VertIcal demos over Common large scale field Trials fOr Rail, energy and media Industries

D4.2 Intra-Field trials integration and vertical services execution and KPI validation

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Executive Summary

5G-VICTORI Work Package (WP) 4 (**WP4**), entitled "Trials of Coexisting Vertical Services, validation and KPI evaluation", focuses on coordinating and conducting large scale field trials for use case (UC) verification in 5G environments. This is carried out along with a number of Vertical Industries from the sector like Transportation, Energy, Media and Factories of the Future, as well as some specific UCs involving cross-Vertical interaction. To achieve the above scope, the trials are being executed at Vertical facility sites where 5G technologies provided by all ICT-17 infrastructures have been deployed. These infrastructures are 5GENESIS (Berlin, Germany), 5G-VINNI (Patras, Greece), 5G-EVE (France/Romania), and the 5GUK testbed (Bristol, UK).

These 5G facilities have been extended to enable integration with the Vertical facility sites and, in all cases, they have been enhanced with features that are required to meet the expected Key Performance Indicators (KPIs) relevant to the UCs they showcase. In this context, existing infrastructures required enhancements in terms of both coverage and other capabilities to demonstrate the 5G-VICTORI Vertical and cross-Vertical UCs in real operational environments.

These facilities arise from a common flexible 5G network architecture, which has been inspired by standardised 5G architectural approaches, i.e. ETSI, 3GPP, IEEE and Open Radio Access Network (O-RAN), adding to these innovative features. The four 5G-VICTORI facilities (Patras, Berlin, Bristol, FR/RO) offer different flavors of 5G implementations.

This deliverable considers the KPIs defined in **WP2** as the reference KPIs to which compare the initial results obtained from the field trials. This is done with respect to the 5G KPIs and to those KPIs related to the services provided by the Vertical Industries. The 5G-VICTORI extensions to the operational environments, including components (5G and Vertical-related) follow the descriptions described in deliverables **D2.2** and **D2.3**. Each of the facilities offer different flavors of 5G implementations but they arise from a common flexible 5G architecture described in deliverable **D2.4** .

The definition of the test cases, services and procedures to assess the KPIs, together with the testing methodology defined in **WP3**, are provided to this deliverable as input for the evaluation of the field trials.

The 5G KPIs and the Vertical-specific KPIs are validated against specific performance targets through well-defined experimentation procedures defined in deliverable **D4.1** [1], leading to specific, meaningful, reproducible, and achievable results in similar contexts. 5G-VICTORI goes beyond the initial harmonisation of procedures at logical level, to the implementation of a common framework to materialise this alignment, namely the 5G-VICTORI Operation System (5G-VIOS), which is partially leveraged for the field trials here captured.

Optimization and improvements to the obtained KPIs are expected in the next deliverable release (**D4.3**), which will contain the last set of results stemming from 5G-VICTORI field trials (June 2023), with a broad use of 5G-VIOS.

1 Acronyms

1.1 General

Acronym	Description
3GPP	Third Generation Partnership Project
4G	a.k.a. Long Term Evolution (LTE)
4K	Same as UHD, using resolution 3840 x 2160 pixels
5G	Fifth Generation cellular system (3GPP related)
5GNR	5G New Radio
5G-VIOS	5G-VICTORI Operation System
5QI	5G NR Standardized QoS Identifier
AMF	Access and Mobility Management Function
AP	Access Point
API	Application Programming Interface
APN	Access Point Name
AR	Augmented Reality
ARP	Allocation and Retention Priority
AUSF	Authentication Server Function
BBU	Baseband Unit
BE	Best Effort
BSCW	The document server used in the 5G-VICTORI project
CCS	Cambridge Communications Systems
CCTV	Closed Circuit TV
CDN	Content Delivery Network
COTS	Commercial Off-The-Shelf
CPE	Customer Premises Equipment
CPRI	Common Public Radio Interface
CPU	Central Processing Unit
CN	Core Network
DCU	Data Capture Unit
DL	Downlink
DN	Data Network
DNN	Data Network Name
DRB	Data Radio Bearer
e2e	End-to-End
EF	Expedited Forwarding, DHCP related
eMBB	Enhanced Mobile Broadband
eNB	Evolved Node B
EMS	Energy Management System
FRMCS	Future Rail Mobile Communication System
FTP	File Transfer Protocol
GBR	Guaranteed Bit Rate

GIS	Geographic Information System
gNB	gNodeB, new base station that goes with NR
GPS	Global Positioning System
GPU	Graphics processing unit
GW	Gateway
HPN	High-Performance Networks group
HSS	Home Subscriber Server
i2SM	i2CAT's Slicing Management
ICM	Inter-domain Connectivity Manager
IMPU	SIP Core Identity
IMS	IP Multimedia Subsystem
IMSI	International Mobile Subscriber Identity
IP	Internet Protocol
iPerf	Measurement tool, can be downloaded here.
K8s	Kubernetes
LAA	Licensed-Assisted Access (5G related)
LAN	Local Area Network
LLC	Last Level Cache
LoS	Line-of-Sight
LTE	Long Term Evolution (4G)
LTE-A	LTE Advanced
LTE-M	LTE-Machine Type Communication (MTC)
M-MIMO	Massive MIMO with beamforming
MaaS	Mobility as a Service
MAC	Medium Access Control
MANO	Management and orchestration
MBB	Mobile BroadBand
MCData	Mission Critical service Data
MCPTT	Mission Critical service PTT
MCS	Mission Critical Service
MCVideo	Mission Critical service Video
MCX	Mission Critical Services, X = {MCPTT, MCData, MCVideo}
MEC	Multi-Access Edge Computing
mMTC	Massive Machine Type Communications
mmWave	Frequency band 24 GHz to 100 GHz
MPEG-SAND	Moving Picture Experts Group Server and Network Assisted DASH
MPLS	Multiprotocol Label Switching
MR	Media Router
MRF	Multimedia Resource Function
M Shed	Museum in Bristol
NBMP	Network Based Media Processing
NF	Network Function
NFV	Network Function Virtualization
NUC	Next Unit Computing

MVB	Merchant Venturers Building
N78	3500 MHz TDD band (3300 – 3800 MHz)
NB-IoT	Narrow Band Internet of Things
NetOS	Zeetta Automate
NR	New Radio (5G related)
NS	Network Service
NSA	Non-Standalone
OAI	OpenAirInterface
OB	Onboard
OCC	Operation Control Center
ONAP	Open Network Automation Platform
OpenMNT	Open Mobile Network Toolchain
O-RAN	Open RAN
OSM	Open Source MANO
P-CSCF	Proxy Call Session Control Function
PCF	Policy Control Function
PDCP	Packet Data Convergence Protocol
PDU	Protocol Data Unit
PHY	Physical layer
PLMN	Public Land Mobile Network
PP	Probe Pair
PTMP	Point-to-MultiPoint
PTT	Push-To-Talk
QCI	QoS Class identifier
QFI	QoS Flow Identifier
RAMS	Reliability, Availability, Maintainability & Safety
RAN	Radio Access Network
RaSTA	Rail Safe Transport Application
RAT	Radio Access Technology, like 4G, 5G, Wi-Fi
RLC	Radio Link Control
RMS	Railway Management System
RRH	Remote Radio Head
RRU	Radio Remote Unit
RS	Rail Signaling
RS485	Serial balanced bus
RSRP	Received Strength Reference Power
SA	Stand Alone
SD	Slice Differentiator
SDN	Software Defined Network
SDR	Software Defined Radio
SDS	Short Data Service
SGX	Software Guard Extensions (Intel® SGX)
SIM	Subscriber Identification Module
SIP	Session Initiation Protocol

SLAM	Simultaneous localization and mapping
SMF	Session management Function
SNMP	Simple Network Management Protocol
S-NSSAI	Single Network Slice Selection Assistance Information
SRA	Shared Resource Allocation
SSID	Service Set IDentifier (Wi-Fi related)
SST	Service Slice Type
TAP	Test Access Point
TDD	Time Division Duplex
TOBA	Telecom On-Board Architecture
TOC	Table Of Content
UC	Use-Case
UDM	Unified Data Management
UE	User Equipment
UHD	Ultra-High Definition (TV or computer screens)
UL	Uplink
UPF	User Plane Function
uRLCC	ultra-Reliable Low Latency Communications
USRP	Universal Software Radio Peripheral
VIOS	VICTORI Infrastructure Operating System (see D2.5)
VLAN	Virtual LAN
VM	Virtual Machine, e.g. using VMware
VNF	Virtual Network Functions
VPN	Virtual Private Network
VR	Virtual Reality
VSI	Vertical Service Instance
Wi-Fi	IEEE 802.11
WTC	We The Curious

1.2 5G-VICTORI specific acronyms, partners and related EU projects

Acronym	Description
5G-EVE	Alba Iulia ICT-19 Cluster (e)
5G-UK	The Bristol ICT-19 Cluster (u)
5G-VINNI	The Patras ICT-19 Cluster (v)
5GENESIS	The Berlin ICT-19 Cluster (g)
5G-PPP	5G infrastructure Public Private Partnership
ADMIE	Aka **IPTO**, Independent Power Transmission Operator (5G-VICTORI Partner)
AIM	Alba Iulia Municipality (5G-VICTORI Partner)
Alstom	Bombardier Transportation Sweden AB has from January 22 2023 changed its name to ALSTOM Rail Sweden AB, but keeps the same registration number and VAT number as before.
COSM	COSMOTE (5G-VICTORI Partner)

DBH	Deutsche Bahn Holding (5G-VICTORI Partner)
DBN	DB Netz (5G-VICTORI Partner)
DCAT	Digital Catapult (5G-VICTORI Partner)
EUR	Eurecom (5G-VICTORI Partner)
FhG	Fraunhofer FOKUS (5G-VICTORI Partner)
ICT-17	The 5G platform developed for the 5G-PICTURE EU project
ICT-19	The 5G platform developed for the 5G-VICTORI
I2CAT	I2CAT Foundation (5G-VICTORI partner)
IASA	Institute of Accelerating Systems and Applications (5G-VICTORI partner)
ICOM	Intracom S.A. Telecom Solutions (5G-VICTORI partner)
IHP	IHP - Leibniz-Institut für innovative Mikroelektronik (5G-VICTORI partner)
IR	Interim Review
IZT	*Institut für Zukunftsstudien und Technologiebewertung gemeinnützige GmbH* (5G-VICTORI partner)
KCC	Kontron Transportation Austria (5G-VICTORI Partner)
MATI	Mativision Limited (5G-VICTORI partner)
M Shed	Museum in Bristol
MVB	Merchant Venturers Building
Orange	Orange France (5G-VICTORI partner)
ORO	Orange Romania (5G-VICTORI partner)
PXI	PaxLife Innovations (5G-VICTORI partner)
RBB	*Rundfunk Berlin-Brandenburg* (5G-VICTORI partner)
TRAINOSE	TrainOSE S.A. (5G-VICTORI partner)
UHA	Urban Hawk Limited (5G-VICTORI partner)
UNIVBRIS	University of Bristol (5G-VICTORI partner)
UoP	University of Patras (5G-VICTORI partner)
UTH	University of Thessaly (5G-VICTORI partner)
WP2	Work Package 2: Description – Use cases/ Specifications
WP3	Work Package 3: Vertical Services to be demonstrated
WP4	Work Package 4: Trials of Coexisting Vertical Services, validation and KPI evaluation
ZN OR **Zeetta**	Zeetta Networks Ltd. (5G-VICTORI partner)

2 Introduction

5G-VICTORI WP4 "Trials of Coexisting Vertical Services, validation and KPI evaluation" focuses on coordinating and conducting large scale field trials for use case (UC) verification in 5G operational environments for a number of verticals, including **Transportation**, **Energy**, **Media** and **Factories of the Future** as well as some specific UCs involving **cross-vertical** interaction. To achieve the above scope, the trials are being executed at vertical facility sites that deployed 5G technologies provided by all ICT-17 infrastructures, namely **5G-VINNI** (Patras, Greece), **5GENESIS** (Berlin, Germany) and **5G-EVE** (France/Romania), and the **5GUK** testbed (Bristol, UK). These 5G facilities have been extended to support integration of the vertical facilities sites and in all cases have been enhanced with features that are required to meet the expected KPIs. In this context existing infrastructures required enhancements in terms of both coverage and other capabilities to demonstrate in real operating environments the 5G-VICTORI vertical and cross-vertical UCs.

This deliverable reports on the first results that stem from the activities related to the trials planned and executed in the context of Work Package 4 (WP4). Following the structure of WP4, the deliverable reports on all extensions performed at the different 5G-VICTORI facility sites for their individual operation and interconnection. In this context, each individual project facility reports on the results of initial trials or lab trials required for initial integration of the verticals in accordance to the UCs planned to be demonstrated at the corresponding facilities at the end of the project. This includes description of components (software and hardware elements) integrated, compliance with the 5G-VICTORI end-to-end (e2e) architecture, 5G technology configurations and experiment descriptions.

The work reported in this deliverable also focuses on the 5G-VICTORI Operation System (5G-VIOS) and the way that is developed and integrated in the Bristol facility, providing guidelines to individual facility sites for the work that will be reported in deliverable **D4.3**.

2.1 Objectives

This deliverable completes the methodology work reported in deliverable **D4.1** [1] and takes into consideration the requirement work and design work reported in deliverables of **WP2.** The work presented in this document focuses on the initial delivery of the facility extensions performed in accordance to the methodology reported in **D4.1** and **WP3** deliverables and has taken into consideration the 5G-VICTORI architecture blueprint adopted by the different facility site i.e. Berlin, Bristol, France/Romania and Patras.. In this context, the deliverable reports on the execution of experiments and initial trial results with emphasis on:

- Description of 5G facilities enhancements and extensions at vertical facility per cluster (Berlin, Patras, Bristol, Alba Iulia).
- 5G configuration and integration with vertical services.
- Initial experiments and/or trials at the vertical facilities.
- Initial KPI evaluation per use case per facility.

It should be noted that according to the 5G-VICTORI trials roadmap at the time of the D4.2 delivery, only two out of four facilities have showcased partially specific UCs.

2.2 Approach and Methodology

As already mentioned, the deliverable focuses on the preliminary experiments and trials at the each facility and specifically reports on the list of activities/experiments that are listed below in Table 2-1, depending on the level of maturity per site and per UC. The detailed description of each use case can be found in deliverable **D2.2** [2]. However, in the section UC testing objective and deployment, some description per UC and testing phase is provided to give some insight on the preparatory (5G related and integration related) work performed in each UC.

Table 2-1 Activity reported in the deliverable per Cluster/Facility

Activity reported in the deliverable per Cluster/Facility
Overall Facility Description with extensions and 5G deployments setups
5G-VICTORI architecture deployments per site
UC testing objective and deployment (per UC)
Updated Slice description (with application components) – if applicable Network Schematic Diagrams (per UC)
High Level 5G Deployment Scenario Description
Lab testing and initial validation of services per UC
Experiment execution and Reports (with reference to WP3 methodology)
KPI evaluation and Conclusions – Lessons learned (per UC)

Furthermore, a section of the deliverable is dedicated to the functional description of 5G-VIOS and its role in inter domain experimentation in 5G-VICTORI. The experience of integration at the 5GUK facility is described and recommendations for the other facilities are provided.

2.3 Purpose of the document

The purpose of this deliverable is to meet the following WP4 objectives:

- Deployment of the vertical use cases in the 5G facility sites, taking input from WP2 and WP3.
- Onsite execution of trials.
- Validation of the vertical specific KPIs optimizing and orchestrating technical and 5G KPIs supported by the platforms as specified in WP2.

Table 2-2 Dependencies with other 5G-VICTORI documents

id	Document Title	Relevance
D2.1 [1]	5G-VICTORI Use case and requirements definition and reference architecture for vertical services	This document presents the 5G-VICTORI UCs and their specific requirements (UC requirements, network performance requirements and functional requirements), as they are dictated by the associated vertical industries.
D2.3 [4]	Final individual site facility planning	The deliverable reports on the set of requirements and initial architecture blueprint for each of the sites and presents a high-level overview of the extensions planned for each of the sites. It also defines per site the timeline and progress of the associated upgrades of the required infrastructures.
D2.4 [5]	5G-VICTORI end-to-end reference architecture	5G-VICTORI e2e reference architecture and the way it has been deployed in all sites and facilities is described in this report. Integration activities and deployment activities follow the specific deliverable and testing is reported in deliverable D4.2.
D4.1 [1]	Field trials methodology and guidelines	The deliverable described in detail the methodology phases of the 5G-VICTORI experimentation and trials. Specifically, it puts emphasis on the co-design phases of this methodology and the procedures for adhering to the 5G-VICTORI architecture.

D3.1 [8], D3.3 [10], D3.5 [12]	**D3.1** Preliminary Use case specification for transportation services **D3.3** Preliminary Use case specification for Media Services **D3.5** Preliminary Use case specification for Energy and Factories of the Future Services	The deliverables describe in detail all test cases that verify 5G-VICTORI applications and services per UC together with the test planning and roadmaps. This procedures are in line with the planning that takes place in deliverable D2.3.
D3.2 [9], D3.4 [11], D3.6 [13]	**D3.2** Final Use case specification for transportation services **D3.4** Final Use case specification for Media Services **D3.6** Final Use case specification for Energy and Factories of the Future services	The deliverables describe in detail all final test cases and lab testing results that verify 5G-VICTORI applications and services per UC. They also entail the testing methodology.

2.4 Document Structure

This deliverable comprises four main sections, which follow a similar cluster-based structure content-wise: overall facility extension and description, initial integration and testing of facilities, 5G configuration and 5G-VICTORI architecture compatibility per cluster, and initial experiment results from the trials:

Section 3 focuses on the initial experiments and testing related to the trials of Berlin Cluster for three use cases.

Section 4 summarises the Patras Cluster initial experiments and testing related to the trials at Patras facility/5G VINNI.

Section 5 details the initial experiments and testing related to the trials Bristol Cluster Facility.

Section 6 describes the initial experiments and testing related to the trials France/Romania Cluster Facility.

Section 7 provides a summary of the 5G-VIOS and the facility integration with the Bristol facility.

Section 8 concludes the deliverable and, finally, Section 10 includes an Appendix with some additional detailed information for each cluster.

3 Technology Integration, Validation and field trials in Berlin

3.1 Overall Facility Description

The 5G-VICTORI Berlin facility has been initially presented in deliverables **D2.2** and **D2.3** [3][4], where details regarding the sites this facility comprise were provided. The owner of the operational environment and host partner for the field trials is the 5G-VICTORI Partner Deutsche Bahn Holding (**DBH**), who has already made available different sites (stations) for field testing, e.g. *Berlin Hauptbahnhof* (aka Berlin Central Station) and the testfield *Berlin-Schöneweide* [9], whose results are captured in this document.

From the field tests carried out in September 2022 at Berlin Central Station, **DBH** together with the rest of the Berlin partners, acknowledged the existing limitations of such operational infrastructure at the time of performing the trials. Such a renowned station provides high visibility for the trials and creates a big impact but, on the other hand, its use shrinks the available time to perform a reasonable number of tests that ensure the success of a field trial. Due to this, the Berlin cluster has taken the decision to shift the tests and field trials to a different operational environment. An alternative railway station within Berlin has been chosen as the venue to host the field trials on the last week of April 2023.

To assess the deployment, discover and overcome pitfalls and optimize the system, a decision was taken to to use (as carried out in deliverable **D3.2**) the testfield of *Berlin-Schöneweide* in East Berlin. In such environment we can operate a dedicated S-Bahn train at an enclosed test track at the S-Bahn (operated by DB) depot premises.

Regarding the 5G setups used in the Berlin facility, there exist two different setups that are dedicated to different purposes: one being indoor and fixed in a lab environment, and the other being a mobile (nomadic) setup that is intended to support the field trials in operational environments.

The **fixed indoor (lab) setup**, provided by **FhG**, represents a segment of Fraunhofer's 5G Playground, which is labelled as "1" in Figure 3-1. The figure depicts the whole 5G playground, which is an open testbed designed to enable innovative product prototyping in a realistic, comprehensive 5G e2e environment. It includes calibration, benchmarking and interoperability tests between new prototypes and products. For this deliverable, part ofthis setup – i.e. that owned by Fraunhofer FOKUS (1 in the figure) – was utilized to test Rail Signaling (RS) services and Mission Critical Services (MCX), where X = {*MCPTT, MCData, MCVideo*}.

Figure 3-1 Fraunhofer 5G playground in West Berlin

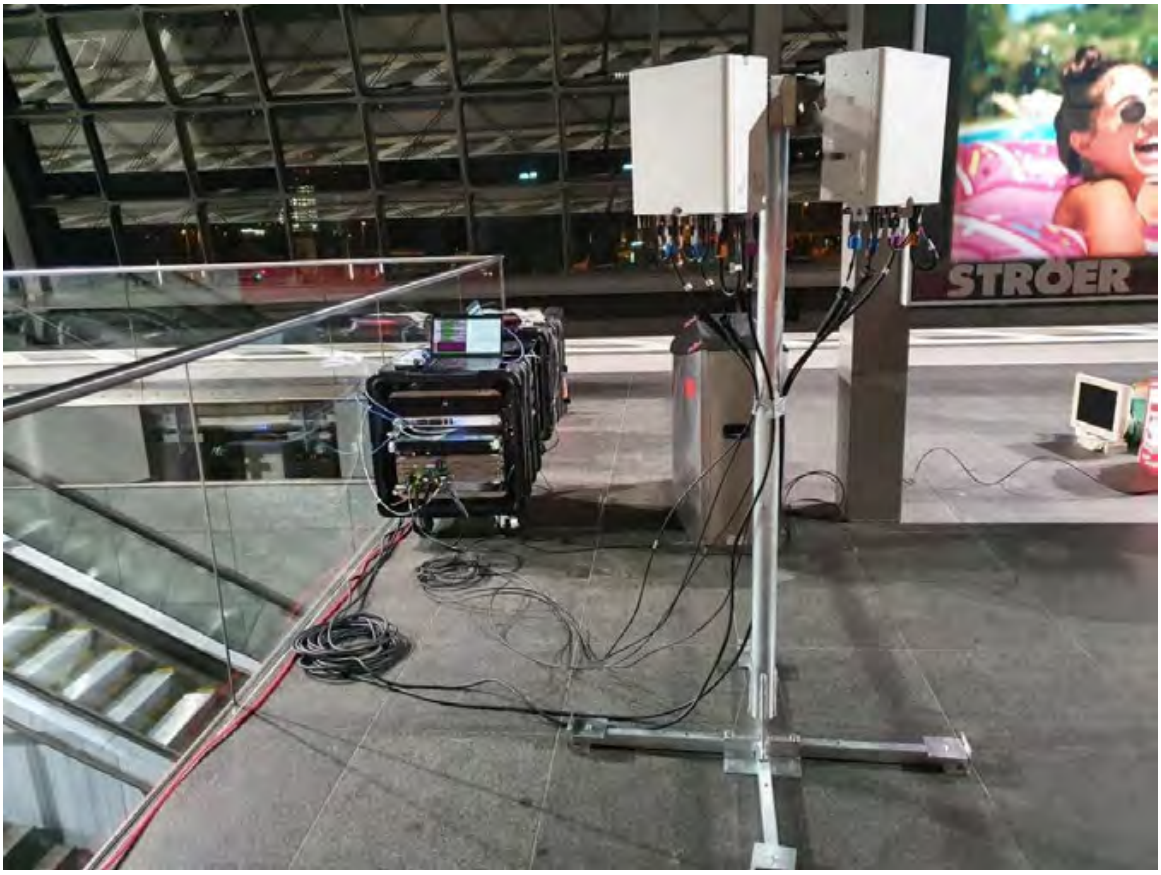


Figure 3-2 Mobile (nomadic) 5G system deployed at Berlin Central Station in September 2022

The **mobile (nomadic) setup** is provided by **IHP** and it is provisionally located at its premises. It is a nomadic 5G cell being deployed in two mobile racks (one being the 5G system together with a compute server, and the other comprising batteries and power supplies). The setup features all necessary equipment for 5G connectivity, including 5G RAN equipment from Nokia, and complemented with the nomadic 5G Edge Network, designed by **FhG,** and the Open5GCore as the software 5G Core Network implementation, also developed by **FhG**. The Nomadic 5G Edge Network is specifically designed to be able to showcase the different UCs when and where needed and, according to the UC requirements, it can be used to test both **UC #1.2** and **UC #1.3** in an operational scenario (see example in Figure 3-2, where a nomadic 5G system deployed at Berlin Central Station in September 2022).

3.2 Network topology

For the three Berlin UCs, the mapping of the infrastructure and the services was presented in deliverable **D3.2** Figure 6-1. The network topology depicted in Figure 3-3 can be seen as a super set of the topology in **FhG** campus for **UC #1.2** and **UC #1.3**. This figure also depicts a lean representation of **UC #3**, which it is described in detail in section 3.6. A more detailed representation of **UC #1.3** services is depicted in Figure 3-4.

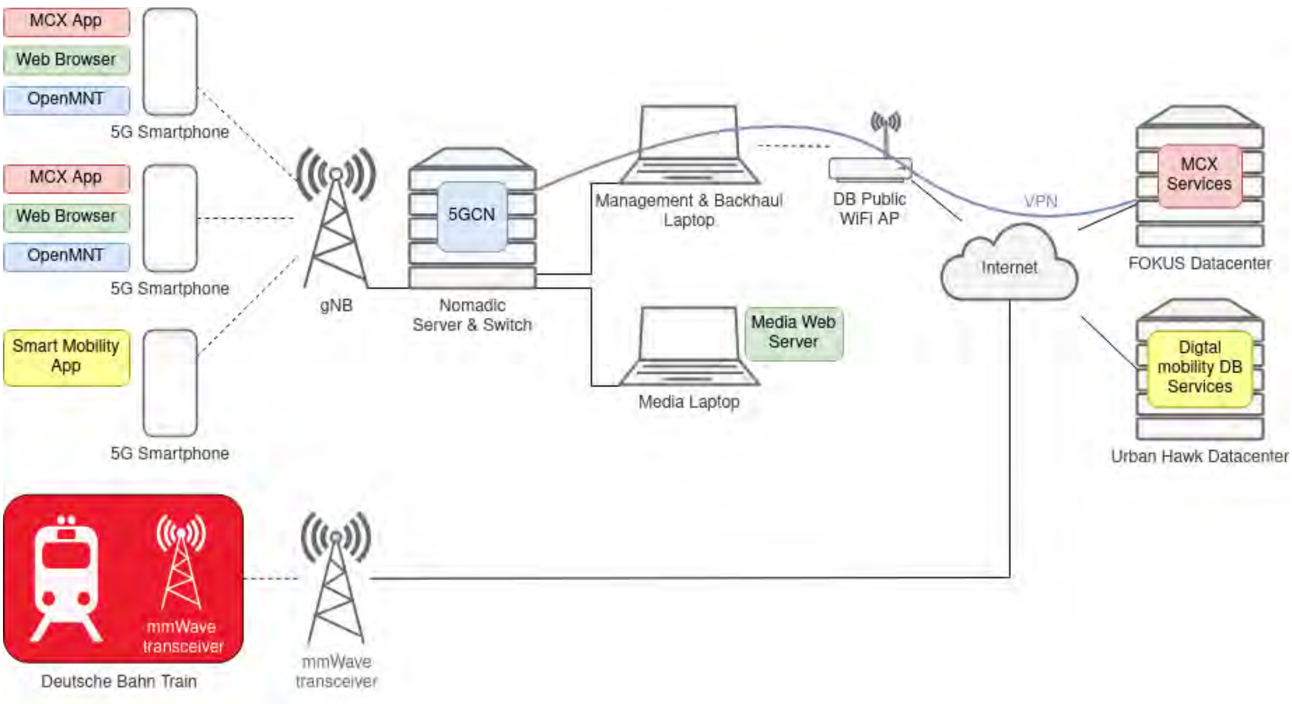


Figure 3-3 Nomadic Edge Node testbed topology at Berlin Central Station.

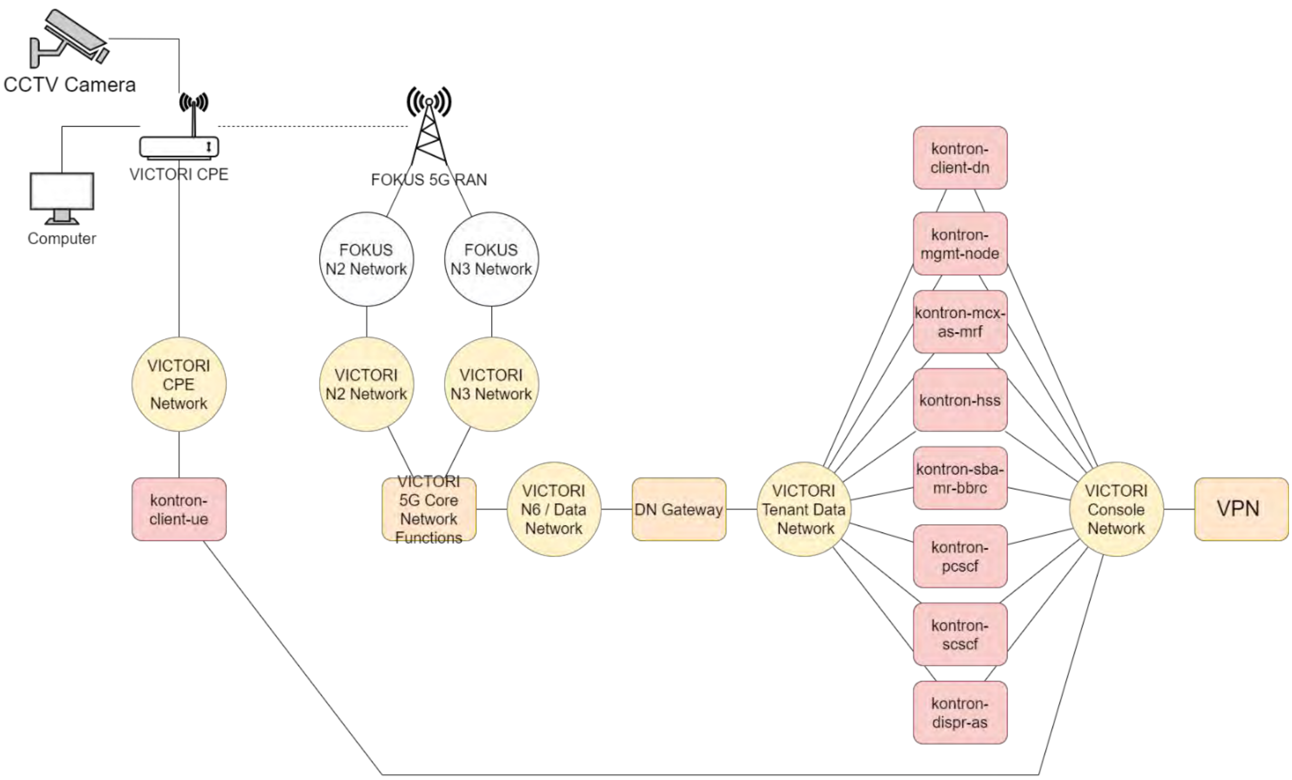


Figure 3-4 Topology of the network for CCTV, Rail Signaling and MCX services

Figure 3-4 depicts the topology of the network where services of **UC #1.3** are running. This network is part of the **FhG** FOKUS testbed. In the RAN part of the figure (up left), the "VICTORI CPE" is connected to the data network using the "FOKUS 5G RAN". The CPE provides 5G connectivity to a CCTV camera and a laptop. The laptop has testing probes (Keysight Hawkeye) for generating UDP and TCP traffic and for measuring the performance of the network. On the right side of the figure, we notice the multiple services – deployed as virtual machines (VMs) – used to provide the functionality of the MCX application. Traffic from and into the MCX services goes through the "*VICTORI Tenant Data Network*" and into the 5G Core Network (in this case **Open5GCore**). This is achieved using routing rules set inside the VMs hosting these services. By default, once these services can access the "*VICTORI tenant data network*" they will be connected to **Open5GCore**, thus no further adjustments to the FOKUS testbed are needed.

Notice that the N2, N3, and N6 interfaces represent the topology of the 5G mobile core network. This is the part of the network provided by the tenant at FhG Campus. Using VPN access to the FhG network, these services and **Open5GCore** can be accessed remotely for management, i.e. no physical presence at the FhG is required for managing these services. Accessing these services for management takes place over SSH using the "*VICTORI console network*".

For the active network monitoring of the **FhG** testbed, the platform Hawkeye from Keysight is used. For the RS UC, it is also used for retrieving network KPI measurements. To verify the proper operation of the services regardless of the Background Traffic, simultaneous parallel tests must be executed on the testbed for both the RS and MCX UCs. Therefore, for accomplishing these tests, a computer with Ubuntu installed is connected to the network. On the computer, Hawkeye probes are installed using the docker containers method, and the image provided by Hawkeye. Parallel simultaneous tests were required to test the Quality of Service (QoS) and the performance of RS while Background Traffic is presented. Multiple VMs were spawned on the data network to enable execution of these parallel tests. In the indoor setup, the CCTV plus RS and Dispatcher services were tested simultaneously. The performance of the 5G networks for both UCs was validated.

The MCX services is shown at the right hand side of Figure 3-4. In this setup, these services have access to the User Equipment (UE) using the public internet through the management interface and, finally, to the radio by the gNB, which is part of the nomadic node. The management laptop in Figure 3-3 has the task of accessing the core network for management purposes, such as debugging and deploying the setup, or adjusting any configurations in the core network. At the same time, through the same interface, another laptop is presented for testing **UC #1.2**, referred to as "Media Laptop" in Figure 3-3. On the left side of the figure we find two 5G Smartphones with 5G capability and multiple mobile-phone apps installed on them. One app is the MCX mobile-phone app, which is part of the whole MCX application. The other mobile-phone app installed on the 5G smartphone is Open Mobile Network Toolchain (OpenMNT), which is used for measuring different metrics in the network. What is measured in this setup using OpenMNT is, e.g. the quality of the signal strength. More about those measurements is presented in section 3.4.4.2.

The topology for the mmWave network is depicted in the bottom left corner of Figure 3-3. Testing of **UC #3** in real world scenarios was carried out in this setup using a train hosting a mmWave device, plus two mmWave devices located at the Berlin Central Station 5G deployment sitting on tripods. A mmWave device was installed on the train while it was stationed at *Berlin-Schöneweide*. The train started its journey from *Berlin-Schöneweide*, and, as it arrived to the platform at Berlin Central station, the data exchange between the mmWave device at the platform and the device on the train began. The data was transferred at an extremely high rate. A video was recorded for this interaction while, at the same time, measurements for the data exchange speed were also recorded and are presented in section 3.6. Additional details about **UC #3** are provided in section 3.6.

Table 3-1 Berlin Facility – 5G Deployment Setups

	Nomadic 5G cell – IHP (mobile)	FhG Lab 5G fixed installation
Open- Source	No	No
SA/NSA	SA	SA
Cloud options	VMware	VMware
MANO	N/A	N/A
Core	Open5GCore	Open5GCore
RAN	Nokia	Amarisoft, Nokia, Huawei
UE	Huawei P40, Nokia X20	Huawei CPE

3.3 5G Deployment Setups

Table 3-1 includes information of each of the setups. The components used in both setups are similar, and only differ in the radio (RAN) part, i.e. the nomadic node uses the RAN from Nokia, and in the FhG testbed there are multiple RAN equipment possibilities from multiple vendors (incl. Nokia). In both setups the data network was provided by **FhG**'s **Open5GCore**. 5G mobile phones (UEs) are used in the mobile (nomadic) setup, while only the Huawei CPE is used in the **FhG** lab.

3.3.1 Fixed indoor (lab) setup at FhG

The deployment at the **FhG** lab is mainly part of the FOKUS testbed, which is based on tenant's approach. This approach uses virtualization to provide 5G connectivity to different entities or users. It ensures that services from different providers can co-exist simultaneously without affecting each other's performance or runtime. In the testbed there exist several radio heads provided by multiple vendors. These radio heads are used to provide 5G radio connectivity, the vendors of these radio heads and gNB's are presented in Table 3-1.

3.3.2 Mobile (nomadic) setup

In the nomadic setup, the UCs tested are **UC #1.2** and **UC #1.3**. The aim of this setup is to test the deployment of these UCs in a real (operational) scenario, the same way they were previously tested inside the **FhG** lab.

For **UC #1.3** it was intended, for the MCX services, to directly migrate the same lab setup into the nomadic setup. However, a number of challenges needed to be solved in a very short time. These challenges included solving incompatibility issues in the VMs and hypervisor where the MCX services are hosted. Therefore, some alternatives were applied in this regard, and the services were not eventually migrated, but rather the services deployed in the lab were used for this. To connect the MCX mobile-phone app with the services running inside the core network, a tunnel into the FOKUS testbed was created. As depicted in Figure 3-3, the MCX app is running on a 5G smartphone, and the Nokia gNB was providing the data network access to these. Using tunnelling, **FhG** VPN, and the public internet of **DBH**, the Open5GCore and the mobile-phone apps were provided connectivity to the MCX service inside the data network.

Regarding **UC #1.2**, the media laptop in Figure 3-3 is used for the edge rendering. A management laptop is used for accessing the data network to setup the **Open5GCore**. At the same time this laptop is connected to the public Wi-Fi and provided access for the nomadic node in the **FhG** FOKUS data centre.

3.4 UC #1.2 "Digital Mobility"

3.4.1 Field Trial at Berlin Central Station

A field trial of **UC #1.2** "Digital Mobility" was carried out using a dedicated 5G Edge nomadic node at Berlin Central Station. The goal was to determine the performance of the 5G connection alongside edge computing to render a complex 3D scene that simulates navigation inside the train station. A client can play and control this scene in a web application running in the browser on a 5G UE that is accessible over the station's 5G connection. This is a key enabler for the future mobility application, which relies on complex graphical processing and huge amount of data originating from the scan of the station performed by Urban Hawk (**UHA**). The concept behind remote rendering is also called in 3GPP terms "Split Rendering", which is an ongoing activity in 3GPP groups related to XR over 5G.

The high-level architecture of this UC is depicted in Figure 3-5. The 5G UE runs the client (5G Media App Client) inside a web browser without the need to install any application. The UE establishes connectivity to the Edge Node via the 5G Nomadic Node previously described in section 3.3.2. The Edge Node runs a Server (5G Media App Edge Server) that renders any 3D scene developed in Unity or Unreal Engine and streams the video/audio output in real-time to client via WebRTC media channel. All user inputs like touch, click and key events are transmitted to the Edge Server via

WebRTC data channels as well. The quality of the 5G connectivity between the UE and Edge Node has a direct impact on the quality of experience for this UC. Reducing the Round Trip Time (RTT) while maintaining stable throughput to keep the image quality is very important. Also, reliability is critical since increases in packet loss led to a higher jitter buffer in the client since lost video/audio packets need to be retransmitted bevor the corresponding audio/video frame is rendered in the client.

In the last field trial at Berlin Central Station, a high-definition 3D scene was used for evaluation. The final application will include a photorealistic 3D capturing of the station. The 3D scanning has already been done by **UHA** during the field trial, but the scanned data are still being processed. Once the processing is completed, the current 3D Scene will be replaced by the 3D scan of Berlin Central Station and the measurements will be repeated. It is important to mention that the new 3D scene will not affect the 5G measurements, but only the time to render the field of view and encode the video stream. The whole process of scanning central station is described in Section 10.1.1.

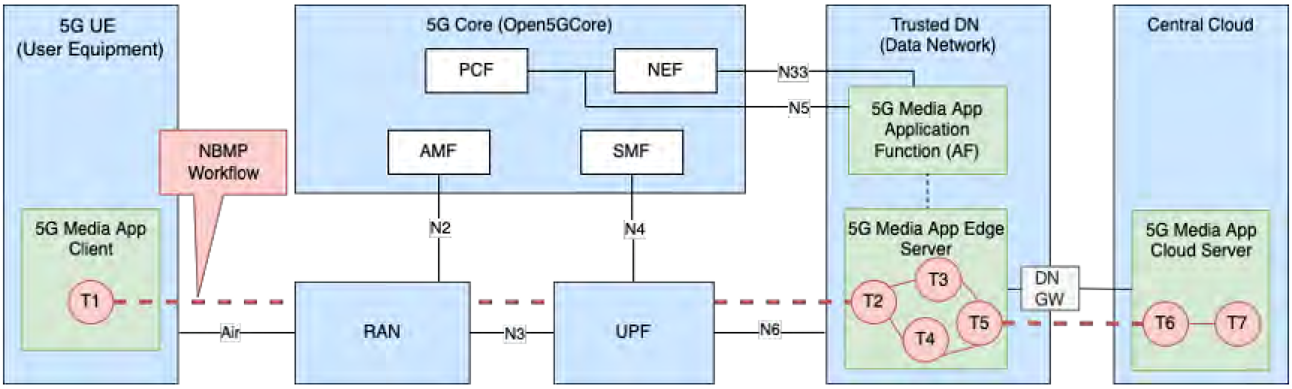


Figure 3-5 5G Edge Rendering Architecture

3.4.2 High Level Deployment Scenario Description

This UC makes use of the same 5G nomadic node described in section 3.3.2, which was placed at the platform by the railway track at Berlin Central Station for the tests carried out in September 2022. The scenario is described in Table 3-2. An edge server, represented by a gaming laptop – Media Laptop – (*12th Gen Intel® Core™ i7-12800H 2.40 GHz, 32.0 GB installed RAM, NVIDIA GeForce RTX 3070 Ti Laptop GPU Memory 16 GB*) is connected to the nomadic node over an Ethernet cable (see Figure 3-6). The laptop is responsible for three tasks: rendering the 3D unity scene, running the signalling server, and hosting the client web application.

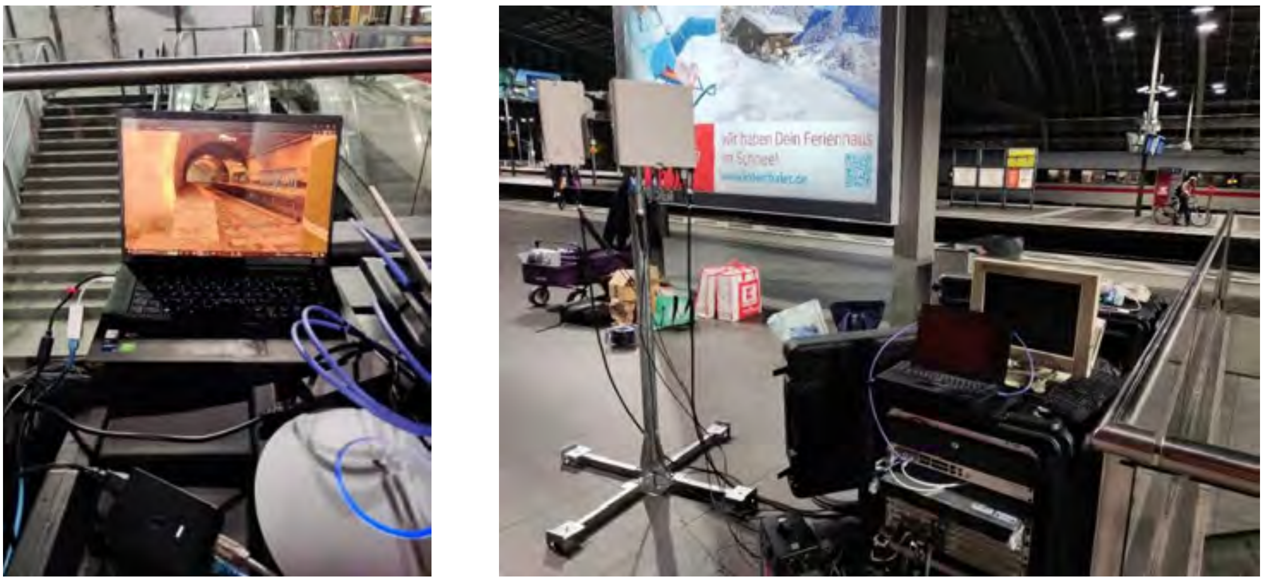


Figure 3-6 Edge Rendering via Nomadic Node at Berlin Central Station

Table 3-2 Digital Mobility 5G Scenario Description

Scenario Description	
Radio access technology	5G NR
Standalone / Non-Standalone	Standalone
Cell Power	23 dBm
Frequency band:	n78
Maximum bandwidth per component carrier	100 MHz
Sub-carrier spacing	30 kHz
Cyclic Prefix	normal
Massive MIMO	4x4
Duplex mode	TDD
User location and speed	0 km/h
Background traffic	low throughput
Computational resources available	N/A

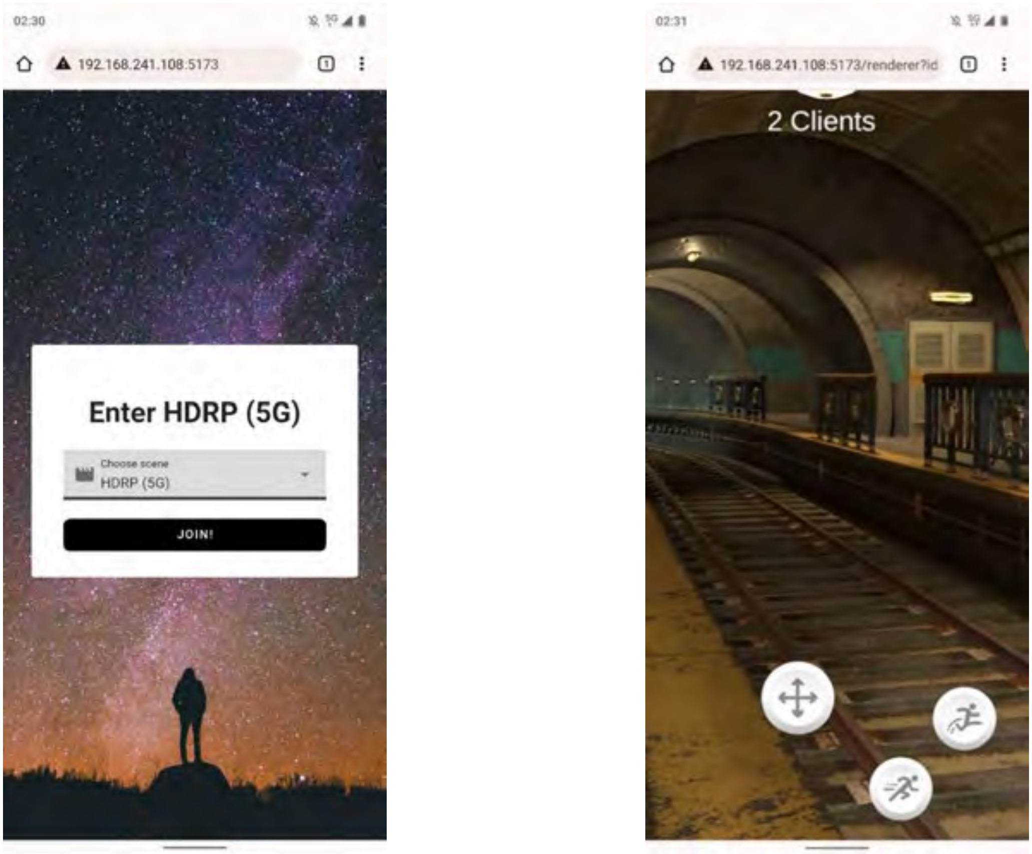


Figure 3-7 5G UE running Web client of the Edge renderer

On the client side, two different smartphones (Huawei P40 Pro and Nokia X20) represent the user ends. Both smartphones are equipped with 5G sim cards, which enables them to connect the 5G network in the station provided by the nomadic edge. Once the smartphones are connected, they can access the web application hosted on the edge server, stream and control the rendered gaming scene over a WebRTC connection. The web application uses the signalling server to gather information about the available scenes provided by the edge server (see Figure 3-7).

3.4.3 Experiment description

Table 3-3 presents **UC #1.2** experiment for 5G Edge rendering.

Table 3-3 Digital Mobility 5G Edge Rendering Experiment

	Description
ExperimentType	Edge Rendering Experiment using mobile (nomadic) 5G system deployed at Berlin Central Station
Automated	Semi-automated (after setup is ready, the tester needs to navigate to a dedicated webpage in a Browser on the 5G UE and start the test)
TestCases	RDFg01 RDFg02 RDFg03 RDFg04 RDFg05 RDFg06
UEs	Nokia X20, Huawei P40 Pro
Network Slice	Network Slicing not required
Network Services	Reliable/stable 5G connectivity with ultra low latency and very low jitter.
Network Scenario	The Rendering Client running in the Browser on the 5G UE opens a peer-to-peer WebRTC media channel to a Rendering server deployed on the edge of the 5G Network. The Rendering server is running on a Gaming Laptop connected to the mobile nomadic node as depicted in Figure 3-6. Once a WebRTC connection between the 5UE and the Rendering server running on the Edge is established, video and audio pakets are transmitted from the Rendering server to
Exclusive Execution	During the test, no other service was connected to the mobile nomadic 5G setup.
ReservationTime	Multiple test runs were deducted for around 5min each
Application	Edge Rendering
Performance targets & SLAs	Round-Trip-Time below 20ms and Jitter below 5ms
Experiment Parameters	N/A
Edges	The mobile nomadic setup with 5G RAN equipment from Nokia, and complemented with the nomadic 5G Edge Network, designed by FhG, and the Open5GCore as the software 5G Core Network implementation, also developed by FhG is used in this experiment
Remote	This is a real Edge experiment, and all components were deployed on the Edge of the 5G nomadic node without the need for any external service running in the cloud
Remote Descriptor	N/A
Version	N/A
Extra	N/A

3.4.4 KPI evaluation

3.4.4.1 RTT and UL/DL rate

The WebRTC connection performance was measured using Google chrome's WebRTC internals feature, which collects data about the peer connections established. During the test, the Nokia X20 has a stable connection with an average round trip time mostly below 30 ms, but in few situations an RTT of 40 ms is measured. The downlink (DL) was stable and measured on average 9 Mbps and the uplink (UL) on average 14 Kbps. It is worth to mention that the 9 Mbps is the bitrate of the video stream configured in the rendering backend which was stable during the field trial.

On the other hand, the Huawei P40 kept disconnecting during the test from the 5G network and had to be reset frequently by switching the airplane mode on and off. The screenshots in Figure 3-8 show the measured metrics on the Nokia X20 during the field trial at Berlin Central Station.

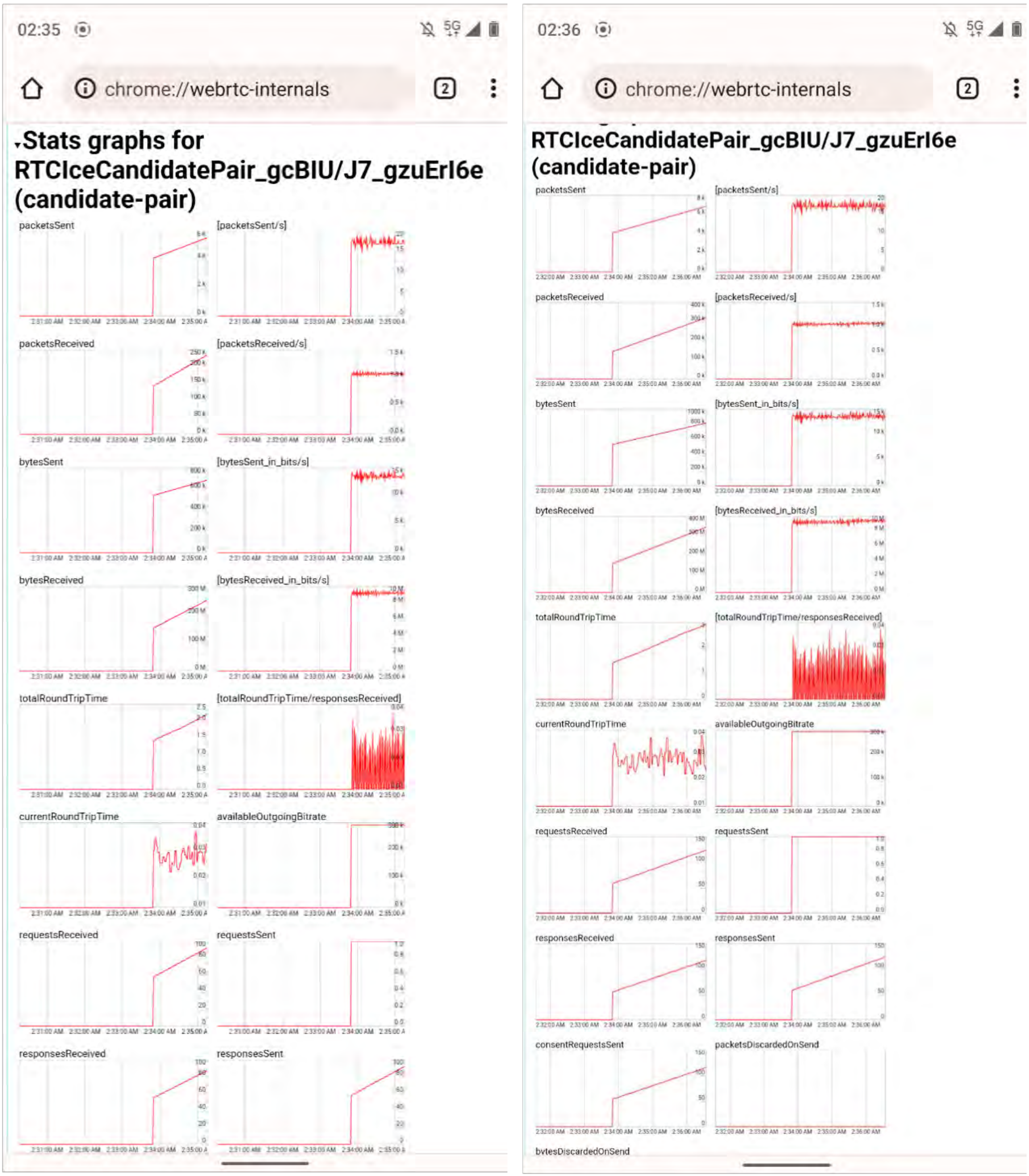


Figure 3-8 WebRTC Performance over 5G Connection

3.4.4.2 Berlin main station signals strength measurements

The tool OpenMNT, which has been developed at **FhG**, was used to collect metrics about the quality of the signal strength at Berlin Central Station. More about examining these measurements are presented in the sequel.

Figure 3-9 Berlin Central Station deployment signal strength quality

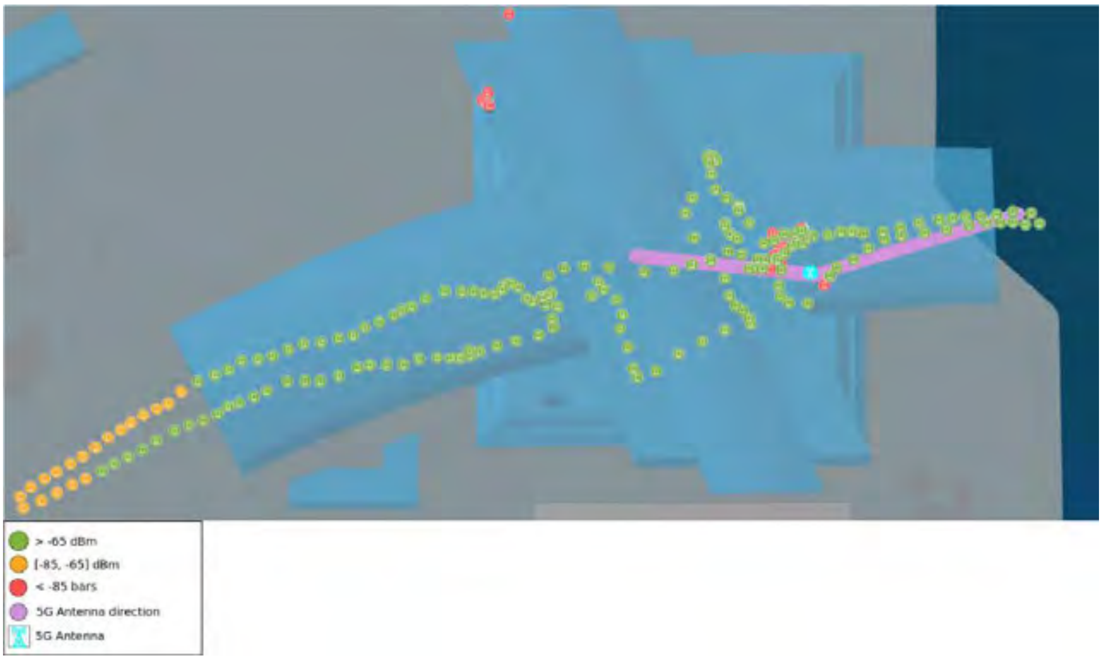


Figure 3-10 “High contrast” Berlin Central Station deployment signal strength quality

Figure 3-9 is taken from a visualization representing the signal strength measurements in Berlin Central Station. The visualization was created using Google’s visualization platform “My Maps”. The above screenshot shows the position of the 5G antenna, and the values of signal strength measured around the antenna in the station. To make the view clearer, some details are removed from the map, which results in Figure 3-10.

As shown in Figure 3-10, the signal strength was around > 65 dBm in almost all areas of Berlin Central Station. However, some areas have shown abnormally low signal strength values while other areas have shown normally low signal strength values. Notice the low signal strength right in front of the 5G antenna. This area is not geographically far from the antenna, yet it has shown low signal strength values. To study the area better, it is represented more clearly in the diagram below.

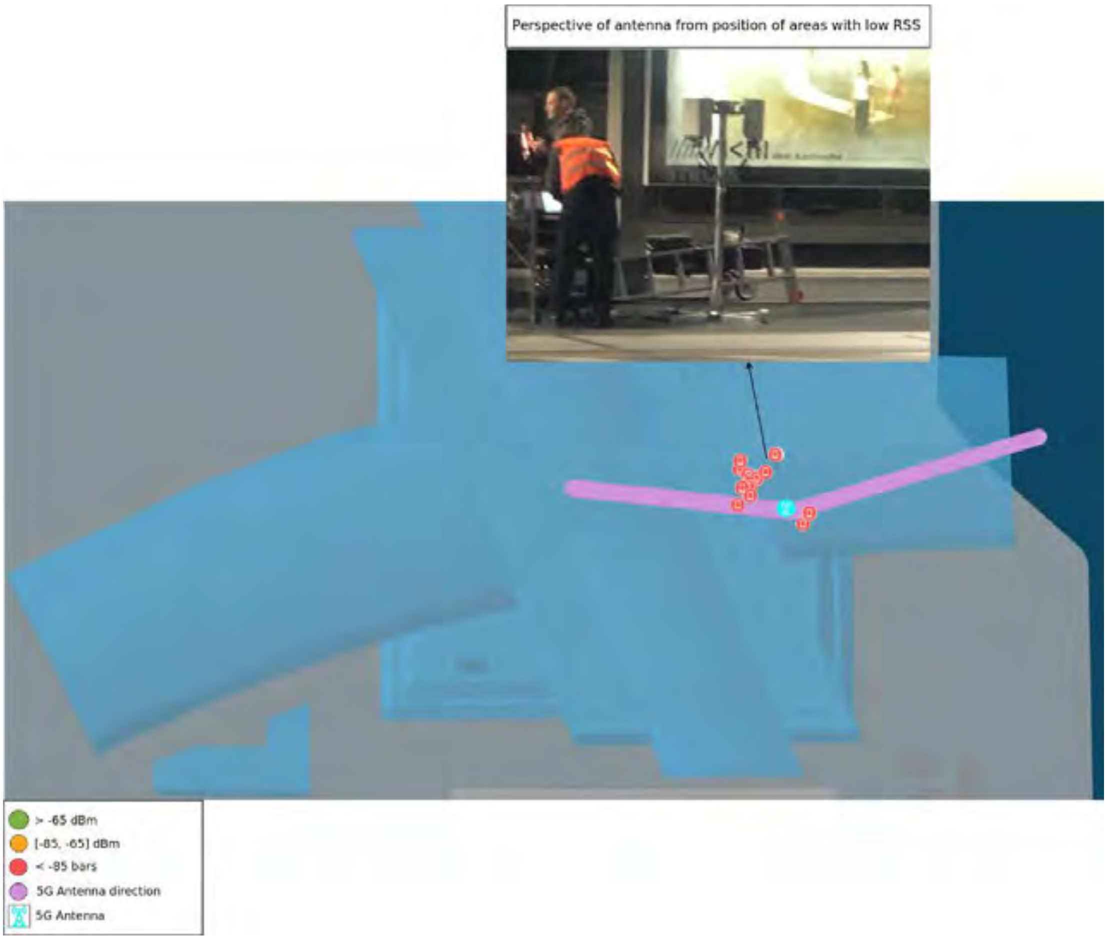


Figure 3-11 Abnormal low signal strength values in Berlin Central Station deployment

The value of the signal strength was measured multiple times at this area, and at multiple time spans. It has shown consistent low signal strength values. Notice the photo accompanied by the visualization. This is a photo of the antenna taken from the point of view of this area. This photo is interesting because it shows the direction of the antenna. It is assumed that this location has low signal strength values, because of the nature of the directed antennas. These areas are almost orthogonal to the lines presenting the direction of the antenna, thus this area is between the lobes of the antennas, hence the low signal strength values.

Another interesting area where the coverage was abolishing was 3 floors below the ground, and as far as 100 meters away from the antenna. This area is presented in the visualization of Figure 3-12. The area in the figure corresponds to the furthest point from the antenna below the ground in Berlin's main station. Exactly at this point the signal strength was showing low values, and the connectivity was even disrupted. The picture in the graph shows the surroundings around the measurement's position.

As for the rest of the areas points in Berlin's main station, the coverage have shown good values, even two floors below the ground and upwards. These are shown in the visualization in Figure 3-13 below.

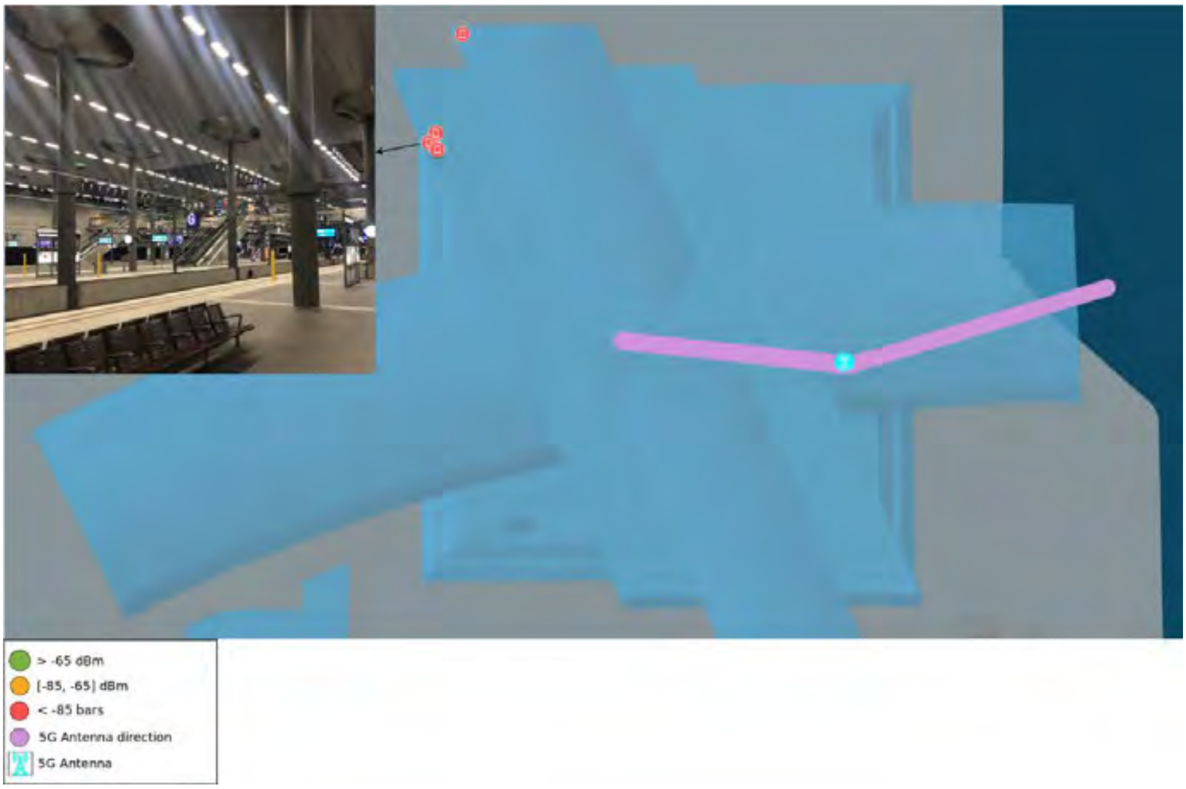


Figure 3-12 Low signal strength values 3 floors below ground

Figure 3-13 High signal strength values 2 floors below ground

All the green values are on 1st floor and 2nd floor below the ground; the coverage was also measured far from the antenna, and inside an elevator. Still the signal strength was of high quality.

3.4.5 Conclusion

The main purpose of the trial was to validate the split rendering of high complex photorealistic 3D scenes on the Edge of the 5G Network. This requires a reliable and ultra-low latency connectivity in order to provide the best user experience. The field trial results show that 5G is a suitable technology for streaming remote rendered 3D applications if reliability and other QoS parameters especially latency can be guaranteed. In a next step, the scanning of Berlin Central Station will be integrated in the Edge Rendering application and additional metrics related to rendering performance and video encoding will be captured and analyzed.

3.5 UC #1.3 "CCTV, Rail Signaling and Rail Critical Services (Telephony)"

As presented in deliverable **D3.2** [9], the 5G-VICTORI project considers Rail Critical Services for demonstration in an operational environment (station) in Berlin. The 5G-VICTORI partners **Alstom** and Kontron (**KCC**) contribute with CCTV and RS, and with Rail Critical Services (Telephony), respectively.

- **CCTV and Rail Signaling** were first tested at Alstom in Stockholm during autumn 2021 using a real CCTV camera and the Alstom Keysight Hawkeye license.

  RS were then tested during Spring 2022 at **FhG** in Berlin, using the FhG Hawkeye license. These tests used a very limited number of probes, without the possibility to run parallel streams, nor using any QoS.

- **Rail Critical Services (Telephony)** was first tested at **KCC** in Vienna during Autumn 2021 using the IMS/MCX core and the MCx App using an Over-The-Top (OTT) setup. It was then later tested with 5G SA in both the Kontron Montigny lab and in the Fraunhofer lab.

A 5G-based lab setup was performed at **FhG** during week 47 of 2022, where **Alstom** and **KCC** deployed their HW and SW based solutions. There, four Hawkeye probe pairs were installed – four on Data Network (DN) servers and four on an Onboard (OB) Ubuntu laptop. The CCTV camera was installed. The Next-Gen Rail Dispatcher Terminal, the Rail MCx Clients and the Rail 5G Onboard Gateway (OBG) were installed in the Fraunhofer lab for the test week 47 2022.

IHP lab setup, using the Kontron 5G OBG and the Open5GCore deployed in IHP's 5G Nomadic Node with the IHP Hawkeye license, is scheduled for Spring 2023 (after the submission of deliverable D4.2). Then the earlier planned QoS 5G NR Standardized QoS Identifier (5QIs) 8 and 69 (as soon it is available at the RAN equipment) shall be used instead of 5QIs 9 and 8, which have performance close to each other. The 5G air interface- bitrate performance shall also be limited to avoid being too close to the Gigabit Ethernet infrastructure – to make sure the 5G air interface is the only bottleneck.

The same equipment as used in the IHP lab is planned for Berlin field demos.

3.5.1 UC #1.3 testing objective and deployment

The objective of testing the CCTV streaming is to assess how it behaves in a 5G network, while the objective of running the RS service is to assess how RS with different QoS settings behaves together with other traffic (other traffic is in the tests done with Background traffic).

The objective of Rail Critical Services (Telephony) is to see how it behaves together with other traffic in the network and if it can take advantage of 5G QIs.

3.5.2 UC #1.3 Network deployment

3.5.2.1 CCTV and Rail Signaling Lab setup at FhG Lab

The FhG Lab uses a fixed installation of Core Network and RAN, which run as VMs on Compute and Storage resources. The FhG Lab base stations are spread out in the building at Kaiserin-Augusta-Allee 31, 10589 Berlin.

3.5.2.1.1 Wayside Equipment

- **FhG Wayside Laptop** to monitor CCTV camera pictures.
- **Alstom personal laptop** connected to the FhG Lab Wi-Fi, being connected to the Hawkeye instance of FhG FOKUS (using a public IP address). Tests can therefore also be done remotely.
- The **Hawkeye Server** instance with the FhG lab license runs as an OVA file on VMware in their data center.
- Four **Wayside Hawkeye probes** installed as separate VMs.
- The **FhG Open5GCore** runs on Compute and Storage resources. Open5GCore shall support an **IP address-based QoS** function for 5G RAN.
- The **FhG Lab RAN** equipment used for the tests were from Huawei.
- Grid-based 230 VAC power supply is used, a fixed installation.

The Onboard equipment at **FhG** Lab shall be very similar to that in the **IHP** Lab / Berlin Central Station Field equipment. However, the **KCC** 5G OBG could not be used, therefore a Huawei 5G CPE Pro 2 was used as backup.

3.5.2.1.2 Onboard Equipment

- FhG Huawei **5G CPE** Pro 2 (supporting a DHCP server).
- FhG 5 port **Ethernet Switch** connected between the CPE and onboard users.
- FhG **PoE Injector** connected in between the Ethernet Switch and CCTV camera.
- The **CCTV camera** is connected to the PoE Injector.
- FhG **Ubuntu laptop** with four **onboard Hawkeye probes** installed as four dockers.
- **IxProbe** used in January and February 2023 for the Background Traffic. It gave a minor improvement compared with using the Ubuntu laptop.
- Grid-based 230 VAC **power supply** is used.

The CPE (Huawei CPE Pro 2) has an inbuilt DHCP server, which in this case handed out an IP address 192.168.6.1 for the CCTV camera.

The laptop got an IP address on the Console network 192.168.242.0/24. The 5GCN UPF router was configured with a path to the Virtual LAN (VLAN) reaching the “DN” Tagged network 192.168.243.0/24.

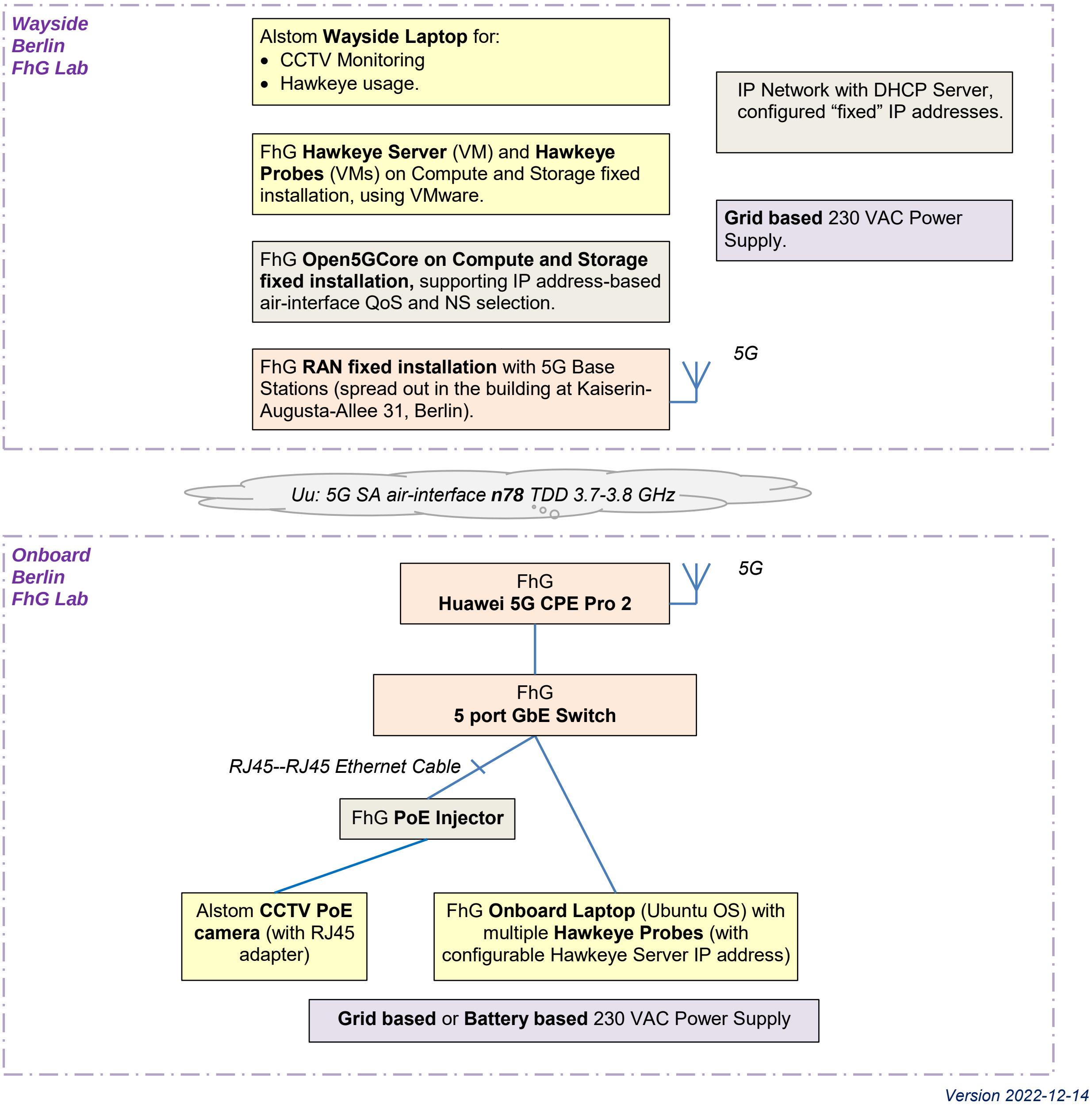
The CPE (the UE) was configured with port forwarding for port 80. In this way the camera could be reached with a browser when addressing the CPE IP address.

3.5.2.1.3 FhG Lab Setup for Rail Signaling and CCTV – without IxProbe

Figure 3-14 gives an overview of the **FhG** Lab setup in Berlin, which was done week 47 2022 at FhG FOKUS in Berlin.

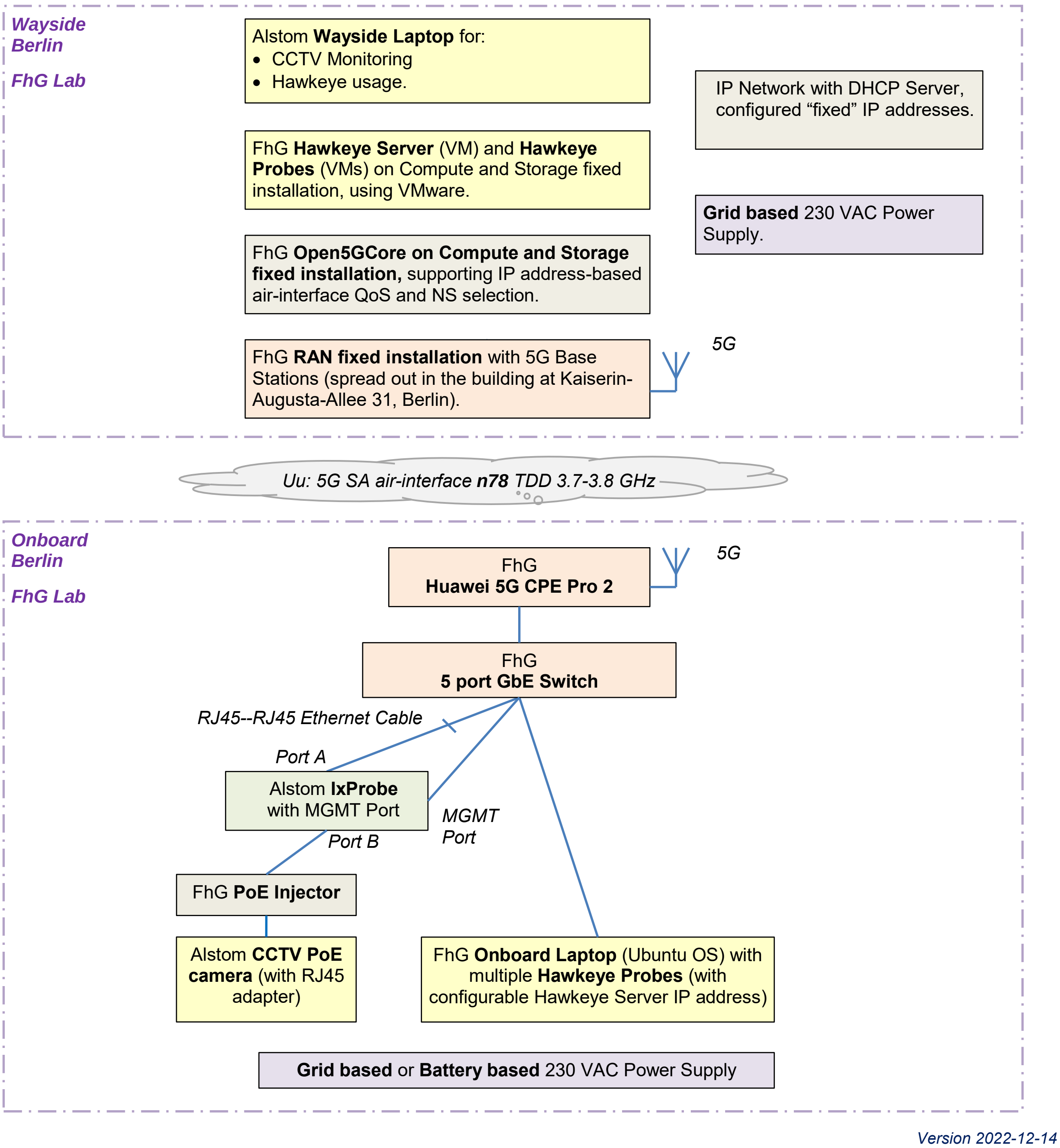
3.5.2.1.1 FhG Lab Setup for Rail Signaling and CCTV – with IxProbe (used 2023)

The setup in Figure 3-15 was deployed in **FhG** at the beginning of 2023.



5G	5th Generation 3GPP defined cellular network	MGMT	Management
CCTV	Closer Circuit Television	OOB	Out Of Band Management
CN	Core Network	PoE	Power over Ethernet
CPE	Customer Premises Equipment (UE onboard GW)	RAN	Radio Access Network
GbE	Gigabit per second Ethernet	SW	Software
GW	Gateway	TDD	Time Division Duplex
HW	Hardware	UE	User Equipment
IP	Internet Protocol		

Figure 3-14 FhG Lab Setup for Rail Signaling and CCTV – without IxProbe



5G	5th Generation 3GPP defined cellular network	MGMT	Management
CCTV	Closer Circuit Television	OOB	Out Of Band Management
CN	Core Network	PoE	Power over Ethernet
CPE	Customer Premises Equipment (UE onboard GW)	RAN	Radio Access Network
GbE	Gigabit per second Ethernet	SW	Software
GW	Gateway	TDD	Time Division Duplex
HW	Hardware	UE	User Equipment
IP	Internet Protocol		

Figure 3-15 FhG Lab Setup for Rail Signaling and CCTV – with IxProbe (used 2023).

This would be an improvement if the Ubuntu onboard laptop had limitations. This can be suspected, based on the test results found during weeks 47-49, 2022.

The CCTV camera was installed at the FhG lab on week 47, 2022. The camera was connected via a Huawei CPE Pro 2 and to the Open5GCore and Data Network (DN) – see Figure 3-16.

Figure 3-17 provides an overview figure of the CCTV setup at the FhG lab in Berlin.

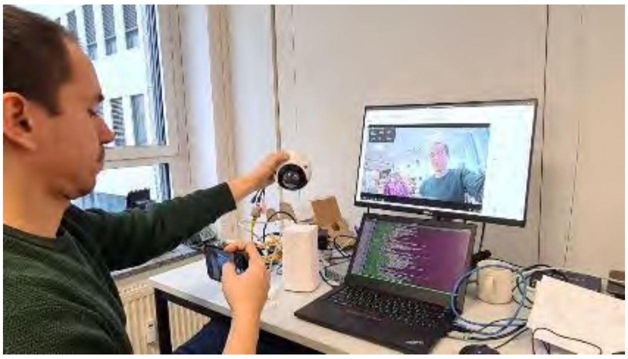
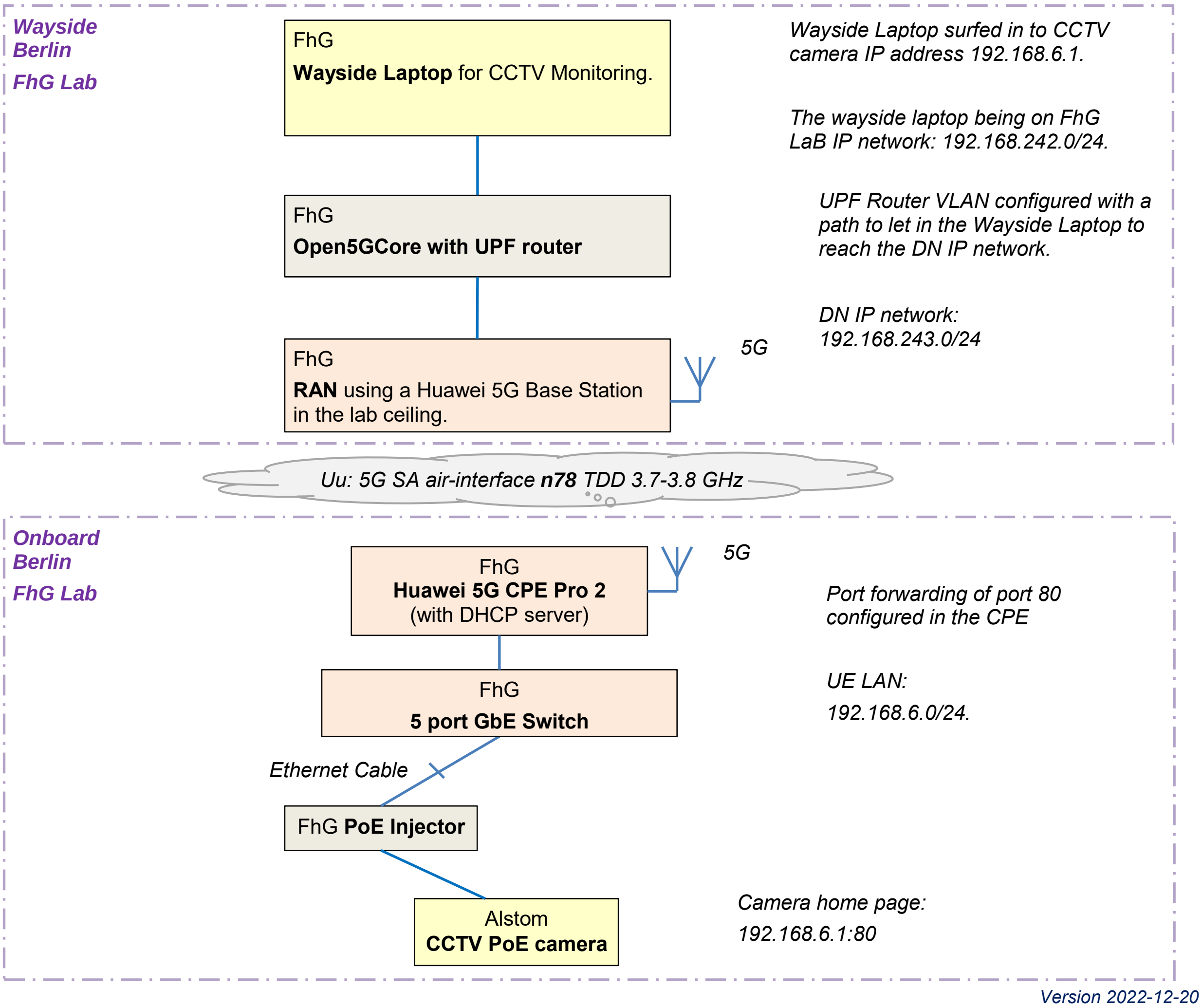


Figure 3-16 The CCTV camera internal processing and coding gives a delay of around 300 ms



5G	5th Generation 3GPP defined cellular network	IP	Internet Protocol
CCTV	Closer Circuit Television	LAN	Local Area Network
CN	Core Network	PoE	Power over Ethernet
CPE	Customer Premises Equipment (UE onboard GW)	RAN	Radio Access Network
FhG	Fraunhofer FOKUS in Berlin	SW	Software
GbE	Gigabit per second Ethernet	TDD	Time Division Duplex
GW	Gateway	UE	User Equipment
HW	Hardware	UPF	User Plane Function

Figure 3-17 Block diagram for the CCTV camera FhG Lab Setup (week 47, 2022)

3.5.2.1.2 Hawkeye Probes

Four probe pairs were installed at the FhG FOKUS Lab. Four **DN** probes on a server, and four **OB** probes on an onboard Ubuntu laptop.

