session event log.

EXP-SES-001 — UE-initiated attach

Status	✅ Accepted
Category	Functional
Components	xCore, xControl
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 15 min
Included in	Installation and Upgrade Verification
Automated by	Platform suite, 4G split core: session flow `attach-detach` (single run, mixed soak and weekly deep soak) Platform suite, Kubernetes-operator managed core: session flow `attach-detach`, once per user plane Release certification: subscriber lifecycle scenarios on the reference 5G configuration

Objective. A UE initiates an attach request to the network and is authenticated. After authentication the network obtains the UE's subscription data from the subscriber database and, based on the default APN and PDN/PDU context in that data, creates the default session. The UE is then attached to the network and passes data.

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Preconditions

- Mobile Asset
  - The UE's Mobile Asset is provisioned in xControl on the System under test, with state **Active** and status **Provisioned** or **Disconnected**.
- Device
  - The UE is powered off or in airplane mode.
  - The UE has the APN of its System Profile configured.
  - The UE has a web browser or a terminal application that can send ICMP echo requests (ping).
- Tooling and access
  - Log in to xControl with an account that can view the Mobile Asset under test.
  - Start a 3GPP signalling capture (pcap) with your preferred tool on the interfaces the procedure exercises.

Procedure

#	Where	Action	Expected result
1	UE	Power on the UE, or take it out of airplane mode, and wait for it to connect to the cellular network.	The UE shows a cellular data connection.
2	UE	Open a web page, or ping a known reachable host.	The page loads, or the ping is answered.
3	xControl	Open **Mobile Assets** and select the UE's IMSI.	The Mobile Asset status is **Connected** and an IP address inside the System's range is shown.
4	xControl	Scroll down to the **Sessions** section and select **Session History**.	On 4G, an HSS entry **Attached** and a PGW entry **Open** with a start time and no end time are present; on 5G the same two entries appear, named after the subscriber database and the SMF.
5	Capture	Inspect the signalling capture.	The messages match the sequence under *Expected signalling*, with no reject or failure message.

Expected signalling

Capture points: S1-MME / N2 (point 1), S11 / N4 (point 3), S6a / N8 (point 4).

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4G 5G

4G (EPS) sequence

1. Attach Request, carrying a PDN Connectivity Request (S1AP Initial UE Message)
2. Identity Request / Identity Response, when the network does not hold the UE's identity
3. Authentication Information Request / Answer on S6a, then Authentication Request / Authentication Response
4. Security Mode Command / Security Mode Complete
5. Update Location Request / Answer on S6a
6. Create Session Request / Create Session Response on S11
7. Initial Context Setup Request, carrying Attach Accept and Activate Default EPS Bearer Context Request
8. Initial Context Setup Response
9. Attach Complete, carrying Activate Default EPS Bearer Context Accept
10. Modify Bearer Request / Modify Bearer Response on S11

5G (5GS) sequence

1. Registration Request (NGAP Initial UE Message)
2. Identity Request / Identity Response, when the network does not hold the UE's identity
3. Authentication Request / Authentication Response, with the AUSF and UDM exchanges on the service-based interfaces
4. Security Mode Command / Security Mode Complete
5. Initial Context Setup Request, carrying Registration Accept
6. Initial Context Setup Response, then Registration Complete
7. PDU Session Establishment Request (UL NAS Transport)
8. PFCP Session Establishment Request / Response on N4
9. PDU Session Resource Setup Request, carrying PDU Session Establishment Accept
10. PDU Session Resource Setup Response

Pass criteria

- The UE obtains a data connection and passes traffic without manual intervention.
- The IP address shown in xControl is inside the address range of the Mobile Asset's System.
- The capture contains the complete sequence and no reject or failure message.

Evidence collected: 3GPP signalling capture (pcap); xControl session event log; UE connectivity check.
References: 3GPP TS 23.401 §5.3.2.1 (E-UTRAN Initial Attach); 3GPP TS 24.301 §5.5.1.2 (Attach procedure for EPS services); 3GPP TS 23.502 §4.2.2.2.2 (General Registration); 3GPP TS 23.502 §4.3.2.2.1 (UE Requested PDU Session Establishment).

EXP-SES-002 — UE-initiated detach

Status	✔ Accepted
Category	Functional
Components	xCore, xControl
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 10 min
Prerequisite procedures	EXP-SES-001 — UE-initiated attach

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Included in	Installation and Upgrade Verification
Automated by	Platform suite, 4G split core: session flow `attach-detach` (single run, mixed soak and weekly deep soak) Platform suite, Kubernetes-operator managed core: session flow `attach-detach`, once per user plane

Objective. The UE initiates a detach procedure and the network releases the session, the user-plane resources and the UE context, and xControl records the end of the session.

Preconditions

- Tooling and access
  - Log in to xControl with an account that holds the **ADMIN** role.
  - Start a 3GPP signalling capture (pcap) with your preferred tool on the interfaces the procedure exercises.
- Procedures executed first
  - EXP-SES-001 — UE-initiated attach

Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-SES-001 — UE-initiated attach** as a prerequisite procedure.	As defined in EXP-SES-001.
2	UE	Power off the UE, or put it in airplane mode, and wait for it to disconnect from the network.	The UE no longer shows a cellular connection.
3	xControl	Open the Mobile Asset.	The status changes to **Disconnected** within a reasonable time (nominally within 30 seconds).
4	xControl	Scroll down to the **Sessions** section and select **Session History**.	The PGW entry of the session is **Closed** with an end time.
5	CLI	Run `cd /lte`, then `read pgw -f imsi=<imsi>` (4G), or `cd /nr`, then `read smf -f imsi=<imsi>` (5G).	No session is listed for the IMSI.
6	Capture	Inspect the signalling capture.	The messages match the sequence under *Expected signalling*.

Expected signalling

Capture points: S1-MME / N2 (point 1), S11 / N4 (point 3).

