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Abstract	This report contains the specification and description of the deployed 6G-XR reference architecture components in the 6G-XR research infrastructure (RI), experimental sites, and test facilities. The specification covers the high-level functionality, logical structure, main functional units, and interfaces of the overall RI. The implementation architecture description covers the physical structure, main parts (e.g., RAN's, network control, user equipment, testing tools), interfaces, and configuration options of the experimental sites and test facility infrastructures.
Keywords	Experimental Infrastructure, Test Facilities, South Node, North Node, Deployment Architecture, Testing Tools, Monitoring Tools, Trials

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DATA: Data sets, microdata, etc.

DMP: Data management plan

ETHICS: Deliverables related to ethics issues.

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EXECUTIVE SUMMARY

The overall 6G-XR Research Infrastructure (RI) and its building blocks are designed and developed to support the Smart Networks and Services Joint Undertaking (SNS JU) programme objectives throughout its lifetime.

Firstly, the 6G-XR RI comprises two experimentation sites: South Node and North Node. The South Node is located in Spain and comprises two separate test facilities, i.e., 5GBarcelona in Barcelona and 5TONIC in Madrid. The North Node is located in Oulu, Finland and comprises two separate test facilities, i.e., UOULU 5G Test Network (5GTN) and VTT 5GTN. At both experimentation sites, the two test facilities are interconnected and able to share resources and data during experiment configuration and execution.

Secondly, instead of building new test infrastructures for the 6G-XR needs from scratch, all test facilities included in the 6G-XR RI – 5GBarcelona, 5TONIC, UOULU 5GTN, and VTT 5GTN – have been developed continuously since the early phases of the 5G Public Private Partnership (5G PPP). With the approach to utilise existing mature infrastructures as the starting point for further development, the project aims to leverage and optimise previous investments to fifth generation (5G) and beyond 5G (B5G) test facilities in Europe.

The modular approach to the deployment of the technology and service enablers at the sites, together with the committed test facility owners to maintain and upgrade the infrastructures well beyond the project's lifetime, will guarantee the reusability and evolvability of the 6G-XR RI well in the future. By taking into account not only the evolution of the already standardised technologies but also the emerging technologies, the 6G-XR RI will also be able to embrace disruptions on its development path towards sixth generation (6G) mobile network capabilities.

The deployed architecture at both the South Node and North Node is tailored for the specific needs of the project use cases deployed and validated at the site. For experimentation and validation purposes, 6G-XR experimentation sites are equipped with a variety of testing and monitoring tools. These tools are available to the experimenters for measuring a variety of network key performance indicators (KPIs), debugging their experiment configurations, and visualising the results. The ability of the 3rd party experimenters to access and utilise the 6G-XR RI as well as the usability of the provided tools in a variety of experiments will be developed and tested throughout the project's lifetime through the 6G-XR Open Calls.

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ABBREVIATIONS

3D	Three Dimensional
3GPP	3rd Generation Partnership Project
4G	4th Generation
5G	5th Generation
5G PPP	5G Public Private Partnership
5G-A	5G-Advanced
5GC	5G Core Network
5GTN	5G Test Network
6G	6th Generation
AI	Artificial Intelligence
AMF	Access and Mobility Management Function
API	Application Programming Interface
B5G	Beyond 5G
BW	Bandwidth
CN	Core Network
CNF	Containerised Network Function
CP	Control Plane
CPE	Customer Premises Equipment
CPU	Central Processing Unit
DAS	Distributed Antenna System
DCSF	Data Channel Signalling Function
DL	Downlink
DN	Data Network
DT	Digital Twin
E2E	End-to-End
EE	Energy Efficiency
EPC	Evolved Packet Core
ETSI	European Telecommunications Standards Institute
EWBI	East-Westbound Interface
FDD	Frequency Division Duplex
GNSS	Global Navigation Satellite System
GPU	Graphics Processing Unit
GUI	Graphical User Interface
HW	Hardware
IEAP	Intelligent Edge Application Platform
IMS	IP Multimedia Subsystem
IMSDC	IMS Data Channel
IoT	Internet of Things
IP	Internet Protocol
K8s	Kubernetes
KPI	Key Performance Indicator
LCM	Lifecycle Management
LTE	Long Term Evolution
LTE-M	LTE Machine Type Communication
MEC	Multiaccess Edge Computing
MEF	MEC Federator
MIMO	Multiple Input Multiple Output
mmWave	Millimetre Wave

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MNO	Mobile Network Operator
MRF	Media Resource Function
NB-IoT	Narrowband IoT
NBI	Northbound Interface
NG-RAN	Next Generation RAN
NEF	Network Exposure Function
NFV	Network Functions Virtualisation
NPN	Non-Public Network
NR	New Radio
NRF	Network Repository Function
NSA	Non-standalone
NSSF	Network Slice Selection Function
NST	Network Slice Template
O-RAN	Open RAN
OPG	Operator Platform Group
OTA	Over-the-Air
PCF	Policy Control Function
PRB	Physical Resource Block
PTP	Precision Time Protocol
PV	Photovoltaic
QoD	Quality of Demand
QoE	Quality of Experience
QoS	Quality of Service
RAM	Random Access Memory
RAN	Radio Access Network
RAT	Radio Access Technology
RI	Research Infrastructure
RIC	RAN Intelligent Controller
SA	Standalone
SCTP	Stream Control Transmission Protocol
SDN	Software-Defined Networking
SDR	Software-Defined Radio
SIM	Subscriber Identity Module
SMF	Session Management Function
SNS JU	Smart Networks and Services Joint Undertaking
TCP	Transmission Control Protocol
TDD	Time Division Duplex
TSN	Time Sensitive Networking
UDM	Unified Data Management
UDP	User Datagram Protocol
UDR	Unified Data Repository
UE	User Equipment
UL	Uplink
UP	User Plane
UPF	User Plane Function
VM	Virtual Machine
VNF	Virtual Network Function
VPN	Virtual Private Network
XR	Extended Reality

1 INTRODUCTION

This document describes the 6G-XR research infrastructure (RI) implementation details and configuration options. The implemented infrastructure is based on the 6G-XR use case requirements defined in 6G-XR deliverable D1.1 [1], the 6G-XR reference architecture features defined in 6G-XR deliverable D1.2 [2], and research result coming out from the project's technical work carried out in five different technical work packages.

The overall 6G-XR RI and its building blocks are designed and developed to support the Smart Networks and Services Joint Undertaking (SNS JU) programme objectives throughout its lifetime. Instead of building new test infrastructures for the 6G-XR needs from scratch, the test facilities included in the 6G-XR RI have all been developed continuously since the early phases of the 5G Public Private Partnership (5G PPP). With the approach to utilise existing mature infrastructures as the starting point for further development, the project aims to leverage and optimise previous investments to fifth generation (5G) and beyond 5G (B5G) test facilities in Europe. This deliverable describes the overall 6G-XR RI as a combination of the existing test facilities located in the Spain and Finland (see Chapter 2), and provides the technical details for each of the test facilities (see Chapters 3 and 4).

The modular approach to the deployment of the technology and service enablers at the sites, together with the committed test facility owners to maintain and upgrade the infrastructures well beyond the project's lifetime, will guarantee the reusability and evolvability of the 6G-XR RI in the future. Relying on the modular design presented in the 6G-XR deliverable D1.2 [2], fully functional subsets of the overall 6G-XR reference architecture functionality have been implemented at the project's experimentation sites based on the needs of the use cases under validation. By considering not only the evolution of the already standardised technologies in the design and deployments, but also the emerging technologies, the 6G-XR RI will also be able to embrace disruptions on its development path towards sixth generation (6G) mobile network capabilities.

In order to benefit the European R&D ecosystem by offering unique experimentation capabilities to 3rd parties outside the project consortium, accessibility of the deployed experimentation assets have also been key principles in the 6G-XR RI design. A variety of testing and monitoring tools are offered to the experimenters to guarantee visibility into the network key performance indicators (KPI) during and after the performed experiments. In addition, the ability of remote experimenters to configure experiments on top of the 6G-XR test facilities and utilise the offered testing capabilities without the need to travel to the physical sites has been enabled through web portals. By offering remote experimentation possibilities to 3rd parties all over Europe, the infrastructure owners of 6G-XR test facilities can also benefit from joint innovations done between them and the 3rd parties exploiting the 6G-XR RI. For this purpose, the 6G-XR project organises three Open Calls for 3rd party contributions on test facility extension and end-to-end (E2E) trials throughout its three-year duration.