- **Data Network Software VM Probes**

  When trying to install probes within Dockers also on the **Data Network** side (wayside), it didn't work (probably due to NATing on both sides, with hidden IP addresses). Hawkeye couldn't establish traffic with measurements.

  When installing probes like Software, it worked between DN and OB. This resulted in the DN probes being installed as Software on several instances of VMs. Then several streams, e.g. DN1-OB1 and DN2-OB2 could run at the same time.

  Note: Hawkeye DN probes are listed as Type: Software.

- **Onboard XR Docker Probes**

  Linux uses the Docker method for installing several probes on the same Ubuntu laptop, which means that several Docker OSes are installed on top of the Linux OS. In this way several Hawkeye Probes can be used on the same Ubuntu laptop. The Probes get a local IP address within the Docker, using a NAT. The Docker principle is used on the Onboard Ubuntu laptop at FhG FOKUS.

  Note: Hawkeye onboard probes are listed as Type: xr_docker.

3.5.2.2 Rail Telephony Network topology and Lab Setup at FhG Lab

The services for MCX presented in deliverable D3.2 [9] are deployed using the indoor **FhG** 5G fixed testbed in the Fraunhofer lab. It is tested with the presence of RS applications of **UC #1.3**. Figure 3-18 depicts the topology of the testbed with the individual services running in the VMs presented in the network. The services are described in more detail below.

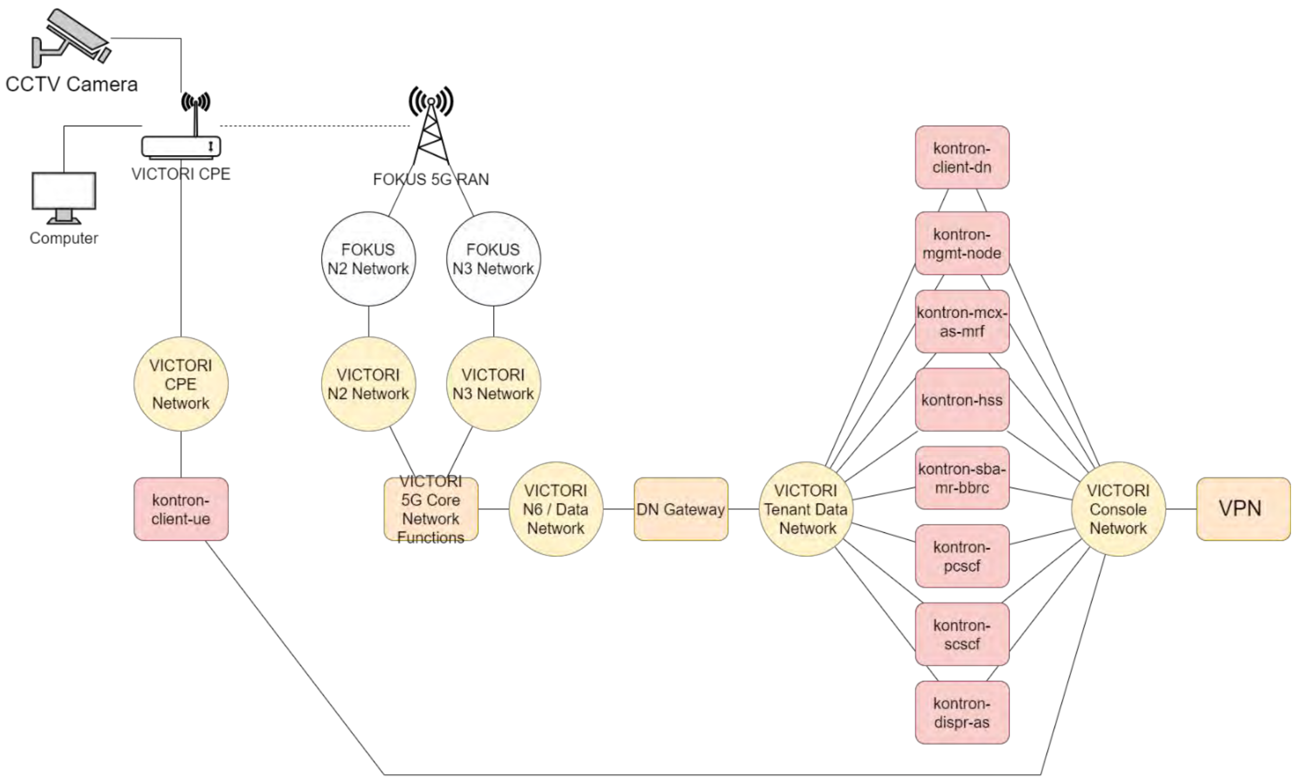


Figure 3-18 FOKUS testbed topology for UC #1.3

The upper left corner represents the radio network. The "VICTORI CPE" is connected to the data network using the "FOKUS 5G RAN". The CPE provides 5G connectivity to a CCTV camera and a laptop. These two nodes are used for testing the RS UC, which is part of **UC #1.3**. The laptop features testing probes for generating UDP and TCP traffic and for measuring the performance of the network. On the right hand side of the figure, one can notice the multiple services used to provide the functionality of the MCx application and services. These services are hosted on VMs. Traffic from and into MCx services goes through the "*VICTORI Tenant Data Network*" and into **Open5GCore**. This is achieved using routing rules set inside the VMs hosting these services. By default, once these services can access the "VICTORI tenant data network" they will be connected to the Open5GCore, therefore no further adjustments to the **FhG** testbed are needed. Notice the N2, N3, and N6 interfaces represent the interfaces of the 5G mobile core network. These interfaces and the components behind them are part of the network provided by the tenant in FOKUS campus. Using VPN access, these services and the core network can be accessed remotely for management, thus no physical presentation at the **FhG** campus is required for managing these services. Accessing these services for management happens over SSH using the "VICTORI console network".

Lab components installed in the **FhG** FOKUS Lab:

- The Open5GCore + RAN from **FhG**.
- All Mission Critical servers run on VMs.
- The Dispatcher Terminal.
- The Mission Critical Handsets (UEs) running both a Push-To-Talk (PTT) App and a Sensor App.
- The **KCC** OBG attached to 2 Huawei CPE Pro 2s.

3.5.2.2.1 Rail Critical System (Telephony) and Components

Kontron's Rail Critical IMS/MCx Core and Application Server were installed at FhG FOKUS using several VM instances hosted on hardware running in the FhG FOKUS Lab. The VMs are outlined below.

- **P-CSCF** – The Proxy Call Session Control Function is the proxy and the first point of contact for the UEs homed in the network or roaming into the network. Encrypted signaling between the UE and the P-CSCF can be enabled on this link.
- **S-CSCF** – The Serving Call Session Control Function, the central node in the signaling plane. The S-CSCF is responsible for session control and for authenticating subscribers connecting to the P-CSCF. This is done with authentication parameters received in the user profile from the HSS.
- **HSS** – The subscriber database which contains user identities, authentication parameters and profiles.
- **MCx-AS** – The MCx Application Server hosts and executes Mission Critical Rail Services (MCx). The MCx-AS is the starting point for all Future Rail Mobile Communication System (FRMCS) Rail Critical Services.
- **MRF** – The Media Resource Function is responsible for connecting voice streams and mixing them for private, conference and group calls. All media flows through the MRF in Rail Critical Networks.
- **MR** and **RTPProxy** – The Media Router and related RTPProxy are used to traverse NAT when MC clients are not directly accessible by the core network routing functions. In addition, the MR serves as a single point which enables the recording and storage of all communications inside of Rail Critical Networks.
- **Dispatcher-AS** – The Application Server (AS) related to the Dispatcher Terminals. It serves to coordinate user profiles and to configure the terminals, and adds another layer of features and functionality specifically related to dispatcher functions.
- **UE Config Server (MGMT)** - Serves user profiles and configurations to the UE smartphone clients, coordinates status and reports between the clients and the core server.

- **UE VMs** – Used to host virtual Rail Critical client instances used for announcements and testing.

In addition, a 5G SA capable smartphone (UE) was installed with the Rail PTT App and a Sensor App, connected to Public Land Mobile Network (PLMN) 99956 and configured for the “mcx” Data Network Name (DNN) used for critical services.

The OBG was configured to use two 5G CPE Pro 2 devices – as depicted in Figure 3-19 – providing access to Rail Critical Services (Telephony) (IMS/MCx core) via the OBG’s Wi-Fi access point steering traffic via 5GS using one of the two CPEs.

3.5.2.2.2 Quality of Service (QoS) for Rail Critical Services

To allow Kontron’s IMS-based MCx Application Function to request the application of the corresponding 5G Policy and Charging Control Rules incl. delay critical ultra-Reliable Low Latency Communications (uRLLC) 5G QoS class and guaranteed flow bit rate for mission-critical applications, the 5GC’s Policy Control Function (PCF) exposes the Rx legacy reference-point to the IMS domain to allow the Proxy Call Session Control Function (P-CSCF) to modify:

- the 5G NR Standardized QoS Identifier (5QI),
- Allocation and Retention Priority (ARP),
- Guaranteed Bit Rate (GBR)/non-GBR of the sessions.

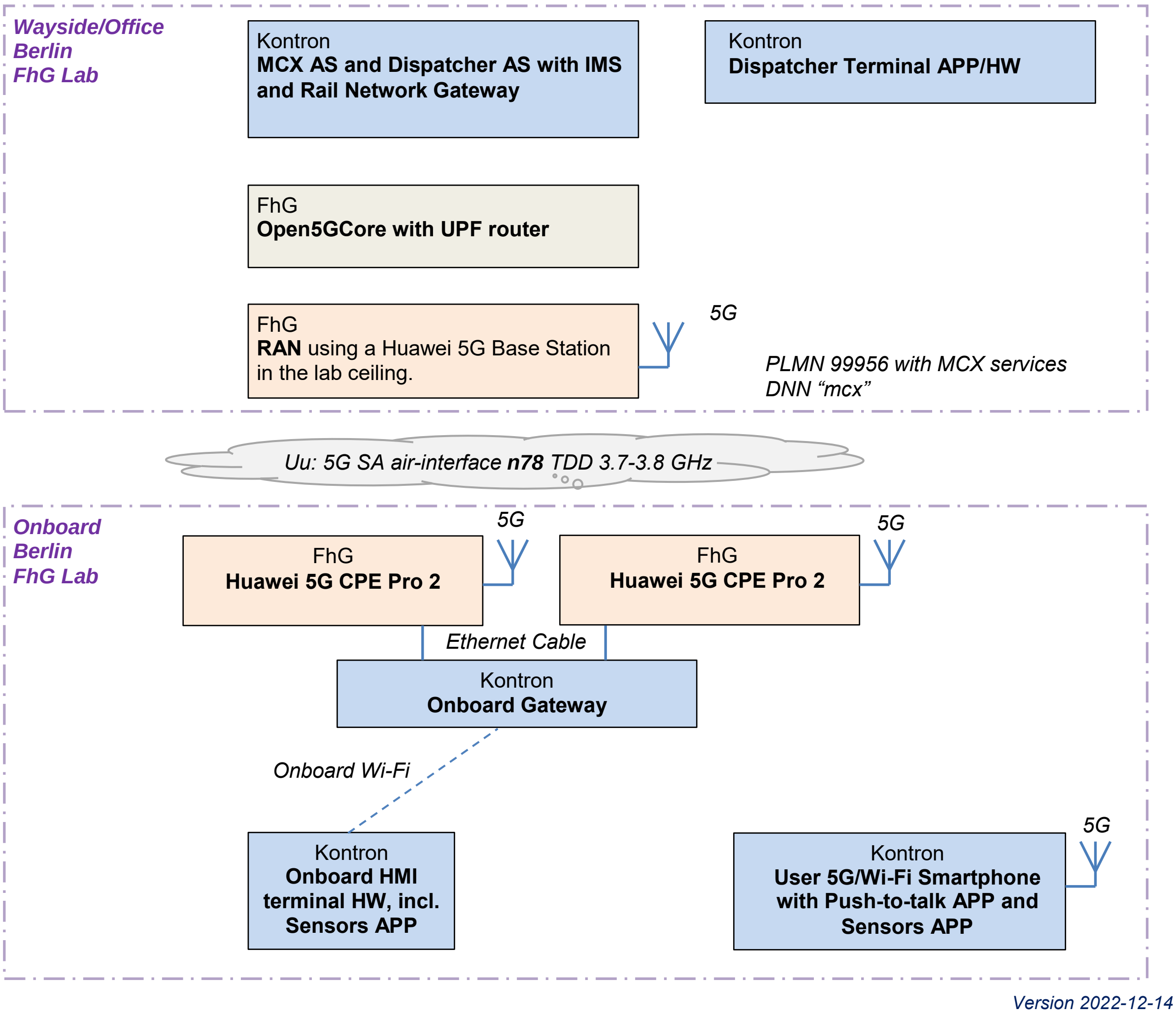
The Fraunhofer PCF’s Rx interface was integrated with Kontron’s P-CSCF to support 5G QoS Class identifier (QCI) modification for specific flows. MCx services are defined by 3GPP to use 5QI GBR 65 for Mission Critical service Push-To-Talk (MCPTT) voice media and 5QI non-GBR 69 for MCPTT signaling. However, these 5QIs are not yet supported by Fraunhofer’s PCF. This means that the traffic of the UEs connected via Wi-Fi to the Onboard Gateway were routed by the CPEs via 5GS to the respective MCx Services using the default DNN with only best-effort providing 5QI 9 (see 3.5.4.1.1).

5G UEs with the PTT App connected directly to the 5GS were configured with a DNN reserved for mission-critical traffic. Although it is intended to use 5QIs 65 and 69, only the supported 5QIs 9 and 8 were used.

5QIs outlined in TS23.501 compared with the FhG Lab usage week 47, 2022:

Table 3-4 5QI values outlined in TS23.501 vs what were used in the FhG Lab

Outlined wanted 5QI values	FhG Lab used 5QI values	Example Services
5QI 65	5QI 9	Mission Critical user plane Push To Talk voice (e.g. MCPTT)
5QI 69	5QI 8	Mission Critical delay sensitive signaling (e.g. MCPTT signaling)



5G	5th Generation 3GPP defined cellular network	IP	Internet Protocol
CCTV	Closer Circuit Television	LAN	Local Area Network
CN	Core Network	PoE	Power over Ethernet
CPE	Customer Premises Equipment (UE onboard GW)	RAN	Radio Access Network
FhG	Fraunhofer FOKUS in Berlin	SW	Software
GbE	Gigabit per second Ethernet	TDD	Time Division Duplex
GW	Gateway	UE	User Equipment
HW	Hardware	UPF	User Plane Function

Figure 3-19 Block diagram for the Rail Critical Services (Telephony) FhG Lab Setup (week 47, 2022)

Figure 3-20 UC #1.3 Office setup with the Dispatcher Terminal.

The MCx Dispatcher Terminal is added to the FhG Lab Setup (see Figure 3-20) and is connected to both the Dispatcher application server (AS) and the MCx IMS Core running in VMs.

All MCx functionality is available:

- Private Calls with and without Floor Control.
- Prearranged Group Calls with Floor Control.
- Private and Group Emergency Calls.
- Private and Group Short Data Service (SDS) Messages including File Distribution for documents, images and videos.
- Panic Alerts.
- Geolocations for the MCx subscribers connected to the 5G network.
- Dynamic group call activated by selecting a polygon and launching a group call to the MCx subscribers inside of that polygon.

The Rail Critical OBG is deployed in the **FhG** Lab (see Figure 3-21). Connectivity to the 5G network is achieved using a CPE and DHCP is deployed for allocation of IP addresses to other wireless clients connecting to the OBG via Wi-Fi. The Quectel RM500Q-GL modem inside of the OBG is capable of connecting to PLMN 00101 but not PLMN 99956.

Figure 3-21 UC #1.3 Rail Critical OBG

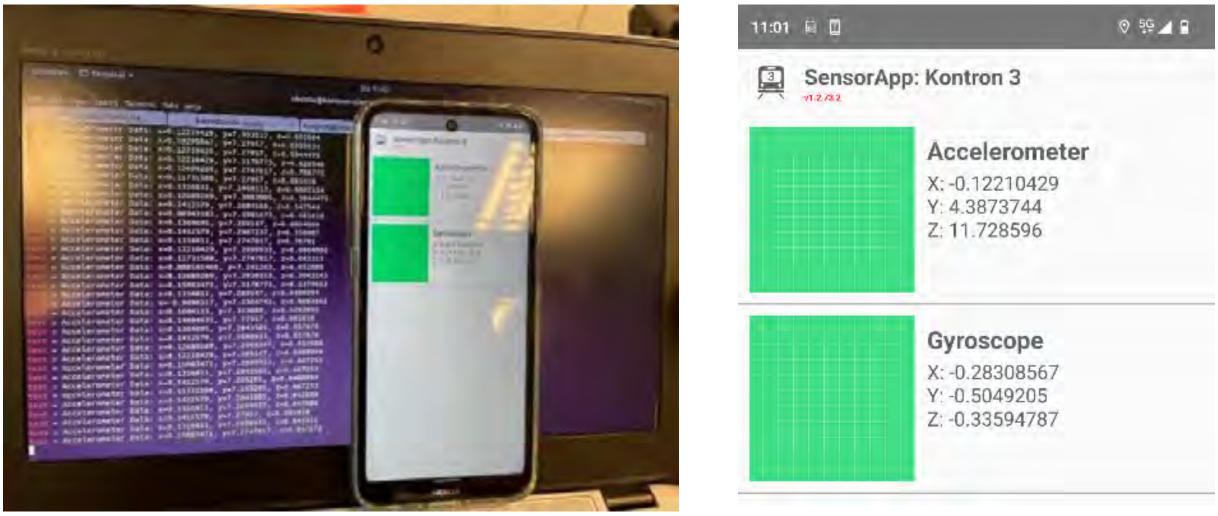


Figure 3-22 UC #1.3 Sensor App Setup

The Sensor App collects readings from the Accelerometer and the Gyroscope at configurable intervals – once every 10 ms to once every 10 seconds (see Figure 3-22). The data collected is sent via MCx SDS to a remote client – in this case a VM running a virtual MCx client.

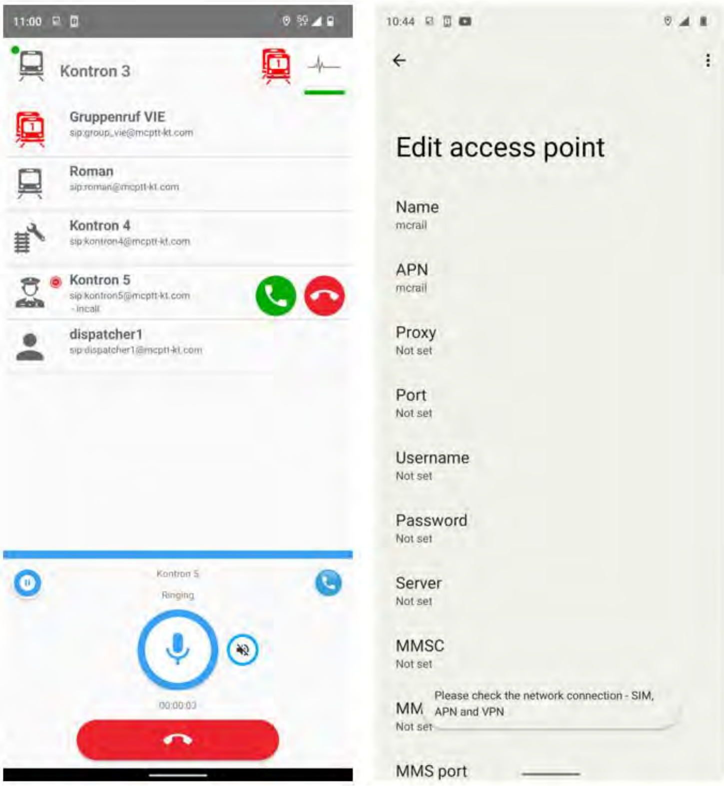


Figure 3-23 UC #1.3 Rail Critical Voice App and the 5G DNN setup

The user interface of the Mission Critical PTT App is designed to be easy-to-use by rail personnel and allows for voice and messaging applications including private calls, group calls, floor management, private messages and group messages.

DNNs are used to manage access to the 5G network with different 5QIs allocated for different applications.

3.5.2.3 Onboard 5G GW and CPE

The 5G GW from **KCC** was not used for this lab setup, as there were some issues with the PLMN number 99956 and the underlying firmware in the modem. The Huawei CPE Pro 2 was used instead, which has an inbuilt DHCP server (see Figure 3-24).

Figure 3-24 5G mobile gateways: KCC 5G GW (black unit) and Huawei CPE Pro 2 (white unit).

Figure 3-25 5G base station remote radio unit – FhG 5G pRRU1

3.5.2.4 Base station 5G radio head

The 5G Radio head for the 5G network was a fixed installation in the FhG FOKUS building (see Figure 3-25). It was mounted in the ceiling in the main lab room.

3.5.3 Components testing at lab setups

3.5.3.1 Maximum bitrates at FhG (infrastructure and 5G air-interface)

These tests were performed during weeks 47-49, 2022, at FhG Lab.

3.5.3.1.1 Speedtest between Hawkeye Probes on computer infrastructure

What is the TCP Speedtest bitrate between two Onboard Probes? This bitrate should go between two Docker probes on the same onboard Ubuntu laptop, via the Linux OS on the same Ubuntu laptop.

- OB1-OB2: One TCP pair: 6,8 Gbps, Ten TCP pairs: 14,8 Gbps
- OB3-OB4: One TCP pair: 6,9 Gbps, Ten TCP pairs: 14,6 Gbps

What is the TCP Speedtest bitrate between two Data Network Probes? This bitrate should go between two VM probes on the same DN Server.

- DN1-DN2: One TCP pair: 6,94 Gbps, Ten TCP pairs: 17,5 Gbps
- DN3-DN4: One TCP pair: 8,58 Gbps, Ten TCP pairs: 9,25 Gbps

3.5.3.1.2 Speedtest between Hawkeye Probes over the 5G network at FhG FOKUS

Speedtest using TCP bi-directional over 5G between OB-DN probe pairs:

- OB1-DN1:
  - One TCP pair: UL 126 Mbps, DL 420 Mbps
  - Ten TCP pairs: UL 113 Mbps, DL 479 Mbps
- OB2-DN2:
  - One TCP pair: UL 126 Mbps, DL 413 Mbps
  - Ten TCP pairs: UL 110 Mbps, DL 472 Mbps
- OB3-DN3:
  - One TCP pair: UL 126 Mbps, DL 432 Mbps
  - Ten TCP pairs: UL 114 Mbps, DL 467 Mbps
- OB4-DN4:
  - One TCP pair: UL 126 Mbps, DL 429 Mbps
  - Ten TCP pairs: UL 112 Mbps, DL 456 Mbps

The maximum bitrate for UL was found to be around 126 Mbps. The maximum bitrate for DL was found to be different depending on what tool that was used. Maximum DL bitrate with:

- iPerf: 850 Mbps
- Hawkeye onboard and wayside probes: 430 Mbps

Note: iPerf probably runs close to the hardware, with a minimum of OS impact (bypassing). Hawkeye onboard Probes run in Docker OS, with NAT:ing to reach Ubuntu OS. The performance difference between these two is probably a factor two or so.

A way forward for upcoming lab tests would be to use the IxProbe hardware-based probe, which probably increases the DL bitrate found by Hawkeye.

3.5.3.1.3 Speedtest over Gigabit Ethernet cables and switches

A useful loss free and short delay bitrate over a Gigabit Ethernet infrastructure has not been tested in the FhG Lab.

However, searching the internet, the full line speed can't be used. To be on the safe side, the bitrate shall probably be maximum 70% for a loss free communication.

3.5.3.2 Hawkeye Probes Pairs at FhG Berlin: 1x Background Traffic, 3x Rail Signaling

Four Hawkeye probe pairs were setup at FhG FOKUS in Berlin.

- One for Background Traffic, for saturating the 5G air-interface.
- Three for RS, each running at 200 kbps. Probe pair nr 2 and 4 uses "best effort" and probe pair 3 high prio QoS.

Note: the HW based IxProbe has also been used instead of onboard probe.

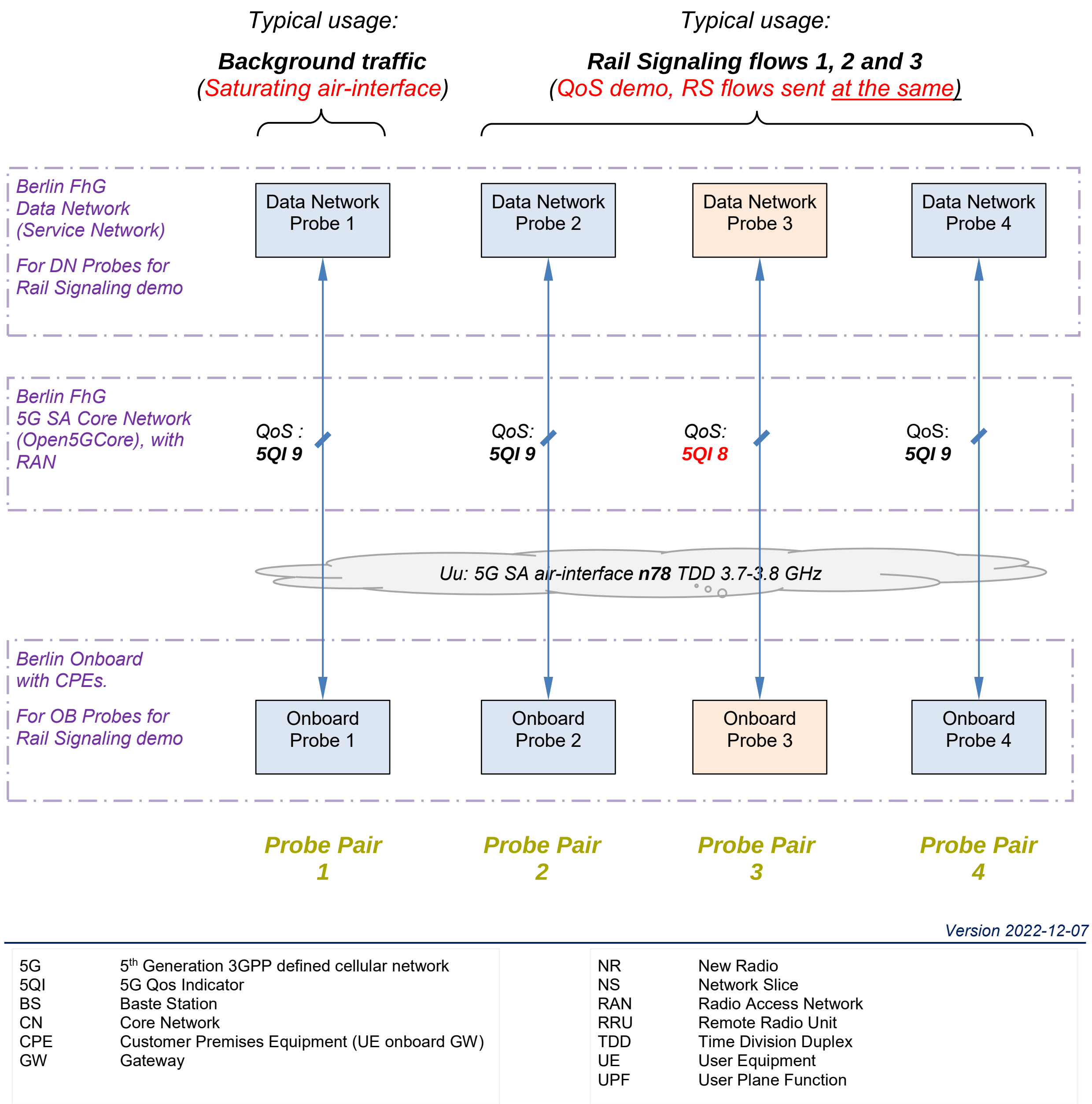


Figure 3-26 Keysight Hawkeye Probes at FhG: Background Traffic and three RS probe pairs

3.5.4 Experimental results

3.5.4.1 Rail Signaling with QoS over the 5G air-interface

The objective with RS over 5G is to test how different RS flows with different QoS behave when there is background traffic which almost saturates the air interface performance.

A lab setup was performed during week 47, 2022, at FhG lab in Berlin. Four Hawkeye probe pairs were installed and QoS was configured for the first time in Open5GCore and its RAN and UE.

3.5.4.1.1 QoS: 5QIs used in the FhG FOKUS Lab

The 5G radio network at FhG FOKUS with its Open5GCore, RAN and UEs have limitations when it comes to supporting the given predefined ones listed in 3GPP TS 23.501.

Open5GCore allows to set any 5QI, it just passes the information along in different protocols to RAN and UE. The limiting factor in the lab is the RAN (from multiple vendors, although the tests ware done using Huawei), which is only configured to accept certain 5QIs and translate them to certain configured Data Radio Bearer (DRB) settings.

Note: this is an issue of configuration (and support) for upcoming tests to be able to set up additional 5QIs.

5QIs outlined in WP3 compared with the FhG Lab usage week 47, 2022:

Table 3-5 5QI values outlined in WP3 5G-VICTORI documentation vs what were used in the FhG Lab

QoS	WP3 outlined 5QI values	FhG Lab used 5QI values
Highest Priority (of the three)	**5QI 69**	
Medium Priority	**5QI 8**	**5QI 8**
Lowest Priority (of the three)		**5QI 9**

5QI 69 is not supported in the lab. The supported ones were 5QI 8 and 5QI 9, which are pretty close to each other performance wise, not optimal for Background Traffic and RS for demo purposes. See the table extract (Table 3-6) with details given in TS 23.501.

The real QoS behaviour difference between 5QI 69 and 8, vs between 8 and 9 also depends on how the schedulers are implemented in the UE and in the Base station. The lowest Default Priority Level value has the highest priority in the schedulers.

Table 3-6 Extract from TS 23.501 for 5QIs 8, 9 and 69

5QI	Resource Type	Default Priority Level	Packet Delay Budget	Packet Error Rate	Default Maximum Data Burst Volume	Default Averaging Window	Example Services
8	Non-GBR	**80**	300 ms	10^{-6}	N/A	N/A	Video (Buffered Streaming) TCP-based (e.g. www, e-mail, chat, ftp, p2p file sharing, progressive video, etc.)
9		**90**					
69		**5**	60 ms	10^{-6}	N/A	N/A	Mission Critical delay sensitive signalling (e.g. MC-PTT signalling)

3.5.4.1.2 QoS in Open5GCore at FhG Lab

3.5.4.1.2.1 QoS implementation in Open5GCore

Multiple 5G functions in the Open5GCore handle 5G QoS (Quality of Service).

The first stage of the QoS functionality is configuring the QoS rules in the PCF and the Unified Data Management (UDM) components. These components have entries for the subscriber's authorized 5QI. In the Open5GCore, UDM stores these in a MySQL database, and PCF is configured using a runtime JSON configuration file.

Upon initiating a subscriber session by the UE, the SMF obtains the QoS rules from PCF and UDM, followed by a creation of a PDU session based on the 5QI. In UPF each 5QI flow is identified by a QoS Flow Identifier (QFI), which can be considered as a local value inside the 5G system. Finally, UPF can prioritize flows, based on their assigned QFI.

A special case for the QoS is the functionality of the IP multimedia service (IMS), which is responsible for the telephony services. The IMS is also integrated in the Open5GCore using a third-party service Kamalio. The IMS requests the connection data bearer from the PCF over the diameter's RF interface, then the IMS communicates with the SMF to initiate a session for the phone call, upon a session initiation, the UPF negotiate the parameters for the flow of the call between the two phones calling each other. It should be mentioned that the IMS service requires low-latency, but has low throughput demand.

3.5.4.1.2.2 QoS rules communicated from 5GCN to RAN and UE

All UDP/TCP traffic in either direction between the UE and 192.168.243.123 (FhG Lab IP address of Probe 3 in the DN) is treated with the following QoS parameters:

- 5QI 8
- Priority 80 (default for 5QI 8)
- ARP (ARP priority level 1, May trigger pre-emption, Not pre-emptable)

All other traffic in either direction between the UE and any address is treated with the following QoS parameters:

- 5QI 9.
- Priority 90 (default for 5QI 9).
- ARP (ARP priority level 8, Shall not trigger pre-emption, Pre-emptable).

Note: TS 23.501 defines other default values for QoS parameters 5QI 8 and 9, but they were not explicitly communicated to the RAN and UE (assuming they are already aware). However, it is doubtful if there is any implementation to enforce values like "packet budget delay" or "packet error rate".

Note: the tests probably didn't result in any ARP-triggered release of QoS flows, so that information is probably a bit superfluous.

3.5.4.1.2.3 QoS on the radio

The lab activities during week 47 2022 did not dig into radio bearer details. As the specs also leave some room to interpretation, the radio configuration on the RAN of how 5QIs are mapped to radio bearers may also be a factor.

3.5.4.1.3 DiffServ Code Point (DSCP) settings

The Hawkeye tool can set the DSCP for a traffic flow, for example Best Effort (BE) or Expedited Forwarding (EF). The Open5GCore 5G system does not support DSCP. Therefore the QoS has been implemented with other means.

It has been tested with different DSCP settings and proved it has no impact.

3.5.4.2 Rail Critical Services (Telephony)

3.5.4.2.1 Results

The following was observed in the **FhG** Lab Setup, week 47 in Berlin.

3.5.4.2.2 Rail Critical Services

Rail critical voice services deployed in the core VMs, were tested using various end-user devices running the rail PTT App. Responsiveness of the PTT App and the quality of the voice communications relies on low-latency network connections with ample throughput for voice services. This was the case in the **FhG** Lab setup in Berlin. Individual KPIs are available with typical call setup times of ~200 msecs and typical times to request the floor of ~30 msecs. Voice communications using 5QIs 65 and 69 were not tested as default 5QIs were configured in the 5GCore for the DNNs that were used for the tests.

The Dispatcher Application running on the Dispatcher Terminal connects to the Dispatcher Application Server (AS) and downloads all available application updates and configuration needed to register and run in the MC network. Both the Dispatcher AS and the Dispatcher Terminal are connected directly to the core via virtual NICs and Ethernet respectively. This implies that they are not directly dependent on 5G for a QoS. Download of the application software and configuration for the Dispatcher Terminal is reliable and fast.

The MC subscribers and all calls between the Dispatcher and the MCx subscribers are dependent on the 5G network for a quality of service related to voice communications between the individual endpoints. Calls between MCx subscribers are dependent on the 5G network for quality of service. Communications between Dispatcher and MCx subscribers are reliable, call setup time is reliably fast and voice quality is good.

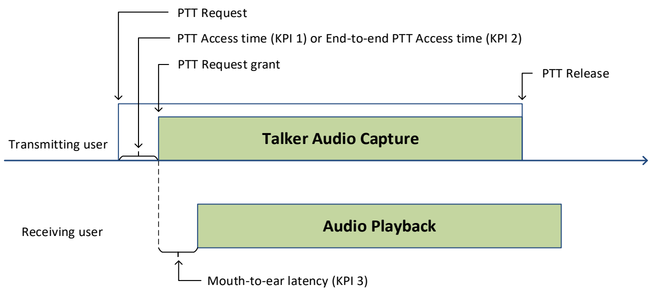
Additionally, it was noted that there is a slight delay when observing the mouth-to-ear latency between the MCx clients. It is noted however that this latency appears to be normal across all clients and transmission technologies. A more advanced setup will be required to measure this latency and analyze why it appears. Some factors contributing mouth-to-ear latency are listed below.

- Implementation of the client hardware – microphone and speaker.
- Implementation of audio buffers to maintain enough data in the buffer to reliably transmit audio information in the RTP packets in a timely manner - i.e. 1 packet every 20 msecs containing around 160 bytes of audio data depending on the sample rate and the compression of the applied audio codec.
- The audio codec applied to the recorded audio data.
- The audio codec applied to the audio data in hardware or software.
- The transmission delay in the 5G network including any congestion and prioritization caused by parallel access of the 5G network by competing clients, and including interference from competing base stations and UE.
- The processing time required by the Media Router (MR) and the Multimedia Resource Function (MRF), including transcoding if required.

3.5.4.2.3 Rail Critical Services – KPIs

Meaningful KPIs for Rail Critical Services are listed below.

1. MCPTT Access Time (cKPI1): the time between when a user of an MCx/FRMCS client requests to speak (normally by pressing a PTT control) and when this user is granted the right to speak. This time does not include confirmations from receiving users or affiliation (if applicable), but does include the call setup request and potentially a bearer establishment. cKPI1 is applicable for both the call setup request and for the subsequent PTT request(s) that are part of the same call.
2. E2E MCPTT Access Time (cKPI2): the time between when an user of an MCx/FRMCS client requests to speak (normally by pressing a PTT control) and when this user is granted the right to speak. This time includes the call setup request (if applicable) and possibly an acknowledgement from the first receiving user before voice can be transmitted. For MCPTT Private Calls with Floor Control, the E2E MCPTT Access Time is measured from the initiating client's private call request to reception of either a private call response for automatic commencement or the MCPTT ringing indication for manual commencement.
3. Mouth-to-ear latency (cKPI3): the time between an utterance by the transmitting user, and the playback of the utterance at the receiving user's speaker.



4. Mean-Opinion Score voice quality: QoE for voice calls.

The results achieved in the **FhG** Lab Setup in Berlin focus on cKPI1 and cKPI2 … as cKPI3 is difficult to measure without additional mediating equipment and Mean-Opinion Scores are somewhat subjective.

cKPIs 1 and 2 were evaluated according to the requirements laid out in 3GPP TS 22.179. The Rail Critical Services shall be capable of providing the performance specified by the standard for all affiliated rail group members.

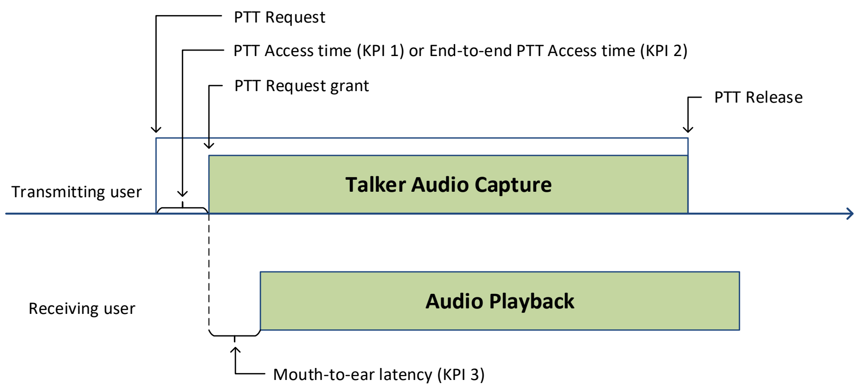


Figure 3-27 3GPP TS 22.179 illustrating PTT access times

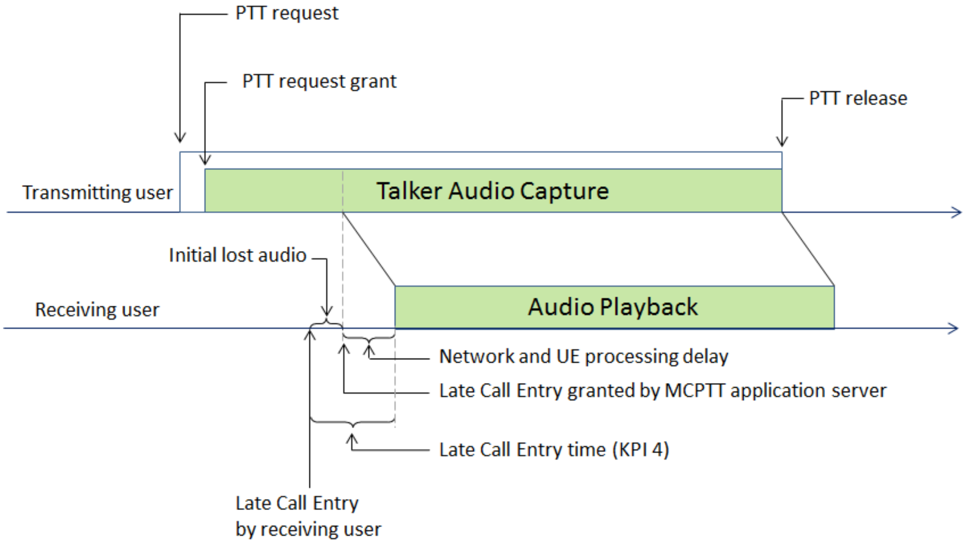


Figure 3-28 3GPP TS 22.179 illustrating late call entry time

For rail applications and users, one of the most important performance criteria is the MCPTT Access Time (cKPI1). The MCPTT Access Time is defined as the time between when a rail user requests to speak (normally by pressing the PTT control on the device) and when the user is granted the right to speak. This time does not include confirmations from receiving users.

The E2E MCPTT Access Time (cKPI2) is defined as the time between when the rail user requests to speak (normally by pressing the PTT control on the device) and when this user is granted the right to speak. This includes call establishment (if applicable) and possibly an acknowledgement from first receiving user before voice can be transmitted. Group calls can be set up with or without acknowledgements from receiving users.

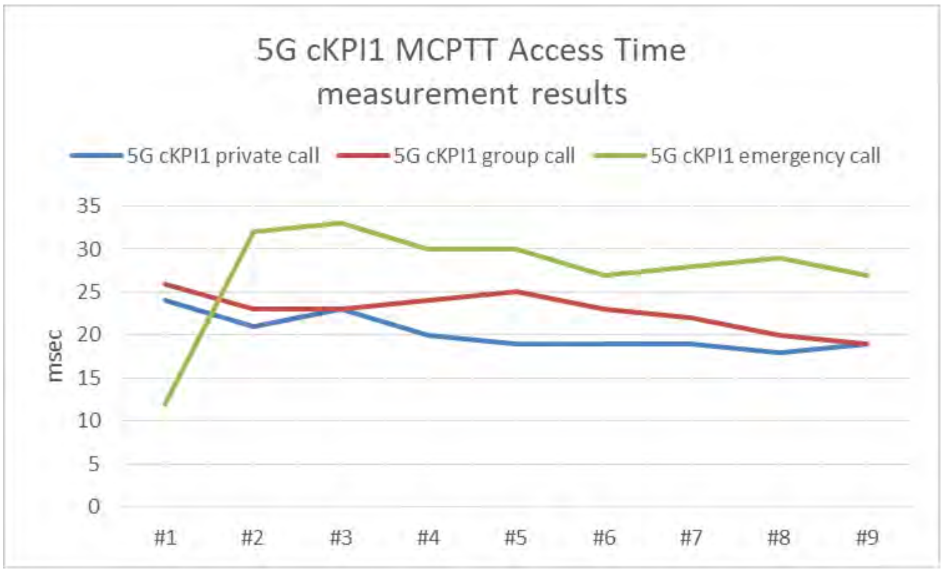


Figure 3-29 Measurement results of 5G cKPI1 MCPTT Access Time

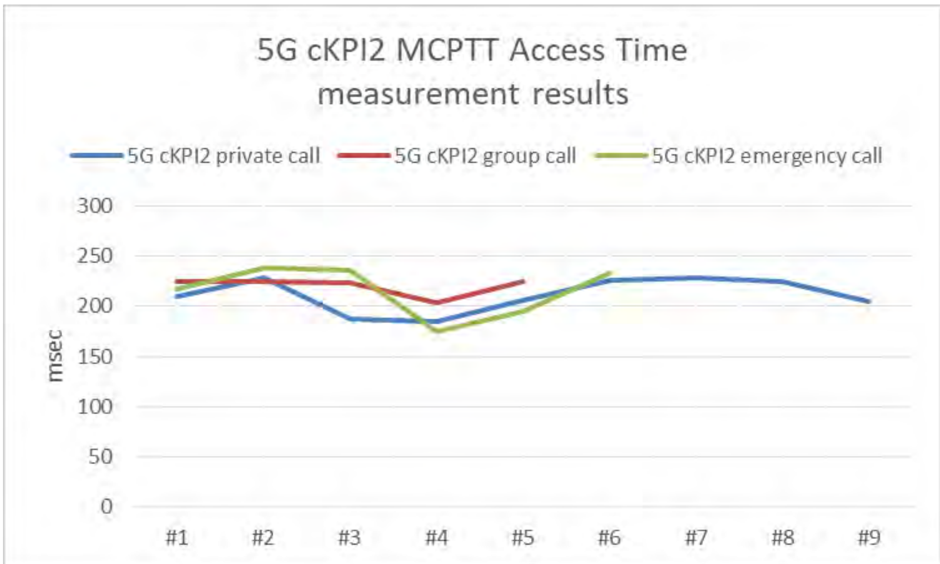


Figure 3-30 Measurement results of 5G cKPI2 E2E MCPTT access time

A rail user is able to leave and rejoin an ongoing MCPTT Group Call. Late call entry is the activity when an Affiliated MCPTT Group Member joins an MCPTT Group Call in which other Affiliated MCPTT Group Members are already active. The Late Call Entry Time (cKPI4) is the time to enter an ongoing MCPTT Group Call measured from the time that a rail user decides to monitor such an MCPTT Group Call, to the time when the MCPTT UE's speaker starts to reproduce the audio. The performance requirements for Late Call Entry Time only apply when there is ongoing voice transmitted at the time the MCPTT User joins the call.

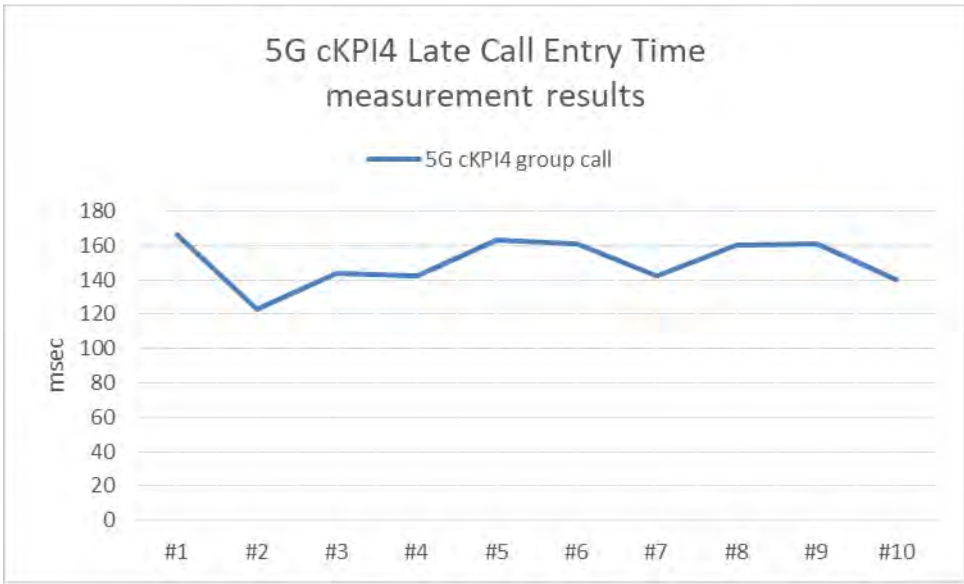


Figure 3-31 Measurement results of 5G cKPI4 Late Call Entry Time

3.5.4.2.4 Rail Critical Onboard Gateway

The Rail Critical Onboard Gateway was connected to the 5G network via a CPE and configured to deliver IP addresses to client devices connecting via Wi-Fi. The IP addresses were requested by the clients using DHCP.

Ping times between the Onboard Gateway and the core network servers were reliable and fast.

3.5.4.3 Maximum bitrate over the 5G air-interface (Hawkeye and iPerf)

The Hawkeye software was used to measure Uplink (UL) and Downlink (DL) **Loss** and **Delay** in. The UL traffic goes between Onboard Probes and the 5G Data Network Probes, and the other way for DL traffic.

This is the result when running RS flows (each having 200 kbps) at the same time with a Background traffic. The Background traffic is stepwise increased to from 0% to 100% of the maximum bitrate measured for the air-interface, and up to 200% when it was found that iPerf showed higher downlink bitrates with speedtest.

The maximum bitrate over the 5G air-interface was measured with two methods:

- iPerf between onboard Ubuntu laptop and a Data Network (DN) laptop
- Hawkeye probes between onboard Ubuntu laptop and DN server.

The maximum bitrate was measured with both Hawkeye and iPerf:

UPLINK:

- o Hawkeye and iPerf UPLINK speedtest showed 126 Mbps

DOWNLINK:

- o Hawkeye showed 430 Mbps
- o iPerf showed 850 Mbps.

Conclusions:

- These tests assume that the air-interface is the only bottleneck.
- However, the 5G air-interface DL bitrate is very close to the performance of the GB ETH infrastructure. This can lead to strange results, as frame losses and delay can occur somewhere else other than over the 5G air-interface, e.g. in OS buffers, ETH switches.

- The iPerf software has been optimized over the years and probably runs close to the hardware, with a minimum OS overhead impact. This is one reason why iPerf shows a higher bitrate in downlink.
- The Hawkeye software is optimized to monitor a big network for data providers. Here each onboard probe runs in a Docker OS (to be able to instantiate several probes on the same Linux computer), with etwork address translation ("NATing") in between the Docker OS and the Ubuntu OS. This means several layers of buffers.

3.5.4.4 CCTV Camera - FhG Lab results

The CCTV service has been tested both with a real CCTV cameras and with Hawkeye emulated video streems.

3.5.4.4.1 Real CCTV Camera – FhG Lab Results

The real CCTV camera was tested over the 5G air-interface, KPIs were measured and estimated. The CCTV camera together with emulated Video flows were not tested.

3.5.4.4.1.1 CCTV Latency

The latency over 5G air-interface from the Onboard (OB) network to the DN is around 10 ms. However, the latency between the reality, via the camera coding, to the decoding in a web browser was found to be around 300 to 500 ms (depending on parameter settings in the camera, e.g. P-frames and frame rate).

3.5.4.4.1.2 Buffering after a 5G air-interface loss

When 5G connectivity was temporarily blocked in the CPE (for testing), the camera pictures froze. When the 5G connectivity was enabled again, the pictures came back but were delayed several seconds, up to 10 seconds.

A picture refresh in the web-browser shortened the buffering again to around 300 ms.

3.5.4.4.2 Emulated CCTV using Hawkeye – FhG Lab Results

Video streams were tested over 5G at FhG FOKUS using Keysight Hawkeye. Two tests were done, shown in the same diagrams two CCTV streams (2x 5 Mbps) with different 5QIs, plus a single 12-trains-CCTV stream (60 Mbps), together with uplink only Background Traffic (stepwise increased from zero to 126 Mbps).

1. Two CCTV streams with two different 5QIs (5QI 9 and 8), each with 5 Mbps, plus stepwise UL Background Traffic increase from 0 to 126 Mbps.
2. Single 12-trains CCTV stream (12x5=60 Mbps) with 5QI 9, plus stepwise UL Background Traffic increase from 0 to 126 Mbps.

Note: 5QI 8 has a priority of 80 and 5QI 9 priority 90, according to TS 23.501, where the lowest priority figure means the higher priority.

These tests use the **Hawkeye** traffic type **Video Stream** with a synthetic video content, simulating video based on RTP/UDP flows.

Figure 3-32 and Figure 3-33 are valid for both these tests (dual 1x and single 12x).

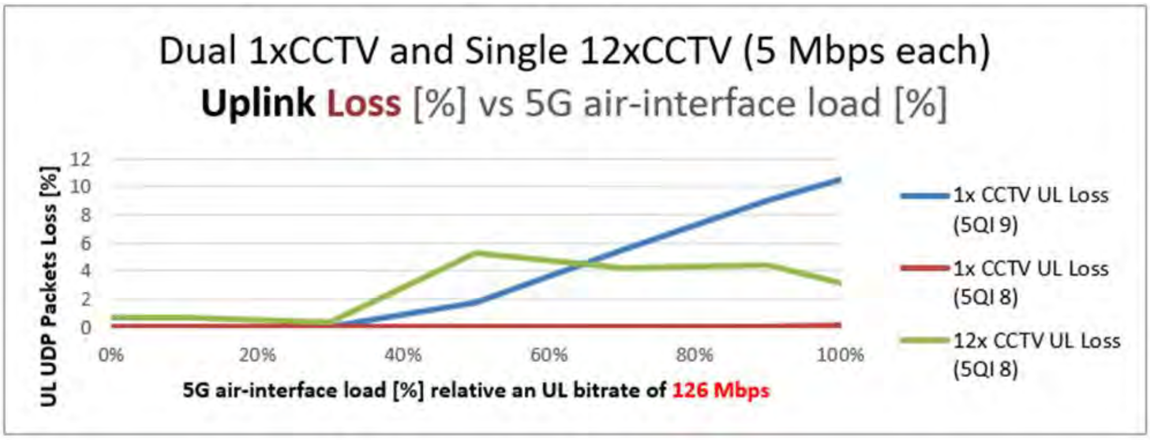


Figure 3-32 Dual 1xCCTV and Single 12xCCTV (5 Mbps each) vs 5G air-interface load – Uplink Loss

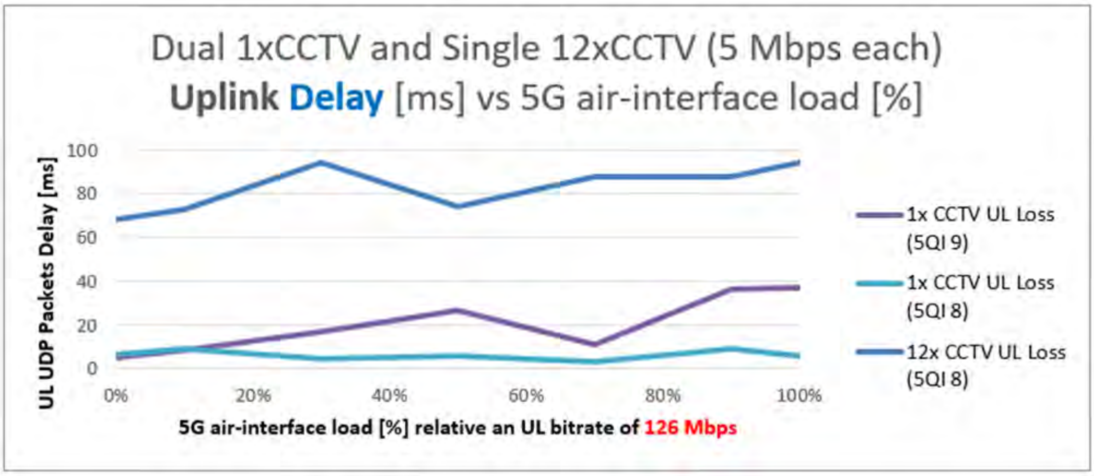


Figure 3-33 Dual 1xCCTV and Single 12xCCTV (5 Mbps each) vs 5G air-interface load – Uplink Delay

When comparing 1x CCTV 5QI 8 with 1x CCTV 5QI 9, the 5QI 8 flow gets a much lower loss than the 5QI 9 flow. This result is expected.

The twelve trains result with a 60 Mbps video stream got a loss up to 5%. This results is not expected result.

Note: the Background traffic during the test shows an increasing uplink loss, from 0 to 46% at 50% load and up to 74% uplink loss at 100% load. This could indicate burst loss, and could impact other flows as well.

Dual CCTV streams were run at the same time, first using 5QI 8 and second using 5QI 9.

Figure 3-33 shows that the 1x CCTV stream gets a constant low uplink delay. This result is expected. The 12x CCTV stream shows a longer constant delay, which is within the expected KPI (this is a single test).

3.5.4.4.2.1 Two 1x CCTV streams with 5QI 9 and 8, plus stepwise UL Background Traffic increase

These dual uplink CCTV streams were run at the same time, using 5QI 8 and 9, while the Background traffic was stepwise increased from 0 to 126 Mbps.

Comparing the two single CCTV streams, it clearly shows that the 1x CCTV 5QI 8 stream got very low uplink loss, while the second one got higher loss as the Background Traffic load increases (it starts to differ at around 50 Mbps).

The first single CCTV stream using 5QI 8 got very low uplink delay (~7 ms) regardless of Background Traffic load. The second one with 5QI 9 got higher delay with increased background traffic load, a clear QoS differentiation.

3.5.4.4.2.2 One 12x CCTV stream with 5QI 8, plus stepwise UL Background Traffic increase

The single 12x CCTV stream corresponding to 12 trains (12 x 5 Mbps = 60 Mbps) shows an increased loss ratio from a low figure (<1%) to higher values (~5%) above 50 Mbps Background Traffic.

The single 12xCCTV stream corresponding to 12 trains shows a longer delay of around 80 ms regardless of Background Traffic load.

3.5.4.5 Rail Signaling - FhG Lab results

These are the **FhG** FOKUS Lab results from weeks 47, 48, 49, year 2022.

3.5.4.5.1 Rail Signaling over 5G air-interface – UPLINK LOSS and DELAY

RS UL Loss and Delay measured with Hawkeye:

- Three single UL RS flows (each using 200 kbps), using 5QI 9, 8 and 9.
- Two Twelve trains RS (each using 2.4 Mbps), using 5QI 9 and 8.

The figures below show:

- Y-axis: UL Loss and Delay for three flows of RS, each using 200 kbps. One flow using 5QI 8 and two flows using 5QI 9.
- X-axis: The background traffic is run bi-directional in Hawkeye, but the diagram shows Uplink only. The background traffic is stepwise increased from 0 to 100% of the maximum found uplink bitrate of 126 Mbps.

Note: Experience from Hawkeye measurements with no result errors when using bi-directional high bitrates: this probably causes loss of the measurement result signaling messages with the probes). It was decided to use Uplink only for the Background Traffic for further testing (for uplink traffic).

3.5.4.5.1.1 Bidirectional Background Traffic and 3x Rail Signaling 200 kbps flows – Uplink Loss and Delay

Figure 3-34 and Figure 3-35 show the expected result for the RS flows using 5QI 8 and 5QI 9, as the 5QI 8 flow is prioritized with a much lower loss and delay compared with the 5QI 9 flows.

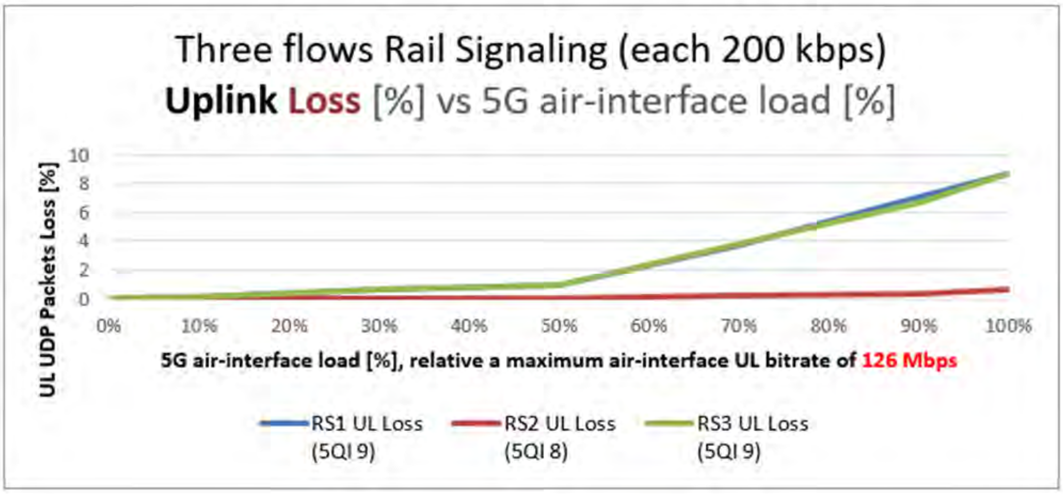


Figure 3-34 Bidirectional Background Traffic and three Rail Signaling 200 kbps flows - Uplink Loss

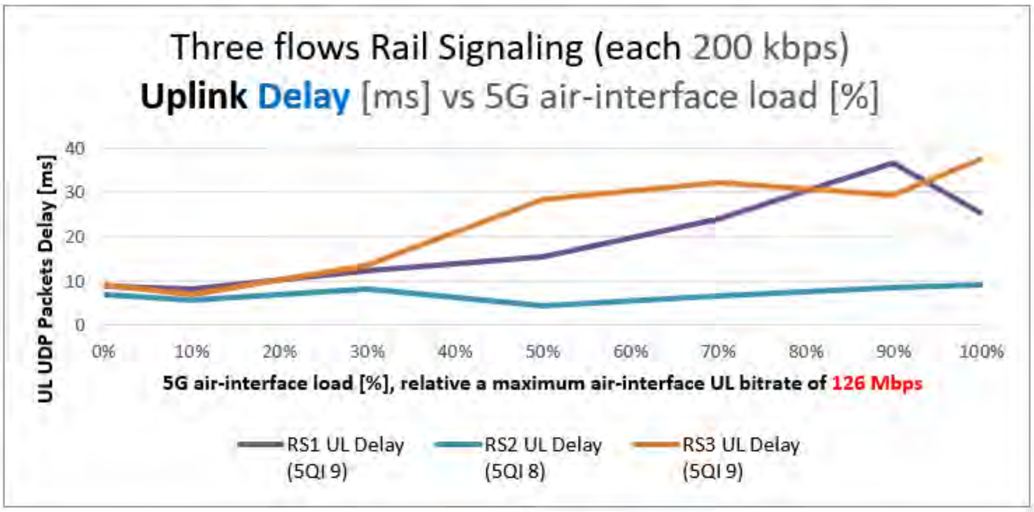


Figure 3-35 Bidirectional Background Traffic and three Rail Signaling 200 kbps flows – Uplink Delay

3.5.4.5.1.2 UL only Background Traffic and 3x Rail Signaling 200 kbps flows – Uplink Loss and Delay

This test uses three RS flows in UL only, each with a bitrate of 200 kbps. The Uplink only Background traffic is stepwise increased from 0 to 100% of the maximum 126 Mbps.

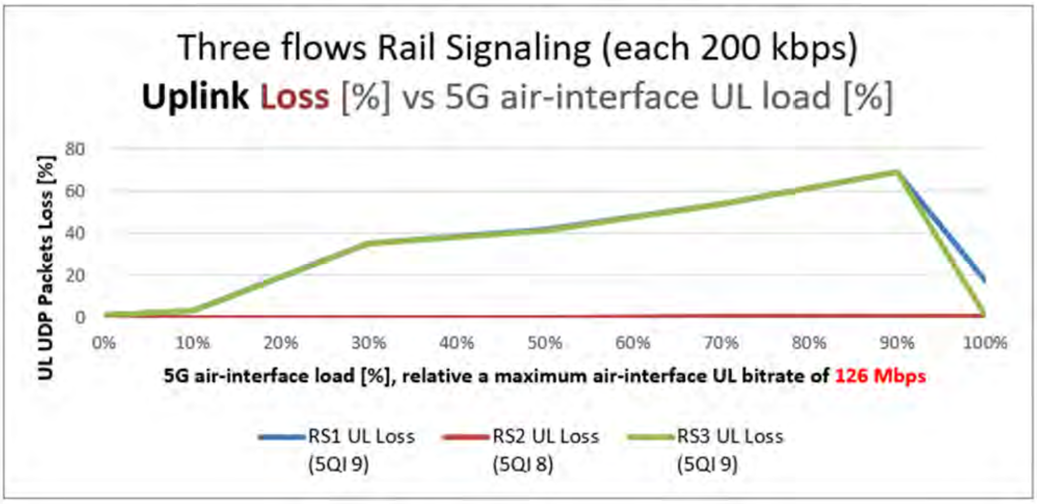


Figure 3-36 UL only Background Traffic and three Rail Signaling 200 kbps flows - Uplink Loss

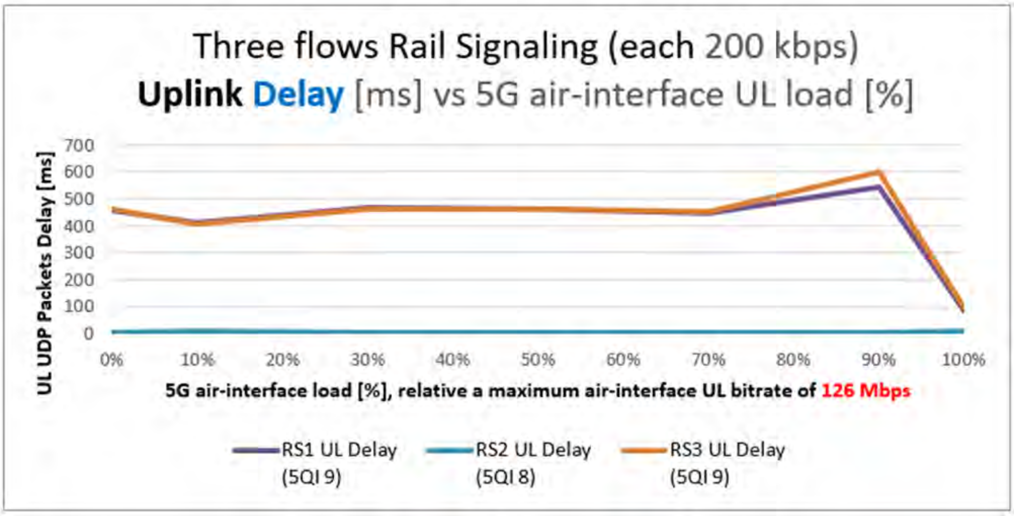


Figure 3-37 UL only Background Traffic and three Rail Signaling 200 kbps flows – Uplink Delay

Figure 3-36 and Figure 3-37 show the expected result, as the 5QI 8 RS flow gets a much lower loss and delay compared with the 5QI 9 flows.

Note: The Uplink Loss behavior looks a bit strange at full Background traffic load (at 100% of 126 Mbps), probably a measurement issue.

3.5.4.5.1.3 Dual 12x Rail Signaling (2.4 Mbps) – Uplink Loss and Delay

The following test uses Dual 12-trains RS in UL, using Hawkeye traffic type "NW KPI Advanced". The Background Traffic is stepwise increased from 0 to 100% of the maximum 126 Mbps.

- Background Traffic uses Probe Pair 1 (5QI 9)
- RS uses Probe Pairs 2 (5QI 9) and 3 (5QI 8)

All flows in this test uses packet size 300 bytes (the test using 1460 bytes showed strange result, probably due to fragmentation).

The Background traffic uses the onboard located hardware probe IxProbe.

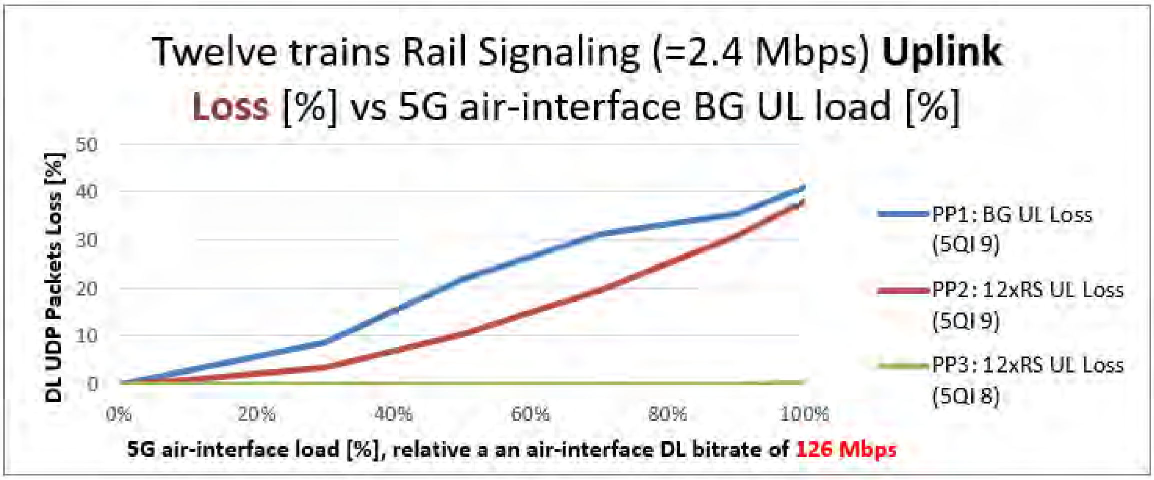


Figure 3-38 2x Twelve trains Rail Signaling (2.4 Mbps) vs Background Traffic UL load – Uplink Loss

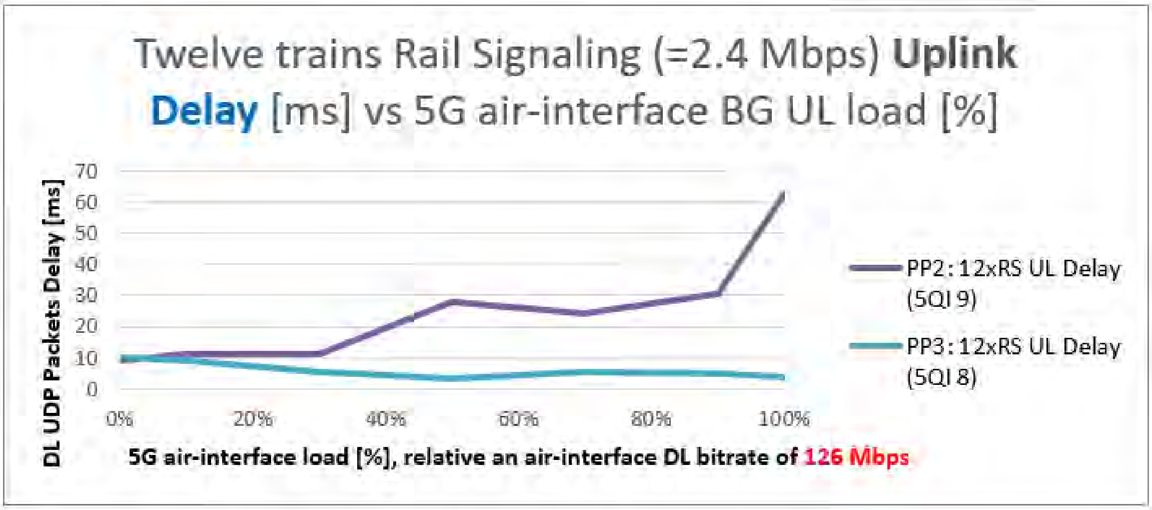


Figure 3-39 Two flows of Twelve trains Rail Signaling (2.4 Mbps) – Uplink Delay

Figure 3-38 and Figure 3-39 show the expected result where the 5QI 8 flow shows very low loss and delay compared with the 5QI 9 flow.

3.5.4.5.2 Rail Signaling over 5G air-interface – DOWNLINK LOSS and DELAY

RS DL frame LOSS and DELAY is tested with Hawkeye in the FhG Lab using different scenarios:

- Three DL 200 kbps RS flows over the FhG 5G network, from "Data Network" probes to "Onboard" probes, using QoS with 5QI 9, 8 and 9.
- Two DL 2.4 Mbps "Twelve Trains" RS flows over the FhG 5G network, with 5QI 8 and 9.

Both tests use 300 bytes packets with Hawkeye traffic type "Network KPI Advanced" (where the UDP bitrate can be configured, and where only the Loss and Delay figure are noted in the lab result).

Note: The maximum downlink bitrate was found to be 430 Mbps using Hawkeye speed test, while iPerf showed up to 850 Mbps. It was decided to step the Background Traffic from 0 all the way up to 200% of the 430 Mbps figure.

Notes from these tests: the Background Traffic got around 75% DL Loss regardless of Background Traffic bitrates (43, 129, 215, 301, 387, 430, 517, 603, 689, 775, 861 Mbps), which indicates data burst losses somewhere in the system.

3.5.4.5.2.1 Three DL 200 kbps RS flows over the FhG 5G – Downlink LOSS and DELAY

This test uses three DL RS flows over 5G. Each flow representing RS with 200 kbps.

The three flows use QoS settings in UE, RAN and Core Network using 5QI 9, 5QI 8, and 5QI 9. 5QI 8 has higher priority than 5QI 9 in the DL schedulers.

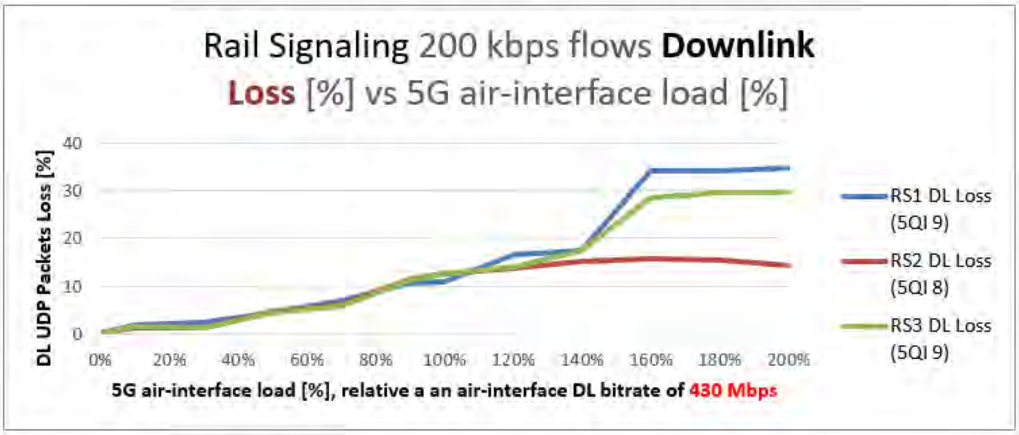


Figure 3-40 Three DL 200 kbps RS flows over 5G, using 5QI 9, 5QI 8, and 5QI 9 - Downlink Loss

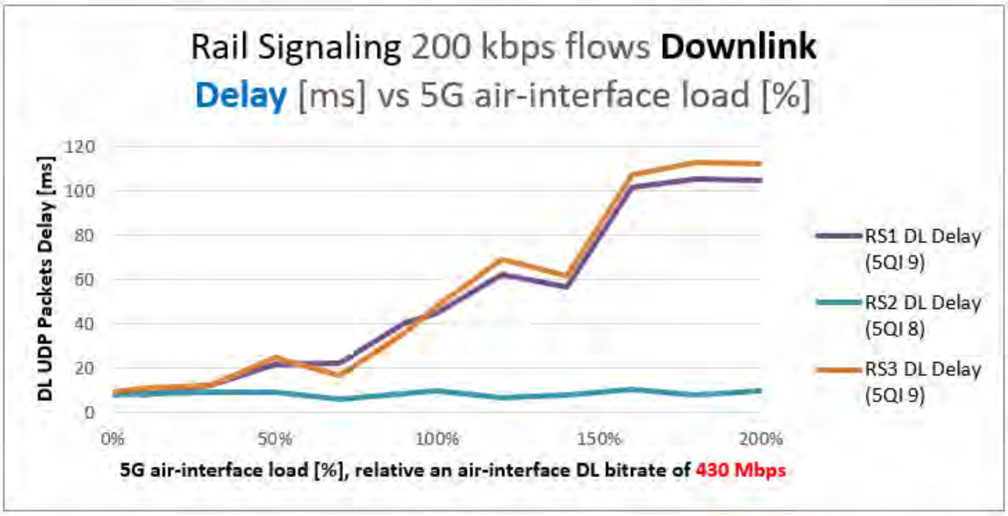


Figure 3-41 Three DL 200 kbps RS flows over 5G, using 5QI 9, 5QI 8, and 5QI 9 - Downlink Delay

Figure 3-40 and Figure 3-41 show a Loss differentiation at higher Background Traffic bitrates, where the 5QI 8 flow gets prioritized. The loss at lower Background Traffic bitrates is probably due to a measurement infrastructure issue with burst traffic losses.

The DL Delay figure shows a very nice delay QoS differentiation where the 5QI 8 flow gets a constant low DL delay regardless of background traffic and other flows.

The figures show the expected result.

3.5.4.5.2.2 Two DL 2.4 Mbps "Twelve Trains" RS flows over 5G – Downlink LOSS and DELAY

This test contains two DL RS flows over 5G which represents a bitrate corresponding to twelve trains RS summing up to 2.4 Mbps (=12x 200 kbps).

The two 12xRS flows use QoS settings in UE, RAN and Core Network using 5QI 9 and 5QI 8. The 5QI 8 flow has the higher priority than the 5QI 9 flow in the DL schedulers and should come out much better with respect to Loss and Delay.

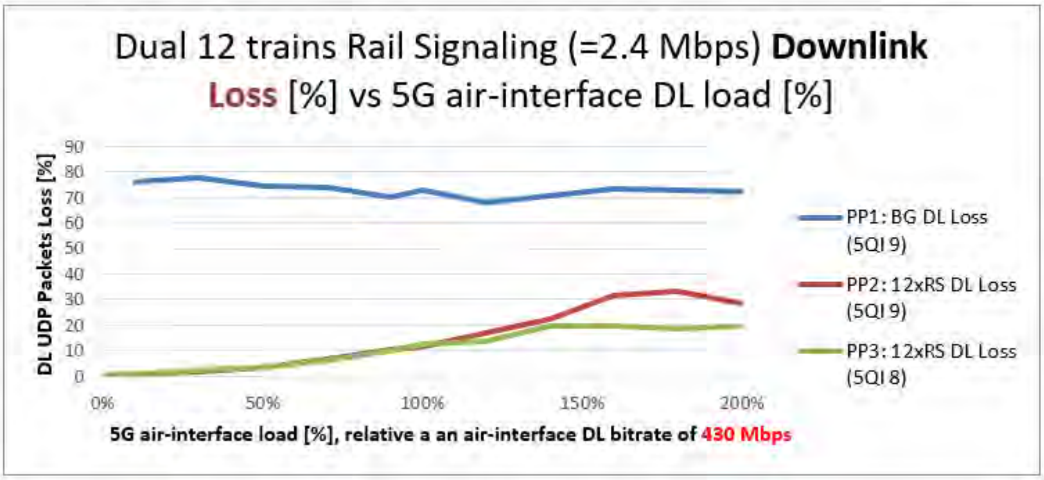


Figure 3-42 Two DL 2.4 Mbps "Twelve Trains" RS flows over 5G – Downlink LOSS

Note: It can be noted in Figure 3-42 that the Background traffic suffers from a constant 75% loss ratio, regardless of Background Traffic (5G air-interface load) bitrates. This is strange, but the reason is probably due to buffer length limitations in the test environment. This might impact the 12xRS flows loss result as well.

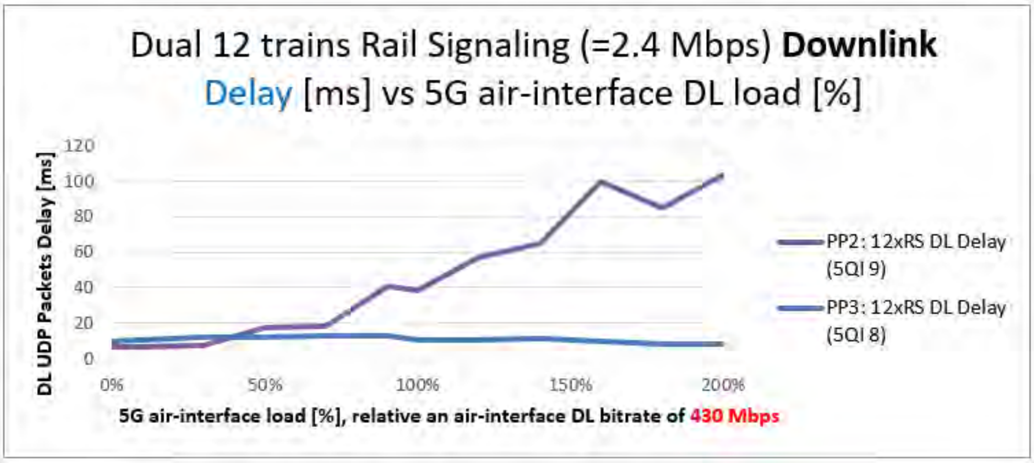


Figure 3-43 Two DL 2.4 Mbps "Twelve Trains" RS flows over 5G – Downlink DELAY

Figure 3-42 and Figure 3-43 indicate that the 5QI 8 flow gets a lower loss than the 5QI 9 flow at higher bitrates. The figure shows a very nice delay QoS differentiation where the 5QI 8 flow gets a constant low downlink delay regardless of background traffic and other flows.

Note: the loss figure increasing to around 10% at 430 Mbps is a bit surprising, but is probably related to the measurement environment rather than a real problem.

The figures show a nice Expected result with QoS differentiation.

3.5.5 Test Cases and KPIs table

This section gives an overview of wanted and measured KPI result for:

- CCTV test-cases (RCC).
- Rail Signaling test-cases (RCS).
- Background Traffic test-cases (RCB).