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4G 5G

4G (EPS) sequence

1. Detach Request (UE originating; the switch-off indication is set when the UE powers off)
2. Delete Session Request / Delete Session Response on S11
3. Detach Accept (absent when the UE indicated switch-off)
4. UE Context Release Command / UE Context Release Complete

5G (5GS) sequence

1. Deregistration Request (UE originating)
2. PFCP Session Deletion Request / Response on N4
3. Deregistration Accept (absent when the UE indicated switch-off)
4. UE Context Release Command / UE Context Release Complete

Pass criteria

- xControl shows **Disconnected** within 30 seconds of the detach.
- The session record is closed with an end time.
- No session context remains for the IMSI on the session-management function.

Evidence collected: 3GPP signalling capture (pcap); xControl session event log; CLI output.
References: 3GPP TS 23.401 §5.3.8.2 (UE-initiated Detach procedure); 3GPP TS 23.502 §4.2.2.3.2 (UE-initiated Deregistration).

EXP-SES-004 — UE idle mode

Status	✅ Accepted
Category	Functional
Components	xCore
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 20 min
Prerequisite procedures	EXP-SES-001 — UE-initiated attach
Included in	Installation and Upgrade Verification
Automated by	Platform suite, 4G split core: session flow `idle-reactivate` Platform suite, 4G split core: session flow `idle-detach`

Objective. A connected UE that stops generating traffic has its radio connection released after the radio's inactivity timer expires. The UE enters the idle state (ECM-IDLE in 4G, CM-IDLE in 5G) while it stays registered and keeps its session and IP address.

Preconditions

- Device
  - The UE has a web browser or a terminal application that can send ICMP echo requests (ping).
  - A UE application that shows the radio connection state, or knowledge of the radio's inactivity timer.
- Tooling and access
  - Start a 3GPP signalling capture (pcap) with your preferred tool on the interfaces the procedure exercises.
  - Log in to xControl with an account that can view the Mobile Asset under test.

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- Procedures executed first
  - EXP-SES-001 — UE-initiated attach

Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-SES-001 — UE-initiated attach** as a prerequisite procedure.	As defined in EXP-SES-001.
2	UE	Make sure the UE generates no data traffic and wait for the inactivity time defined by the radio configuration.	The UE's radio connection is released while the UE remains registered.
3	CLI	For a private radio, run `cd /lte`, then `read mme -f imsi=<imsi>` (4G), or `cd /nr`, then `read amf <imsi>` (5G).	The context exists and its **state** (4G) or **Status** (5G) shows the UE as idle (ECM-IDLE or CM-IDLE).
4	xControl	Open the Mobile Asset.	The status is still **Connected** and the IP address is unchanged; the idle transition does not end the session.
5	Capture	Inspect the signalling capture.	The messages match the sequence under *Expected signalling*.

Expected signalling

Capture points: S1-MME / N2 (point 1), S11 / N4 (point 3).

4G 5G

4G (EPS) sequence

1. UE Context Release Request from the eNodeB, cause user inactivity
2. Release Access Bearers Request / Response on S11
3. UE Context Release Command / UE Context Release Complete

5G (5GS) sequence

1. UE Context Release Request from the gNodeB, cause user inactivity
2. PFCP Session Modification Request / Response on N4, deactivating the N3 tunnel and enabling downlink buffering or notification
3. UE Context Release Command / UE Context Release Complete

Pass criteria

- The radio connection is released within the radio's configured inactivity time and the UE stays registered.
- The session and IP address survive the idle transition.

Evidence collected: 3GPP signalling capture (pcap); CLI output.
References: 3GPP TS 23.401 §5.3.5 (S1 release procedure); 3GPP TS 23.502 §4.2.6 (AN release).

EXP-SES-005 — UE-triggered service request

Status	✅ Accepted

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Category	Functional
Components	xCore, xControl
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 15 min
Prerequisite procedures	EXP-SES-001 — UE-initiated attach EXP-SES-004 — UE idle mode
Included in	Installation and Upgrade Verification
Automated by	Platform suite, 4G split core: session flow `idle-reactivate`

Objective. A registered UE in idle state generates new uplink traffic. The network re-establishes the radio connection and the user-plane path with a service request, without a new attach, and the UE keeps its IP address.

Preconditions

- Device
  - The UE has a web browser or a terminal application that can send ICMP echo requests (ping).
- Tooling and access
  - Start a 3GPP signalling capture (pcap) with your preferred tool on the interfaces the procedure exercises.
  - Log in to xControl with an account that holds the **ADMIN** role.
- Procedures executed first
  - EXP-SES-001 — UE-initiated attach
  - EXP-SES-004 — UE idle mode

Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-SES-001 — UE-initiated attach** as a prerequisite procedure.	As defined in EXP-SES-001.
2	—	Execute **EXP-SES-004 — UE idle mode** as a prerequisite procedure.	As defined in EXP-SES-004.
3	UE	Open a web page, or ping a known reachable host.	The UE regains its radio connection and the page loads, or the ping is answered.
4	xControl	Open the Mobile Asset.	The status is **Connected** with the same IP address as before the idle period, and no new session was created in the **Event Log**.
5	Capture	Inspect the signalling capture.	The messages match the sequence under *Expected signalling*; there is no Attach Request or Registration Request.

Expected signalling

Capture points: S1-MME / N2 (point 1), S11 / N4 (point 3).

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4G 5G

4G (EPS) sequence

1. Service Request (S1AP Initial UE Message)
2. Initial Context Setup Request / Initial Context Setup Response
3. Modify Bearer Request / Modify Bearer Response on S11

5G (5GS) sequence

1. Service Request (NGAP Initial UE Message)
2. Initial Context Setup Request, carrying Service Accept, and Initial Context Setup Response
3. PFCP Session Modification Request / Response on N4, re-activating the N3 tunnel

Pass criteria

- Traffic resumes without a new attach or registration and with the same IP address.

Evidence collected: 3GPP signalling capture (pcap); xControl session event log.
References: 3GPP TS 23.401 §5.3.4.1 (UE triggered Service Request); 3GPP TS 23.502 §4.2.3.2 (UE Triggered Service Request).

EXP-SES-007 — Multiple UE attach

Status	Accepted
Category	Functional
Components	xCore, xControl
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 30 min
Prerequisite procedures	EXP-SES-001 — UE-initiated attach
Included in	Installation and Upgrade Verification
Automated by	Platform suite, 4G split core: mixed-flow soak (100 live sessions, random flow per session) and weekly deep soak

Objective. Several UEs connect to the network at the same time, each obtains its own address and service, and xControl shows all of them connected.