2 6G-XR RESEARCH INFRASTRUCTURE OVERVIEW

The overall 6G-XR RI comprises two experimentation sites called South Node and North Node, as shown in Figure 1. The 6G-XR South Node is located in Spain and comprises two separate test facilities, i.e., 5TONIC in Madrid and 5GBarcelona in Barcelona. The 6G-XR North Node is located in Oulu, Finland and comprises two separate test facilities, i.e., UOULU 5G Test Network (5GTN) and VTT 5GTN. For each experimentation site, the two test facilities are interconnected and able to share resources and data during experiment configuration and execution. More specifically, 5TONIC and 5GBarcelona can share core network resources and federated edge platforms. Similarly, UOULU 5GTN and VTT 5GTN can share core network resources and energy-related monitoring data. More details on the configuration options and assets available for the experimenters at 5GBarcelona, 5TONIC, UOULU 5GTN, and VTT 5GTN can be found in 3.2, 3.1, 4.1, and 4.2, respectively.

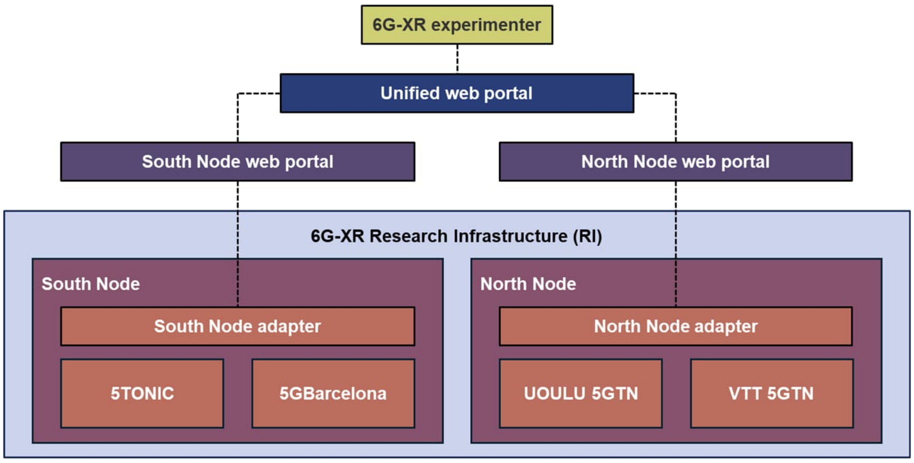

Figure 1. 6G-XR research infrastructure, experimentation sites, and test facilities.

From the point of view of the use cases, the South Node experimentation site focuses on real-time holographic communications. This application area comprises three use cases developed in parallel:

- UC1 – Resolution Adaptation or Quality on Demand (QoD)
- UC2 – Routing to the Best Edge
- UC3 – Control Plane Optimisations

The experimentation architecture deployed at the South Node for the validation of the abovementioned use cases is presented in 3.3.

The North Node experimentation site focuses on two separate application areas: the collaborative three dimensional (3D) digital twin-like environment, and the energy measurement framework for energy sustainability. One use case is developed for each of them:

- UC4 – Collaborative 3D Digital Twin-like Environment
- UC5 – Energy Measurement Framework for Energy Sustainability

The experimentation architecture deployed at the North Node for the validation of the above-mentioned use cases is presented in 4.3.

For experimentation and validation purposes, both 6G-XR experimentation sites are equipped with several testing and monitoring tools. The main network KPI measurement tool offered to the experimenters in 6G-XR KPI collection system is Qosium [3]. Qosium is a network KPI monitoring tool developed by Kaitotek using a passive measurement approach. It measures the uplink (UL), downlink (DL) and end-to-end (E2E) network performance (throughput, latency, jitter, packet loss, etc.) without generating additional traffic into the network. Qosium consists of three parts: Scope, Probe, and Storage. Scope is responsible for measurement configuration and execution, as well as gathering and visualising the measurement results. Scope is not part of the measurement path and requires a network connection to one or more of the Probes. Probes are installed and executed in the network components along the E2E data path. Probes serve as the endpoints of the measured network segment, where the measured traffic passes through them transparently, i.e., without affecting data forwarding at the network component. One-way delay measurements require accurate time synchronisation between the measurement endpoints. Storage is the dedicated database server used to collect the KPI measurement results. It also includes a web user interface for visualisation and accessing the results.

At the 6G-XR experimentation sites, Qosium is preconfigured to measure and store all network KPIs. After an experiment is executed at the site, the 6G-XR experimenter can remotely filter and view the KPIs of his/her interest using the visualisation tools offered by the Qosium framework. A separate log file containing the KPIs of the executed experiment can also be provided to the experimenter for post-analysis. Other tools available for the experimenters to measure KPIs, debug their experiment configurations, and visualise the results, are listed for the South Node and North Node in 3.4 and 4.4, respectively.

In order to support 3rd party experiments, 6G-XR RI allows remote experimentation through web portals. The common interface for an external experimenter to access 6G-XR RI resources is called unified web portal, shown on the top in Figure 1. In the unified 6G-XR web portal, the experimenters are able to authenticate themselves into the system and choose the experimentation site they want to use for their experiments. In the node specific web portal for the selected experimentation site, the experimenter can configure his/her experiment on top of the related test facilities. As shown in Figure 1, the experimenter can configure experiments on top of the 5TONIC and 5GBarcelona test facilities through the South Node web portal, and on top of the UOULU 5GTN and VTT 5GTN test facilities through the North Node web portal. Based on the configuration options selected by the experimenter, a network slice template (NST) is populated and fed into the node adapter that configures related test facility resources for the experiment. The configuration workflow and actions taken by the South Node and North Node web portals and adapters are described in 3.5 and 4.5, respectively.

All five use cases listed above are described in detail in the 6G-XR deliverable D1.1 [1]. More information on the remote access workflow through the 6G-XR's unified and node-specific web portals can be found in the 6G-XR deliverable D1.2 [2].

3 SOUTH NODE EXPERIMENTATION SITE

The 6G-XR South Node comprises two separate test facilities located in Spain (see Figure 2). The test facilities are called 5TONIC (located in Madrid) and 5GBarcelona. In the context of the 6G-XR project, the two test facilities are being federated to support multi-domain use cases. 5GBarcelona is provided by i2CAT, 5TONIC is operated in 6G-XR by Ericsson, providing the 5G core network (5GC) and radio access network (RAN), Capgemini providing the edge infrastructure and Multi-access Edge computing capabilities, and Telefonica as telco operator.

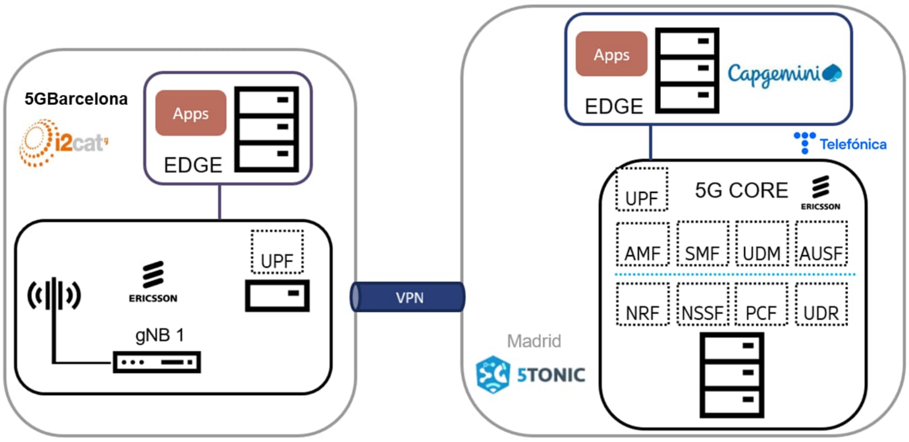

Figure 2. South Node experimentation site with 5TONIC and 5GBarcelona test facilities.

The South Node test facilities focus on the following use cases to optimise real-time holographic communications:

- UC1 – Resolution Adaptation or QoD
- UC2 – Routing to the Best Edge
- UC3 – Control Plane Optimisations

Subsections 3.2 and 3.1 detail the South Node test facilities being available during the experimentation phase of the 6G-XR project. Subsection 3.3 focuses on the deployment architectures of the hosted use cases, implementing subsets of the overall 6G-XR reference architecture described in deliverable D1.2 [2]. The detailed use case descriptions are in deliverable D1.1 [1]. Subsection 3.4 depicts the testing, monitoring, and measurement tools, available for the experimenters at the South Node test facilities, while 3.5 outlines the experiment on-boarding and execution procedures.

3.1 5TONIC

5TONIC[1] is an open research and innovation laboratory based in Leganes, Madrid (Spain) focusing on 5G technology integration, adoption, and evolution. 5TONIC constitutes an open global environment where members of industry and academia are working together on research and innovation projects related to 5G and B5G technologies. 5TONIC members leverage their combined insight allowing them to boost technology and business innovation ventures. Three 6G-XR partners are members of 5TONIC: i) Telefonica, which provides innovative digital services, growth, and market opportunities ii) Ericsson,

[1] 5TONIC website, https://www.5tonic.org/

which provides the RAN and the 5G core network, and iii) Capgemini which provides edge infrastructure and multiaccess edge computing (MEC) capabilities.