Table 3-7 Test case group RCC (CCTV) – Wanted and Measured result

Test case group RCC (CCTV)			
Test case ID	Title	Target result	Measured result
RCCg02	One train CCTV (5 Mbps in uplink)	Bitrate: 5 Mbps. Latency: <150 ms latency (a guesstimate) Loss ratio: <0.5% (a guesstimate).	Uplink 5 Mbps bitrate no problem. Latency over 5G well below 150 ms. However, the moving pictures coding and decoding in the camera and web browser showed a latency of around 300 ms. Loss ratio for the higher prio QoS 5QI 8 (compared with 5QI 9 streams) used by 1 stream CCTV was below 0.5%.
RCCg03	Twelve trains CCTV (12x5=60 Mbps in uplink)	Bitrate: 60 Mbps. Latency: <150 ms latency (a guesstimate) Loss ratio: <0.5% (a guesstimate).	Uplink 60 Mbps bitrate with some issues. Latency over 5G well below 150 ms. However, the moving pictures coding and decoding in the camera and web browser showed a latency of around 300 ms. Loss ratio for the higher prio QoS 5QI 8 (compared with 5QI 9 streams) used by 1 stream corresponding to 12 trains CCTV was around 0.5% with an air-interface load of up to around 40%. Above 40% air-interface load, the loss become 3 to 5%.

Table 3-8 Test case group RCS (Rail Signaling) – Wanted and Measured result

Test case group RCS (Rail Signaling)			
Test case ID	Title	Target result	Measured result
RCSg02	One train Rail Signaling (200 kbps UL/DL)	Bitrate: 200 kbps. Latency: low Loss ratio: low.	• 200 kbps is no problem. • UPLINK loss below 1% for the high prio flow, even at high uplink background load. • UPLINK delay less than 10 ms • DOWNLINK loss increased with 5G air-interface load, from 0% to around 15% with high load, for the high prio flow. Note: the background traffic load however suffered from a loss ratio of around 75% regardless of bitrate, which impact this measurement. DOWNLINK delay was below 10 ms, regardless of background traffic load.
RCSv03	Twelve trains RS (2.4 Mbps UL/DL)	Bitrate: 12x200= 2.4 Mbps. Latency: low Loss ratio: low.	• The UPLINK loss result for a 12 trains rail signaling of 2.4 Mbps flow showed a very low loss, less than 1% for the high prio flow. • UPLINK delay was below 12 ms • DOWNLINK loss increased with 5G air-interface load, from 0% to around 20% with high load, for the high prio flow. Note: the background traffic load however suffered from a loss ratio of around 75% regardless of bitrate, which impact this measurement. DOWNLINK delay was less than 15 ms regardless of background load.

Table 3-9 Test case group RCB (Background Traffic) – Wanted and Measured result

Test case group RCB (Background Traffic)			
Test case ID	Title	Target result	Measured result
RCBg01	Background Traffic for saturating 5G air-interface	• Inter-OB and Inter-DN probes bitrate much higher than the 5G air interface bitrate. • Gigabit Ethernet infrastructure at least twice higher than the 5G air interface bitrate.	• Inter-OB and Inter-DN probes show a bitrate of several Gbps. • The 5G air-interface shows a downlink bitrate of more than 430 Mbps with Hawkeye and around 850 Mbps with iPerf. Note: a too high air-interface bitrate compared to the Gigabit Ethernet infrastructure is risky, as the air-interface might not be the only bottleneck showing losses and delay. Due to bursty traffic generation, high loss ratio figures can be observed.

3.5.6 5G Network Deployment Description at FhG FOKUS – Lab

Table 3-10 describes the 5G network at FhG in Berlin. These are the characteristics, configuration and settings that were used at the FhG Lab for the tests in Q4 2022. No field measurements have been performed as of this report (D4.2), therefore the corresponding table is void.

Table 3-10 5G Network Deployment Description at FhG FOKUS – Lab

Scenario Description Template – Lab	
Radio access technology (RAT)	5G NR
Standalone / Non-Standalone (if applicable)	Standalone
Cell Power	23 dBm
Frequency band:	n78
Maximum bandwidth per component carrier	100 MHz
Sub-carrier spacing	30 kHz
Cyclic Prefix	normal
Massive MIMO	4x4
Duplex mode	TDD
TDD uplink/downlink pattern	DDDSU
User location and speed	0 km/h
Background traffic	Potentially, but sporadic and low throughput
Computational resources available	N/A

3.5.7 Experiment Description

3.5.7.1 Experiment Description and Report for CCTV

Table 3-11 gives a Description overview of the CCTV Experiments.

Table 3-11 Experiment Description for CCTV

	Description
ExperimentType	CCTV Lab Experiment at FhG.
Automated	Manual installation of the real CCTV camera and running tests for 12 cameras via Hawkeye.
TestCases	**RCCg02** One train CCTV (5 Mbps in uplink) **RCCg03** Twelve trains CCTV (12x5=60 Mbps in uplink)
UEs	Huawei 5G CPE Pro 2
Network Slice	Network Slicing not supported.

Network Services	5G always connected, best effort.
Network Scenario	CCTV moving pictures from one real camera or twelve emulated cameras using Hawkeye. The emulated CCTV streams were run while saturating the 5G air-interface stepwise from 0 to 100%.
Exclusive Execution	The Lab experiments were alone, no other services available.
ReservationTime	Test-case with moving pictures from real CCTV camera had a duration of 10 minutes or so. Hawkeye test-cases were each run for 2 minutes.
Application	CCTV
Performance targets & SLAs	The guestimate from WP3 documentation outlined a bitrate of 5 Mbps, a latency of less than 150 ms, and a loss ratio of less than 0.5%.
Experiment Parameters	The 5G air-interface was stepwise saturated from 0 to 100% while the emulated CCTV traffic testcase run.
Edges	The Open5GCore network with RAN used a 5G base station from Huawei, part of the fixed installation at FhG.
Remote	The Hawkeye used at FhG in Berlin was the instance FhG owns, with their license. The Hawkeye server has a public IP address on which several users can login. In this way tests could be run both during the on-site week 47, plus weeks 48 and 49 (2022) from Stockholm.
Remote Descriptor	na
Version	na
Extra	na

Table 3-12 gives a summary of the CCTV tests done at FhG Lab 2022.

Table 3-12 CCTV Report from tests done at FhG Lab 2022

Field	**Description**	
Test Case ID	**RCCg02**, **RCCg03**	
Facility, Site	Fraunhofer FOKUS Lab in Berlin (**FhG**)	
Description	The real CCTV camera produced moving pictures over the 5G network (Open5GCore with RAN and UE) to a Wayside laptop. A CCTV bitrate corresponding to twelve trains was emulated by the Hawkeye software. Note: the real CCTV camera and the emulated flows were not run over 5G at the same time, but the emulate flows used a background traffic where was stepwise incread from 0 to 100% of the 5G air-interface maximum bitrate.	
Executed by	Partner: **Alstom**, **FhG**	Date: 2022 weeks 47-50. Updated up to 2023 w06
Purpose	To see how CCTV behaves over 5G.	
Scenario	CCTV over 5G	
Slice Configuration	Network Slicing not supported.	
Components involved	**RCCg02**: Wayside laptop for CCTV monitoring, Open5GCore with UPF Router, RAN with Huawei base station. TDD 5G air-interface. Huawei 5G CPE Pro 2, Ethernet Switch, PoE injector, CCTV camera. **RCCg03**: Wayside Hawkeye Probes, Open5GCore with UPF Router, RAN with Huawei base station. TDD 5G air-interface. Huawei 5G CPE Pro 2, Ethernet Switch, Ubuntu Laptop with Hawkeye Probes.	
KPIs collected (Metrics collected)	Bitrates, loss and latency were measured.	
Tools involved	CCTV camera with visual comparison between physical movements and movements presented on the screen. Hawkeye software with probes for background traffic and video streams.	
Results and KPIs	The result is mainly as expected. However, a loss ratio of 5% was seen for the 12 trains video stream when the air interface background load became 50% and higher.	

Primary Complementary	The loss ratio for the one train video stream got a loss below 1%. Note: the higher loss could be due to measurement issues, with losses occurring elsewhere than over the 5G air interface.
Target metric/KPI and verification (pass/fail)	In general: the target CCTV over 5G KPIs are met.

3.5.7.2 Experiment Description and Report for Rail Signaling

Table 3-13 provides a description overview of the Rail Signaling Experiments.

Table 3-13 Experiment Description for Rail Signaling

	Description
ExperimentType	Rail Signaling Lab Experiment at Fraunhofer FOKUS Berlin.
Automated	Manual handling and running Hawkeye tests for Rail Signaling, both for one and twelve trains.
TestCases	**RCSg02** One train Rail Signaling (200 kbps UL/DL) **RCSv03** Twelve trains RS (2.4 Mbps UL/DL)
UEs	Huawei 5G CPE Pro 2
Network Slice	Network Slicing not supported.
Network Services	5G always connected, using 5QI 8 for the higher priority flows and 5GI 9 for the lower priority flows.
Network Scenario	Rail Signaling using Hawkeye, emulating one and twelve trains, while saturating the 5G air-interface stepwise from 0 to max air interface capacity.
Exclusive Execution	The Lab experiments were alone, no other services available.
ReservationTime	Hawkeye test-cases were each run for 2 minutes.
Application	Rail Signaling.
Performance targets & SLAs	The guestimate from WP3 documentation outlined a bitrate of 200 kbps.
Experiment Parameters	The 5G air-interface was stepwise saturated with a Background traffic from 0 to the maximum air interface capacity while the emulated CCTV video stream test case run.
Edges	The Open5GCore network with RAN used a 5G base station from Huawei, part of the fixed installation at FhG.
Remote	The Hawkeye used at FhG was the instance FhG owns, with their license. The Hawkeye server has a public IP address on which several users can login. In this way tests could be run both during the on-site week 47, plus updates up to 2023 week 06.
Remote Descriptor	na
Version	na
Extra	na

Table 3-14 gives a summary of the Rail Signaling tests done at FhG Lab 2022.

Table 3-14 Rail Signaling Report from tests done at FhG Lab 2022

Field	Description
Test Case ID	**RCSg02**, **RCSg03**
Facility, Site	Fraunhofer FOKUS Lab in Berlin (**FhG**)
Description	Rail Signaling is emulated using the Hawkeye software and four probe pairs. Each probe pair has one onboard probe and one wayside probe. Also the hardware-based IxProbe has been used as the Onboard Background Traffic probe. Typical usage of the probes: • PP1: Background traffic, increased stepwise from 0 to 100% • PP2: Rail Signaling 1, using 5QI 9

	• PP3: Rail Signaling 2, using 5QI 8 (higher priority than 5QI 9) • PP2: Rail Signaling 3, using 5QI 9 Rail Signaling for one or twelve trains and for uplink or downlink were tested while the background traffic was stepwise increased from 0 to the maximum air interface capacity.	
Executed by	Partner: **Alstom**, **FhG**	Date: 2022 weeks 47-50. Updates up to 2023 w06.
Purpose	To see how Rail Signaling behaves over 5G.	
Scenario	Rail Signaling over 5G.	
Slice Configuration	Network Slicing not supported.	
Components involved	**RCSg02** and **RCSg03**: Wayside Hawkeye Probes, Open5GCore with UPF Router, RAN with Huawei base station. TDD 5G air-interface. Huawei 5G CPE Pro 2, Ethernet Switch, Ubuntu Laptop with Hawkeye Probes.	
KPIs collected (Metrics collected)	Bitrates, loss and latency were measured.	
Tools involved	Hawkeye software with probes.	
Results and KPIs Primary Complementary	The result is mainly as expected. The bitrates were conveyed over 5G. Latency and loss were low. Note: the downlink background traffic loss was often around 75%, regardless of background traffic bitrate, which probably is due to bursty traffic and too short buffers in the test environment. Note: complementary measurements with iPerf found a downlink UDP traffic of up to 850 Mbps over the 5G network, while Hawkeye with the probes came to 430 Mbps. Therefore the downlink tests use a background traffic up to 200% of the 430 Mbps.	
Target metric/KPI and verification (pass/fail)	In general: the target Rail Signaling over 5G KPIs are met.	

3.5.8 Testcase findings

3.5.8.1 CCTV

The CCTV camera behaves with expected KPIs.

The 5G network latency is very short, around 10 ms. However, the CCTV camera itself with coding and decoding moving pictures (using H.264 in this case) causes a latency of around 300 to 500 ms (depending on settings).

3.5.8.2 Rail Signaling

In general, the higher priority flows (using 5QI 8) got lower loss and shorter delays, compared with the lower priority flows (using 5QI 9). In general expected KPIs.

Note: In some cases however, it is suspected that loss occurs between the traffic generator and the operating system, before being sent over the 5G air-interface, and might also occur after having been received, before reaching the Hawkeye. Some test cases show high loss figures.

3.5.8.3 Background Traffic

The Background Traffic was used for saturating the 5G air-interface. The 5G performance, especially the downlink was found to be 430 or 850 Mbps. These bitrates could be too close to the performance of the Gigabit Ethernet infrastructure with computers and Ethernet switches, plus the somewhat old Ubuntu laptop with its processor and operating system protocol stacks.

In several test cases, the downlink loss figures for the Background traffic was 75% regardless of bitrate. This indicates losses due to short buffers compared with too long traffic bursts.

3.5.8.4 Upcoming tests

The QoS settings should also use the WP3 outlined usage of 5QI 69 and 8, which show a bigger difference than in between 5QI 8 and 9.

Note: the reason why 5QI 8 and 9 were used at FhG was that these were the only ones supported. 5QI 69 would need support from Huawei on how to configure the base station and CPE.

3.5.9 Conclusions – Lessons learned

Experience from tests performed at **FhG** Lab in Berlin (on site and remote) during weeks 47 with updates up to 2023 w06, with hints on improvements for upcoming tests:

- Reduce the 5G downlink air-interface bitrate performance compared with the Gigabit Ethernet infrastructure. The assumption is that the air-interface shall be the only bottleneck, but when the air interface performance becomes too high relative to the Gigabit Ethernet infrastructure, this cannot be guaranteed. Examples for reducing the 5G air-interface performance:
  - Increasing air-interface gap by using a CPE further away.
  - Reduce the transmitted power of the base station and CPE.
  - Block the higher order of modulation, e.g. 256 QAM.
- Configure **Open5GCore** for RAN and UE with the 5QIs outlined in earlier project documentation. Depending on how the schedulers work in the base station and the UE, there might be a bigger difference between 5QI 69 and 5QI 8 vs 5QI 8 and 5QI 9.
- The **FhG** Lab tests used the Huawei 5G CPE Pro 2. When a **KCC** 5G GW is used for upcoming tests, the involved scheduler for uplink and downlink might work differently and also support 5QIs 69 and 8.
- The **Hawkeye software** contains many GUI handling bugs.
  - The quality can be questioned. For example, the maximum bitrate found with Keysight Hawkeye is much less than found with iPerf.
  - The Keysight Hawkeye tool is probably more optimized for long term monitoring, it can generate reports, etc., but it is not optimized for very high bitrates which are close to what the hardware can support, like what probably is the case for iPerf.
- The 5G network with QoS and Keysight Hawkeye is not fully deterministic. Different results can happen between identical tests.

3.6 UC #3 "CDN services in dense, static and mobile environments"

3.6.1 UC #3 testing objective and deployment

The objective of this UC is to provision of large amounts of data from a fixed 5G system (platform) to a mobile 5G "user" (train) and to assess the suitability of the 5G-VICTORI technologies to fulfil the requirements of the UC (see deliverable **D2.1** [1]) and the experience of the travellers when accessing media content.

To that end, a field trial of the media CDN **UC #3** was performed using a dedicated S-Bahn train operating on an enclosed test track at the S-Bahn (operated by **DB**) Depot premises in *Berlin-Schöneweide*. The field trial is an extension of the preparatory work that consisted of static Point-to-MultiPoint (PTMP) mmWave link tests, reported in deliverable **D3.4** section 3.3.2 [11]. The technical goal of this field trial is to determine the performance of the mmWave link and the e2e data transfer from the landside to the trainside cache server running railSTACK (see 3.4.5.3 in deliverable **D2.3** [4]) under mobility conditions and with an e2e integration of the UC.

3.6.2 Network diagram and High Level Deployment Scenario Description

On the side of the track, two station nodes, annotated as **S1** and **S2** (in Figure 3-44), are mounted on tripods and connected through a switch to the landside server, acting as the video data source in the trial. Both station nodes and the server are powered from battery power supplies of 1.2 kWh (a Bluetti EB180 power station), providing for up to 5h operation time. Onboard the train, one train node **T** (see Figure 3-45) is temporarily mounted behind the window using vacuum suction mounts and connected via fibre to the railSTACK server, a rail-grade EN50155 compliant server hardware powered by the trains internal 110VDC power supply, that receives and hosts the video data cache. Additionally, a notebook is used for monitoring the link performance via a Simple Network Management Protocol (SNMP) connection to the T node in real-time during the trial, using a custom developed MATLAB GUI application. All three used mmWave nodes are MetroLinq Tri-Band Omni Commercial Off-The-Shelf (COTS) 802.11ad devices that were used in the previous static lab trials reported in deliverable **D3.4** [11].

The overall system setup is shown in Figure 3-44 and Figure 3-45. With respect to the geometry of the setup, the station nodes were mounted at a height of 1.8 m similarly to the train node, at a distance of 12 m to each other and 4 m to the track, as depicted in Figure 3-46. The field trial is performed such that it resembles the typical S-Bahn train operation, by arriving at the mock-up station and stopping with the T node at the mid-position between the S1/S2 nodes. During the 30-second stop, the data transfer from the landside to the railSTACK server is automatically initiated, after which the train departs from the station.

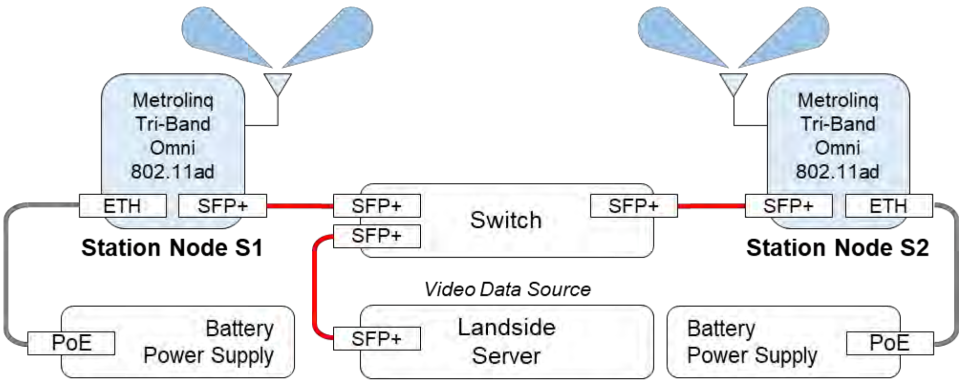


Figure 3-44 Track-side system setup for the DB Berlin field trials

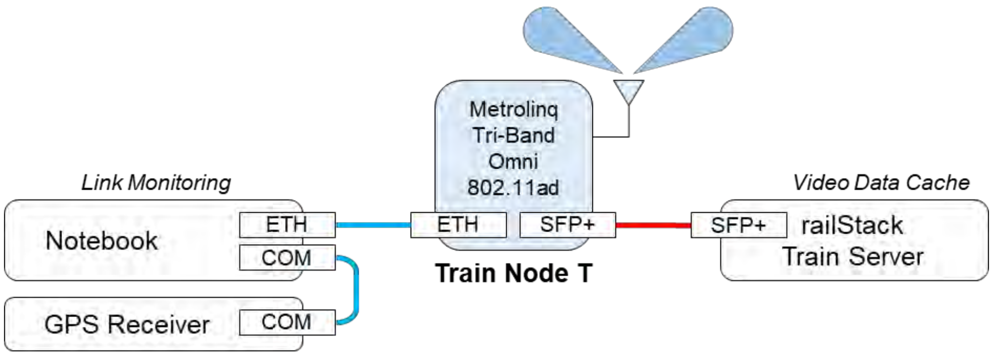


Figure 3-45 Train-side system setup for the DB Berlin field trials

Figure 3-46 Overview of the system setup for the *Berlin-Schöneweide* field trial: a) View of the station node S1,b) View of the station node S2, c) View of the train node T e) the railSTACK server on the train

Table 3-15 Scenario description *Berlin-Schöneweide* tests for UC #3

Scenario Description Template	
Radio access technology (RAT)	mmWave track-to-train
Standalone / Non-Standalone (if applicable)	n/a
Cell Power	14 dBm
Frequency band:	58,32 GHz
Maximum bandwidth per component carrier	2,16 GHz
Sub-carrier spacing	n/a
Number of component carriers	n/a
Cyclic Prefix	normal

Massive MIMO	n/a
Multiple-Input Multiple-Output (MIMO) schemes (codeword and number of layers)	n/a
Modulation schemes	Downlink: π/2-QPSK 13/16 Uplink: π/2-QPSK 13/16 (802.11ad MCS7 2502Mbps)
Duplex mode	TDD
TDD uplink/downlink pattern	n/a
Contention based random access procedure/contention free	contention based
User location and speed	0 km/h and 20km/h
Background traffic	none
Computational resources available	n/a

3.6.3 Experiment Description (with reference to WP3 test cases)

Table 3-16 gives an overview of characteristics of the experiment.

Table 3-16 Experiment Description for Berlin UC #3

	Description
ExperimentType	Standard
Automated	Manual
TestCases	**MCBg03**
UEs	n/a
Network Slice	n/a
Network Services	definition of the network services Catalogues
Network Scenario	refers to Table 3-15
Exclusive Execution	n/a
ReservationTime	0.5 min
Application	Not yet onboarded
Performance targets & SLAs	1.7 Gbps
Experiment Parameters	S1/S2 antenna height 1,8m S1/S2 antenna distance to track 4m S1/S2 inter-antenna distance 12m
Edges	n/a
Remote	n/a (no additional platform considered)
Remote Descriptor	n/a (no additional platform considered)
Version	n/a
Extra	n/a

3.6.4 Experiment execution and results

To evaluate the relevant link parameters such as node association time and throughput under realistic operating conditions in a railway environment, two different measurements were undertaken on the track depicted in Figure 3-46. In the first measurement, the throughput of the mmWave link was characterized by running a TCP/IP iperf3 test, with the train moving in the direction E-W. The results presented in Figure 3-47 show that both mmWave links **T-S1** and **T-S2** are established as soon as the train reached the parking position, which can be inferred from the local maxima on the T-S1 angle plot. The test yielded a stable average / maximum net throughput of 1.572 Gbps / 1.640 Gbps respectively, which corresponds to the conducted lab trials. In the second measurement, the data shower use case was tested with video data set of 7.1 GB being cached from the landside to the railSTACK server during another train ride, in the direction W-E. In this case, the mmWave links were established during the arrival of the train and shortly before reaching the stop, as shown in Figure 3-48. The video data set was fully cached onto the railSTACK server using **PXI**'s railSTACK technology with minor adoptions for the envisioned UC, within the planned 30 second stop.

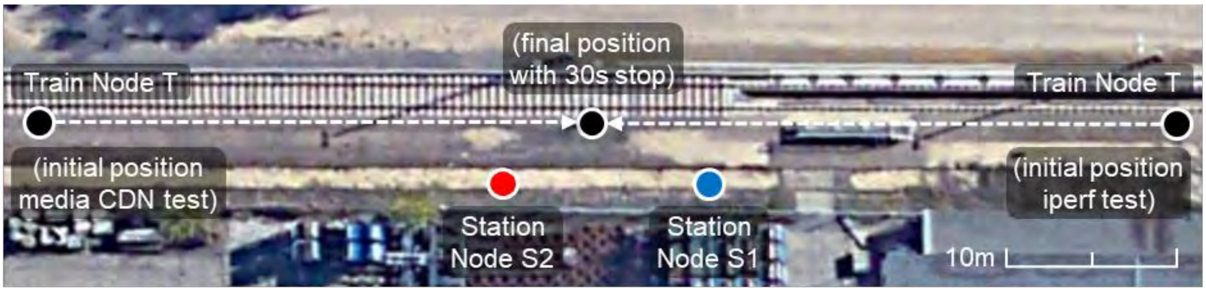


Figure 3-47 Overview of the test track and node positions for the *Berlin-Schöneweide* trial

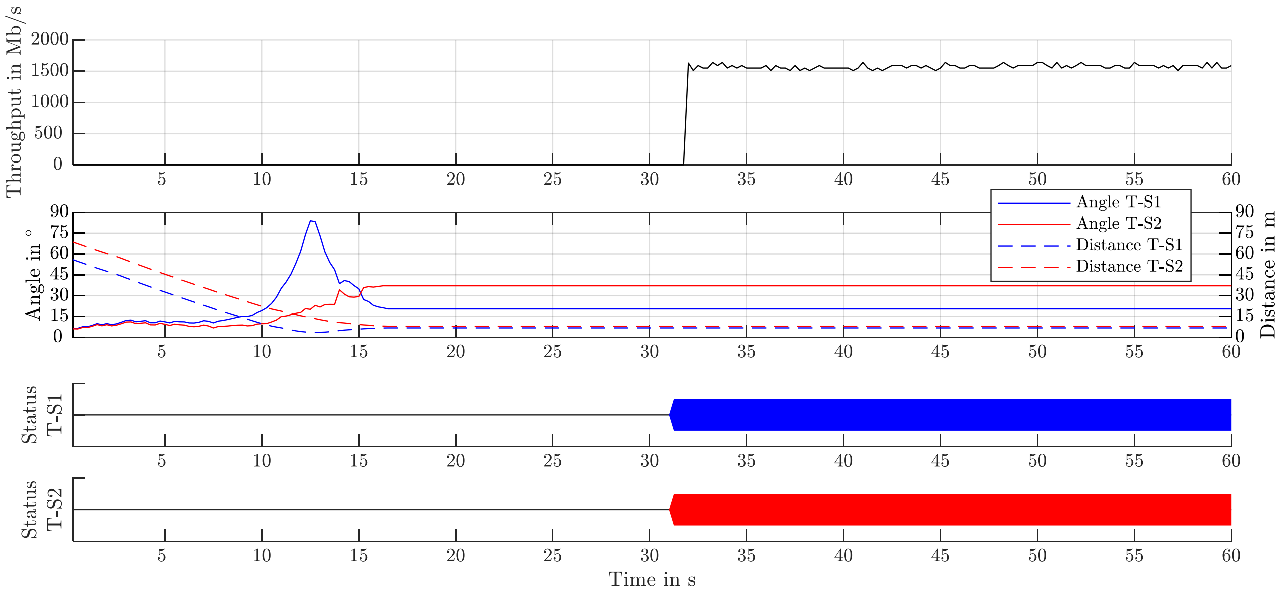


Figure 3-48 Performance of the mmWave link in the *Berlin-Schöneweide* trial (iperf TCP/IP)

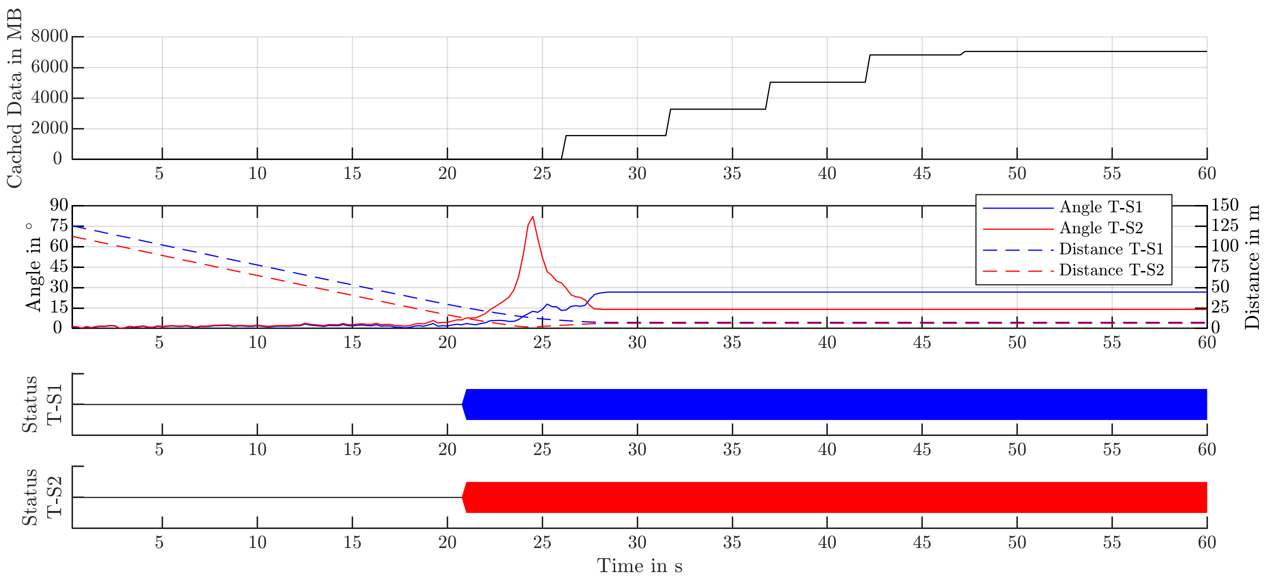


Figure 3-49 Performance of the mmWave link in the *Berlin-Schöneweide* trial (media CDN)

Table 3-17 Test Report for Berlin UC #3

Field	Description
Test Case ID	**MCBg03**
Facility, Site	5G-VICTORI (5GENESIS), **Berlin-Schöneweide** site
Description	Media data in the station cache (that were not contained in the train's media cache already), also known as "media content delta", shall be uploaded to the train's media cache via the mmWave data link whilst the train is stopped at the station. To transmit the media content delta during the train's standing time, an average PHY data rate of at least 2.5 Gbps is required. The test case succeeds if the entire media content delta is transmitted to the train cache.
Executed by	Partner: **IHP**, **PXI**
Purpose	On board Network deployment and track-to train connectivity testing, static and under mobility
Scenario	refers to Table 3-15
Slice Configuration	No slice configuration was performed
Components involved	1. 5G data link (mmWave in this case) 2. Media cache in station (5G platform) 3. Media cache on train (5G train)
KPIs collected (Metrics collected)	node association time, throughput
Tools involved	iperf3, ping, GUI developed by **IHP**
Results and KPIs Primary Complementary	***Mobility testing:*** *mmWave track-to-train connectivity: Throughput=~1.572 Gbps / 1.640 Gbps* *cached data: 7.1 GB within 30 second stop*
Target metric/KPI and verification (pass/fail)	*Throughput KPI passed for the mmWave nodes*

3.6.5 Preliminary Field Trial at Berlin Central Station

After performing a successful field trial of the **UC #3** in a realistic railway environment in *Berlin-Schöneweide*, the system setup is used for a preliminary link test at the Berlin Central Station.

3.6.5.1 High Level Deployment Scenario Description

The goal is to perform another assessment of the link performance, as a step towards the final demonstration planned at this station. It is worth noting that due to the limited access to the platform and S-Bahn train outside the regular operating times, only one static measurement is performed while the train is parked on the platform, as depicted in Figure 3-50. The same system setup is used as for the *Berlin-Schöneweide* field trial, with a slightly adjusted geometry, where the distance is 10 m between the station nodes and 3 m to the track.

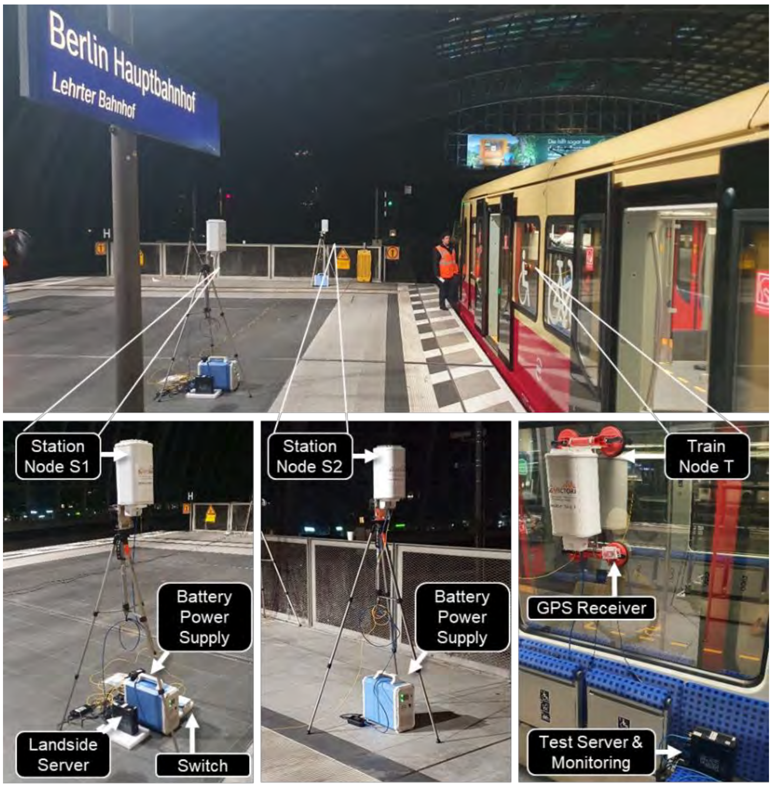


Figure 3-50 Overview of the mmWave nodes setup for the mobility scenario: a) View of the station node S1, b) View of the station node S2, c) View of the train node T

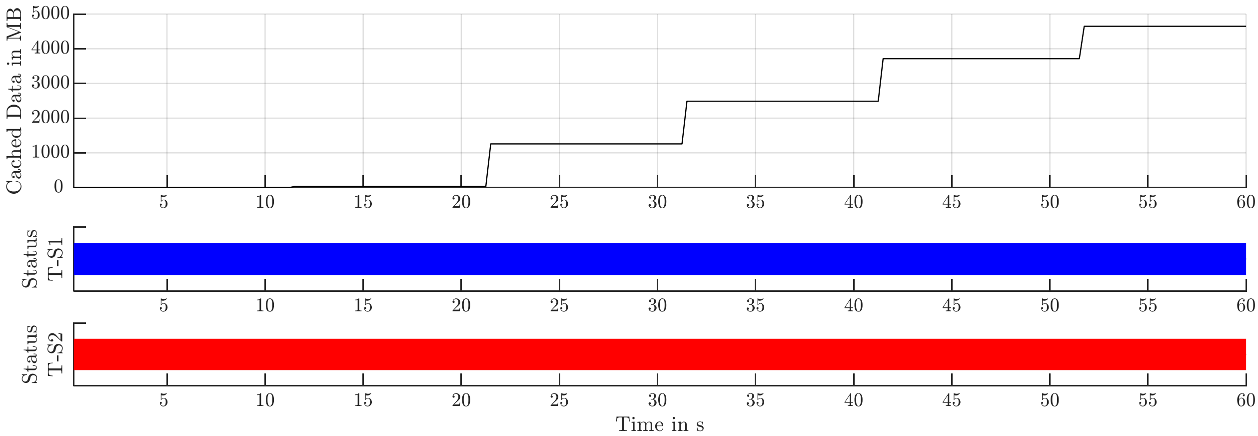


Figure 3-51 Performance of the mmWave link in preliminary static test at Berlin Central Station

3.6.5.2 KPI evaluation (Results)

A static data shower test with a 60 s duration is performed while the train remained in the parked position, with the T node placed at the mid-position between the platform-mounted **S1**/**S2** nodes. As shown in both mmWave links **T-S1** and **T-S2** are operational and a video data set of 4.7 GB was fully cached to the railSTACK server during the test using the automatically triggered copying routines provided by railSTACK and could be played from the local cache as expected. As the next step, the media CDN **UC #3** will be verified under mobility in context of the final demonstration.

3.6.5.3 Conclusions and further work

It should be noted that conducting the preliminary link test at the Berlin Central Station presented significant challenges due to the availability of the tracks and train scheduling. The trial was performed outside of public S-Bahn train operation, but the tracks are still being actively used for S-Bahn internal traffic such as vehicle relocation, maintenance, and test runs. Therefore, only a limited time window was available that only allowed a static test at the platform and did not allow for detailed calibration of the setup. Further mobility tests are required, pending availability of the S-Bahn train and platform.

3.6.6 Conclusions and further work

One observation that can be made in the context of mobility measurements, is that the association time of the mmWave nodes varied significantly, as can be seen from the two different tests. In summary, this field trial in its two instances has successfully demonstrated both the feasibility of the wireless links for high-speed data transfer and the caching of the video data in **UC #3**.

3.7 Conclusions

This section reports on the trials activities that took place in the Berlin cluster, with results stemming from the three UCs considered for the cluster. Regarding network design work reported in previous deliverables, only small deviations have occurred. Still some of the planned test cases defined in WP3 deliverables need to be performed in an operational environment during the 2023 field trials.

A summary of the main trial activities is as follows:

- All UCs have been demonstrated in 2022 in lab environment.
- Some of the UCs (and the related services) were demonstrated in operational environments during 2022, and some services will be showcased in the April 2023 field trials.
- **UC #1.2** has proved in an operational environment that 5G is a suitable technology for streaming remote rendered 3D applications if reliability and other QoS parameters especially latency can be guaranteed.
- **UC #1.3** services have been partially tested in an operational environment, but the lab tests have proven the suitability of the 5G technology to offer the requirements imposed by the services. Still work is required to better assess the services' KPIs in an operational environment jointly with other services.
- **UC #3** will be delivered as per the DoW for the April 2023 field trials, i.e. using mmWave as the wireless transport technology providing track-to-train connectivity. A datarate of up to 1.6 Gbps has been obtained in two field trials in operational environments.
- Regarding **UC #3**, additional work will be performed until the end of the project to implement the UC using the nomadic 5G node.

4 Technology Integration, Validation and field trials in Patras

4.1 Overall Facility Description

Figure 4-1 a) shows the updated 5G-VICTORI transport network deployment in Patras for executing most of the trials and UCs described herein. Patras 5G-VINNI main facility on University of Patras (UoP) campus is interconnected with ADMIE main facility in Rion (**B1** for execution of trials and tests related to **UC #2**) and with TRAINOSE (**TRA**) Depot in Patras City Center (**D1** for execution of trials and tests related to **UC #1.1** and **UC #3**). Points **D0-D3** below correspond to the stanchions along the rail track in the **TRA** facility. **UC #4** is currently being tested in the lab and partially executed in Corinthos (see Figure 4-1 b).

The Patras 5G-VICTORI facility focuses on demonstrating four 5G-VICTORI UC (**UC #1.1**, **UC #2**, **UC #3** and **UC #4**). Please see a summary of these UC below and for more details refer to deliverables **D2.1** to **D2.3** [2]-[4]:

(a)

(b)

Figure 4-1 a) Patras area and overlay transport network deployment for the execution of Greek cluster UC #1.1, UC #2 and UC #3. b) Corinthos area, where power station and train station are interconnected with Autonomous Edge for Greek cluster deployment of UC #4.

UC #1.1 – Enhanced Mobile Broadband under High Speed Mobility (Vertical: Transport). The objective of this UC is to demonstrate eMBB functionality through heterogeneous access technologies for on-board network connectivity in a railway setup leveraging the 5G-VINNI facility in Patras.

UC #2 – Digitization of Power Plants (Vertical: Smart Factory) The goal of this UC is to demonstrate how different types of applications included in the concept of Smart Factory can be efficiently supported by the services provided by an underlying 5G ICT infrastructure

UC #3 – CDN services in dense, static and mobile environments (Vertical: Media). The specific UC objective in 5G-VICTORI is to provide a 5G enabled solution that integrates seamlessly with the vCDN solution incorporating Multi-Access Edge Computing (MEC) capabilities to content providers

UC #4 – Smart Energy Metering (Cross-Vertical: Rail and Smart City). The objective of this UC is to demonstrate how smart energy operation is enabled from the use of advanced ICT infrastructures relying on 5G technology. For the Greek cluster **UC #4.1** aims specifically at bridging the transportation-rail and the energy digital utilities sectors in the process of HV electrical energy monitoring.

4.1.1 5G Deployment Setup and Testbed Expansions

Table 4-1 presents a high-level description of the five 5G deployment options considered for the 5G-VICTORI UCs and trials at the Patras cluster. The choice of the technology for the specific UCs is justified in the corresponding sections to ensure the achievement of the 5G KPIs and functional requirements. In some UCs, more than one deployment option is tested, e.g. in the Factories of the Future-related services two technologies are being benchmarked and evaluated.

Table 4-1 Patras Facility – 5G Deployment Setup

Deploy-ment Options	Option_5GVINNI_1 - OAI For UC #1.1	Option_5GVINNI_2 AW2S- (UC #3, UC #4.1)	Option_5GVINNI_3 AW2S for UC #2	Option_5GVINNI_4 Callbox for UC #2	Option_5GVINNI_5 Autonomous edge with various gNodeB options [4]
Comments	This is an indoor (onboard) option for UC #1.1	This is an outdoor option for: - UC #3, - UC #4.1		This is an indoor option for - UC #1.1, - UC #2	Mobile cloud infrastructure with Radio support from other options.
Open-Source	Yes	No	yes for Core	No	yes for core
SA/NSA	SA	SA		SA	SA
Cloud options	Yes (OpenStack, Kubernetes, Openshift)	Yes (OpenStack)		Yes (OpenStack)	Yes (Kubernetes cluster)
MANO	OSM	OSMv		OSMv	Helm chart
Core	OpenAirInterface Core Network	Amarisoft (local and cloud based)	containerized / Open5GS	Amarisoft (local and cloud based)	various options
RAN	USRP B210, USRP N310, USRP X310	Remote Radio Head - CPRI connectivity	Amarisoft PCI-e cards	Amarisoft PCI-e cards	various options
UE	Google Pixel 6, Quectel RMQ500GL	Huawei CPE Pro			various options

All technologies are hosted at the 5G-VINNI main facility in Patras, which comprises the Patras5G cloud facility that is used also to (co)host third parties software and hardware and provide access to the 5G facility for testing and experimentation. The Patras5G experimentation facility (https://wiki.patras5g.eu/) comprises numerous technologies.

The specific facility extensions that are used for the lab trials and facility demos in the context of 5G-VICTORI are the following:

- Integration of Amarisoft 5G RAN (Classic boxes), with various 5G equipment and CPEs for indoor and outdoor testing (https://wiki.patras5g.eu/radio-equipment)
- Deployment of 5G standard-conformant components and Core Network Functions (NFs) as extension of the **FhG Open5GCore** toolkit but also other 5G core implementations. 5G Core solutions that are available and can be orchestrated in the facility: **FhG** Open5GCore, AMARISOFT 5G, Software Radio Systems (SRS) 5G, etc.
- Outdoor 5G base station (AW2S) installed on the roof of the building, as part of a split setup. The Remote Radio Head (RRH) is fixed on the mast and is connected to the processing unit via CPRI link over 2 pairs of optical fiber, providing enough bandwidth for 4x4 MIMO 100 MHz cell operation.
- Deployment of Intracom Telecom (**ICOM**) mmWave backhaul as transport segment between the access and the Core Network.
- Deployment of multi technology access network nodes along the railtrack for train-to-stanchion connectivity (**UTH**, **IHP**).
- Supporting deployment and orchestration at MEC for the support of **UC #2** and **UC #3**.
- Integration of the developed mobility management features for **UC #1.1** (**UTH**).
- UEs based on Limemicro's Software Defined Radio (SDR) and SRS software, as well as commercial UEs: Mobile phones LG and Samsung, Huawei CPE.
- **UoP** 5G Autonomous Edge, is a mobile box, ideal for on-premise 5G deployments, containing everything from the 5GNR and 5G Core, Network and Service Orchestrations including a Virtualized environment based on OpenStack.
- Deployment of OpenAirInterface (OAI).

4.1.2 Patras Facility deployments of 5G VICTORI architecture

In the Patras facility, for UCs that involve non-public network services (NSs) like, for example, **UC #2** and **UC #4**) or in some initial trials/testing, we consider the 5G RAN and 5G Core placed close together. For all UCs we deployed the Amarisoft solution that architecturally follows the 3GPP standards, with all softwarised NFs integrated on the same hardware [2], [3]. In Figure 4-2 the high-level 5G architecture is depicted.

Instantiation of the 5G-VICTORI architecture in **UC# 1.1** is based on the fully disaggregated option [4]. The cell disaggregation is based on the 3GPP Option-2 split, which splits the base station stack to the Central Unit (CU), implementing the Packet Data Convergence Protocol (PDCP) and above layers, and the Distributed Unit (DU) implementing the Radio Link Control (RLC), Medium Access Control (MAC) and Physical (PHY) layers. The concept of flexible functional splits take place (see Figure 4-2) at the point between CUs (that incorporate the functionality of the layers from the PDCP layer and upwards) and the DUs (that provide the functionality of the RLC layer and downwards), in order to allow the incorporation of other lower layer splits inside the DU.

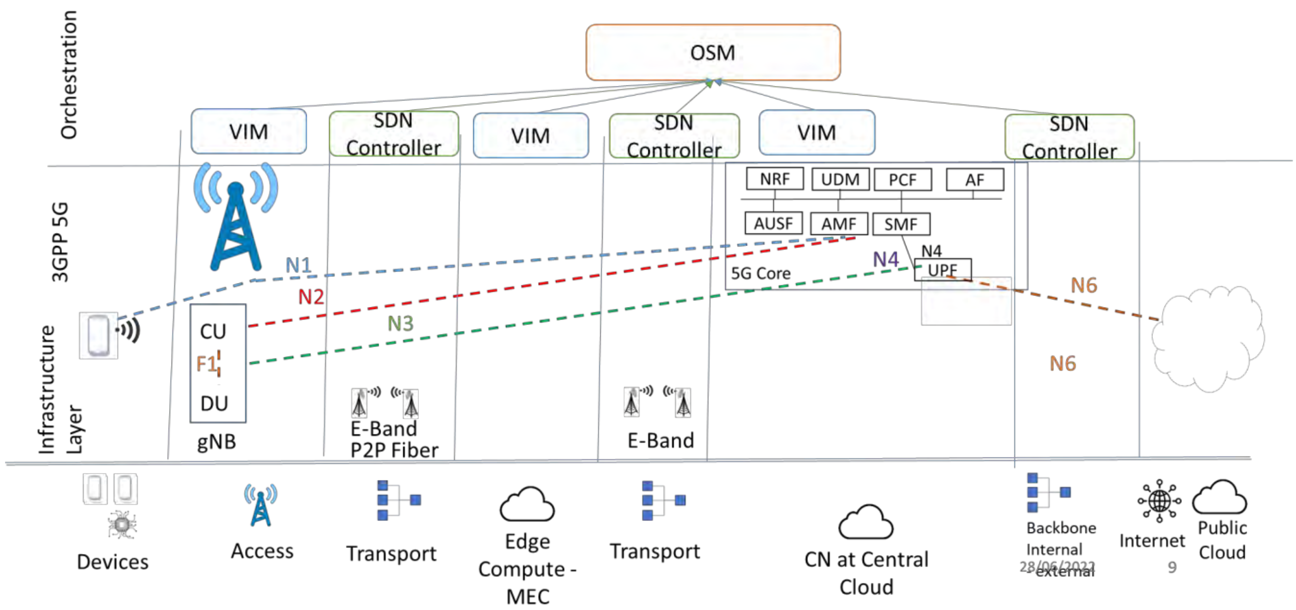


Figure 4-2 High-level description of the 5G-VICTORI architecture as deployed in Patras facility

```
(enb) qos_flow -a
                                      -DL--------------- -UL---------------
   UE_ID PSI SST        SD QFI 5QI  MFBR  GFBR GFBRre  MFBR  GFBR GFBRre
   42595   2   1       0xa   1   9
   42595   1   1       0xa   1   5
   42594   1   1       0xa   1   9
   42594   1   1       0xa   2   4 15.0M 5.00M   899k 15.0M 5.00M   988k
   42658   1   1       0xa   1   9
   42654   5   1       0xb   1   9
   42599   2   1       0xa   1   9
   42599   1   1       0xa   1   5
```

Figure 4-3 Definition of Slices in 5G Core

4.1.2.1 Slicing

The Patras5G experimentation facility allows the creation and management of network slices to meet the requirements of various users. Each deployed slice (fulfilling Rel. 16 specifications) is described by the Slice Differentiator (**sd**) and the Service Slice Type (**sst**), as can be seen in Figure 4-3. At the moment, the supported slices are of service type 1 (eMBB) and can have one or more of the following characteristics:

- Maximum bitrate (either uplink UL and or downlink DL).
- Guaranteed bitrate (either uplink and or downlink).
- Priority of the slice.

Slices can be instantiated based on:

- different DNNs (APNs) meaning that each DNN (APN) supports a different slice.
- Per sd, sst, where depending on these values different UEs (see Figure 4-3) can have different slice characteristics regardless of the DNN (APN) used. IP header criteria like source or destination IP address, source or destination port number, Type of Service, etc.

4.1.2.2 Orchestration options

Network orchestration is performed through OSM (10.1) and service orchestration is based on OpenSlice (https://openslice.readthedocs.io/en/stable/), an University of Patras-led open-source service creation and orchestration platform. OpenSlice enables e2e deployment of multiple customised-slices over the whole network – access, transport and core.

For the cross-facility UC, e2e service provision and orchestration is provided by 5G-VIOS. The specific microservices communicate with Open Source MANO (OSM) to manage the life cycle of NSs (see section 7).

4.1.2.3 Monitoring

Monitoring is available through: Grafana, Prometheus, Netdata, while OSM also can be configured with VNF telemetry support. Real time monitoring of 5G network elements is also available for both Amarisoft based core and gNB.

4.2 UC #1.1 Provisioning of Railway Services

Railway related digital services rely on a variety of public and private network deployments in versatile environments addressing end-users with stringent requirements and privileges. 5G-VICTORI proposes the use of 5G technology in legacy railway environments as the only solution that can guarantee service provisioning independently of the multi-technology legacy communication system. This specific UC provides a prototype network and deployment to facilitate train operations and services considering the FRMCS service definition (as detailed in [2]). All services will be supported through creation of separate infrastructure slices that will concurrently: 1) provide “Business services” to train passengers using dedicated disaggregated femtocells deployed on-board and, 2) support “Critical” and “Performance” services over an heterogeneous wireless deployment.

The services will be provided while the moving train crosses the Patras city centre, through heterogeneous technologies, establishing high capacity low latency connections. High capacity is needed for the “Business services”, to provide high quality of service to TRAINOSE/HELLENIC TRAIN passengers, whereas for the “Critical” and “Performance” low latency / ultra-reliable connections are needed to support the transmission of real time data obtained from various sources to the train operations, driver and control center, like PTT.

4.2.1 UC testing objective and deployment

The deployment takes place at the TRAINOSE/HELLENIC TRAINS area are shown in Figure 4-1 and Figure 4-15. To demonstrate multi-technology track-to-train communication, the proposed setup comprises both mmWave (at **D0** and **D1**) and Sub-6 APs to be deployed along the track between the two stations (see points **D4** and **D2**). At the train side, to maximise connectivity and minimise the disconnection times between handovers from the train to the track APs, the proposed scheme requires antenna modules to be installed both at the front and at the rear of the train.

UC #1.1 will be tested using four groups of test cases described in deliverables **D3.1** and **D3.4**. The testing roadmap also assumed three phases (lab test, static and under mobility).

The first group tests the network deployment and interconnections. The overall e2e 5G-VICTORI transport network comprises three main segments: the mmWave backhaul, the stanchion network and the onboard network, as shown in Table 4-2. Network segments are initially deployed and tested in the lab and then are interconnected. Then each segment is tested according to the Network Deployment test cases. At this stage both static and mobility tests were performed for initial performance evaluation.

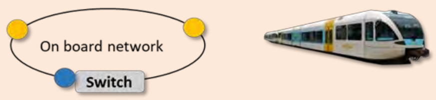
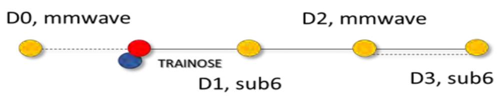
The on-board network that is loaded and integrated on the TRAINOSE train, is initially deployed at the **UTH** Lab and is based on fibre ring network technology. This onboard network interconnects all access points (Onboard 5GNR see Option 1 and Wi-Fi AP) and rooftop antennas via an SDN enabled switch (P4 switch in the figures), together with edge computing elements as shown in Figure 4-6 and various UC specific elements. Then a multi-technology stanchion to Core Network deployment has to be assumed and tested in terms of connectivity between each on board antenna to 5G-VINNI Central Office, including, 1) connectivity of each onboard antenna to trackside stanchions, 2) connectivity of each trackside stanchion to 5G-VINNI cloud (at 5G-VINNI central office), and 3) e2e connectivity testing over 5G-VINNI – 5G-VICTORI railway deployment. Since two technologies were used, testing was performed separately for each technology. To ensure that the trial can take place at a railway environment (i.e. under mobility), the feasibility of handover between two subsequent heterogeneous transport nodes is tested and this also was performed in the lab and in the field trial (static and under mobility).

Table 4-2 below illustrates the testing phases and corresponding network segments. Under mobility testing for the “stanchions interconnection” network deployment was performed during a 4-day trial at HELLENIC TRAIN premises (September 2022). The actual trial took place during the night of the 20th of September when the single line rail track is not used for operational travel. An operational wagon was used (Railbus) on which the tested onboard network was deployed. The trial was performed in the area shown in Figure 4-9 with the dedicated train moving on the part of the rail-track that did not cross the roads of Patras. This was necessary as crossing of roads and blocking the city traffic during the night required special permissions.

The e2e interconnection and Services testing phase will be performed in the next months, after the transport network has been fully deployed.

The rest of the test cases concern service deployment over the Patras facility. Initial integrations and lab test have been reported in deliverables **D3.1** [8] and **D3.4** [11]. As far as the services are concerned, each service relates to a group of test cases that are also tested in the lab with sub equipped version of the e2e deployment that was explained above assumed.

Table 4-2 UC #1.1 testing phases

Network deployment per segment	In-Lab test	Static Test (in the field)	Mobility test (first field trial)
 **On board network deployment**	✓ June 2022	✓ (September 2022)	✓ (September 2022)
 **by the stanchions network deployment**	✓ June 2022	✓ (September 2022)	✓ (September 2022)

4.2.2 Network diagram

Figure 4-4 illustrates the e2e transport network deployment.

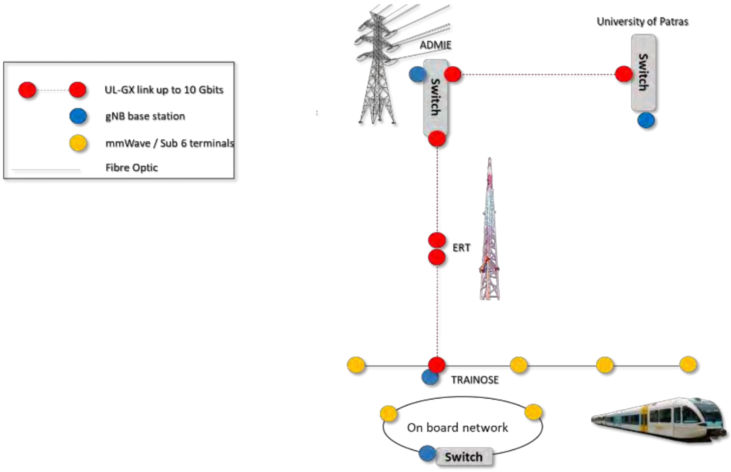
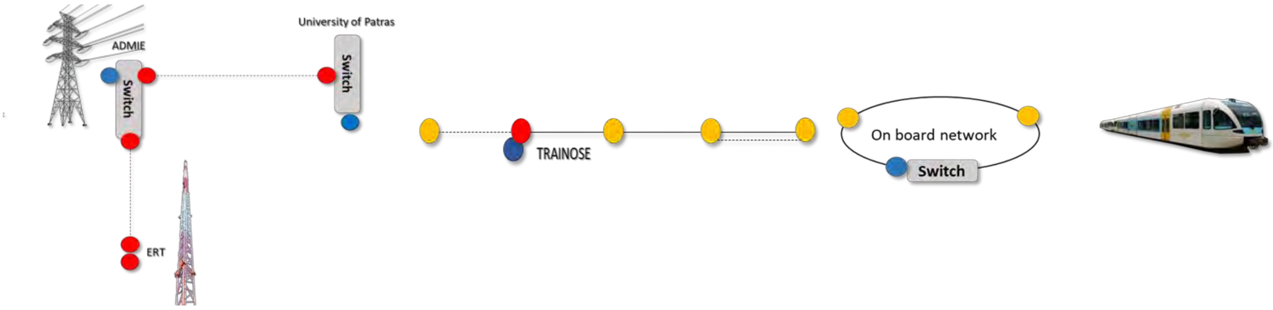


Figure 4-4 E2e transport network deployment



(a) mmWave backhaul network deployment (**UoP** to **TRA**)

b) by the stanchions network deployment

c) on board network deployment

Figure 4-5 Patras Facility transport network segment links

4.2.3 Components Testing at Lab setups

4.2.3.1 Lab testing of on board network deployment

Towards ensuring appropriate operation of the mobility management [14] and Sub-6 GHz track-to-train links, a test setup was configured and evaluated in the premises of University of Thessaly (**UTH**). The test network was configured with two different entities of the mobility management framework (on board entity and cloud entity) and the session maintenance across different Sub-6 GHz handovers was tested.

For the configuration of the network, 10 machines of the NITOS testbed were used, in order to emulate the overall train communication network (Figure 4-6). Six of them were configured as the communication network, with four of them playing the role of the track-side stanchions, and two of them the on-board communication nodes. Four Sub-6 GHz wireless networks (IEEE 802.11ac with 3x3 MIMO) were configured, two of them emulating the mmWave links, and two of them the actual Sub-6 GHz network. Two nodes are used for the mobility management, one of them on the track side, converging all the links from the stanchions, and one on the train. In case of a handover scenario, the P4 nodes independently decide on the selection of active link for forwarding the traffic. The process relies on SNMP polling of the devices from the P4 controllers, allowing us to know when exactly each link is available and can be used. Finally, two more nodes are connected as compute infrastructure at the two ends of connection – one on the cloud (after the P4 cloud controller) and one on the train (after the P4 on-board controller).

For the tests, we initiated traffic between the on-board server and the "cloud" located server, in order to measure latency and achieved throughput.

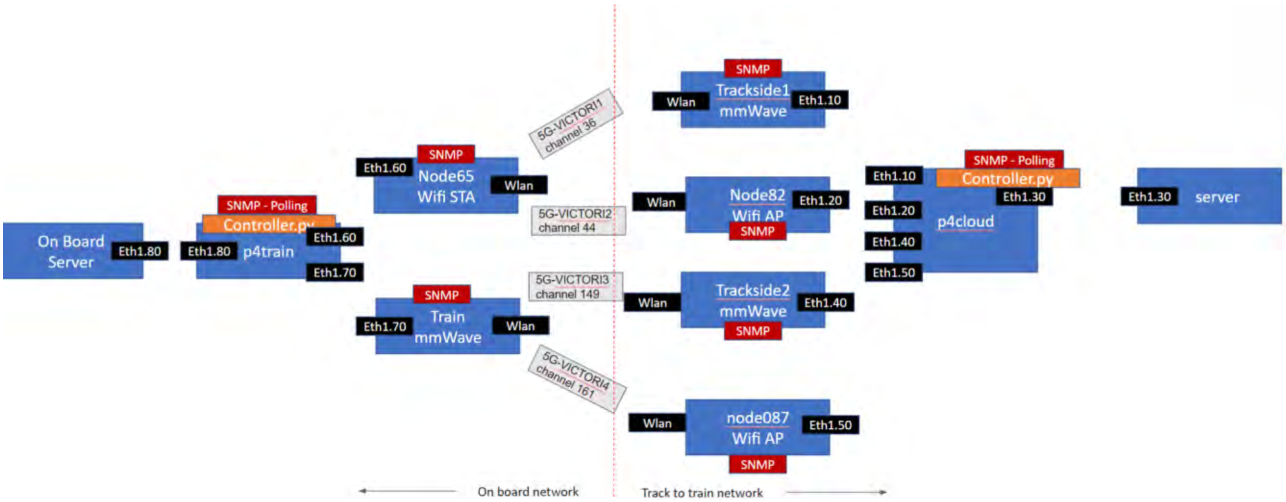


Figure 4-6 NITOS lab deployment for mobility management function development and testing

Indicative latency and achieved throughput results for TCP or UDP traffic are shown below (Table 4-3). The results include switching of the different track-to-train networks periodically, and reflect the fact that when using the p4-based mobility management entity they can reconfigure the link within less than a millisecond.

Table 4-3: RTT Measurements

	RTT
min	2.9 ms
max	10.74 ms
avg	3.72 ms
deviation	0.86 ms

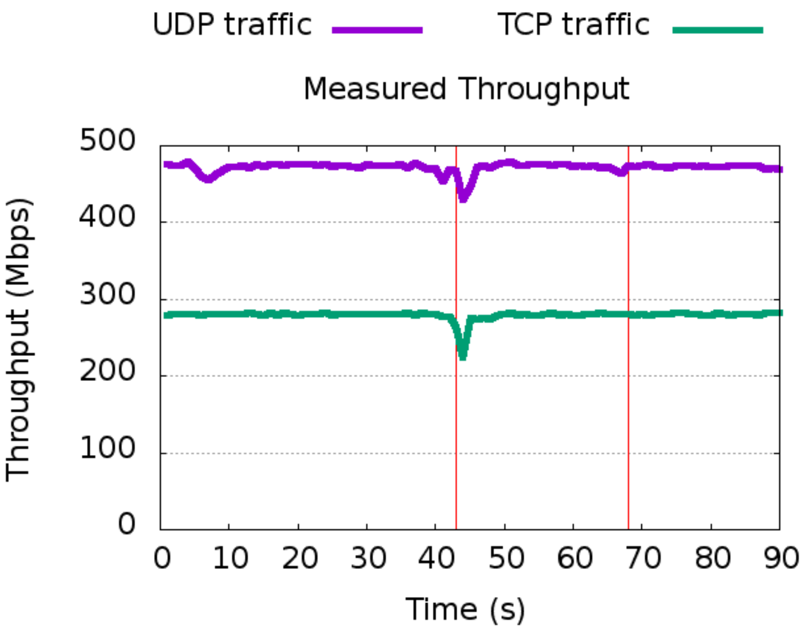


Figure 4-7 Measured Throughput for the in-lab setup when changing connected stanchions: red lines denote the points in time that the handover happens.

As it can be seen from the results (Figure 4-7), the e2e throughput is very slightly affected from the changes in the network, as the P4 controllers either on-board or the core network can automatically detect the network change and establish the flows in a reactive manner. The achieved throughput is close to the maximum that can be achieved under this setup (IEEE 802.11 ac wave 1 for the specific cards used - Atheros Qualcomm QCA9880).

4.2.3.2 Lab testing of Stanchion network – mmWave

As a preparation step for the field trial of **UC #1.1**, an initial lab trial is performed under similar operating conditions at **IHP**. For this purpose, two station nodes **S1**/**S2** are mounted on tripods alongside a street and one train node T is mounted on a van and being driven in a scenario that resembles the field trial train ride, as shown in Figure 4-8. The goal is to determine the performance of the mmWave links intended for stanchions **D0** and **D2** in this scenario (see Figure 4-9), particularly the required link range and angles for the beamsteering under which the links are operational.

The mmWave link characterization is done by running an iperf3 test from the **T** node to the **S1**/**S2** nodes, such that it is dynamically initiated during the mobility test, depending on when the mmWave links are established and disconnected. For this purpose, each station node is connected via Ethernet to a server PC, configured to wait for an iperf3 test connection. The train node **T** is connected to a notebook acting as the trainside server for initiating iperf3 tests as soon as links are established, which is monitored through a MATLAB GUI application parsing the train node link parameters via SNMP. The used mmWave nodes are COTS Mikrotik wAP 60Gx3 802.11ad-compliant devices capable of providing up to 1 Gbps net throughput. They are based on Qualcomm QCA6335 baseband and QCA631 RF front-ends, integrated with three 6x6 phased arrays for a 180º beamsteering range. Both sides of the setup are powered by battery power supplies and are respectively shown in Figure 4-8, Figure 4-10, Figure 4-11. With respect to the setup geometry, the nodes **S1**/**S2** are placed at a distance of approx. 400 m and 2 m perpendicular to the train node during the van crossing. The test is performed by driving the van at speed of approx. 12 km/h along the test track depicted in Figure 4-12 and recording the link performance in real-time.

Figure 4-8 Overview of the system setup for the IHP lab trial: a) View of the train node T, b) View of the station node S1

Figure 4-9 Overview of the test track and node positions for the field trial mobility scenario

Figure 4-10 Track-side system setup for the Patras cluster lab trial

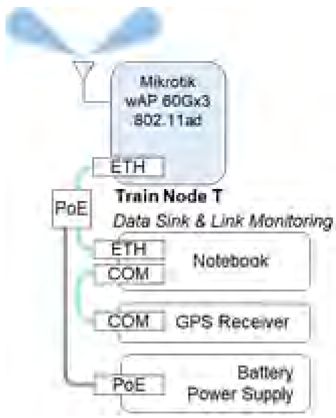


Figure 4-11 Train-side system setup for the Patras cluster lab trial

Figure 4-12 Overview of the test track and node positions for the IHP lab trial

KPI evaluation (Results)

The results of the lab trial are presented in Figure 4-13. It can be observed that the link **T-S1** to the nearest trackside node is established in the range of 75 m before and 104 m after the node **S1**. The timepoint of crossing the nodes can be inferred from the local maxima in the angle plots, which in theory yield 90 degrees when the van is perpendicular to the corresponding node. During the link **T-S1** duration of 40 s, an average and maximum iperf3 TCP/IP throughput of 853 Mbps and 948 Mbps was measured, respectively. Subsequently, after navigating the roundabout on the track, the link **T-S2** is established in the range of 62 m before and 80 m after the node **S2**. The second link **T-S2** had a duration of approx. 30 s, with an average and maximum iperf3 TCP/IP throughput of 506 Mbps and 936 Mbps, respectively. The link activity and operating conditions are summarized in Table 4-4. In summary, the lab trial provided a successful proof of concept for operating the mmWave link in the envisioned mobility scenario. On one hand, by achieving close to the maximum throughput rates of the used devices and on another, being capable of establishing the connection at up to approx.100m under relatively narrow angles of view. However, several challenges have been identified that need to be taken into account for the railway testbed planning. Primarily, the variability of the throughput, particularly for the link **T-S2**, where significant drops can be observed. This performance degradation can be mainly attributed to the propagation channel and occurrences of destructive interference due to ground, trees or other object reflections, as mmWave links rely dominantly on line-of-sight (LoS) propagation. In addition, it should be noted that the selected track has an inclination of approx. 1.5 deg, or 6 m elevation difference, between the highest and lowest point along the track, which can respectively affect the orientation of the nodes during the trial.

Furthermore, the association time of the nodes is an additional factor that plays a large role in positioning the subsequent nodes, as there needs to be sufficient time granted for the handover between the nodes, which is a task of the mobility management entity. Finally, as Doppler frequency shift can often be an important factor in mobility scenarios, in the presented test case it amounted to 1.9 kHz at the given speed and carrier frequency of 60.48 GHz. Since this range can be efficiently compensated by the carrier frequency offset algorithms in the COTS 802.11ad radio implementation, the mmWave link is less susceptible to this effect as compared to Sub-6 GHz solutions.

Table 4-4 mmWave link operating conditions in the mobility scenario

	Link Up		Link Down		Throughput	
Link	Distance	Angle	Distance	Angle	Avg.	Max.
T-S1	75 m	6º	104 m	2º	853 Mbps	948 Mbps
T-S2	62 m	1º	80 m	2º	506 Mbps	936 Mbps

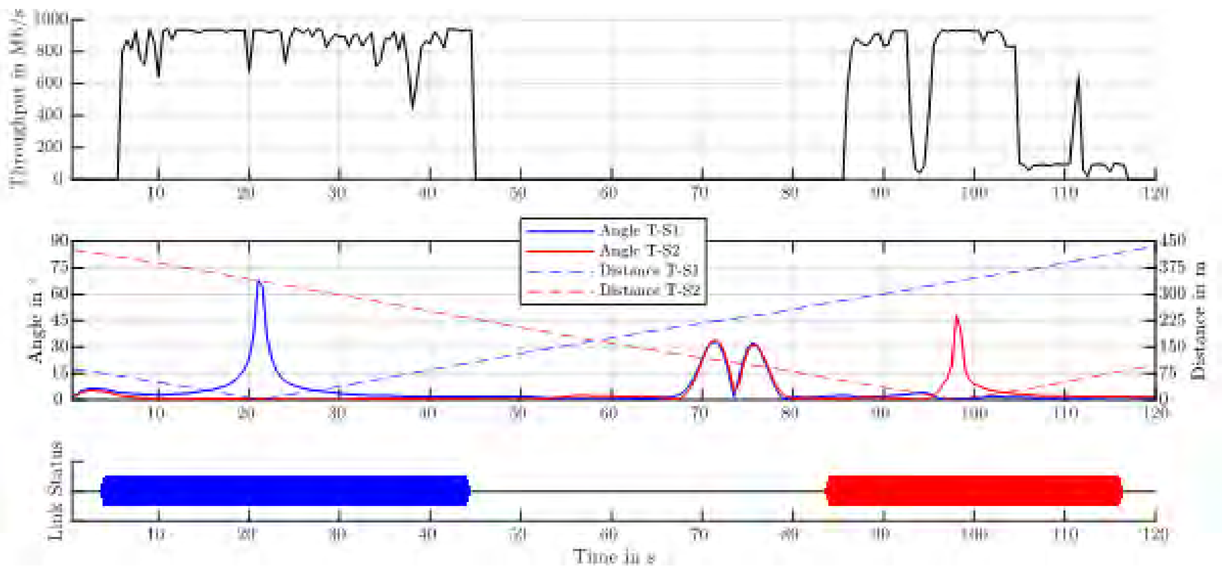


Figure 4-13 Performance of the mmWave link in the IHP lab trial

4.2.4 Patras Facility Setup at TRAINOSE and Component Testing

At the delivery of this report all lab testing for each network segment has been finalised and field trials for segments of the network deployment have been completed. As the overall e2e transport network was not available at the time of the initial trials, a Control room was set up at the TRAINOSE/Hellenic Trains premises and the central room, and all four stanchions were interconnected to the central station either via fibre and/or Power over Ethernet (PoE) technology. As described in all transport use cases, deploying equipment on trains and stanchions in operating environments is not allowed unless specific permissions are granted, making the execution of trials a non-trivial task. Specifically, all network segments were deployed in a non-intrusive way, hence various options were tested and performed for interconnecting the 4 nodes to the central room together with deploying power supplies. All deployed elements for the trial are depicted in Figure 4-14 (Patras Facility Control Room), Figure 4-15 (nodes at points D0, D1, D2 and D3 as deployed in the field), Figure 4-16 (Indoor onboard network) and Figure 4-17 (Outdoor onboard network deployment).

As mentioned, the actual trial took place during the night of the 20th of September. The deployed train wagon with the onboard network was moving back and forth on the rail tracks shown in Figure 4-9 between two major road crossings. The speed of the train was 20 km/h and two teams (on board and at the Control room) were working together to set up the point-to-point links and enable connectivity between technologies.

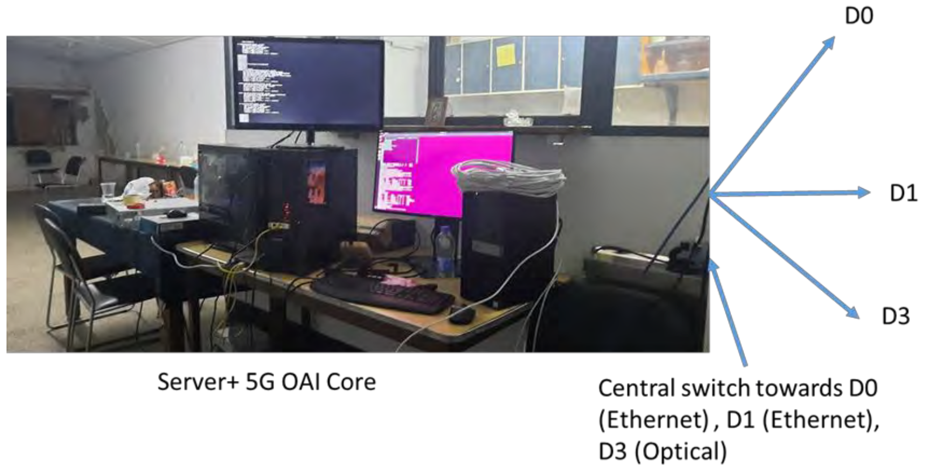


Figure 4-14 Patras Facility Control Room

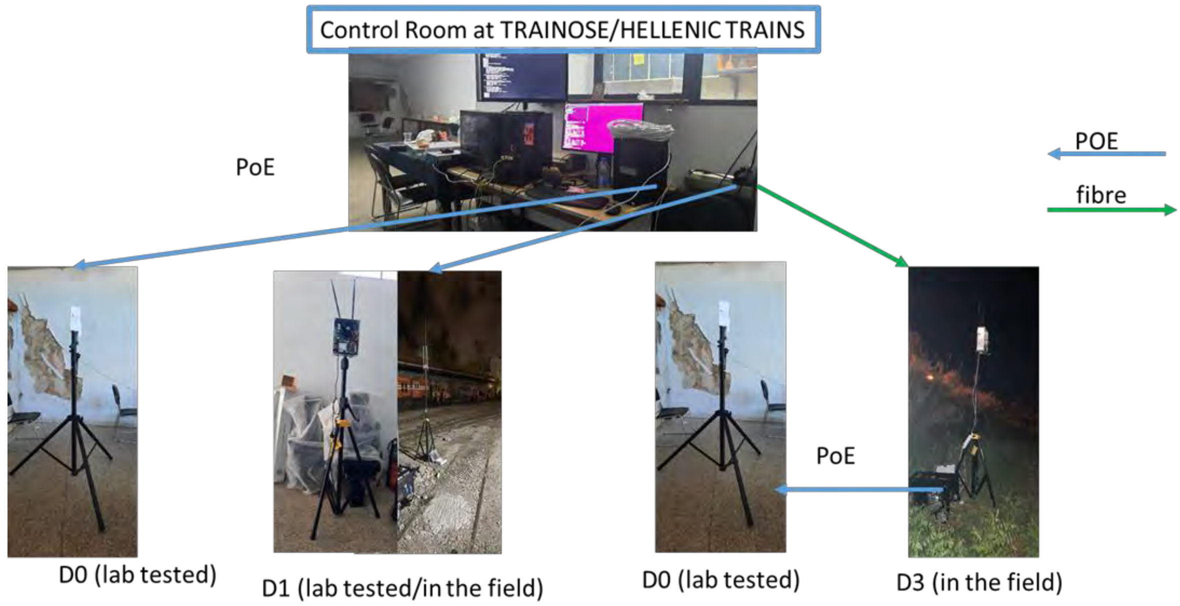


Figure 4-15 Multi technology nodes at points D0, D1, D2 and D3 used for static testing and deployed in the field

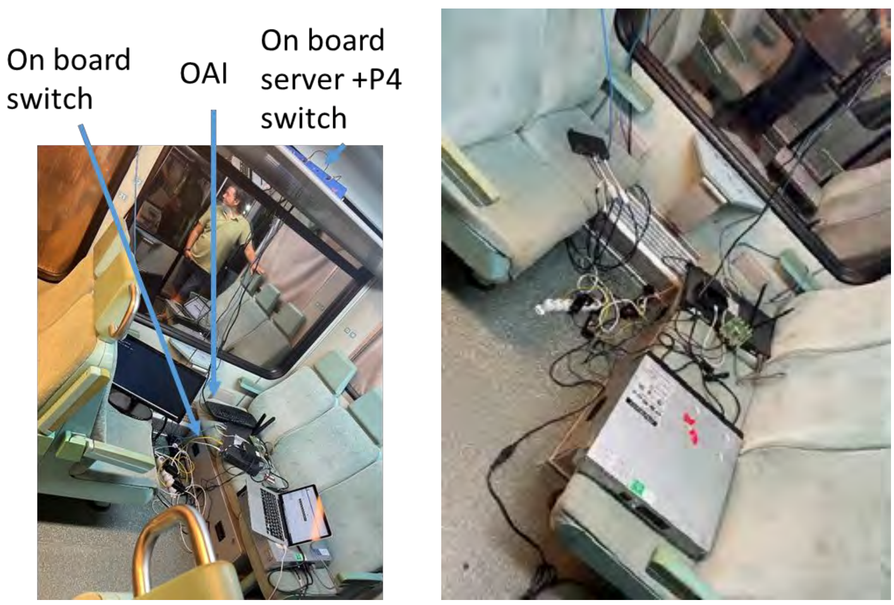
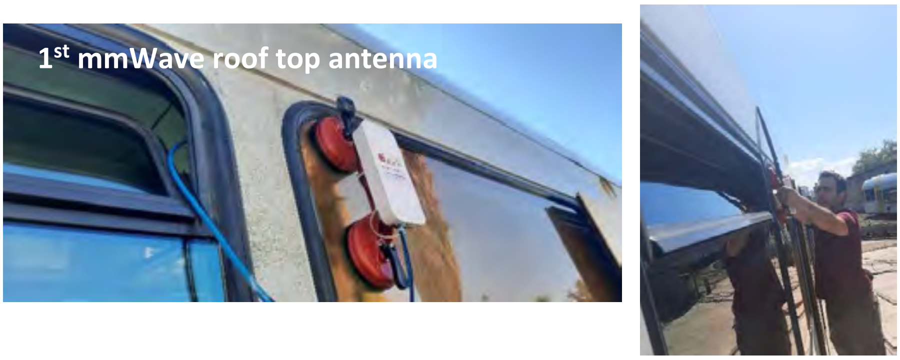


Figure 4-16 Indoor onboard network



2nd mmWave roof top antenna+ sub 6 antenna

Figure 4-17 Outdoor onboard network deployment

4.2.4.1 Static testing of onboard network deployment option at TRAINOSE premises

Static testing Sub-6 GHz nodes

In the field setup at the **TRA** premises, a static testing of the connectivity was performed using the sub-6 GHz stanchion nodes and the on-board train node. Two different types of antennas were used for the track-side nodes, for testing different coverage scenarios and achieved throughput performance. Both types of antennas were omni-directional, outdoor type, with different dBi gains per antenna (5dBi and 9 dBi). Their configuration was tested for an IEEE 802.11ac wave 1 setup, with a 2x2 MIMO configuration. Therefore, the static setups were expected to produce less throughput than the in-lab setups (3x3 MIMO).

Both types of antennas showed that their coverage is approx. 300 m able to achieve 5 Mbps at the farthest point, and 50 Mbps the average speed from experiments covering the entire coverage. Although the experiments demonstrate low throughput values, the initial test was focused on achieving the e2e connectivity, as well as configuring the p4 mobility scheme to work with the mmWave nodes in the field. The overall setup also added a compute server on the train, equipped with a USRP B210 device in order to create the in-train 5G network, and a separate compute server at the train depot was running the core network, interconnected through the Sub-6 GHz and mmWave networks.

Static testing 5GNR (onboard network)

For the 5G related testing, a Google Pixel 6 device was used as the UE. The device was able to successfully connect to the network, receive an IP address and establish a PDN connection with the Internet, through the core network deployed at the depot side. Throughput tests revealed a peak value of 52 Mbps for the UE with the Internet.

Figure 4-18 Deployment of sub-6 GHz node at TRAINOSE premises

Figure 4-19 Sub-6 GHz track-side nodes mounted with different types of antennas

Figure 4-20 on-board UE connected to the on-board 5G network

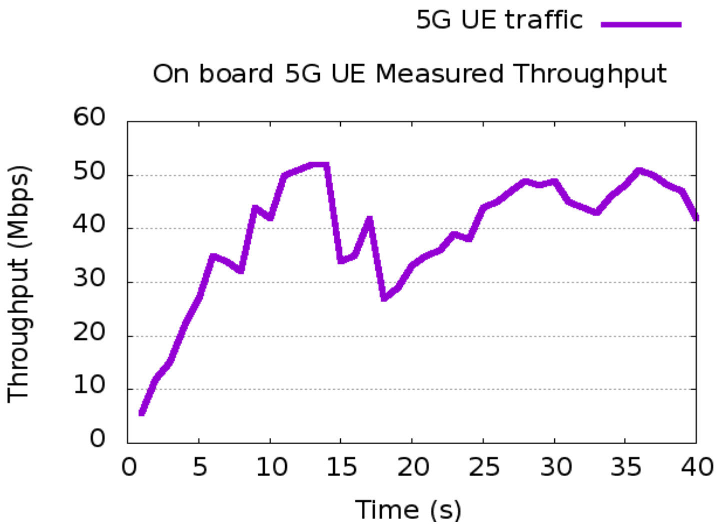


Figure 4-21 on-board UE achieved throughput

Static testing mmWave nodes

A preliminary field trial of the mmWave link connectivity for the mobility handover management is reported in this Section. The field trial took place at the premises of the **TRA** depot in Patras, Greece by using a dedicated sub-urban train on the track within the depot limits. As an extension to the preparatory lab trial reported in Section 3.1, the goal is to evaluate the mmWave link connectivity in a realistic railway environment.

In comparison to the conducted lab trial (see section 3.2.3.1), the system setup is expanded with two nodes being mounted on the train at the front and rear side, annotated as **T1** and **T2**, respectively. The nodes are mounted outside the windows of the front and back side of the train using suction cups, at a distance of approx. 35 m, as shown in Figure 4-22. The train nodes are connected through a switch to a notebook that has the task of initiating iperf3 test connections to a landside server in the control room via the station nodes. The link metrics are recorded and monitored onboard the train in real-time during the tests using a custom MATLAB GUI application connected to the nodes via SNMP. Furthermore, a GPS receiver is used to track the location of the train for a coherent link analysis with the GPS antenna being mounted next to node **T2**.

On the track side, two station nodes, annotated as **D0** and **D2**, are mounted on tripods at a height of approx. 3 m, alongside the track on the respective locations, as shown in Figure 4-23 and Figure 4-24. Both station nodes are powered using intermediate PoE-capable switches over the Ethernet connection, due to the large distance to the landside server placed in the control room. A simplified overview of the system setup on both link sides is shown in Figure 4-23 and Figure 4-24. The field trial consists of performing an iperf3 link test while the train is running from its initial to the final position as marked in Figure 4-12 and crossing the stanchions **D0** and **D2**. A static link test is performed beforehand in the parked position as a preliminary check of the mmWave connectivity.