Preconditions

- Mobile Asset
  - Several Mobile Assets are provisioned in xControl on the System under test, one per UE, each with state **Active**.
- Device
  - The UE is powered off or in airplane mode.
  - The UE has the APN of its System Profile configured.
  - The UE has a web browser or a terminal application that can send ICMP echo requests (ping).
- Tooling and access
  - Log in to xControl with an account that can view the Mobile Asset under test.
- Procedures executed first
  - EXP-SES-001 — UE-initiated attach

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Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-SES-001 — UE-initiated attach** as a prerequisite procedure.	As defined in EXP-SES-001.
2	UE	Repeat the previous procedure for each remaining provisioned UE, without detaching the ones already attached.	Every UE shows the results of EXP-SES-001.
3	xControl	Open **Mobile Assets** filtered by the System.	All the UEs are **Connected** at the same time, each with a distinct IP address.

Pass criteria

- Every UE is connected and passing traffic simultaneously, with no two UEs sharing an address.

Evidence collected: xControl Mobile Asset status; UE connectivity check.

EXP-PRV-002 — Deactivate a Mobile Asset

Status	✅ Accepted
Category	Functional
Components	xCore, xControl
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 15 min
Prerequisite procedures	EXP-SES-001 — UE-initiated attach
Included in	Installation and Upgrade Verification

Objective. A connected Mobile Asset is set to **Inactive** in xControl. The subscriber database cancels its location without requesting a re-attach, the network releases its session, and every new attach attempt is rejected while it stays inactive.

Preconditions

- Tooling and access
  - Log in to xControl with an account that holds the **ADMIN** role.
  - Start a 3GPP signalling capture (pcap) with your preferred tool on the interfaces the procedure exercises.
- Procedures executed first
  - EXP-SES-001 — UE-initiated attach

Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-SES-001 — UE-initiated attach** as a prerequisite procedure.	As defined in EXP-SES-001.

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#	Where	Action	Expected result
2	xControl	On the Mobile Asset's detail page click **Edit**, set **Status** to **Inactive**, and click **Submit**.	The change is saved.
3	xControl	Watch the Mobile Asset status.	The status changes to **Disconnected**.
4	UE	Observe the UE.	The UE loses its cellular connection, and any reconnection attempt fails.
5	Capture	Inspect the signalling capture.	The messages match the sequence under *Expected signalling*; the Cancel Location Request does not carry the Reattach-Required flag and the Detach Request has detach type re-attach not required.

Expected signalling

Capture points: S6a / N8 (point 4), S1-MME / N2 (point 1).

4G 5G

4G (EPS) sequence

1. Cancel Location Request on S6a without the Reattach-Required flag, and Cancel Location Answer
2. Detach Request (network originating), detach type re-attach not required, and Detach Accept
3. Delete Session Request / Response on S11 and the release of the UE context
4. On each reconnection attempt, Attach Request followed by Attach Reject

5G (5GS) sequence

1. Deregistration notification from the UDM without re-registration required
2. Deregistration Request (UE terminated) and Deregistration Accept, then the release of the session and the UE context
3. On each reconnection attempt, Registration Request followed by Registration Reject

Pass criteria

- The session is released without any action on the UE, and the UE is not told to re-attach.
- Every reconnection attempt while the Mobile Asset is **Inactive** is rejected.

Evidence collected: xControl session event log; 3GPP signalling capture (pcap).
References: 3GPP TS 23.401 §5.3.8.4 (HSS-initiated Detach procedure); 3GPP TS 29.272 §5.2.2.2 (Cancel Location (CLR-Flags)).

EXP-PRV-005 — Unknown UE attach rejected

Status	Accepted
Category	Functional
Components	xCore
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant

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Duration	About 15 min
Included in	Installation and Upgrade Verification
Automated by	Platform suite, 4G split core: unknown-IMSI signalling soak (250 unserved IMSIs)

Objective. A UE whose IMSI is not provisioned in xControl attempts to attach, and the network rejects the attempt.

Preconditions

- Mobile Asset
  - The UE's IMSI is **not** provisioned as a Mobile Asset in xControl.
- Device
  - The UE is powered off or in airplane mode.
- Tooling and access
  - Log in to xControl with an account that can view the Mobile Asset under test.
  - Start a 3GPP signalling capture (pcap) with your preferred tool on the interfaces the procedure exercises.

Procedure

#	Where	Action	Expected result
1	UE	Power on the UE, or take it out of airplane mode, and wait for it to attempt to connect.	The UE fails to connect to the network.
2	Capture	Inspect the signalling capture.	The messages match the sequence under *Expected signalling*.

Expected signalling

Capture points: S1-MME / N2 (point 1), S6a / N8 (point 4).

4G 5G

4G (EPS) sequence

1. Attach Request, then Identity Request / Identity Response for the IMSI when the UE presented a GUTI
2. Authentication Information Request on S6a answered with an error result for an unknown user
3. Attach Reject with an EMM cause

5G (5GS) sequence

1. Registration Request, then Identity Request / Identity Response when needed
2. The authentication request to the UDM fails for an unknown subscriber
3. Registration Reject with a 5GMM cause

Pass criteria

- The UE obtains no service and no context or session is created for the IMSI.

Evidence collected: 3GPP signalling capture (pcap).
References: 3GPP TS 24.301 §5.5.1.2.5 (Attach not accepted by the network); 3GPP TS 24.501 §5.5.1.2.5 (Initial registration not accepted by the network).

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EXP-POL-001 — Limit bandwidth (AMBR)

Status	✅ Accepted
Category	Functional
Components	xCore, xControl
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 30 min
Prerequisite procedures	EXP-SES-001 — UE-initiated attach
Included in	Installation and Upgrade Verification

Objective. When the Mobile Asset is moved to a System Profile with lower uplink and downlink bitrates (AMBR) in xControl, the subscriber database pushes the change into the live session: the bearer is modified without a detach, the UE keeps its address, and the measured upload and download throughput drops to the new limits.