3.1.1 Radio access network

5Tonic offers a set of indoor Ericsson's Dot antennas and 5G multi-input multiple-output (MIMO) outdoor Ericsson's antennas for coverage in mid-band inside and around the 5TONIC building. The antennas operate in the B78L band (3500-3800 MHz). The bandwidth used at 5TONIC is the 100 MHz portion, which is assigned to Telefonica in Spain.

Table 1: Licensed frequency bands available at 5TONIC test facility

Band #	Frequency	Max. bandwidth	Remarks
B78L	3500-3800 MHz	100 MHz	Using Telefonica's range

There is one cell configured for the indoor Dots coverage, a second cell configured for indoor coverage with a 5G MIMO antenna in one of the rooms at 5TONIC and a third cell for outdoor coverage with a 5G MIMO antenna installed the roof of the building.

There are several models of user equipment (UE) and customer premises equipment (CPE), with the required subscriber identity modules (SIMs) for being allowed to connect to the 5TONIC 5G network, that can be used for experimenting.

3.1.2 Core network

The 5G Core available at the 5TONIC serves as a centralised core for 5G non-public networks (NPNs) deployed in several locations (5TONIC and 5GBarcelona). This core controls the UEs that can get attached to the 5G network, how to start the data sessions, etc. In the core, different slices can also be defined with various quality of service (QoS) for different purposes.

Ericsson's software products for 5GC are based on containerised network functions (CNFs) that run on a Kubernetes cluster. Those network functions are the well-known components of a 5G network access and mobility management function (AMF), session management function (SMF), user plane function (UPF), unified data management (UDM) + unified data repository (UDR), network repository function (NRF), policy control function (PCF), and network slice selection function (NSSF).

Ericsson also provides an Internet protocol (IP) multimedia subsystem (IMS) platform with the new IMS Data Channel (IMSDC) enhancement, required for the control plane communications use case UC3 (see 6G-XR deliverable D1.1 [1] for details). The IMS core components are deployed in 5Tonic, and the novel IMSDC components are deployed on an Azure cloud environment. The IMSDC elements are the data channel signalling function (DCSF) and the media resource function (MRF), which interact with the vertical signalling and media servers respectively, through the DC4 and MDC2 interfaces.

3.1.3 Edge and cloud computing

Capgemini is providing Edge computing infrastructure as part of the 5TONIC testbed, as well as a MEC orchestrator (that is being deployed at 5TONIC) which is compliant with European Telecommunications Standards Institute's (ETSI) MEC specification. It offers multiple capabilities, accelerators and frameworks for rapid development of MEC solutions with optimised hardware (HW) infrastructure resource and increased computing capacity.

The current infrastructure at 5TONIC includes two edge servers (provided by Capgemini: HPE ProLiant DL360 Gen10- Controller and HPE ProLiant DL360 Gen10 – Compute. The characteristics for each of the servers are collected in Table 2.

Table 2: 5TONIC edge server characteristics

	HPE ProLiant DL360 Gen10
Processors	2 X Intel(R) Xeon(R) Silver 4114 CPU @ 2.20GHz (10 cores, 20 threads)
Memory	128GB
Networking	1 x 4 Port Broadcom NetXtreme BCM5719 Gigabit Ethernet PCIe 1 X 2 Port Intel Ethernet Controller X710 for 10GbE SFP+
Local Storage	2 X HPE Enterprise - Hard Drive - 1.2 Tb - SAS 12GB/S Model=EG001200JWJNQ

This computing capacity is planned to be expanded with two graphics processing units (GPUs) cards (NVIDIA Tesla T4 offering 16 GB passive, single slot, full height GPU) and at least 1 additional server with similar HW specifications as above. This new server will be based on use cases requirements defined in the project.

3.1.4 Orchestration and management

The MEC orchestrator at 5TONIC– Intelligent Edge Application Platform (IEAP) by Capgemini – includes a set of in-house developed application programming interfaces (APIs) to control the location of the application. Besides, it allows to control the application life cycle management (LCM) following GSMA Operator Group recommendations and UE to Edge interaction following GSMA Operator Platform Group (OPG) [4].

Besides, it will offer APIs compliant with Linux Foundation CAMARA APIs [5], which are being applied in the context of the 6G-XR project, to ease the access to network capabilities for the application providers. These APIs aligned with the use cases defined for the South Node and related to the management of QoD, the selection of the best edge infrastructure and the optimisation of routing path, being integrated as needed with 5G Core provided by Ericsson (more detailed information is provided in 6G-XR deliverable D2.1 [6]).

3.2 5GBARCELONA

5GBarcelona is an experimentation site located near the Polytechnic University of Catalonia in Barcelona. To support experiments validating use cases, the infrastructure encompasses two distinct locations within the campus area. These locations allow experimenters to simulate scenarios utilising various points in the cloud-edge continuum. The buildings are connected by optical fibre, which minimises latency differences and allows scenarios to be run seamlessly in both locations based on resource availability. The 5GBarcelona site offers 5G radio coverage and includes a UPF, enabling the separation of user plane and control plane paths. This helps, keeping the user plane physically close to the end user while the control plane travels to a remote 5GC located in Madrid.

3.2.1 Radio access network

At the 5GBarcelona site, a 5G new radio (NR) RAN, supplied and deployed by Ericsson, provides outdoor coverage to an area near i2CAT premises in Barcelona. It makes available mid and millimetre wave (mmWave) bands, while using carrier aggregation to achieve sustained throughput beyond 1 Gbps in downlink and round-trip latency down to 4 ms between the UE and a close by application server.

The used mid-band antenna supports the B77D band (3800-3980 MHz). Due to the location in the middle of Barcelona, Spanish mobile network operators (MNOs) already provide their commercial mid-band coverage in this area. To avoid interference, an antenna model which supports the range of mid-band spectrum that is managed by the Spanish Government has been selected. The project is allowed to use 40 MHz of bandwidth within that range. On the other hand, the mmWave antennas support the full B258 band (24.25-27.5 GHz) with a maximum operating bandwidth of 800 MHz in DL and 400 MHz in UL. In this frequency range, no interferences are foreseen in the area, so frequencies are used within the range assigned to Telefonica in Spain. The available frequency bands are summarised in Table 3.

Table 3: Licensed frequency bands available at 5GBarcelona test facility

Band #	Frequency	Max. bandwidth	Remarks
B77D	3800-3980 MHz	40 MHz	Bandwidth (BW) of 40 MHz assigned by the Spanish Government
B258	24.25-27.5 GHz	800 MHz	Max. UL BW of 400 MHz

The setup is built with a mid-band cell and two mmWave cells. In the experiments, the end user device will connect to the network through the mid-band cell and the mmWave carriers will be aggregated for capacity increase. The RAN hardware is equipped with Ericsson's latest software, which include many features compliant with the 3rd Generation Partnership Project's (3GPP) Release 16 and 17. The RAN basebands are installed inside a flight rack located at 5GBarcelona. Askey's CPEs and SIMs are also available for end user experimentation. The RAN initial design was documented in 6G-XR deliverable D4.1 [7]. The final deployment will be further detailed in future 6G-XR deliverables as the design work progresses.

3.2.2 Core and transport network

The only 5G Core component physically located at 5GBarcelona is the UPF provided by Ericsson. This is an endpoint of the N3 interface, so in the uplink direction, it terminates the GTP tunnel coming from the RAN and sends IP traffic via N6 interfaces towards the data network (DN), and in the downlink direction, it receives packets from the DN and encapsulates them into GTP towards the RAN. It allows the local breakout of the user plane to keep the application traffic close to the end user if also the applications are running on an Edge server close to the RAN, keeping a very low latency. It is a 3GPP-compliant software product that runs on a general-purpose server inside the flight rack installed at 5GBarcelona.

Since the 5G network requires a 5GC control plane (CP) to work, 5GBarcelona is connected to the 5GC CP in 5Tonic. This is an NPN architecture, where there are RAN and UPF components used privately, and a centralised 5GC CP that is common for all users. To achieve the required connectivity with 5Tonic, there are two network elements: a router in 5GBarcelona and a virtual private network (VPN) established between 5GBarcelona and 5Tonic sites. The router is supplied by Ericsson inside the flight rack at 5GBarcelona and links all the RAN equipment and the UPF locally, while also connecting to the outside world. Additionally, there is an operational layer 2 VPN between sites using RedIris [8] network, a backbone transport network among Spanish research centres.