Figure 4-22 Overview of the mmWave train-mounted nodes T1 (right) and T2 (left)

Figure 4-23 Overview of the mmWave station node at position D0: a) mmWave node D0, b) View towards D1, c) View towards end of track

Figure 4-24 Overview of the mmWave station node at position D2: a) mmWave node D2, b) View towards D3, c) View towards D1

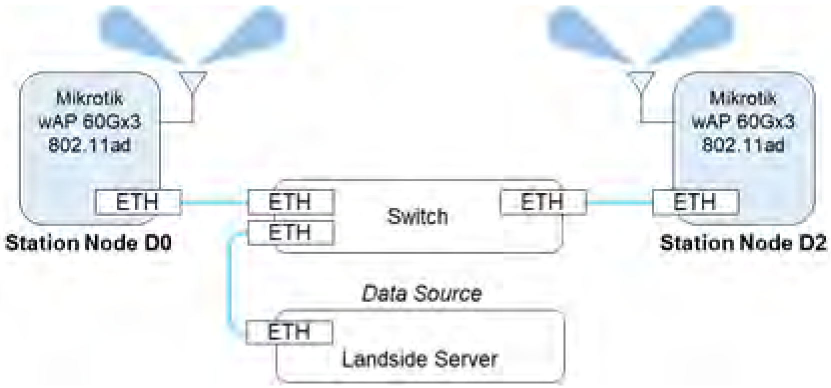


Figure 4-25 Track-side system setup for the Patras cluster field trial

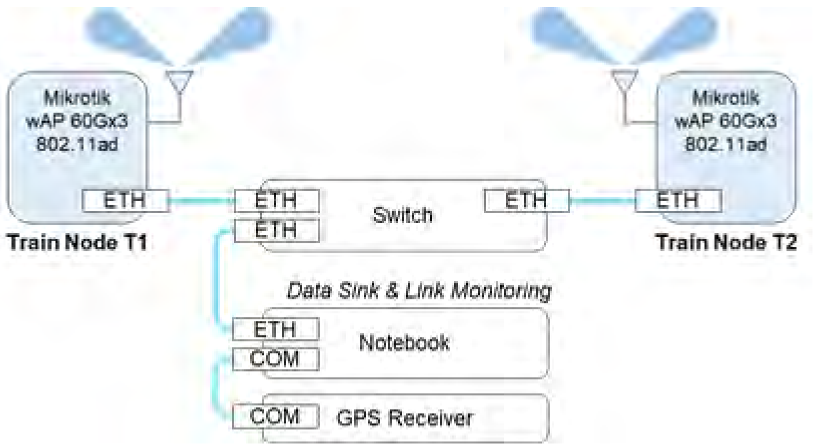


Figure 4-26 Train-side system setup for the Patras cluster field trial

KPI evaluation - Static measurements

The performance of the mmWave link was initially tested with the train in the parked position. In the parked position, the throughput of the mmWave link was measured by running an iperf3 TCP/IP test between the trainside notebook and the landside server with 60 seconds duration, as shown in Figure 3-12 The link exhibited a stable net throughput with a mean of 934 Mbps and st. dev. of 6 Mbps. It is worth noting that the maximum achievable throughput, not accounting for the protocol overhead, is limited to 1 Gbps due to the 1000BASE-T Ethernet interface of the used Mikrotik wAP 60Gx3 mmWave nodes. The latency of the unloaded mmWave link was likewise measured, by performing a ping test of a 60 seconds duration in the same setup. The results, shown in Figure 4-27, yielded a round-trip time of min 0.870/ avg 1.317/ max 4.131 / mdev 0.406 ms.

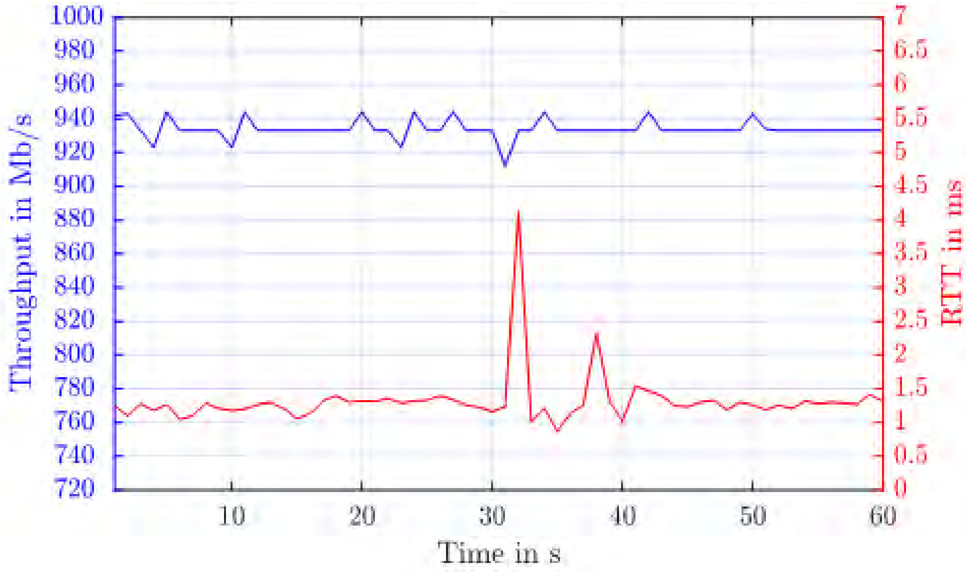


Figure 4-27 Throughput and latency measurements in static conditions

4.2.4.2 Testing under mobility conditions of onboard network deployment option at TRAINOSE premises

Under mobility testing Sub-6 GHz nodes

The connectivity test under mobility were performed during the night of September the 20th. All equipment were set up prior to the mobility in a non-intrusive way. The train speed was approximately 20 km/h and the train was moving back and forth between points D0 and D4 (see Figure 4-28).

Figure 4-28 Photos taken during the overnight trials at Patras premises corresponding to the deployed stanchions

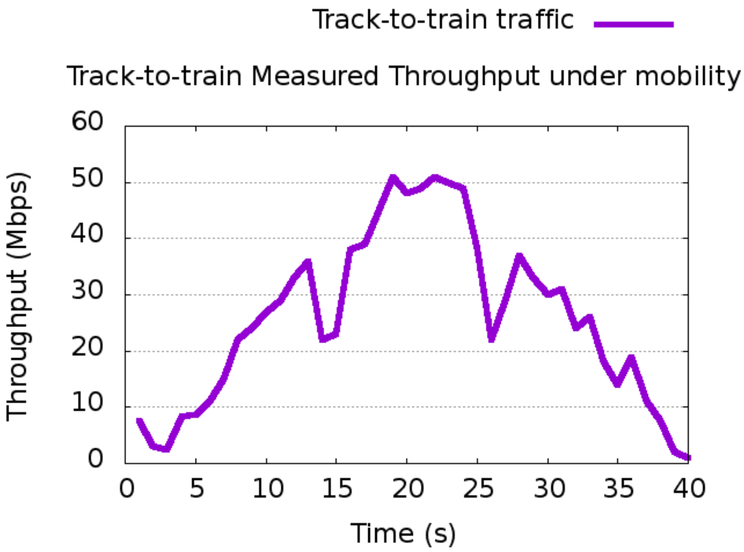


Figure 4-29 Track-to-train Sub-6 GHz testing under mobility

The results for the track-to-train network connectivity were tested with only one stanchion, which was the one able to achieve the highest possible throughput performance in the static test. The results are shown in Figure 4-29. As it can be seen, peak bandwidth is achieved only when the node is close to the stanchion, allowing the connection to reach up to 51 Mbps connection with the core network server. As different types of antennas were used for the two trackside nodes, the connection between the on-board Sub-6 GHz and the two stanchions (**D1** and **D3**) was not seamless, hence the experiment provides the measured results from the first stanchion (**D1**).

Under mobility testing mmWave node

The results of the mobility tests are presented in Figure 3-13, with the iperf3 measured net throughput and the Ethernet port rates of the train nodes **T1** and **T2** shown in the first, second and third row respectively. The measured distance and angle to the station nodes **D0** and **D2**, relative to the train node **T2** is shown in the fourth row. Finally, the link status of each individual pair of the links **T1-D0**/**D2** and **T2-D0/D2** is depicted in the final row of the figure. In terms of the mmWave link connectivity, it can be observed that all pairs of links in the mmWave PTMP setup are operational under mobility conditions. The train was driven in the direction from **D3** to **D0**. In this scenario, the train node **T2** is the front and the node **T1** is the rear node. As the train approaches the first mmWave stanchion in its path (**D2**), the front train node **T2** connects first at a range of approx. 100 m, followed by the rear train node **T1** as soon as it reaches the same range. The connection relative to both train nodes remains active up to a range of approx. 140 m after departing node **D2**. In the traversal of the second mmWave stanchion (**D0**), the links both are established and disconnected at a range of approx. 35 m before and after the stanchion, due to the curvature of the track and LoS obstruction by a nearby building in both directions. The location of the stanchion **D0** was unhapply chosen, mainly determined by the requirement to keep the setup within the depot limits. Placing **D0** outside the depot boundaries, as planned, was not allowed. Thus, **D0** was located too close to the railtrack because of the nearby depot building (Figure 4-23) and the presence of a nearby concrete pillar obstructed the LoS towards the end of the track. This leads to the conclusion that placement of the mmWave node stanchions along the track needs to be strategically planned in order to maximize the link coverage, as the topology of the site and the LoS visibility play a key role in this frequency range. With respect to the link throughput, one interesting observation is that for the periods in the approach and departure to each stanchion where the physical setup does not change much, the measured iperf3 net throughput is relatively stable and ranges from 900 Mbps to 950 Mbps, whereas in the periods of crossing the stanchions at close proximity, significant drops in the performance can be observed. This is in line with expectations and can be attributed to several factors, such as the rapid change in the angles and the beamsteering index adjustment, the variation in the received signal power at the closest crossing points as well as possible destructive interferences due to objects in the vicinity. Finally, in context of mobility, it can be observed that the traffic flows initially through the front train node **T2**, as it gets connected first to each incoming stanchion, then being switched to the rear node **T1** as soon as its connection is established. This traffic is monitored at the individual ETH ports of both **T1** and **T2** nodes. In summary, the field trial provided a successful proof of concept for the mmWave connectivity within the mobility handover use case with several implications from the realistic environment, as annotated above.

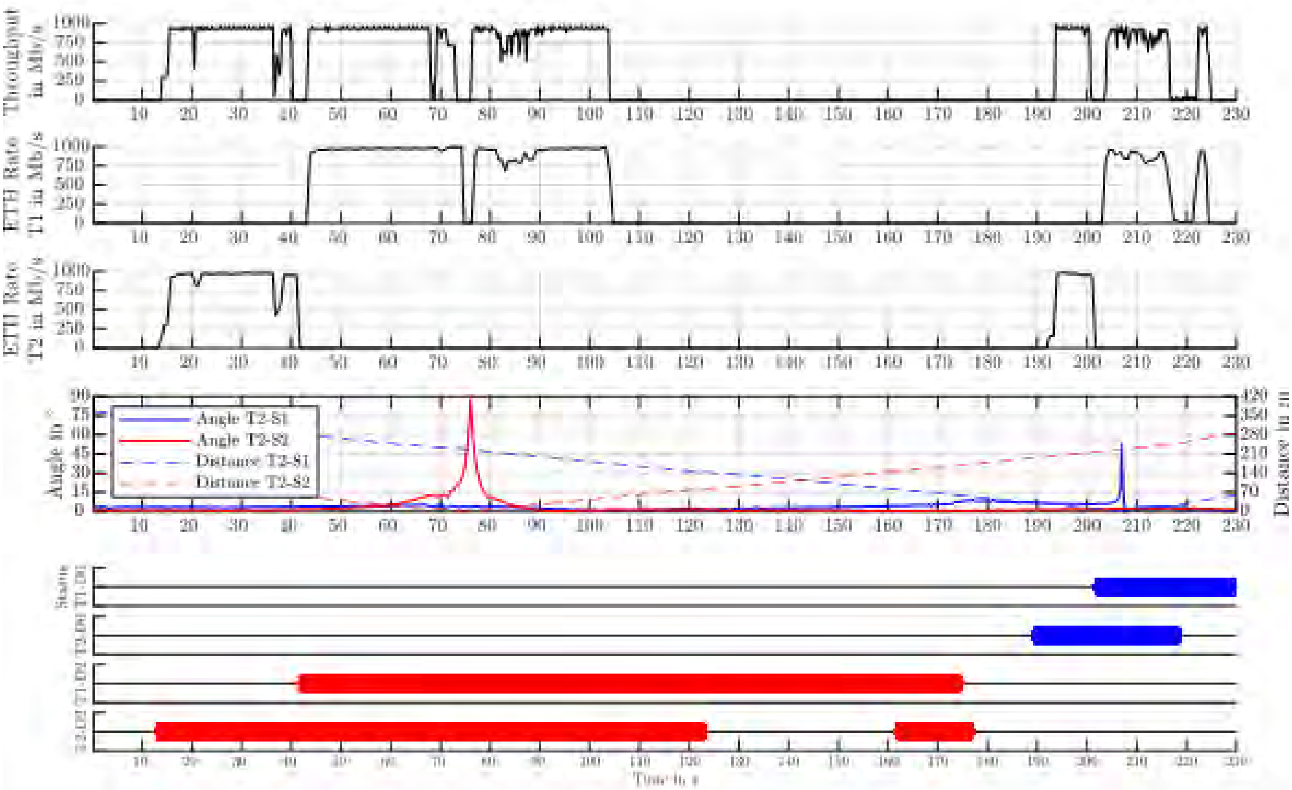


Figure 4-30 Performance of the mmWave link in the TRAINOSE field trial

4.2.5 Test Cases and KPIs

Test case group RED			
Test case name	**Place**	**Key UC requirements and KPIs**	**Network performance requirements and KPIs**
REDv01	NITOS Lab (UTH) / 5G-VINNI Patras	Latency, Uplink and Downlink capacity between the train and the UoP data center **U-PE-1103-** KPI: latency min. between UE and service end-points 20 ms.	**U-PE-1103** Latency between UE and service end-points 20 ms. **F-CA-1104** Air Interface – Access Network Capacity

4.2.6 High Level 5G Deployment Scenario Description

The section concerns the details of the scenarios that correspond to the 5G Deployment options described in Patras Introduction and used in this specific UC. Based on the configurations included in Table 4-5, the initial trials were executed.

Table 4-5 Scenario description for UC #1.1

Scenario Description Template		
Radio access technology (RAT)	5G	sub-6GHz track-to-train
Standalone / Non-Standalone (if applicable)	SA	n/a
Cell Power	14 dBm	30 dBm
Frequency band:	N78	sub-6GHz, 5GHz
Maximum bandwidth per component carrier	50 MHz, 100 MHz, 200 MHz, 400 MHz, 800 MHz, 1 GHz, 2 GHz	n/a
Sub-carrier spacing	30 kHz	n/a
Number of component carriers	1	n/a
Cyclic Prefix	normal	
Massive MIMO	1x1 SISO	
Multiple-Input Multiple-Output (MIMO) schemes (codeword and number of layers)	n/a	3x3 MIMO
Modulation schemes	Downlink: QPSK, 16 QAM, 64 QAM, 256 QAM UplinK: QPSK, 16 QAM, 64 QAM, 256 QAM	Downlink: QPSK, 16 QAM, 64 QAM, 256 QAM UplinK: QPSK, 16 QAM, 64 QAM, 256 QAM
Duplex mode	TDD	n/a
TDD uplink/downlink pattern	nrofDownlinkSlots = 7; nrofUplinkSlots = 2;	n/a
Contention based random access procedure/contention free	contention based	contention based
User location and speed	0 km/h and 20km/h	0 km/h and 20km/h
Background traffic	none	none
Computational resources available	5G	n/a

4.2.7 Experiment Description

In this section the exact details of the experiments are described. The experiments described in the September 2022 tests were executed without orchestration, therefore the descriptors templates are not relevant for this Use Case testing phase. Only the RED group of test cases were executed here and emphasis was given to the REDv01. To that respect the Option_5GVINNI_1- OAI for the onboard network was used with the corresponding UE (see Table 4-6).

4.2.8 Experiment execution and Reports (with reference to WP3 methodology)

Table 4-6 Experimental execution and results

Field	Description
Test Case ID	**REDv01**
Facility, Site	5G-VINNI, **TRA** site
Description	This test case demonstrated the connectivity within the onboard network and the connectivity between the onboard (standalone) network to the 5G-VINNI facility (control room). (Without testing the backhaul network.)
Executed by	Partner: **UTH**, **IHP**, **UoP**, **TRA**
Purpose	On board Network deployment and track-to train connectivity testing, static and under mobility
Scenario	**REDv01**
Slice Configuration	No slice configuration was performed
Components involved	Onboard Ethernet Switch. Onboard 5GNR with SDR. Onboard fibre network. On board server. 5G Core Network VM in the control room. 5G UE for connecting to the network. Onboard mmWave and Sub-6 nodes D0-D4 stanchions (mmWave and Sub-6 nodes)
KPIs collected (Metrics collected)	Throughput and latency (RTT) measurements
Tools involved	iperf3, ping
Results and KPIs **Primary** **Complementary**	**static testing:** mmWave track-to-train connectivity: Throughput=~940 Mbps, RTT=~1,3 ms Sub-6 GHz track-to train connectivity: Throughput= ~50 Mbps 5G-NR static testing: Throughput = 52 Mbps **Mobility Testing:** mmWave track-to-train connectivity: Throughput around 900-950 Mbps during LoS but with significant drops during handover Sub-6 GHz track-to train connectivity: Throughput maximum 5-50 Mbps depending on the distance (no handover)
Target metric/KPI and verification (pass/fail)	Throughput KPI passed for the mmWave nodes, for the Sub-6 nodes different antennas needed to improve throughput. RTT passed but without the backhaul connection to the UoP cloud

4.2.9 KPI evaluation and Conclusions – Lessons learned

The first field trials performed in Patras for **UC #1.1** were successful as the initial goal was to integrate together all required elements and test connectivity of the infrastructure in a real rail environment. There were tests performed both under static and mobility conditions. Some specific features and services associated with the relevant UC were left for the next trial phase such as the mobility management function (only initial tests were performed) as well as the specific services that will run on top (currently tested in lab). Furthermore, the e2e transport network is under deployment.

What we learned from these first trials is that we need to carefully choose the position of the trackside stanchions depending on the technology (mmWave or Sub-6) and then try to improve the handover time through more suitable antennas in the case of Sub-6 nodes and optimisation of the association time of the nodes. On board 5G-NR UE throughput will also improve in the next trials as we achieved speeds up to 200 Mbps in the lab. Since the mobility function was successfully tested in the lab it is crucial to be correctly configured for the field trials so that proposed services will run seamlessly on top of the infrastructure.

There are two major trial phases that are envisaged before the final trial takes place. The first one is going to test interconnection of all components and the mobility management under mobility in a “lab” environment (UoP car park). The second will test all the above together with the three envisaged services on top.

4.3 UC #2 Factories of the future

As mentioned already, the peculiarities of the IPTO facilities – high voltage (HV) areas with sensitive data that require security – combined with the variety of terrains in the specific facilities make these verticals very demanding with respect to network planning. In order to evaluate the various services that are required for the specific UC and achieve the expected KPIs, testing was performed in three phases: a) in the lab, b) over the facility interconnected with isolated 5G private network, and c) over the facility configuring independent slices in support of each service (multi service test). Three groups of test cases were envisaged depending on the vertical service requirements. Currently there are two identical gNBs deployed at Patras5G cloud facility (lab environment) and at the ADMIE Rion facility (facility environment). The former is fed with CPE connected emulated sensors and is being used for testing and benchmarking purposes while the latter is being fed with data from the sensors in the facility.

Furthermore, for the specific UC deployment various tests were performed for applying the 5G-VICTORI architecture. To exploit the SBA for the benefit of the Surveillance related services, Option 3 from 5G-VINNI technologies has been used [5]. This option entails core functions based on the disaggregated paradigm described in [5] implemented as containers on the 5G VINNI cloud facility and MEC. To that respect various options of vertical service VNF and core functions were integrated at various distances of the vertical facility, in order to investigate efficiency versus latency issues.

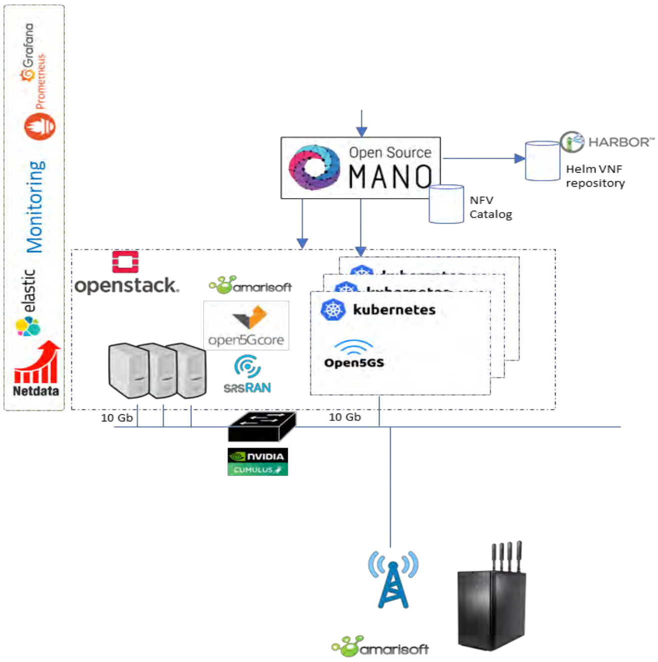
At the time of delivery of the report, the backhaul link interconnecting Patras5G cloud and ADMIE facility was down, as explained in the introductory sections. Therefore, test cases requiring e2e transport network deployment were not optimised (see Table 4-7). To realise the testing roadmap that is similar to the previous UC, a Control room was set up at ADMIE power station such all tests are currently run at the ADMIE facility (see first row). As soon as the interconnection to Patras cloud (at UoP) is re-established, the tests will be performed again (see Table 4-7 second row).

4.3.1 UC #2 Slice description (with application components)

Figure 4-31 illustrates the instantiation of three concurrent services, as envisaged in UC #2 by the Greek cluster and described in detail in deliverable D3.6 [13]. As mentioned already, the background work required for taking advantage of the service based 5G architectural elements have been developed. All 5G core functions and ADMIE services have been deployed at the edge (a special 5G private network and standalone server deployed at the ADMIE facility). Furthermore, slicing has been tested with two concurrent services. The benefits of the specific deployments will be unveiled as soon as the e2e testing is executed.

Table 4-7 Testing phases for UC #2

Network deployment per segment	In-Lab test	Isolated private network (in the field)	Multi service test (field trial)

 **ADMIE** Facility interconnection (no backhaul interconnection)	✓ June 2022	✓ September 2022	✓ November 2022
e2e transport network with cloud interconnection	✓ February 2022 (backhaul was available for testing)	To be tested after the transport network has been set up	To be tested after the transport network has been set up

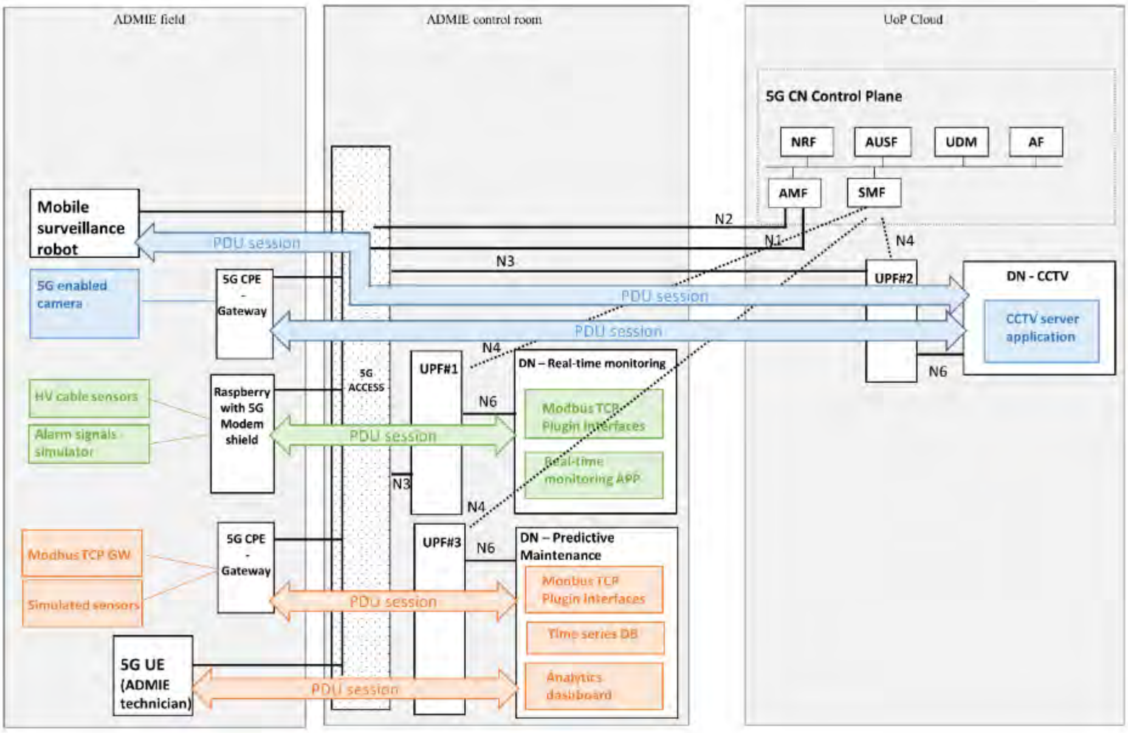
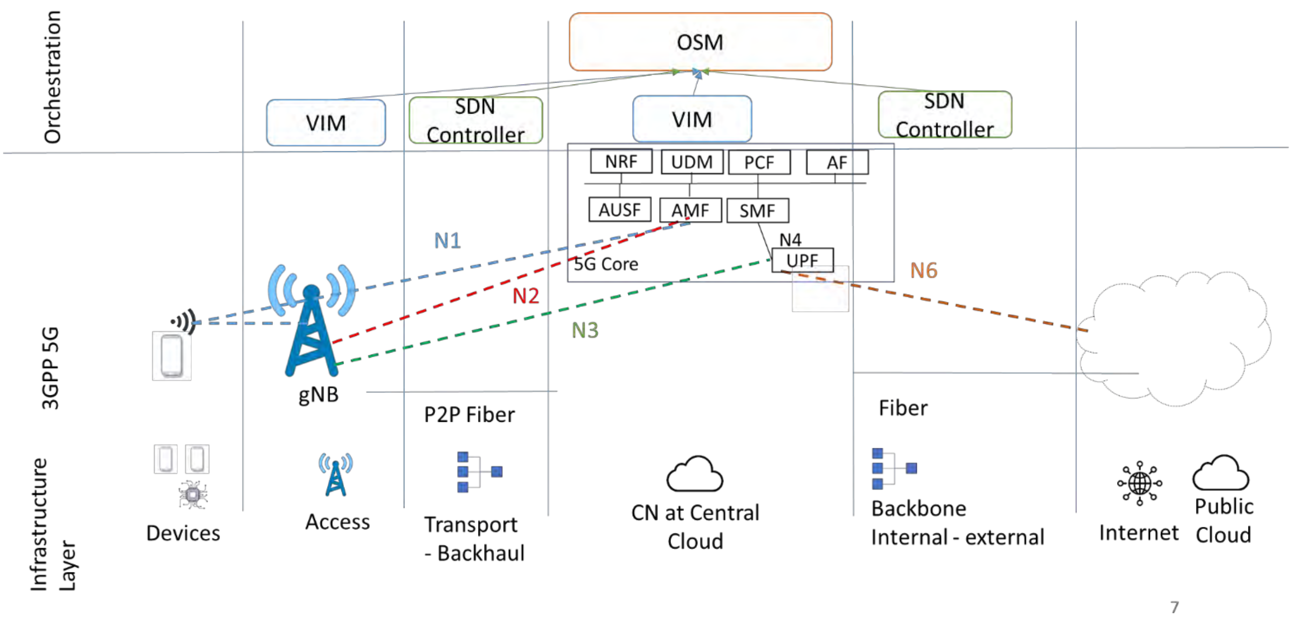


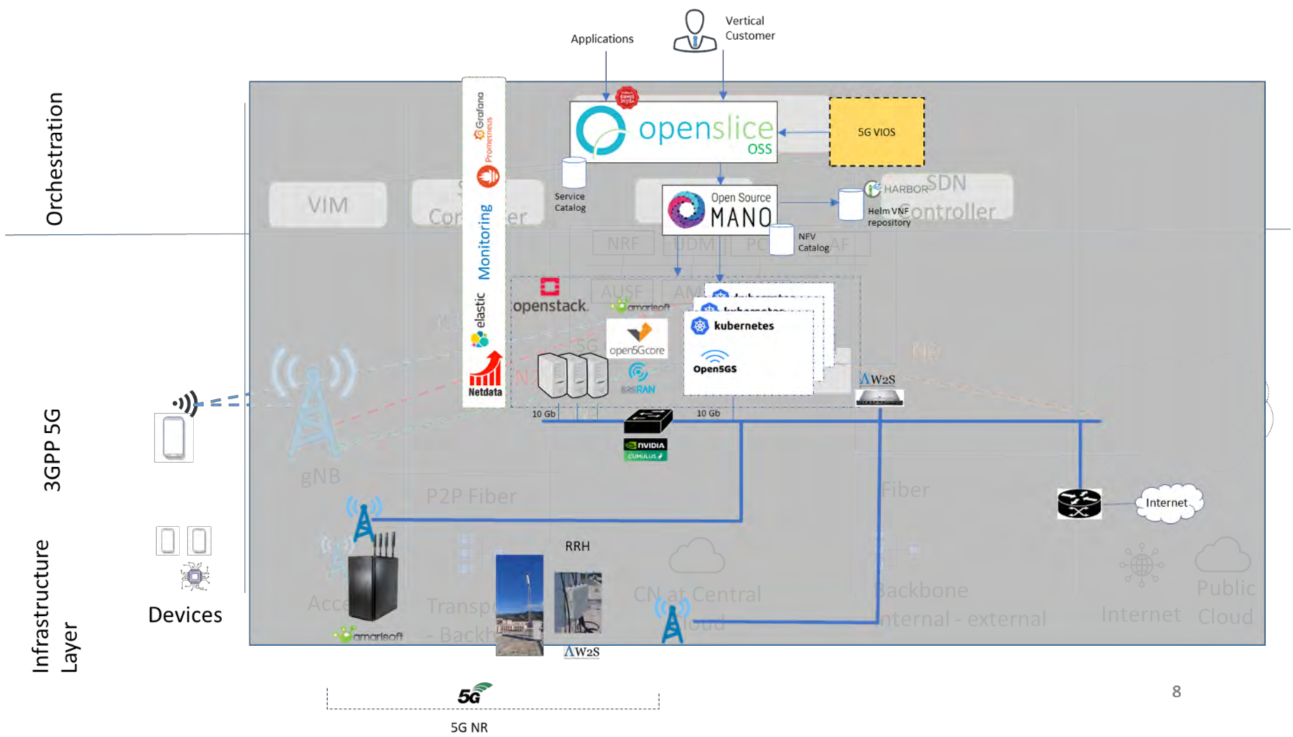
Figure 4-31 Final UC #2 deployment with concurrent instantiation of three services as described in D3.6

4.3.1.1 Network Schematic diagram

Together with the previous figure, the SBA is depicted in Figure 4-32. The deployment of the 5G-VICTORI architecture at the ADMIE facility for the scope of **UC #2** is shown in the figure below (b). Two 5G deployment options are used here (see Table 4-1) and Table 4-9 for the actual configuration of both. As shown in these figures there are two gNodeB options deployed here corresponding to indoor and outdoor testing for **UC #2** (see Table 4-1). To benefit from the flexibility of the SBA, the 5G core technology utilised here is based on the Open 5GS option deployed flexibly on containers.



(a)



(b)

Figure 4-32 (a) Architectural flavour of the 5G-VICTORI architecture deployed at Patras facility for UC #2 testing and trials (b) hardware and software components deployed for the deployment of the architecture

4.3.1.2 Architecture @ Lab

A sub equipped version of Figure 4-33 was used as shown in Figure 4-34 below (no backhaul is used here). All technologies mentioned in the figure were used for testing of the multi service experiments. The gNB deployed for lab testing at the ADMIE and at UoP is Option 4 (Intro).

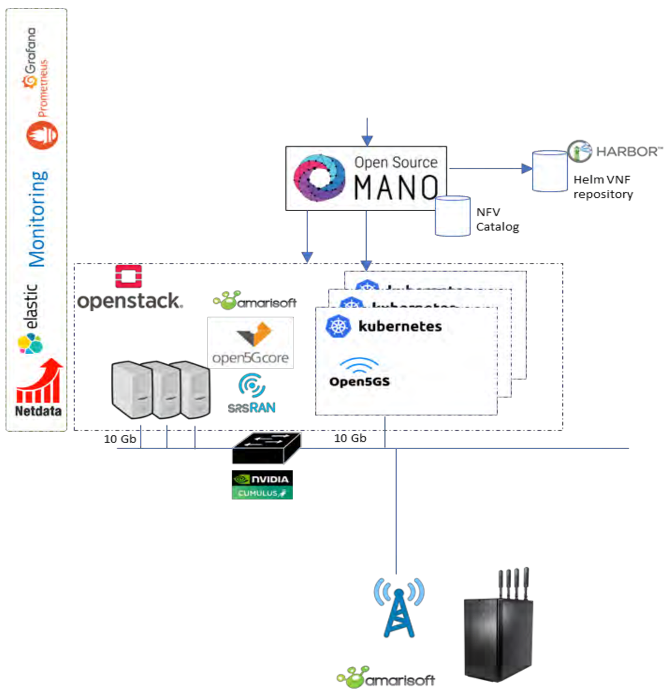


Figure 4-33 5G technologies used for UC#2 testing

WP3 lab tests focused on the validation of the three vertical services, their requirements, and their initial onboarding on a typical 5G network. For benchmarking, the monolithic approach of Amarisoft Callbox was used, while the different services were deployed on the UoP cloud. **UC #2** focuses on two significant requirements: 1) the simultaneous support of different services over a shared infrastructure, and 2) the flexible placement of network and application functions at the edge or the cloud. The next Greek cluster lab trials focus on evaluating the support of these requirements in the lab.

4.3.1.3 QoS for guaranteed minimum throughput

To demonstrate the support of one or more services with guaranteed performance, the Preventive Maintenance application is chosen. According to the preliminary results of D3.6 [13], Preventive Maintenance application requires a total bandwidth of approximately 5 Mbps for 100 sensors. Since this service should not be interrupted at any time, it is supported by a dedicated network slice, configured to support a minimum throughput of 5 Mbps. All other services are served by a second network slice with typical configuration.

The proposed lab setup (Figure 4-34) comprises Amarisoft Core hosted on the cloud, an Amarisoft callbox as gNB, and two network slices. Following the setup of D3.6 (for EDH and EDS related tests). A raspberry Pi 4 with a SIM8200EA-M2 5G HAT (UE_511) is used as device simulator and the Preventive Maintenance application is deployed on the UoP cloud. Moreover, a laptop with a 5G CPE (UE_721) and a mobile phone (UE_632) are used to generate traffic with the use of iperf tool. Traffic generated by each UE is monitored through the monitoring solution hosted also on UoP cloud.

Initially, only the Preventive Maintenance (UE_511) is deployed and achieves a stable 5Mbps uplink. Then, uplink traffic is generated by UE_721 which occupies the free bandwidth of the channel. Finally, UE_632 initiates an uplink stream to the server. As shown in Figure 4-35 , UE_511, which serves the Preventive Maintenance application, continues its stable transmission. The remaining bandwidth of the channel is shared among the other two UEs, causing a reduction in throughput for UE_721. When the transmission of UE_632 ends, uplink of UE_721 returns to its previous value. At any time, UE_511 uplink remains stable and does not fall under the 5 Mbps limit.

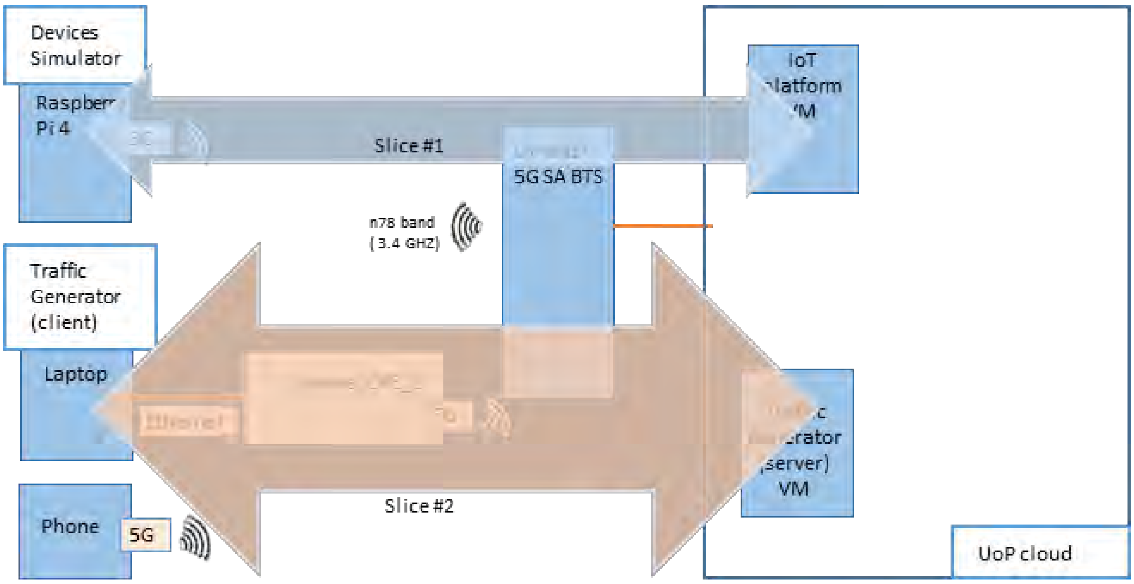


Figure 4-34 Lab setup for QoS testing

Figure 4-35 Snapshot from Netdata during testing

4.3.1.4 Multiple UPFs support

UC #2 leverages the 5G SBA of Option #3 to place the 5G Core Network and application functions on the cloud or the edge datacenter (MEC), according to the requirements of each service – following a cloud-edge architectural approach. More specifically, and with reference to the deployment described in Figure 4-32, CCTV application is hosted on the cloud in order to provide assets surveillance via internet. On the contrary, real-time monitoring and preventive maintenance services collect and act on critical data, which for latency and security reasons should not leave ADMIE premises. The fulfilment of this diversity in requirements is accomplished through the use of different UPFs co-located with each vertical application.

As a preparation step, prior to the deployment at **ADMIE** facilities, the validation of the cloud-edge architecture was performed in the lab. Figure 4-34 illustrates the lab setup which except from the UoP cloud, incorporates the Autonomous Edge solution acting as the MEC. During lab testing, Open5gs solution was tested in two different setups. In the first one, all 5G Core functions (including UPF) are deployed on Patras5G cloud. In the second setup, 5G Core functions are still deployed on the cloud, except from UPF which is deployed on the Autonomous Edge.

In the lab experiment, Autonomous Edge is in proximity with the UoP cloud and connected with it via an Ethernet switch. So, it is not expected to log significant differences in performance between the two setups. Nevertheless, this is a functional test validating the capability to instantiate 5GC and application functions in a distributed fashion, and thus fulfilling the isolation and localization requirements of the use case.

For each deployment, sets of uplink, downlink and icmp measurements were performed through a mobile phone. Table 4-8 presents the results of the two deployment options. It is shown that option #1, where UPF is deployed on the Autonomous Edge solution, outperforms option #2 in average ping and downlink measurements, while for uplink, they achieve similar results. This is a consequence of the allocated resources for each deployment. Patras5G cloud supports many services simultaneously so a VM with minimum specifications was allocated for the test. On the contrary, the Autonomous Edge solution was dedicated to the test, and more resources were allocated to host the UPF functionality.

Table 4-8 Latency benchmark measurements (multi UPF)

Option	Open5gs (Core)	Open5gs (UPF)	Down/Up	ping	jitter	loss
#1	Cloud (OpenStack)	Autonomous Edge	555/25.8 Mbps	13.7 ms	4 ms	3.9
#2	Cloud (OpenStack)	Cloud (OpenStack)	534/26.7 Mbps	15.1 ms	5 ms	3.6

With the inclusion of the mmWave connection (backhaul) in the setup, it is expected that the latency of the centralized setup will be slightly increased (added propagation delay from the link). However, the decentralized architecture allows for local processing (data network will close locally) This means increased security on critical data that do not need to travel outside the facility and reduction on bandwidth needs for the backhauling connection since only control data will ultimately use the backhaul link.

4.3.1.5 @ Facility for testing

Phase two of **UC #2** testing regards the replication of lab setup in the facility through an isolated 5G private network. With no connection with UoP cloud, all 5G core and application services are deployed at the edge. 5G-VINNI option #4 is used for 5G connectivity, while processing power at the edge is provided by the Autonomous Edge solution.

Physical infrastructure integration

Since it was infeasible to use the physical facility sensors in the lab, lab testing was performed only with simulated devices though dockerized Modbus TCP simulators instantiated in 5G enabled Raspberry devices [13]. The objective of this phase is to validate the actual field setup, and investigate possible impediments imposed by the nature of the facilities in the quality of services (high voltage, iron constructions, real sensors reporting setup, etc.)

Figure 4-36 a) presents the actual setup inside the control room, at ADMIE facilities. In the legacy setup, physical sensors are hardwired to an electrical panel and provide their analogue and digital measurements on the front panel’s dashboard. Physical sensors provide a great range of binary and scalar signals which can be divided into time-critical and maintenance related information. For the purposes of the trial, the panel has been equipped with Modbus TCP gateways which provide IP connectivity to the sensors. Finally, the Modbus TCP gateways use a 5G CPE to connect to the NPN 5G network. The different vertical services and monitoring tools are deployed on the Autonomous Edge solution (left side of photo).

As a first step, the correct configuration of end devices, 5G gateways and 5G NPN network was validated. Then, the vertical applications were deployed locally, on the Autonomous Edge solution. Figure 4-36 b) depicts the dashboard of UiTOP where real and simulated data are combined for validation purposes.

4.3.1.6 5G coverage measurements

In the present setup at ADMIE facilities, sensors are hardwired to the legacy gateway inside the control room. The final objective is to investigate if it is feasible to plant 5G enabled sensors across the facility. The peculiarities of the HV area around the ADMIE facility are expected to bring about many fluctuations to signal strength and intersymbol interference affecting signal quality. The specific radio propagation environment inflicts multi path propagation where various signal components interfere with changes to their relative strengths and phases. Especially when reflected by HV obstacles or variety of surfaces, received signal power may fluctuate rapidly with respect to the average expected value.

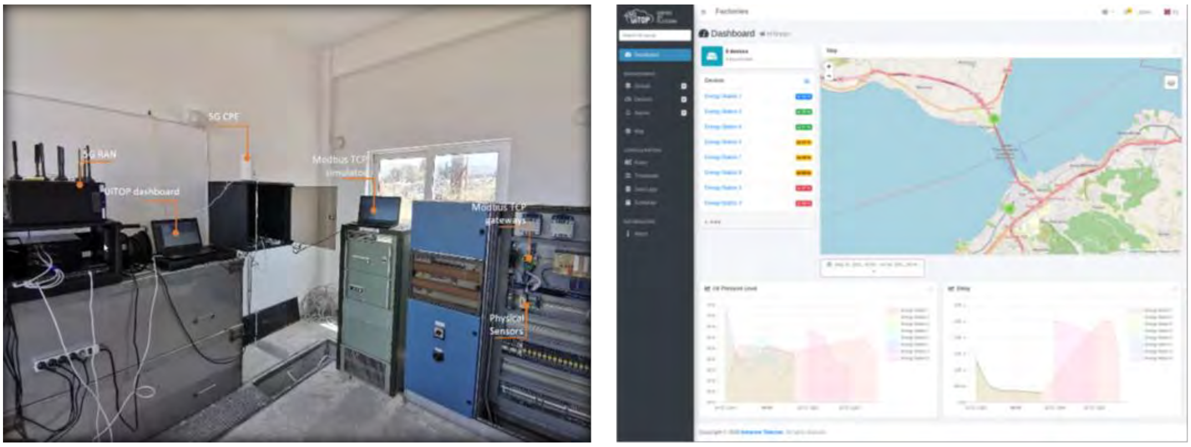


Figure 4-36 a) Facility setup for Phase 2 testing, b) UiTOP dashboard with real and simulated sensors' data

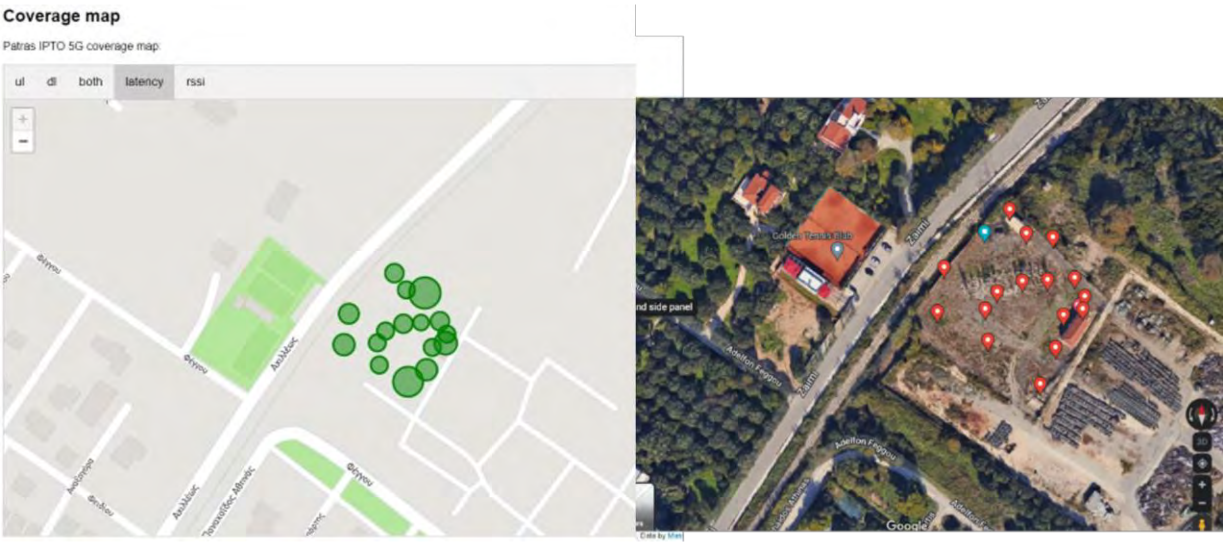


Figure 4-37 Coverage Map: latency heatmap (left), google maps view (right)

One of the objectives of this field trial is to investigate the connectivity quality at different locations inside the facilities. Amarisoft callbox was deployed inside the control room (point_0). A raspberry Pi4 with a 5G HAT (SIM8200 Series modem + GNSS module) was used to perform several sets of measurement at key locations of the facility. Each set of measurement comprised uplink, downlink and ping measurements using standard network configuration. Besides, signal quality indications (RSSI, RSRP, RSQP, RSNR) from the UE perspective were captured at each location via AT commands issued at the modem (and location was logged in the same way). Measurements were stored, analysed and monitored through a custom coverage monitoring tool provided by UoP. Figure 4-37 depicts the 15 measurement points as shown in google maps (right side of figure). On the left, a snapshot of the tool illustrates a heatmap of the latency from each spot (circles' radius is proportional to the measured latency).

The following scatter diagram illustrates the relation between the distance from point 0 and the uplink, downlink and latency performance. Uplink and downlink performance is shown to be reduced with the distance. Nevertheless, with a closer view to the points, it is shown that there are points which may be closer to the gNB but achieve worse average uplink and downlink measurements. This is a result of the presence of obstacles between a measurement point and the gNB. It should be noted that option #4 regards an indoor deployment and walls, HV or iron obstacles may interfere with the signal strength and quality. For Preventive Maintenance and CCTV applications, we are mostly interested in the uplink performance at different spots. Assuming that a Modbus TCP gateway could support more than 100 sensors, the aggregated throughput of 20 Modbus TCP gateways combined in a single 5G gateway, produce an aggregated uplink flow of 2 Mbps. Heatmap of Figure 4-38 shows the weaker and stronger points of the facilities where such 5G gateways can be installed.

Red points indicate that the average achieved uplink was below the 2 Mbps threshold. They are blind points, behind walls and iron structures, which cannot be supported by the indoor deployment. Nevertheless, it is proved that the 5G deployment at ADMIE premises can sufficiently support the Preventive maintenance application both in guaranteed throughput and coverage at the facilities.

Regarding the average latency results, it was expected that it would be significantly increased with the distance, but its line is imperceptibly inclined. This result proves that the average latency is mostly impacted by processing delays rather than the over-the-air distance. Moreover, the network latency at every point of the facility complies with the maximum permitted network latency for the support of the real-time monitoring application (EDH).

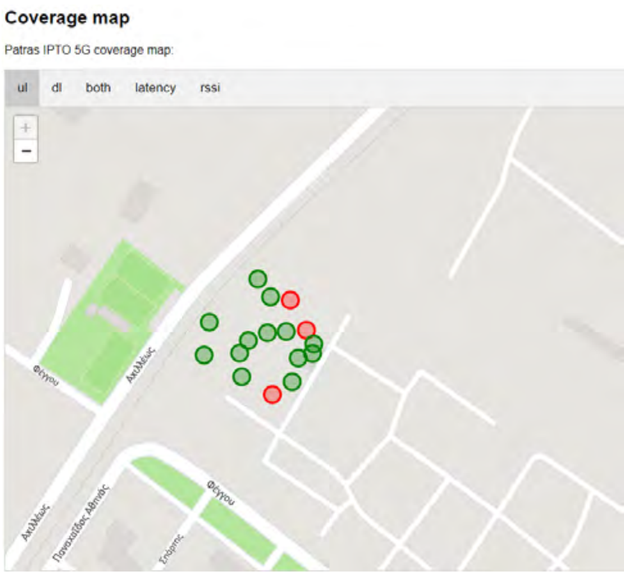


Figure 4-38 Coverage Map: sufficient (green), insufficient (red) wrt 2Mbps

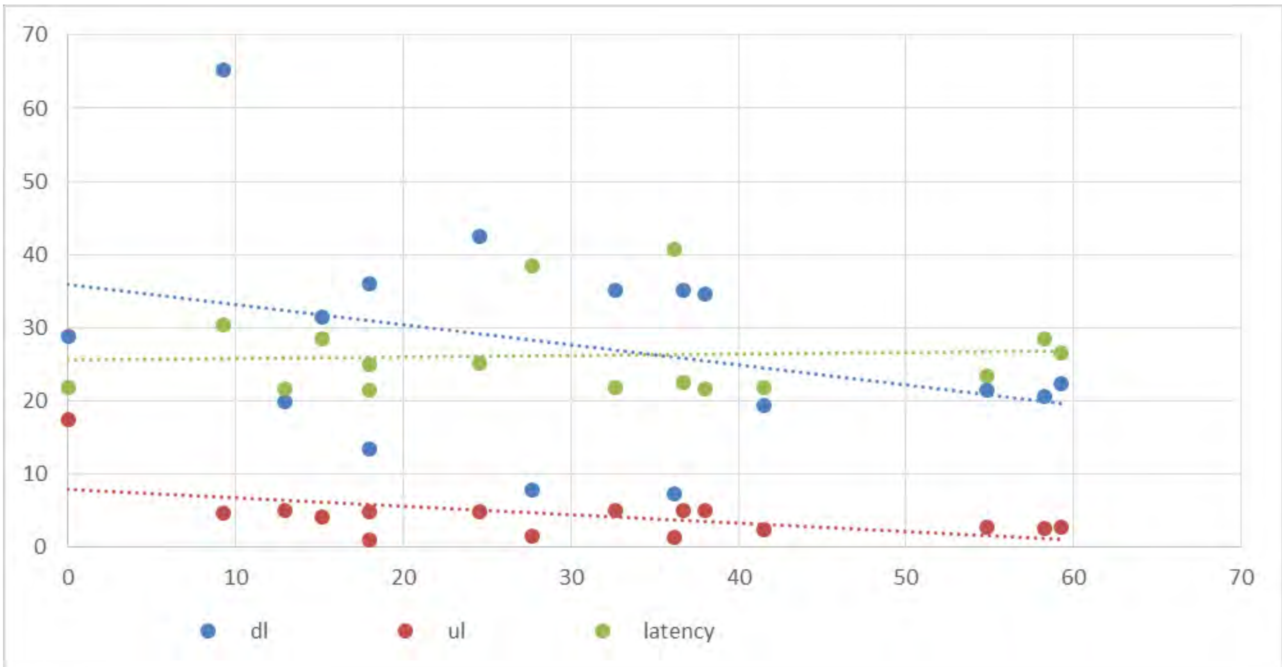


Figure 4-39 Throughput (ul and dl) and latency (msec) measurements with respect to the distance from point_0 (m)

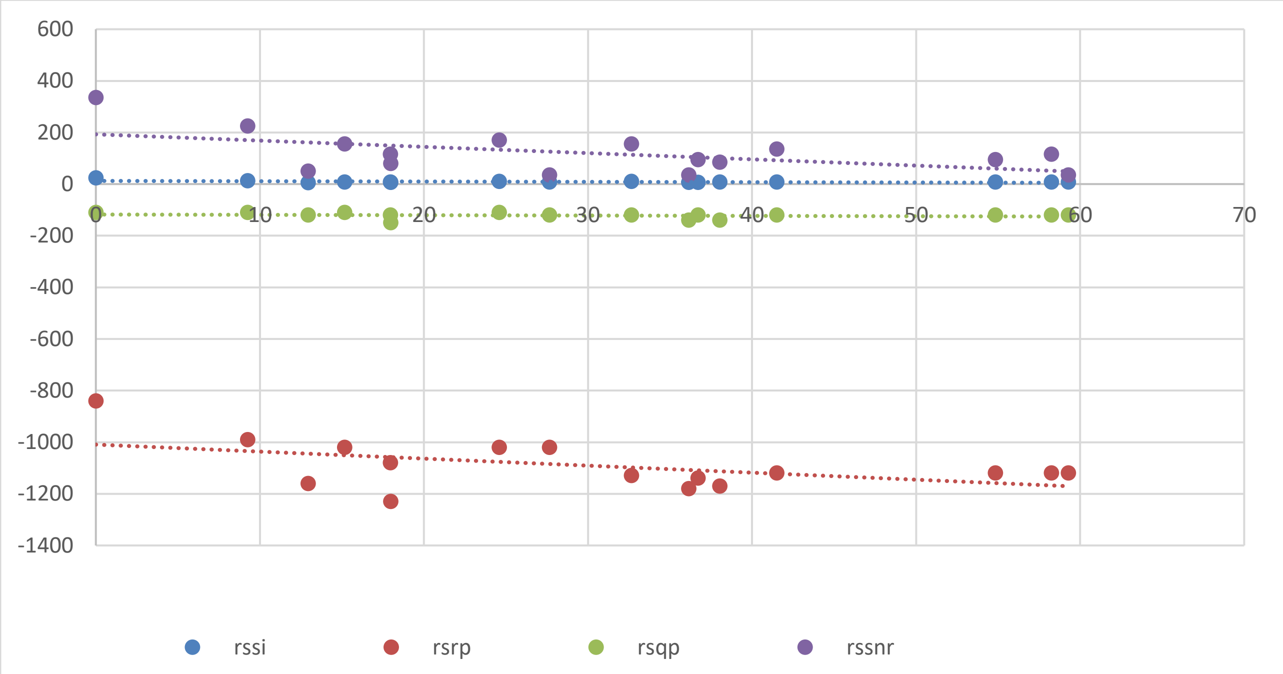


Figure 4-40 Signal quality measurements [dBm*10 or dB*10] with respect to the distance from point_0 [m]

At the same time, the diagram of Figure 4-40 depicts the relation between key signal quality indicators and distance from point_0. It is observed that there is a degradation in signal quality when the distance from point_0 is increased, but it does not drop significantly until the 60m distance at the facilities' fence.

4.3.1.7 End-to-End transport network with cloud interconnection

As described in deliverable D2.3 [4], equipment installation at the ADMIE facility was performed during a power cut of the facility (Figure 4-41). Four months since the initial installation of ICOM's telecommunication equipment at ADMIE's premises at Rio, during a thunderstorm, a lightning stroke ADMIE's high-voltage power distribution network, in the proximity of the Rio premises. It wasn't a direct hit on the power tower where the backhauling equipment is installed, yet the electrical discharge was powerful, and was conveyed from the near-by pylons through the grounding system to all electrical networks at the area.

Although ICOM had provisioned for protecting both indoor and outdoor equipment according to practices and regulations that apply on telecommunication towers, the installation of telecom equipment on a high-voltage electricity tower proved to be a tough challenge. Need to note that this type of deployment haven't been tried before in the past, by ICOM and involved subcontractors.

Detailed investigation revealed that the strike had blown out major over-voltage protection circuitry of the equipment, render them functionless. In order to secure the equipment the best way possible, should a future event happens again, ICOM contacted experts in the field of lightning protection, from both the academia and industry sectors. The outcome was a thorough analysis of the causes, as well a detailed design and build of specialized charge-protection equipment, tailored for the Rio power-tower case. In particular, ICOM communicated and collaborated with a renowned surge protector vendor in order to design a custom and future-proof solution.

Figure 4-41 Pictures from the backhaul equipment installed at UoP premises and ADMIE poles for the transport network interconnecting ADMIE facility (the red dotted line indicates LoS)

At the time of deliverable D4.2 final editing, the new state-of-the-art lightning protection was been delivered, and is ready for installation at the ADMIE power plant, yet it will be deployed at the next available power-cut.

4.3.2 High-Level 5G Deployment Scenario Description

For the integration of testing and initial field trial tests two 5G deployment options have been used. The description of the exact configuration is listed in Table 4-9.

Table 4-9 High-Level 5G Deployment Scenario UC #2

Scenario Description Template – Lab		
Radio access technology (RAT)	5G VINNI _3 (AW2S)	5G VINNI_4 (Callbox Classic)
Standalone / Non-Standalone (if applicable)	SA	SA
Cell Power	33 dBm	20 dBm
Frequency band:	n78	n78
Maximum bandwidth per component carrier	100 MHz	50 MHz
Sub-carrier spacing	30 KHz	30 KHz
Number of component carriers	n/a	n/a
Cyclic Prefix	n/a	n/a
Massive MIMO	n/a	n/a
Multiple-Input Multiple-Output (MIMO) schemes (codeword and number of layers)	4x4 MIMO	2x2 MIMO
Modulation schemes	Downlink: 256 QAM Uplink : 256 QAM	Downlink: 256QAM Uplink: 256QAM
Duplex mode	TDD	TDD
TDD uplink/downlink pattern	7 Down / 2 Up timeslots	7 Down / 2 Up timeslots
Contention based random access procedure/contention free	n/a	n/a
User location and speed	n/a	n/a
Background traffic	n/a	n/a
Computational resources available	n/a	n/a

4.3.3 Experiment execution and Reports (with reference to WP3 methodology)

In the tables below initial experiments are reported for **UC #2** trials

Table 4-10: Experiment report for EDHv01

Field	Description
Test Case ID	**EDHv01** (field test)
Facility, Site	5G-VINNI, ADMIE site
Description	This test case demonstrated the connectivity of both physical and virtual sensors with the application via a private 5G network deployed at ADMIE premises. (Without testing the backhaul network.)
Executed by	Partner: ADMIE, UoP, ICOM — Date: 2022-07-28
Purpose	To validate the correct configuration of physical sensors and their connection to the private network. To measure the e2e latency between the app and the physical sensors.
Scenario	-
Slice Configuration	No slice configuration was performed
Components involved	Physical sensors with Modbus TCP interface sensors' data simulator (virtual Modbus TCP sensors) 5G CPE Raspberry Pi4 with 5G shield Amarisoft callbox (SA deployment with standard configuration) Edge server (Autonomous Edge) VM running the application
KPIs collected (Metrics collected)	E2E Latency, network latency, network jitter
Tools involved	custom code implementing Modbus TCP protocol, ping, iperf
Results and KPIs Primary Complementary	**e2e latency – 1000 measurement requests:** for physical sensors: min 13 ms / mean 38 ms / max 86 ms for simulated sensors: min 13.5 ms / mean 38.3 ms / max 86.1 ms **Network latency – 1000 ping requests:** min 11.2 ms / mean 21 ms / max 31.5 ms **Network jitter:** mean 0.27 ms / max 0.37 ms
Target metric/KPI and verification (pass/fail)	e2e latency passed for physical and simulated sensors. Latency difference must be evaluated when the sensors from the second site and the backhauling will be ready. Availability, Reliability not tested.

Table 4-11: Experiment report for EDHv03

Field	Description
Test Case ID	**EDSv03** (field test)
Facility, Site	5G-VINNI, ADMIE site
Description	This test case demonstrated the correct e2e functionality of the application, when hosted at the edge infrastructure and its communication through the private 5G network.
Executed by	Partner: ADMIE, UoP, ICOM — Date: 2022-10-23
Purpose	To validate the correct e2e functionality of the app and the ability to provide QoS guarantees (e.g., in bandwidth)
Scenario	-
Slice Configuration	2 slices with QoS. 1. for UiTOP with guaranteed min. 5mbps throughput

Components involved	2. for other services (simulated traffic through iperf tool) Physical sensors with Modbus TCP interface sensors' data simulator (virtual Modbus TCP sensors) 5G CPE Raspberry Pi4 with 5G shield Amarisoft callbox (SA deployment with 2 slices configuration) Edge server (Autonomous Edge) VM running the application Laptop simulating the background traffic through iperf tool
KPIs collected (Metrics collected)	Deployment time, QoS for guaranteed bandwidth
Tools involved	iperf
Results and KPIs Primary Complementary	**Vertical application (UiTOP) deployment time:** Average VNF deployment time: 11.5 min **Guaranteed min bandwidth for the slice:** Configured at 5Mbps – passed (more info in the relevant chapter)
Target metric/KPI and verification (pass/fail)	VNF deployment time is adequate for the nature of the application. Guaranteed min. bandwidth regardless of background traffic - Passed

4.3.4 KPI evaluation and Conclusions – Lessons learned

The trials performed at **ADMIE** premises in Patras for **UC #2** were successful as the primary objective was to integrate the different components (legacy sensors, 5G NPN, vertical applications, etc.) in a real HV industrial environment. There were tests focused on the integration of legacy equipment to the solution, and tests to assess the connectivity of equipment at different locations inside the facilities. The e2e architecture could not be validated due to the damage of the backhauling connection.

What we learned from the first trials is that network deployment in an industrial environment (and particularly in one that involves HV) requires detailed investigation, organization and effort. This was highlighted due to the effort that was needed to integrate the legacy equipment into the solution, but also due to the damage of the mmWave antennas, even though all typical precautions were made. Nevertheless, the initial results were promising, and the showed that a 5G NPN can be used to simultaneously support different applications in an industrial environment.

There is one major trial phase in the roadmap of this use case. As already mentioned, the capability to place applications and NFs on the cloud or at the edge according to their specific needs, has been already tested in a lab environment. The e2e transport network with cloud interconnection phase (see 4.3.1.7) is going to test the interconnection of all components, demonstrate the actual placement of functions on the UoP cloud or at ADMIE premises, and present the results of the different deployment options.

4.4 UC #3 Content Delivery Network services

As the Media services are becoming increasingly available in transportation environments, a variety of media-related services can be offered and used to facilitate passengers' needs in various directions, especially infotainment and safety/security. The 5G-VICTORI Media UC in Patras (**UC #3**) targets both of these directions and proposes the use of 5G technologies in railway environments as the enabler to deliver uninterrupted high-quality CDN-aided infotainment services to railway passengers as well as surveillance and safety services at the railway premises, sufficiently supporting their high data rates and low latency requirements. Infotainment services require high data rates in order to achieve fast multimedia caching on-board for sufficient content volume available to cover the duration of the trip, whereas surveillance and safety services require high data rates for high quality video streaming and low latency for smooth interchange of field-of-views. The services will be deployed utilizing infrastructures located both at the train station and at Patras5G cloud facility.

The CDN-aided infotainment services will be demonstrated during the train's stop at the TRAINOSE Depot station in Patras city center, which will be 5G- and MEC-enabled, communicating at the same time with the central CDN facilities at UoP cloud premises. The central CDN facilities (at UoP cloud premises) are connected to a niche content origin extending the commercial COSMOTE TV platform (deployed at central COSM premises), feeding the CDN platform with live TV content apart from COSMOTE TV VoD content stored at CDN repositories. The surveillance services will be showcased at the railway control room which will be co-located with the Patras5G cloud facility, receiving surveillance footage from equipment placed at the depot station.

4.4.1 UC testing objective and deployment

For the deployment and evaluation of the different services of the above use case, the first testing phases took place in a lab setup. The next phases are planned to take place at the facility (on-site), possibly with local deployment without use of the backhaul network at first, and finally with full exploitation of Patras facility, creating the final target field setup. Two groups of test cases were identified to cover the whole range of proposed services. The first group concerns the CDN scenario and includes test cases regarding the application deployment, the network connectivity evaluation, the caches synchronization, the data shower and the streaming experience of the end users. The second group targets at evaluating the surveillance application deployment and network connectivity, the 360° camera high quality streaming and the field-of-view rotation.

Currently the components for both scenarios have been deployed in the lab, and specifically in UoP's Cloud facility, where they were locally interconnected through UoP's local gNB. All the test cases were executed in the lab in two phases, and this report includes the results from the second phase of lab testing. Since ICOM's CDN solution is fully 5G-ready and deployed in Network Function Virtualization (NFV)-compatible format and UoP's Cloud facility offers the capability for remote testing by using a remote CDN client instance connected to the cloud through 5G access instead of deploying a local physical machine on premises, a set of remote tests was executed before the second phase of lab testing for preliminary evaluation of the scenario. A subset of the defined test cases was evaluated during the remote tests, and their results were verified during the lab tests where the full set of the defined test cases was executed. Also, at this second phase of lab testing, COSMOTE TV streaming content provided by the remote niche (CDN) Content Origin platform deployed at COSMOTE premises in Athens was integrated with the CDN platform and was used both in remote and lab testing. The COSMOTE Content Origin platform comprises an Origin, an OTT Encoder and Headend equipment with interfaces that provide access to a number of COSMOTE TV linear channels for the CDN platform.

The defined test cases will be again executed during the field trials, where for the CDN scenario the central CDN server will remain at the same location at UoP's Cloud. The same applies to the 360° camera client, which will facilitate the security staff in the surveillance scenario. The progress that has been made in **UC #1.1**'s infrastructure deployments will be exploited for Media UC too, as in the planned field trials the gNB will be co-located with the mmWave stanchion at point D1 of the facility.

4.4.2 UC #3 Slice description (with application components) and Network diagram

The diagram of Figure 4-42 includes all the elements (hardware/software) required for supporting both applications of the Media UC at Patras facility. The onboard train network will allow interconnection of the local CDN application components to the relevant components at the train station level through 5G-NR, eventually allowing the supply of passenger UEs with streaming content provided by the train station level. Both the train station level and the Cloud level will host components for both applications (Train Station CDN cache, 360° camera and camera server at former, central CDN server and camera client at the latter) and will be interconnected between them through the backhaul mmWave link. Finally, the cloud level (UoP Premises) will be interconnected to the remote COSMOTE premises through the public Internet. In general, the diagram shows the overall set of network and application components that are necessary for the update of the train with the latest COSM content and its distribution to passengers UEs, as well as for the interconnection of the 360° camera and its streams with a remote security operator through 5G.

The topology showing the interconnections between the various sites of the facility that are involved in both applications of the Media UC is depicted in Figure 4-42. The onboard network at the train level is interconnected through 5G-NR with the gNodeB at the train station level (once connectivity becomes available), which is in turn interconnected with UoP Cloud through the mmWave backhaul network.

For the remote tests of the CDN scenario, the central CDN server, the train station cache as well as the train cache were deployed as VNFs in UoP's cloud environment, which for the central CDN server also form its final deployment for the field trials. The train cache was connected to the train station cache through the local 5G network of UoP lab and the experiments were mainly focused on the full exploitation of the available 5G data rate by the data shower mechanism.

After the preliminary remote tests, the lab testing took place at UoP's Cloud facility lab, with all the data shower-related components being deployed locally. Since the mmWave backhauling link is not yet available to use at the time of this report, the whole 5G connectivity was supported within the UoP lab. The central CDN server and the train station cache as well as the train cache were deployed as VNFs in UoP's OpenStack environment. The train cache was deployed on a laptop brought by ICOM, which had an Ethernet connection to UoP's 5G-CPE and was able to connect to the train station cache through UoP's local gNodeB. The same laptop also emulated the end user/passenger UE. The CDN components were connected to the remote niche (CDN) Content Origin platform deployed at COSMOTE premises in Athens, which provided the central CDN server with access to a number of linear channels of COSMOTE TV streaming content. The network conditions and metrics were being monitored by a monitoring software provided by UoP and the results were displayed on a local screen. The described setup for the lab testing of the CDN scenario along with the different facilities of the deployment is illustrated in Figure 4-43.

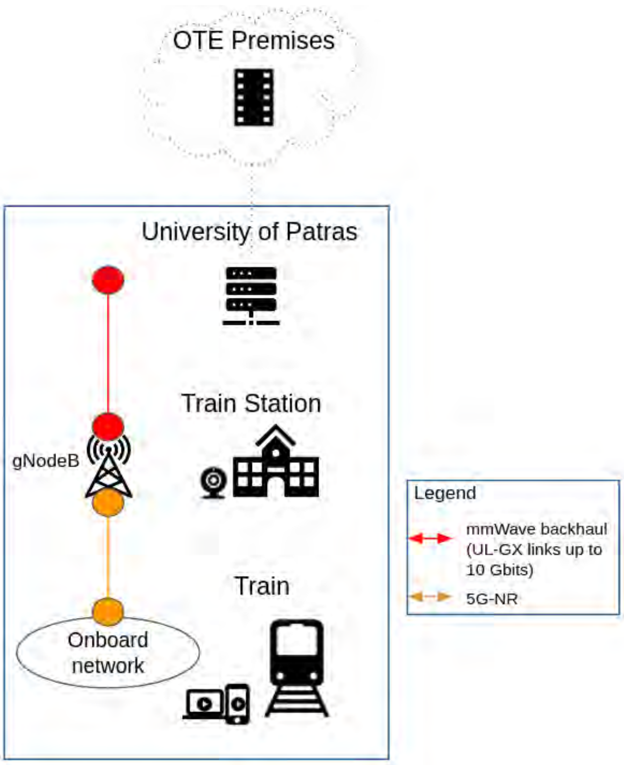


Figure 4-42 End-to-end network diagram for UC #3 in Patras

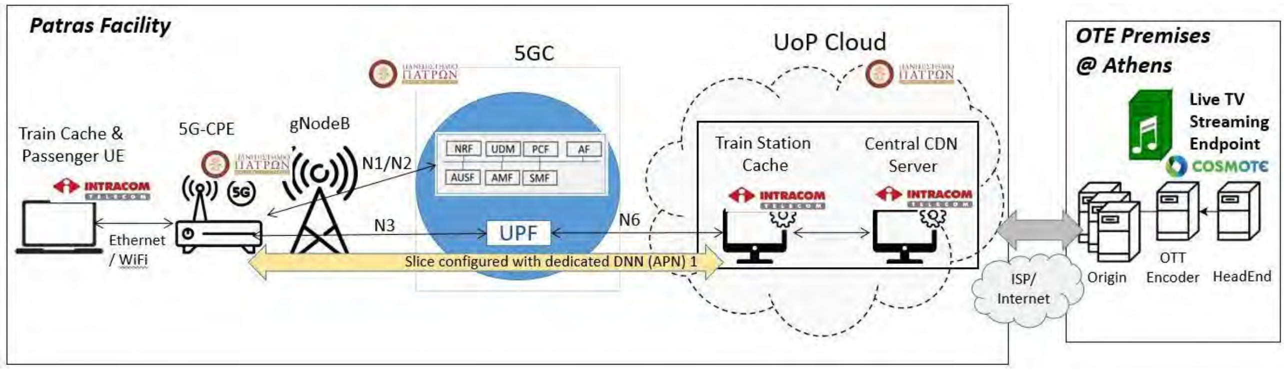


Figure 4-43 The setup for the lab testing of the CDN scenario

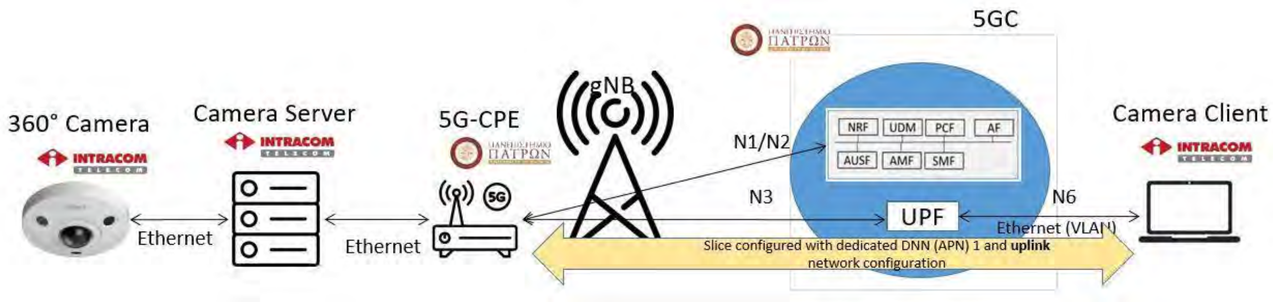


Figure 4-44 The setup for the lab testing of the surveillance scenario

For the remote surveillance scenario, the lab testing took place without previous remote testing. The experiments were again hosted at UoP's Cloud facility lab, with all the components being deployed locally. The 360° camera IPC-EBW81230 provided by ICOM was set to monitor the lab's interior and was connected through Ethernet to ICOM's camera server, responsible for the streams processing and transmission. A 5G connection was established between the camera server and the receiving end (camera client laptop) through UoP's 5G-CPE and local gNodeB. The camera server was connected through Ethernet to the 5G-CPE and the camera client was also connected through Ethernet to a VLAN directly forwarding the traffic to the gNodeB. The network conditions were again constantly being monitored by the monitoring software provided by UoP as described in the data shower scenario. The lab tests focused on repeating the measurements of the previous lab testing phase using the same setup to improve the results, so both the high quality stream and the low quality stream as well as the control plane of the surveillance application was served by one high-bandwidth slice with uplink network configuration to facilitate the high data rate requirement. The target is to dedicate a low-latency slice to the low quality stream and the control plane during the next evaluation phases. The described setup for the lab testing of the surveillance scenario is illustrated in Figure 4-44.

The results of the second lab testing cycle conducted at UoP premises met the defined target KPIs and set the basis for the migration towards the field and the relevant field trials.

The **CDN (data shower) application** was evaluated in detail through the execution of the five defined test cases and the measurement of the relevant KPIs. For test case ***MCDv01: CDN Application Scenario Deployment***, the CDN components were deployed through the orchestration layer of OSM at UoP cloud and the average time required for the VNFs deployment was measured. After the deployment of the CDN components, initial connectivity between all of them was verified and evaluated for test case ***MCDv02: CDN Connectivity Evaluation***. The link between the train cache and the train station cache was measured, as well as the data rate between the Central CDN server and the train station cache (despite deployed as VNFs at the same facility i.e. UoP's OpenStack environment in the context of lab testing). The data rate of the actual link will be measured when the train station cache will be deployed at the train station, during the field trials. Moving on the synchronization of the train station cache with the latest COSMOTE TV content from the central CDN server (***MCDv03: MEC (Train Station Cache) Periodic Update***), was measured. The next step was to evaluate the data shower mechanism from the train station cache to the train cache in the context of test case ***MCDv04: Data Shower from MEC to train cache***. The CDN (data shower) scenario experimentation ended with the measurements for the test case ***MCDv05: Content Distribution to passengers onboard***.

For the **surveillance scenario** two test cases were run and evaluated. Since at the time of the tests it was not possible to have a low latency slice, only one high-bandwidth slice was deployed and served the experimentation process. The slice was deployed with uplink network configuration in order to facilitate the uplink nature of the data streams in this scenario. For test case ***MCSv01: 360° Camera Scenario Initialization***, the relevant components (360° camera, camera server, camera client) were deployed and the initial connectivity between all of them was verified. Then, the connectivity across all of them was evaluated, especially in terms of data rate and latency of the communication links. For the test case ***MCSv02: 360° camera HQ streaming***, the camera was set to transmit the field-of-view to the camera client. The test case ***MCSv03: 360° camera FoV rotation*** is targeted to be measured in later experiments when a low latency slice will also be available.

At the time of the delivery of this report, all lab testing for each application of the Media use case has been finalised and the integration of the various components on the facility towards the field trials has started. Specifically, for the CDN scenario, the central CDN server is already deployed as VNF at **UoP** cloud facility (Figure 4-45) in order to feed the train station cache with the latest content. The connection with the remote niche (CDN) Content Origin platform at **COSM** premises in Athens (Figure 4-46) has also been finalized and verified to be fully functional, and the server is ready to be connected to the train station cache once the backhaul link from the UoP facility to the train station becomes available.

Regarding the train station setup, the progress that has been made during **UC #1.1**'s first field experimentations at the premises of the TRAINOSE depot in Patras also consists part of the Media Use Case field deployments. A first site survey for the Media UC has been performed at Patras facility at the same time with **UC #1.1**'s field trials, in order to determine the placement and deployment of the application components. Four stanchions together with their power supplies have been deployed along the tracks of TRAINOSE premises, all interconnected to a central switch at the depot via Ethernet or fibre. The gNodeB for both applications of the Media UC will be placed at point D1 at the TRAINOSE depot (Figure 4-47) co-located with the mmWave stanchion.

Figure 4-45 UoP's cloud facility hosting Central CDN Server

Figure 4-46 COSMOTE remote niche Content Origin platform installations

Figure 4-47 The deployment of the stanchion at D1 point at TRAINOSE depot which will host the gNodeB

Figure 4-48 The gNodeB that was used in the lab tests and will be used in the field trials connected to the stanchion

Figure 4-49 The dedicated sub-urban train for the field trials

Figure 4-50 The train interior and the target placement of the CDN-related components

A dedicated sub-urban train on the track within the depot area will be used in the field trials, depicted in Figure 4-49. The train interior, which is depicted in Figure 4-50, was thoroughly inspected to determine the exact deployment of the CDN-related components. The 5G-CPE will be deployed along with the Train Cache at the front side of the train, right behind the driver's room at the first row of passenger seats (Figure 4-50).

As per the surveillance scenario, the 360° camera will be placed at a central point of the TRAINOSE depot, in order to capture the maximum possible field-of-view. The exact location has not yet been decided, but several possible alternatives are being examined, e.g.:

- At the small chamber right beside the tracks (Figure 4-51).
- Outside the railway staff room (Figure 4-52).

Figure 4-51 The chamber

Figure 4-52 The railway staff room

4.4.3 Test Cases and KPIs

The test cases and the relevant KPIs that are tested are summarised in the tables below.

Table 4-12 Test cases for UC #3

Test case group MCD		
Test case name	***Key Use-case requirements and KPIs***	***Network performance requirements and KPIs***
MCDv01	The total duration shall be as minimum as 90 minutes.	**U-PE-6217:** Low deployment time of CDN's VNFs and for the complete graph of CDN application.
MCDv02	**U-PE-6210:** Very high data rates for proactive transfer of large volumes of high quality (e.g. 4K) VoD or TV streaming content from central CDN servers to local MEC host **U-PE-6211:** Very high data rates for proactive transfer of prefetched high quality VoD or TV streaming content from MEC host to on-train Edge server	Data rate between MEC Main Cache & Central CDN server: ~ 100 Mbps Data rate between MEC Main Cache & Edge Cache: 150-500 Mbps depending on live channels parameters / VoD content amount
MCDv03	**U-PE-6210:** Very high data rates for proactive transfer of large volumes of high quality (e.g. 4K) VoD or TV streaming content from central CDN servers to the local MEC host.	**Network KPIs:** Data rate between MEC Main Cache & Central CDN server: ~ 100 Mbps High Connectivity to external hosts.
MCDv04	**U-PE-6211:** Very high data rates for proactive transfer of prefetched high quality VoD or TV streaming content from MEC host to on-train Edge server.	Data rate between MEC Main Cache & Edge Cache: 150-500Mbps, depending on live channel parameters and/or amount of VoD content. Amount of content transferred: 10 - 15GB VoD content / content from 3 live channels
MCDv05	**U-PE-6212:** Uninterrupted streaming of high-quality videos or TV content to train passengers	**Network KPIs** Wi-Fi data rate per passenger: ~15Mbps

Test case group MCS		
Test case name	*Key Use-case requirements and KPIs*	*Network performance requirements and KPIs*
MCSv01	**U-PE-6213 & U-PE-6214:** Very high data rates for high resolution video transmission from 360° camera to the receiving control center **U-PE-6215 & U-PE-6216:** Very low latency for lower resolution video streams transmission from 360° camera to the receiving control centre.	**Network KPIs:** Low deployment time of scenario components. Deployment time should be as low as 90 min. Data rate between Camera server and Camera receiver: 50-100 Mbps Latency between Camera server and Camera receiver: up to 20 ms
MCSv02	**U-PE-6213 & U-PE-6214:** Very high data rates for high resolution video transmission from 360° camera to the receiving control center	Data rate between Camera server and Camera receiver: ~ 50-100 Mbps
MCSv03	**U-PE-6215 & U-PE-6216:** Very low latency for lower resolution video streams transmission from 360° camera to the receiving control center **U-FU-6318:** Video continuity when switching to a new FoV during head motion, for smooth and seamless transition from high to lower resolution video and vice versa.	Latency between Camera server and Camera receiver: up to 20 ms

4.4.4 High Level 5G Deployment Scenario Description

Scenario Description Template THE SAME AS ABOVE	
Radio access technology (RAT)	5G VINNI 2 (AW2S)
Standalone / Non-Standalone (if applicable)	SA
Cell Power	33dBm
Frequency band:	n78
Maximum bandwidth per component carrier	100MHz
Sub-carrier spacing	30KHz
Multiple-Input Multiple-Output (MIMO) schemes (codeword and number of layers)	4x4 MIMO
Modulation schemes	Downlink: 256 QAM Uplink: 256 QAM
Duplex mode	TDD

4.4.5 Experiment Description

Table 4-13 gives an overview of the experimentation during the second phase of lab testing, describing the characteristics of the experiment for both applications that were tested.

Table 4-13 Characteristics of the experiment for both applications

Type		Description
ExperimentType	Lab experiment	The experimentation for this testing cycle was performed in the lab environment.