Preconditions

- Device
  - The UE has a web browser application.
- Tooling and access
  - Log in to xControl with an account that holds the **ADMIN** role.
  - A tool that measures upload and download throughput from the UE against a server on the enterprise network, such as iperf3 or OpenSpeedTest.
  - Start a 3GPP signalling capture (pcap) with your preferred tool on the interfaces the procedure exercises.
- Procedures executed first
  - EXP-SES-001 — UE-initiated attach

Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-SES-001 — UE-initiated attach** as a prerequisite procedure.	As defined in EXP-SES-001.
2	UE	Run a speed test and record the upload and download results as the baseline.	Baseline upload and download figures are recorded.
3	xControl	Create, or select, a System Profile whose APN Profile has a significantly lower **Upload Bitrate** and **Download Bitrate** than the current one (for example one quarter).	The System Profile is available on the Mobile Asset's System.
4	xControl	On the Mobile Asset's detail page click **Edit**, select the new System Profile, and click **Submit**.	The change is saved.

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#	Where	Action	Expected result
5	xControl	Open the Mobile Asset and its **Event Log**.	The status stays **Connected** with the same IP address; the session record stays **Open**; no detach and no new session.
6	Capture	Inspect the signalling capture.	The messages match the sequence under *Expected signalling*; the modified bearer or session carries the new bitrate limits, and there is no Detach Request or Deregistration Request.
7	UE	Run the speed test again and record the upload and download results.	Both figures are below the baseline and do not exceed the new limits.

Expected signalling

Capture points: S6a / N8 (point 4), S11 / N4 (point 3), S1-MME / N2 (point 1).

4G 5G

4G (EPS) sequence

1. Insert Subscriber Data Request on S6a from the HSS with the new APN-AMBR, and Insert Subscriber Data Answer
2. Modify Bearer Command on S11 from the MME, then Update Bearer Request from the PGW and Update Bearer Response
3. E-RAB Modify Request / Response and Modify EPS Bearer Context Request / Accept carrying the new APN-AMBR

5G (5GS) sequence

1. Nudm_SDM_Notification from the UDM with the new subscribed Session-AMBR
2. PFCP Session Modification Request / Response on N4
3. PDU Session Resource Modify Request / Response carrying PDU Session Modification Command with the new Session-AMBR, and PDU Session Modification Complete

Pass criteria

- The change takes effect with no detach and no new session; the UE keeps its address.
- The signalled AMBR values equal the bitrates configured in the APN Profile.
- Measured upload and download after the change do not exceed the new limits.

Postconditions

- Restore the original System Profile if later tests assume it.

Evidence collected: Speed test result; xControl session event log; 3GPP signalling capture (pcap).
References: 3GPP TS 23.401 §4.7.3 (Bearer level QoS parameters (APN-AMBR)); 3GPP TS 23.401 §5.3.9.2 (Insert Subscriber Data procedure); 3GPP TS 23.401 §5.4.2.1 (HSS Initiated Subscribed QoS Modification); 3GPP TS 23.501 §5.7.2.6 (Session-AMBR); 3GPP TS 23.502 §4.3.3.2 (UE or network requested PDU Session Modification).

EXP-POL-002 — Enterprise access through the public radio network

Status	✔ Accepted

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Category	Functional
Components	xRouter, xCore
Applies to	4G, 5G · Public radio · Single node, HA cluster, Geo-redundant
Duration	About 20 min
Included in	Installation and Upgrade Verification

Objective. A Mobile Asset attached through the mobile operator's public radio network is authenticated by Expeto Gateway (xRouter), reaches the enterprise private LAN through the customer-dedicated xCore, and passes upload and download traffic.

Preconditions

- Platform
  - An xCore in the public configuration is installed and operational.
  - An xRouter is installed, configured, and integrated with that xCore.
- Mobile Asset
  - The Mobile Asset is imported into xControl and authorized (state **Active**).
- Tooling and access
  - Log in to xControl with an account that can view the Mobile Asset under test.
  - A signalling capture at the xRouter (capture point 4) and on the secure link (capture point 5).

Procedure

#	Where	Action	Expected result
1	UE	Connect the UE to the mobile operator's public network.	The UE shows a connection to the public network.
2	UE	Access a resource on the enterprise private LAN.	The resource is reachable from the UE.
3	UE	Transfer data in both directions (for example, upload and download a file).	Upload and download traffic is sent and received.
4	xControl	Open the Mobile Asset.	The status is **Connected** and the session is attributed to the xRouter site.
5	Capture	Inspect the captures.	The authentication and session setup arrive at xRouter from the operator's core, and only GTP-U user-plane traffic crosses the secure link.

Expected signalling

Capture points: S6a / N8 at xRouter (point 4), secure link (point 5).

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4G 5G

4G (EPS) sequence

1. Authentication Information Request / Answer and Update Location Request / Answer from the operator's MME to the HSS in xRouter
2. Create Session Request / Response from the operator's SGW to the GTP proxy in xRouter (S8)
3. GTP-U on the secure link between xRouter and the xCore

5G (5GS) sequence

1. Authentication and subscription exchanges from the operator's core to the UDM in xRouter
2. N9 session setup toward the GTP proxy in xRouter
3. GTP-U on the secure link between xRouter and the xCore

Pass criteria

- The UE reaches the enterprise LAN and passes traffic in both directions.
- No signalling crosses the secure link; only user-plane traffic does.

Evidence collected: UE connectivity check; xControl Mobile Asset status; 3GPP signalling capture (pcap).

EXP-SEC-001 — UE-to-UE communication prevented

Status	✅ Accepted
Category	Security
Components	xCore
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 15 min
Prerequisite procedures	EXP-SES-007 — Multiple UE attach
Included in	Installation and Upgrade Verification

Objective. The network blocks direct communication between two Mobile Assets served by the platform.