3.2.3 Edge and cloud computing

i2CAT has deployed a private cloud infrastructure in Barcelona, distributed across two buildings near the university campus. This infrastructure supports various components of the Cloud-Edge continuum. The 6G-XR project will utilise the Edge segment, compatible with ETSI MEC specifications [9]. The primary computing resources for the Edge are detailed in Table 4.

Table 4: 5GBarcelona edge server characteristics

	Edge 1	Edge 2
Model	Dell PowerEdge R640	Supermicro SuperServer 1029GP-TR
Processor	2 x Intel (R) Xeon (R) Gold 5218R (2.1 GHz) 2x 20 Cores/ 2x 40 threads → 80 threads	2 x Intel (R) Xeon (R) Gold 5218R (2.1 GHz) 2x 20 Cores/ 2x 40 threads → 80 threads
Memory (RAM)	256 GB	256 GB
Storage	2x480 GB SSD 4x1.92 TB SSD	2x480 GB SSD 2x4 TB SSD
Networking	2x1GbE 2x10GbE	2x1GbE 2x10GbE
GPU	NVIDIA Tesla T4 16GB 2560 cores, 320 Tensor cores	NVIDIA Tesla T4 16GB 2560 cores, 320 Tensor cores

3.2.4 Orchestration and management

In the 5GBarcelona test facility of the South node, private cloud management has been implemented using OpenStack [10], an industry-standard open-source platform for private cloud management. OpenStack enables tenant isolation, which can be configured as required for different scenarios.

For the 6G-XR project and the 5GBarcelona Edge, i2CAT is developing an edge orchestration management tool called i2EDGE, aligned with the ETSI MEC reference architecture. This tool interacts with a virtual infrastructure based on Kubernetes (K8s) clusters, deployed over the previously mentioned OpenStack tenant. For 6G-XR, two clusters have been implemented, each with different nodes providing various types of computing resources and functionalities. i2EDGE can intelligently deploy applications based on their context, selecting nodes with enhanced GPU capabilities as required by different applications.

Note that by design and as decided by the project consortium, the Edge in the 5GBarcelona site is not exposed directly but through federation with the Edge in Madrid. Both sites follow the reference implementation proposed by GSMA in the OPG [11]. The OPG is working on defining the East-Westbound interface (EWBI) for federation [12]. This requires both sites to implement the MEC federator (MEF) component, which interfaces with the local Edge orchestrator on one site and the partner MEF component on the other.

3.3 6G-XR USE CASE DEPLOYMENTS

The deployed architecture at the 6G-XR South Node experimentation site is tailored for testing the three use cases UC1, UC2, and UC3 related to real-time holographic communications as described in 6G-XR deliverable D1.1 [1]. Consequently, the South Node implements a subset of architectural components and interfaces defined in the overall reference architecture in 6G-XR deliverable D1.2 [2], as shown in Figure 3. New architectural enablers targeting the specific KPIs and functionalities required by the project use cases are drawn as purple blocks and developed in the project's technical work packages WP2-6. The existing technology enablers that are extended and modified to be applied to the 6G-XR use cases are drawn as dark blue blocks. The orange blocks depict components and functionalities related to the applications utilised in the experiments. The applications can change from use case to use case. Finally, the yellow blocks represent the main actors in the experimentation workflow, i.e., the 6G-XR experimenter performing the experiments using the offered configuration options and APIs, and the 6G-XR site owner having full configuration access and monitoring visibility into the infrastructure.

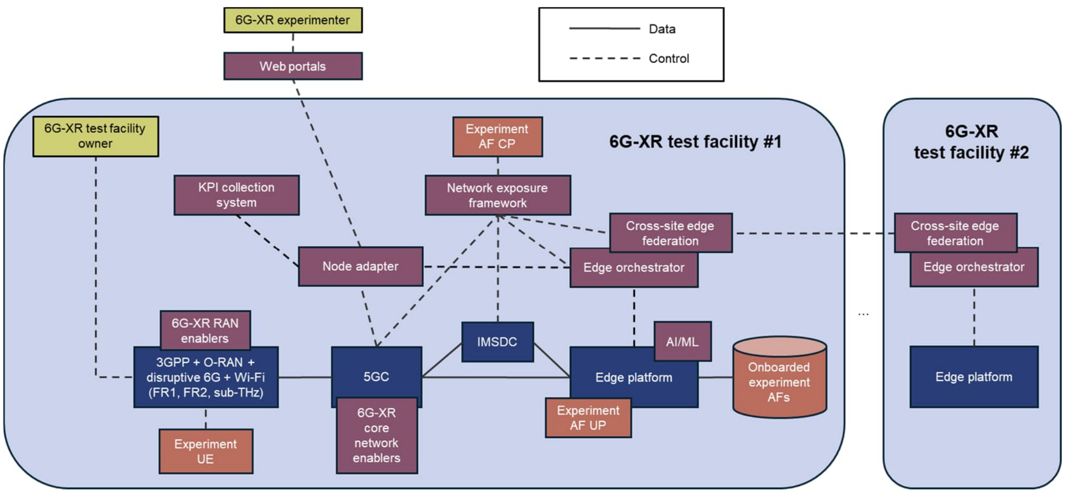

Figure 3. South Node use case deployment architecture.

Based on the UC1, UC2, and UC3 requirements, the UE-related enablers deployed across the South Node test facilities focus on extended reality (XR) capture and presentation hardware and XR application functionality as well as on RAN enablers covering 3GPP technology evolution and open RAN (O-RAN) network components. The core network enablers are focused on the network exposure function (NEF) and IMSDC. The network side XR application functionality is running at the network edge platforms distributed between two test facilities and the resources of both edges can be managed jointly with XR and edge orchestration functionalities.

The utilisation of different network resource and capability exposure interfaces in the South Node is focused on the open-source CAMARA APIs as well as on the standardised IMS and NEF APIs.

3.4 TESTING, MEASUREMENT AND MONITORING TOOLS

In addition to Qosium, which is the main network KPI measurement tool used in the 6G-XR RI as introduced in Chapter 2, additional information is also available for post-analysis from variety of tools at different test facilities if needed. These tools are not automatically running during the experiments and must be configured for use separately by the test facility owners. A short introduction to these additional testing, measurement, and monitoring tools available at the South Node test facilities is provided in the following subsections.

3.4.1 5Probe KPI measurement probe

The 5Probe [13] is a sniffer software tool that analyses the data plane traffic flows of the 5G network and measures KPIs. It can measure uplink throughput, downlink throughput, round trip time latency and one-way delay latency between two end points. The 5Probe can be deployed in different sections of the network. It works on top of any Linux machine.

3.4.2 InfluxDB and Grafana

At the South Node, the 5G network KPIs calculated by the 5Probes are stored in an InfluxDB [14]. That data is later visualised in Grafana [15] through dashboards for a more user-friendly interface.

3.4.3 Edge infrastructure monitoring

At the MEC orchestrator graphical user interface (GUI) at 5TONIC, the users, typically application providers, can access detailed reports regarding monitoring of Applications and Edge nodes. There are two types of reports can be created:

- Application-based reports
- Edge-based reports

For both kinds of reports, it is possible to obtain in a graphical way how the resource utilisation metrics -evolves over a period of time. Those specific metrics that can be known on resource utilisation per application, and per edge are: central processing unit (CPU), random access memory (RAM), disk, and GPU.

The edge node in Barcelona features a Prometheus [16] server that aggregates and collects real-time metrics for managing the orchestrator. There are no external public endpoints for obtaining monitoring information. Access to the Barcelona edge node is always routed through the Madrid node via the federation API.

3.5 TRIAL ON-BOARDING, EXECUTION AND RESULTS COLLECTION

The building blocks in green in Figure 4 represent the internal envisioned architecture of the experimentation site adapter on top of the South Node infrastructure. The experiment configuration done by the experimenter in the South Node web portal is provided to the South Node adapter in an NST. The South Node web portal is accessed through a common unified web portal as was shown in Figure 1 in Chapter 2.

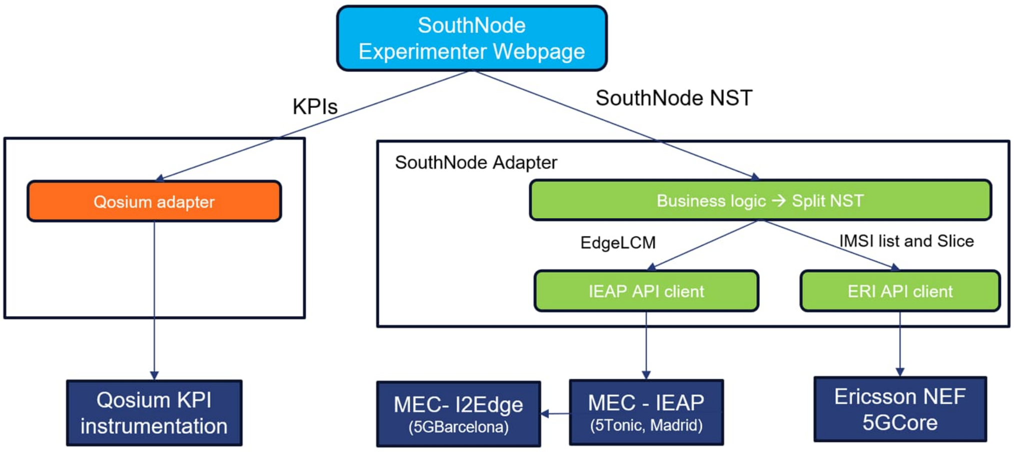

Figure 4. 6G-XR trial controller – South Node adapter.