Automated	Hybrid	The experimentation followed a hybrid approach, with automated application deployment and some manual testing configurations.
TestCases	**MCDv01 - MCDv05, MCSv01 - MCSv02**	The total of the defined test cases were executed for the CDN scenario, whereas for the surveillance scenario the two out of the three defined test cases were executed, due to unavailability of two concurrent network slices at the moment.
UEs	5G-CPE	For both applications, the 5G-CPE served as the 5G UE connected to the gNodeB.
Network Slice	eMBB for both apps	For the CDN scenario, an eMBB network slice was configured, including the Train Station Cache VNF and providing high data rates to the application. For the surveillance scenario, due to absence of uRLLC slices at the moment, only one eMBB slice with uplink network configuration was used at this time which served both of the camera streams.
Network Services	N/A	
Network Scenario		
Exclusive Execution	Exclusive during this testing cycle	Each application was tested separately during this testing cycle, but they can also be run simultaneously.
Reservation Time	Approx. 2-3 hours	The total of the test cases per application was executed in approximately 1-2 hours, resulting in an approximate duration of 2-3 hours for the whole experiment.
Application	1. CDN-aided Data shower application 2. Surveillance application	Two applications are supported by the Media UC, the CDN-aided data shower and the surveillance application, which were both tested during the lab tests.
Performance targets & SLAs	• Low application deployment time • High data rates • Low latency • Large volumes of transferred content	The low application deployment time, < 90 min, is a key target KPI which was measured from the difference between the timestamps of the application deployment request and the application deployment completion (++achieved). High data rates were set as target KPIs for both applications and were achieved, as an average of around 95Mbps was measured using iperf tool and/or computing the volume of transferred data in a specific amount of time. The low latency target was set for the surveillance scenario but since a low-latency slice was not yet available, it was measured around 35ms on average on a high-bandwidth slice.
Experiment Parameters		
Edges	1	*In the lab*
Remote	No	
Remote Descriptor	N/A	-
Version	2	This is the second lab testing cycle, after the one reported in D3.4.
Extra	-	-

4.4.6 Experiment execution and Reports (with reference to WP3 methodology)

The tables below describe in detail each test case of the experiment for the two applications that were tested, the results that occurred from the measurements procedure and the evaluation of each test case outcome.

Table 4-14 Results from the CDN application deployment time

Field	CDN Application Scenario Deployment
Test Case ID	**MCDv01**

Facility, Site	5G-VINNI facility in Patras, at UoP Patras5G lab environment	
Description	The test case assesses the deployment of the network slice that will serve the CDN application and the initial connectivity between all the deployed components. The speed of deployment will be measured.	
Executed by	Partner: **ICOM**	Date: 2022-10-20
Purpose	Verification of low deployment time of the CDN components and connectivity between them.	
Scenario	CDN Application Scenario Deployment, the CDN components were deployed through the orchestration layer of OSM at UoP cloud and the average time required for the VNFs deployment was measured. The scenario followed was the one described in section 4.4.4.	
Slice Configuration	eMBB slice configured as mentioned in section earlier. The eMBB slice was defined by sd and sst, set to 1 (acc. Rel. 16 specifications).	
Components involved	UoP Cloud servers Central CDN server VM at UoP Cloud Train Station cache VNF at UoP Cloud Train (Edge) server SW on laptop Local 5G-CPE, gNodeB and 5G-Core 5G-VINNI Orchestration platform	
KPIs collected (Metrics collected)	Deployment time of CDN's VNFs and for the complete graph of CDN application: should be less than 90 minutes.	
Tools involved	OSM and cloud VIM Management Interfaces.	
Results and KPIs **Primary** **Complementary**	CDN Deployment time: 5 min 36 sec on average	
Target metric/KPI and verification (pass/fail)	Target: <90 min. **Pass**	

Table 4-15 Results of the Connectivity Evaluation

Field	CDN Connectivity Evaluation	
Test Case ID	**MCDv02**	
Facility, Site	5G-VINNI facility in Patras, at UoP Patras5G lab environment	
Description	The e2e connectivity across all CDN components (including VNF) is verified and evaluated with regards to data rate achieved between the various CDN interfaces for the support of the data shower mechanism. In particular, the link between the train cache and the train station cache supporting the data shower functionality was measured through iperf test sessions with 20 simultaneous connections. The data rate between the Central CDN server and the train station cache, was measured through iperf sessions between the VNFs (deployed at the same facility i.e. UoP's OpenStack environment). The data rate of the actual link will be measured when the train station cache will be deployed at the train station, during the field trials.	
Executed by	Partner: ICOM	Date: 2022-10-20
Purpose	Evaluation of the data rate offered by the network between the CDN components.	
Scenario	The scenario followed was the one described in section 4.4.4.	
Slice Configuration	eMBB slice configured as mentioned earlier. The eMBB slice was defined by sd and sst set to 1 (acc. Rel. 16 specifications).	
Components involved	UoP Cloud servers Central CDN server VM at UoP Cloud Train Station cache VNF at UoP Cloud Train (Edge) server SW on laptop Local 5G-CPE, gNodeB and 5G-Core	

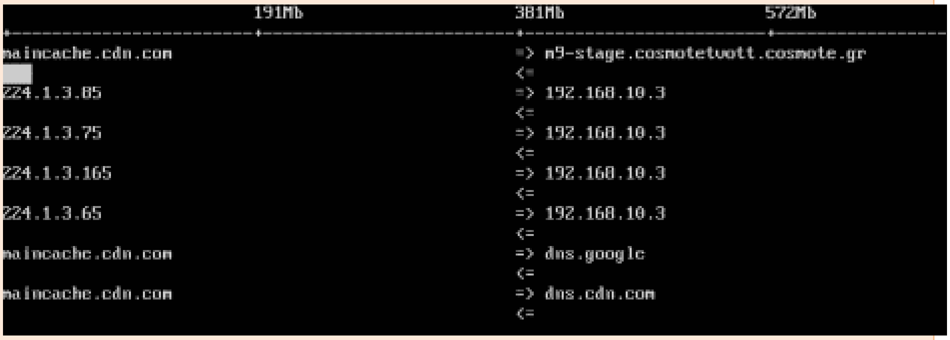
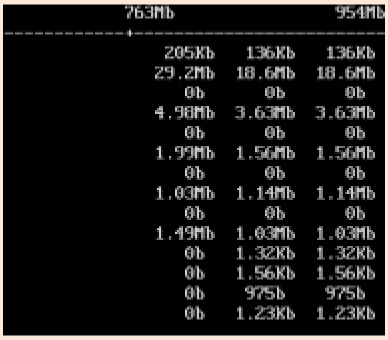
KPIs collected (Metrics collected)	Data rate between MEC (Train Station) Cache and Central CDN server and Data rate between MEC (Train Station) Cache and Train Cache
Tools involved	iperf
Results and KPIs Primary Complementary	Data rate between MEC (Train Station) Cache and Central CDN server: very high (in the order of Gbps), as both components were deployed on the same machine. Will be measured again when the components are separately deployed. The synchronisation capability was verified through the Train station Cache interface (see Figure 4-53).   **Figure 4-53 The Train Station Cache update with COSM TV content from the Central CDN Server** Data rate between MEC (Train Station) Cache and Train Cache: 93.45 Mbps on average
Target metric/KPI and verification (pass/fail)	<u>**Pass**</u>, as data rates offered by the network are in the range of 5G data rates

Table 4-16 Results on the MEC update rate

Field	MEC (Train Station Cache) Periodic Update)	
Test Case ID	**MCDv03**	
Facility, Site	5G-VINNI facility in Patras, at UoP Patras5G Cloud environment. Remote connectivity to COSMOTE premises in Athens.	
Description	This tests focused on ensuring that the Train Station Cache is being updated with the latest COSM TV content that constantly becomes available; in other words on verifying the synchronization of the train station cache with the latest COSMOTE TV content from the central CDN server.	
Executed by	Partner: **ICOM**	Date: 2022-10-20
Purpose	Verification of the latest content availability on the Train Station Cache and measurement of the update data rate.	
Scenario	The scenario followed was the one described in section 4.4.4.	
Slice Configuration	eMBB slice configured as mentioned earlier. The eMBB slice was defined by sd and sst, set to 1 (acc. Rel. 16 specifications).	
Components involved	UoP Cloud servers Central CDN server VM at UoP Cloud Train Station cache VNF at UoP Cloud	

	Train (Edge) server SW on laptop COSM TV content Origin at OTE premises
KPIs collected (Metrics collected)	Train Station Cache update data rate
Tools involved	iftop
Results and KPIs Primary Complementary	Train Station Cache update data rate: 16 - 39 Mbps
Target metric/KPI and verification (pass/fail)	**Pass**, as measured data rate is enough to keep the train station cache filled with latest content

Table 4-17 Results on the data rate between MEC and cache

Field	Data Shower from MEC to train cache	
Test Case ID	**MCDv04**	
Facility, Site	5G-VINNI facility in Patras, at UoP Patras5G Cloud environment	
Description	The data shower functionality is examined and evaluated in order to verify that large amounts of COSMOTE TV content are transferred to the onboard server in a very short time through 5G connectivity.	
Executed by	Partner: ICOM	Date: 2022-10-20
Purpose	Evaluation of the data shower data rate and the volume of content transferred onboard.	
Scenario	The scenario followed was the one described in section 4.4.4.	
Slice Configuration	eMBB slice configured as mentioned earlier. The eMBB slice was defined by sd and sst set to 1 (acc. Rel. 16 specifications).	
Components involved	Central CDN server VM at UoP Cloud Train Station cache VNF at UoP Cloud Train (Edge) server SW on laptop Local 5G-CPE, gNodeB and 5G-Core COSM TV content at Train Station Cache	
KPIs collected (Metrics collected)	Data rate between MEC (Train Station) Cache & Train Cache Amount of content transferred onboard	
Tools involved	Verification through preview of COSMOTE TV content.	
Results and KPIs Primary Complementary	Data rate between MEC (Train Station) Cache & Train Cache: 75.273 Mpbs on average Amount of content transferred onboard: ≈2.25 GB in 4 minutes	
Target metric/KPI and verification (pass/fail)	**Pass**, as the data shower exploits the total of the available 5G data rates provided by the network and the content transferred onboard is the maximum possible with the provided data rates	

Table 4-18 Results on the CDN distribution

Field	Content Distribution to passengers onboard	
Test Case ID	**MCDv05**	
Facility, Site	5G-VINNI facility in Patras, at UoP Patras5G Cloud environment	
Description	This test case examines the smooth distribution of the COSMOTE TV content to train passengers through ICOM's CDN application running on laptops/smartphones and the uninterrupted streaming experience. The examined parameters are the available Wi-Fi capacity to support the passengers onboard and the amount of content stored onboard so that the passengers can stream without interruptions until the next train stop.	
Executed by	Partner: ICOM	Date: 2022-10-20
Purpose	Evaluation of the Wi-Fi data rate for passengers and the maximum possible streaming time according to the volume of content loaded onboard.	

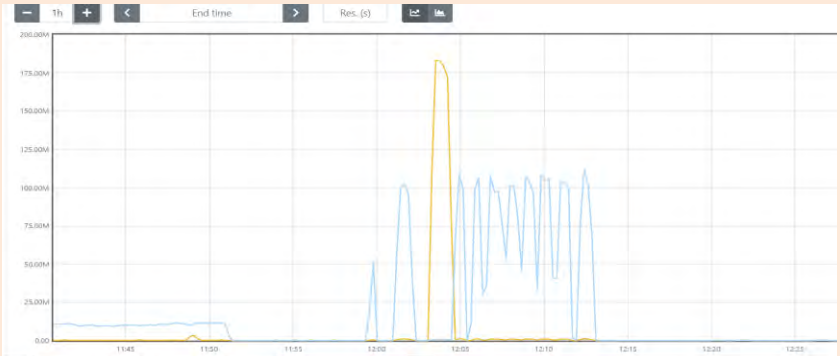
Scenario	The scenario followed was the one described in section 4.4.4.
Slice Configuration	eMBB slice configured as mentioned earlier. The eMBB slice was defined by sd and sst set to 1 (acc. Rel. 16 specifications).
Components involved	Train (Edge) server SW on laptop COSM TV content at Train Cache (onboard) Passenger UE (laptop) ICOM CDN application on passenger UE
KPIs collected (Metrics collected)	Wi-Fi data rate for passenger Maximum possible streaming time with content transferred onboard
Tools involved	iperf
Results and KPIs Primary Complementary	Wi-Fi data rate for passenger: 88.36 Mbps Maximum possible streaming time with content transferred onboard: 37.6 minutes
Target metric/KPI and verification (pass/fail)	Target Wi-Fi data rate for passenger: 10-15 Mbps. Target maximum possible streaming time with content transferred onboard: duration of trip until next stop (less than half an hour). **Pass**

Table 4-19 Results on the 360º camera initialization

Field	**360° Camera Scenario Initialization**	
Test Case ID	**MCSv01**	
Facility, Site	5G-VINNI facility in Patras, at UoP Patras5G Cloud environment	
Description	The scenario is deployed and the e2e connectivity across all components (360° camera, camera server, camera client) is verified and evaluated with regards to the data rate and latency achieved between the various interfaces. For the evaluation of the link between the camera server and the camera client, additional iperf test sessions with 20 simultaneous connections were performed with an uplink network configuration.	
Executed by	Partner: ICOM	Date: 2022-10-20
Purpose	Connectivity verification and evaluation of network conditions.	
Scenario	The scenario followed was the one described in section 4.4.4.	
Slice Configuration	eMBB slice configured as mentioned earlier. The eMBB slice was defined by sd and sst, set to 1 (acc. Rel. 16 specifications). The slice was deployed with uplink network configuration in order to facilitate the uplink nature of the data streams in this scenario. A URLLC slice will be configured for next stage testing.	
Components involved	360° surveillance camera and camera server PC Camera client at UoP Cloud Streams processing and optimization SW on camera server Streams coordination and rendering SW on camera client Local 5G-CPE, gNodeB and 5G-Core	
KPIs collected (Metrics collected)	Data rate between Camera Server and Camera Client Latency between Camera Server and Camera Client	
Tools involved	iperf, ping	
Results and KPIs Primary Complementary	Data rate between Camera Server and Camera Client: 96.68 Mbps on average Latency between Camera Server and Camera Client: 36 ms on average, on a high-bandwidth slice since a low-latency is not available, so the metric is expected to meet the target KPI value once a low-latency slice becomes available	
Target metric/KPI and verification (pass/fail)	Target data rate between Camera Server and Camera Client: 50-100 Mbps, Target latency between Camera Server and Camera Client: up to 20 ms. **Pass**	

Table 4-20 Results on the 360º HQ streaming

Field	**360° camera HQ streaming**

Test Case ID	MCSv02	
Facility, Site	5G-VINNI facility in Patras, at UoP Patras5G Cloud environment	
Description	The functionality of the surveillance application and its components is verified, and the high quality streaming operation of the surveillance camera is monitored for at least 20 seconds during FoV stability and evaluated in terms of required data rate.	
Executed by	Partner: **ICOM**	Date: 2022-10-20
Purpose	High quality streaming monitoring during FoV stability and high quality streaming data rate requirement measurement	
Scenario	The scenario followed was the one described in section 4.4.4.	
Slice Configuration	eMBB slice configured as mentioned earlier. The eMBB slice was defined by sd and sst (Service Slice Type, Slice Differentiator), set to 1 (acc. Rel. 16 specifications). The slice was deployed with uplink network configuration in order to facilitate the uplink nature of the data streams in this scenario. A URLLC slice will be configured for next stage testing.	
Components involved	360° surveillance camera and camera server PC Camera client at UoP Cloud Streams processing and optimization SW on camera server Streams coordination and rendering SW on camera client Local 5G-CPE, gNodeB and 5G-Core	
KPIs collected (Metrics collected)	High quality streaming data rate	
Tools involved	Prometheus environment	
Results and KPIs **Primary** **Complementary**	High quality streaming data rate during FoV stability (with motion capturing): ≈12.012 Mbps The data rates offered by the network cover this data rate requirement and it can be computed that even 8 simultaneous cameras can be supported.  **Figure 4-54 The data rates between the camera server and the camera client (blue line), as shown in local Prometheus environment**  **Figure 4-55 The data rates required for camera high quality streams transmission with and without motion capturing, as shown in local Prometheus environment**	

Target metric/KPI and verification (pass/fail)	High quality streaming for at least 20s. Target data rate between camera server and camera client: 50-100 Mbps. Offered network data rate covers the high quality streaming data rate requirement for even multiple cameras. **Pass**

4.4.7 KPI evaluation and Conclusions – Lessons learned

The second phase of lab testing produced improved results in comparison to the first phase, for both applications examined. The **CDN (data shower) application** was evaluated in detail through the execution of the five defined test cases and the measurement of the relevant KPIs. For test case ***MCDv01: CDN Application Scenario Deployment***, the CDN components were deployed through the orchestration layer of OSM at UoP cloud and the average time required for the VNFs deployment was measured at *5:37 minutes*, covering the requirement for deployment times lower than 90 minutes. After the deployment of the CDN components, initial connectivity between all of them was verified and evaluated for test case ***MCDv02: CDN Connectivity Evaluation***. The link between the train cache and the train station cache offered an average data rate of *93.45 Mbps* for the data shower functionality, measured through an iperf test session with 20 simultaneous connections. As for the data rate between the Central CDN server and the train station cache, an iperf session showed that it was very high (in the order of Gbps) as they were deployed as VNFs at the same facility i.e. UoP's OpenStack environment. The data rate of the actual link will be measured when the train station cache will be deployed at the train station, during the field trials. Moving on to the synchronization of the train station cache with the latest COSMOTE TV content from the central CDN server (***MCDv03: MEC (Train Station Cache) Periodic Update***), it was measured that the train station cache continuously downloads the latest content from the Central CDN server with a data rate of 16 - 39 Mbps (Figure 4-53). Again, since the Central CDN server and the train station cache where deployed as VNFs at the same facility, an iperf session on the link between them showed that the data rate is high enough to cover the synchronization rate of the train station cache. The next step was to evaluate the data shower mechanism from the train station cache to the train cache in the context of test case ***MCDv04: Data Shower from MEC to train cache***. The average data rate with which the COSM TV content was downloaded in the train cache was measured to *75,273 Mbps*, thus exploiting the available data rate provided by the network as reported in MCDv02 above and downloading a respective average data volume of *2.25 GB* of content in a 4-minute window at the train cache. The CDN (data shower) scenario experimentation ended with the measurements for the test case ***MCDv05: Content Distribution to passengers onboard***. Iperf sessions were run between the train cache and an emulated passenger UE, both connected to the local 5G-CPE, and the average data rate for the passenger to watch the content of preference from the train cache was *88.36 Mbps*, which covers the requirement for 10-15 Mbps to stream high quality video. In overall, for the CDN scenario, the integration of ICOM's CDN with COSMOTE TV content was successful. The data shower mechanism utilized the total data rate offered by the network and achieved to store content onboard that is adequate for around 37 minutes of trip duration.

For the **surveillance scenario** two test cases were run and evaluated. Since at the time of the tests it was not possible to have a low latency slice, only one high-bandwidth slice was deployed and served the experimentation process. The slice was deployed with uplink network configuration in order to facilitate the uplink nature of the data streams in this scenario. For test case ***MCSv01: 360° Camera Scenario Initialization***, the relevant components (360° camera, camera server, camera client) were deployed and the initial connectivity between all of them was verified. Then, the connectivity across all of them was evaluated, especially in terms of data rate and latency of the communication links. For the link between the camera server and the camera client, iperf test sessions with 20 simultaneous connections were performed with an uplink network configuration, resulting in much better results than the previous lab testing cycle. The average uplink data rate measured was *96.68 Mbps* (blue line of Figure Figure 4-54), giving the ability to support traffic generated even from multiple surveillance cameras. The average latency on the same link was measured to be *36 ms*, occurring from different ping requests with 100 packets each. For the test case ***MCSv02: 360° camera HQ streaming***, the camera was set to transmit the field-of-view to the camera client. It was observed that the high-quality stream of the camera requires an average bandwidth of *12.012 Mbps* to be transmitted, while motion is being captured (Figure 4-55). The data rates offered by the network cover this data rate requirement and it can be computed that even 8 simultaneous cameras can be supported. The test case ***MCSv03: 360° camera FoV rotation*** is targeted to be measured in later experiments when a low latency slice will also be available.

In overall, for the surveillance scenario, the high quality stream was successfully watched by the remote client and it was observed that even multiple cameras may be supported, network-wise. The next step is to move towards the field trials and evaluate the same metrics on the field setup at UoP and TRAINOSE premises at Patras.

4.5 UC #4 Smart Energy Metering

For the deployment and evaluation of the simultaneous deployment of two stringent applications, the first testing phases took place in a lab setup and they were reported in deliverable **D3.5** [12]. There the applications were tested separately in independent private networks for the integration of the applications components (hardware and software) with the 5G functions. Then again as separate services were tested in real environments with NSA/4G private network deployments that were at the time available at the facilities of the verticals (power station and train rail track). Again test results were reported in deliverable **D3.6** [13] and initial reports test cases were presented therein.

In this deliverable the second testing phase was executed in the lab, where coexistence of the two service was performed. This is equivalent to testing the static deployment of the trial, as the final test at the facility (on-site), will be performed in Corinthos.

Two groups of test cases were identified to support both proposed services for the Energy UC. The first group concerns the power station related services while the second concerns the train station energy measurements.

Currently the components for both scenarios have been deployed in the lab, at **UoP**'s Cloud facility, where they were locally interconnected through UoP's local gNodeB. Both services (EMS and RMS) IASA were deployed in NFV-compatible format at UoP's Cloud facility. To that respect, compatibility with the 5G architecture was ensured and, furthermore, initial remote testing by using a remote access to premises was executed before the second phase of lab testing for preliminary evaluation of the scenario.

A subset of the defined test cases was evaluated during the remote tests, and their results were verified during the lab tests where the full set of the defined test cases was executed. Also at this second phase of lab testing, slicing of the private network purposely built at the UoP lab was utilized in order to ensure that both service will be executed simultaneously.

At the time of deliverable **D4.2** submission, after the integration of all hardware and software components, optimization of the slices for the UC execution is performed.

4.6 Conclusions

This chapter reports on the trial's activities that have taken place at large scale within the Greek cluster, covering mainly three out of four use cases and corresponding vertical industries, and the preparatory work that has been performed for the fourth one. With respect to initial planning and design work that has been performed in previous deliverables only small deviations have been performed. A large percentage of the planned test cases have been performed and KPI evaluation has been delivered in most of those. More specifically with respect to the overall deployment the extensions were delivered for the 5G-VICTORI trial execution:

- As far as the transport network is concerned due to major unpredictable weather issue (thunders and storms) the deployed equipment became non-operational before the trial execution, and will be replaced before their final delivery. However, the three use cases that are expected to be executed in Patras city center and are using the transport network have been initially tested without the transport network segment (for example in **UC #1.1** the central office and data center has been relocated to the Train station, and for **UC #2** the IPTO control room has been set up close to the IPTO facility),
- Edge computing has been successfully deployed in all facilities to ensure that vertical services can be deployed successfully.
- As far as the as the applications and integration to the 5G service oriented architecture is concerned this has been completed for **UC #2** and **UC #3** and tested in the lab environment.
- KPI evaluation of the 5G infrastructure has been thoroughly performed in the extended facilities in order to ensure successful execution of trials for three out of four UCs.
- Initial trials on the TRAINOSE (**TRA**) train for testing the mobility framework have been executed.

5 Technology Integration, Validation and field trials in Bristol

5.1 Overall Facility Description

The Bristol cluster demonstration is performed at the Bristol 5G-VICTORI facility in four locations within Bristol city centre as follows: (refer to deliverable D2.3 [4] for a detailed description of the network setup and performance along the full route):

1. Outside the M Shed Museum,
2. Boat trip at waterfront along the Bristol Harbourside (shown in blue colour); starting the boat trip at M Shed towards and finishing at Millennium Square (MSq), via SS G. Britain Steam Ship,
3. We The Curious (WTC) / MSq,
4. Smart Internet Lab, High Performance Networks group (HPN), Merchant Venturers Building (MVB).

Figure 5-1 shows the 5G-VICTORI Digital Mobility **UC #1.2** Demonstration setup locations in Bristol facility.

Figure 5-1 5G-VICTORI Bristol- Digital Mobility UC Demonstration setup

These locations correspond to four network edges; WTC, M Shed and HPN (Smart Internet Lab) are part of the 5GUK Testbed while the Nomadic Node with edge processing capabilities is deployed as an additional edge on the boat for the needs of 5G-VICTORI Digital Mobility UC (UC #1.2) and providing seamless connectivity and mobility to the users on-board. 5G SA coverage is available at all 5GUK edges (100MHz @ n77, 40 MHz @ n78) as well as the Nomadic Node (50MHz @ n77). Computational resources at the edge and the utilization of a disaggregated 5G core allows the placement of the UPF and the application services closer to the edge, achieving lower latency and relaxed backhaul requirement. Additionally, monitoring capability is also deployed at each edge detailed in section 5.1.2.2.

The Bristol 5G-VICTORI facility demonstrated 5G-VICTORI Digital Mobility UC (**UC #1.2**) App1, **App2** and **App3** during the Bristol Field Trail (03-05 October 2022). Please see a summary of these applications below and for more details refer to D2.1 to D2.3 [1].

- Application 1 (**App1**) provides immersive media and AR/VR services to travelers provided by Mativision (MATI).
- Application 2 (**App2**) involves a 360° VR Multi-camera Live streaming and focuses mainly on large user connectivity and greater number of users provided by MATI.
- Application 3 (**App3**) Urban Hawk (**UHA**) Future Mobility application providing 5G enabling multiuser / multi agent planning.

The set of different solutions and services developed by the partners involved in the Bristol demonstration (e.g. Zeetta Automate slicing solution, 5G-VIOS, i2SM, MATI Apps 1 and 2 storage/stream/backhaul NSs, Amarisoft 5G-call-box, etc.) were fully integrated to the already existing testbed as well as the newly created **Nomadic Node**.

5.1.1 5G Deployment Setup and Testbed Expansions

Figure 5-2 shows the 5G-VICTORI Digital Mobility **UC #1.2** demonstration setup in Bristol facility, while details are provided in Table 5-1.

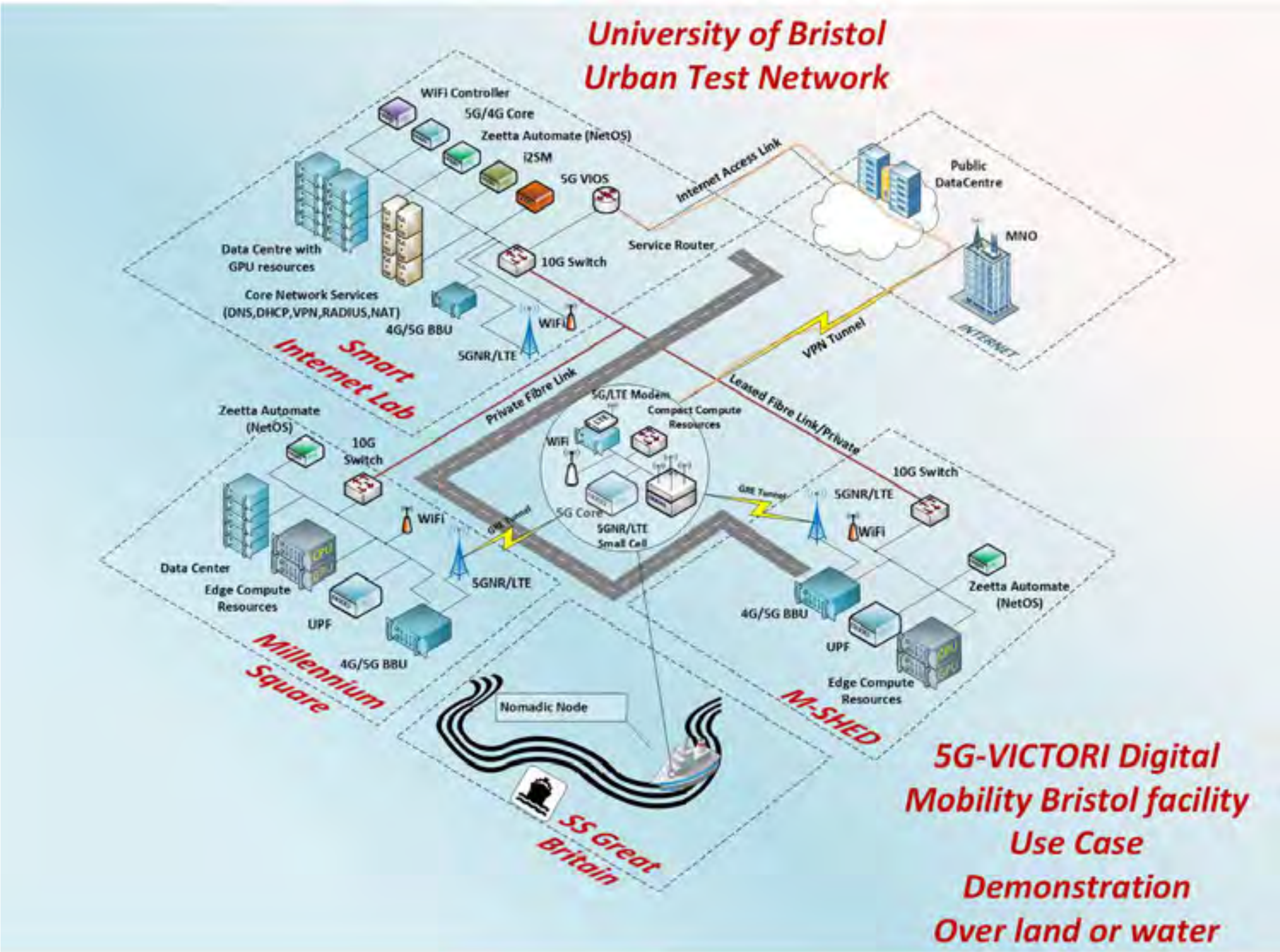


Figure 5-2 5G-VICTORI Bristol facility Digital Mobility UC (UC #1.2) demonstration at related edges

Table 5-1 Bristol Facility – 5G Deployment Setup

	M Shed	WTC/MSQ	Nomadic Node	Smart Internet Lab
Open-Source	Yes	Yes	Yes	Yes
SA/NSA	SA	SA	SA	SA
Cloud options	OpenStack Bare-Metal	OpenStack Bare-Metal	OpenStack Bare-Metal	OpenStack Bare-Metal
MANO	OSM Zeetta Automate	OSM Zeetta Automate	OSM i2SM	OSM Zeetta Automate
Core	Open5gs	Open5gs	Open5gs	Open5gs
RAN	Nokia gNB	Nokia gNB	Amarisoft gNB	Accelleran CU/DU Benetel RU
UE	Redmi Note 9 Pro 5G Samsung S20+ 5G Huawei P40 Pro 5G 5G CPE (in-house built)	Redmi Note 9 Pro 5G Samsung S20+ 5G Huawei P40 Pro 5G 5G CPE (in-house built)	Samsung S20+ 5G Huawei P40 Pro 5G 5G CPE (in-house built)	Redmi Note 9 Pro 5G 5G CPE (in-house built)

During the 5G-VICTORI Bristol Field Trial, **UNIVBRIS** successfully extended the 5GUK Testbed in order to accommodate the 5G-VICTORI Digital Mobility **UC #1.2** Apps 1, 2, and 3. The most important extensions are presented in the following paragraphs:

5.1.1.1 Access network segment deployment

In particular, the Nokia RAN available at M Shed (n78, 40MHz) and WTC (n77, 100MHz) edges is connected to an open-source 5G core (Open5GS) and is configured to provide 5G SA services. Similarly, an O-RAN compliant Benetel RU (n77, 100MHz) with Accelleran CU/DU solutions is also connected to the same 5G core to provide 5G SA connectivity at the HPN edge. The disaggregation of the 5G core components allows a multi-UPF deployment, improving the network latency while relaxing the backhaul throughput requirements. In addition, the 5GUK Testbed installed two new 5GNR supporting band n77 on the roof top of M Shed to provide network coverage towards SS Great Britain (see Figure 5-1).

5.1.1.2 5G Core network deployment

The 5G network was changed from NSA (4G core) to SA (5G core). The computational resources at all existing 5GUK Bristol facility edges, i.e., HPN, WTC, M Shed are upgraded and properly configured into different availability-zones (OpenStack) to achieve edge isolation.

5.1.1.3 Nomadic Node deployment

The Nomadic Node is a combination of networking (5G RAN/Core, Wi-Fi 6 AP, switches, CPEs), computational (servers) and software components (OpenStack, SDN Controllers, OSM) that provides a small-scale capability and services of a fully operational e2e network including the cloud, the core and the RAN. As shown in Figure 5-3, the Amarisoft 5G-in-a-box provides the 5G RAN for the Nomadic Node, along with a local 5G core (Open5GS). Mobile Edge Computing (MEC) capability is also available, which allows the instantiation of the different application services locally. The Nomadic Node is connected to the rest of the 5GUK Test Network via multiple wireless links using a multi-modem CPE over trusted (private) or untrusted (public) 4G/5G networks.

The in-house built CPE device with dual 5G Modems ensures a layer-2 connectivity between the Nomadic Node and the 5GUK Testbed, either via the testbed's Nokia 5G solution or a public operator's network. Given the wireless connectivity between the Nomadic Node and the rest of the 5GUK network, this implementation minimizes the latency while requiring a minimal information exchange between over a limited wireless link.

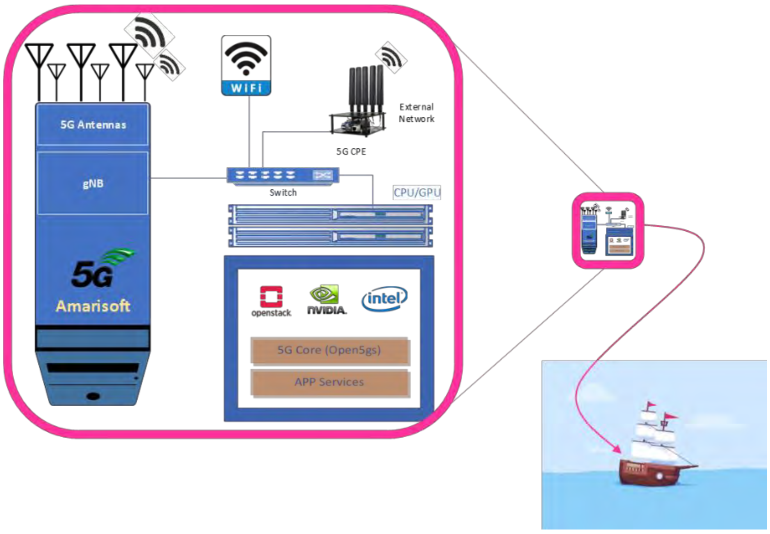


Figure 5-3 Nomadic Node – inside the box (High-level)

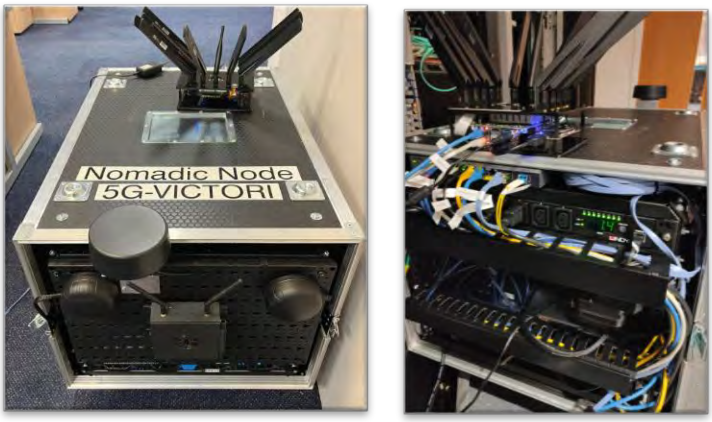


Figure 5-4 Nomadic Node - outside the box

Figure 5-4 provides an overview on the outside and back of this Nomadic Node box. This Node was built and integrated to the rest of the network by the 5GUK Testbed team where **i2CAT** integrated an Amarisoft 5G box (provided by **DCAT**) to the Nomadic Node, along with the i2CAT Slice Manager (i2SM) and a Wi-Fi6 AP. Furthermore, an in-house built CPE with multiple 5G modems was used to establish wireless connectivity with the 5GUK network, either via the testbed's 5G network or a public operator's LTE/5G network. A software solution was developed on the CPE to check the connectivity every 500 ms, switching between the 5GUK and public operator modems, demonstrating seamless layer-2 over layer 3 wireless connectivity between the nomadic and 5GUK networks, using both trusted and untrusted networks. Consequently, the demonstration was also possible at locations out-of-coverage of the 5GUK Testbed.

During the 5G-VICTORI Bristol field trail (03-05 Oct 2022), all 5G-VICTORI Digital Mobility UCs (**Apps 1**, **2**, and **3**) were demonstrated along the demonstration route, either using the 5GUK Testbed (Nokia 5G RAN) or the Nomadic Node on the boat. For instance, as shown in Figure 5-5, Nomadic Node OpenStack: "Slice App 1" included **MATI**'s **App1** cache, which was connected to UEs network through an OpenStack router. In the case of **App3**, UEs were connected to Nomadic Node's network in order to reach Internet. DHCP Server images were used for the Wi-Fi UEs (in 5G DHCP is solved by the 5G Core).

In addition, the 5G-VIOS was integrated into the 5GUK test network, where **Apps 1** and **2** NSs were deployed, orchestrated, monitored, and profiled through the 5G-VIOS. Moreover, the transport networks – VLANs, Dynamic Multipoint VPN (DMVPN), Open Shortest Path First (OSPF) – among edges (M Shed, HPN, WTC, Nomadic) and their connectivity for deployment of **Apps 1** and **2** were automatically deployed by 5G-VIOS and were tested during the trail.

Host	Name	Image Name	IP Address	Flavor	
nomad	dhcp_vlan_3110	dhcp_server	172.16.0.48	dhcp.flavor	Slice App 1
nomad	core_nomadic-node-rs-1	open5gs_v2.4_metricbeat	**nomadic-node-nc-data-1** 172.16.0.34, 192.168.149.190 **nomadic-node-nc-access-1** 172.16.1.8	open5gs.flavor	Slice App 1
nomad	MATI_App1_caches-1-mati_app1_cache_vnfd-VM-0	MATI-APP1-CACHE	192.168.149.105	mati_app1_cache_vnfd-VM-flv	Slice App 1
nomad	dhcp_vlan_3109	dhcp_server	172.16.2.37	dhcp.flavor	Slice App 3
nomad	core_nomadic-node-rs-2	open5gs_v2.4_metricbeat	**nomadic-node-nc-data-2** 172.16.2.31, 10.68.114.22 **nomadic-node-nc-access-2** 172.16.3.31	open5gs.flavor	Slice App 3

Figure 5-5 Nomadic Node OpenStack: Slice App1 and Slice App3

5.1.2 Bristol Facility deployments of 5G-VICTORI architecture

The Digital Mobility demonstration for **Apps 1** and **3** includes all three of the 5GUK Testbed edges (M Shed, WTC, Smart Internet Lab/HPN) along with the Nomadic Node as an additional edge. **App2** is only demonstrated within the three 5GUK Testbed edges.

The 5GUK edges are differentiated physically using different servers at different network locations, while being logically separated into WTC, M Shed and HPN edges using OpenStack's Availability-Zone separation. The 5GUK Cloud+ OpenStack controller is physically and logically installed in Smart Internet Lab with at least one OpenStack Computational Node in any of the 5GUK edges. The Nomadic Node edge computing is implemented using a local OpenStack implementation. The hardware specifications of the edge and cloud computing are included in Table 5-4. .

The 5GUK edges are interconnected with dark fibre, the length of each link being less than 10 km. The inter-edge latency and throughput was measured at <1 ms and ~9.5 Gbps, respectively. The Nomadic Node is physically installed on a boat travelling across the Bristol harbour with wireless connectivity to the rest of the 5GUK Testbed using a GRE tunnel, either via the 5GUK Nokia 5G RAN or a public operator's network (using VPN). Depending on the boat's location and the 5GUK/public network selection, the latency and throughput of the inter-edge connectivity between the Nomadic Node and the 5GUK edges varied between {5-135} ms and {10-650}/{5-220} Mbps {DL}/{UL}. All inter-edge measurements are included in Table 5-6 and Table 5-7.

As shown in Figure 5-6, the 5GUK 5G core (Open5gs) instantiated in Smart Internet Lab serves the 5GUK Nokia RAN, while different Open5gs instances are created per App on the Nomadic Node to provide the 5G services locally.

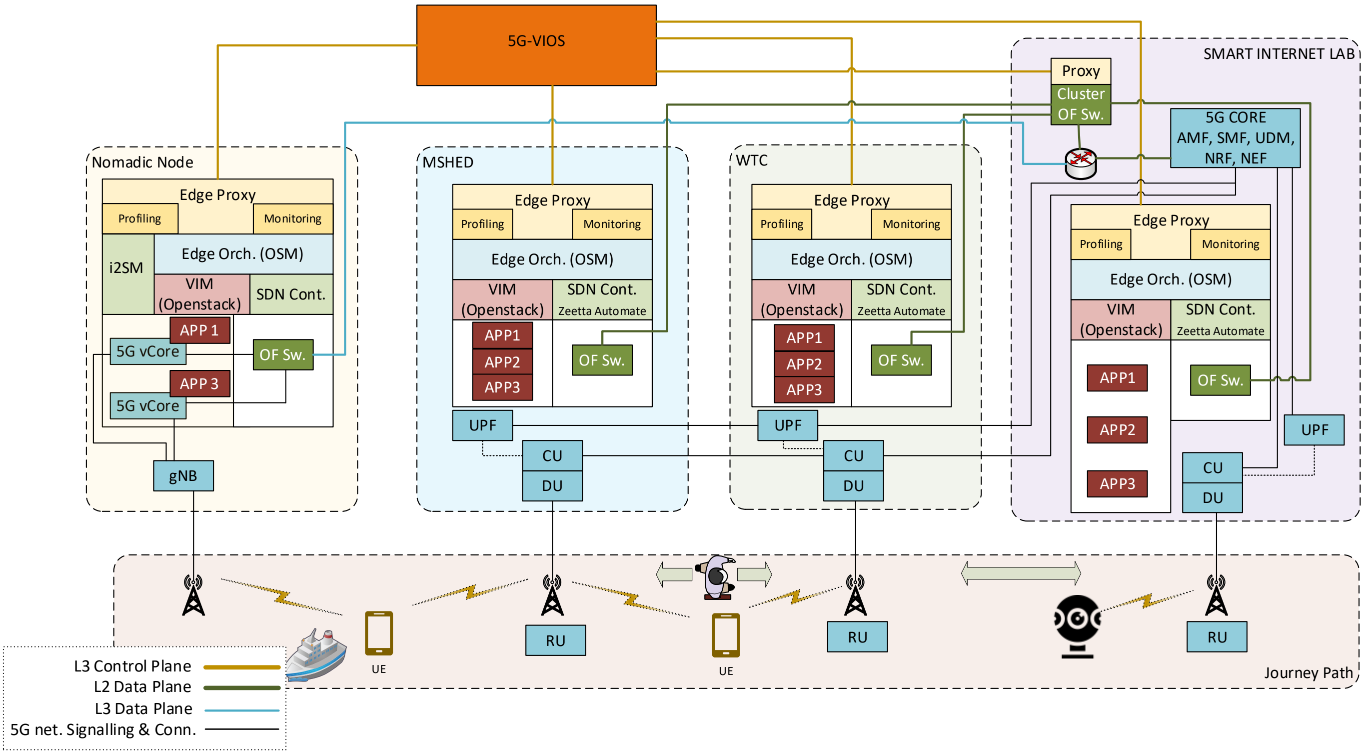


Figure 5-6 E2E deployments of 5G-VICTORI architecture to demonstrate the Digital Mobility UC (#1.2) Apps 1 to 3

5.1.2.1 Orchestration options

End-to-End service provision and orchestration is provided by 5G-VIOS through the Edge Proxy, which interacts with Zeetta Automate or i2SM to create the intra- and inter- edge slicing, and creates all the OpenStack instances required for Apps 1-3.

As shown in Figure 5-6, 5G-VIOS is integrated into the 5GUK test-network to orchestrate the inter-edge NSs. In addition, Zeetta Automate and i2CAT Slice Management and i2CAT RAN controller are integrated into the 5G-VIOS and 5GUK test-network to manage the slices at the corresponding edges, i.e, WTC, M Shed, and the Smart Internet Lab, and the Nomadic node, respectively. These components are detailed in the following:

- **5G-VIOS:** 5G-VIOS microservices communicate with OSM via edge proxy to manage the life cycle of NSs. Newly instantiated NSs and VMs are equipped with the Node Exporter and Metricbeat components. The exposed data metrics and KPIs are stored in databases at the edge Monitoring using Elasticsearch and are visualized by Kibana. In addition, the VIOS Monitoring visualizes the Application and NSs KPIs and shows the visualized plots in the portal.
- **Zeetta Automate**: An SDN Controller is instantiated at each edge to achieve e2e slicing. Three Zeetta Automate instances control the layer-2 Edgecore switches at the 5GUK edges (WTC, M Shed, HPN), while i2SM implements the slicing within the Nomadic Node. For slicing the Edge Proxy communicates with the Zeetta Automate controllers through APIs that were specifically developed for the 5G-VICTORI requirements. The APIs provide functionality for VLAN-based NS creation/enable/disable on specific switch ports. For the demonstration, slices were created from each Zeetta Automate instance on the managed devices. During execution of each use case 5G-VIOS activated and deactivated network slices in each location as needed.
- **I2CAT Slice Manager (I2SM):** It manages the deployment of infrastructure slices in the Nomadic Node Edge. More specifically, it manages the VIM (OpenStack in this case) for creating a tenant dedicated to the slice users in the compute resource and providing the

required networking setup inside the VIM for the considered slice (in this case, the application network created by 5G-VIOS is connected via a vRouter to the network ending the requests from mobile and Wi-Fi UEs). This component also manages the deployment of network functions required for ensuring the connectivity provided by the slice, such as the mobile core and/or a DHCP server for Wi-Fi users. Finally, it coordinates the requests towards the RAN Controller for managing the RAN segment of the slice.

- **RAN Controller:** It manages the configuration and operation of the RAN resources in the Nomadic Node. In particular, it was used to remotely configure 5G cells at the Amarisoft gNB (e.g. bandwidth, frequency, TDD configuration…) and to instantiate different 5G SA slices according to the PLMNID and S-NSSAI parameters. At the Wi-Fi side, it also allowed to remotely configure the Wi-Fi devices (e.g. bandwidth and band) and to instantiate virtual Access Points according to the specified parameters (e.g. SSID).

5.1.2.2 Monitoring

UNIVBRIS designed, implemented, and demonstrated **Edge Monitoring**. Metrics were collected from all NSs within an edge using Metricbeat and Prometheus Node Exporter. Data was stored in corresponding edge's Elasticsearch, automatically and visualised in Kibana web interface. Additionally, an Android application was developed by the 5GUK testbed team as part of the 5GUK Monitoring and Measurement tools to monitor and measure KPIs on the UEs. Handset 5G metrics (Cell ID, RSRP, RSRQ, SINR, GPS coordinates, DL/UL throughput, etc.) and Wi-Fi metrics (Link speed, Link quality, etc.) were directly sent to the Edge Monitoring (Elasticsearch). This capability was demonstrated live on the headsets alongside the demonstrations of **Apps 1-3**. The metrics were later visualised on Kibana.

Figure 5-7 shows the monitoring capability (Edge Monitoring) deployed at each edge using the 5GUK Testbed's Monitoring and Measurement Tool (MaM) and other open-source solutions such as the Prometheus and Node Exporter to not only monitor the NSs running at each edge, monitor the Applications, infrastructure, and UEs but also store them in Elasticsearch to analyse them and visualise them through Kibana, Prometheus, and other visualizing tools. In addition, e2e monitoring of Applications and NSs across edges is provided through the VIOS Monitoring implemented and developed by **DCAT**. In addition, the Zeetta Automate instance at the edges except the Nomadic Node monitors each connected switch device, to read port receive and transmit byte rates. These metrics are provided to each edge Monitoring Elasticsearch instance to be stored in the ElasticSearch at each edge. Furthermore, at the Nomadic Node edge, the Amarisoft and the Wi-Fi AP devices can be monitored remotely through custom Prometheus Exporters (RAN metrics) and through the Prometheus Node Exporter (Node metrics) (see Figure 5-15) which can be then stored in Nomadic Node edge's Elasticsearch automatically. The VMs hosting the 5G Core instance also uses Prometheus Node Exporter to expose node metrics to the Edge Monitoring framework and store them in Elasticsearch automatically.

Figure 5-8 shows the details on how the 5GUK Testbed (**UNIVBRIS**) offers three layers of monitoring. These layers are provided in the following:

1. **Infrastructure Monitoring:** Transport network metrics are collected from the 5GUK SNMP-enabled (SNMP) layer-2 switches which are configured in Zabbix. The required KPIs are then visualised using Grafana.
2. **Applications Monitoring:** Metrics are collected from the different UC applications (1-3) using Prometheus NodeExporter along with the Elasticstack. For every application instance, NodeExporter exposes the required metrics for each VIM, while Metricbeat structures them into a format that is compatible with the Elasticsearch. All KPIs are stored in Elasticsearch databases at the edge, ready to be collected by 5G-VIOS. Edge metrics are visualised by Kibana.
3. **UE Monitoring**: Cellular (5G) and Wi-Fi metrics are collected from user phones using an in-house developed Android application referred to as the 5GUK Monitoring and Measurement tool (MaM).

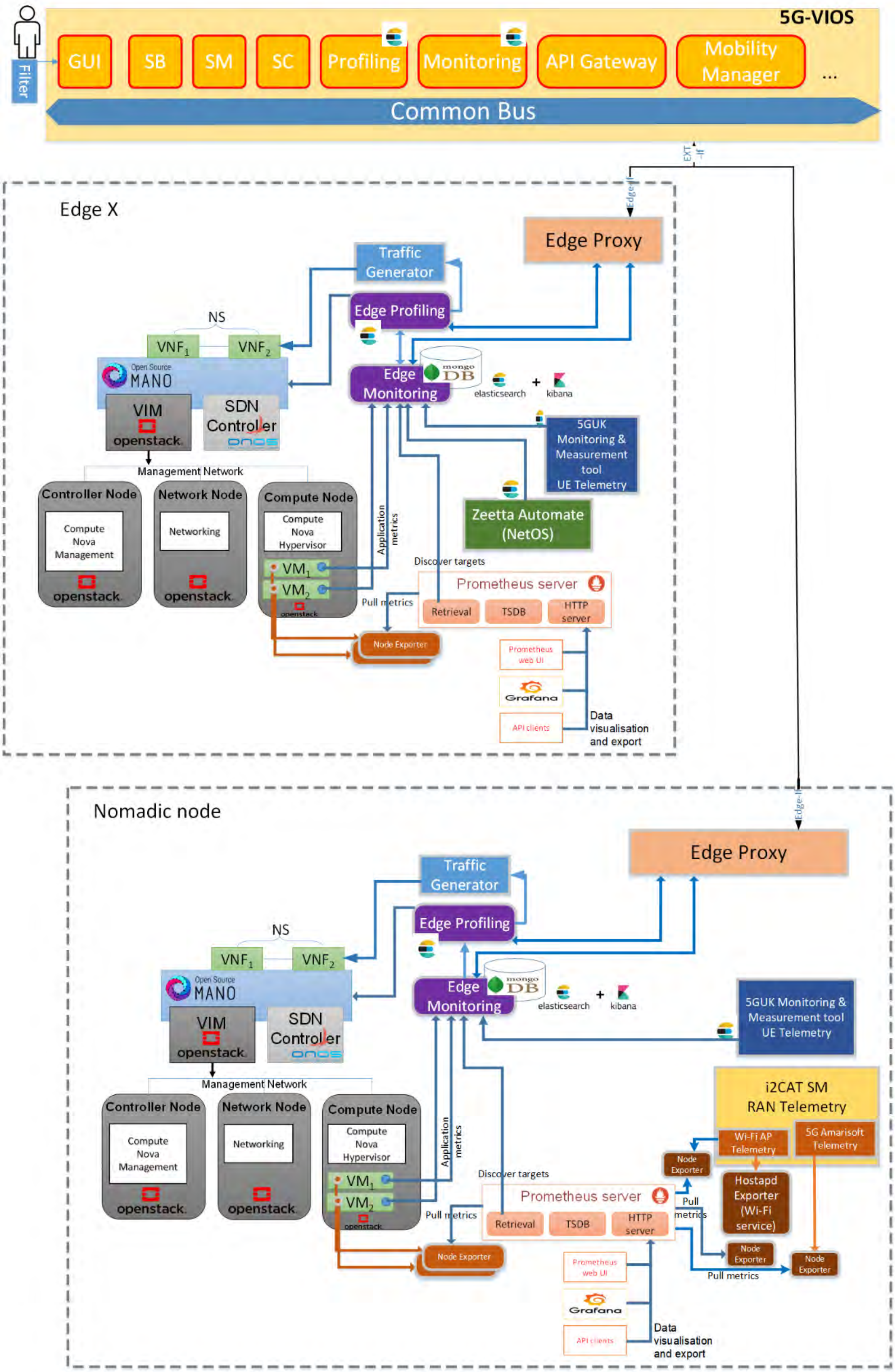


Figure 5-7 E2E monitoring of Applications, Network Services, infrastructure and UEs across edges

The GUI is shown in Figure 5-9. The collected UE data is directly sent to the Edge Monitoring and is stored in Elasticsearch. UE metrics are visualised by Kibana. These 5G and W-Fi features and metrics are shown in Figure 5-10, Figure 5-11, Figure 5-12, and Figure 5-13. In addition, Figure 5-14 shows Wi-Fi6 UE Radio KPIs on the Nomadic Node including Signal Quality and MCS.

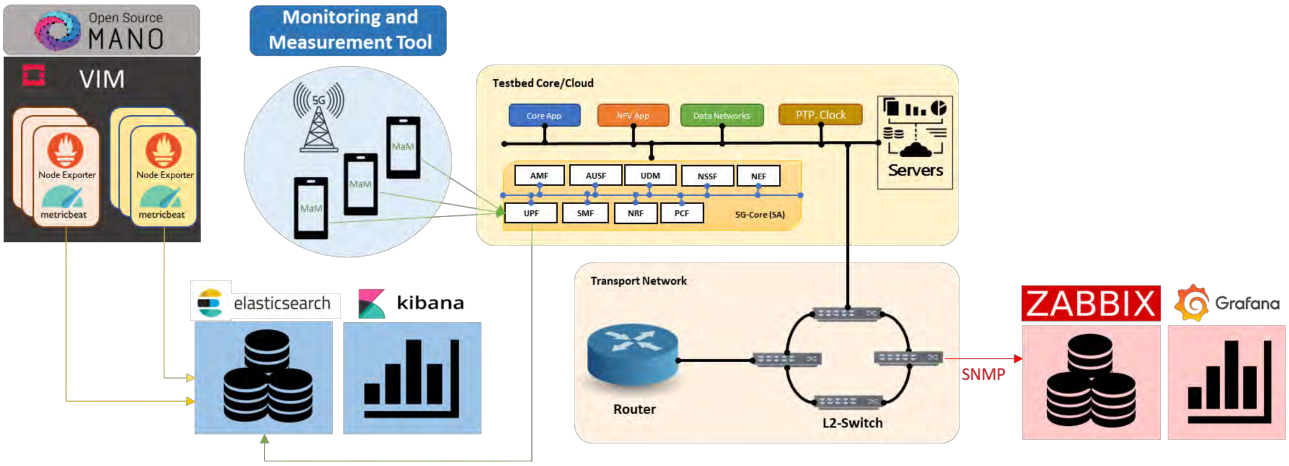


Figure 5-8 KPIs Measurement and Monitoring Implementation

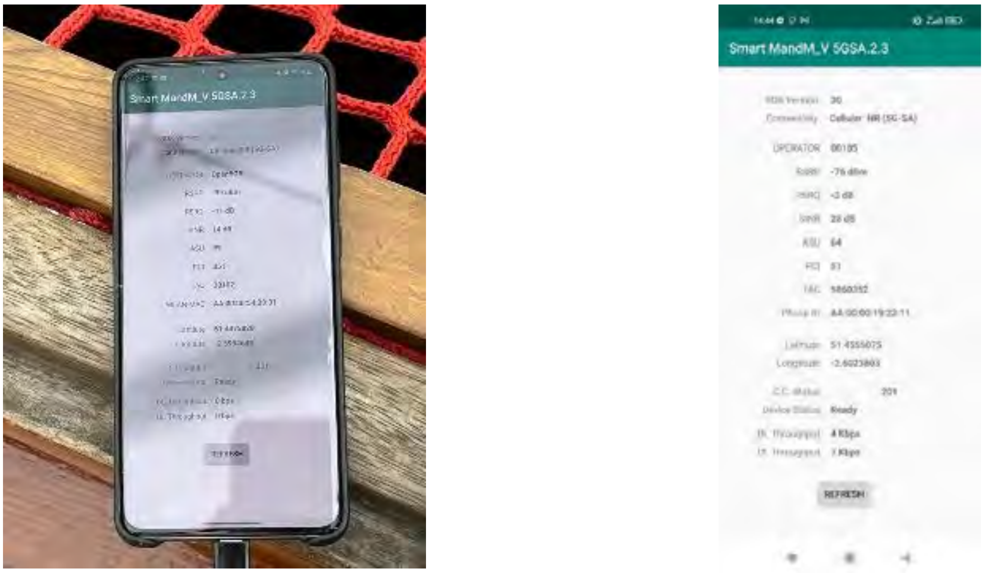


Figure 5-9 5GUK testbed Monitoring and Measurement tool – GUI

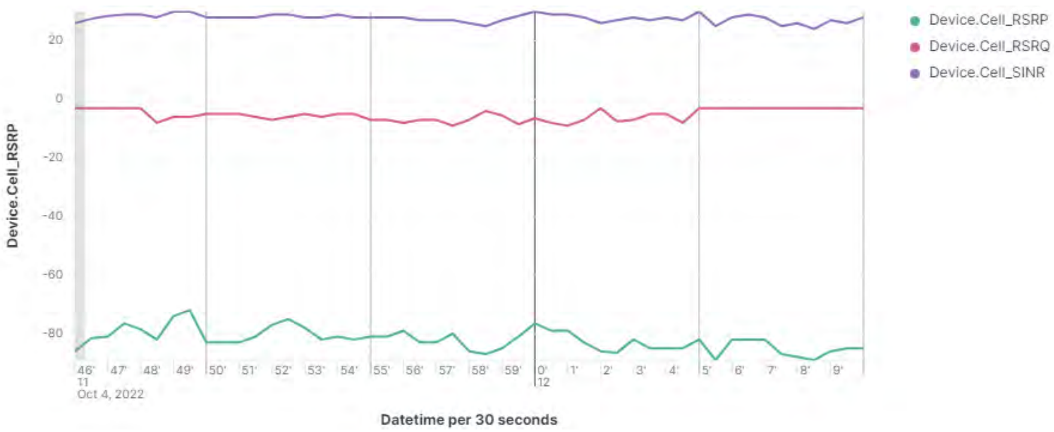


Figure 5-10 5GSA UE Radio KPIs including RSRP, RSRQ and SNIR

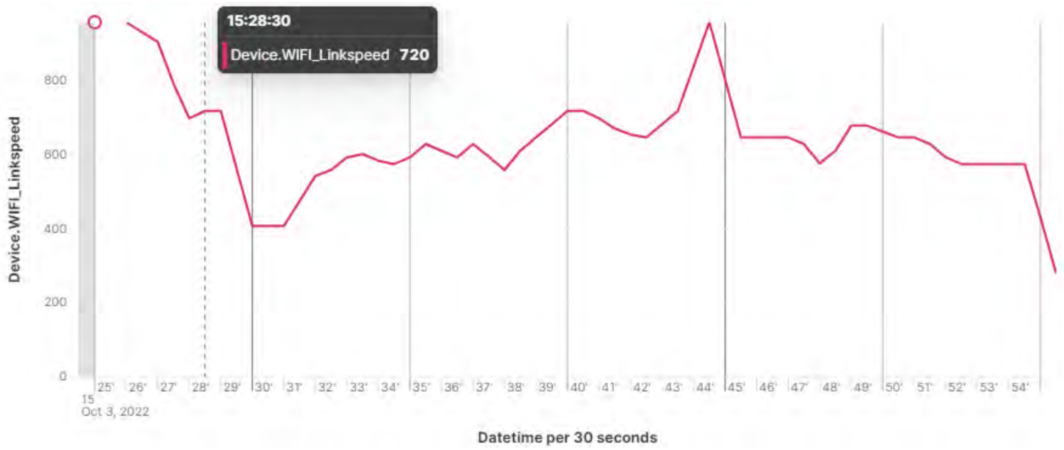


Figure 5-11 UE Wi-Fi link speed (Mbps)

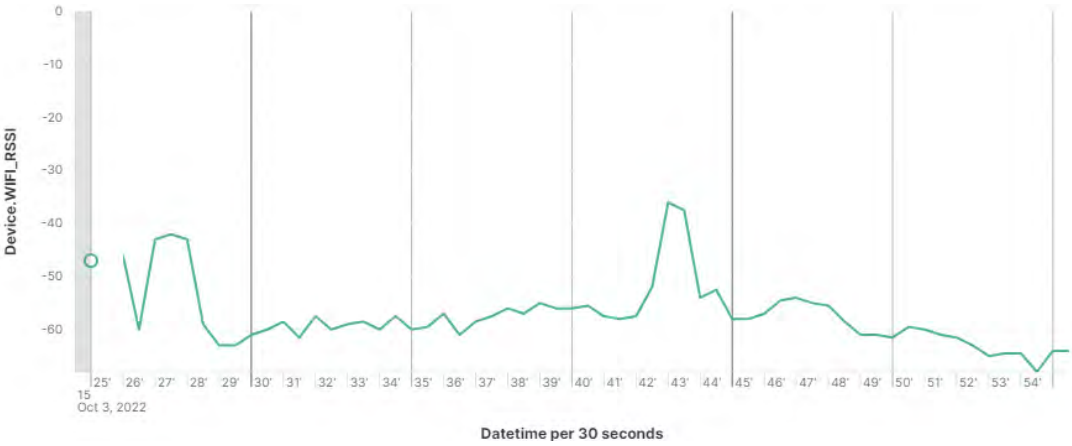


Figure 5-12 UE WI-FI RSSI

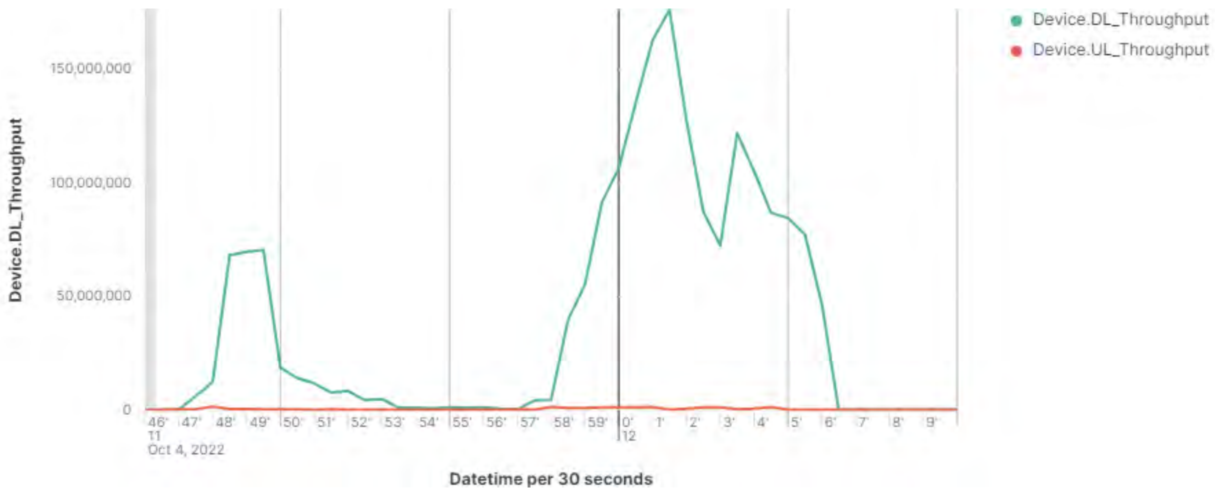


Figure 5-13 UE DL/UL Throughput (Bps) monitoring

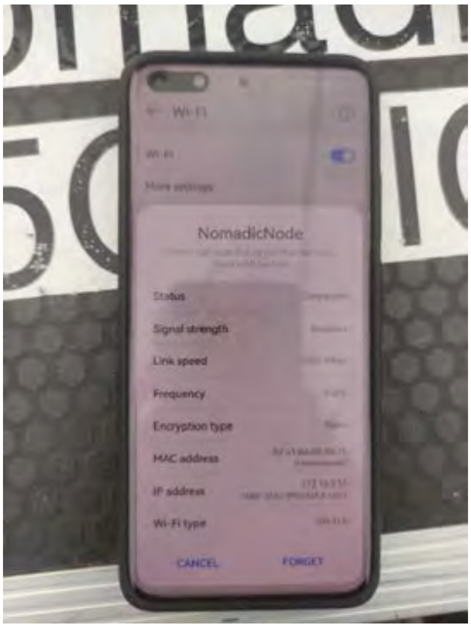


Figure 5-14 Wi-Fi6 UE Radio KPIs on the Nomadic Node including Signal Quality and MCS

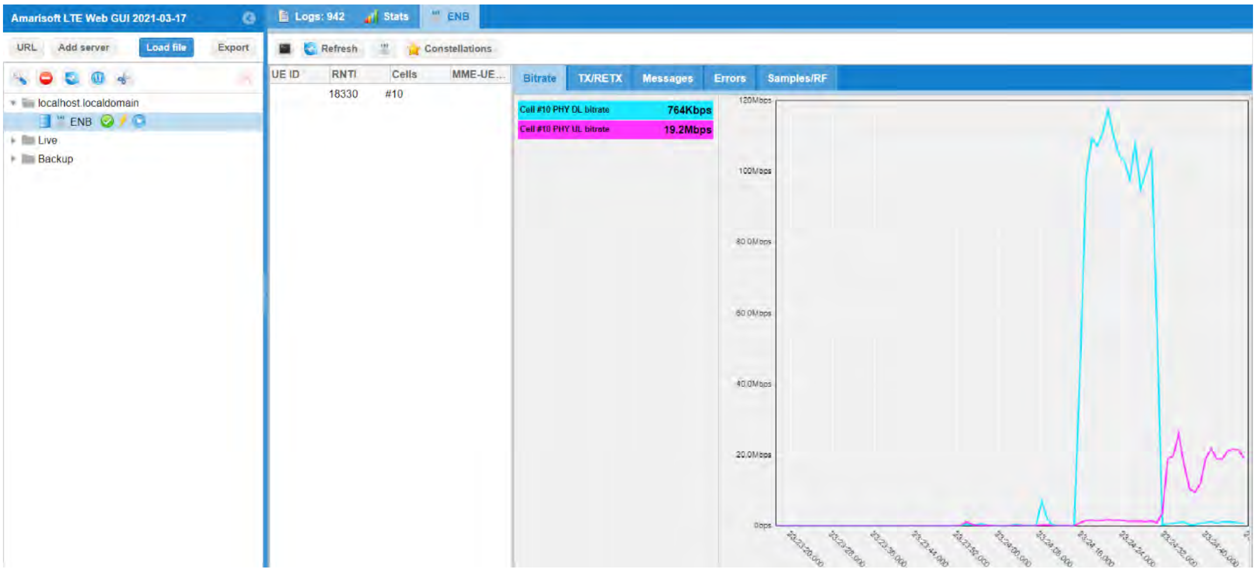


Figure 5-15 Amarisoft DL/UL Cell Throughput during Bristol October's FieldTrial (speedtest on the Nomadic Node)

5.2 App1: MATI immersive media and AR/VR services to travelers

MATI **App1** focuses on exploiting the performance and added capabilities of the 5G Network to deliver to passengers' location-based informative content by means of an immersive application in the city centre. It gives a 360° tour guide via 5G at specific geolocation video spots:

When or after travellers arrive at M Shed and as they move between specific geolocation spots, immersive content will be delivered either as AR or to their 5G-enabled devices presenting relevant information for the route they are following including the M Shed and MSQ edges and the boat ride on Bristol Canal (served by the Nomadic Node) and a walk to Smart Internet Lab (MVB).

Seamless service provisioning during mobility is demonstrated – also by deploying and testing the service on a movable base (a boat).

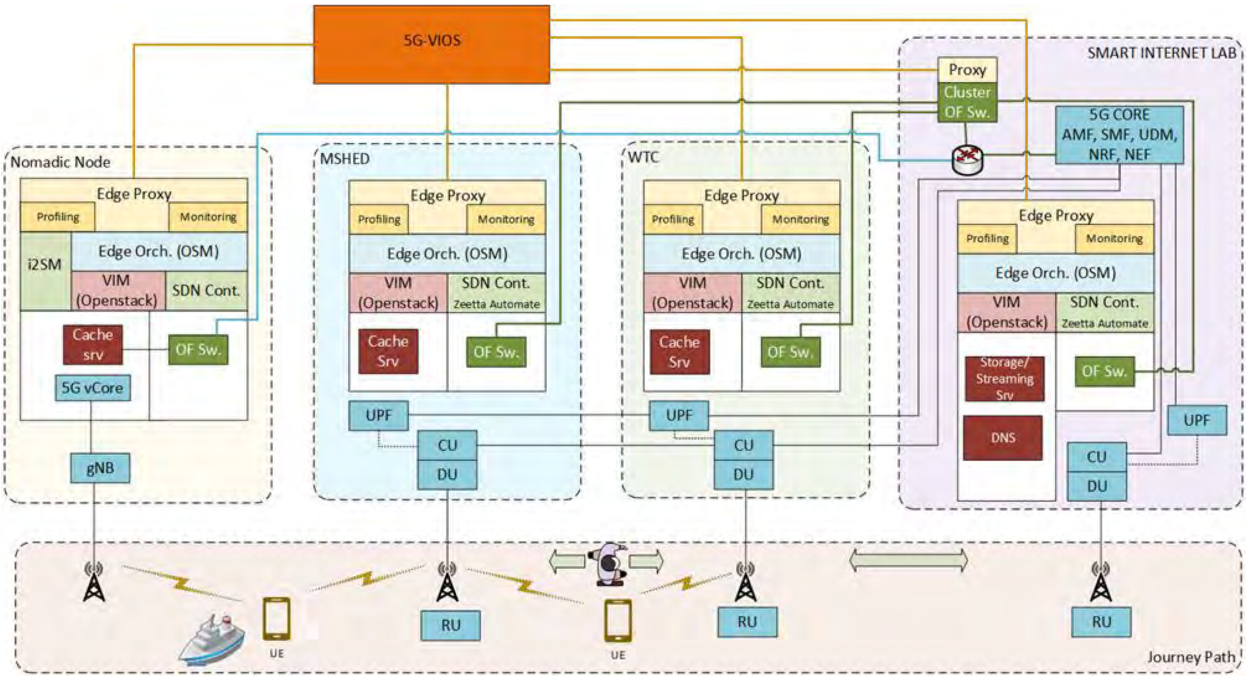


Figure 5-16 App1 high-level 5G deployment architecture

5.2.1 UC testing objective and deployment

App1 services were deployed and tested running through 5G-VIOS. Both the services running at backhaul server – at Smart Internet Lab (HPN) – and edge services proved reliable and were performant when tested at corresponding hotspot locations. The content was hosted in the backhaul server while the edge service provided caching and synchronization services. Multiple devices were tested. One master device controlled multiple client devices at the same time with low latency. The client devices were used to playback high bitrate 360° video. The objective of the field trial was to test the deployment of all software needed to run **App1** and validate the use case by synchronizing multiple end user devices via one master device. The monitoring of metrics was also tested and reported back to 5G-VIOS and shown in the metrics visualization page. During the move of our group around Bristol, the services were migrated on multiple edges including M Shed, Nomadic Node, WTC and supported the playback of multiple high bitrate 360 videos on multiple devices at the same time.

5.2.2 App1 Slice description (with application components) and Network diagram

Figure 5-16 shows the **App1** NSs deployed at each edge. The details of the 5G components and equipment at each edge are provided in section 5.1.

5.2.2.1 Lab Deployment

The Bristol cluster lab trial (in May 2022) tested the network infrastructure at all edges while implementing application-related tests involving the HPN and WTC edges (see Figure 5-17). Nokia 5G RAN was installed inside the Smart Internet Lab (HPN) to test e2e service provision for **Apps 1** and **2** but without mobility. All required **App1** VMs such as Streaming server, caching servers and DNS, were instantiated at HPN and WTC, testing some basic inter-edge communication and 5G-VIOS operation. Further information regarding the lab deployment and corresponding results are provided in **D3.2** [9]. The Nomadic Node edge computing was also deployed and tested as a wired extension of the 5GUK testbed (see Figure 5-18). The Amarisoft gNB was configured using the 5GUK 5G core (open5gs) and the e2e communication was validated with 5G Android and in-house built CPE devices.

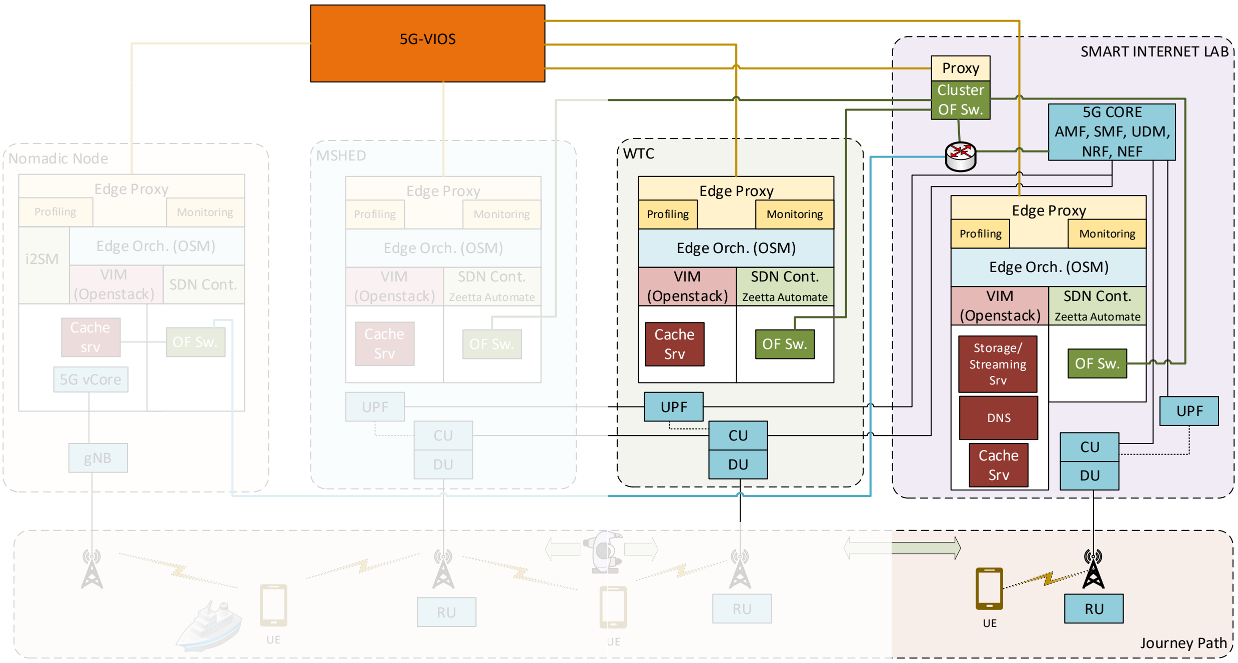


Figure 5-17 Bristol facility's lab trail setup in May 2022 to demonstrate Digital Mobility UC

Figure 5-18 Nomadic node setup during the May's lab trail 2022

5.2.2.2 Facility for testing

Please refer to section 5.1.2 and Figure 5-6 for the e2e architecture configured to demonstrate **App1** during the Bristol Field trail in October 2022.

5.2.3 Test Cases and KPIs

The KPIs measured by **App1** are as follows (see the following items as well as Table 5-2):

1- Synchronization latency between master device and client devices ([8][9] **RDIu01** test case).

2- The bandwidth achieved by each device, reported as an average to 5G-VIOS reporting ([8][9] **RDIu02** test case).

3- The mobility event latency between sending a mobility event and the service being instantiated in the new location ([8][9] **RDIu03** test case).

4- The caching performance of the edge service. ([8][9], **RDIu04** test case).

Table 5-2 App1 test cases and KPIs

Test case group RDIu				
Test case name	**Place**	**Key UC requirements and KPIs**	**Network performance requirements and KPIs**	
RDIu01	M Shed, UNIVBRIS		Synchronization latency	< 200 ms
RDIu02	M Shed, UNIVBRIS		Bandwidth achieved	> 10000 kbps
RDIu03	Not tested		Mobility latency	< 60 s
RDIu04	M Shed, UNIVBRIS		Network savings	> 30%

The Network KPIs have been measured through the following test cases (see the following items and Table 5-3):

1- 5GUK Infrastructure test case between Core and Edges, and between the Edges ([8][9] **RDNu01** test case).
2- 5GUK Infrastructure test case Between Core (HPN) and the Nomadic Node ([8][9] **RDNu02** test case).
3- Throughput and Latency tests between UE and Core/Edges. ([8][9] **RDNu03** test case).
4- 5GUK Infrastructure test case for Multi-RAT Slice Deployment ([8][9] **RDNu04** test case).

Table 5-3 Network test cases and KPIs

Test case group RDNu					
Test case name	**Place**		**Key UC requirements and KPIs**	**Network performance requirements and KPIs**	
RDNu01	M Shed, WTC and HPN edges.	Transport network test between core and edges, and between the edges.		Latency, Throughput	<1ms, >1Gbps
RDNu02	HPN, Nomadic Node	5G backhaul test between core (HPN) and Nomadic Node.		Latency, Throughput	<100 ms, >100 Mbps
RDNu03	M Shed, WTC and HPN edges.	5G network test between core and edges, and between the edges.		Latency, Throughput	<100 ms (UE to edge), <500 ms (UE to core), >100 Mbps
RDNu04	Nomadic Node	Slice deployment time		< 90 min	Nomadic Node

Please note that the initial tests had the 5G core of the Nomadic Node instantiated within the 5GUK test network, i.e. on a physical server in HPN – the connectivity of this deployment being tested in **RDNu02** test case [9] for the corresponding results}. However, the core was later deployed locally in the Nomadic Node. The connectivity between the Nomadic Node and the rest of the 5GUK network (including the HPN edge) was tested as part of the **RDNu03/04**.

5.2.4 High Level 5G Deployment Scenario Description

Table 5-4 describes the Bristol cluster setup for **App1** demonstration at HPN (Smart Internet Lab), M Shed, WTC, and Nomadic Node

Table 5-4 Scenario description – Configuration of setup at Bristol facility edges

	HPN (Smart Internet Lab) Edge	M Shed Edge	WTC Edge	Nomadic Node Edge; 5G RAT	Nomadic Node Edge; Wi-Fi RAT
Radio access technology (RAT)	5GNR, Sub-6GHz	5GNR, Sub-6GHz	5GNR, Sub-6GHz	5GNR, Sub-6GHz	Wi-Fi 6
Standalone / Non-Standalone (if applicable)	SA	SA	SA	SA	N/A
Cell Power	27 dBm	41 dBm	42 dBm	< 10 dBm	Max. 30 dBm
Frequency band:	n77	n78	n77	n77	Channel 36 (primary)
Maximum bandwidth per component carrier	100 MHz	40 MHz	100 MHz	50 MHz	80 MHz
Sub-carrier spacing	Sub 6 GHz: 30 kHz	Sub 6 GHz: 30 kHz	Sub 6 GHz: 30 kHz	Sub 6 GHz: 30 kHz	
Number of component carriers	Maximum number of CC = 4 (5G)	Maximum number of CC = 4 (5G)	Maximum number of CC = 4 (5G)	1	1
Cyclic Prefix	N/A	N/A	N/A	N/A	N/A
Massive MIMO	No	Yes, 64T64R	No	No	No
Multiple-Input Multiple-Output (MIMO)	4x2	4x2	4x2	4x2	2x2
Modulation schemes	DL: QPSK, 16 QAM, 64 QAM, 256 QAM UL: QPSK, 16 QAM, 64 QAM, 256 QAM	DL: QPSK, 16 QAM, 64 QAM, 256 QAM UL: QPSK, 16 QAM, 64 QAM, 256 QAM	DL: QPSK, 16 QAM, 64 QAM, 256 QAM UL: QPSK, 16 QAM, 64 QAM, 256 QAM	DL: QPSK, 16 QAM, 64 QAM, 256 QAM UL: QPSK, 16 QAM, 64 QAM, 256 QAM	Up to 1024-QAM
Duplex mode	TDD	TDD	TDD	TDD	
TDD DL:UL slots ratio	7:3	7:3	7:3	7:S:2	
Contention based random access procedure/contention free	N/A	N/A	N/A	N/A	CSMA/CA
User location and speed	N/A	N/A	N/A	N/A	N/A
Background traffic	N/A	N/A	N/A	N/A	N/A
Computational resources available	112 CPU cores, 256GB RAM, 4TB storage (shared)	56 CPU cores, 128GB RAM, 2TB storage (shared)	56 CPU cores, 128GB RAM, 2TB storage (shared)	56 CPU cores, 128GB RAM, 1TB storage	56 CPU cores, 128GB RAM, 1TB storage

5.2.5 Experiment Description

- The aforementioned deployment descriptions on setting up the Bristol facility edges (M Shed, WTC, Smart Internet Lab/HPN, Nomadic Node) are provided in section 5.1.1. For **App1 and App2**, an experiment descriptor is onboarded from the 5G-VIOS portal to create and deploy the NSs to distinct edges. Table 5-5 shows a sample of Experiment Descriptor which includes information about edges, NSDs as well as the resource requirements (in the form of minimum and maximum values) and target KPIs and SLAs. The portal's role is to capture the information provided in each segment of the experiment descriptor and forward it to the relevant micro-service.

  - If an experiment descriptor file is not available, the user can provide all the necessary experiment descriptor information in a form on the portal.

- Then, the VIOS Profiler computes the optimum configuration of resources needed to meet the KPIs utilizing Machine Learning (ML) techniques and posts them to the VIOS.
- The 5G-VIOS instantiates and orchestrates the **App1** NSs at corresponding edges. Newly instantiated NSs and VMs are equipped with the Node Exporter and Metricbeat components.
- The 5G-VIOS sets the inter-edge and intra-edge connectivity by Inter-edge Connectivity Manager and Edge proxy microservice by utilising Zeetta Automate, VyOS, i2CAT SM (at Nomadic Node edge) and OpenStack APIs. In more details, an SDN Controller is instantiated at each edge to achieve e2e slicing. Three Zeetta Automate instances control the layer-2 Edgecore switches at the 5GUK edges (WTC, M Shed, HPN), while i2SM implements the slicing within the Nomadic Node. The Edge Proxy communicates with the Zeetta Automate controllers through APIs that were specifically developed for the 5G-VICTORI requirements. The APIs provide functionality for VLAN-based NS creation/enable/disable on specific switch ports.
- Then, the application runs on all UEs, and through the Edge Monitoring, the measured metrics related to the Application NSs, computing resources, and UE 5G and Wi-Fi network metrics at each edge will be stored in the Edge Monitoring Elasticsearch and can be visualized through Kibana, and Prometheus. In addition, the VIOS Monitoring integrates the Application and inter-edge NSs' KPIs from corresponding edges, visualizes them, and shows the visualized plots in the portal.