Preconditions

- Platform
  - An xCore is deployed and operational, and its Site shows as online in xControl.
  - The xCore is configured to prevent UE-to-UE communication (the default configuration).
  - The xCore has a System.
- Mobile Asset
  - Two Mobile Assets are provisioned on the System.
- Tooling and access
  - Log in to xControl with an account that can view the Mobile Asset under test.
- Procedures executed first
  - EXP-SES-007 — Multiple UE attach

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Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-SES-007 — Multiple UE attach** as a prerequisite procedure.	As defined in EXP-SES-007.
2	xControl	Open **Mobile Assets**, select the target UE, and note its IP address.	The target UE's IP address is recorded.
3	UE	From the source UE, ping the target UE's IP address, then attempt a TCP connection to a port the target UE listens on (for example a local web server or file-sharing application).	The ping receives no reply and the connection attempt fails.
4	UE	Repeat from the target UE toward the source UE.	No reply and no connection in the other direction either.

Pass criteria

- No packet from one UE reaches the other in either direction.

Evidence collected: ICMP result from the UE.

EXP-SEC-002 — UE-to-platform communication prevented

Status	✅ Accepted
Category	Security
Components	xCore
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 20 min
Prerequisite procedures	EXP-SES-001 — UE-initiated attach
Included in	Installation and Upgrade Verification

Objective. The network blocks communication from a UE to the software components of the Expeto Platform: the xCore's own addresses, its monitoring endpoints and the cluster's node addresses.

Preconditions

- Platform
  - An xCore is deployed and operational, and its Site shows as online in xControl.
  - The xCore is configured to prevent UE-to-UE communication (the default configuration).
  - The xCore has a System on which the UE is provisioned.
- Tooling and access
  - Log in to xControl with an account that can view the Mobile Asset under test.
  - The node addresses of the cluster hosting the xCore (`kubectl get nodes -o wide`).
- Procedures executed first
  - EXP-SES-001 — UE-initiated attach

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Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-SES-001 — UE-initiated attach** as a prerequisite procedure.	As defined in EXP-SES-001.
2	xControl	Open **Mobile Assets**, select the UE, and open the details page of its Site. Note the IP addresses of the Site and of its monitoring endpoints.	The platform IP addresses are recorded.
3	UE	From the UE, ping each recorded address and each cluster node address.	No ping receives a reply.
4	UE	From the UE, attempt TCP connections to the Kubernetes API port (6443), the metrics ports and the CLI pod's service ports on those addresses.	Every connection attempt fails.

Pass criteria

- No platform or node address answers the UE on any protocol tried.

Evidence collected: ICMP result from the UE.

EXP-REC-001 — Session record completeness

Status	✅ Accepted
Category	Functional
Components	xControl, xCore
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster, Geo-redundant
Duration	About 20 min
Prerequisite procedures	EXP-SES-001 — UE-initiated attach EXP-SES-002 — UE-initiated detach
Included in	Installation and Upgrade Verification

Objective. The record of a completed session carries every field an MNO needs to account for it, and the values agree with the signalling capture of the same session.

Preconditions

- Tooling and access
  - Log in to xControl with an account that holds the **ADMIN** role.
  - An API token for the Customer.
- Procedures executed first
  - EXP-SES-001 — UE-initiated attach
  - EXP-SES-002 — UE-initiated detach

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Procedure

#	Where	Action	Expected result
1	—	Execute **EXP-SES-001 — UE-initiated attach** as a prerequisite procedure.	As defined in EXP-SES-001.
2	—	Execute **EXP-SES-002 — UE-initiated detach** as a prerequisite procedure.	As defined in EXP-SES-002.
3	xControl	Open the Mobile Asset's **Event Log**, select **Session**, and use the **Column Chooser** to show every column.	The closed session shows the Site and System names, the IMSI and IMEI, start and end time, the IP address and state **Closed**.
4	xControl API	Retrieve the session report for the IMSI through the API.	The record carries the IMEI, start and stop time, MCC, MNC, tracking area, radio identifier, bearer identifier, IP address, APN name, radio access technology, state, cause code, upload and download bytes, and links to the Site, System and subscriber.
5	Capture	Compare the record with the capture of EXP-SES-001 and EXP-SES-002.	The IP address equals the PDN or PDU address assigned; MCC, MNC and tracking area equal the tracking area identity in the attach; the radio identifier equals the cell identity in the attach; the start time is within one minute of the Attach Complete and the end time within one minute of the detach.

Pass criteria

- Every field listed is present and consistent with the capture.
- Start and end times are within 5 seconds of the corresponding signalling messages.

Evidence collected: xControl screenshot; 3GPP signalling capture (pcap).
References: 3GPP TS 32.251 §5.2 (PS domain charging principles).

EXP-HA-001 — xCore user-plane node failure

Status	✔ Accepted
Category	Resilience
Components	xCore
Applies to	4G, 5G · Local radio, Public radio · HA cluster
Duration	About 45 min
Included in	Installation and Upgrade Verification
Automated by	Platform suite, split user plane: one user-plane instance deleted while sessions are held on the other

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Objective. Expeto Edge (xCore) on a Kubernetes HA cluster continues to serve Mobile Assets when the node hosting the user-plane services (UPF / PGW-U) fails: the pods restart on the remaining nodes and the device regains service.

> **Service impact**
>
> This procedure interrupts service. Run it in a maintenance window or in a pre-production environment.

Preconditions

- Platform
  - An xCore is deployed on a Kubernetes HA cluster and operational.
  - You have identified the node (VM) hosting the user-plane pods (UPF / PGW-U).
  - Enough nodes remain available to host the user plane after the failure.
- Mobile Asset
  - One Mobile Asset is connected and passing data (execute the UE-initiated attach procedure first if it is not).
- Tooling and access
  - A tool that measures upload and download throughput from the UE against a server on the enterprise network, such as iperf3 or OpenSpeedTest.

Procedure

#	Where	Action	Expected result
1	UE	Start a continuous ping to a host on the enterprise LAN. Note the time.	Replies arrive.
2	Infrastructure	Shut down the node hosting the user-plane pods.	The node is reported as not ready by Kubernetes.
3	Kubernetes	Watch the pods that were running on that node.	All of them start successfully on the remaining nodes.
4	UE	Put the UE in airplane mode, then take it out again.	The UE authenticates and connects to the network.
5	UE	Run a speed test, then stop the ping and count the lost replies.	The UE uploads and downloads data; the interruption is recorded.
6	Infrastructure	Start the node again.	The node returns to ready and the cluster is back to its full size.