Based on a common NST that will be used to define each experiment over 6G-XR Research Infrastructure, the South Node adapter will be considering the specific NST fields tailored for the deployment of the experiment into the South Node (South Node NST). It will be in charge of implementing the needed logic to launch each experiment into the South Node infrastructure, i.e., experiment (application) onboarding, instantiation and monitoring.

For that purpose, a specific South Node NST is being built considering the Northbound interface (NBI) APIs of the MEC orchestrator and the 5GC components at 5TONIC. The deployment of the experiments at the 5GBarcelona facility will be managed through the MEC NBI at 5TONIC and the federation implemented between both facilities.

The South Node adapter will first process the South Node NST to be understandable by the MEC orchestrator (i.e., IEAP) on one hand and by the Ericsson 5GC NEF on the other. Then, it also includes specific logic to call the API of those two main components at 5TONIC. Further details on the South Node Adapter and South Node NST will be provided in the future deliverables as the design and implementation work progresses. Besides the monitoring information that IEAP and NEF components will provide to the South Node adapter, the Qosium adapter will be implemented for other complementary metrics to be exposed to the experimenter.

The detailed workflow for the remote 3rd party experimenters to access the 6G-XR RI assets and configure the selected experimentation site through the project's web portals will be described in the Open Call 3 documentation.

4 NORTH NODE EXPERIMENTATION SITE

The 6G-XR North Node comprises two separate test facilities located in Oulu, Finland. The two test facilities are called UOULU 5GTN and VTT 5GTN. The North Node test facilities host two 6G-XR use cases focusing on enabling technologies for 3D digital twins (DTs) and E2E energy efficiency (EE) optimisation:

- UC4 – Collaborative 3D Digital Twin-like Environment
- UC5 – Energy Measurement Framework for Energy Sustainability

Subsections 4.1and 4.2 provide details of the North Node test facilities as they are available during the experimentation phase of the 6G-XR project. The deployed architectures of the hosted use cases, implementing subsets of the overall 6G-XR reference architecture described in deliverable D1.2 [2], are covered in 4.3. The detailed descriptions of the use cases themselves can be found in deliverable D1.1 [1]. Subsection 4.4 lists the testing, monitoring, and measurement tools available for the experimenters at the North Node test facilities, and 4.5 outlines the utilised experiment on-boarding and execution procedures.

4.1 UOULU 5GTN

The 5G Test Network (5GTN)[2] of the University of Oulu is deployed primarily at the Linnanmaa campus (both outdoor and indoor 5G installation), and with remote indoor deployment at the local university hospital TestLab near the centre of the city of Oulu. 5GTN offers extensive experimenting possibilities with its small cell, macro-cell and distributed antenna system (DAS)-based cellular network. It is complemented by network functions virtualisation (NFV)-based evolved packet core (EPC) and 5G backhauling solution. 5GTN can be considered as a micro-operator at the University of Oulu campus area with its own SIM cards.

The 5G test network supports the use of 5G devices, higher frequency bands, cognitive management functionalities, and system testing tools for new solutions. The 5G Test Network feature evolution follows 5G research and standardisation, acting as a verification platform for theoretical and practical 5G research. The network is composed of tens of fourth generation (4G) long term evolution (LTE) small cells (2.1, 2.6 GHz) and several macro cells with different LTE and 5G capabilities (700MHz, 2.6GHz, 3.5 GHz). The network has three 5G NR base stations (3.5 GHz) complemented with UEs from MediaTek, Quectel and several other manufacturers that are easily integrated into any device, and tens of 5G-enabled mobile phones from several vendors. For research purposes, it has also pre-standard 5G-capable NOKIA prototype devices at 26-28 GHz and newly introduced commercial grade mmW base station on the 25 GHz band. The network is controlled by an operator-grade 4G EPC, and 5G standalone (SA) and non-standalone (NSA) cores, thus making OULU in practice a network operator with its own SIM production for mobile devices. The current EPC version is 5G NSA compliant but a new commercial grade 5G SA core that has also the NSA capability has been taken into use. 5GTN has also open-source cores available. For example, Open5GS [17] with one macro base station in SA mode. Several OAIBOXes [18] offer complete SA 5G network functionality with Core, software radios with USRP HW radios. Recently the whole IP network has been renewed and the transmission network speed has increased from 1Gbps to 100Gbps. The network within the campus is complemented by a wireless sensor network / Internet of Things (IoT) extension with estimated 2000 different kinds of sensors with wireless connectivity through narrowband IoT (NB-IoT), LTE machine type communication

[2] 5GTN website: http://5gtn.fi/

(LTE-M) and LoRa. Furthermore, the network has dedicated servers for network data analytics purposes. Some of these servers are distributed within the network thus allowing MEC as well as caching services. University of Oulu 5GTN architecture is presented in Figure 5.

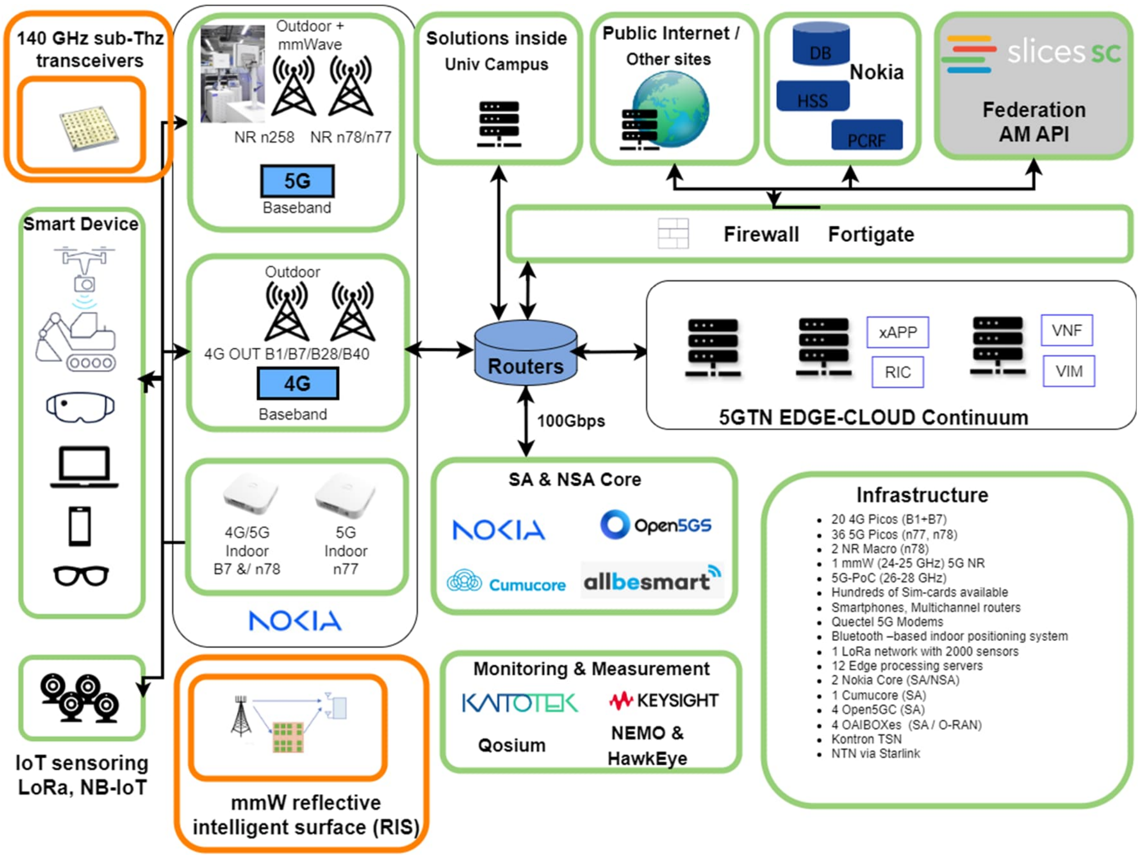

Figure 5. UOULU 5GTN architecture.