Table 5-5 Experiment Descriptor related to MATI App1

	Value	Comments
ExperimentType	Standard	
Automated	True	
TestCases	Test Case 1	
UEs	UE1, UE2	UE Models are provided in section 5.2.6.
Network Slice	Mativision_App1_cacheserver, Mativison_App1_storageserver	The required network slices to run App1 NSs at corresponding edges. Refer to section 6.2 for more details.
Network Services	NSD IDs: `5867207d-c4a7-4c88-bb8c-9fd2479d0c89`, `3ac5d3de-81f3-45d2-b2f8-1b49cf9d3061`	Details are provided in Section 8.2.4
Network Scenario	Scenario 1	
Exclusive Execution	True	
ReservationTime	N/A	
Experiment Name	Mativision_App1	
Performance targets & SLAs	Network Service KPIs: • cpu_utilisation: 0.98, • memory_utilisation: 100 Application KPIs:	The target KPIs include the Application KPIs, Network Service KPIs, etc. These KPIs will be used by 5G-VIOS profiler to find the optimum configuration of resources to assign to NSs and then through the Experiment Life Cycle Management, send alerts if the NSs are not

	• Mobility latency": 3	meeting these KPIs in real time. Note: these KPIs (name and/or value) can be updated based on each experiment.
Experiment Parameters	Minimum and Maximum configuration of Resources: cpu: • min_cores: 2, • max_cores: 8 memory: • min: 200, • max: 1000 link_capacity: • min: 400000000, • max: 1400000000	The Minimum and Maximum configuration of resources. The 5G-VIOS Profiler will use them to profile the NSs and predict the optimum configuration of each resource (a value between min and max) utilising ML techniques to assign to each NS.
Edges		{VLANs: 143, 145,147,149 , Edge_IDs}
Remote	N/A	
Remote Descriptor	N/A	
Version	v1.0	
Extra	N/A	

5.2.6 Experiment execution and Reports (with reference to WP3 methodology)

During the Bristol Field Trial (03-05 October 2022), for **App1**, MATI ran the full stack of the application software through 5G-VIOS. Both the storage VM and the caching VM were instantiated through 5G-VIOS at corresponding edges close to the end user devices. The content was streamed from the storage VM and cached on the caching VM before reaching multiple UEs. The master application was run on one device while the client player was run on other two devices. The monitoring of metrics (KPIs measured by **App1**) was also tested and reported back to 5G-VIOS through appropriate APIs and shown in the metrics visualization 5G-VIOS portal. During the move of our group around Bristol, the services were migrated on multiple edges including M Shed, Nomadic Node, WTC and supported the playback of multiple high bitrate 360 videos on multiple devices at the same time. Please note that for the Bristol Field Trial in October, we used 2x Samsung S20+ 5G, 1x Huawei P40 Pro 5G, and 1x Redmi Note 9 5G as UEs. Figure 5-19 shows the measured latency (RTT) for 1 minute test between UE and different edges. Please note that these measurements may change if the user moves, or due to the weather conditions, distance to the radios, etc.

Table 5-6 Test report: RDNu01

Field	**5GUK Infrastructure test case between Core and Edges, and between the Edges.**	
Test Case ID	**RDNu01**	
Facility, Site	Bristol cluster	
Description	Test the performance of dedicated 5G network resources such as latency, and throughput between the core and various edges. For testing the network KPIs detailed in related test cases, dummy VMs were instantiated at each edge (M Shed, WTC). Throughput and latency tests were conducted between the dummy VMs (instantiated at each edge) and the 5G Core (MVB). iPerf3 was ran for 20 s to measure the TCP DL/UL throughput. Ping was run for 20 s to measure latency.	
Executed by	Partner: **UNIVBRIS**	Date: 03/10/2022 - 04/10/2022

Purpose	Pass/fail results; Pass if the Latency is <1 ms and Throughput is >1Gbps Note: Create two test records one for M Shed and another for WTC edge servers.
Scenario	Refer to the right scenario template used for the test (see Table 5-4)
Slice Configuration	N/A
Components involved	Dummy Linux VMs on OpenStack machines located at HPN, M Shed and WTC.
KPIs collected (Metrics collected)	DL/UL Throughput, Latency (RTT).
Tools involved	Iperf3, ping
Results and KPIs Primary Complementary	HPN (5G Core) – M Shed: DL/UL 9.3/9.3 Gbps , 0.46 ms HPN (5G Core) – WTC: DL/UL 9.3/9.3 Gbps , 0.46 ms WTC – M Shed: 9.3/9.3 DL/UL Gbps , 0.6 ms
Target metric/KPI and verification (pass/fail)	PASS

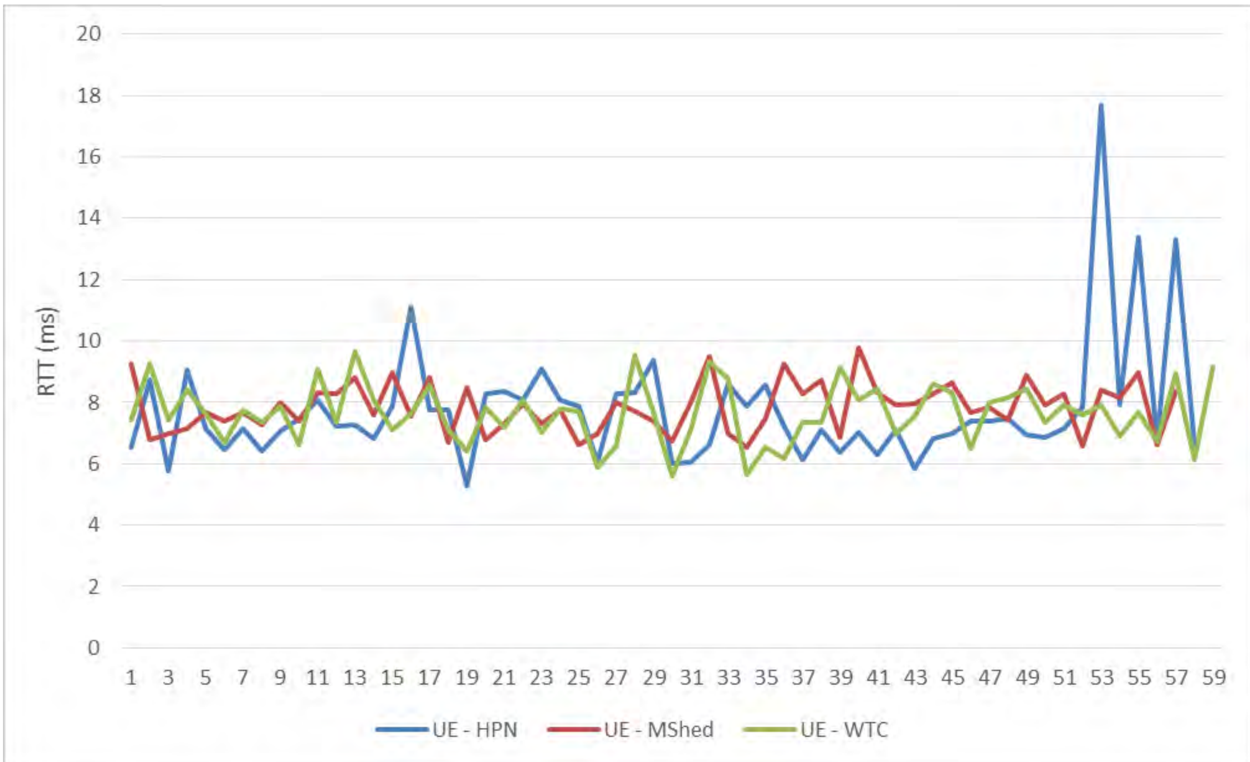


Figure 5-19 measured latency (RTT) for 1 minute test between UE and different edges (related to RDNu03)

Table 5-7 Test report: RDNu03

Field	**Throughput and Latency tests between UE and Core/Edges.**
Test Case ID	**RDNu03**
Facility, Site	Bristol cluster
Description	Throughput and latency tests were conducted between UEs connected to the 5GNR at WTC and the 5G Core (HPN) or the Dummy VMs (M Shed, WTC). iPerf3 with 50 parallel connections (-P50) was run for 20s

	to measure the TCP DL/UL throughput. Ping was run for 20s to measure latency.
Executed by	Partner: **UNIVBRIS** — Date: 03/10/2022 - 04/10/2022
Purpose	Pass/fail scenario 1: • Pass if the Latency between the UE and corresponding edges (M Shed, MSQ, and Nomadic node) is <100 ms **and** Throughput is >100 Mbps • Fail if the Latency between the UE and corresponding edges (M Shed, MSQ, and Nomadic node) is >=100 ms **or** Throughput is <=100 Mbps Pass/fail scenario 2: • Pass if the Latency between the UE and the Core is <500 ms **and** Throughput is >100 Mbps • Fail if Latency between the UE and the Core is >=500 ms **or** Throughput is <=100 Mbps
Scenario	Refer to the right scenario template used for the test (see Table 5-4)
Slice Configuration	N/A
Components involved	5G SA phone and 5G CPE, server (bare metal) / VM (OpenStack) hosting the 5G core (HPN for 5GUK edges or Nomadic Node), dummy VMs at edges.
KPIs collected (Metrics collected)	DL/UL Throughput, Latency (RTT).
Tools involved	Iperf3, ping
Results and KPIs Primary Complementary	HPN (5G Core) – UE @ M Shed: DL/UL (peak) : 315/8 Mbps, 13 ms HPN (5G Core) – UE @ WTC: DL/UL (peak) 700/100 Mbps, 12 ms Nomadic Node (5G Core) – UE DL/UL (peak) @ Amarisoft: 300/40 Mbps, 30 ms HPN (dummy VM) – UE @ Amarisoft: 280/35 Mbps, 70 ms M Shed (dummy VM) - UE @ WTC: 700/100 Mbps, 15 ms WTC (dummy VM) - UE @ M Shed: 315/8 Mbps, 15 ms
Target metric/KPI and verification (pass/fail)	PASS

Table 5-8 Test report: RDNu04

Field	5GUK Infrastructure test case for Multi-RAT Slice Deployment
Test Case ID	**RDNu04**
Facility, Site	Bristol cluster
Description	This test case demonstrates the performance of slice management, and in particular, it is aimed to validate the effective establishment of a network slice and measure the required slice deployment time, considering multiple Radio Access Technologies (RATs) such as 5GNR and Wi-Fi
Executed by	Partner: **i2CAT** — Date: 03/10/2022 - 04/10/2022
Purpose	Pass/fail results; Pass if the Slice Deployment time is < 90 mins. Deployed slice has to be validated by connecting a 5G SA UE and a Wi-Fi UE to the slice resources.
Scenario	Nomadic Node (see Table 5-4)
Slice Configuration	The test case comprehends one multi-RAT slice, which joins Wi-Fi and 5G SA RANs, and connects them to the deployed applications.

Components involved	eMBB slice, 5QI 9 Nomadic Node hardware (Amarisoft gNB, Wi-Fi 6 AP, switches, 5G CPE, servers, 5G SA UE and Wi-Fi 6 UE) and software (OpenStack, SDN controllers, OSM, ELK, i2CAT's Slice Manager and RAN Controller, MATI App 1).
KPIs collected (Metrics collected)	Slice deployment time
Tools involved	Ping and iperf to validate UE connectivity.
Results and KPIs Primary Complementary	Slice deployment time was about 1 minute.
Target metric/KPI and verification (pass/fail)	PASS

Report of KPIs being measured by MATI **App1**:

Table 5-9 Test report: RDIu01

Field	Mativision Synchronization Latency	
Test Case ID	**RDIu01**	
Facility, Site	Tested on boat from M Shed edge	
Description	Synchronization latency between master device and client devices	
Executed by	Partner: MATI	Date: 2022-10-04
Purpose	Test synchronization latency	
Scenario	see Table 5-4.	
Slice Configuration	Configuration of the slices (if any) and details about them with respect to above	
Components involved	Mativision Synchronization edge service	
KPIs collected (Metrics collected)	Synchronization latency	
Tools involved	Custom latency reporting	
Results and KPIs Primary Complementary	10-22ms	
Target metric/KPI and verification (pass/fail)	<100ms	

Table 5-10 Test report: RDIu02

Field	Mativision 360 VR Video Streaming	
Test Case ID	**RDIu02**	
Facility, Site	Tested on boat from M Shed edge	
Description	Bandwidth achieved by devices	
Executed by	Partner: MATI	Date: 2022-10-04
Purpose	Get the most common bitrate achieved by devices	
Scenario	see Table 5-4	
Slice Configuration	Configuration of the slices (if any) and details about them with respect to above	
Components involved	Mativision Backhaul storage server, Mativision edge caching service	
KPIs collected (Metrics collected)	Bandwidth in kbps	

Tools involved	Custom bitrate reporting
Results and KPIs Primary Complementary	5000-6000kbps
Target metric/KPI and verification (pass/fail)	>10.000kbps

Table 5-11 Test report: RDIu04

Field	**Mativision Edge Caching Performance**
Test Case ID	**RDIu04**
Facility, Site	Tested on boat from M Shed edge
Description	Network savings between backhaul server and UE devices
Executed by	Partner: MATI Date: 2022-10-04
Purpose	Test the network savings of the caching on the edge
Scenario	see Table 5-4
Slice Configuration	Configuration of the slices (if any) and details about them with respect to above
Components involved	Mativision Backhaul storage server, Mativision edge caching service
KPIs collected (Metrics collected)	Network savings in percentage
Tools involved	bmon[1]
Results and KPIs Primary Complementary	49-60%
Target metric/KPI and verification (pass/fail)	>30%

The monitoring data generated by **App1** are stored in 5G-VIOS Monitoring database and were visualized by 5G-VIOS Portal. The plots of Figure 5-20 show monitoring data i.e., the master delay and bandwidth, (**RDIu01** and **RDIu02**, respectively) for a timeframe of 9 minutes while the application were running during the October's 2022 Field trial in Bristol.

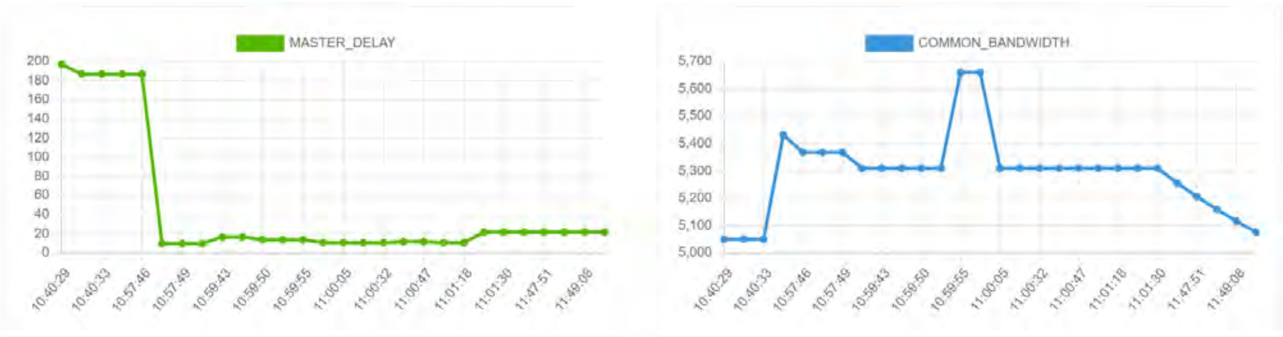


Figure 5-20 5G-VIOS Monitoring MATI App1

[1] **bmon** is a monitoring and debugging tool to capture networking related statistics. **MATI** uses bmon to monitor the traffic coming in and going out of the caching server at any given time and also uses the tool to compare the volume of data received and transmitted during streaming.

5.2.7 KPI evaluation and Conclusions – Lessons learned

The 5GUK testbed could deliver a satisfactory service provision along most of the demonstration route. However, depending on the users' locations, the throughput and latency performance of the 5G link varied significantly. This performance variation also affected the wireless connectivity between the Nomadic Node and the rest of the 5GUK network/edges. Networks services for future mobility should always take into account these performance variations and be able to efficiently protect the e2e service provision.

Furthermore, regarding **App1** NSs, **MATI** tested both the synchronization and caching services on multiple devices running in parallel. The latency when synchronizing the devices proved to be ultra-low and provided fast synchronization between devices. The devices didn't receive the full allotted bitrate provided from the storage server and **MATI** will be further investigating how this can be improved in the coming months.

5.3 App2: MATI VR Multicamera Live streaming at UNIVBRIS campus

App2 not only demonstrates 360° VR Live streaming to multiple Users (one to many) but also demonstrates connectivity and bandwidth availability for multiple users at the same time. It focuses on exploiting the performance and added capabilities of the 5G Network to implement Remote Virtual Classroom Applications, which will deliver immersive training/education to remote groups of trainees. The Service will capture and deliver immersive content and applications and will offer the potential to connect remote educational/training facilities across Europe:

Lecturers who are in any one of the connected locations, will be able to deliver lectures as immersive VR immersive experiences to full classrooms of trainees/students, who will be wearing appropriate 5G-enabled VR headsets. The students will have the impression that they are sitting in the lecture theatre from which the Lecturer is delivering the lecture.

5.3.1 UC testing objective and deployment

App2 demonstrated the use of a streaming high bitrate 360 video stream, live to multiple end user devices moving around the city of Bristol. The deployment of **App2** consisted of a streaming server hosted at the backend – Smart Internet Lab (HPN) – and an edge caching service that each end user device connected to. The 360 video camera was connected to the network in **UNIVBRIS** Smart Internet Lab and pushed the 360 video content via RTMP to the backhaul streaming server. The streaming server split the content into chucks that can be easily cacheable on the edge service. The test consisted of running the 360 video live stream on multiple devices at the same time.

5.3.2 App2 Slice description (with application components) and Network diagram

Figure 5-21 shows the **App2** NSs deployed at each edge. The details of the corresponding 5G components and equipment are provided in section 5.1. For the needs of the field demo, a 360 camera was connected to the 5GUK network at HPN. The camera could provide connectivity over Ethernet or Wi-Fi. **UNIVBRIS** also made it possible to connect the camera over the 5G network using a 5G CPE device. However, due to the lack of stable 5G connectivity at the HPN edge, the camera was finally connected using Ethernet.

5.3.2.1 Lab Deployment

As opposed to the latest field trial in October, May's 2022 test was limited to two edges: HPN and WTC. Being the first test to include a multi-edge deployment, the number of edges was set to a minimum and the basic inter-edge functionality was tested with all necessary components (see Figure 5-22) such as the 5G-VIOS, Edge-Proxy, Monitoring and Profiling, Streaming and Cache Servers (**Apps 1** and **2**), etc. The test helped the Bristol cluster discover several issues and bugs in the applications as well as the network which were successfully resolved. This was an essential part for the successful filed trial-demo in October 2022 with the network and services being fully operational while being deployed across the whole network.

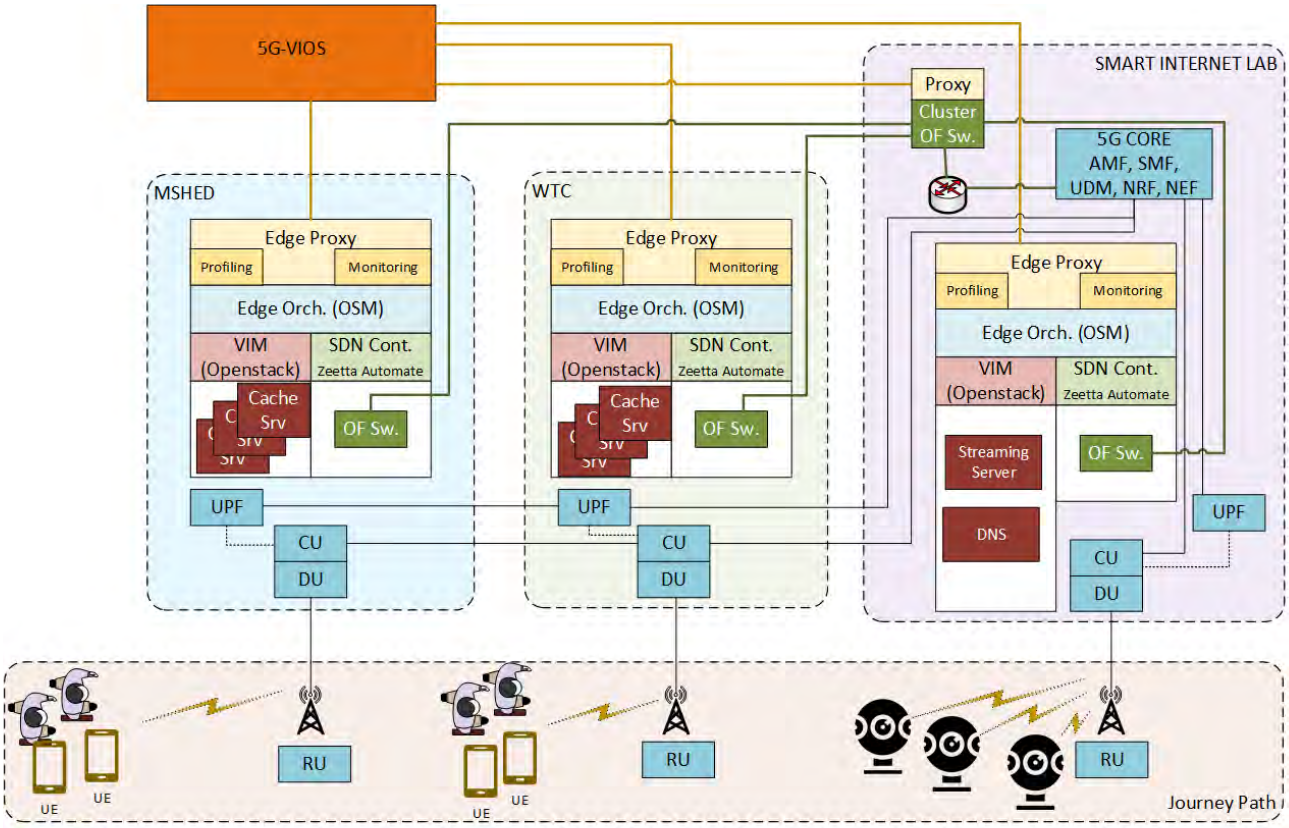


Figure 5-21 Bristol Facility- E2E architecture to demonstrate Digital Mobility UC, App2

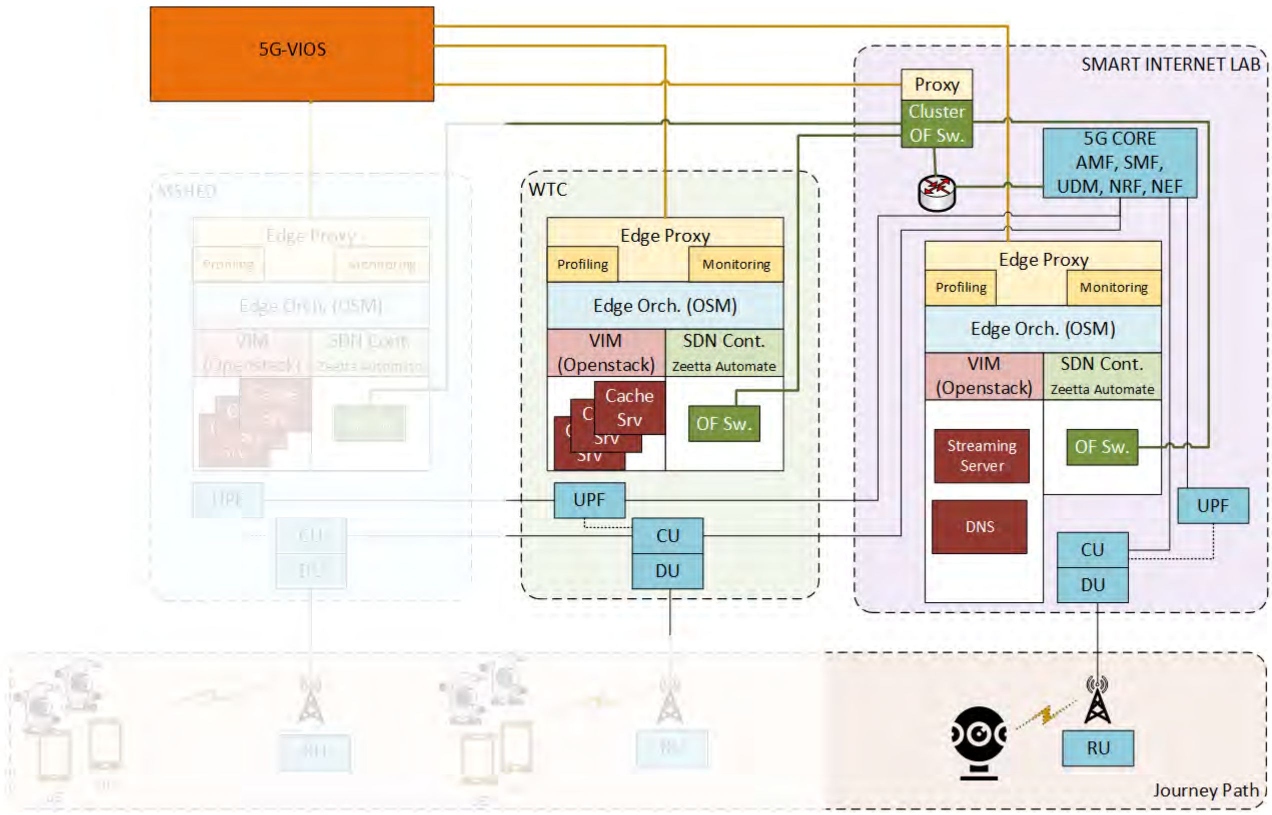


Figure 5-22 Bristol facility's lab trial setup in May 2022 to demonstrate Digital Mobility UC, App2

5.3.2.2 Facility for testing

Please refer to section 5.1.3 and Figure 5-6 for the e2e architecture configured to demonstrate **App2** during the Bristol Field trail in October 2022.

5.3.3 Test Cases and KPIs

The KPIs measured by **App2** are:

- The bandwidth achieved by each device, reported individually to the edge service. The edge service calculates the mean of all reported metrics and posts it to the 5G-VIOS reporting tool (test-case **RDLu01** [8][9]).
- The latency between the request for an edge service and the edge service being up and running (test-case **RDLu02** [8][9]).
- The network benefits of using an edge caching service and reduction in network load of the backhaul server (test-case **RDLu03** [8][9]).

Table 5-12 App2 test cases and KPIsTest case group RDLu

Test case name	Place	Key Use-case requirements and KPIs	Network performance requirements and KPIs	
RDLu01	M Shed, UNIVBRIS		Bandwidth achieved	>10000 kbps
RDLu02	Not tested		Latency achieved	<60s
RDLu03	M Shed, UNIVBRIS		Network savings	>30%

5.3.4 High Level 5G Deployment Scenario Description

Refer to section 5.2.4 and Table 5-4 for the 5G deployment scenarios also valid for deploying **App2** in corresponding edges (Smart Internet Lab, WTC, M Shed) at 5GUK Test network.

5.3.5 Experiment Description

Table 5-13 provides the experiment descriptor related to MATI **App2**. Please refer to the section 5.2.5 for more details about how an experiment descriptor will be utilised by 5G-VIOS and specifically by the 5G-VIOS Profiler.

Table 5-13 Experiment Descriptor related to MATI App2

	Value	Comments
ExperimentType	Standard	
Automated	True	
TestCases	Test Case 2	
UEs	UE1, UE2	UE Models are provided in section 5.2.6.
Network Slice	Mativision_App2_streamingserver Mativision_App2_cacheserver	The required network slices to run App2 NSs at corresponding edges. Refer to section 8.2 for more details.
Network Services	NSD IDs: 5867207d-c4a7-4c88-bb8c-9fd2479d0c89, 3ac5d3de-81f3-45d2-b2f8-1b49cf9d3061	Details are provided in Section 8.2.4
Network Scenario	Scenario 1	

Exclusive Execution	True	
ReservationTime	N/A	
Application	Mativision_App2	
Performance targets & SLAs	Network Service KPIs: • cpu_utilisation: 0.98, • memory_utilisation: 100 Application KPIs: • Bandwidth: 300000	The target KPIs include the Application KPIs, Network Service KPIs, etc. These KPIs will be used by 5G-VIOS profiler to find the optimum configuration of resources to assign to NSs and then through the Experiment Life Cycle Management, send alerts if the NSs are not meeting these KPIs in real time. Note: these KPIs (name and/or value) can be updated based on each experiment.
Experiment Parameters	Minimum and Maximum configuration of Resources: cpu: • min_cores: 2, • max_cores: 8 memory: • min: 200, • max: 1000 link_capacity: • min: 400000000, max: 1400000000	The Minimum and Maximum configuration of resources. The 5G-VIOS Profiler will use them to profile the NSs and predict the optimum configuration of each resource (a value between min and max) utilising ML techniques to assign to each NS.
Edges		{VLANs: 144, 146, 148, 150, Edge_IDs}
Remote	N/A	
Remote Descriptor	N/A	
Version		
Extra		

5.3.6 Experiment execution and Reports (with reference to WP3 methodology)

During the Bristol Field Trial (03-05 October 2022), for **App2**, MATI ran the caching VM of the application, instantiated through 5G-VIOS while keeping the streaming server VM close to the 360° video camera. The 360° video camera was placed in the Smart Internet Lab and we tested streaming high bitrate 360° video content for more than 15 hours throughout the two days of the 5G-VICTORI field trial. The stream was cached on the caching VM which was migrated to multiple edges. The 360° video content was played back on multiple devices while on the move around Bristol. The metrics were reported through the cache server back to 5G-VIOS and were displayed on the visualization page of 5G-VIOS.

Table 5-14 Test report: RDLu02

Field	Description	
Test Case ID	**RDLu02**	
Facility, Site	Tested on boat from M Shed edge	
Description	Bandwidth achieved by devices	
Executed by	Partner: MATI	Date: 2022-10-04

Purpose	Get the most common bitrate achieved by devices
Scenario	see Table 5-4
Slice Configuration	Configuration of the slices (if any) and details about them with respect to above
Components involved	MATI Backhaul storage server, MATI edge caching service
KPIs collected (Metrics collected)	Bandwidth in kbps
Tools involved	Custom bitrate reporting
Results and KPIs Primary Complementary	~4000 kbps
Target metric/KPI and verification (pass/fail)	>10.000 kbps

Table 5-15 Test report: RDLu03

Field	Description	
Test Case ID	**RDLu03**	
Facility, Site	Tested on boat from M Shed edge (Table 5-4)	
Description	Network savings between backhaul server and UE devices	
Executed by	Partner: MATI	Date: 2022-10-04
Purpose	Test the network savings of the caching on the edge	
Scenario	see Table 5-4	
Slice Configuration	Configuration of the slices (if any) and details about them with respect to above	
Components involved	MATI Backhaul storage server, MATI edge caching service	
KPIs collected (Metrics collected)	Network savings in percentage	
Tools involved	*bmon*[2]	
Results and KPIs Primary Complementary	*45-61%*	
Target metric/KPI and verification (pass/fail)	*>30%*	

5.3.7 KPI evaluation and Conclusions – Lessons learned

MATI tested live streaming 360 video on multiple devices with edge caching enabled. The live stream provided an excellent experience when running on multiple devices with quick buffering. The next steps are to test high bitrate video with transcoding enabled on the streaming server and edge caching of multi-bitrate streaming to a larger number of devices.

5.4 App3: UHA Future Mobility

UHA's Future Mobility UC is about passenger guidance outdoors and indoors based on OpenStreetMap GIS data and Lidar scans. The visual experience is streamed from GPU cloud to

[2] **bmon** is a monitoring and debugging tool to capture networking related statistics. Mativision uses bmon to monitor the traffic coming in and going out of the caching server at any given time and also uses the tool to compare the volume of data received and transmitted during streaming.

front-end in a low latency high bandwidth 5G environment. Please refer to deliverable D2.3 [4] and deliverables D3.1 and D3.2 [8][9] for more details on this UC.

5.4.1 UHA Future Mobility testing objective and deployment

The test's main objective for Bristol's field trail in October 2022 was to demonstrate the system up and running and fully connecting Back- and Front-ends while deploying multiple end users. Live sharing of the back-end was via WebRTC that required the ICE servers. Thanks to the STUN server users could connect peer to peer with the Back-end located in UHA's Bristol offices. One video and two data channels were established. Users could collaboratively interact with the situational awareness map of Bristol Central running at back-end.

5.4.2 UHA Future Mobility Slice description (with application components) and Network diagram

Figure 5-23 shows different NSs of Future Mobility Application aiming to be deployed at each edge. It is worth mentioning that these NSs (UHA Future Mobility App) were not integrated into the 5GUK test Network as well as to the 5G-VIOS during the October's Field trail in Bristol. UHA plans to integrate **App3** to the 5GUK Test Network as well as 5G-VIOS until the submission of deliverable D4.3.

Refer to section 5.1.3 and Figure 5-6 for more details on the 5G equipment at each edge. Please note that Slicing does not apply to the Future Mobility UC.

5.4.2.1 Architecture @ Lab

UHA operated a live simulation streaming data from the UHA office over the 5G network – as well as comparative connections from non-5G enabled devices. This was to validate the comparative performance and feedback of the 5G connected devices (both the native devices) and the 5G Mobile Hotspot node. Additionally, UHA performed some tests to pull in Mobile Scan data – from both a Stereo Neural Camera and Lidar enabled simultaneous localization and mapping (SLAM) device – as well as photogrammetry data. Some GPS tracks were also collected – however these haven't been implemented yet. Refer to D3.2 [9] for more details on the lab setup and the corresponding lab results.

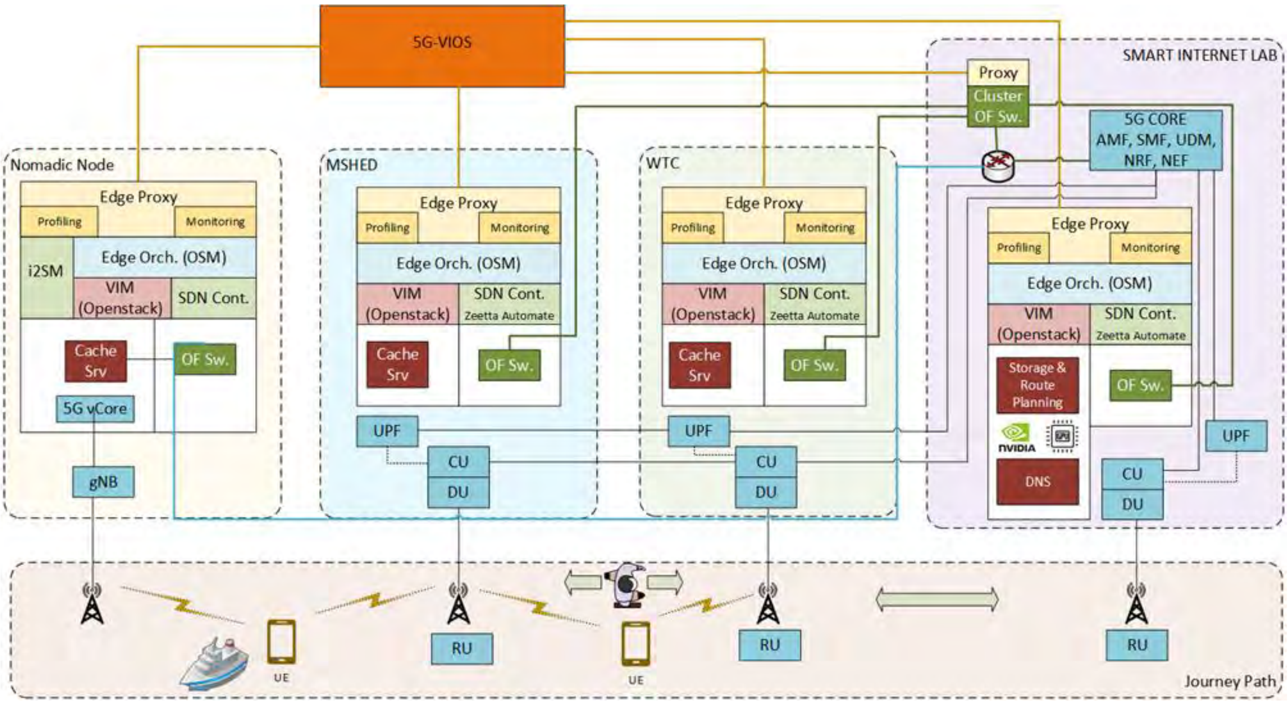


Figure 5-23 Future Mobility App- Network Diagram including related Network Services at each edge

5.4.2.2 Facility for testing

The Basic workflow as shown in Figure 5-24 is: Server > Web RTC Stun / Turn Server > End user device. We were able to show the mentioned live interactions and network resolutions (see section 5.4.2.1) over multiple connection methods supported the E2E test – and we had 8 concurrent users on the Mathew vessel interfacing with the simulation.

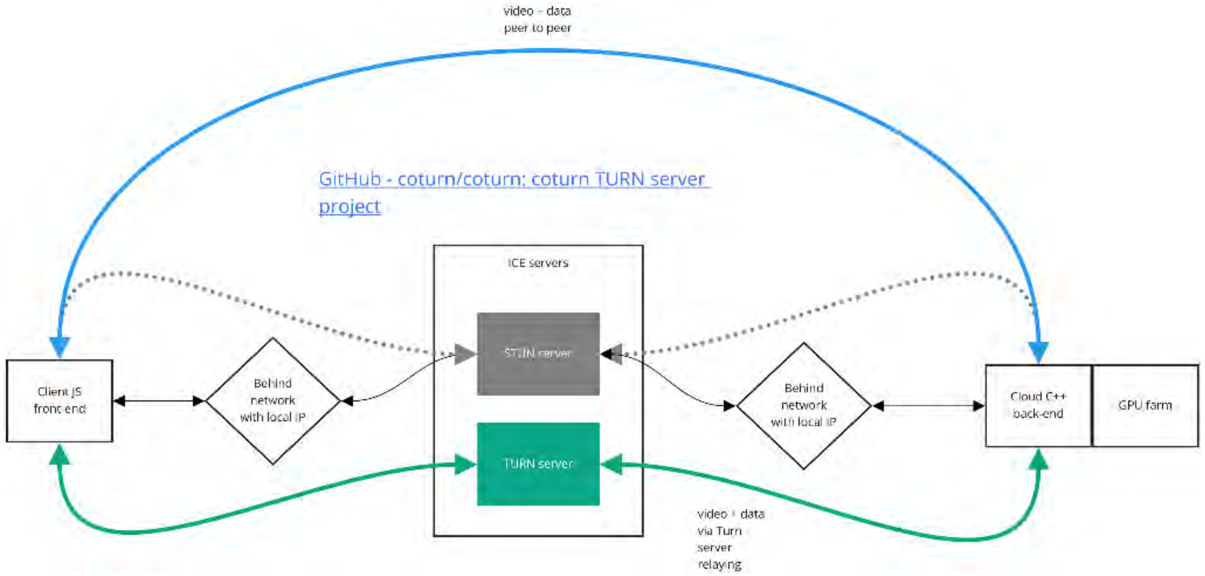


Figure 5-24 Future Mobility App- UHA network WebRTC Diagram including network diagram and connections.

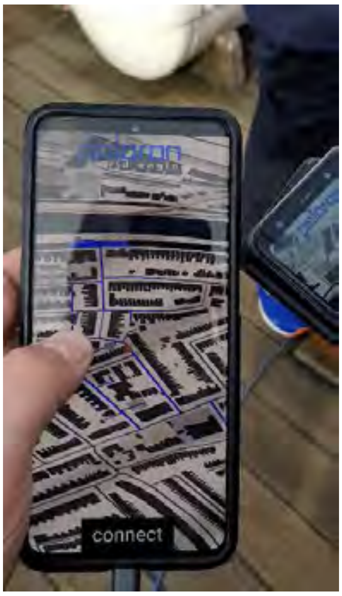


Figure 5-25 Future Mobility App- Live interactions using a dynamic walking map accessible concurrently via multiple phones and users. Edit and Read rights allowed change to the scene (e.g. Road closure / etc).

Figure 5-25 shows live interactions using a dynamic walking map accessible concurrently via multiple phones and users. Edit and Read rights allowed change to the scene (e.g. Road closure, etc.). This image is accessed via Web Browser on Android Chrome. Lightweight JS was used to deliver client side config to open / connect to WebRTC connection via STUN / TURN server.

Some outcomes of the Bristol field trial in October 2022 are listed in the following: Please refer to deliverable D2.3 [4] for more details on the Application specifics.

1) Custom developed C source code embedded WebRTC client into Polaron to permit live streaming.
2) Client JS file delivered via web browser (on Http opening).
3) STUN & Turn Server components (essentially a P2P and Connection Broker).
4) Backend Polaron (GPU / CPU).
5) Tested on both STUN & TURN server config – to allow both P2P connections and Connection brokerage
   - Important to have tested as the P2P connection might be the method to connect multiple Edge Based instances – else allow for Edge based hopping of the STUN / TURN server – which allows a simulation service to be located at the edge or connected via an Edge based node.
   - Issuing both GUI commands and other data types / format over the connection – and tested both 2D and 3D instances of Polaron (now merged – 21/11/22).

5.4.3 Test Cases and KPIs

List of KPIs measured by UHA Future Mobility Application (**App3**): Please refer to **D3.2** [9] for more details on these test cases' specifics.

- **RDFu01**: Future Mobility edge location spatial scanning/mapping (lab & field).
- **RDFu02**: Future Mobility communication between Backend, Frontend and Edge nodes (lab & field).
- **RDFu03**: Future Mobility high bitrate data distribution between Back-end and Edge nodes (field test).

5.4.4 High Level 5G Deployment Scenario Description

Refer to Section 5.2.4 and Table 5-4 for 5G deployment scenarios in corresponding edges (Smart Internet Lab, WTC, M Shed) at 5GUK Test network.

5.4.5 Experiment Description

A series of vignettes were loaded into Polaron and used to present a 2D & 3D experience – with both a guided experience and user driven experience. E.g. Scanning of the M Shed permitted us to present a full 3D model – whereas the 2D experience allowed users to query where they could reach from any point in Bristol in 10 min by foot. We also permitted the addition of impassable terrain (e.g. a closed footpath) as well as the addition of waterways and new roads (e.g. bridges) to permit simulation of change.

Finally, data was issued to and from the edge devices as well as using the local 5G network to issue larger files, such as 3D scans into Polaron and an estimation of the time to ingest made. Since this determines the round trip from scan to simulation – whereas the net upload speed is a function of network capacity (addressed in detail by other partners).

Lidar was able to be ingested in 0.3 - 0.7 second @10 cm resolution. Obj files from scan in approximately the same amount of time (near instant).

In the multiuser experiment we were able to scale up from one user, to two and we were able to support up to 8 concurrent sessions with full edit / read / write before encountering any noticeable latency. We believe that when we got to 8-10 this triggered a crash in our system due to some unforeseen bugs in our network and interface layers. This is currently being addressed and will be worked on further alongside **FhG** in the Berlin Cluster – as well as pushing a stream of data into their Unity based 3D experience.

5.4.6 Experiment execution and Reports (with reference to WP3 methodology)

In Bristol Field Trail (03-05 October 2022), **UHA** performed a series of demonstrations to facilitate different functionality and stress tests on the **App3** platform. This included a live dynamic multi-user mapping experience that permits a user to add in live updates to the map (new possible routes and blockages) to simulate user added data layers with multiple users adding and interacting in real-time.

UHA then used a combination of COTS phone scanning tech and high tech lidar, as well as some of the stereo cams taken in situ and a priori to present a 3d experience of the vessel, the M Shed and the surrounding area. Finally, UHA concluded with a stress test where we invited multiple sessions and users to the demo in order to drive network traffic and challenge the real-time routed traffic via both the 5G and 4G networks.

Next plan: to demonstrate the in-edge routing and streaming, UHA will look to conduct a post event validation of WebRTC on the edges via the Linux containers.

- **RDFu01**: Future Mobility edge location spatial scanning/mapping (lab & field)

For the Bristol field trial in October 2022, UHA scanned M Shed and the Matthew (boat) within the spatial error threshold described in earlier submissions (see Figure 5-26 and Figure 5-27 for scan of the Matthew boat and Figure 5-28 for M Shed). Lidar within tolerance – using OxRo supplied Velodyne Lidar and SLAM system. The key benefit here is the SLAM is conducted on the device at run time – permitting the near instant ingestion of a 3D model. Rather than conventional scanning methods. Please note that in Figure 5-28, maps were fused to provide the overall fused map. Scanning focussed on machine workshops and behind the scenes areas – which featured a lot of clutter and challenging scan locations.

Regarding the Photogrammetry via S20, it was tolerable (lower threshold than required – but supports use of COTS hardware (processed via device) - could be higher if using NeRF or Photogrammetry software to achieve tolerance.

Also, regarding the GPS tracker data, some issues existed with the updates – causing a highly erratic path. UHA plans to extract data in the future or re-map the pathway. It will be undertaken in the future – but sufficient to plot a path.

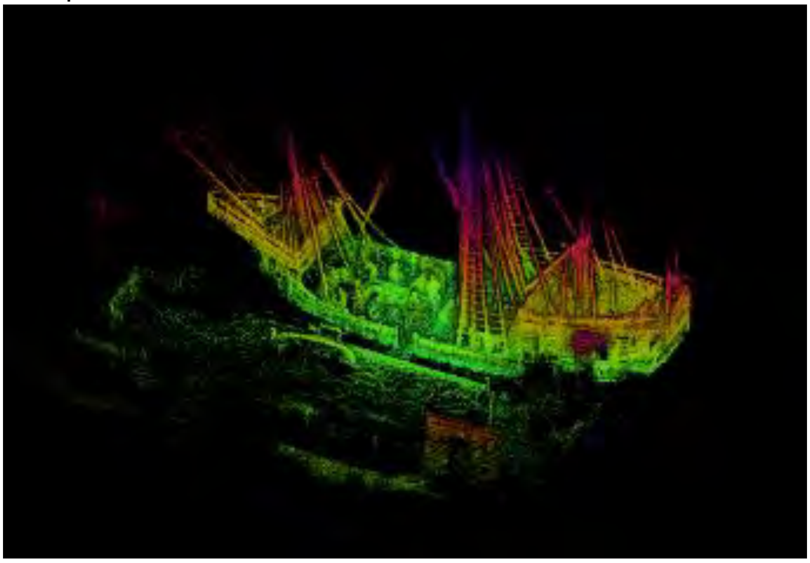


Figure 5-26 Future Mobility App- UHA Lidar scan of the Mathew boat


Figure 5-27 Future Mobility App-Photogrammetry (S20) to model in about a second

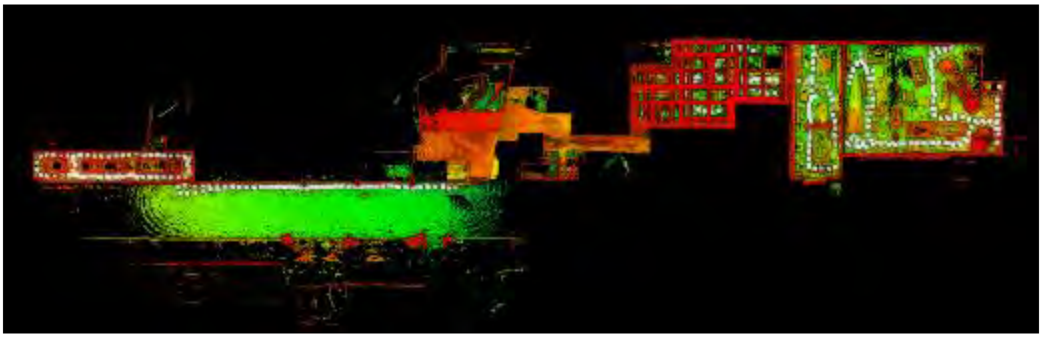


Figure 5-28 Future Mobility App- UHA M Shed scan via Lidar unit

Table 5-16 UHA Test report: RDFu01

	Description
Test Case ID	**RDFu01**
Facility, Site	Bristol cluster
Description	3D Spatial scanning of exterior and interior passenger relevant infrastructure.
Executed by	Partner: **UHA** Date: 2022-10-04
Purpose	To be used in indoor guidance with the Polaron Engine's route planner in the next phase of the project.
Scenario	
Slice Configuration	N/A
Components involved	Polaron Engine back-end (Windows, C++, OpenCL, WebRTC). Polaron Engine front-end (Android, vanilla Javascript, Web browser). Nvidia RTX 3090 GPU farm.
KPIs collected (Metrics collected)	Spatial resolution and error when registering separately scanned point-clouds.
Tools involved	Oxford Robotics SLAM sensor (from an earlier DARPA challenge).
Results and KPIs Primary Complementary	The whole of M-Shed and the Matthew were scanned between 1 to 10 cm accuracy.
Target metric/KPI and verification (pass/fail)	PASS

- **RDFu02**: Future Mobility communication between Backend, Frontend and Edge nodes (lab & field)

Multiple users (4) were live connected via WebRTC with the Polaron Engine's GPU back-end where the spatial scenario was running. The back-end was physically located in Bedminster Bristol (at UHA's offices) on optical fiber connection. 1 video channel and 2 data channels were established with each front-end. 2 data channels for dual communications where users were able to control the back-end experience from their smartphones. A 1 meter resolution map of Bristol central with an AI agent constantly doing route planning was streamed in H264 format. Users were able to alter the Bristol map from their phones where the AI agent instantly adapted to the new GIS landscape.

An average of 60 ms latency (see Figure 5-29) was measured which is a good result and also a biased one as it included additional delays caused by the Bedminster fiber connection and the Polaron Engine's own back-end. Therefore, the 5G side of the latency was even lower.

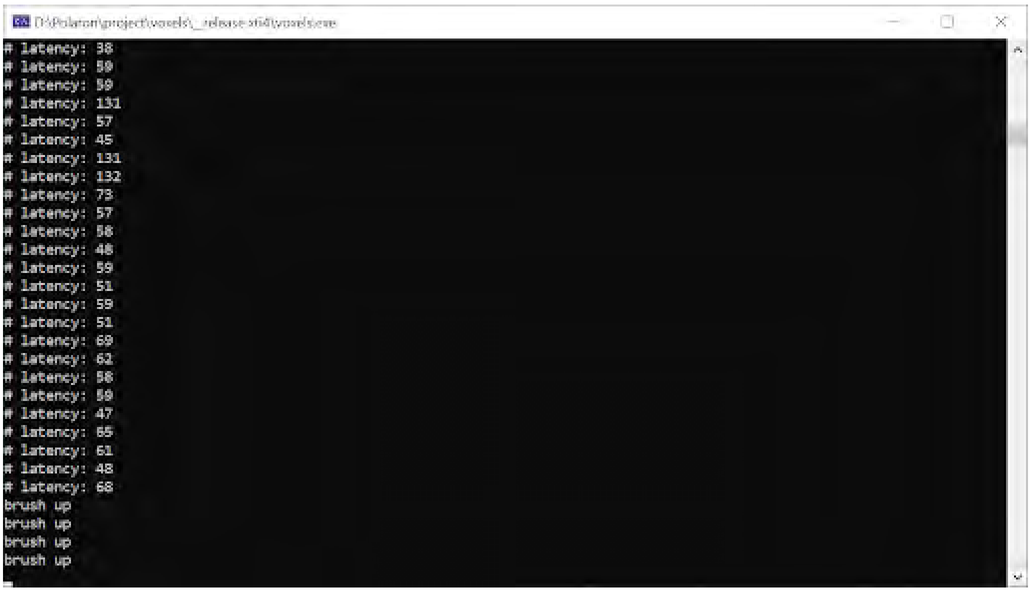


Figure 5-29 Future Mobility App- UHA Round trip latency – a listener and calculation for the net latency for the overall calculation of packet tracking from Device to Sim.

Table 5-17 UHA Test report: RDFu02

Field	Description	
Test Case ID	**RDFu02**	
Facility, Site	Bristol cluster	
Description	Future Mobility communication between Backend, Frontend and Edge nodes (lab & field).	
Executed by	Partner: **UHA**	Date: 2022-10-04
Purpose	To measure latency when a non-cached brute force simulation at back0-end is streamed to front-end users.	
Scenario	1 meter resolution map of Bristol central with an AI agent constantly doing route planning.	
Slice Configuration	N/A	
Components involved	Polaron Engine back-end (Windows, C++, OpenCL, WebRTC). Polaron Engine front-end (Android, vanilla Javascript, Web browser). Nvidia RTX 3090 GPU farm.	

KPIs collected (Metrics collected)	Latency between back and front-end.
Tools involved	WebRTC
Results and KPIs Primary Complementary	Successful connection and streaming with dual way data comm. Average latency of 60 ms measured.
Target metric/KPI and verification (pass/fail)	PASS

- **RDFu03**: Future Mobility high bitrate data distribution between Back-end and Edge nodes (field test)

Since the experience was run through smartphone browsers where WebRTC in compiled into the browser itself (machine code) we did not measure bandwidth use as of yet. A C++ front-end version has also been implemented, that is UHA's source code therefore most values measurable, but not yet operational in the Linux/Android environment. The Polaron Engine's 3D spatial data cache will be operational in the next phase of the project, that will also allow Edge side measuring of the arriving data packets, and from those bandwidth use projections can be given. WebRTC was compiled from source at Polaron's back-end, therefore also suited to measure most values in the coming phase.

- We expect the performance to improve – as we further develop our WebRTC component as well as potentially being able to run the WebRTC server on an edge based server.
- Polaron requires GPU acceleration and is Windows Native – therefore we pivotted from attempting a Linux rebuild – to creating a Linux based Web-RTC client – that can run at the edge and direct the traffic. When operated in tandem with dark fiber connections and a remote server – we would expect these latencies to at least halve. Although 38-131 ms over a range of 3G, 4G and 5G connections over different network topographies and speeds for this test is a useful benchmark for hybrid deployments of 5G and other communications technologies accessing a simulation via multiple pathways.

5.4.7 KPI evaluation and Conclusions – Lessons learned

UHA plans to improve their containerization efforts and processes to support the Edge computing.

Owing to multiple challenges – we had to concentrate our efforts on ensuring a stable WebRTC streamed experience over the different potential channels and ensure a fallback and multi-channel method. Some initially planned activations e.g. GPS based Geofencing for triggering different experiences – were then de-prioritised.

UHA has now provided a WebRTC Linux image to the Bristol Smart Internet Lab – which will permit a further e2e test and performance evaluation of the WebRTC Edge service – which will provide further feedback on the robustness and performance of the overall service. Owing to some technical challenges we were not able to implement this fully for the experiment and fell back to passing data through the 5G edge based system – rather than hosting parts of our service there.

UHA plans to finalize their spatial caching solution that can sit at Edge else deliver smaller payloads of data – whilst still delivering a cutting edge experience. This is part of our scaling up process and is not a single WP but requires maturation in many different domains. It is possible that we might leverage some of **FhG**'s Unity capabilities to deliver this – since as a game engine the simulation output can be decimated and rendered as a simplistic model – sufficient for some end user tasks.

UHA have committed to engaging with more conversations with **UNIVBRIS** and **DCAT** to ensure that we are more closely aligned on the expectations of the remaining phase of the project to for the integration into the 5GUK Test Network and the 5G-VIOS whilst also supporting the other clusters.

UHA have also begun to try and co-ordinate testing and data gathering exercises better between the clusters – to avoid a situation where we had to conduct a multi-day exercise in Berlin – then straight into a 5G field test in Bristol – which affected our participation in some of the networking and configuration meetings.

5.5 Conclusions

UNIVBRIS deployed a network with all the required integrations as part of the 5G-VICTORI deliverables. From Cloud, to MEC and 5G, the 5GUK testbed successfully delivered service provisioning at all network edges supporting the demonstration route for the October's field trial in Bristol. For this activity, the Cloud network was enhanced with numerous high-end servers capable of running the virtualized network and application functions for **App1**, **App2**, and **App3** (**Apps 1-3**). This activity was completed despite the rooftop fire and the limited access at one of the UNIVBRIS's edge nodes, the WTC Museum. For this trial, the 5G RAN was recovered by moving the Nokia gNB and 5GNR from WTC balcony to M Shed West rooftop creating an alternative cell for this demonstration. By doing so, we ensured that the demonstration route was properly covered by the 5GUK 5G network and the minimum threshold of KPIs were met for all APPs. Further computational resources were also installed at the network edges, including WTC, M Shed and the Nomadic Node, accommodating all the virtual functionality required to provide services for APPs 1-3. In addition, the set of different solutions and services developed by the partners involved in the Bristol demonstration (e.g. Zeetta Automate slicing solution, **i2CAT** Slice Management - i2SM, and DCAT's Amarisoft 5G-call-box and Wi-Fi Access Point) were fully integrated to the already existing testbed as well as the newly created Nomadic Node.

For **App1**, **MATI** tested both the synchronization and caching services on multiple devices running in parallel. For **App2**, MATI tested live streaming of 360 video on multiple devices with edge caching enabled. Both tests were run successfully, meeting the required KPIs and providing the expected quality of experience. For **App3**, UHA ran some basic tests of their solution where their application was implemented based on WebRTC and data streaming from the Cloud (MVB – HPN lab) to the edges over 5G connection. With additional integration of a GPU at the edge node and further testing App3 application services at the edge node could have created a better user experience for **App3**. Due to the limitations during the field trial the GPU resources were not available at any of the edges.

5G-VIOS was fully integrated to the 5GUK testbed and all the edges, including the Nomadic Node. 5G-VIOS was mainly hosted in the 5GUK Cloud (MVB - HPN), while some of its components, such as the edge proxy and edge monitoring were deployed at the edges. **App1** and **App2** were fully integrated to the VIOS ecosystem, supporting a dynamic e2e service creation and deletion at any network location (HPN, M Shed, WTC, Nomadic Node) while also storing the measured KPIs at each edge and then sharing them with the central profiling service. **App3** is planned to be integrated into the 5G-VIOS until the final field trial at the end of the project. In addition, all **Apps 1** and **2** NSs were profiled through the VIOS Profiler, and their profiling dataset were stored in Elasticsearch data repository. Finally, The VIOS Profiler could predict the optimum configuration of resources per each NS through utilising ML techniques. So, the VIOS could assign optimum resource values to each application.

Planning ahead for the final field trial in Summer 2023, the Bristol and Patras clusters will demonstrate an inter-cluster service provision involving App2. In addition, the Bristol and Berlin will demonstrate an inter-cluster **App3**. The inter-cluster communication will be implemented using a VPN-secured link between the sites over the internet. 5G-VIOS will provide the inter-cluster service creation, with the remote class being available at both clusters (in case of **App2**). The Nomadic Node will also be upgraded with additional computational resources and 5G RAN. For the final demo, Bristol cluster is not planning any field demonstrations, however, Apps1-3 demonstrations could take place inside the HPN lab using the Nomadic Node.

6 Technology Integration, Validation and field trials in AIM

6.1 Overall Facility Description

The FR/RO cluster field trials are performed in the Alba Iulia Municipality (AIM) facility at one location in the city center (Citadel) and around the city center. A detailed description of the network setup can be found in deliverable D2.3 [4].

The UCs that are shown in the FR/RO cluster are:

- **UC #1.2** Digital Mobility - Electric Bus connected to 5G SA network, running in the area of the 5G Site.
- **UC #4.2** Energy – Low-Voltage (LV) metering devices located in different municipality locations in the city, in the area of the site coverage.

Figure 6-1 shows the 5G-VICTORI Digital Mobility **UC #1.2** and **UC #4.2** demonstration setup locations in FR/RO facility.

The location corresponds to the Orange Romania (ORO) network edge deployment of the 5G SA infrastructure and related computing capacity for the UCs running in real life deployment in a multi-slice environment, answering to the UC requirements in terms of connectivity.

6.1.1 5G Deployment Setup and Testbed Expansions

FR/RO facility is based on the ICT-17 5G-EVE platform, whose baseline infrastructure has been initially described in deliverable D2.2 [3]. The 5G-VICTORI FR/RO facility has been built extending the ICT-17 5G-EVE facility in France, providing 5G services and 5G functionality to the Romanian sites, i.e. the Bucharest and AIM locations.

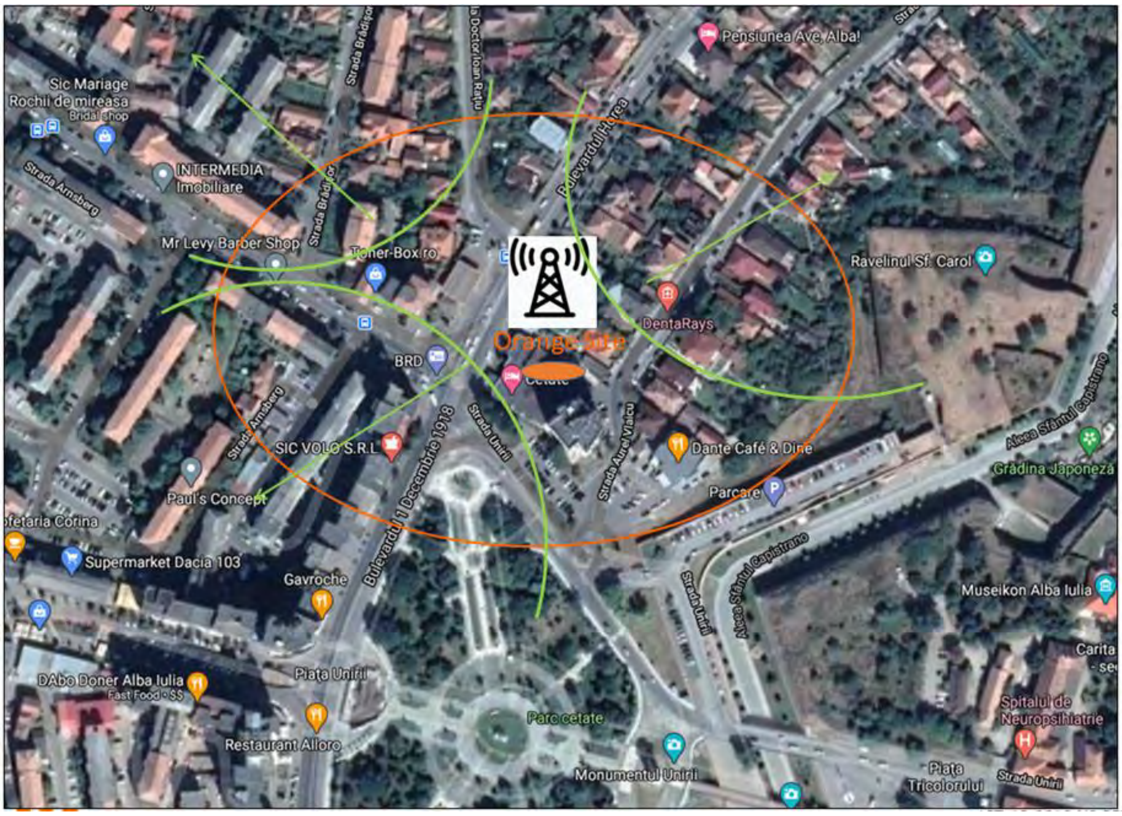


Figure 6-1 FR/RO cluster UCs demonstration area

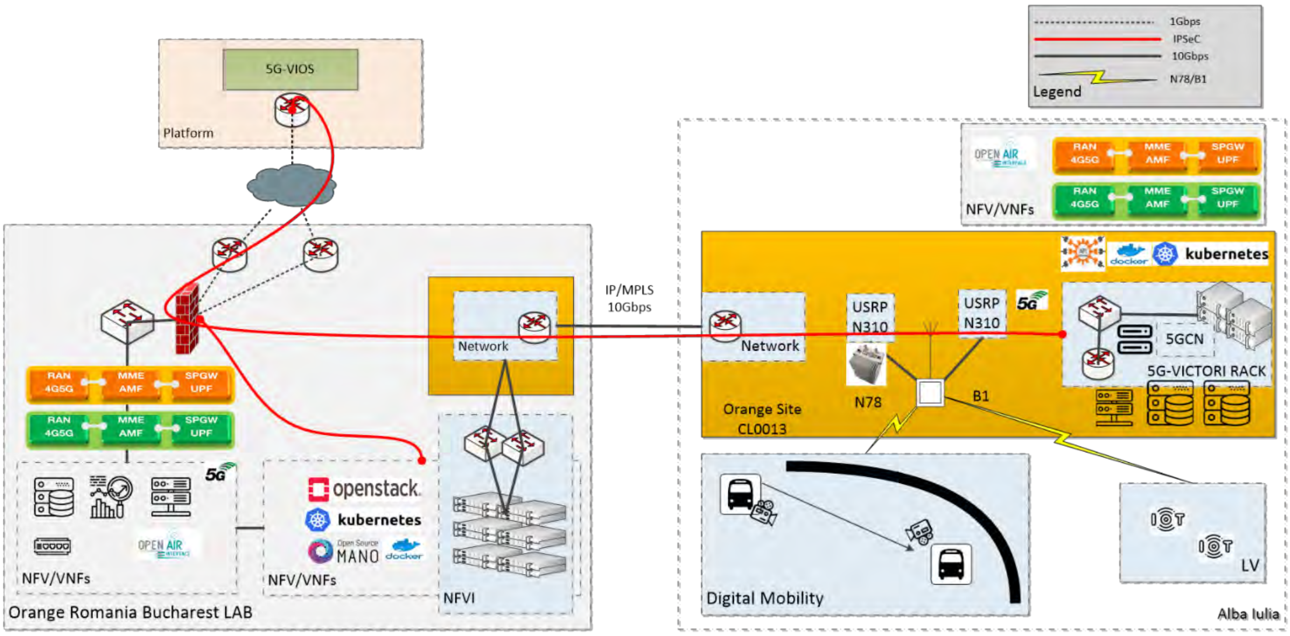


Figure 6-2 High-level network design Romanian facility

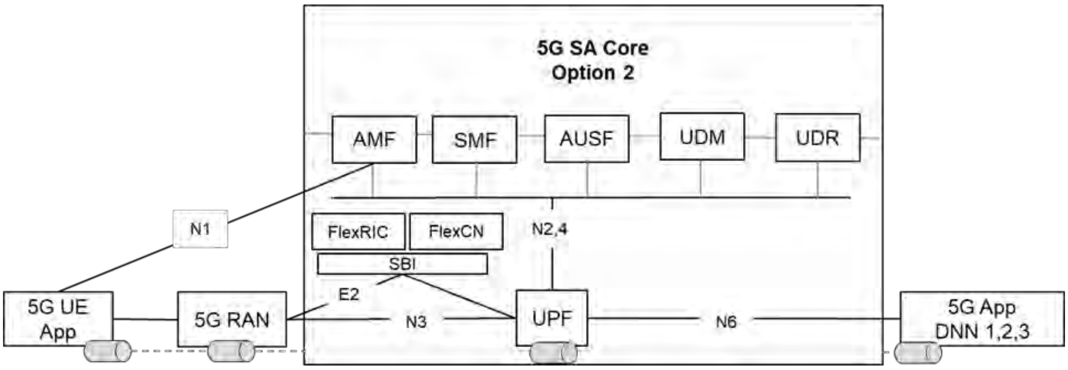


Figure 6-3 FR/RO 5G-OAI SA RAN and Core Architecture deployment

The high-level network design to support the planned services is highlighted in Figure 6-2, describing the main architectural cluster components for the UCs services instantiation and experimentation. For clarity, all the 5G components have been integrated and tested from 5G services and 5G network functionality, as it has been demonstrated in AIM within the live scenario. The network architecture implemented is as described in Figure 6-2, highlighting the network design and components, including the 5G-VIOS, 5G SA network (RAN and Core) and the virtualized environment cluster where the network functions are deployed.

The 5G deployment in the FR/RO cluster is based on the OAI 5G Stack implemented at the ORO facility. It integrates the RAN, CN software and hardware components for 5G SA systems. These are described in detail in deliverable D2.3 [4], together with the software functions and interfaces integration (cf. Figure 6-3).

The current 5G system for testing, is described as:

- 5G SA option 2 in ORO
  - AMF, SMF, UPF (SPGWU), NRF, UDM, UDR, AUSF, MYSQL
- FLEXRIC
  - O-RAN-compliant flexible RAN intelligent controller allowing to perform slicing in the RAN domain.

The tested setup scenario in the field is depicted in Figure 6-4. The same hardware components and software solutions were used at the laboratory.

Figure 6-4 5G demo setup in real field environment (AIM)

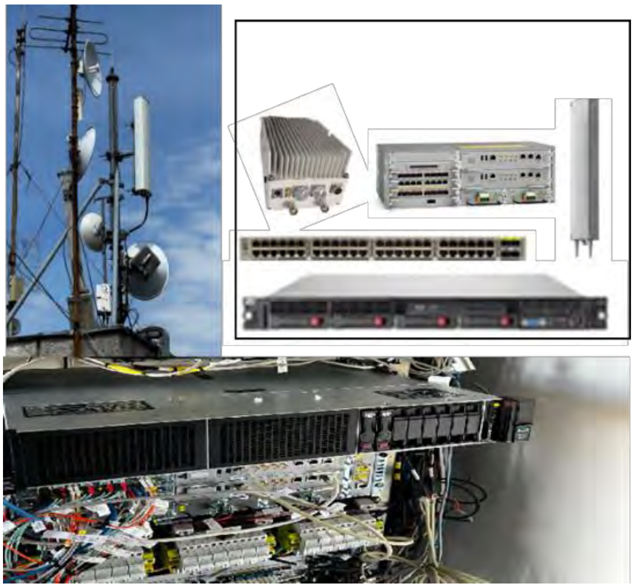


Figure 6-5 5G SA software and hardware components

The components presented in Figure 6-5 are briefly described in the sequel. The reader can refer to deliverable D2.4 [5] for additional details:

- 5G SA option 2 network ready in the field, 1st RAN/Core real life environment implementation
  - Hardware
    - Compute infrastructure(HPE)
    - IP/Network (Cisco)
    - Security/Access(Fortinet)
    - RHU(2x2 MIMO)
    - 5G Antennas(2x2 MIMO)
  - Software
    - Kubernetes
  - 5G OAI for 5G SA RAN/Core running in virtualized infra(K8s)
- Radio spectrum:N78 [50MHz]
- Readiness for open infrastructure for components integration (5G-VIOS)
  - Integration framework 5G-VIOS portal

Figure 6-6 5G SA deployment in LAB environment

Table 6-1 5G Deployment setup FR/RO

Technology	5G-EVE for UC #1.2 and UC #4.2
Open- Source	OpenAirInterface (mosaic5g)
SA/NSA	SA option 2
Cloud options	IaaS/CaaS • OpenStack • Kubernetes
MANO	OSMv10
Core	Mosaic5G Rel.16
RAN	Mosaic5G Rel.16
UE	Quectel /Huawei Multiple devices 2 network slices(eMBB/URLLC)

The deployment setup and software releases, related to the running UCs are described in Table 6-1, for the Open-RAN and Open-Core solution, Cloud implementation and orchestration and 5G SA 3GPP option.

6.1.2 FR/RO Facility deployments of 5G VICTORI architecture

The FR/RO architecture deployment is based on the 5G setup, as described in deliverable D2.4 [5] and contains the actual deployment and operation of the two use-cases running in FR/RO cluster, already evaluated though experiments and KPIs collection.

The FR/RO cluster UCs include Digital Mobility Services and LV Energy metering carried out in **AIM** are in accordance to the 5G system architecture of 5G-VICTORI and are mapped to the solution described in Figure 6-7.

The two UCs are running in parallel over a single 5G SA network, with each of the services flows running over a 5G configured slice respecting and preserving the traffic characteristics: traffic prioritization and low latency, broadband traffic or IoT traffic, as described in D2.1 [1]:

- eMBB Slice.
- Last Level Cache (LLC) slice – non-prioritized.
- LLC slice – prioritized.
- eMBB slice and LLC slice.

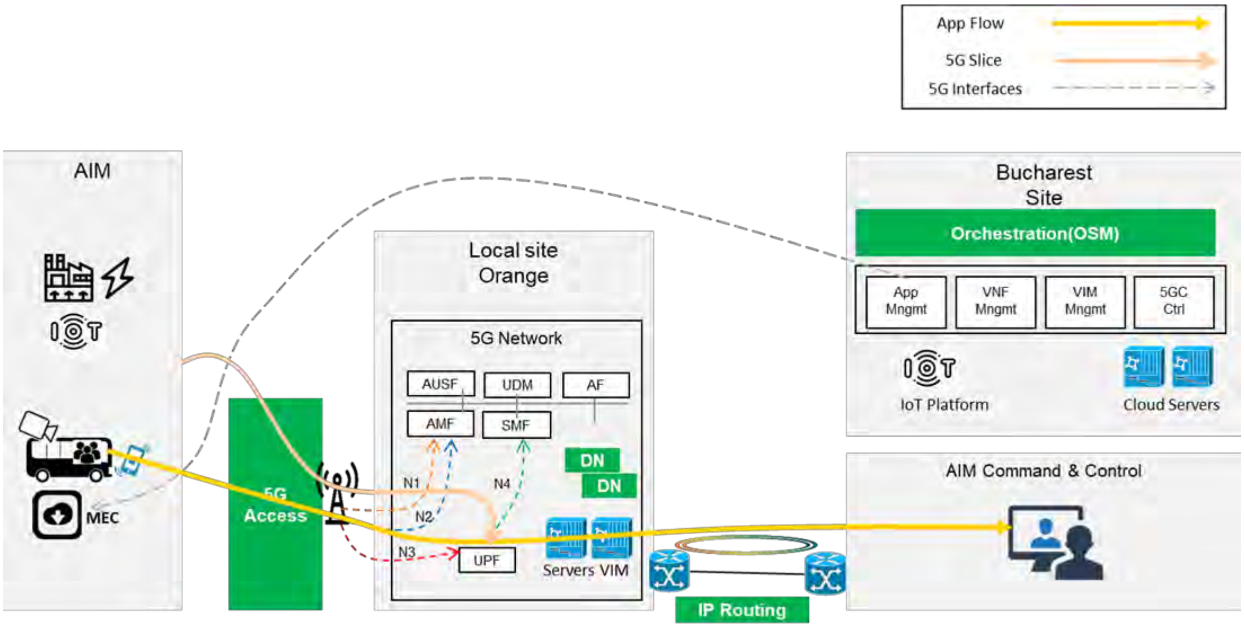


Figure 6-7 FR/RO UCs mapping on 5G architecture

The 5G system architecture and the integration of Apps in the network (see Figure 6-7) are fully implemented following several steps of integration and validation, in the lab and in the field:

- 5G Infrastructure deployment.
- 5G SA software blocks implementation.
- 5G SA network and 5G solution field functionality validation.
- 5G service slice implementation (eMBB/LLC).
- 5G SA 5GC, FlexRIC
  - O-RAN-compliant flexible RAN intelligent controller (RIC) allowing to perform slicing in the RAN domain.
  - With RAN slicing, the requested bandwidth is released and the required radio resources are allocated to the slice ensuring the required QoS.
- 5G SA setup & data traffic PDNs (UL/DL/latency), multiple-APNs.
- Integration with video analytics system.

The 5G deployment responds to the UCs service challenges in the field and implemented a 5G SA Open RAN/Open Core with the required network stability during the field trials. This demonstration is the first 5G SA deployment based on the open source OAI solution that has been carried out in a real operational environment. This network deployment is used to support real UCs in **AIM**, focusing on two main requirements: (1) Service slice prioritization and resources allocation for LLC traffic implementation and (2) Network triggering for the analytics application.

6.1.2.1 Infrastructure Layer (access, transport, edges, central data centre)

The FR/RO infrastructure layer involves an open source 5G SA deployment, described previously in deliverable D2.4, Figure 6-8, illustrates the mapping of deployed services over the 5G infrastructure. We have also defined and implemented the specific related interfaces for the required 5G SA functionality and services definition, interconnecting the 5G DNN interfaces to the ORO DC for application hosting in the cloud, able to cope with the testing scenarios described in Figure 6-8. The FR/RO 5G infrastructure is 3GPP Rel.16 compliant.

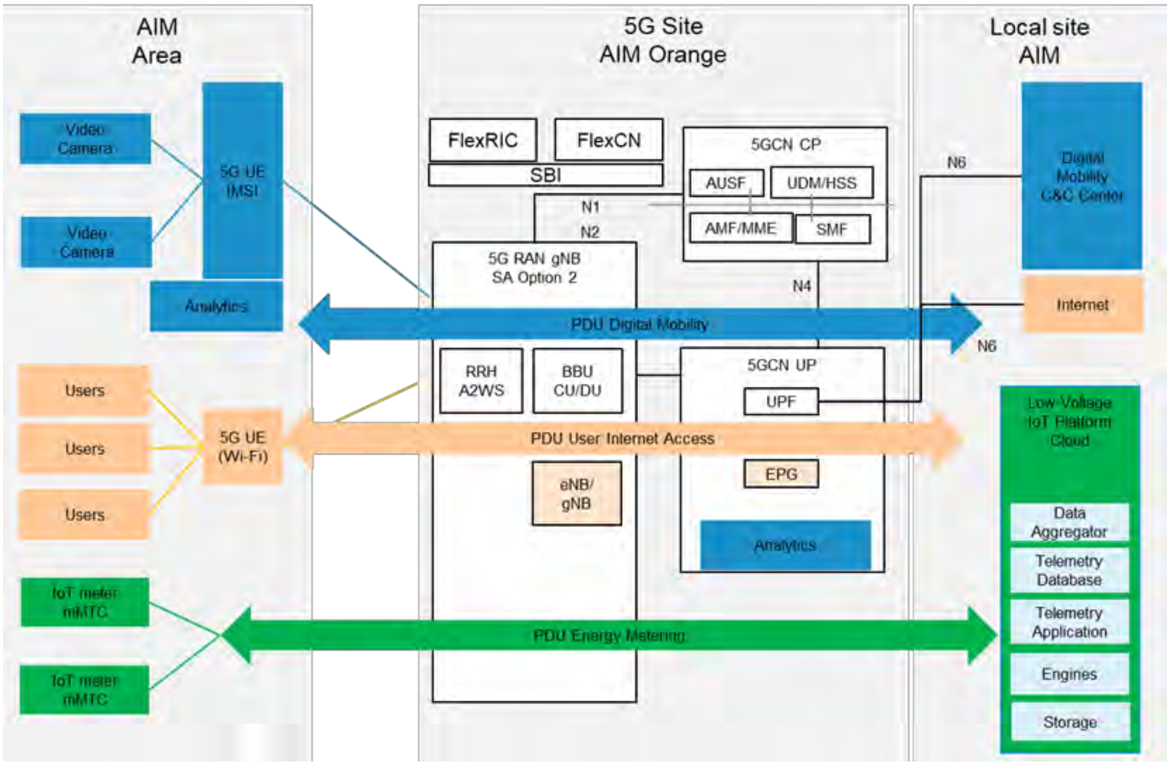


Figure 6-8 Service mapping to the 5G infrastructure

	UC Media - eMBB	*UC Media - prioritized URLLC*	*UC LV Energy - mMTC*	*UC LV Energy - mMTC combined*
Services tested	✓ user's data traffic as authentication, internet browsing, video streaming;	✓ single UE/Video cameras streams	✓ ~30 IoT devices running in parallel (sending data to Telemetry application)	✓ ~30 IoT devices running in parallel ✓ 3000 devices traffic simulated in the network in parallel
Measurements	• throughput tests Ookla & iperfv3 performance, network traffic	• data traffic • network latency • packet loss	• network load measurements	• network load measurements
FR/RO cluster combined test-case 1	x		x	
FR/RO cluster combined test-case 2		x	x	
FR/RO cluster combined test-case 3	x	x	x	
FR/RO cluster combined test-case 4	x	x	x	x

Figure 6-9 FR/RO combined 5G test case scenarios

Table 6-2 FR/RO Infrastructure software versions

Software	Version
docker engine	19.03.6, build 369ce74a3c
docker-compose	1.27.4, build 40524192
Host operating system	Ubuntu 18.04.4 LTS
Container operating system	Ubuntu 18.04

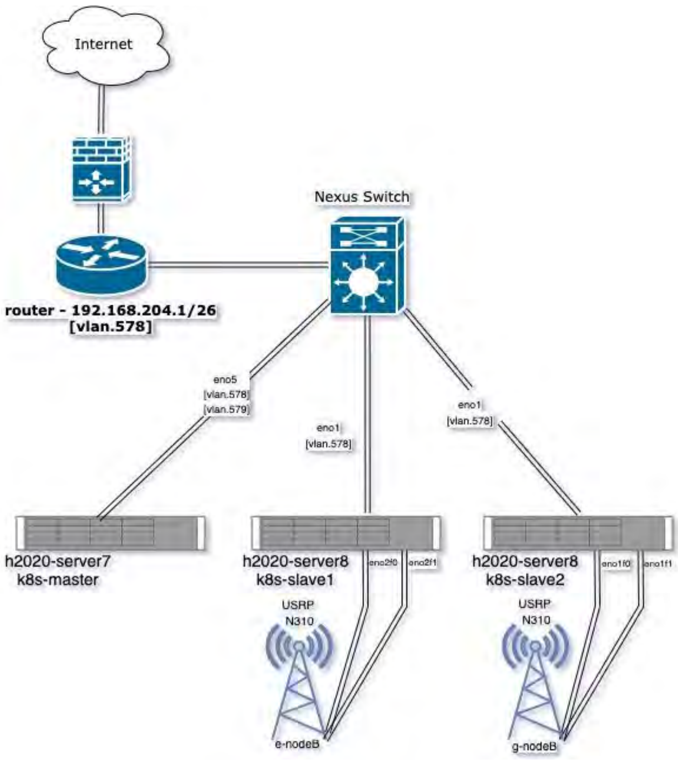


Figure 6-10 FR/RO Infrastructure layer implementation

The versions presented in Table 6-2 correspond to the infrastructure software on top of which we have built the 5G SA virtualized layer. Regarding the physical infrastructure (HPE servers and Cisco Routers, AWS2 RHU) we have implemented an e2e environment running the network illustrated in Figure 6-10. From the infrastructure layer perspective, all components are installed and integrated, as all the live demos have already been performed and relevant results (KPIs) have been collected.

6.1.2.2 Orchestration options

The FR/RO cluster is embedded with an ETSI MANO OSMv12 orchestrator, running in the ORO virtualized infrastructure and being connected to the IaaS/CaaS virtualized infrastructure, connected to the OpenStack and K8s environments. The two Virtualised Infrastructure Manager (VIM) flavours in the infrastructure provide the testbed with the capabilioty to deploy both Cloud Native Functions (CNFs) for 5G SA containerized software functions and VNFs/VMs for UCs Applications. The orchestration solution implemented in the FR/RO the testbed involves (Figure 6-11-Figure 6-13):

- testbed OSMv12 Orange's orchestrator that is compliant with the ETSI MANO architecture. This is offering an orchestrator tool that integrates with the infrastructure controllers and can build different VNFs and NSs across all the platforms within the 5G testbed (SOL005 ETSI Interface). It is connected and communicates with the VIM for the virtualized segments and from the container segment.