Pass criteria

- Every pod of the failed node is running on another node without manual intervention.
- The UE regains service and passes traffic after the failover.

Postconditions

- Record the measured service interruption in the results sheet.

Evidence collected: Kubernetes pod and node status; Speed test result; UE connectivity check.

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EXP-HA-004 — xCore restart recovery

Status	Accepted
Category	Resilience
Components	xCore
Applies to	4G, 5G · Local radio, Public radio · Single node, HA cluster
Duration	About 45 min
Included in	Installation and Upgrade Verification

Objective. A non-redundant Expeto Edge (xCore) recovers after every resource hosting it is power-cycled (turned off and back on), and devices regain service without manual intervention.

> **Service impact**
>
> This procedure interrupts service. Run it in a maintenance window or in a pre-production environment.

Preconditions

- Platform
  - An xCore is deployed and operational, and its Site shows as online in xControl.
- Mobile Asset
  - One Mobile Asset is connected and passing data (execute the UE-initiated attach procedure first if it is not).
- Tooling and access
  - A tool that measures upload and download throughput from the UE against a server on the enterprise network, such as iperf3 or OpenSpeedTest.

Procedure

#	Where	Action	Expected result
1	Infrastructure	Shut down all nodes (VMs) hosting the xCore site. Note the time.	The site is down.
2	Infrastructure	Start all the nodes that were shut down.	The nodes boot.
3	Kubernetes	Check the xCore workloads.	All services of the xCore are running; every pod is ready.
4	UE	Observe the UE.	The UE reconnects to the network on its own.
5	UE	Run a speed test.	The UE uploads and downloads data.
6	xControl	Open **Sites** and select the Site.	The Site is online.

Pass criteria

- Every service is running after the power cycle without manual intervention.
- The UE reconnects on its own and passes traffic.

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Postconditions

- Record the time from power-on to the UE regaining service in the results sheet.

Evidence collected: Service status after recovery; UE connectivity check.

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6.7 Standards Coverage

Each acceptance test cites the 3GPP procedure it exercises. This page inverts that mapping: for each specification clause cited anywhere in the catalog, it lists the tests that cover it. Use it to check that a procedure you care about is exercised, and to find the test to run. The item-level standards conformance statement records what the platform implements; this page records what the acceptance tests verify end to end.

6.7.1 3GPP TS 23.003 — Numbering, addressing and identification

Conformance statement: TS 23.003.

Clause	Procedure	Tests
2.2B	Subscription Concealed Identifier (SUCI)	EXP-SEC-009

6.7.2 3GPP TS 23.007 — Restoration procedures

Conformance statement: TS 23.007.

Clause	Procedure	Tests
19	Restoration of PFCP entities	EXP-HA-011
20	Path failure handling	EXP-HA-013

6.7.3 3GPP TS 23.040 — Technical realization of the Short Message Service (SMS)

Clause	Procedure	Tests
3.2.7	Alert-SC (message waiting)	EXP-MSG-005
9.2.3.24	TP-User-Data (concatenated short messages)	EXP-MSG-003
10	Short message procedures	EXP-MSG-001, EXP-MSG-004
10.3	Short message mobile terminated	EXP-MSG-005

6.7.4 3GPP TS 23.060 — General Packet Radio Service (GPRS); Service description, Stage 2

Clause	Procedure	Tests
6.5	Attach function (GPRS attach	EXP-PUB-002
9.2.2.1	PDP Context Activation Procedure	EXP-PUB-002

6.7.5 3GPP TS 23.122 — NAS functions related to Mobile Station (MS) in idle mode

Clause	Procedure	Tests
3.1	Forbidden PLMN list (definition)	EXP-SEC-012
4.4	PLMN selection	EXP-MOB-005, EXP-MOB-006, EXP-MOB-007

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6.7.6 3GPP TS 23.401 — General Packet Radio Service (GPRS) enhancements for E-UTRAN access

Conformance statement: TS 23.401.

Clause	Procedure	Tests
4.7.3	Bearer level QoS parameters (APN-AMBR); Bearer level QoS parameters	EXP-POL-001, EXP-POL-004
5.3.2.1	E-UTRAN Initial Attach	EXP-SES-001
5.3.3.0	Triggers for tracking area update	EXP-SES-009
5.3.3.1	Tracking Area Update procedure with Serving GW change (inter-MME)	EXP-MOB-004
5.3.3.2	E-UTRAN Tracking Area Update without Serving GW change	EXP-MOB-003
5.3.4.1	UE triggered Service Request	EXP-SES-005
5.3.4.3	Network Triggered Service Request	EXP-SES-006
5.3.5	S1 release procedure	EXP-SES-004
5.3.8.2	UE-initiated Detach procedure	EXP-SES-002
5.3.8.3	MME-initiated Detach procedure; MME-initiated Detach procedure (implicit detach)	EXP-SES-003, EXP-SES-010
5.3.8.4	HSS-initiated Detach procedure	EXP-PRV-002, EXP-SES-003
5.3.9.2	Insert Subscriber Data procedure	EXP-POL-001
5.3.10.3	User Identity Confidentiality (GUTI reallocation)	EXP-SES-008
5.4.2.1	HSS Initiated Subscribed QoS Modification	EXP-POL-001, EXP-POL-004
5.5.1.1.2	X2-based handover without Serving GW relocation	EXP-MOB-001
5.5.1.2.2	S1-based handover	EXP-MOB-002
5.10.2	UE requested PDN connectivity	EXP-SES-013
5.10.3	UE requested PDN disconnection	EXP-SES-012
D.3	Interoperation with Gn/Gp SGSNs	EXP-PUB-003

6.7.7 3GPP TS 23.501 — System architecture for the 5G System (5GS)

Conformance statement: TS 23.501.

Clause	Procedure	Tests
5.7.1	QoS model	EXP-POL-004
5.7.2.6	Session-AMBR	EXP-POL-001
5.15.5.2.1	Network slice selection at registration	EXP-POL-008

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6.7.8 3GPP TS 23.502 — Procedures for the 5G System (5GS)

Conformance statement: TS 23.502.