4.1.1 Radio access network

The University of Oulu 5GTN offers 4G LTE and 5G NR RAN technologies. The 5GN network has indoor and outdoor coverage with multiple 4G, 5G NSA and SA base stations. Both commercial eNBs/gNBs from Nokia and software-defined radio (SDR)-based gNBs are offered. The network is continuously upgraded to keep up to date in 3GPP development. The network can be tailored to suit different experiment needs by configuring the network components parameters. 5GTN frequency bands are listed in Table 5.

Table 5: Licensed frequency bands available at UOULU 5GTN test facility

Frequency band	Type	Duplexing		Start freq.	Stop freq.	BW (MHz)
700 MHz (B28)		FDD	DL	789,9	790,1	0,2
			UL	734,9	735,1	0,2
2.1 GHz (B1)	TTO radio permit	FDD	DL	2125.2	2130	4,8
			UL	1935,2	1940	4,8
2.1 GHz (B1)	TTO radio permit	FDD	DL	2130	2134,8	4,8
			UL	1940	1944,8	4,8
2.3 GHz (B40)	Private LTE	TDD		2300	2320	20
2.6 GHz (B7)	TTO radio permit	FDD	DL	2640	2650	10
			UL	2520	2530	10
3.5 GHz (N78)	TTO radio permit	TDD		3510	3570	60
4.0 GHz (N77)	5G	TDD		3800	4000	200
25 GHz (N258)	5G	TDD		24250	25100	850

4.1.2 Core and transport network

The core of the network supports 100 Gbps. 5G Cores and the main Edge nodes are connected with 100 Gbps speed. The second-tier equipment has speed of 40 Gbps, while the nodes like base stations at the edge are connected with 10 Gbps speed. The network offers an internet connection, protected by a commercial-grade firewall. For remote users, a VPN connection is available.

The 5GTN has several 5G cores and both SA and NSA networks available. Two different commercial grade 5G cores (Nokia & Cumucore [19]) and two open-source cores (CN5G [20] and Open5GS [17]) can be used. Several independent 5G networks utilising OAIBOXes [18] are available.

More information on the utilisation of different cores and their functionalities in the 6G-XR experiments can be found in the 6G-XR deliverable D2.1 [6].

4.1.3 Edge and cloud computing

Several Edge computers complemented by 100 TB Data Storage are available. Edge computers offer virtualisation with virtual machines (VMs) or they can be also offered as bare metal. Several powerful GPU accelerators are available and a 3D scanner that can be used to scan human sized objects is available. Local breakout with UPF is supported.

4.1.4 Orchestration and management

5GTN has several federation and orchestration activities ongoing. Orchestration and management are being developed in several EU-funded projects. It follows a list of different projects and their federation and/or orchestration activities:

- Slices-SC: Remote access and experiment planning offered through unified web portal.
- Slices-PP: Slices-PP blueprint federation and orchestration is to be introduced during 2024.
- 6G-Sandbox: Federation and orchestration of several test facilities.
- Sunrise-6G: Federation utilising different methods. 5GTN uses Slices-PP Blueprint. Orchestration of several facilities.

4.2 VTT 5GTN

The VTT 5GTN test facility is operated and maintained by VTT Technical Research Centre of Finland (VTT) in Oulu, Finland. The deployed 5G/6G test network enables performance and functionality testing of new communication technologies and services in a flexible configurable network environment. The infrastructure has been designed to support dynamicity in experimentation and provides multiple configuration options for its network architecture. They range from wireless access technologies to network core and edge solutions. The exact E2E test setup can be tailored based on the needs and requirements of the planned experiments. A high-level overview of the different types of network components available at the test facility is provided in Figure 6.

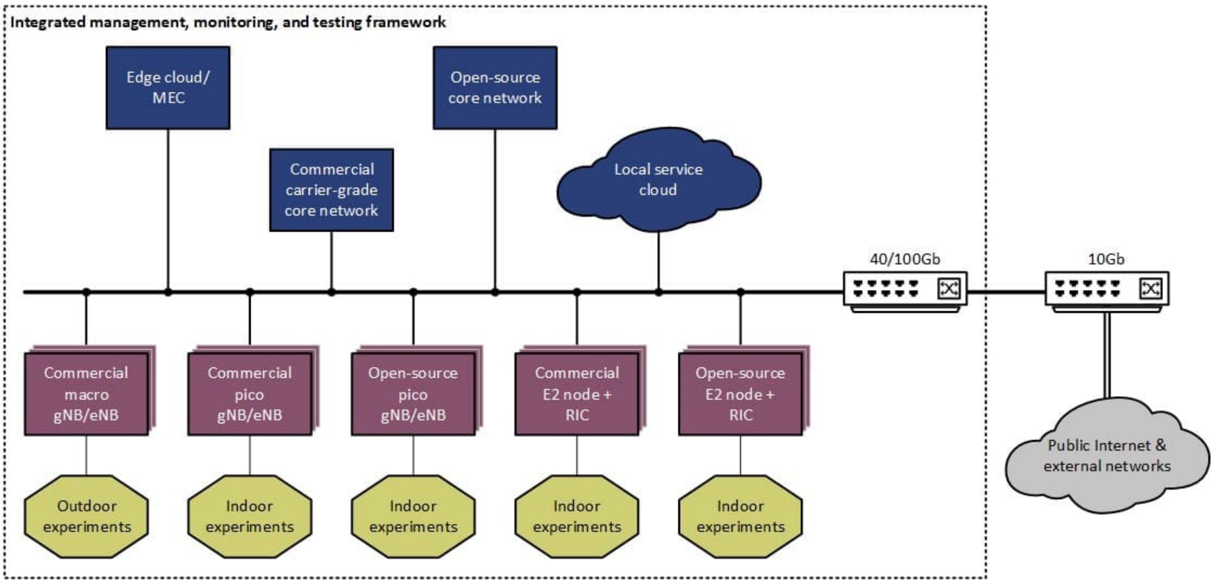

Figure 6. High-level overview of the VTT 5GTN test facility components.

The test site also includes a multi-functional and uninterruptible power supply system based on Victron Energy's Multiplus-II inverter/charger technology [21]. The applied microgrid topology and its practical setup in the test facility enables both flexible grid-parallel and islanded off-grid type of usage and fast transfers between these modes (< 20 ms). The system contains bi-directional controllable grid interface and distribution cabinets equipped with required the protection systems. The system is supplying power to the RAN and core network (CN) components in VTT 5GTN.

The power supply system comprises of local renewable solar energy production with photovoltaic (PV) modules, $LiFePO_4$ battery energy storage system, and local and cloud-based intelligent energy monitoring and control systems that can be used to continuously control the utilised energy sources (i.e., usage of solar yield to battery charging/discharging and grid-intake or feed-in) and follow up KPIs. Based on previous and aggregated power consumption in the microgrid, the energy controller tries to optimise the daily control patterns by means of monitored state of the system, solar yield and consumption forecasts, and other data from external cloud services. When forecasting errors occur, the controller utilises available resources to get energy management back on predicted track. The power system is modular and capable of supplying both 48 VDC and 230 VAC devices.

4.2.1 Radio access network

The main radio coverage at VTT 5GTN is deployed using 4G LTE and 5G NR technologies. The RAN infrastructure installed at the VTT Oulu premises comprises a multi-radio access technology (RAT) outdoor macro cell site and multiple indoor small cells providing both 4G and 5G connectivity. Commercial eNBs/gNBs (Nokia) and SDR-based eNB/gNB implementations running an open-source srsRAN protocol stack [22] are available. Both RAN options are continuously updated towards 5G-advanced (5G-A) by adopting new 3GPP Release 16-18 recommendations as they become available in the base station software. Base station configurations (e.g., number of cells, frequency band, bandwidth, transmission power, UL/DL ratio) and antenna setups can be tailored towards the specific requirements of a planned experiment. In addition to the cellular coverage, Wi-Fi 6/6E/7 technology is also available for indoor experiments.

The licensed frequency bands and maximum bandwidths that can be used for mobile network technologies at the VTT 5GTN test facility are listed in Table 6. While the network coverage with the 5G NR is typically < 1 km due to the relatively low installation height of the outdoor macro site antennas, the attained coverage can reach > 10 km when sub 1 GHz frequencies are used with LTE-M and NB-IoT technologies.