- OpenStack Ussuri distributed cluster based on containers.
- Container Kubernetes cluster.
- Rancher, containers orchestrator based on Kubernetes that is making easy for development, operations, testing and management of containers.

Figure 6-11 FR/RO cluster ETSI MANO orchestrator

Figure 6-12 FR/RO Cluster OpenStack VIM

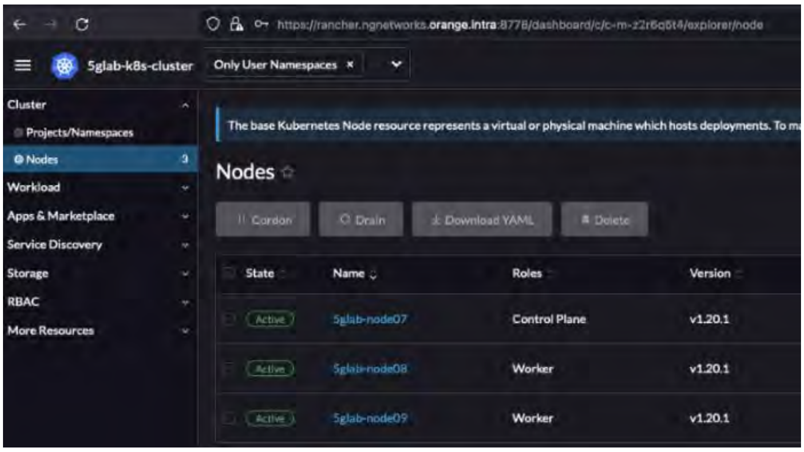


Figure 6-13 FR/RO Cluster K8s VIM

FR/RO virtualized infrastructure deployment is currently running in the ORO network, for both 5G SA software network components and for the UCs, as the testbed is capable to cope with automatic application deployments.

6.1.2.3 Monitoring

The FR/RO testbed is able to support network and services monitoring capabilities, the process of data collection of a variety of metrics, benefitting by different open software tools used for monitoring (e.g. Prometheus) and data presentation through dashboards. The monitoring capabilities focus on two main streams:

- Infrastructure monitoring, collecting the data from the infrastructure components, e.g. UE, RAN, Core network, Transport, virtualized infrastructure, MEC for analytics.
- Network and service performance monitoring, evaluating network resources, services status, users.

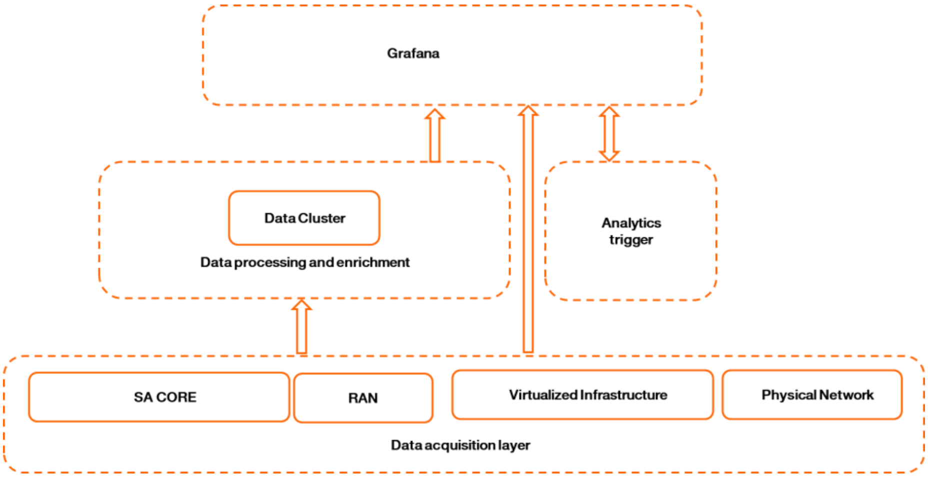


Figure 6-14 FR/RO monitoring cluster framework

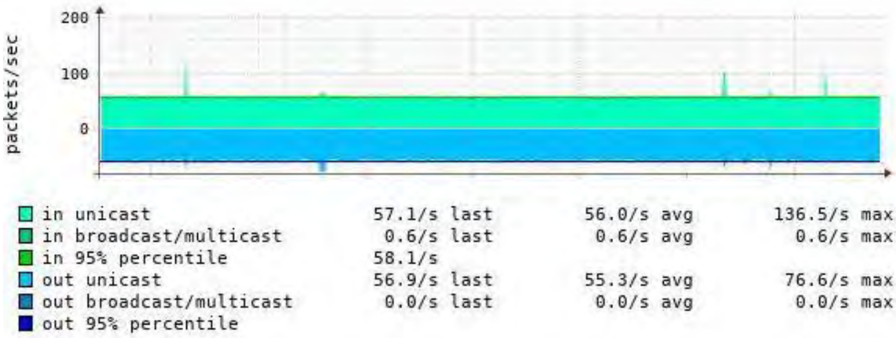


Figure 6-15 FR/RO cluster traffic load monitoring

For appropriate testing of the 5G SA communication services and UCs functionality, testing tools such as iperfv3, FTP have been used, and for the live streaming scenario the latency has been validated, using ping testing tools in the AIM demos.

6.2 UC #1.2 Digital mobility and public safety

UC #1.2 for digital mobility and public safety several applications have been used, namely:

- **App1**: Infotainment/ video services in dense, static and mobile environment.
- **App2**: AI recognition and identification of emergency situations.
- **App3**: Prioritized communication to command and control center.

Detailed UC descriptions can be found in deliverables **D2.1**, **D3.3** and **D3.5**.

6.2.1 UC testing objective and deployment

The FR/RO cluster network diagram for **UC#1.2** is described by Figure 6-16, including all software and hardware elements for the UCs' implementation and demonstration.

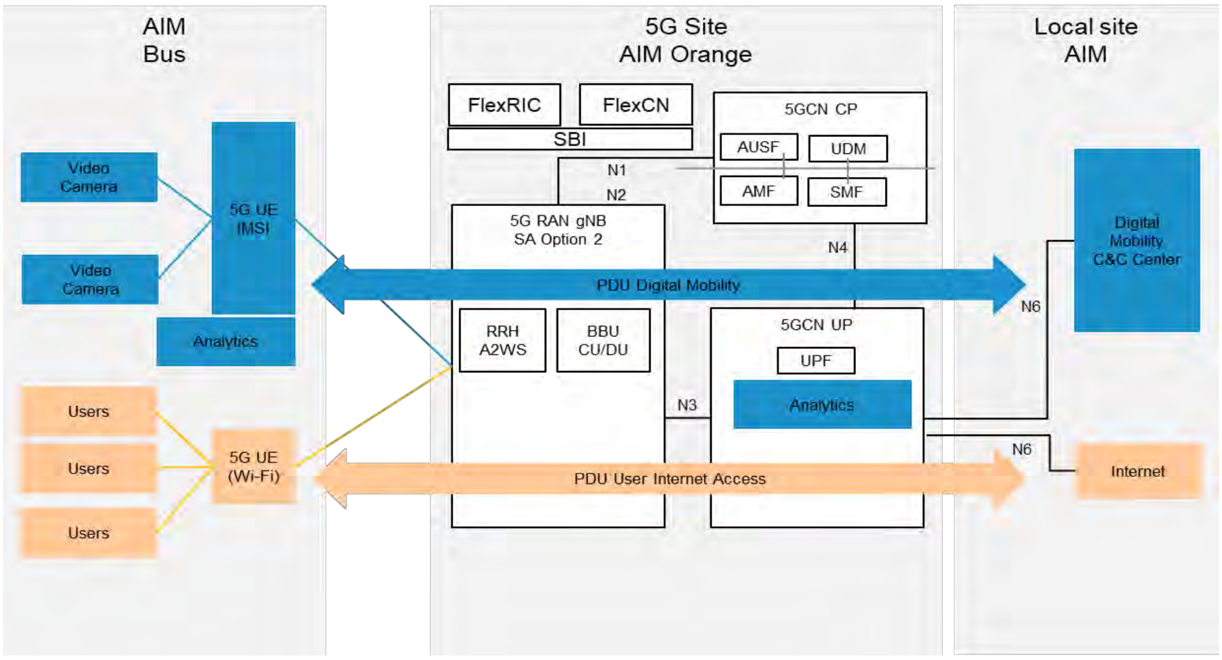


Figure 6-16 Digital Mobility Services mapped on 3GPP 5G-SA infrastructure

The UCs has been tested and validated in both scenarios, laboratory tests and live field tests with the following specificities:

- 5G UE and Video camera, the camera was located in a moving bus, connected to the analytics server (Edge Computing Component for video service), the communication component is provided over the Low Latency PDN slice.
- 5G SA Network, installed in Orange 5G site, as RRH/BBU, 5GCN core network components, network interfaces and local processing servers.
- Digital Mobility C&C, connected through N6 interface to the Emergency video services.
- 5G UE Wi-Fi, was located in the bus, providing Internet access through Wi-Fi, to passengers connected to the AIM service portal and internet, the communication component provided over the broadband PDN slice.
- Analytics application: performing real time video services analytics for the emergency UC.

6.2.2 UC1.2 Slice description (with application components)

We have configured two network slices, (1) the eMBB slice, as the DNN is connected to the internet for bus user access to different media types and (2) the URLLC slice, as the DNN is connected to the EDGE computing for analytics and traffic prioritization. The two network slices are configured and properly prioritized in the network based on 5QI and QoS parameters, as in Table 6-3 and Table 6-4.

Table 6-3 5G SA network slice configuration

Slice Name	Silce/Service Type	Slice Differentiator	Supported DNN
NSSAI-1	1	abcdef	eMBB
NSSAI-2	2	abcdea	URLLC

Table 6-4 5GQI QoS translation table

UPF 5QI Translation Table		
5QI	**DSCP**	**GBR/non-GBR**
1	EF (46)	GBR

2	AF31 (26)	
3	EF (46)	
4	AF32 (28)	
5	AF41 (34)	non-GBR
6	AF21 (18)	
7	AF22 (20)	
8	AF11 (10)	
9	BE (0)	

The two-network slices are configured in the network, based on the presented parameters and can be seen as an output in next Figure 6-17.

```
NSSAI
  Slice Name : NSSAI-1                              SST : 1    SD : 0xabcdef
  Slice Name : NSSAI-2                              SST : 2    SD : 0xabcdea
```

Figure 6-17 FR/RO UC#1.2 slice implementation

6.2.2.1 Lab Deployment

The lab architecture is shown in Figure 6-18 and implemented following the architecture and design presented in Figure 6-18. More details of this implementation and design can be found in deliverables D3.3 and D3.6.

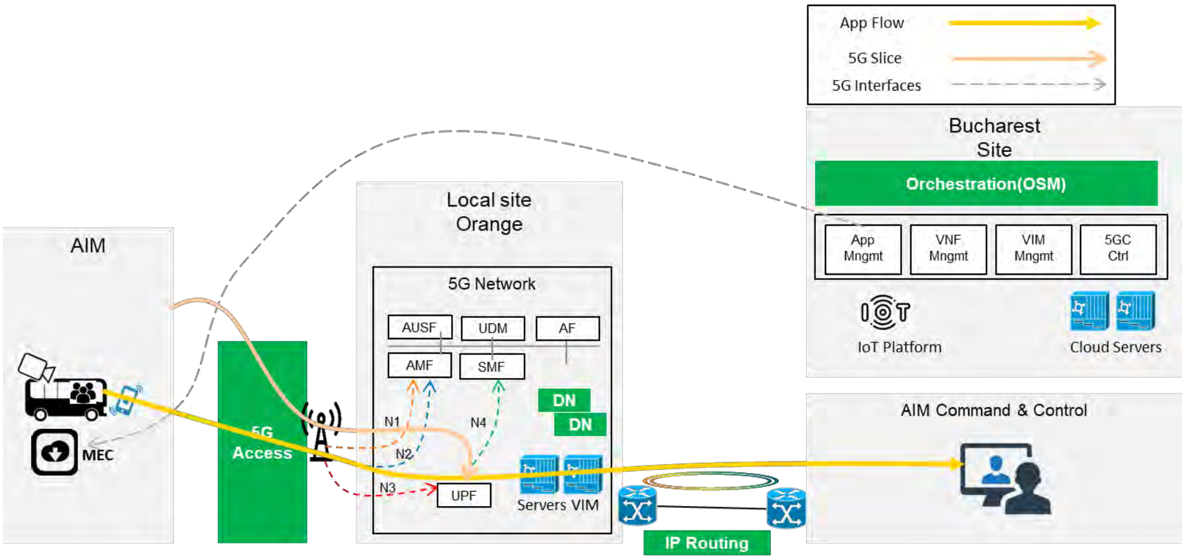
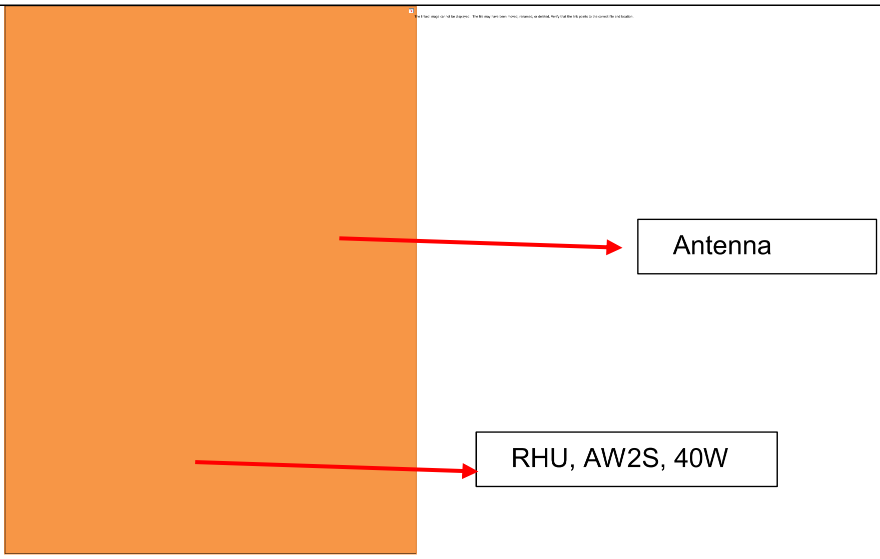
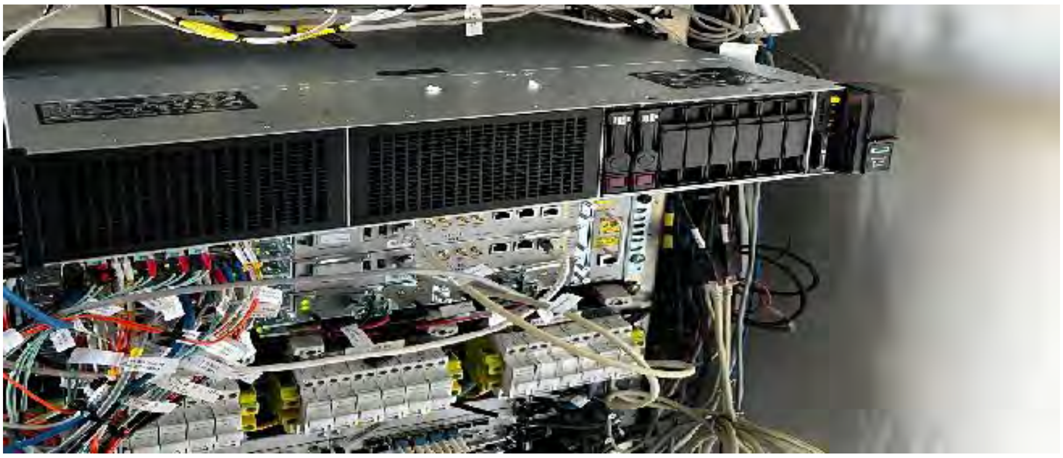
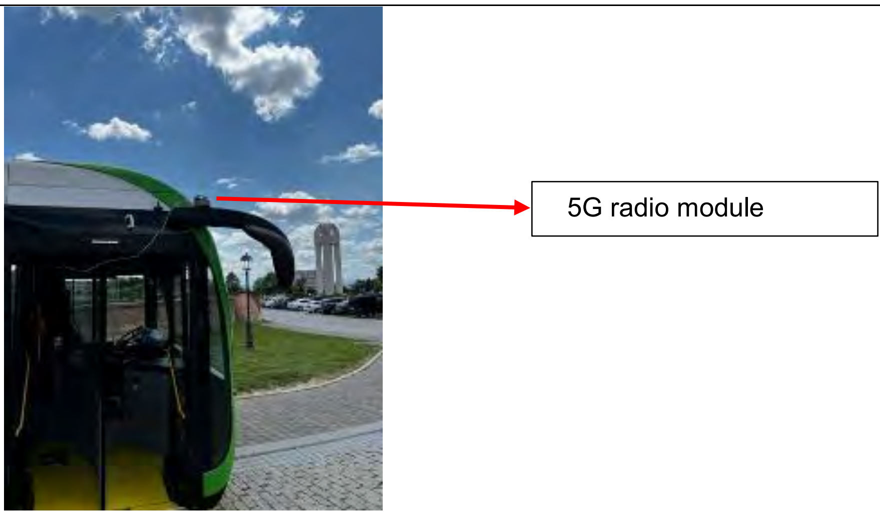
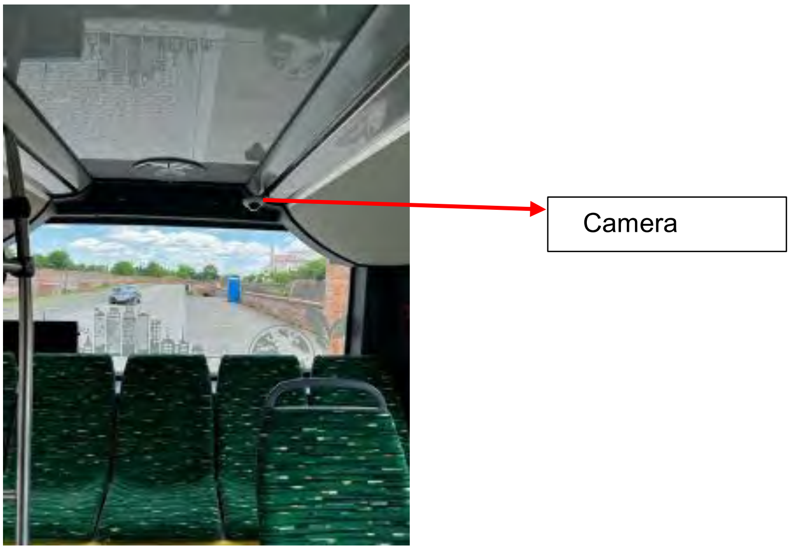


Figure 6-18 FR/RO media UC architecture

No	5G LAB element
1	Antenna, installed in ORO site, connected through coaxial cable to the RHU RHU, AW2S, N78 capable, connected to the server with Optical Fiber, OM3, 10Gbps interface in the demo area

	
2	Compute server, running the 5G SA software components, connected to the RHU with Optical Fiber, OM3, 10Gbps and also connected to ORO switches NX-OS for management purpose 
3	Bus Running experiments, demo area  5G module installed in the bus

	
4	Video camera in the BUS for analytics, demo area 

6.2.3 Test Cases and KPIs

The following tables summarise the key results of the **UC #1.2** requirements and KPIs that have been evaluated in the FR/RO cluster during the field demonstration. The extracted results confirm that the 5G technical implementation addresses the needs of the UCs under evaluation.

Table 6-5 KPIs and requirements evaluation for MDI group test cases

Test case group MDI (Infotainment)			
Test case name	**Place**	**Key UC requirements and KPIs**	**Network performance requirements and KPIs**
MDIe01	FR/RO AIM	DL 20 Mbps; UL 10 Mbps RTT external < 100 ms RTT internal 60 ms	DL: 28 Mbps UL:20 Mbps RTT external 40 ms RTT internal 20 ms
MDIe02	FR/RO AIM	Browsing time <3 s Service availability > 99%	www.gsp.ro browsing time latency <1.8 s service availability 99,999 % during tests

Table 6-6 KPIs and requirements evaluation for MDC group test cases

ç			
Test case name	**Place**	**Key Use-case requirements and KPIs**	**Network performance requirements and KPIs**
MDCe01	FR/RO AIM	DNS ping 8.8.8.8 < 60 DNS ping ORO < 40	40 ms 28 ms EDGE & C&C < 29 ms
MDCe02	FR/RO AIM	Network slice capabilities/management (Yes/No); E2E latency for interactive service (in ms) < 30ms; E2E latency for public safety service (in ms) < 5ms; High bandwidth required for data intensive public safety applications and HD video streaming > 20 Mbps; Jitter for URLLC < 1 ms	YES RTT < 28 ms RTT < 5-6 ms 30 Mbps DL 15 Mbps UL 0.05 ms 100%(ping/service tests)
MDCe03	FR/RO AIM	E2E latency for interactive service (in ms) < 30 ms; E2E latency for public safety service (in ms) < 5 ms; High bandwidth required for data intensive public safety applications and HD video streaming > 20 Mbps; Jitter for URLLC < 1 ms	20 ms 7 ms >40 Mbps 0.05 ms
MDCe04	FR/RO AIM	iperf the average, min and max values for throughput and latency, for both slices	100%

Table 6-7 describes the main 5G radio characteristics that sustained the proper demonstration activities.

Table 6-7 FR/RO 5G RAN network characteristics

AIM	
Radio access technology (RAT)	5GNR, Sub-6GHz
Standalone / Non-Standalone (if applicable)	SA Option 2
Cell Power	27 dBm
Frequency band:	n78
Maximum bandwidth per component carrier	50 MHz
Sub-carrier spacing	Sub 6 GHz: 30 kHz
Number of component carriers	Maximum number of CC = 1 (5G)
Cyclic Prefix	N/A
Massive MIMO	No
Multiple-Input Multiple-Output (MIMO)	2x2
Modulation schemes	Downlink: 16 QAM UplinK: 16 QAM

Duplex mode	TDD
TDD DL:UL slots ratio	8:1
Contention based random access procedure/contention free	N/A
User location and speed	N/A
Background traffic	N/A
Computational resources available	112 CPU cores, 1TB RAM, 4TB storage (shared)

The following experiments descriptor related to **UC #1.2** applies to all validation experiments defined as MDIe MDCe and MDAe tests.

Table 6-8 Experiment Descriptor related to UC #1.2

	Value	Comments
Experiment Type	Standard	
Automated	Manual	
TestCases	Test Case 1	
UEs	UE1, UE2	*4 x Quectel 5G SA module* 2x PI2 router
Network Slice	eMBB QCI 9 slice URLLC QCI 5 slice	*3GPP Rel.16*
Network Services	NSD IDs: `eMBB & URLLC`	*N/A*
Network Scenario	Scenario #1.2	
Exclusive Execution	True	
ReservationTime	N/A	
Experiment Name	UC#1.2_App1_2	
Performance targets & SLAs	Network Service KPIs: RTT (ms): eMBB 30ms; URLLC 10ms DL/UL(Mbps): eMBB 30; URLLC 15; Application KPIs: Mobility latency": 3	*Network KPIs throughput/latency* *MDe01-04* Apps KPIs: Analytics Object detection Apps KPIs: MDAe01-04
Experiment Parameters	Resources: Application vCPU Core:min 8 max 16, RAM: min:16GB, max: 32GB link_capacity(Mbps): min: 40 max: 1000	
Edges	HPE Gen10 K8s 5G SA EDGE Apps	*VLANs:* *101 DNN eMBB* *102 DNN URLLC*
Remote	N/A	
Remote Descriptor	N/A	
Version	v1.0	
Extra	N/A	

6.2.4 Experiment execution and Reports (with reference to WP3 methodology)

The following tables describe the **UC #1.2** experiment execution and test description, as have been planned and organized in D3.2 deliverable, reporting the test case results for each Test Case ID, Test purpose, components involved, Target KPIs and Results.

Table 6-9 Test report for Test Case MDIe01 (User authentication using captive portal)

Field	Authentication	
Test Case ID	**MDIe01**	
Facility, Site	FR/RO cluster	
Description	The aim of this test case is to check the user authentication process using the captive portal. The UE attaches to SSID Wi-Fi from the bus, is redirected to the portal that is offering administration information such as surveys, local news and tourism ads. For free internet access an authentication procedure based on Mobile Station International Subscriber Directory Number (MSISDN) is performed, the traveler inputs the number on the captive portal, receives a code by SMS, which can be used in the portal for gaining free internet access	
Executed by	Partner: ORO	Date: Sep 2022
Purpose	Pass/fail scenario: • Pass if within KPIs • Fail if outside KPIs	
Scenario	D3.4 Table 5 1 **MDIe01**: User authentication using captive portal	
Slice Configuration	eMBB	
Components involved	One laptop/tablet Wi-Fi AP eMBB slice configured over 5G network	
KPIs collected (Metrics collected)	Portal access and authentication: < 5s DL/UL: 28/30 Mbps RTT: 30 ms(internal)	
Tools involved	Iperf3, tcpdump	
Results and KPIs Primary Complementary	Authentication and network KPIs Portal access and authentication: < 3s DL/UL: 30/30 Mbps RTT: 22 ms (internal)	
Target metric/KPI and verification (pass/fail)	passed	

Table 6-10 Test report for Test Case MDIe02 (Captive portal data availability)

Field	Data availability
Test Case ID	**MDIe02**
Facility, Site	FR/RO cluster
Description	The scope of the test is to check the successful integration of the portal with different content sources. The portal should contain information from multiple data sources, all of equal importance from the municipality's point of view. Another objective of the test case is to measure the time necessary to display the requested information, the backhaul of the Wi-Fi AP is an eMBB slice

Executed by	Partner: ORO	Date: Sept 2022
Purpose	Pass/fail scenario: Pass if within KPIs Fail if outside KPIs	
Scenario	D3.4 Table 5-2 - MDIe02: Captive portal data availability	
Slice Configuration	eMBB slice is enabled in the network.	
Components involved	One laptop/tablet Wi-Fi AP Wi-Fi portal eMBB slice configured over 5G network One synthetic monitoring tool.	
KPIs collected (Metrics collected)	loading times for each of the data sources	
Tools involved	Tcpdump, synthetic monitoring tool(portal)	
Results and KPIs Primary Complementary	loading times threshold < 2-3s min/average/max loading times for each of the data sources 1.5/2.1s/4s Total number of unsuccessful tests for each data source: <0.01% Total number of successful tests for each data source: 99.99%	
Target metric/KPI and verification (pass/fail)	pass	

Table 6-11 Test report for Test Case MDCe01 (Establishment of basic E2E connectivity over a specific slice)

Field	**End-to-end connectivity over a specific slice**	
Test Case ID	**MDCe01**	
Facility, Site	FR/RO cluster	
Description	The scope of this test case is to verify the establishment of E2E connectivity over an interactive eMBB slice for a tablet which is already authenticated on the portal towards the Control and Command Centre server, using ping and traceroute. Also to verify the Fully Qualified Domain Name (FQDN) function, necessary to browse over the internet, the server of the CCC will be checked with ICMP protocol having as attribute the IP or the URL of the server	
Executed by	Partner: ORO	Date: Sept 2022
Purpose	Pass/fail scenario: Pass if within KPIs Fail if outside KPIs	
Scenario	D3.4 Table 5 3 **MDCe01**: Establishment of basic E2E connectivity over a specific slice	
Slice Configuration	eMBB preconfigured slice	

Components involved	One laptop Wi-Fi AP eMBB slice configured over 5G network.
KPIs collected (Metrics collected)	RTT: 30 ms DL/UL: 30/20 Mbps
Tools involved	Icmp/iperftool
Results and KPIs Primary Complementary	ping towards the IP of the Command & Control server works. ping towards the URL of the Command & Control server works (meaning that also the URL is resolved by the DNS service) RTT: 28 ms DL/UL: 30/20 Mbps
Target metric/KPI and verification (pass/fail)	pass

Table 6-12 Test report for Test Case MDCe02 (Establishment of advanced E2E connectivity over two different slices with different QoS metrics configured)

Field	**End-to-end connectivity over two slices with different QoSs**	
Test Case ID	**MDCe02**	
Facility, Site	FR/RO cluster	
Description	This test checks the deployment of two different network slices having two different quality of service metrics: one eMBB slice for interactive service/camera's video and one slice with uRLLC capability. For each slice one tablet or laptop is used, measuring the performance of the network (bandwidth, jitter, latency) through iperf application	
Executed by	Partner: ORO	Date: July 2022
Purpose	Pass/fail scenario: Pass if within KPIs • Fail if outside KPIs	
Scenario	MDCe02: Establishment of advanced E2E connectivity over two different slices with different QoS metrics configured	
Slice Configuration	Two slices configured in the network	
Components involved	Two laptops/tablets, Wi-Fi AP Two slices configured over 5G network: URLCC, eMBB. Two laptops/tablets are connected to the two different slices: eMBB & URLCC; the connection is performed directly over 5G using SIM, two slices are configured in the 5G network with the needed QoS. On each of the two laptops/tablets iperf is activated for measuring network performance (bandwidth, latency and jitter).	
KPIs collected (Metrics collected)	eMBB DL/UL: 20/20 Mbps eMBB RTT: 25 ms URLLC DL/UL: 10/10 Mbps URLLC RTT: 6 ms Jitter: 0.1 ms	
Tools involved	Iperf3, icmp, tcpdump, oss tool	

Results and KPIs Primary Complementary	eMBB DL/UL: 25/25 Mbps eMBB RTT: 20 ms URLLC DL/UL: 15/15 Mbps URLLC RTT: 5 ms Jitter: 0.1 ms
Target metric/KPI and verification (pass/fail)	passed

Table 6-13 Test report for Test Case MDCe03 (Load test for observing the QoS prioritization among slices with congestion on radio part)

Field	QoS prioritization on slices with congestion on radio part	
Test Case ID	**MDCe03**	
Facility, Site	FR/RO cluster	
Description	Once the threat alarm is triggered, the CCC operator needs to access camera images from the bus to decide what further emergency measures need to be taken. In this respect, the QoS of the slices with guaranteed bandwidth and low latency must be fulfilled. To test this scenario the radio cell is congested pushing traffic through all two slices, checking if the critical services are prioritized against the interactive ones	
Executed by	Partner: ORO	Date: July 2023
Purpose	Pass/fail scenario 1: • Pass if within KPIs	
Scenario	MDCe03: Load test for observing the QoS prioritization among slices with congestion on radio part	
Slice Configuration	eMBB slice URLLC slice	
Components involved	Two laptops/tablets, Two slices configured over 5G network: URLCC, eMBB	
KPIs collected (Metrics collected)	Two tests are performed on the 2 slices (eMBB and URLCC) simultaneously (one test/slice). For eMBB the traffic flow is configured with a bandwidth of 20Mbps. The tests are repeated three times, resulting in a total number of 6 tests. eMBB DL/UL: 20/20Mbps eMBB RTT: 25ms URLLC DL/UL: 10/10Mbps URLLC RTT: 5ms Jitter: 0.04 ms	
Tools involved	Iperf3, oss	
Results and KPIs Primary Complementary	Slices configuration and performance during the tests UL/DL performance and QoS assurance between slices	
Target metric/KPI and verification (pass/fail)	passed	

Table 6-14 Test report for Test Case MDCe04 (Stability test - injecting traffic over one slice for 7 consecutive days)

Field	Stability test over consecutive days	
Test Case ID	**MDCe04**	
Facility, Site	FR/RO cluster	
Description	Being a UC in the public safety and security area, the availability and the stability of the services are very important. The following test-case measures the performance of the E2E connectivity over one slice for a period of seven days. The interactive slice was chosen to be tested in order to check also the connectivity via Wi-Fi AP. The expected result is to have network availability over 99.9% and latency lower than 30 ms.	
Executed by	Partner: ORO	Date: June 2022
Purpose	Pass/fail scenario: Pass if within KPIs Fail if outside KPIs	
Scenario	**MDCe04**: Stability test - injecting traffic over one	
Slice Configuration	slice configured (e.g. eMBB)	
Components involved	Laptop Iperf3 server, server connected to eMBB slice	
KPIs collected (Metrics collected)	UL/DL performance: min 20/20 Mbps max 25/22 Mbps Connectivity time:4h of testing	
Tools involved	Iperf3, oss	
Results and KPIs Primary Complementary	UL/DL min 22/21Mbps max 25/23Mbps Connectivity time	
Target metric/KPI and verification (pass/fail)	pass	

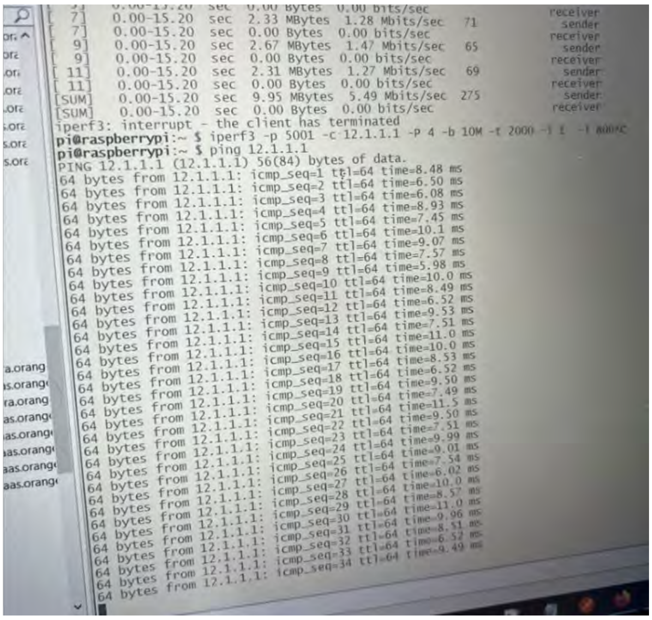
Table 6-15 Test report for Test Case MDAe01 (Passenger fall detection in an emergency break)

Field	AI emergency identification and alerting	
Test Case ID	**MDAe01 – MDAe04**	
Facility, Site	FR/RO cluster	
Description	We track passengers as they enter and leave the bus. We also track carried baggage that we link to the passenger's body pose when entering. If the baggage stays on board while the passenger (to whom it has been linked) leaves we trigger an alert.	
Executed by	Partner: ORO	Date: Sept 2022
Purpose	Pass/fail scenario: Pass if within KPIs Fail if outside KPIs	
Scenario	MDAe01: Passenger fall detection in an emergency break MDAe04: Lost item – detection and alerting	

Slice Configuration	URLLC slice Min 10 Mbits/s connection for the camera video streaming with maximum 20 ms latency
Components involved	RGB camera. GPU compute capability in the Edge node. People pose detection code for the parallel AI network execution AI app's Edge
KPIs collected (Metrics collected)	Monitoring frequency is 10-15 times per second
Tools involved	EDGE Analytics
Results and KPIs Primary Complementary	the automatic detections against the ground truth data 
Target metric/KPI and verification (pass/fail)	passed

6.2.5 KPI evaluation and Conclusions – Lessons learned

In FR/RO cluster all the **UC #1.2** have been achieved based on the 1st OAI RAN/Core solution implemented. For sake of clarity, the 5G SA network deployed in AIM KPIs are significantly improved compared to the existing 4G LTE commercial network in AIM.



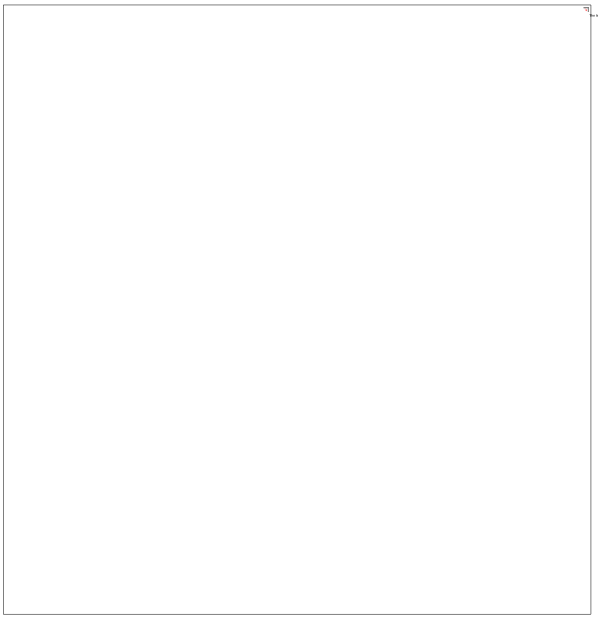


Figure 6-19 FR/RO 5G SA cluster results during the field trial

For **UC #1.2** we have achieved the results in terms of 5G SA service communication and UCs experimentation in the field, from the 5G SA network integration and deployment to the network configuration and use case onboarding on top of the 5G SA. Table 6-16 summarizes the results achieved, demonstrating the successful implementation of the 5G SA deployment.

Table 6-16 Experiment results of UC #1.2

Test Case	*Result*
MDIe01 ***User authentication using captive portal***	*Single user network slice, 5G SA, Radio BW 50MHz in N78* Results: • DL: 112 Mbps • UL: 30 Mbps • RTT external server (8.8.8.8) 40 ms • RTT internal server (edge computing) 20 ms
MDIe01 Passed/Failed	*Passed*
MDIe02 Captive portal data availability	*eMBB slice is enabled in the network* Results: • www.gsp.ro • Browsing time (latency) – time to display the requested information <3s; • Service availability>99% • tcpdump ~ 1.8s
MDIe02 Passed/Failed	*passed*
MDCe01 Establishment of basic E2E connectivity over a specific slice	Results: • Ping towards DNS 8.8.8.8 ~40 ms • Ping towards internal DNS(ORO) ~ 28ms • Ping towards EDGE C&C (through ORO) ~ 29ms
MDCe01 Captive portal data availability	passed
MDCe02 Establishment of advanced E2E connectivity over two different slices with	Results: • Network slice capabilities/management (Yes/No);

different QoS metrics configured	o The two network slices are manually configured (eMBB/Low Latency) • E2E latency for interactive service (in ms) < 30ms; o ~28ms • E2E latency for public safety service (in ms) < 5ms; o ~5 ms • High bandwidth required for data intensive public safety applications and HD video streaming > 20Mbps; o Test performed in the N78 50MHz context o 100Mbps DL throughput • Jitter for URLLC < 1ms o < 0.070
MDCe02 Passed/Failed	passed
MDCe03 *Load test for observing the QoS prioritization among slices with congestion on radio part*	Results: • Slices configured • E2E latency for interactive service (in ms) < 30 ms o ~28 ms • E2E latency for public safety service (in ms) < 5 ms o ~ 12 ms • High bandwidth required for data intensive public safety applications and HD video streaming > 10 Mbps o 20 Mbps • Jitter for URLLC < 1 ms o ~0.05 – 0.5 ms Comment: proper optimization resource allocation will be performed in LAB condition
MDCe03 passed/failed	passed
MDCe04 *Stability test - injecting traffic over one slice for 3 consecutive days*	Results: • Network availability reached highly traffic load • E2E latency for interactive service (in ms) < 27ms;
MDCe03 passed/failed	Passed (3 field testing days)
MDAe01-MDAe04 (for all AI recognition and identification of emergency situation test-cases)	Results (measurements performed from the device level): • 40Mbps DL/20Mbps UL, • RTT ~5ms
MDAe01-MDAe04	Passed

6.3 UC #4.2 Low Voltage Energy Metering

The **UC #4.2** LV Energy metering comprises the following applications:

- **App1**: Real-time LV energy metering services for designated points of interests
- **App2**: Energy Analytics for predictive and proactive maintenance for designated points of interest

6.3.1 UC testing objective and deployment

The FR/RO cluster network diagram for **UC #4.2** is shown in Figure 6-20, including all software and hardware elements for **UC #4.2** implementation and demonstration.

The UCs has been tested and validated in both scenarios, laboratory tests and live field tests with the following specificities, seen also in the next figures:

- **IoT end device**: the IoT metering device, connected to the IoT Telemetry analytics server, acting as aggregating component, the communication component is provided over the Low Latency PDN slice.
- **5G NSA/SA Network**: installed in Orange 5G site, as RRH/BBU, vEPC/5GCN core network components, network interfaces and local processing servers.
- **Telemetry platform**: installed in cloud, acting as Telemetry Data Aggregator, Telemetry Database, Telemetry Application and engines and telemetry data storage, connected through N6/SGi interface to the IoT devices.

In Figure 6-20 we describe the LV solution implemented and the IoT device deployed in AIM, as described in Figure 6-21, devices that are connected and configured to provide the UC metering requested values in terms of network KPIs and Application KPIs, highlighted in section 6.3.2 supported by the values measured in the next tables.

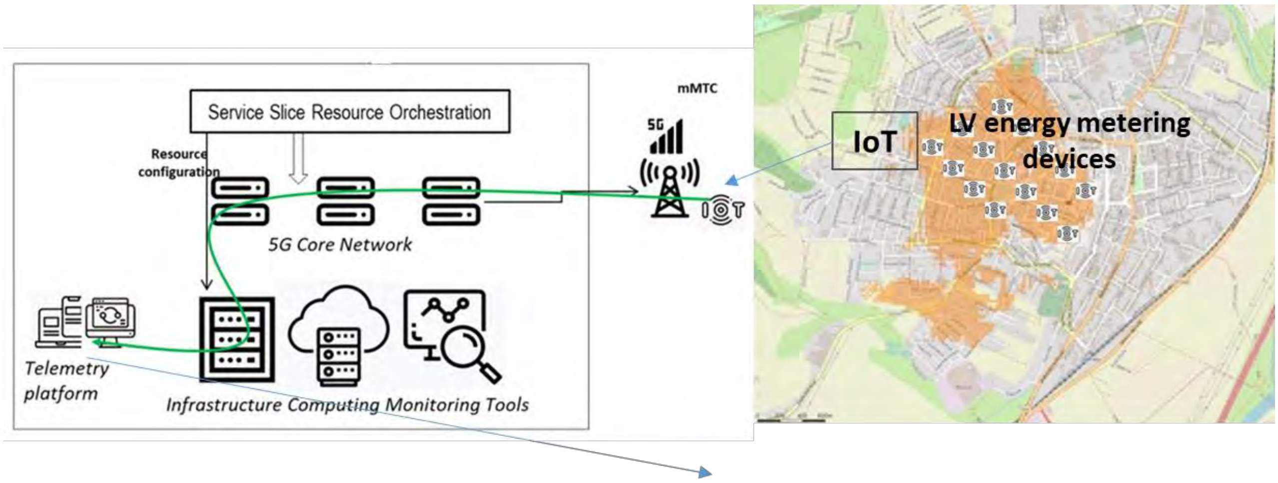


Figure 6-20 FR/RO cluster LV UC#4.2 AIM

Figure 6-21 LC IoT devices installed in AIM

Figure 6-22 LV Energy monitoring dashboards

The slice configuration is the one described in section 6.2.2., and the components are the same as described in section 6.2.2.1 and 6.1.2.1.

6.3.2 Test Cases and KPIs

Table 6-17 and Table 6-18 summarize the key results of the UC requirements and KPIs that have been evaluated in the FR/RO cluster during the demonstration in the field, results that confirm the technical implementation, answering to the needs of the UCs.

Table 6-17 KPIs and requirements evaluation for ESM group test cases

Test case group ESM (Energy Metering)			
Test case name	**Place**	**Key Use-case requirements and KPIs**	**Network performance requirements and KPIs**
ESMe01	FR/RO AIM	E2E connectivity over smart energy slice	E2E Latency < 100ms mMTC packet size < 20kB Service Availability > 99.9%
ESMe02	FR/RO AIM	advanced E2E connectivity over smart energy slice with different QoS metrics configured	E2E Latency < 100ms mMTC packet size < 20kB Service Availability > 99.9%
ESMe03	FR/RO AIM	traffic generated simultaneously by 3000 LV metering devices	E2E Latency < 100ms mMTC packet size < 20kB Service Availability > 99.9%
ESMe04	FR/RO AIM	dynamic resource allocation 5G capability against service stability	E2E Latency < 100ms mMTC packet size < 20kB Service Availability > 99.9%

Table 6-18 KPIs and requirements evaluation for ESA group test cases

Test case group ESA (Energy Analytics)			
Test case name	**Place**	**Key Use-case requirements and KPIs**	**Network performance requirements and KPIs**
ESAe01	FR/RO AIM	energy consumption monitoring accuracy	E2E slice connectivity
ESAe02	FR/RO AIM	Preventive maintenance	E2E slice connectivity

6.3.3 Scenario Description

The proposed scenario is supported by the network characteristics described in Table 6-19, with the comment that for the particular LV/IoT implementation, we have performed two type of actions: (1) using the 5G SA network for emulating the mMTC UC supported by 5G SA (eMTC slice definition), (2) using a traditional virtualized (vEPC/LTE-M) solution to cope with today's field already deployed equipment's.

Table 6-19 Experiment Descriptor related to UC #4.2

	Value	**Comments**
Experiment Type	Standard	
Automated	Manual	
Test Cases	Test Case LV	
UEs	mMTC-LV1; mMTC-LV2	mMTC/LTE-M devices
Network Slice	mMTC QCI 9 slice	3GPP Rel.16
Network Services	NSD IDs: `mMTC`	N/A
Network Scenario	Scenario #4.2	
Exclusive Execution	True	
ReservationTime	N/A	
Experiment Name	UC#4.2_App1	
Performance targets & SLAs	E2E latency 100 ms mMTC packet size 20kB Service availability	Network KPIs ESMe01-04 Apps KPIs: Energy monitoring & performance identification Apps KPIs: ESAe01-02
Experiment Parameters	Resources: Application vCPU Core:min 2max 4, RAM: min:4GB, max: 8GB link_capacity(Mbps): min: 40 max: 40	
Edges	HPE Gen10 K8s 5G SA EDGE Apps Thingboard Platform	VLANs: 103 DNN eMTC slice
Remote	N/A	
Remote Descriptor	N/A	
Version	v1.0	
Extra	N/A	

6.3.4 Experiment execution and Reports (with reference to WP3 methodology)

Table 6-20 Test report for Test Case ESMe01 (Establishment of basic E2E connectivity over mMTC smart energy slice)

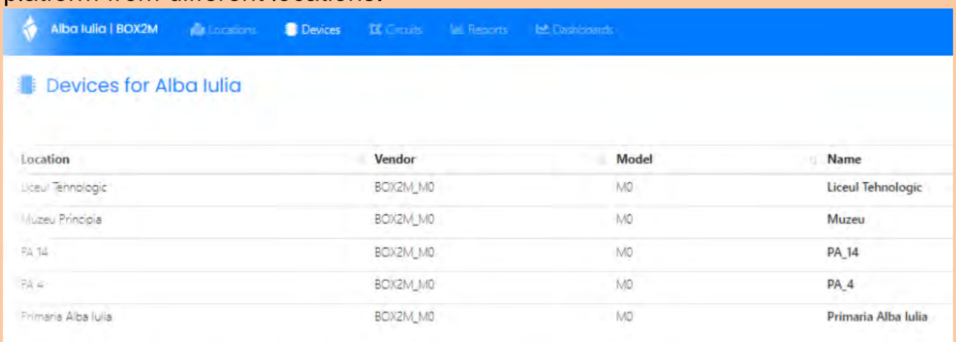
Field	Basic E2E connectivity over mMTC slice	
Test Case ID	**ESMe01**	
Facility, Site	FR/RO cluster	
Description	The aim of the proposed test case is to evaluate the site connectivity between 5G-VICTORI facilities. The purpose of the test case is to validate the e2e slice connectivity between different components/facilities involved: low voltage metering device - 5G IoT device - 5G radio access - 5G core networks – 5G-VIOS – Bucharest Orange Datacenter / Telemetry platform	
Executed by	Partner: ORO	Date: Sept 2022
Purpose	Pass/fail scenario: Pass if within KPIs Fail if outside KPIs	
Scenario	ESMe01 – Establishment of basic E2E connectivity over mMTC smart energy slice(4G EPC)	
Slice Configuration	Dedicated slice configured in the network. Connect LV metering device over 5G radio and test connectivity over slice towards test IP	
Components involved	LV metering device 5G / LTE-M IoT device Telemetry platform mMTC network configuration	
KPIs collected (Metrics collected)	e2e connectivity over the mMTC (100kbps/device) Raw data packets are sent toward Telemetry platform	
Tools involved	Telemetry platform.	
Results and KPIs Primary Complementary	Several metering devices are declared and are communicating to the Telemetry platform from different locations.  	
Target metric/KPI and verification (pass/fail)	passed	

Table 6-21 Test report for Test Case ESMe02 (Establishment of advanced E2E connectivity over smart energy slice with different QoS metrics configured)

<table>
<tr><th>Field</th><th colspan="2">Advanced E2E connectivity over mMTC slice with different Q0S metrics</th></tr>
<tr><td>Test Case ID</td><td colspan="2">ESMe02</td></tr>
<tr><td>Facility, Site</td><td colspan="2">FR/RO cluster</td></tr>
<tr><td>Description</td><td colspan="2">The goal of the second test case is to check the QoS performance of the smart energy network slice. In order to have enough samples for relevant statistics, the traffic is generated by a sensor simulator.</td></tr>
<tr><td>Executed by</td><td>Partner: ORO</td><td>Date: Sept 2022</td></tr>
<tr><td>Purpose</td><td colspan="2">Pass/fail scenario:
Pass if within KPIs
Fail if outside KPIs</td></tr>
<tr><td>Scenario</td><td colspan="2">ESMe2 - Establishment of advanced E2E connectivity over smart energy slice with different QoS metrics configured</td></tr>
<tr><td>Slice Configuration</td><td colspan="2">mMTC configured</td></tr>
<tr><td>Components involved</td><td colspan="2">LV sensor simulator
5G / LTE-M IoT device
Telemetry platform
mMTC configured</td></tr>
<tr><td>KPIs collected (Metrics collected)</td><td colspan="2">Service availability
RTT
Packet loss</td></tr>
<tr><td>Tools involved</td><td colspan="2">Telemetry platform, Iperf3, tcmpdump</td></tr>
<tr><td>Results and KPIs Primary Complementary</td><td colspan="2">Service Availability > 99.9%
E2E latency for smart metering service < 100 ms
Packet loss rate < 0.01%
<table>
<tr><th>Key</th><th>Location</th><th>Name</th><th>Sensor</th><th>Modbus</th><th>Params</th><th>Main</th></tr>
<tr><td>[illegible]</td><td>Muzeu Principal</td><td>Circuit Sumator Fotovoltaic</td><td>Lovato - DMG110</td><td>2</td><td>17</td><td></td></tr>
<tr><td>[illegible]</td><td>Muzeu Principal</td><td>Circuit Fotovoltaic 01</td><td>Lovato - DMG110</td><td>3</td><td>6</td><td></td></tr>
<tr><td>[illegible]</td><td>Muzeu Principal</td><td>Circuit Fotovoltaic 02</td><td>Lovato - DMG110</td><td>4</td><td>6</td><td></td></tr>
<tr><td>[illegible]</td><td>Muzeu Principal</td><td>Circuit Fotovoltaic 03</td><td>Lovato - DMG110</td><td>5</td><td>5</td><td></td></tr>
<tr><td>[illegible]</td><td>Muzeu Principal</td><td>Circuit Fotovoltaic 04</td><td>Lovato - DMG110</td><td>6</td><td>5</td><td></td></tr>
<tr><td>[illegible]</td><td>Muzeu Principal</td><td>Circuit Fotovoltaic 05</td><td>Lovato - DMG110</td><td>7</td><td>5</td><td></td></tr>
<tr><td>[illegible]</td><td>Muzeu Principal</td><td>Circuit Fotovoltaic 06</td><td>Lovato - DMG110</td><td>8</td><td>5</td><td></td></tr>
<tr><td>[illegible]</td><td>Muzeu Principal</td><td>Circuit Fotovoltaic 07</td><td>Lovato - DMG110</td><td>9</td><td>5</td><td></td></tr>
<tr><td>[illegible]</td><td>Muzeu Principal</td><td>Circuit Fotovoltaic 08</td><td>Lovato - DMG110</td><td>10</td><td>6</td><td></td></tr>
<tr><td>[illegible]</td><td>Muzeu Principal</td><td>Circuit Fotovoltaic 09</td><td>Lovato - DMG110</td><td>11</td><td>6</td><td></td></tr>
<tr><td>[illegible]</td><td>Muzeu Principal</td><td>Circuit Fotovoltaic 10</td><td>Lovato - DMG110</td><td>12</td><td>5</td><td></td></tr>
<tr><td>[illegible]</td><td>Muzeu Principal</td><td>Circuit General</td><td>Lovato - DMG110</td><td>1</td><td>17</td><td>✓</td></tr>
</table>
Data rates are evaluated / device
<pre>UL: iperf3.exe -c 172.28.16.27 -p 5001 -b 1Mbps -l 100 -t 100
[4]   3.00-4.00   sec 1.54 KBytes 32.9 Kbits/sec
[6]   3.00-4.00   sec 1.55 KBytes 33.0 Kbits/sec
[8]   3.00-4.00   sec 1.55 KBytes 33.0 Kbits/sec</pre></td></tr>
<tr><td>Target metric/KPI and verification (pass/fail)</td><td colspan="2">passed</td></tr>
</table>

Table 6-22 Test report for Test Case ESMe03 (Establishment of simultaneous 5G raw data transfer to process the traffic generated simultaneously by 3000 LV metering devices)

Field	Simultaneous 5G raw data transfer from 3000 LV metering devices	
Test Case ID	**ESMe03**	
Facility, Site	FR/RO cluster	
Description	The density of devices in a specific area can be high, mainly in urban zones, increasing the probability that at a certain time multiple devices send/ receive traffic towards/ from the IoT platform. The third test case evaluates the establishment of simultaneous 5G raw data transfer to process the traffic generated simultaneously by 3000 LV metering devices over Alba-Iulia – 5G-VIOS mMTC slice	
Executed by	Partner: ORO	Date: Sept 2022
Purpose	Pass/fail scenario: Pass if within KPIs Fail if outside KPIs	
Scenario	ESMe03: Establishment of simultaneous 5G raw data transfer to process the traffic generated simultaneously by 3000 LV metering devices	
Slice Configuration	mMTC configured	
Components involved	3000 5G/ LTE-M IoT devices displaced over 300 square meters using IoT simulators Telemetry platform LV sensor simulator attached to the network/slice	
KPIs collected (Metrics collected)	Raw data received successfully by the Telemetry platform from all 3000 simulated devices	
Tools involved	Telemetry platform	

Results and KPIs Primary Complementary	data rates capacity for simultaneously transfers of large raw data volumes of LV metering devices
	`5gvictori@telemetry:~$ ping 10.87.69.60`
	`PING 10.87.69.60 (10.87.69.60) 56(84) bytes of data.`
	`64 bytes from 10.87.69.60: icmp_seq=1 ttl=62 time=46.11 ms`
	`64 bytes from 10.87.69.60: icmp_seq=4 ttl=62 time=55.53 ms`
	`64 bytes from 10.87.69.60: icmp_seq=5 ttl=62 time=48.58 ms`
	`64 bytes from 10.87.69.60: icmp_seq=6 ttl=62 time=51.51 ms`
	Data rates are evaluated by 3000 devices simulated (Lab approach)
	`UL: iperf3.exe -c 172.28.16.27 -p 5001 -b 10Mbps -l 100 -t 100 -P 12`
	`[ 4] 3.00-4.00 sec 7.81 KBytes 8.9 Mbits/sec`
	`[ 6] 3.00-4.00 sec 6.43 KBytes 8.0 Mbits/sec`
	`[ 8] 3.00-4.00 sec 7.55 KBytes 8.2 Mbits/sec`
	`..........................................................`
	`[SUM] 3.00-4.22 sec 93.75 KBytes 96 Mbits/sec`	

Target metric/KPI and verification (pass/fail)	passed	

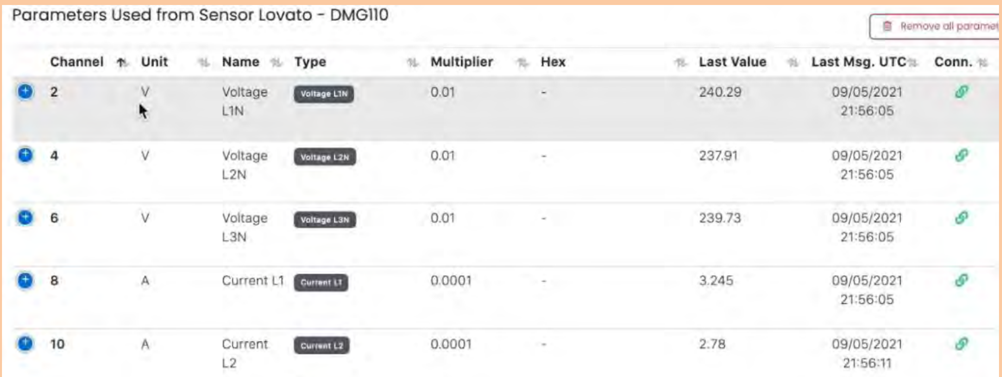
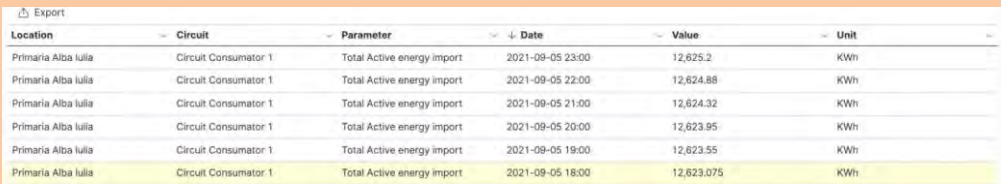
Table 6-23 Test report for Test Case ESMe04 (Dynamic resource allocation 5G capability against service stability)

Field	Dynamic resource allocation
Test Case ID	**ESMe04**
Facility, Site	FR/RO cluster

<table>
<tr><td>Description</td><td colspan="2">This test case checks the deployment of four different network slices having four different quality of service metrics: one slice for interactive service, one slice to transport video, one slice with URLLC capability and one slice for mMTC. For each slice performance measurement is performed from network (bandwidth, jitter, latency) and Telemetry (SR%) perspective.</td></tr>
<tr><td>Executed by</td><td>Partner: ORO</td><td>Date: Sept 2022</td></tr>
<tr><td>Purpose</td><td colspan="2">Pass if within KPIs
Fail if outside KPIs</td></tr>
<tr><td>Scenario</td><td colspan="2">ESMe04 - Dynamic resource allocation 5G capability against service stability</td></tr>
<tr><td>Slice Configuration</td><td colspan="2">eMBB slice
URLLC slice
mMTC smart energy slice</td></tr>
<tr><td>Components involved</td><td colspan="2">Three laptops/tablets and Wi-Fi AP
3000 5G/ LTE-M IoT
AIM Edges
Bucharest Data center - hosting the Telemetry platform components, engines and compute/storage</td></tr>
<tr><td>KPIs collected (Metrics collected)</td><td colspan="2">Slices configured
<pre>
==
IMSI/IMEI(#)   APN   Type   Beare* UE Address (IPv4/IPv6)   Ref-pt/Si*
  /MSISDN(^)/MAC(`)
  /SubId/SEID(~)
==
0x410120~   eMBB   IPv4   1   10.87.69.10/-   N/A
  226107900000077
0x2870130~   urllc   IPv4   1   10.87.69.13/-   N/A
  226107900000078
0x2930130~   mMTC   IPv4   1   10.87.69.14/-   N/A
  226107900000079
</pre>
DL(eMBB)
<pre>
DL: iperf3.exe -c 172.28.16.27 -p 5001 -b 50Mbps -P 8 -l 1310 -t 86400
[4]   3.00-4.00   sec 1.54 MBytes 12.9 Mbits/sec
[6]   3.00-4.00   sec 1.55 MBytes 13.0 Mbits/sec
[8]   3.00-4.00   sec 1.55 MBytes 13.0 Mbits/sec
[10]   3.00-4.00   sec 1.52 MBytes 12.7 Mbits/sec
[12]   3.00-4.00   sec 1.54 MBytes 12.9 Mbits/sec
[14]   3.00-4.00   sec 1.50 MBytes 12.6 Mbits/sec
[16]   3.00-4.00   sec 1.52 MBytes 12.8 Mbits/sec
[18]   3.00-4.00   sec 1.55 MBytes 13.0 Mbits/sec
[SUM]   3.00-4.00   sec 12.3 MBytes   103 Mbits/sec
</pre>
RTT(mMTC)
<pre>
5gvictori@telemetry:~$ ping 10.87.69.14
PING 10.87.69.14 (10.87.69.14) 56(84) bytes of data.
64 bytes from 10.87.69.14: icmp_seq=1 ttl=62 time=56.11 ms
64 bytes from 10.87.69.14: icmp_seq=4 ttl=62 time=55.53 ms
64 bytes from 10.87.69.14: icmp_seq=5 ttl=62 time=63.58 ms
64 bytes from 10.87.69.14: icmp_seq=6 ttl=62 time=59.51 ms
</pre>
UL(mMTC)
<pre>
UL: iperf3.exe -c 172.28.16.27 -p 5001 -b 1Mbps -l 100 -t 100 -P 12
[4]   3.00-4.00   sec 6.81 KBytes 6.9 Mbits/sec
[6]   3.00-4.00   sec 5.43 KBytes 5.5 Mbits/sec
[8]   3.00-4.00   sec 4.55 KBytes 4.65 Mbits/sec
</pre></td></tr>
<tr><td>Tools involved</td><td colspan="2">Iperf3
Telemetry platform</td></tr>
<tr><td>Results and KPIs Primary Complementary</td><td colspan="2">transfer capacity volume of aggregated information for all 3 slices
RTT; UL/DL per slice</td></tr>
</table>

Target metric/KPI and verification (pass/fail)	passed

Table 6-24 Test report for Test Case ESAe01 (Smart metering energy consumption accuracy)

Field	Smart Metering accuracy	
Test Case ID	**ESAe01**	
Facility, Site	FR/RO cluster	
Description	The test case is proposing to evaluate the functionality of the Analytics component by testing the accuracy of the data collected from the LV devices and the algorithm used to calculate the energy consumption. Smart metering consumption values calculated with the Analytics component of the Smart Metering Telemetry platform, will be evaluated against the values collected with the manual reading method	
Executed by	Partner: ORO	Date: Sept 2022
Purpose	Pass/fail scenario: Pass if within KPIs Fail if outside KPIs	
Scenario	**ESAe01** - Smart metering energy consumption accuracy	
Slice Configuration	mMTC network slice	
Components involved	LV metering devices 5G / LTE-M IoT device Telemetry platform	
KPIs collected (Metrics collected)	Calculate delta between Analytics platform recorded consumption values vs values collected with manual method	
Tools involved	Telemetry platform, measurement devices	
Results and KPIs Primary Complementary	Consumption accuracy %  	

Parameters Used from Sensor Lovato - DMG110

Remove all paramet

Channel	Unit	Name	Type	Multiplier	Hex	Last Value	Last Msg. UTC	Conn.
2	V	Voltage L1N	Voltage L1N	0.01	-	240.29	09/05/2021 21:56:05	
4	V	Voltage L2N	Voltage L2N	0.01	-	237.91	09/05/2021 21:56:05	
6	V	Voltage L3N	Voltage L3N	0.01	-	239.73	09/05/2021 21:56:05	
8	A	Current L1	Current L1	0.0001	-	3.245	09/05/2021 21:56:05	
10	A	Current L2	Current L2	0.0001	-	2.78	09/05/2021 21:56:11	

Export

Location	Circuit	Parameter	Date	Value	Unit
Primaria Alba Iulia	Circuit Consumator 1	Total Active energy import	2021-09-05 23:00	12,625.2	KWh
Primaria Alba Iulia	Circuit Consumator 1	Total Active energy import	2021-09-05 22:00	12,624.88	KWh
Primaria Alba Iulia	Circuit Consumator 1	Total Active energy import	2021-09-05 21:00	12,624.32	KWh
Primaria Alba Iulia	Circuit Consumator 1	Total Active energy import	2021-09-05 20:00	12,623.95	KWh
Primaria Alba Iulia	Circuit Consumator 1	Total Active energy import	2021-09-05 19:00	12,623.55	KWh
Primaria Alba Iulia	Circuit Consumator 1	Total Active energy import	2021-09-05 18:00	12,623.075	KWh

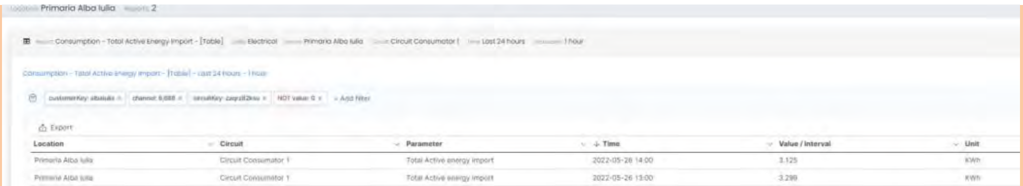
	
Target metric/KPI and verification (pass/fail)	passed

Table 6-25 Test report for Test Case ESAe02 (Preventive maintenance alerting accuracy test)

Field	Alerting accuracy	
Test Case ID	**ESAe02**	
Facility, Site	FR/RO cluster	
Description	The aim is to check the alerting accuracy performance related to monitored elements by sending maintenance alerts on the email service to multiple recipients.	
Executed by	Partner: ORO	Date: Sept 2022
Purpose	Pass/fail scenario: Pass if within KPIs Fail if outside KPIs	
Scenario	**ESAe02** - Preventive maintenance alerting accuracy test	
Slice Configuration	mMTC slice configured	
Components involved	LV metering devices 5G / LTE-M IoT device Telemetry platform	
KPIs collected (Metrics collected)	detection accuracy	
Tools involved	Telemetry platform	
Results and KPIs Primary Complementary	detection accuracy calculated through the comparison of the automatic detections, the ground truth data and the associated email alert received	

Target metric/KPI and verification (pass/fail)	passed

6.3.5 KPI evaluation and Conclusions – Lessons learned

The KPIs described have been achieved in the setup described within the 5G/LTE-M network capability, using a limited number of physical devices and extending the functionality with an IoT simulator developed by Orange. The LTE-M/mMTC slice network has been configured based on a dedicated Access Point Name (APN) with proper UL/DL and RAN scheduler mapped to the LV UC requirements (device density and low service throughput per IoT device).

6.4 Conclusions

The tests and experiments performed in FR/RO facility have been implemented in both laboratory and Field environment. The final 5G SA network deployment and UCs configuration have been validated in AIM, with the support of the local partners, for both UCs, achieving several key milestones:

- 5G SA option 2 implementations (RAN/Core) using an open source platform (OAI).

- Slice and service configuration, different network slices and DNN configuration to the EDGE.
- UCs running in an operational environment, for Media and Energy, demonstrated in real scenarios.

Table 6-26 Test cases results for Digital Mobility UC

Test Case	Result
MDIe01 ***User authentication using captive portal***	*Single user network slice, 5G SA, Radio BW 50MHz in N78* Results: • DL: 112 Mbps • UL: 30 Mbps • RTT external server (8.8.8.8) 40 ms • RTT internal server (edge computing) 20 ms
MDIe01 Passed/Failed	*Passed*
MDIe02 Captive portal data availability	*eMBB slice is enabled in the network* Results: • www.gsp.ro • Browsing time (latency) – time to display the requested information <3s; • Service availability>99% • tcpdump ~ 1.8s
MDIe02 Passed/Failed	*passed*
MDCe01 Establishment of basic E2E connectivity over a specific slice	Results: • Ping towards DNS 8.8.8.8 ~40 ms • Ping towards internal DNS(ORO) ~ 28ms • Ping towards EDGE C&C (through ORO) ~ 29ms
MDCe01 Captive portal data availability	passed

MDCe02 ***Establishment of advanced E2E connectivity over two different slices with different QoS metrics configured***	Results:
	• Network slice capabilities/management (Yes/No);
	  o The two network slices are manually configured (eMBB/Low Latency)
	• E2E latency for interactive service (in ms) < 30 ms;
	  o ~28 ms
	• E2E latency for public safety service (in ms) < 5 ms;
	  o ~5 ms
	• High bandwidth required for data intensive public safety applications and HD video streaming > 20 Mbps;
	  o Test performed in the N78 50MHz context
	  o 100 Mbps DL throughput
	• Jitter for URLLC < 1 ms
	  o < 0.070

MDCe02 Passed/Failed	passed
MDCe03 ***Load test for observing the QoS prioritization among slices with congestion on radio part***	Results: • Slices configured • E2E latency for interactive service (in ms) < 30 ms o ~28 ms

	• E2E latency for public safety service (in ms) < 5 ms
	  o ~ 12 ms
	• High bandwidth required for data intensive public safety applications and HD video streaming > 10 Mbps
	  o 20 Mbps
	• Jitter for URLLC < 1 ms
	  o ~0.05 – 0.5 ms
	Comment: proper optimization resource allocation will be performed in LAB condition

MDCe03 passed/failed	passed
MDCe04 *Stability test - injecting traffic over one slice for 3 consecutive days*	Results: • Network availability reached highly traffic load • E2E latency for interactive service (in ms) < 27 ms;
MDCe03 passed/failed	Passed (3 field testing days)
MDAe01-MDAe04 **(for all AI recognition and identification of emergency situation test-cases)**	Results (measurements performed from the device level): • 40 Mbps DL / 20 Mbps UL, • RTT ~5 ms
MDAe01-MDAe04	Passed

The **FR/RO** cluster and its deployment in **AIM** has validated the performance and the functionality of the implemented UC scenarios, highlighting the LV results for energy metering, pro-active management and automatic alarming system in case of issues.

7 5G-VIOS integration at various sites

7.1 5G-VIOS system description

5G-VIOS is a platform for inter-domain management and orchestration of NSs. The different domains are represented by facilities called *edges*, registered in 5G-VIOS. The platform's components are designed as cloud-native microservices and communication among the components is possible over a common service bus using open APIs. The 5G-VIOS components are described in deliverable **D2.6** [7], and are the following:

- 5G-VIOS Portal (Portal).
- Service Manager (SMA).
- Service Broker (SBR).
- Mobility Manager (MOB).
- Inter-domain Connectivity Manager (ICM).
- API Gateway (AGA).
- Monitoring (MON).
- Profiling (PRO).
- Edge Proxy (EPA).

Each microservice is developed locally, using either the Django, Flask, or FastAPI Python frameworks. Git is used to continually upload new code to version control repositories hosted on GitHub[3]. GitHub stores the latest images of each of the microservices as packages within each respective repository. Therefore, a miroservice's package can be then deployed to production environments as and when needed.

Updating each microservice package is an automatic process that is managed by GitHub Actions. When new code is submitted to its respective repository, an automatic workflow starts in which a number of checks are performed. These checks include running any application unit testing, and code linting to ensure that things are functioning as expected, and new bugs have not been introduced into the various code bases. Each of these checks must successfully pass first before a new package is automatically built and ready for deployment.

As described in deliverable **D4.1** [1], a common methodology has been adopted by each facility for experimentation procedures supported by 5G-VIOS. The role of 5G-VIOS in this methodology is to facilitate end-users (facility administrators and Vertical users) to interact with the 5G-VICTORI infrastructure and services. Facility administrators are able to onboard their facilities onto 5G-VIOS and expose the capabilities they offer. Vertical users can then define experiments utilizing a common service repository to deploy services across different domains supporting mobility UCs. 5G-VIOS is also able to aggregate, store and visualize experiment monitoring data from the deployed NSs and applications.

7.2 5G-VIOS integration at 5G VICTORI facilities

Communication between each edge and 5G-VIOS for the purpose of deploying and managing NSs is possible with the deployment of the following components using open APIs for intra- and inter-edge communication.

7.2.1 Edge Setup

For the purposes of this project, we have adopted the term "edge"[4], which represents an individual administrative domain and, in some cases, a facility, where, for example, there is only one

[3] https://github.com/orgs/5G-VICTORI-project/repositories

[4] More details in Deliverable **D2.5** [6]

administrative domain. To interact with 5G-VIOS, several components are required to be setup at each edge. Some may be existing for the operations of the edge, while others are specific to 5G-VICTORI.

- **5G-VIOS Edge Proxy**: responsible for the communication between edge components and 5G-VIOS central platform. This is a specific component developed for this purpose as defined in D2.6.
- **Virtual Infrastructure Manager (VIM)**: VIMs facilitate the deployment of the virtualized NSs. Currently only OpenStack is supported as VIM but can be extended to a Kubernetes cluster. Facilities are expected to provide an OpenStack environment to deploy VNFs.
- **Edge Network Service Orchestrator**: Controlled by 5G-VIOS through the Edge Proxy using SOL005 APIs, the edge orchestrator controls the VIM to manage and orchestrate the virtualized NSs. Currently, OSM (version >= 10) APIs have been integrated with 5G-VIOS Edge Proxy to perform life cycle management of NS. It is expected that OSM will be available at each edge facility.
- **VyOS Router**: used for the deployment of the transport network between each edge and 5G-VIOS as well as among edges. This is deployed as an OpenStack VM along with the Edge Proxy.
- **SDN Controller:** manages the available VLANs of physical switches and updates the Edge Proxy regarding changes in the established VLANs. This is provided by the facility manager responsible for controlling the physical infrastructure. 5G-VIOS Edge Proxy uses the Open APIs form the controller to manage the VLAN configuration.

7.2.2 Edge Descriptor

The registration of an edge to 5G-VIOS is required for 5G-VIOS to be able to deploy NSs on this edge. To successfully register an edge in 5G-VIOS, an edge descriptor is needed provided in a JSON format, with information included such as the name, the IP address and port of the Edge Proxy, the range (min and max values) of the pool of VLAN IDs available for the edge and finally the location (longitude and latitude) as well as the coverage radius of the edge. Location information is used for mobility management and migration of services. An example is shown below:

```
{
  "edge_name": "hpn",
  "edge_ip_address": "10.68.113.111",
  "edge_port": "30001",
  "edge_vlan_pool_min": 147,
  "edge_vlan_pool_max": 148,
  "edge_longitude": 0,
  "edge_latitude": 0,
  "edge_radius": 100
}
```

A Python script is available to automatically configure each edge descriptor based on settings specified in a configuration file.

7.2.3 Experiment Descriptor

To create an experiment in 5G-VIOS, the user has two options. The first is through the 5G-VIOS portal to use the form provided and fill-in the information manually or, alternatively, to use an Experiment Descriptor in JSON format, with information included as described in section 5.2.5. In principle, the on-line form creates the same fields that will drive the rest of the experiment life-cycle. An example is shown below:

```
{
  "Name": "Mativision_APP1",
  "Type": "Standard",
  "Exclusive": true,
  "UEs": [
```

```
      "UE_1",
      "UE_2"
    ],
    "Scenario": "Scenario1",
    "Automated": true,
    "NSDIDs": [
      "5867207d-c4a7-4c88-bb8c-9fd2479d0c89,cc5ee461-220f-405d-b74e-
7e62ffe2dd11,mshed",
      "3ac5d3de-81f3-45d2-b2f8-1b49cf9d3061,a254c09c-fe34-4c42-af55-0b98cc8cc546,hpn"
    ],
    "resources": {
      "cpu": {
        "min_cores": "2",
        "max_cores": "8"
      },
      "memory": {
        "min": "2000",
        "max": "10000"
      },
      "link_capacity": {
        "min": "400000000",
        "max": "1400000000"
      }
    },
    "ns_kpis": {
      "cpu_utilisation": 0.98,
      "memory_utilisation": 100
    },
    "app_kpis": {
      "latency": 3
    }
  }
```


A Python script is available to automatically configure an experiment descriptor with the appropriate NSs based on settings specified in a configuration file.

7.2.4 Network Service Descriptor (NSD) & Virtual Network Function Descriptor (VNFD)

Each edge is supplied with Network Service Descriptors (NSDs), which can be viewed in the 5G-VIOS Repository. These descriptors are used by 5G-VIOS to build the experiment NS that can consist of multiple NSs belonging to different edges. The network infrastructure owner needs to provide the virtual network name (in this case “5G-VICTORI-Management”).


```
nsd:
  nsd:
  - id: MATI_App1_cacheserver
    name: MATI_App1_cacheserver
    designer: Mativision
    description: NSD for Mativision APP1 Cache (frontend)
    version: '1.0'
    vnfd-id:
    - mati_app1_cache_vnfd
    df:
    - id: default-df
      vnf-profile:
      - id: "1"
        vnfd-id: mati_app1_cache_vnfd
```

```
          virtual-link-connectivity:
          - virtual-link-profile-id: 5G-VICTORI-Management
            constituent-cpd-id:
            - constituent-base-element-id: "1"
              constituent-cpd-id: vnf-cp0-ext
      virtual-link-desc:
      - id: 5G-VICTORI-Management
        mgmt-network: true
```


The above example NSD is associated with the below Virtual Network Function Descriptor (VNFD). The VNFD includes information regarding the description, the network connectivity and virtual infrastructure requirements for instantiating the VM hosting the VNF. The application owner needs to provide virtual storage (in “virtual-storage-desc”), cpu and memory (in “virtual-compute-desc”) information and the name of the image (in “sw-image-desc”).


```
vnfd:
  id: mati_app1_cache_vnfd
  product-name: mati_app1_cache_vnfd
  description: VNFD for Mativision APP1 cache (Frontend)
  provider: OSM
  version: '1.0'
  mgmt-cp: vnf-cp0-ext
  virtual-storage-desc:
  - id: mati_app1_cache_vnfd-VM-storage
    size-of-storage: 50
  virtual-compute-desc:
  - id: mati_app1_cache_vnfd-VM-compute
    virtual-cpu:
      num-virtual-cpu: 2
    virtual-memory:
      size: 4
  sw-image-desc:
  - id: "MATI-CacheServer"
    name: "MATI-CacheServer"
    image: "MATI-APP1-CACHE-V1"
  df:
  - id: default-df
    instantiation-level:
    - id: default-instantiation-level
      vdu-level:
      - vdu-id: mati_app1_cache_vnfd-VM
        number-of-instances: 1
```

```
      vdu-profile:
      - id: mati_app1_cache_vnfd-VM
        min-number-of-instances: 1
        max-number-of-instances: 1
      # At least one VDU need to be specified
      # Additional VDUs can be created by copying the
      # VDU descriptor below
    vdu:
    - id: mati_app1_cache_vnfd-VM
      name: mati_app1_cache_vnfd-VM
      description: mati_app1_cache_vnfd-VM
      sw-image-desc: "MATI-CacheServer"
      cloud-init-file: mativision_init
      virtual-storage-desc:
      - mati_app1_cache_vnfd-VM-storage
      virtual-compute-desc: mati_app1_cache_vnfd-VM-compute
      int-cpd:
      - id: eth0-int
        virtual-network-interface-requirement:
        - name: eth0
          virtual-interface:
            type: PARAVIRT
    ext-cpd:
    - id: vnf-cp0-ext
      int-cpd:
        vdu-id: mati_app1_cache_vnfd-VM
        cpd: eth0-int
```


7.2.5 5G-VIOS Monitoring

The 5G-VIOS Monitoring (MON) component is responsible for collecting and storing metric data submitted by each edge monitoring service in order to be used by the Profiling (PRO) component and visualized by the 5G-VIOS Portal.

The submitted data is stored in a MongoDB database via HTTP requests, using time series collections. The data is classified either as application data or as NS data. When an application or NS first sends data to MON then a new collection is created based on this first data entry and is dedicated to it. The format of the payload to be submitted to MON should be as follows:


```
{
    "timestamp": "2022-10-04T10:40:29.048000",
    "application_name": "Mativision_APP1",
    "app_data": {
        "master_delay": 197,
```

```
            "common_bandwidth": 5051.304347826087,
            "mobility_latency": 0
        }
    }

{
    "timestamp": "2022-09-24T23:55:50.991211",
    "ns_name": "MATI_App1_storageserver",
    "ns_data":{
        "cpu_utilization": 8,
        "memory_utilization": 16
    }
}
```


The data source needs to submit the time the data was created (in ISO 8601 format), the name of the field “application_name” along with the name of the application or “ns_name” if the source is a NS along with the name of the NS. Then “app_data” (or “ns_data”) is the field that includes the application or NS KPIs together with their respective values. The KPIs must be unique per data entry, i.e., the KPI name inside “app_data” or “ns_data” must be mentioned only once.

7.2.6 5G-VIOS Profiling

One of the key innovations of 5G-VIOS is the aspect of performance profiling using AI/ML models for optimal resource allocation. This is supported by the 5G-VIOS Profiling component as explained in deliverable **D2.6** [7]. To generate the performance profiles, there needs to be a training period for that particular NS. Currently this functionality is performed at the edge Profiler available at **UNIVBRIS** facility. The other clusters would need to share the image of the VNFs to be profiled with the edge Profiler. The edge Profiler, selects various configuration of resources, and asks the OSM which is already in the edge to deploy the NS and assign those resources to it. Then, the edge Profiler profiles them and generates Performance Profile dataset for each VNF under profiling. It looks at the VNF/NS under profiling as a black box. So, the image should be enough to profile each VNF. Currently, the Profiler considers KPIs such as CPU Utilisation, Memory Utilisation and Latency utilising monitoring tools such as the Prometheus and Ping. However, if any other KPI is important for the other clusters, they should provide appropriate monitoring APIs, so, the edge Profiler/ edge Monitoring can query them. In addition we have iperf client and iperf server VNFs, which are used as the traffic generator and receiver, respectively which will host at **UNIVBRIS**. Of course, we can develop the edge Profiling at other clusters as well. However, it can be currently done through the Edge Profiler at **UNIVBRIS**.

After the Profiling time is over, the Profiler exposes the generated Performance Profile dataset of each VNF as well as the ML trained file to the 5G-VIOS Profiler through the edge Proxy. Then, during executing an experiment, when 5G-VIOS wants to deploy a NS/VNF on an edge, the 5G-VIOS Profiler predicts the optimum configuration of resources needed to meet the defined required KPIs (referred to as Profile) and post this Profile to the 5G-VIOS.

The Profiling time for each NS depends on the accuracy of the predicted metrics/resources. Usually, within 2 or 3 days of profiling each NS, we can generate around 150 to 200 performance dataset which can be used by the Neural Network at 5G-VIOS Profiling to predict the metrics/resources with an appropriate accuracy or error rate.

Table 7-1 Minimum compute resources for deploying the 5G-VIOS Kubernetes cluster

	VCPU	VRAM	VHDD
5G-VIOS main cluster	6	16	100
OSM + Edge Proxy	6	12	100
OSM	3	6	50
Edge Proxy	3	6	50
VyOS	2	4	25

7.2.7 Minimum Hardware Requirements

As described in deliverable **D2.6**, there are different options in terms of deployment of 5G-VIOS in the facilities. The first is to deploy a complete instance of the main 5G-VIOS cluster and the Edge Proxy and associated components. This would be used for testing and scenarios where facilities are not interconnected to others. The second option is to install the 5G-VIOS main cluster to one facility or a third party hosting infrastructure (e.g. AWS) and only have the Edge Proxy and associated components installed at that facility, which would be the case for inter-facility scenarios.

The compute resources required for deploying the main 5G-VIOS Kubernetes cluster as well as OSM and Edge Proxy are provided in Table 7-1. For the OSM and Edge proxy deployment there is the possibility for the facility owner to choose if they would like to use their own OSM deployment or not and deploy the Edge Proxy separately.