Clause	Procedure	Tests
4.2.2.2.2	General Registration; General Registration (Allowed NSSAI); General Registration (mobility registration update)	EXP-MOB-003, EXP-POL-008, EXP-SES-001
4.2.2.3.2	UE-initiated Deregistration	EXP-SES-002
4.2.2.3.3	Network-initiated Deregistration	EXP-SES-003
4.2.3.2	UE Triggered Service Request	EXP-SES-005
4.2.3.3	Network Triggered Service Request	EXP-SES-006
4.2.6	AN release	EXP-SES-004
4.3.2.2.1	UE Requested PDU Session Establishment	EXP-SES-001, EXP-SES-013
4.3.3.2	UE or network requested PDU Session Modification	EXP-POL-001, EXP-POL-004
4.3.4.2	UE or network requested PDU Session Release	EXP-SES-012
4.9.1.2	Xn based inter NG-RAN handover	EXP-MOB-001
4.9.1.3	Inter NG-RAN node N2 based handover	EXP-MOB-002

6.7.9 3GPP TS 24.008 — Mobile radio interface Layer 3 specification; Core network protocols, Stage 3

Clause	Procedure	Tests
4.7.3	GPRS attach procedure	EXP-PUB-002

6.7.10 3GPP TS 24.301 — Non-Access-Stratum (NAS) protocol for Evolved Packet System (EPS)

Conformance statement: TS 24.301.

Clause	Procedure	Tests
5.3.7	Handling of the periodic tracking area update timer and mobile reachable timer	EXP-SES-010
5.4.2.5	Authentication not accepted by the network	EXP-SEC-003
5.4.2.7	Abnormal cases in the UE (synch failure); Authentication procedure, abnormal cases on the network side	EXP-SEC-010, EXP-SEC-011
5.5.1.2	Attach procedure for EPS services	EXP-SES-001
5.5.1.2.5	Attach not accepted by the network	EXP-POL-006, EXP-PRV-005, EXP-SEC-011, EXP-SEC-012
5.5.1.3	Combined attach procedure for EPS services and non-EPS services	EXP-PUB-003
5.5.2.3	Network initiated detach procedure (re-attach required)	EXP-PRV-007

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Clause	Procedure	Tests
5.5.3.2	Normal and periodic tracking area updating procedure	EXP-SES-009
5.5.3.2.5	Normal and periodic tracking area updating procedure not accepted by the network	EXP-MOB-004
6.5.1	UE requested PDN connectivity procedure	EXP-SES-013
6.5.1.3	UE requested PDN connectivity procedure accepted by the network (protocol configuration options)	EXP-POL-007
6.5.1.4	UE requested PDN connectivity procedure not accepted by the network	EXP-SES-011
6.5.2	UE requested PDN disconnect procedure	EXP-SES-012

6.7.11 3GPP TS 24.501 — Non-Access-Stratum (NAS) protocol for 5G System (5GS)

Conformance statement: TS 24.501.

Clause	Procedure	Tests
5.3.7	Handling of the periodic registration update timer and mobile reachable timer	EXP-SES-010
5.4.1.3.5	Authentication not accepted by the network	EXP-SEC-011
5.4.1.3.7	Abnormal cases in the UE (5G AKA synch failure)	EXP-SEC-010
5.4.3	Identification procedure	EXP-SEC-009
5.4.4	Generic UE configuration update (5G-GUTI reallocation)	EXP-SES-008
5.5.1.2.4	Initial registration accepted by the network (Allowed and Rejected NSSAI)	EXP-POL-008
5.5.1.2.5	Initial registration not accepted by the network	EXP-PRV-005, EXP-SEC-011, EXP-SEC-012
5.5.1.3	Registration procedure for mobility and periodic registration update	EXP-SES-009
6.4.1.2	UE-requested PDU session establishment procedure initiation (S-NSSAI	EXP-POL-008
6.4.1.4	UE-requested PDU session establishment procedure not accepted by the network	EXP-SES-011
6.4.3	UE-requested PDU session release procedure	EXP-SES-012
9.11.3.4	5GS mobile identity (SUCI)	EXP-SEC-009

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6.7.12 3GPP TS 29.002 — Mobile Application Part (MAP) specification

Conformance statement: TS 29.002.

Clause	Procedure	Tests
8.1	Location management services (UpdateLocation	EXP-PUB-002
8.5	Authentication management services (SendAuthenticationInfo)	EXP-PUB-002
8.8	Subscriber management services (InsertSubscriberData)	EXP-PUB-002
12.1	SendRoutingInfoForSM	EXP-MSG-001
12.2	MO-ForwardSM	EXP-MSG-001, EXP-MSG-002
12.4	AlertServiceCentre	EXP-MSG-005
12.8	ReadyForSM	EXP-MSG-005
12.9	MT-ForwardSM	EXP-MSG-001, EXP-MSG-003

6.7.13 3GPP TS 29.060 — GPRS Tunnelling Protocol (GTP) across the Gn and Gp interface (GTPv1)

Conformance statement: TS 29.060.

Clause	Procedure	Tests
7.3.1	Create PDP Context Request	EXP-PUB-002
7.3.2	Create PDP Context Response	EXP-PUB-002
7.3.3	Update PDP Context Request	EXP-PUB-003
7.3.5	Delete PDP Context Request	EXP-PUB-002

6.7.14 3GPP TS 29.244 — Interface between the Control Plane and the User Plane nodes (PFCP)

Conformance statement: TS 29.244.

Clause	Procedure	Tests
6.2	PFCP association and heartbeat procedures	EXP-HA-011

6.7.15 3GPP TS 29.272 — MME and SGSN related interfaces based on Diameter protocol (S6a)

Conformance statement: TS 29.272 (HSS role), TS 29.272 (MME role).