Table 6: Licensed frequency bands available at VTT 5GTN test facility

Band #	Frequency	Max. bandwidth	Remarks
B1	2100 MHz	10 MHz	-
B3	1800 MHz	5 MHz	-
B7	2600 MHz	10 MHz	-
B28	700 MHz	3 MHz	LTE-M/NB-IoT
B31	450 MHz	5 MHz	LTE-M/NB-IoT
n77	3700 MHz	100 MHz	-
n78	3500 MHz	60 MHz	-
n258	26 GHz	800 MHz	Max. UL BW: 400 MHz

In addition to the typical 3GPP next generation RAN (NG-RAN) architecture, O-RAN E2 nodes with open monitoring and RAN control APIs are available. Experimenters can interact with the E2 nodes through a RAN intelligent controller (RIC) and xApps. O-RAN functionality can be provided with both commercial (Accelleran) and open source (srsRAN protocol stack with FlexRIC [23]) solutions. The O-RAN architecture provides additional components and interfaces into the 3GPP NG-RAN architecture enabling more dynamic monitoring and programmable centralised control for the RAN resources. Enhanced support for distributed RAN deployments and artificial intelligence (AI) workflows in RAN management also provide more deployment flexibility and additional experimentation possibilities compared to the NG-RAN.

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The available end device options include newest commercial UEs (smartphones and wireless routers) and programmable modem development/evaluation boards. An SDR-based UE emulator (Keysight) can also be used for scalability testing, as it is capable of generating CP and user plane (UP) traffic for up to hundreds of 4G LTE or tens of 5G NR UEs simultaneously.

More information on the developed enhancements and utilisation of RAN enablers in the 6G-XR project can be found in deliverable D4.1 [7].

4.2.2 Core and transport network

The CN services are running as virtual network functions (VNFs) in the local data centre at VTT Oulu premises. Depending on the required functionality and performance, different implementation options are available for the trials. The desired core network functionality can be provided as a carrier-grade EPC/5GC telco cloud (Nokia) or a more lightweight open-source 5GC implementation (Open5GS [17]). Similarly to the RAN part of the test facility, the software of both core network instances is continuously updated towards 5G-A functionalities.

The fixed backbone network at the test facility is based on 40/100 Gb connections. Connectivity towards public Internet and remote test sites is based on 10 Gbps transport connections. Links to remote test sites utilise the Finnish University and Research Network (Funet) [24] or GÉANT [25] fibre infrastructures are available when possible. Transport connections to external networks or remote test sites which are out of reach of the Funet/GÉANT infrastructures can be set up relying on VPN tunnels over public Internet.

The test facility supports network slicing in the core network. The transport network can be sliced using software-defined networking (SDN). Slicing can be extended into the wireless access network with dynamic traffic prioritisation using 3GPP equipment or with fixed physical resource block (PRB) shares per UE using O-RAN.

4.2.3 Edge and cloud computing

Edge processing capacity is available for varying needs ranging from VNFs to data analysis and multimedia processing. Edge resources can be used jointly with all available commercial and open-source RAN and CN solutions. AI workloads are supported by using edge servers equipped with Nvidia H100 GPUs. The deployed edge solutions include general-purpose hardware and open-source software, as well as commercial proprietary solutions. Local data breakout following the ETSI MEC specifications is also supported.

4.2.4 Orchestration and management

The integrated network management and monitoring framework has been deployed using a combination of proprietary and open-source tools. The management of individual network components in the RAN and CN is performed through APIs made available in the deployed software either connecting to them directly or through a network management software provided by the vendor of the software/hardware component in question. The level of automation and dynamicity of network management procedures are planned and implemented case-by-case based on the experimentation needs. The overall network management functionality is based on the interworking of network subsystem managers. For example, separate RAN, CN, and edge resource managers can be used to provide the overall network management functionality needed in an E2E use case trial.

There is no test network wide orchestration layer deployed in the VTT 5GTN test facility. The orchestration capabilities for remote experimentation configuration and setup are provided through the 5G-XR trial controller and North Node adapter described in 4.5.

4.3 6G-XR USE CASE DEPLOYMENTS

The deployed architecture at the 6G-XR North Node experimentation site is tailored for testing the project's use cases on collaborative 3D digital twins in UC4 and E2E energy efficiency in UC5 as described in 6G-XR deliverable D1.1 [1]. Consequently, the North Node implements a subset of architectural components and interfaces defined in the overall reference architecture in 6G-XR deliverable D1.2 [2], as shown in Figure 7. New architectural enablers targeting the specific KPIs and functionalities required by the project use cases are drawn as purple blocks and developed in the project's technical work packages WP2-6. The existing technology enablers that are extended, modified, and applied to the 6G-XR use cases are drawn as dark blue blocks. The orange blocks depict components and functionalities related to the applications utilised in the experiments. The applications can change from use case to use case. Finally, the yellow blocks represent the main actors in the experimentation workflow, i.e., the 6G-XR experimenter performing the experiments using the offered configuration options and APIs, and the 6G-XR site owner having full configuration access and monitoring visibility into the infrastructure.

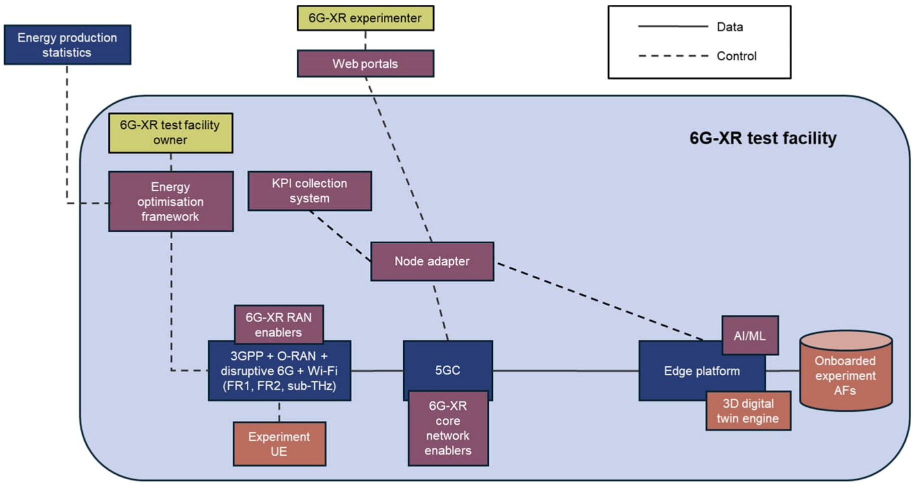

Figure 7. North Node use case deployment architecture.

Based on the UC4 needs, the UE enablers deployed across the North Node test facilities focus on XR presentation hardware. The deployed RAN enablers cover the three 6G development avenues from 3GPP technology evolution and open-source/O-RAN network components to disruptive 6G technologies in the form of sub-THz transceivers. In addition, Wi-Fi based time sensitive networking (TSN) is available. In the core network, the focus is on network slice management. The deployed enablers at the edge platform include AI/ML algorithms for network resource management and 3D digital twin engine.

For UC5, the RAN deployment includes the 3GPP technology evolution, open-source and O-RAN components, as well as the slicing enablers in the core network. The energy optimisation framework is deployed at the network edge platform and connected cloud services provide open data related to cost and CO2 counters of the energy consumed in the network.

The utilisation of open and standardised interfaces in the North Node is focused on O-RAN specified and vendor-specific APIs, which are able to serve the specific needs of both UC4 and UC5. When utilising open-source implementations of network functions in the experimentation setup, additional interfaces and APIs can potentially be made available if necessary.

4.4 TESTING, MEASUREMENT AND MONITORING TOOLS

In addition to Qosium, which is the main network KPI measurement tool used in the 6G-XR RI as introduced in Chapter 2, additional information for post-analysis is also available from variety of tools at different test facilities if needed. These tools are not automatically running during the experiments and must be configured for use separately by the test facility owners. A short introduction to these additional testing, measurement, and monitoring tools available at the North Node test facilities is provided in the following subsections.

4.4.1 Keysight Nemo Handy/Nemo Outdoor Playback

Keysight Nemo Handy [26] is a handheld monitoring solution for drive testing and in-building measurements. Nemo Handy supports all the latest wireless technologies and runs on Android-based 5G handheld devices. Nemo Handy measures the performance of various applications at the air interface, as well as the application layer QoS / quality of experience (QoE) levels. It also provides the monitoring of the control signalling performed between the UE and network. Accompanied by the Nemo Outdoor playback analysis software that can be used to replay and analyse measurement runs recorded with Nemo Handy, these tools are mostly used for throughput measurements during the field trials as well as for monitoring and debugging of the air interface.

4.4.2 Keysight UeSIM

Keysight UeSIM [27] is a testing system for generating traffic and emulating the behaviour of UEs. UeSIM emulates 4G LTE, 5G NR NSA, and 5G NR SA user devices over the air interface, supporting over-the-air (OTA) testing. UeSIM can be used to build standalone test campaigns where the KPI measurements are performed for the group of emulated UEs or for generating realistic background traffic for physical UEs under measurement.