To deploy 5G-VIOS and its microservices, two key technologies are used. With Helm, a declarative set of instructions, or charts, are created, and version controlled, for how each microservice is to be deployed, and its required resources to operate. Kubernetes within an OpenStack environment acts as a Docker container orchestration manager. In Kubernetes, a virtual 5G-VIOS cluster is created with the necessary virtual resources, in which each microservice is installed. A number of provisioning scripts exist that allow the automatic setup of an appropriate 5G-VIOS Kubernetes cluster, along with the auto installation of the microservices.

When a new package for a microservice successfully builds, Flux will automatically detect this and deploy the new package to a specified 5G-VIOS instance. This seamlessly and automatically maintains the latest revisions of each microservice within a 5G-VIOS instance. This keeps each 5G-VIOS instance up-to-date.

With the deployment of all microservices to a 5G-VIOS instance, a set of automated API Integration tests, currently amounting to 69 checks, using the PyTest framework can be initiated. The API Integration Test Suite is split into several functional workflows that automatically run through each of the different processes necessary to deploy a NS e2e. The integration tests check that external calls from microservice-to-microservice are working as expected.

This approach allows the 5G-VIOS platform to be continually developed in a robust and repeatable manner, and for new updates to be automatically deployed to any 5G-VIOS instance on a rolling basis.

7.2.8 5G-VIOS integration at University of Bristol

Figure 7-1 depicts the deployment of 5G-VIOS microservices at the **UNIVBRIS** infrastructure. These microservices are deployed inside a Kubernetes cluster that is deployed within a VM in the M Shed edge. To manage the life cycle of the experiment, four edges have been prepared known as M Shed, WTC, HPN and Nomadic node.

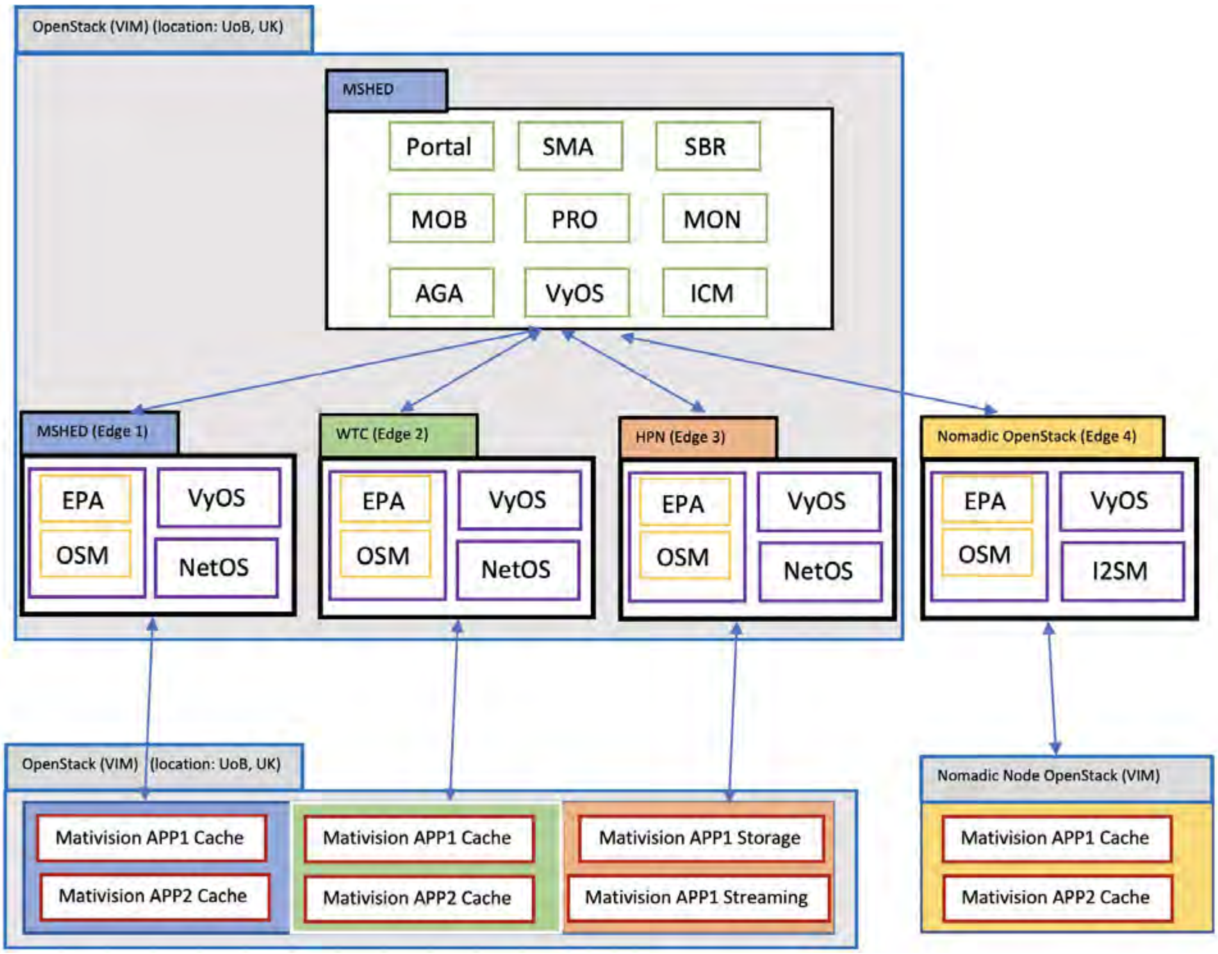


Figure 7-1 5G-VIOS Deployment at UNIVBRIS Infrastructure

The edges M Shed, WTC and HPN are created using three availability zones in the same OpenStack. Additionally, each edge is prepared by deploying and configuring Edge Proxy, OSM, VyOS, and Zeetta Automate (also known as NetOS). An Edge Proxy deployed at each edge manages the deployment of virtual networks and NS in the corresponding edge. On the other hand, Nomadic node is an isolated edge having separate OpenStack for the deployment of edge components such as Edge Proxy, OSM, VyOS, and i2CAT Slice Manager (i2SM) as well as for the deployment of virtual network and NSs.

During the Bristol trial, we have deployed two separate experiments for MATI **App1** and **App2**. The experiment descriptor for MATI **App1** includes two NSs, namely, the Cache Server and the Storage Server. During deployment of the experiment, a transport network is created by the Inter-domain Connectivity Manager (ICM) that includes the Dynamic Multipoint VPN (DMVPN) configuration among edges as well as the deployment of VLANs for each NS (both on OpenStack and the physical switches using Edge Proxy and Zeetta Automate). During the field trial, the Storage Server for MATI **App1** is deployed at the HPN edge while the Cache Server is initially deployed at M Shed and then migrated to Nomadic and WTC edges based on the location of the user. Similarly, for the MATI **App2**, the streaming server is deployed at HPN edge and Cache server is deployed at M Shed, Nomadic and WTC edges.

An example of how monitoring data is visualized on the Portal can be seen in Figure 7-2, showing the monitoring data captured during the trials in Bristol from the two virtual machines that host the NSs (the cache server and storage server) of MATI **App1**. The Portal is also visualizing the monitoring data in real-time using open source JavaScript libraries, by requesting updates from 5G-

VIOS Monitoring (MON) that queries the requested data from its MongoDB database and returns the results to the Portal.

Figure 7-2 5G-VIOS Monitoring data example for App1

7.3 5G-VIOS integration test cases – template

In deliverable D3.2 we have defined a set of integration tests related to 5G-VIOS. Specifically,

- **RDNu05**: 5G-VIOS experiment deployment (lab test).
- **RDNu06**: 5G-VIOS experiment deployment across multiple facilities (field test).

These test cases demonstrate how efficiently 5G-VIOS can deploy an experiment. The main objective is to have an automated inter-domain service orchestration platform that is able to utilise existing services offered by different domains to build an e2e service. **RDNu05** focuses on a single facility while **RDNu06** is for inter-facility testing.

In parallel, **RDIu03** tests the mobility of MATI **App1**, which is linked to 5G-VIOS but it is not a dedicated 5G-VIOS integration test case.

The template of the test cases is repeated here for methodology purposes.

Table 7-2 RDIu03 test case descriptor

RDNu05	**5G-VIOS experiment deployment (Lab test) on Bristol facility**
Testbed	**5G-UK Bristol**
Description	This test deploys an experiment to the virtualized testbed of Bristol. In this test, an experiment includes two NSs deployed to the multiple intra-facilities edges.
Key use-case requirements and KPIs	N/A
Network performance requirement and KPIs	All the resources belonging to the experiment are deployed and configured within 90 mins.
Network function requirements and KPIs	VNFD, network function descriptors (NSD), and experiment descriptors required for the experiment deployment are already onboarded and exposed to the VIOS platform.
Components and configurations	**Components:** • OpenStack • OSM • K8s cluster • 5G-VIOS platform. **Configurations:** • Edge proxy is deployed at the edge. • Edge is registered with 5G-VIOS • API Gateway, OSM, NetOS, profiler, and monitoring platform are configured with edge proxy. • OpenStack is registered with OSM.
Test Procedure	**Preconditions:** • Each edge is registered. • VIOS and edges are connected. • VNFDs and NSDs are onboarded to OSM and exported to the VIOS. **Test case steps:** • User creates the experiment. • Initiate the experiment deployment. • Deploy the experiment. • Monitor the experiment and terminate the experiment.

Measurements	**Methodology** • Monitor OSMs to check the Network services are created. • Monitor OpenStack to check VMs, VLANs, and private networks are created successfully. • Monitor 5G-VIOS for creation and completion time of experiment deployment. • Monitor 5G-VIOS portal for experiment status is deployed. **Calculation process** • Analyse 5G-VIOS log to measure the time required for the experiment deployment.
Expected Result	All the resources belonging to the experiment are deployed to the expected infrastructure. Pass/Fail results: Pass: If the experiment deployed correctly within the 90 mins threshold. Fail: If the experiment is not deployed correctly within 90 mins.

Table 7-3 RDIu06 test case descriptor

RDNu06	5G-VIOS experiment deployment across multiple facilities (field test).
Testbed	**5G-UK Bristol**, **5G-VINNI Patras**
Description	This test deploys an experiment to the virtualised testbed of Bristol and Patras. During this filed trial, an experiment with two NSs will be deployed to the multiple inter-facilities edges.
Key use-case requirements and KPIs	NA
Network performance requirement and KPIs	All the resources belonging to the experiment are deployed and configured within 90 mins.
Network function requirements and KPIs	VNFD, network function descriptors (NSD), and experiment descriptors required for the experiment deployment are already onboarded and exposed from both the facilities/edge to the VIOS platform.
Components and configurations	**Components:** • OpenStack • OSM • K8s cluster • 5G-VIOS platform. **Configurations:** • Edge proxy is deployed at the edge. • Edge is registered with 5G-VIOS • API Gateway, OSM, NetOS, profiler, and monitoring platform are configured with edge proxy.

	• OpenStack is registered with OSM.
Test Procedure	**Preconditions**: • Both facilities/edges have connectivity. • Each edge is registered. • VIOS and edges are connected. • VNFDs and NSDs are onboarded to OSM and exported to the VIOS. **Test case steps:** • User creates the experiment. • Initiate the experiment deployment. • Deploy the experiment. • Monitor the experiment and terminate the experiment.
Measurements	**Methodology** • Monitor OSMs to check the Network services are created. • Monitor OpenStack to check VMs, VLANs and private networks are created successfully. • Monitor 5G-VIOS for creation and completion time of experiment deployment. • Monitor 5G-VIOS portal for experiment status is deployed. **Calculation process** • Analyse 5G-VIOS log to measure the time required for the experiment deployment.
Expected Result	All the resources belonging to the experiment are deployed to the expected infrastructure. **Pass/Fail results:** **Pass**: If the experiment deployed correctly within the 90 mins threshold. **Fail**: If the experiment is not deployed correctly within 90 mins.

7.4 5G-VIOS test cases at Bristol – results

During the Bristol Trials in October 2022 we have been able to evaluate the performance of 5G-VIOS, particularly against **RDNu05** test case. This test case has been successfully passed, with the deployment of MATI **App1** under 90 min. **App1** NS consists of two VNFs as explained in section 5 (Bristol cluster), the cache server image is 5.75 GB, and the storage server image is 10.67 GB, respectively.

Specifically we have the following results and metrics related to the operations of 5G-VIOS:

Metric/KPI	Measurements (average)
Registration of an edge	1.27 sec
Creation of experiment	1.59 sec
Instantiation of experiment	64.5 sec
Termination of experiment	18.35 sec

These times are impacted by the size of image and the service utilisation of the machine that run the VIM (OpenStack).

8 Conclusions

This deliverable report describes the execution of initial trials that took place in the framework of 5G-VICTORI, within **WP4** “Trials of Coexisting Vertical Services, validation and KPI evaluation”. The large scale trials that have been designed and methodologically discussed in **WP3** are being executed in WP4 and this report focuses on how these large scale field trials for a variety of verticals including Transportation, Energy, Media and Factories of the Future are executed. WP4 started with the delivery of **D4.1** were the methodology for integrating in vertical application in the 5G-VICTORI architecture was described. The testing methodology in lab environmetns and in the field is described and initiated in WP3 deliverables. This report leverages upon the methodology and the facility designs that are presented in **WP2** deliverables and evaluates the progress of trials with respect to requirements and KPIs as initially set in WP2.

5G-VICTORI UCs are being executed at vertical facility sites that deployed 5G test-beds provided by all ICT-17 infrastructures, namely **5GENESIS** (Berlin, Germany), **5G-VINNI** (Patras, Greece), **5G-EVE** (France/Romania), and the **5GUK** testbed (Bristol, UK). The latter have been extended to integrate the vertical facilities sites that corresponding UC are delivered by and in all cases have been enhanced with features that are required to meet the expected KPIs. The maturity of testing at each facility varies according to the level of integration that had to be performed among the vertical applications and the 5G-VICTORI elements deployed in each facility. In some cases extension of the 5G facility through newly deployed transport extensions is performed. In some UCs, where access to the vertical premises and equipment is performed with specific precaution measures (trains in Berlin and Patras cluster, HV environments in Patras cluster, etc.), only initial trials have been performed. Nevertheless, all lab integrations and testing has been delivered with sufficient results in all facilities and in some cases initial trials have taken place that exhibit very good KPI delivery for the vertical facilities.

Specifically, the progress for each facility is described on a per UC basis with a large percentage of test cases delivered.

For the **Berlin** cluster, where three UC are planned to be delivered, extensive integration work and lab testing has been performed while initial trials at Berlin Central Station unveiled many challenges that are currently being dealt with. For **UC #1.2** an initial field trial is carried out using a dedicated 5G Edge nomadic node in Berlin Central Station, in order to investigate the performance of the 5G connection alongside edge computing to for future mobility applications. In this case, 5G enables rendering a gaming scene to simulate navigation inside the train station, and relies on complex graphical processing a huge amount of data originating from the scan of Berlin Central Station.

At the same time initial testing of CCTV and rail signaling in 5G-VICTORI project for Berlin demos is reported for the Rail Critical Services area (**UC #1.3**). All integration work and lab testing is finalized and reported in this document. CCTV and Rail Signaling were first tested at **Alstom** in Stockholm during autumn 2021 using the real camera and the Alstom Hawkeye license. Rail Signaling was then tested during spring 2022 at **FhG** in Berlin, using the FhG Hawkeye license, all performed with limited number of existing probes. All tests are repeated with QoS and large number of probes with the same equipment that will be used for the final trials. Finally, **UC #3** for Berlin cluster was tested at another station, unveiling the challenges related to the testing and optimization time required and the stringent limitation for equipment installation.

In the **Patras** facility, all integration and lab testing has been finalized with initial vertical specific and network KPIs indicating very promising results. For **UC #1.1** the initial trial at Patras depot exhibits the challenges that relate to the installation of the equipment and the limitations of time for testing (overnight time slots). The progress in initial testing is satisfactory with respect to mobility management over a multi technology environment and service integration. e2e FRMCS service delivery and a new phase of tests are planned before the final execution of trials. **UC #2** and **UC #3** are currently being finalized, as the final transport deployment with allow the e2e delivery of the services at the vertical facilities and measurements of KPIs.

It is interesting to notice that various 5G deployments according to the 5G-VICTORI architecture are currently being tested in the field and are being deployed at the trials with two major breakthroughs concerning utilizing OAI on board and multi UPF technology for the 5G core network. These milestones allow 5G-VICTORI to fulfill its original vison with respect to open source technologies and KPIs to be met. Furthermore, e2e slicing is delivered at the lab, with the equipment that are expected to be used for the final phase in the field trials.

In **FR/RO** cluster all the **UC#1.2** objectives have been achieved based on the OAI RAN/Core solution implemented. For UC#1.2 the first trials took place in June 2022 and the results in terms of 5G SA service communication and UCs experimentation in the field, from the 5G SA network integration and deployment to the network configuration and use case onboarding on top of the 5G SA have been produced. For the LV UC, initial trials have been finalized and the KPIs described have been achieved in the setup described within the 5G/LTE-M network capability, using a limited number of physical devices and extending the functionality with an IoT simulator developed by Orange. The LTE-M/mMTC slice network has been configured based on a dedicated APN with proper UL/DL and RAN scheduler mapped to the LV UC requirements (device density and low service throughput per IoT device).

The tests and experiments performed in FR/RO facility have been implemented in both lab and field environment. The final 5G SA network deployment and UCs configuration have been validated in AIM, with the support of the local partners, for both UCs, achieving several key milestones:

- 5G SA option 2 implementations (RAN/Core) using an open source 5G platform.
- Slice and service configuration, different network slices and DNN configuration to the EDGE.
- UCs running in real environment, for Media and Energy, demonstrated in real scenarios.

UNIVBRIS deployed a network with all the required integrations as part of the 5G-VICTORI deliverables. From Cloud, to MEC and 5G, the 5GUK testbed successfully delivered service provisioning at all network edges supporting the demonstration route followed during the October field trial in Bristol. For this activity, the Cloud network was enhanced with numerous high-end servers capable of running the virtualized network and application functions for **App1**, **App2**, and **App3**. This activity was completed despite the rooftop fire and the limited access at one of the UNIVBRIS's edge nodes, the WTC Museum. For this trial, the 5G RAN was recovered by moving the Nokia gNB and 5GNR from WTC balcony to M Shed West rooftop creating an alternative cell for this demonstration. By doing so, we ensured that the demonstration route was properly covered by the 5GUK 5G network and the minimum threshold of KPIs were met for all APPs. Further computational resources were also installed at the network edges, including WTC, M Shed and the Nomadic Node, accommodating all the virtual functionality required to provide services for Apps 1-3. In addition, the set of different solutions and services developed by the partners involved in the Bristol demonstration (e.g. **Zeetta** Automate slicing solution, **i2CAT** Slice Management - i2SM, and **DCAT**'s Amarisoft 5G-call-box and Wi-Fi Access Point) were fully integrated to the already existing testbed as well as the newly created Nomadic Node.

For **App1**, **MATI** tested both the synchronization and caching services on multiple devices running in parallel. For **App2**, MATI tested live streaming of 360 video on multiple devices with edge caching enabled. Both tests were run successfully, meeting the required KPIs and providing the expected quality of experience. For **App3**, UHA ran some basic tests of their solution where their application was implemented based on WebRTC and data streaming from the Cloud (MVB – HPN lab) to the edges over 5G connection. With additional integration of a GPU at the edge node and further testing **App3** application services at the edge node could have created a better user experience for **App3**. Due to the limitations during the field trial the GPU resources were not available at any of the edges.

5G-VIOS was fully integrated to the 5GUK testbed and all the edges, including the Nomadic Node. 5G-VIOS was mainly hosted in the 5GUK Cloud (MVB – HPN), while some of its components, such as the edge proxy and edge monitoring were deployed at the edges. **App1** and **App2** were fully integrated to the VIOS ecosystem, supporting a dynamic e2e service creation and deletion at any network location (HPN, M Shed, WTC, Nomadic Node) while also storing the measured KPIs at each edge and then sharing them with the central profiling service. **App3** is planned to be integrated into the 5G-VIOS until the final field trial at the end of the project. In addition, **App1** and **App2** Network services were profiled through the VIOS Profiler, and their profiling dataset were stored in Elasticsearch data repository. Finally, The VIOS Profiler could predict the optimum configuration of resources per each Network service through utilising Machine Learning techniques. So, the VIOS could assign optimum resource values to each application.

Planning ahead for the final field trial in Summer 2023, the Bristol and Patras clusters will demonstrate an inter-cluster service provision involving **App2**. In addition, the Bristol and Berlin will demonstrate an inter-cluster experiment considering **App3**. The inter-cluster communication will be implemented using a VPN-secured link between the sites over the internet. 5G-VIOS will provide the inter-cluster service creation, with the remote class being available at both clusters (in case of **App2**). The Nomadic Node will be also upgraded with additional computational resources and 5G RAN. For the final demo, Bristol cluster is not planning any field demonstrations, however, **Apps1-3** demonstrations could take place inside the HPN lab using the Nomadic Node.

List of Figures

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9 References

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10 Appendix

10.1 Additional work/results stemming from UC #1.2 in the Berlin facility

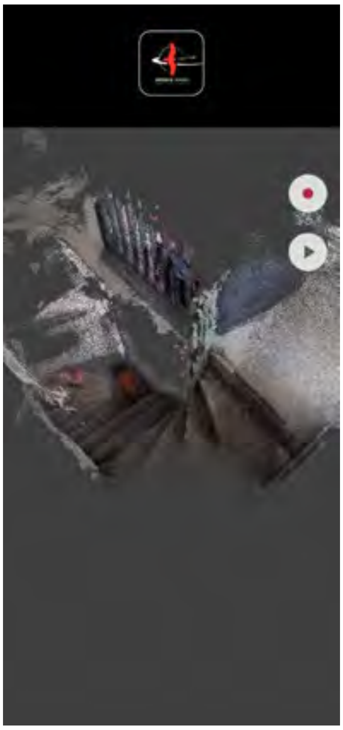
10.1.1 3D Scan of Berlin Central Station

Urban Hawk undertook a series of scans to produce a large model of the Berlin Central Station using three different sensor systems:

1) Leica BLK2Go – a handheld LIDAR scanner that uses a puck and 360 photographs to allow for feature mapping – utilizing a combination of manual and semi-automated feature alignment to permit large scale maps to be produced.

Figure 10-1 Leica BLK2GO on calibration puck

2) Basic photogrammetry using Galaxy S20 – and the 3D Map Pro application – essentially a cloud augmented Photogrammetry mapping application that generates a mesh – and applies post processed photogrammetry to generate a 3D model



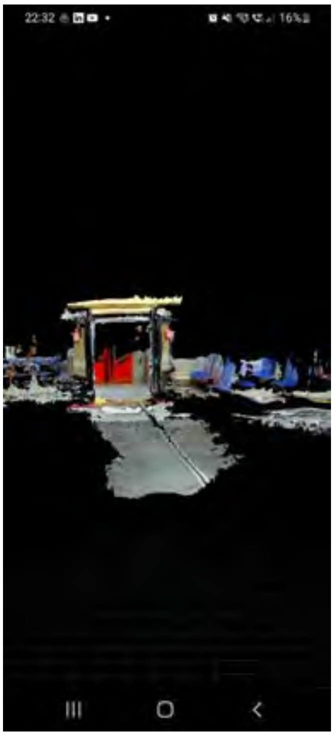


Figure 10-2 One of the phone applications tested in the station – using Google AR Core

3) Oxford Robotics – Rooster – a 5th gen prototype unit utilizing a proprietary SLAM algorithm – called Vilens – partially developed as part of their work on the DARPA Sub-Terranean competition. Whilst this uses a lower fidelity LIDAR (sadly the standard unit was inoperable) its key feature is the ability to accurately record 20-30 mins of SLAM data and process this on the unit.

Figure 10-3 OxRO – ROOSTER protoype

4) Stereo Neural Camera scans were taken – however the need to carry the gaming laptop and kit alongside the scanner didn't make it practical for use within the station. Some scans and movement within the DB offices were taken to permit use later in an enlarged 3D volume. This is fairly generic data – since it can be generated via most stereo neural cameras – and

we have since upgraded to a newer and more robust device – with the planned acquisition of a Jeson Xavier to permit man portable – or fixed scanning operations to simulate intelligent CCTV. Given other work within the group in this domain – this was de-prioritised over large scale scans – given the constrained time frame to undertake the scanning.

Figure 10-4 Stereo Neural Camera testing & config in DB offices.

The focus of our work was to capture and produce a 3D map of the upper station areas allowing for a model to be created to permit a digital twin to be generated. Unlike the use of previous 3D assets or CAD and BIM data (requested but not available) the 3D model produced is an as built model.

OxRO – ROOSTER prototype scans

Shown below are the SLAM generated maps via the OxRo Rooster device – with virtually no post processing of the data. Despite being an advanced prototype – it is not their production model which led to a few aberrations – however it is interesting to note how well the LIDAR Device performed against the “Dulux effect” where high gloss and glass surfaces play havoc with untuned / untrained LIDAR models. The production model utilizes a combination of Video & LIDAR based SLAM and utilized a far more robust IMU. Additionally, we were able to cover a significantly larger area and even capture and recapture areas (allowing for better map merging) than the Leica Device. Since the processing and SLAM is done on device – it is also far easier to see where issues and errors have occurred. Additionally, the device allowed for a much faster pace – and doesn’t require frequent re-localization against a base puck and performed very well in the Metro section of the station. Map warping (a consistent map – but essentially accumulated drift) proved an issue in some scans – but is an artifact of the sensor being typically mounted to a SPOT or ANYmal robotic quadroped – and the visual slam unit was not available for use (which all but eliminates this).

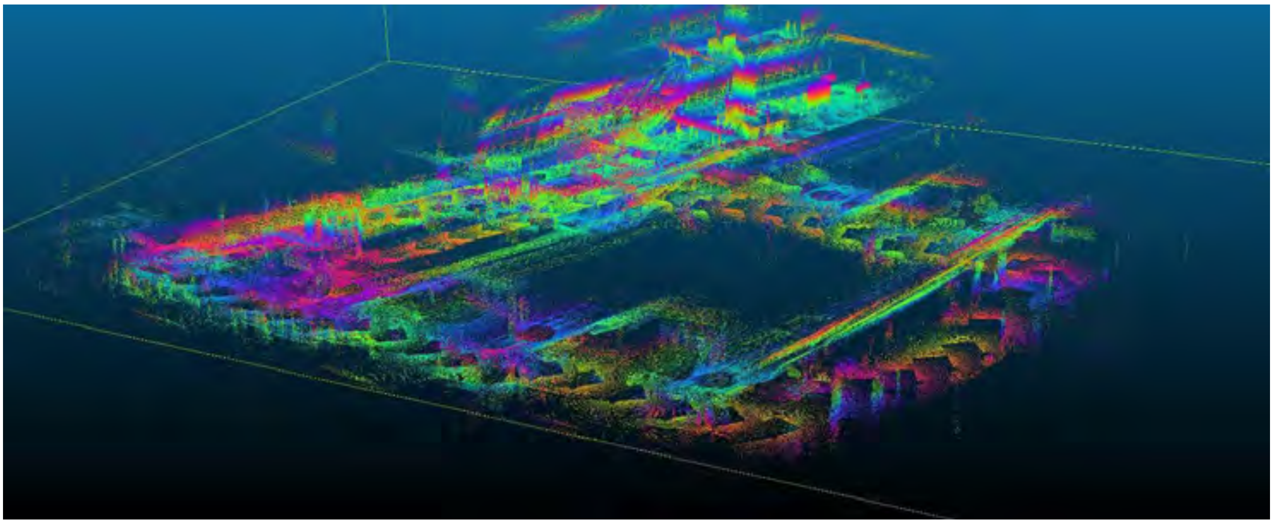


Figure 10-5 Fused map of upper section and concourse of HBH via ROOSTER

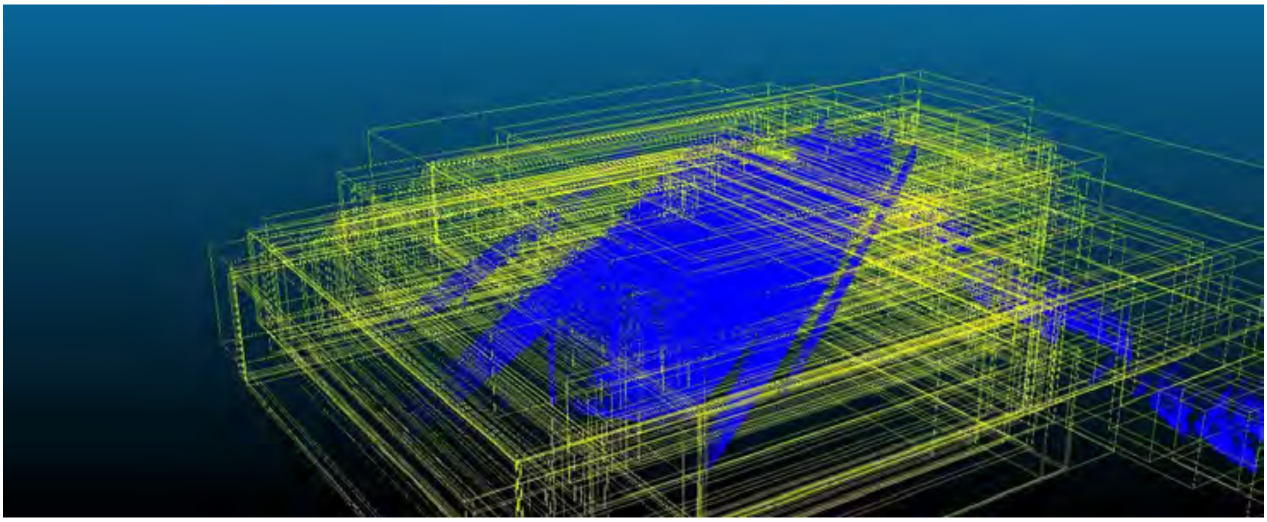


Figure 10-6 Sub-map sections highlighted

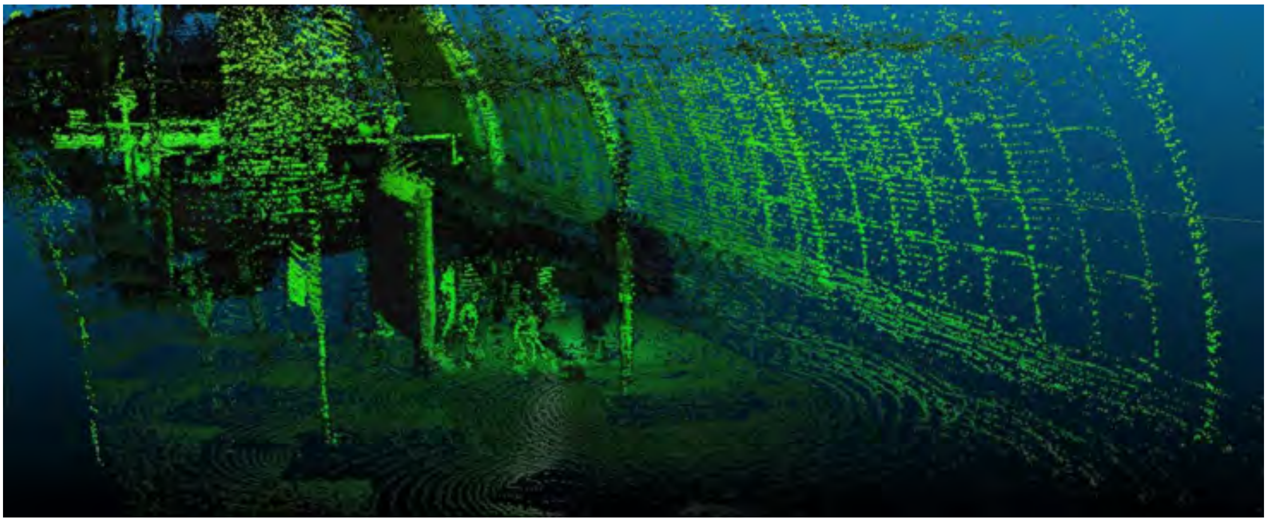


Figure 10-7 5G testing team hard at work awaiting the arrival of the testing train.

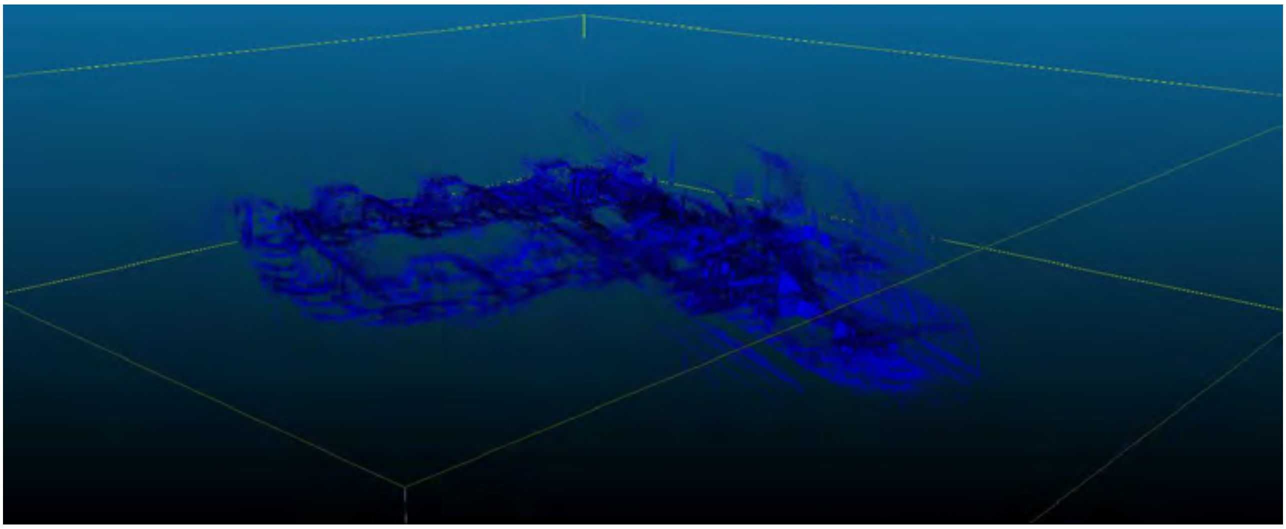


Figure 10-8 Basic Scan > Mesh generation – in support of Fraunhofer Unity work.

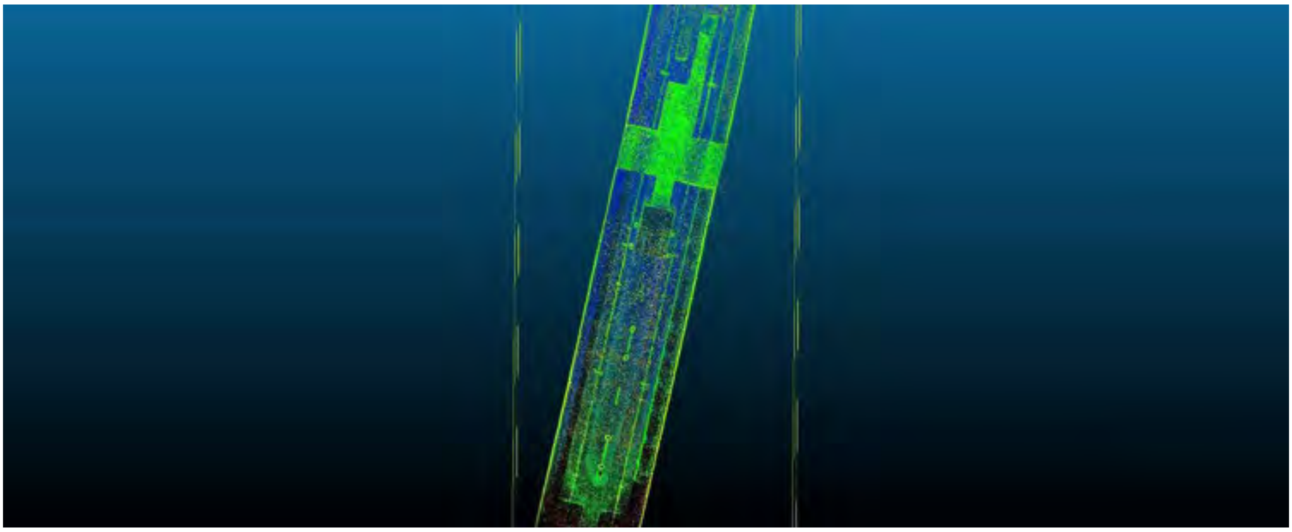


Figure 10-9 Topdown view of one of the lower platform runs (several hundred meters length)

From this have then been able to ingest this into the Polaron 3D model – to generate a large-scale map – which allows for the semantic modelling of the space (e.g. Accessible / Inaccessible / Platform / Stairway), etc. We have found that simple Ransac or Object models – whilst useful for reducing the complexity of a scene need additional training. Polaron is highly suited to “inpainting” and “annotation” allowing very quick feature identification from human tagging – leading to an automatic feature extraction – similar to computer vision from satellite imagery – but conducted within the 3D space. At the time of writing, we are refining the GUI for the 3D interface to allow this be much easier to use – essentially allowing “shapes” and data volumes to be tagged and then features auto-extracted.

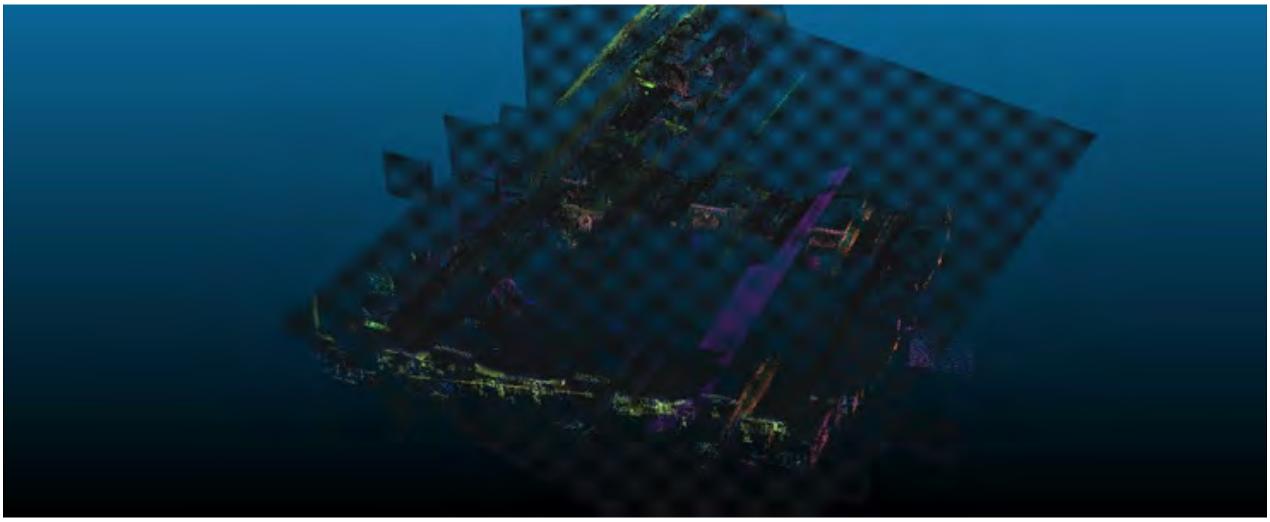


Figure 10-10 Primitive feature extraction via CloudCompare – using RANSAC and plane detection.

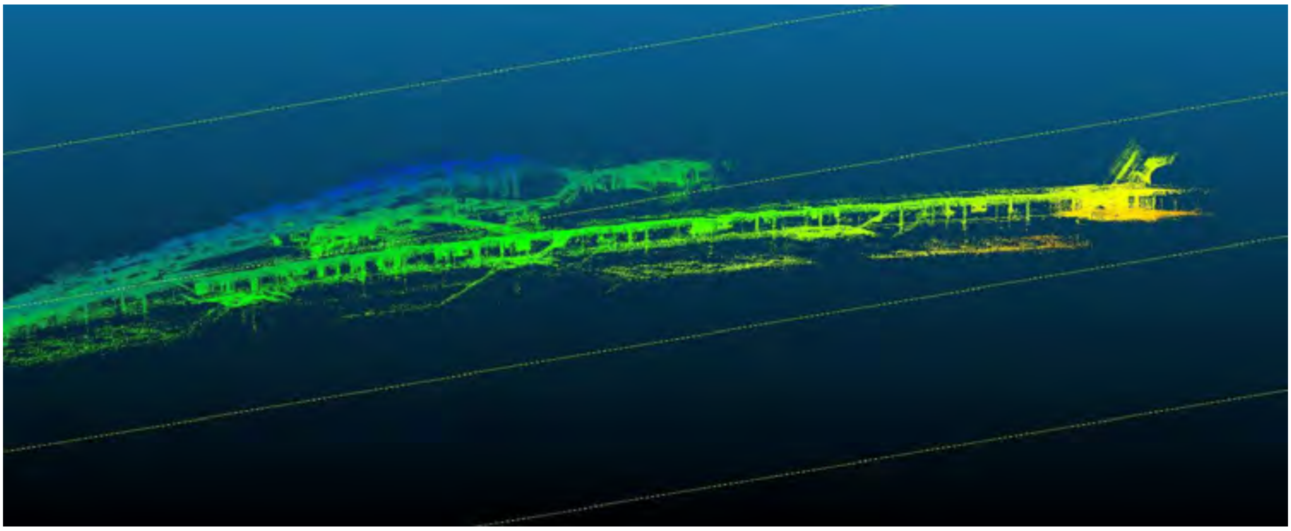


Figure 10-11 A failed point cloud – due to overly inquisitive members of the public. This reduces the efficacy of the onboard SLAM – and requires post processing to fix. Easily resolved by ensuring overlap between larger clouds – and morphing the Point cloud back to a basemap / point of reference (essentially what Leica's software does).

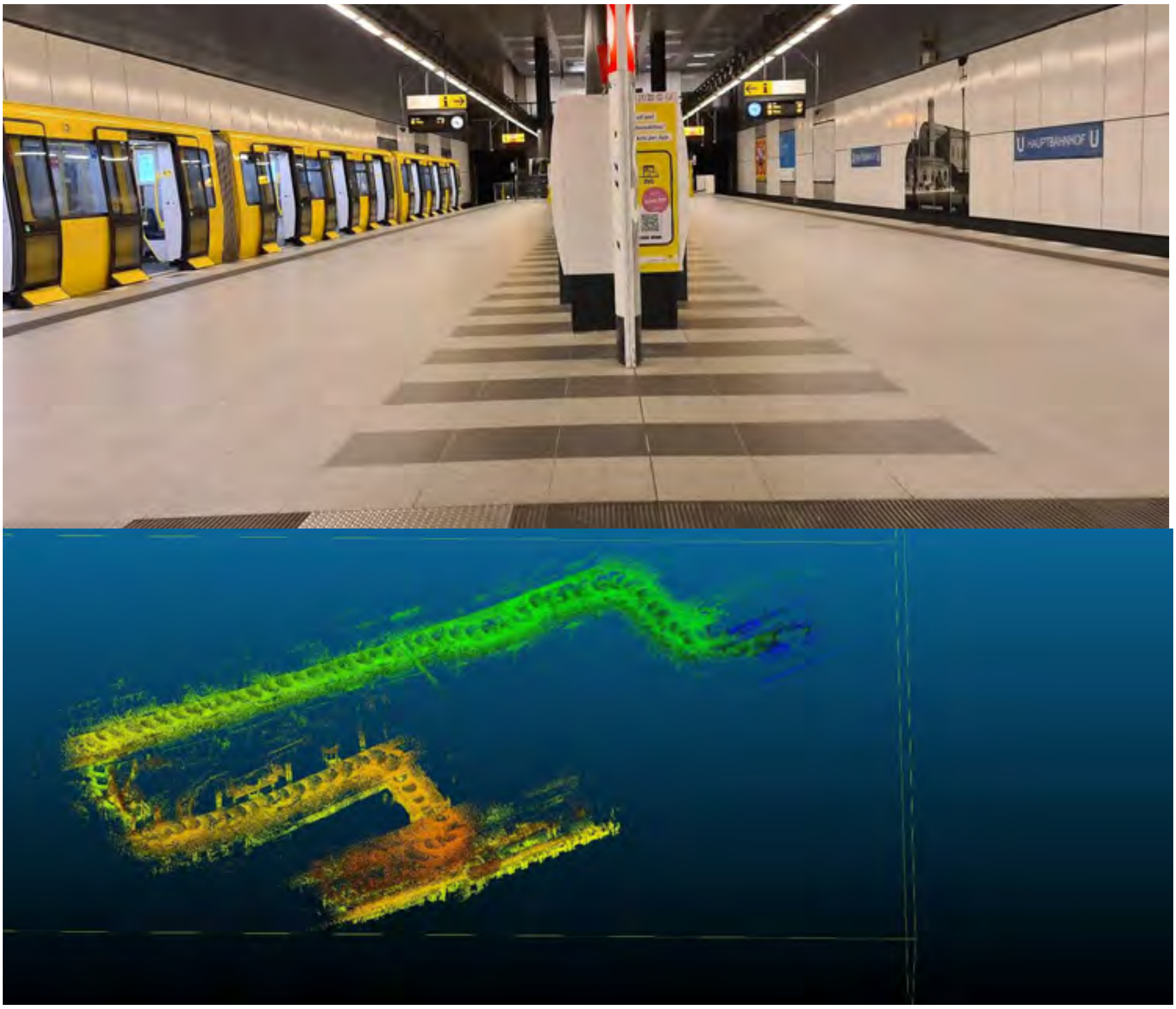


Figure 10-12: Berlin Central Station – Metro > Concourse scan

Approximately 8 hours of scanning was undertaken with several hours of setup and tests in advance and after the event – as well as consultation with Leica Hexagon and Oxford Robotics on the optimized usage of each device.

Several test runs were undertaken – and the Leica BLK2GO device used to map the upper floors of Berlin Central Station – with the Rooster device being taken into the metro and the lower floors.

Leica BLK2Go & Cyclone Register 3D

Days worth of effort was required to post process the BLK2GO data via Cyclone Register & Register 360 – in order to produce a Point Cloud map – as well as a B67 (survey standard) map. Given the scale of the site and some challenges with homogenous features – the map isn't perfect. However, this is expected – since the scale of the HBH is significant – and the scanning occurred whilst there was still significant human activity – as well as the need to have two operators present for health and safety concerns – and combat an inquisitive public – which has led to a number of artifacts in the scan.

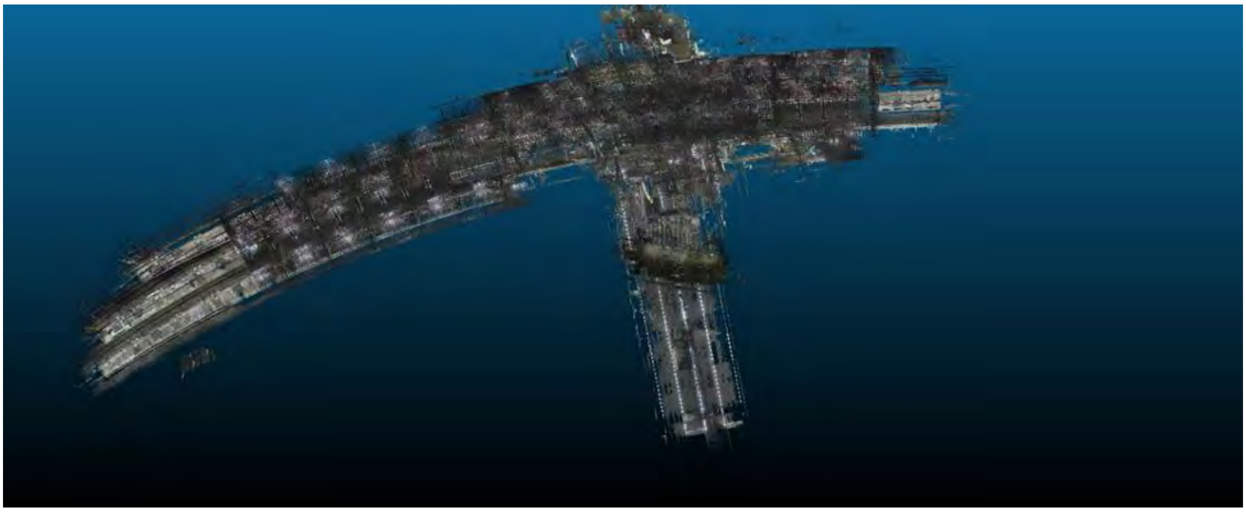


Figure 10-13 Berlin Central Station top down Leica BLK2GO Scan

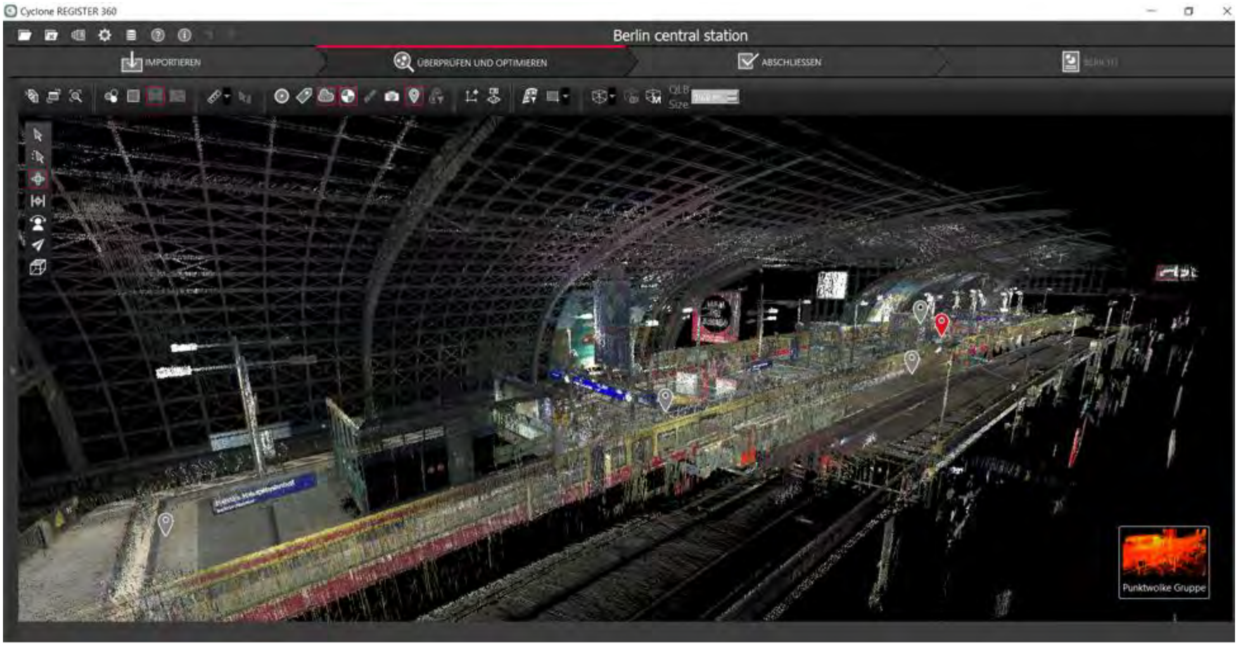


Figure 10-14 Berlin Central Station top-down Leica BLK2GO Scan

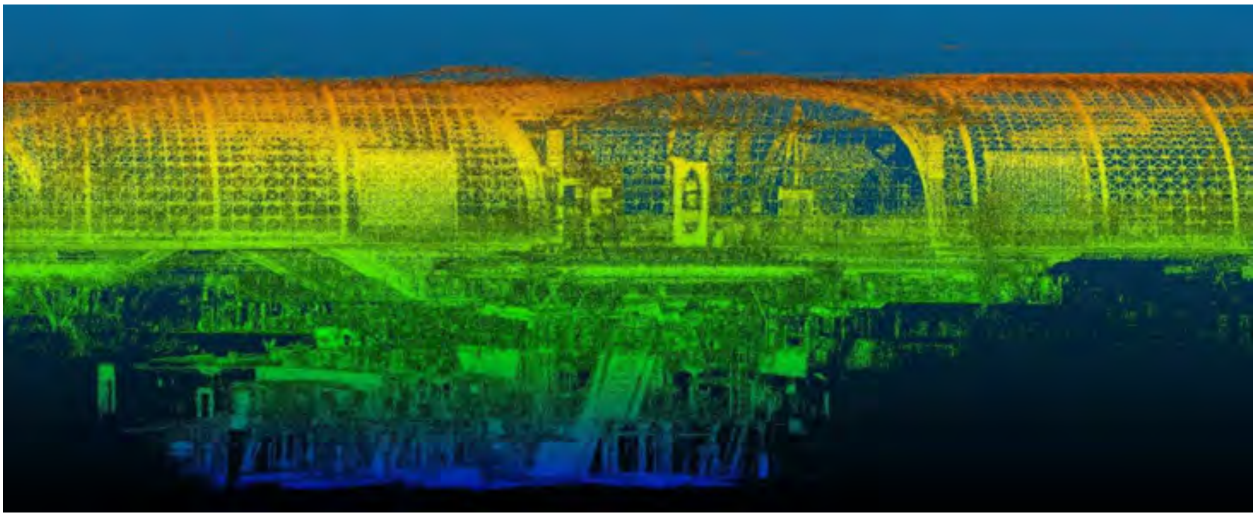


Figure 10-15 Berlin Central Station top-down Leica BLK2GO Scan side profile with height ramp applied

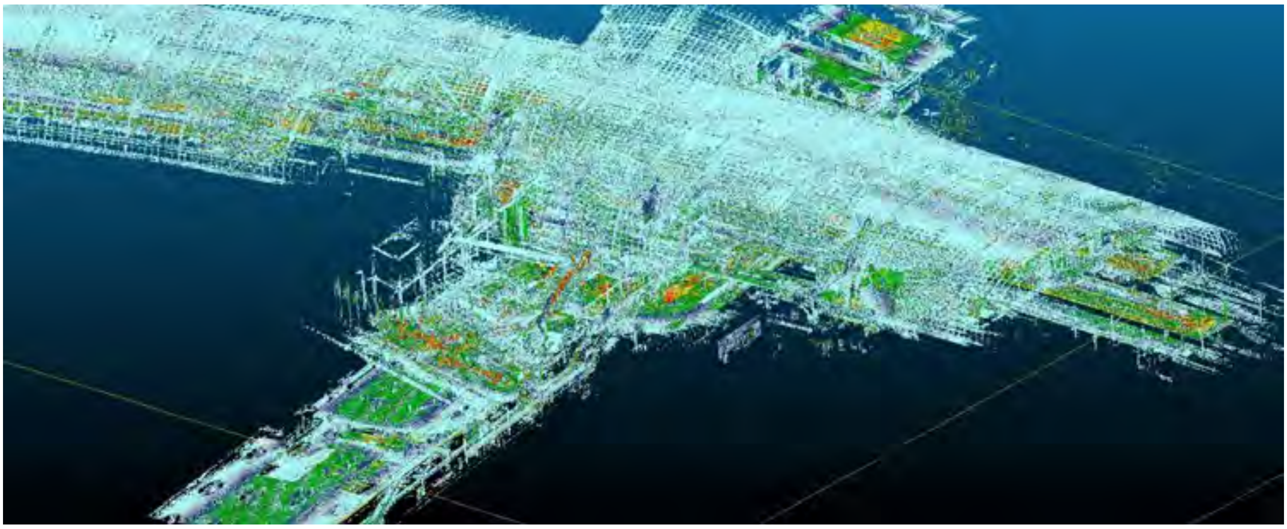


Figure 10-16 Berlin Central Station top down Leica BLK2GO Scan with luminosity applied (correlation between main thoroughfares and high luminosity)

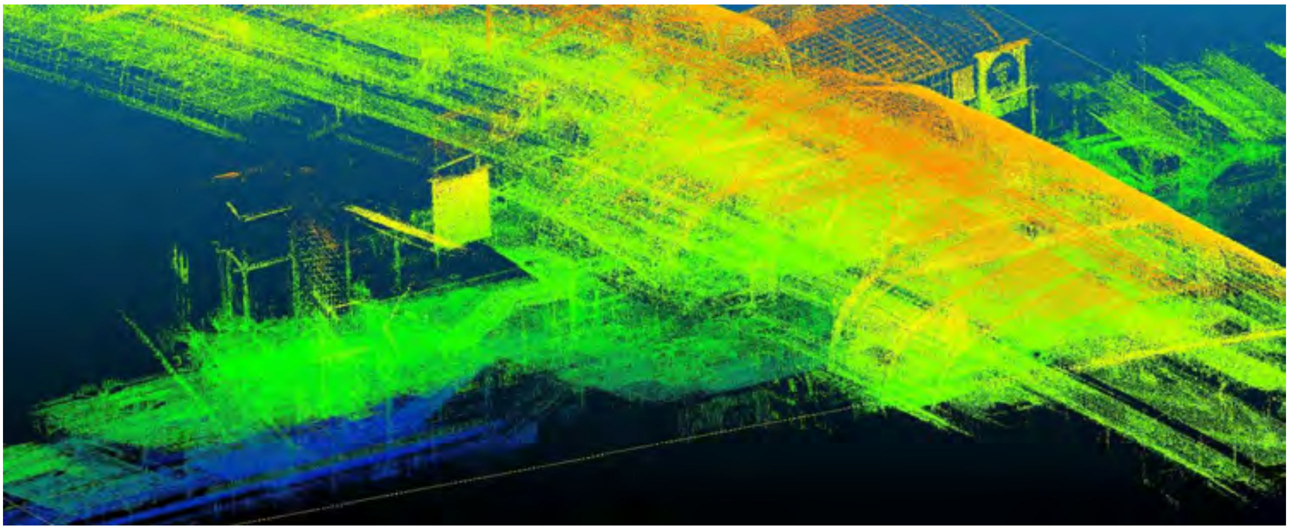
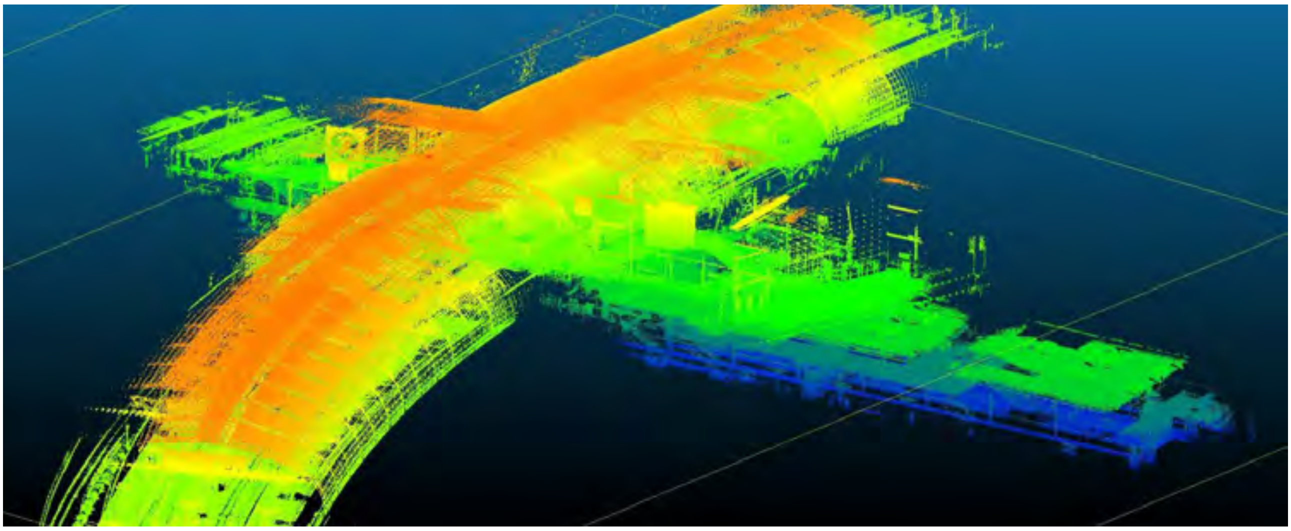
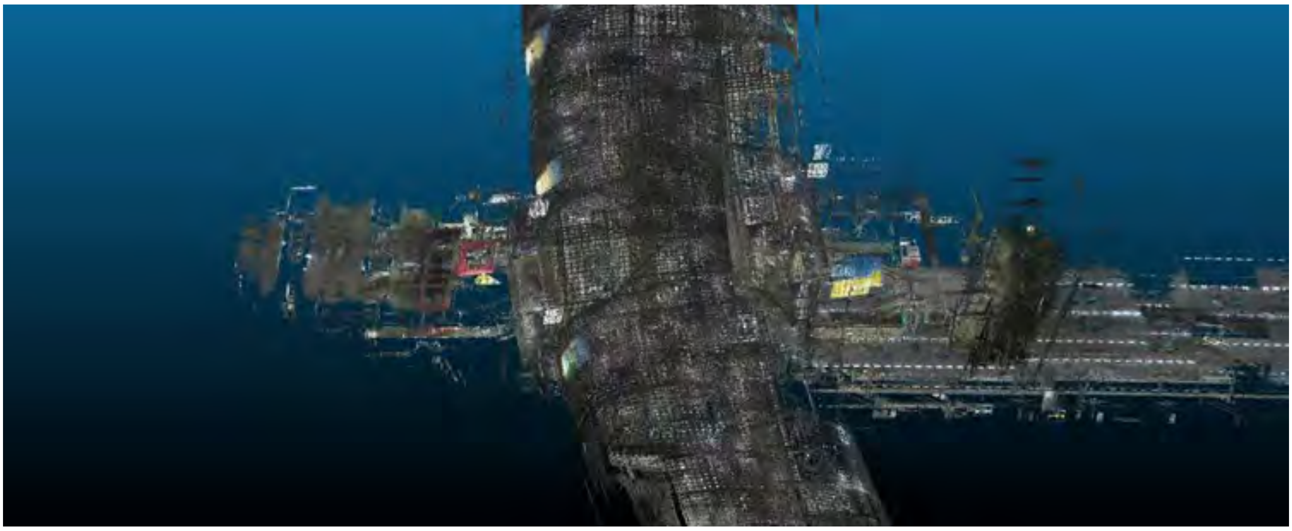
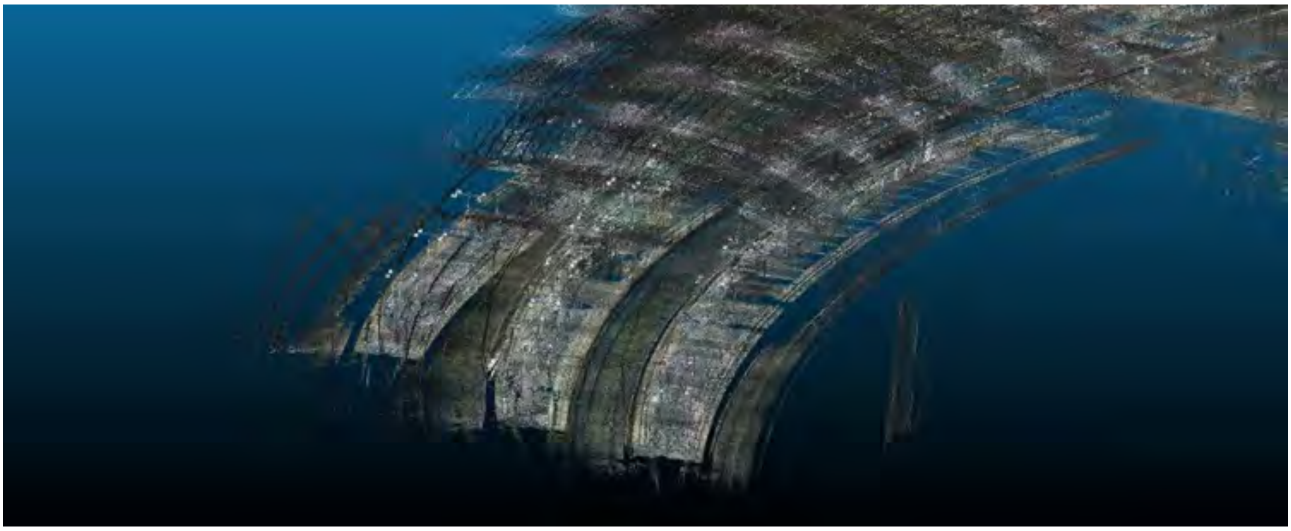
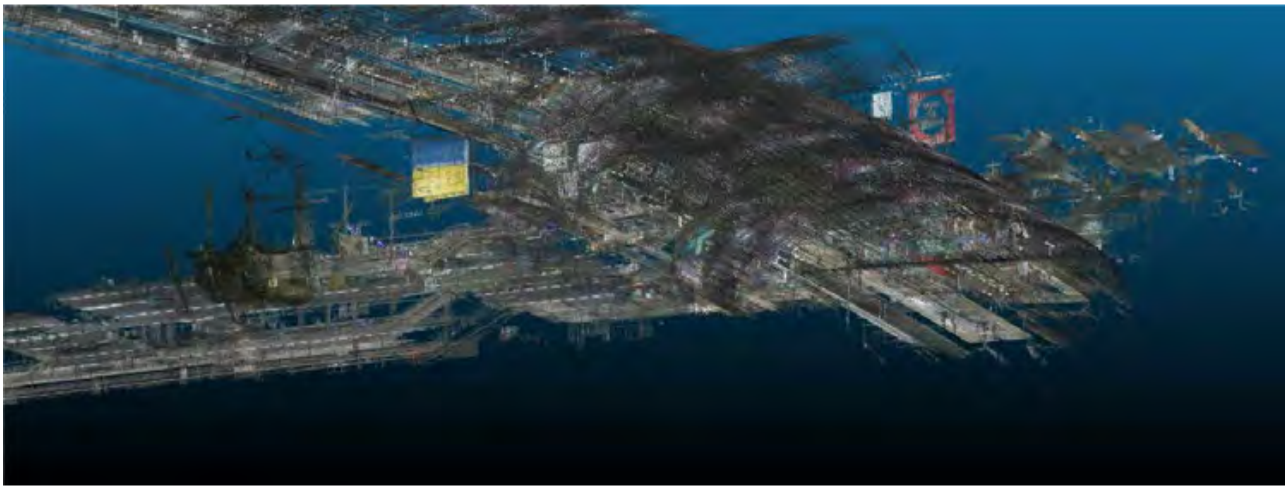


Figure 10-17 Berlin Central Station top down Leica BLK2GO scan showing sub level to top levels









However, the scan is a significant model – that can be used in support of other parts of the 5G team and the model has been provided (within the team – with **DBH**'s consent) for their use.

Urban Hawk plan to connect the model from Polaron into a range of use cases – most notably the **FhG** Unity multi-user experience – thereby allowing seamless updating of both the base map data – as well as local mapping information, changes and route planning – with the ability to push this experience to the multi-user experience delivered in Unity. (Late Q1 – 2023).

Overall, the scanning was successful and we had some valuable input from Leica Hexagon in terms of potential future collaboration (they already have a good relationship with other parts of DB) which also included the potential use a SPOT enabled quadropedal robot to automate the mapping and capture of these large facilities) as well as the potential means to maintain the maps. Due to German regulations, it is not possible to fly a drone indoors – which given the size and volume of the space – would significantly expedite this process.

10.1.2 Privacy-Preserving Data Collection and Analytics

When collecting performance statistics of a service it is important to not forget the privacy of individuals contributing data. Aside from legal issues, good privacy protection can gain the trust of potential data subjects and thereby increase their numbers[5]. The last 20 years in privacy research have shown that there are many pitfalls to protecting privacy. For this reason, this section discusses how location-based *Quality of Service* (QoS) data for 5G can be collected and analyzed in a privacy-preserving way in the context of **UC #1.2 – Future Mobility UC at the Berlin platform**.

Private information can leak during each step of the data collection and analysis process. Raw data can be misused for purposes it was not initially collected for by those who have direct access to it (see the Cambridge Analytica scandal[6]). Even if so-called identifiable fields are removed from a data set, it is possible to reconstruct these using additional knowledge[7]. This is particularly difficult for time series data such as location traces or continuous data collection. The larger the contribution of a person to a calculation, the easier it becomes to re-identify them. Data extraction though malicious queries is another issue. An analyzer who can only pose queries to a database can reconstruct the entire contents if mechanisms for privacy protection are insufficient.

It is also important to take a look at functional requirements for data analysis. So results with good utility can be obtained the collected data have to be representative. Data sources however can act in maliciously and distort final results or break the analysis. It is therefore essentially that the quality of data can be verified before it is used in an evaluation.

There are various approaches how data can be collected while preserving privacy. Each method has its own advantages and draw-backs. One option is data collection with *Local Differential Privacy* mechanisms such as *Randomized Response[8].* Hereby, a data source decides randomly with a certain probability if it will send its real data to the analyzer. With the inverse probability it will send random data. Such approaches suffer from noisy results. Also they do not provide protection against data sources behaving maliciously.

Cryptographic approaches such as *Multi-Party Computation* and *Homomorphic Encryption* provide strong privacy guarantees regarding the computation of statistics[9]. Multi-party computation allows a number of data holders to jointly compute a function on their private data. During the computation the data remains private. Using secret-sharing schemes and multiple non-colluding server this approach can be applied to data collection scenarios with many clients. Homomorphic encryption allows to do calculations on encrypted data. Results can only be decrypted by the owner of the

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corresponding private key. The nature of those methods ensures that an analyzer does not learn data used for a computation but will receive a result. To protect the privacy of data sources, these methods have to be combined with *Differential Privacy*[10] which sanitizes results from the contribution of individuals. Although such an approach provides strong privacy guarantees, realizing a data collection scheme using these cryptographic techniques is difficult due to high performance and computation costs[11].

Trusted Execution Environments (TEE)[12] are an orthogonal solution for securing computation and data. Here, the execution of an application is protected from an underlying host system by using co-processors or enforcing time sharing on the CPU. Various vendors such as Intel and AMD released designs for TEEs with different security guarantees. While the privacy protection is weaker than for cryptographic approaches, the performance overhead is more manageable. Also new tools like Gramine[13] make development for TEEs and the adaption of existing applications of straighter forward.

We will focus on this promising approach and propose an architecture for secure data collection and analytics based on the TEE design of Intel called Intel SGX.

10.1.2.1 Preliminaries

In this section we will introduce the *Intel SGX* platform as described by Costan and Devadas[14] and give a definition of differential privacy.

10.1.2.2 Intel SGX

SGX is Intel's solution for realizing TEE on their platform. SGX allows to isolate trusted application in *enclaves* while running on an untrusted host. The goal of SGX is to provide data integrity and confidentiality with regards to private data stored and used inside the enclave.

An enclave shares the CPU and caches with the host system. The host is responsible for scheduling of the enclave, meaning it assigns CPU time to the enclave. Enclave data is protected from direct accesses through the host by the memory management unit. This way, only the enclave can access data which is stored in the enclave memory. However, it relies on the host for address translation. One host can run multiple enclaves which are also isolated from another.

An important feature of SGX and other TEEs is remote attestation. Hereby an external party communicating with the enclave can verify that it indeed executes the trusted application. For this purpose a quote is presented. This quote contains a measurement which proves the integrity of the SGX platform as well as as code, data and layout of the enclave.

To verify this quote the attesting party needs to obtain the expected measurement from the *enclave developer*. This enclave developer is responsible for the code, for building the enclave and for updates to it. They therefore need to be trusted. In our case, we assume that this is the same party as the one collecting and analyzing data. We therefore use the term *analyzer* interchangeably. To ensure the authenticity of the quote it also has to be presented to an attestation service. The owner of the attestation service depends on the version of SGX and the attestation protocol. The most

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[10] DWORK, Cynthia, et al. The algorithmic foundations of differential privacy. *Foundations and Trends® in Theoretical Computer Science*, 2014, 9. Jg., Nr. 3–4, S. 211-407.

[11] DE VITI, Roberta, et al. CoVault: A Secure Analytics Platform. *arXiv preprint arXiv:2208.03784*, 2022.

[12] JAUERNIG, Patrick; SADEGHI, Ahmad-Reza; STAPF, Emmanuel. Trusted execution environments: properties, applications, and challenges. *IEEE Security & Privacy*, 2020, 18. Jg., Nr. 2, S. 56-60.

[13] https://gramineproject.io/, Accessed: 2022-10-06

[14] COSTAN, Victor; DEVADAS, Srinivas. Intel SGX explained. *Cryptology ePrint Archive*, 2016.

simple to use are the attestation services belonging to Intel. If the enclave measurement does not contain the expected values this means a different software than expected is running inside the enclave and it cannot be trusted.

SGX has many weaknesses. This partially due to the fact that various types of side-channels were deemed as out of scope during the initial design. Especially cache-based side-channels pose a reoccurring problem[15]. Most attacks focus on breaking the confidentiality of data inside the enclave.

Integrated in Intel's Core CPUs from 2015 to 2022, SGX is widely available in many consumer products. From 2022 onward SGX has become a feature of the more expensive server CPU series. Intel's third generation of Xeon Scalable processors comes with a SGX that allows enclave sizes from 8 GB up to 512 GB[16]. This means time consuming swapping of pages and verify integrity after reloading are not necessary anymore.

10.1.2.3 Differential Privacy

Simplified, differential privacy is a method for anonymising aggregates calculated on private data by adding noise. While multiple variants exist, we focus on simple ε-differential privacy. The formal definition following Dwork et al. (see Footnote above) goes as follows.

Definition Differential Privacy: We have two databases *x* and *y*. Both databases consist of records from an universe *X*. We represent them here by their histograms: $x, y \in \mathbb{N}^{|X|}$. Let $\|x - y\|$ denotes the L_1-Distance between *x* and *y*. A randomized algorithm M with domain $\mathbb{N}^{|X|}$is ε-differentially private if for all$x, y \in \mathbb{N}^{|X|}$ such that $\|x - y\| \leq 1$ and for all $S \subseteq Range(M)$:

$$Pr[\, M(x) \in S \,] \leq exp(\varepsilon) \; Pr[\, M(y) \in S \,]$$

Differential privacy requires that the result of a mechanism M run on two adjacent databases is less than *exp(ε)*. The value ε is generally assumed to be very small (less than 10) a smaller values provide better privacy protection.

To calculate the noise required to fullfill differential privacy for a function *f* the impact of a single individual to the calculation is important. This value is called the *sensitivity s.* For a counting query, the sensitivity is 1 as this is the largest impact the existence or non-existence of data of an individual in a database can have. For summation queries, the sensitivity is the largest possible value that can possible occur. When summing for example age, this upper bound might be 130 as no recorded person has ever exceeded this age. As we see, sensitivity is highly domain depended. The larger the impact of as single person, the more noise has to be added.

One way to realize an ε-differentially private algorithm for a function *f* is to compute *f* on the provided data and then draw from a Laplace function which is scaled to the sensitivity.

Definition Laplace Mechanism: The Laplace Distribution (centered at 0) with scale *b* is the distribution with probability density function: $Lap(x|b) = 1/(2b) \; exp\,(\, -|x|/b \,)$. The variance of this distribution is $\sigma^2 = 2b^2$. Given any function$f\colon \mathbb{N}^{|X|} \to \mathbb{R}^k$, the Laplace mechanism is defined as:

$$ML(x, f(\cdot), \varepsilon) = f(x) + (Y_1, \ldots, Y_k)$$

where Y_i are independently and identically distributed random variables drawn from $Lap(x \mid s/\varepsilon)$.

Algorithms for differential privacy are immune against post processing. This means that an analyzer can not break privacy for results returned by a differentially private algorithm without having access to the underlying data. This means multiple algorithms for differential privacy can be composed in a

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[15] NILSSON, Alexander; BIDEH, Pegah Nikbakht; BRORSSON, Joakim. A survey of published attacks on Intel SGX. *arXiv preprint arXiv:2006.13598*, 2020.

[16] https://www.intel.com/content/www/us/en/support/articles/000059614/software/intel-security-products.html, Accessed: 2022-10-06

program without harming privacy. If both mechanisms used the same data then the final ε *is:* $\varepsilon=\varepsilon_1+\varepsilon_2$. If two disjoint data sets were used as input then the composition has $\varepsilon=max(\varepsilon_1, \varepsilon_2)$.

10.1.2.4 Design for a Privacy-Preserving Analytics Platform

Intel SGX can be used in different deployment settings to realize privacy-preserving data collection and analysis. In the following we describe our solution by improving step by step on a naive approach. Table 10-1 provides an overview of the approaches discussed in the following.

In the following, we trust that the SGX mechanism is correctly implemented and Intel correctly supports remote attestation. However, we acknowledge that side-channels are an open question for Intel SGX. We will take a look at this issue in a later contribution when discussing implementation details.

In this setting, a *semi-honest* adversary is interested in data and observes the computation passively. It does not interfere, send messages or conduct elaborate side-channel attacks.

Table 10-1 Overview of the presented approaches on privacy-preserving data collection. DP stands for differential privacy, while RA is short for remote attestation.

		Naive	SGX with RA	SGX with RA+DP
Trust	Analyzer	Trusted	Trusted	Semi-honest
	Server	Trusted	Semi-honest	Semi-honest
Security	Data Protection	GDPR	SGX	SGX, DP
	Data Misuse Protection	No	No	Yes
	Remote Attestation	No	Yes	Yes

10.1.2.5 Naive Approach

The simplest approach is the one taken for example by Apple's ReseachKit[17]. Here, data sources make their data available by installing an app on their mobile devices which is provided by the analyzer. This app collects data and sends it to servers of the analyzers who can then conduct their analysis. Analyzing clear-text data making it easy to find and remove outliers or corrupted data points. The privacy of data sources is only protected by legal frameworks such as the GDPR and the app's terms and conditions.

We model this approach by requiring a trustworthy analyzer to run its application on a trustworthy server.

10.1.2.6 Approach 1: Using SGX Server with Remote Attestation

An approach with better privacy properties than the naive setting places the server application inside a SGX enclave. The collected data is stored in a database inside the enclave or inside encrypted blocks located in the host memory. An Analyzer working on the data can query the database by sending requests to a corresponding interface exposed by the enclave. However, they cannot access raw data. Data sources can verify the enclave measurement before sending their data and ensure that a trusted application is running inside the enclave. They compare the measurement received from the server against one provided to them by the analyzer. This allows the analyzer to run their software in a semi-honest cloud.

[17] https://developer.apple.com/design/human-interface-guidelines/researchkit/overview/introduction/ , Accessed: 2022-10-06

Using an enclave also ensures some protection against simple attackers on the same system. Using SGX raises the bar for an advarsary and mitigates automated attacks such as malware. The analyzer can easily update the code inside the enclave during data collection as long as they distribute the new enclave measurement in a timely manner. Since the code running inside the enclave is never verified by a third party data sources do not have any guarantee that their data is not extracted and stored as clear-text somewhere else. While analyzer can make their code open source, the enclave measurement is difficult to verify for the general public. Additionally, data inside the enclave can be migrated to enclaves signed by the same entity. In this case, encalves are signed by the analyzer. So even if the analyzer does not extract data immediately, it can be moved to a different enclave at a later point in time. This means the analyzer have to be trusted.

We model this approach by requiring trustworthy analyzer running an application on a semi-honest server.

10.1.2.7 Approach 2: Using SGX Server with Differential Privacy

In the prior approach, we allowed an analyzer to send queries to the enclave database to run statistics. A malicious analyzer might try to extract as much information as possible with their limited access to the database. By sending specifically crafted queries they can reconstruct its contents even if only aggregates are returned[18]. Therefore, the enclave database should only return results sanitized by differential privacy. The privacy budget needs to be maintained by the application inside the enclave so it cannot be tempered with. If the budget is used up, no more queries can be answered and the collected data has to be discarded.

Allowing only differential privacy results ensures that a malicious analyzer cannot extract private data by simply sending queries. Also results which might be released to the public at some point hide the contribution of single data sources.

However, allowing only differentially private queries can lead to insufficient utility if only a small amount of data has been collected. This is due to the fact that the quantity of noise scales with the impact of a single individual. If there are only few data points in the database more noise has to be added. Additionally the number of queries a researcher can pose is limited as each time a part of the privacy budget is used up. This means that analyzers have to use the budget wisely.

We model the approach discussed in this section by assuming semi-honest analyzer runs their software on a semi-honest servers. See Figure 10-18 for a graphical representation of Approach 2 with multiple data sources. A SGX server and an analyzer accessing the servers query interface for differentially private results

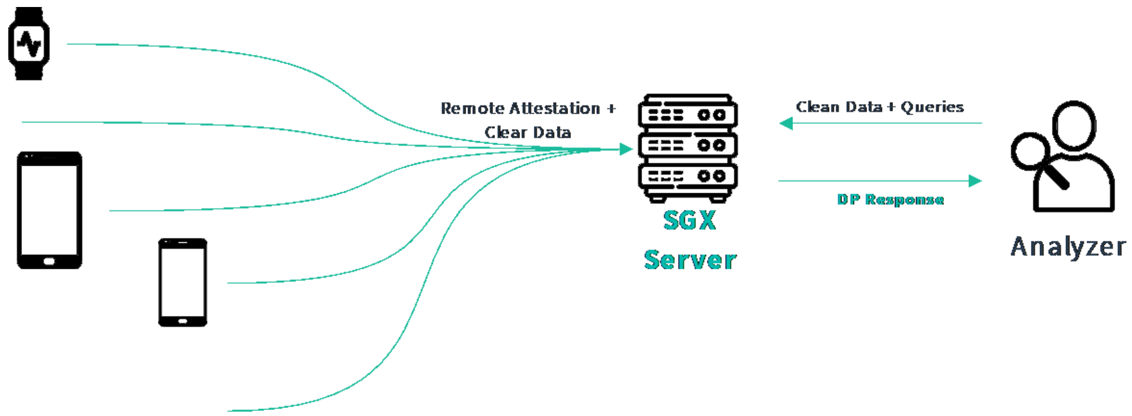

Figure 10-18 Graphic representation of Approach 2 with multiple data sources

[18] DWORK, Cynthia, et al. The algorithmic foundations of differential privacy. *Foundations and Trends® in Theoretical Computer Science*, 2014, 9. Jg., Nr. 3–4, S. 211-407.

10.1.2.8 Further Work

As mentioned earlier side-channels are a big problem of Intel SGX. Since control flow can leak private information, additional measures need to be taken to hide access patterns and the volume of data required to answer specific queries. Both can lead to leakage of private data[19]. For this purpose it is important to use a hardened database relying for example on *oblivious RAM (ORAM)*[20] for storing data received from data sources. We will discuss approaches for hardened enclave databases and their guarantees in a later deliverable.

[19] LACHARITÉ, Marie-Sarah; MINAUD, Brice; PATERSON, Kenneth G. Improved reconstruction attacks on encrypted data using range query leakage. In: *2018 IEEE Symposium on Security and Privacy (SP)*. IEEE, 2018. S. 297-314.

[20] SMART, Nigel P.; SMART, Nigel P. *Cryptography made simple*. Springer, 2016.