Clause	Procedure	Tests
5.2.1.1	Update Location procedure (roaming not allowed)	EXP-POL-006
5.2.2.2	Cancel Location (CLR-Flags; Cancel Location (CLR-Flags)	EXP-PRV-002, EXP-PRV-007, EXP-SES-003
5.2.3.1	Authentication Information Retrieval (Re-Synchronization-Info)	EXP-SEC-010
7.1.1	Use of Diameter base protocol	EXP-HA-018

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Clause	Procedure	Tests
7.3.10	Supported-Features and Feature-List (NR as Secondary RAT)	EXP-PUB-001
7.3.31	Access-Restriction-Data	EXP-PUB-001

6.7.16 3GPP TS 29.274 — Evolved GPRS Tunnelling Protocol for Control plane (GTPv2-C)

Conformance statement: TS 29.274.

Clause	Procedure	Tests
7.1	Path Management Messages (Echo Request and Response)	EXP-HA-013
7.2.7	Modify Bearer Request	EXP-PUB-003
8.132	Secondary RAT Usage Data Report	EXP-PUB-001

6.7.17 3GPP TS 29.338 — Diameter based protocols to support SMS capable MMEs (SGd, S6c)

Clause	Procedure	Tests
5.3	SGd interface procedures	EXP-MSG-004
6.3	MO-Forward-Short-Message and MT-Forward-Short-Message	EXP-MSG-004

6.7.18 3GPP TS 29.503 — Unified Data Management Services (Nudm)

Clause	Procedure	Tests
5.2.2.2	Subscription data retrieval (NSSAI)	EXP-POL-008

6.7.19 3GPP TS 32.251 — Charging management; Packet Switched (PS) domain charging

Clause	Procedure	Tests
5.2	PS domain charging principles	EXP-REC-001, EXP-REC-002

6.7.20 3GPP TS 33.102 — 3G security; Security architecture (AKA re-synchronisation)

Conformance statement: TS 33.102.

Clause	Procedure	Tests
6.3.5	Re-synchronisation procedure	EXP-SEC-010

6.7.21 3GPP TS 33.401 — 3GPP System Architecture Evolution (SAE); Security architecture

Clause	Procedure	Tests
6.1.1	AKA procedure	EXP-SEC-003, EXP-SEC-011
7.2.4	NAS security mode command procedure	EXP-SEC-004

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6.7.22 3GPP TS 33.501 — Security architecture and procedures for 5G System

Conformance statement: TS 33.501.

Clause	Procedure	Tests
6.1.3	Authentication procedures	EXP-SEC-003
6.1.3.3	Synchronisation failure or MAC failure	EXP-SEC-010
6.7.2	NAS security mode command procedure	EXP-SEC-004
6.12	Subscription identifier privacy	EXP-SEC-009

6.7.23 3GPP TS 36.413 — S1 Application Protocol (S1AP)

Conformance statement: TS 36.413.

Clause	Procedure	Tests
8.7.1	Reset	EXP-HA-012
8.7.3	S1 Setup	EXP-HA-012, EXP-INS-003

6.7.24 3GPP TS 37.340 — Multi-connectivity; Stage 2 (EN-DC)

Clause	Procedure	Tests
4.1	Multi-RAT Dual Connectivity overview (EN-DC)	EXP-PUB-001

6.7.25 3GPP TS 38.413 — NG Application Protocol (NGAP)

Conformance statement: TS 38.413.

Clause	Procedure	Tests
8.7.1	NG Reset	EXP-HA-012
8.7.3	NG Setup	EXP-INS-003

6.7.26 IETF RFC 6733 — Diameter Base Protocol

Conformance statement: RFC 6733.

Clause	Procedure	Tests
5.5	Transport failure detection (Device-Watchdog)	EXP-HA-018
5.6	Peer state machine	EXP-HA-018
6.1	Diameter request routing overview	EXP-HA-018

6.7.27 SMPP Protocol Specification v3.4 — Short Message Peer-to-Peer protocol

Clause	Procedure	Tests
4.4	submit_sm	EXP-MSG-003

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Clause	Procedure	Tests
4.6	deliver_sm	EXP-MSG-002

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6.8 Campaign Planning and Results

Use this page to size an acceptance campaign: how long each domain takes, what it needs in devices, radios and sites, and in which order to run it. Durations are planning figures for one engineer executing the published procedure once, excluding environment preparation.

6.8.1 Effort and resources by domain

Domain	Tests	Planned duration	UEs (max)	Radios (max)	Sites (max)
Installation checks	5	3 h 35 min	1	1	1
Session lifecycle	13	7 h 10 min	3	1	1
Provisioning	11	4 h 15 min	2	1	1
Policy and traffic	8	3 h 40 min	2	1	1
Public network access	3	1 h 45 min	1	0	1
Mobility and access transitions	7	7 h 30 min	1	2	2
Security and isolation	12	5 h 45 min	2	1	2
Messaging (SMS)	6	2 h 30 min	2	0	1
Session records and usage	6	2 h 40 min	1	1	2
Resilience and high availability	16	13 h 15 min	3	1	2
Capacity and stability	4	29 h 45 min	rated tier	1	1
Operations and maintenance	6	4 h 40 min	3	1	1
Total	**97**	**86 h 30 min**			

6.8.2 Suggested sequence

1. **Installation and Upgrade Verification** (19 tests, about 7 h 10 min). Run first; it proves the deployment is ready for the rest of the campaign.
2. **Installation checks** (5 tests, about 3 h 35 min).
3. **Session lifecycle** (13 tests, about 7 h 10 min).
4. **Provisioning** (11 tests, about 4 h 15 min).
5. **Policy and traffic** (8 tests, about 3 h 40 min).
6. **Public network access** (3 tests, about 1 h 45 min).
7. **Mobility and access transitions** (7 tests, about 7 h 30 min).
8. **Security and isolation** (12 tests, about 5 h 45 min).
9. **Messaging (SMS)** (6 tests, about 2 h 30 min).
10. **Session records and usage** (6 tests, about 2 h 40 min).
11. **Resilience and high availability** (16 tests, about 13 h 15 min).
12. **Capacity and stability** (4 tests, about 29 h 45 min).
13. **Operations and maintenance** (6 tests, about 4 h 40 min).

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6.8.3 Recording results

Download results-template.csv: one row per published test, with columns for the result (**Pass**, **Fail**, **Deviation**, **Not run**), the tester, the date, the evidence reference and the deviation record. Expeto reviews the completed sheet with the operator before sign-off.

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