4.4.3 Vendor-specific monitoring tools

Vendor-specific software is used to collect additional monitoring information and high-level measurement logs from the commercial solutions installed in the North Node test facilities. The vendor-specific software provides direct access to the internal management interfaces of the network components, which are not accessible with external monitoring and measurement tools. Examples of utilised vendor-specific tools include the software used to access the measurement logs recorded internally by the 5G modems and 4G/5G base stations during experiments.

4.4.4 iPerf performance measurement tool

iPerf [28] uses an active measurement approach to determine the maximum achievable bandwidth in IP networks. Measurements can be performed with test traffic relying on transmission control protocol (TCP), stream control transmission protocol (SCTP), user datagram protocol (UDP), as well as on IP versions 4 and 6.

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4.4.5 InfluxDB and Grafana

InfluxDB [14] is used as a central database for gathering and storing network KPIs and energy measurement data from multiple data sources at the North Node test facilities. The data from InfluxDB are visualised for monitoring and post-analysis purposes with Grafana [15] dashboards. It provides multiple options for data visualisation, tools for automated alerts and integration with several other collaboration and DevOps tools.

4.4.6 Energy measurement framework

The mobile network infrastructure has been equipped with accurate real-time energy analysers and electricity metering systems enabling monitoring of power consumption of network components and connected devices. Measurement results (several datapoints per meter) can be collected at 1/s intervals and stored into InfluxDB to enable profound retrospective energy consumption analysis. Almost real-time data of selected locally constructed data pipes can be visualised by means of Grafana dashboards. In addition, 1/min data widgets are available in the cloud service and can be utilised to monitor embedded sensors datapoints and construct needed KPIs to tailor-made trials. More detailed specification of the equipment and hardware/software systems applied in the energy measurement framework can be found from the 6G-XR deliverable D5.1 [29].

4.4.7 Time synchronisation tools

Accurate time synchronisation for the deployed network equipment is provided with a global navigation satellite system (GNSS)-based precision time protocol – version 2 (PTPv2) grandmaster clock. Accurate and robust atomic clock-based time synchronisation is also available for mobile clients and indoor environments with a mobile compact PTP time server. Time synchronisation plays a key role in the accurate data delivery and measurement timing needed in the various validation test cases related to low-latency services.

4.5 TRIAL ON-BOARDING, EXECUTION AND RESULTS COLLECTION

In the North Node, the node adapter has a central role in the management and orchestration of the experiments and network resources related to the experimentation setups. It interfaces the configurable network and service infrastructure components at the North Node experimentation site and handles the measurement triggering towards the KPI collection system for the experiments. Overall, the North Node adapter is responsible for:

- Management and orchestration of the experiments
- Configuring the test facility components according to NST received from the North Node web portal
- Starting the experiment
- Transferring the measurement parameters from the Qosium measurement system / Cumucore monitoring APIs to AI during the experiment
- Transferring the reconfiguration parameters from AI to Qosium/Cumucore during the experiment
- Recording the different experiment configurations to a log file
- Stopping the experiment

The detailed workflow for the remote 3rd party experimenters to access the 6G-XR RI assets and configure the selected experimentation site through the project's web portals will be described in the Open Call 3 documentation.

5 SUMMARY

This document provided a detailed description of the deployment details of the 6G-XR RI, experimentation sites (South Node and North Node), and test facilities (5GBarcelona, 5TONIC, UOULU 5GTN, and VTT 5GTN).

The structure and building blocks of the 6G-XR RI were described in Chapter 2. The description covered the overall 6G-XR RI comprising two experimentation sites located in Spain and Finland, and explained how both experimentation sites include two separate but interconnected test facilities, which are able to share resources and data in their experimental setups if needed. In addition, high-level details on how the 6G-XR RI resources and assets can be accessed remotely and how network KPIs are collected during experimentation were presented.

The details of the South Node and North Node experimentation sites and their two test facilities were provided in Chapter 3 and 4, respectively. The available RAN, core network, edge, cloud, orchestration and management domain enablers, and configuration options were described. These configuration options provide the required flexibility of for the 6G-XR RI when deploying different use case trials on top of the test facilities. As an example of the different deployment options utilised at the experimentation sites, the specific architectures used to validate the 6G-XR use cases at the South and North Node were also presented.

The testing, measurement, and monitoring tools available for the experimenters at the test facilities were also listed in Chapter 3 and 4. In addition to the main KPI measurement, a variety of logs are available from the different test facility components for troubleshooting and results analysis purposes. The high-level experiment onboarding, execution, and management processes were also summarised for both the South and North Node experimentation sites.

6 REFERENCES

[1] 6G-XR, ”Requirements and use case specifications,” Deliverable D1.1, Sep. 2023. Available: https://www.6g-xr.eu/deliverables/

[2] 6G-XR, ”Reference architecture description,” Deliverable D1.2, Jun. 2024. Available: https://www.6g-xr.eu/deliverables/

[3] Kaitotek Qosium, [Online]. Available: https://www.kaitotek.com/qosium [Accessed 9 May 2024].

[4] GSMA Operator Platform Group – Requirements and Architecture, Version 5.0, July 2023. Available: https://www.gsma.com/solutions-and-impact/technologies/networks/wp-content/uploads/2023/07/OPG.02-v5.0-Operator-Platform-Requirements-and-Architecture.pdf

[5] Linux Foundation CAMARA project, [Online]. Available: https://camaraproject.org/ [Accessed 13 June 2024].

[6] 6G-XR, ”Orchestration, AI techniques, End-to-end slicing and Signalling for the core enablers – design,” Deliverable D2.1, February 2024. Available: https://www.6g-xr.eu/deliverables/

[7] 6G-XR, ”State-of-the-art analysis and initial design of beyond 5G RAN, core, and open-source networks, disruptive RAN technologies and trial controller,” Deliverable D4.1, March 2024. Available: https://www.6g-xr.eu/deliverables/

[8] RedIris,[Online]. Available: https://www.rediris.es/lared/ [Accessed: 13 June 2024].

[9] ETSI – Multi-access Edge Computing – Standards for MEC, [Online]. Available: https://www.etsi.org/technologies/multi-access-edge-computing [Accessed 13 June 2024].

[10] OpenStack, [Online]. Available: https://www.openstack.org/ [Accessed 13 June 2024].

[11] GSMA Operator Platform Group (OPG), [Online]. Available: https://www.gsma.com/solutions-and-impact/technologies/networks/operator-platform-hp/ [Accessed 13 June 2024].

[12] GSMA, “East-Westbound Interface APIs,” OPG.04 version 4.0, Feb. 2024. Available: https://www.gsma.com/solutions-and-impact/technologies/networks/wp-content/uploads/2024/02/OPG.04-v4.0-EWBI-APIs.pdf

[13] 5Probe, [Online]. Available: https://github.com/5GEVE/5Probe [Accessed 13 June 2024]

[14] InfluxDB, [Online]. Available: https://www.influxdata.com/ [Accessed 9 May 2024].

[15] Grafana, [Online]. Available: https://grafana.com/ [Accessed 9 May 2024].

[16] Prometheus, [Online]. Available: https://prometheus.io/ [Accessed 26 June 2024].

[17] Open5GS, [Online]. Available: https://github.com/open5gs [Accessed 9 May 2024].

[18] OAIBOX, [Online]. Available: https://oaibox.allbesmart.pt/ [Accessed 11 June 2024].

[19] Cumucore, [Online]. Available: https://cumucore.com/ [Accessed: 12 June 2024].

[20] CN5G, [Online]. Available: https://gitlab.eurecom.fr/oai/cn5g [Accessed 12 June 2024].

[21] MultiPlus-II, [Online]. Available: https://www.victronenergy.com/inverters-chargers/multiplus-ii [Accessed: 28 June 2024].

[22] srsRAN Project, [Online]. Available: https://github.com/srsran/srsran_project [Accessed 9 May 2024].

[23] FlexRIC, [Online]. Available: https://gitlab.eurecom.fr/mosaic5g/flexric [Accessed 9 May 2024].

[24] Funet, [Online]. Available: https://wiki.eduuni.fi/display/funet/info.funet.fi [Accessed 11 June 2024].

[25] GÉANT, [Online]. Available: https://geant.org/ [Accessed 11 June 2024].

[26] Keysight Nemo, [Online]. Available: https://www.keysight.com/us/en/products/nemo-wireless-network-solutions.html [Accessed 9 May 2024].

[27] Keysight UeSIM, [Online]. Available: https://www.keysight.com/us/en/product/P8800S/uesim-ue-emulation-ran-solutions.html [Accessed 9 May 2024].

[28] iPerf, [Online]. Available: https://iperf.fr/ [Accessed 9 May 2024].

[29] 6G-XR, ”Description of sustainability experimentation framework,” Deliverable D5.1, Jun. 2024. Available: https://www.6g-xr.eu/deliverables/