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

D2.3 Final individual site facility planning

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Editor(s):	Christina Politi "Tanya" (**UoP**)
Authors:	Peter Lundh (**Alstom**); *(note: Bombardier Transportation joined the Alstom Group on 2021-01-29);* Ioanna Mesogiti, Fofy Setaki (**COSM**); Christian Schlehuber, Steven Karch (**DBH**); Louay Bassbouss, Anita Chen, Eric Troudt, Marc Emmelmann (**FhG**); Miguel Catalán-Cid, Adriana Fernández-Fernández (**i2CAT**); Martin Piovarci, Manfred Taferner (**KCC**); Luke Kazanis, Athina Metridou, Anthony Karydis (**MATI**); Christina Politi "Tanya", Panagiotis Papaioannou, Christos Tranoris, Spyros Denazis (**UoP**); Robert Sugar, Erika Fucsok (**UHA**); Shadi Moazzeni, Constantinos Vrontos, Amin Emami, Hojjat Baghban, Hamid Falaki (**UNIVBRIS**); Kostas Katsaros (**DCAT**); Stefan Schinkel (**PXI**); Ed Dening (**ZN**); Maria-Evgenia Xezonaki, Vasileios Theodorou, Konstantinos Stamatis, Dimitrios Kritharidis, Kostas Chartsias (**ICOM**); Nikos Makris, Paris Flegkas (**UTH**); Alexandros Dalkalitsis (**TRAINOSE**) Carmen Patrascu, Marius Iordache (**ORO**); Navid Nikaein (**EUR**); Nikolaos Tzanis, Eleftherios Mylonas (**ADMIE**); Anna Tzanakaki, Markos Anastasopoulos (**IASA**); Nebojsa Maletic, Darko Cvetkovski, Jesús Gutiérrez (**IHP**)

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1.0	Final version and submission to the European Commission Participant Portal	Jesús Gutiérrez (**IHP**)	2021-06-11

Table of Contents

List of Figures

List of Tables

Executive Summary

5G-VICTORI focuses on conducting large scale field trials for advanced use case (UC) verification in commercially relevant 5G 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. In this context, 5G-VICTORI exploits main sites of all ICT-17 infrastructures, namely 5G-VINNI (Patras, Greece), 5GENESIS (Berlin, Germany) and 5G-EVE (France/Romania), and the 5GUK testbed (Bristol, UK). To achieve this, the 5G-VICTORI activities involve providing enhancements to the existing infrastructures in order to extend their coverage and capabilities to integrate operational environments required for the demonstration of the large variety of 5G-VICTORI vertical and cross-vertical UCs.

This deliverable is the final deliverable planned for Task 2.2 “Individual site facility planning and experimentation plan per facility”. It has taken input from the set of functional and non-functional requirements identified for each facility and UC as well as from the preliminary project architecture defined as part of the activities of Task 2.1, reported in deliverable D2.1 [1] This document presents a high-level overview of the different facility UCs, a detailed description of the planned test-beds and the required extensions to support integration of the vertical UCs in the corresponding facilities. In this context, this deliverable also includes description of specific materials, software and hardware elements to be purchased, developed and integrated as well as their interconnection requirements. Finally, it provides a brief preliminary discussion on the cross-vertical UCs that will be showcased at individual facility sites, as well as on cross domain UCs, i.e. common UCs that may be demonstrated at more than one facilities.

The outcomes of this work will feed Task 2.3, where the 5G-VICTORI end-to-end (E2E) reference architecture is defined. This deliverable provides input also to the test planning activities of **WP3** “Vertical Services to be demonstrated“, and act offers initial design inputs for **WP4** “Trials of Coexisting Vertical Services, validation and KPI evaluation”.

Acronyms

1.1 General

Acronym	Description
3GPP	Third Generation Partnership Project
4G	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
BSCW	The document server used in the 5G-VICTORI project
CCS	Cambridge Communications Systems
CCTV	Closed Circuit TV
CDN	Content Delivery Network
CPE	Customer Premises Equipment
CPRI	Common Public Radio Interface
CPU	Central Processing Unit
CN	Core Network
DCU	Data Capture Unit
DL	Downlink
E2E	End-to-End
eMBB	Enhanced Mobile Broadband
eNB	Evolved Node B
EMS	Energy Management System
ENDC	E-UTRAN New Radio – Dual Connectivity
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
HPN	High-Performance Networks group
HSS	Home Subscriber Server
i2SM	i2CAT’s Slicing Management
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
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
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	Mobile 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
MShed	Museum in Bristol
NBMP	Network Based Media Processing
NUC	Next Unit Computing
MVB	Merchant Venturers Building
N78	3500 MHz TDD band (3300 – 3800 MHz)
NB-IoT	Narrow Band Internet of Things
NetOS	
NR	New Radio (5G related)
NS	Network Slice
NSI	Network Slice Instance
NSA	Non-Standalone
OAI	Open Air Interface
OCC	Operation Control Center
ONAP	Open Network Automation Platform
O-RAN	Open RAN
P-CSCF	Proxy Call Session Control Function
PCF	Policy Control Function
PDU	Protocol Data Unit
PLMN	Public Land Mobile Network
PTT	Push-To-Talk
RAMS	Reliability, Availability, Maintainability & Safety
RAN	Radio Access Network
RaSTA	Rail Safe Transport Application
RAT	Radio Access Technology, like 4G, 5G, Wi-Fi
RMS	Railway Management System
RRH	Radio Remote Head
RRU	Radio Remote Unit

RS485	Serial balanced bus
RSRP	Received Strength Reference Power
S-NSSAI	Single Network Slice Selection Assistance Information
SA	Stand Alone
SDN	Software Defined Network
SDR	Software Defined Radio
SDS	Short Data Service
SIM	Subscriber Identification Module
SIP	Session Initiation Protocol
SMF	Session management Function
SRA	Shared Resource Allocation
SSID	Service Set IDentifier (Wi-Fi related)
TAP	Test Access Point
TDD	Time Division Duplex
TOBA	Telecom On-Board Architecture
TOC	Table Of Content
UC	Use-Case
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 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	(formerly **BT**: Bombardier Transportation joined the Alstom Group on 2021-01-29) (5G-VICTORI Partner)
COSM	COSMOTE (5G-VICTORI Partner)
D3.1	Deliverable D3.1 (within T3.1)

DB	Deutsche Bahn (DB Holding) (5G-VICTORI Partner)
DCAT	Digital Catapult
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 Microelectronics (5G-VICTORI partner)
IR	Interim Review (done 2020-10-08)
KCC	Kontron Transportation Austria
MATI	Mativision Limited (5G-VICTORI partner)
MShed	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)
T3.1	Task 3.1 (within **WP3**)
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	Zeetta Networks Ltd. (5G-VICTORI partner)

2 Introduction

5G-VICTORI is focusing on large scale field trials for advanced use case (UC) verification in commercially relevant 5G 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. In this context 5G-VICTORI exploits main sites of all ICT-17 infrastructures, namely 5G-VINNI (Patras, Greece), 5GENESIS (Berlin, Germany) and 5G-EVE (France/Romania), and the 5GUK testbed (Bristol, UK). To achieve this, the 5G-VICTORI activities involve providing enhancements to the existing infrastructures in order to extend their coverage and capabilities to integrate operational environments required for the demonstration of the large variety of 5G-VICTORI vertical and cross-vertical UCs.

In this context, the project brought together facility operators, vertical industries as well as technology and service developers in order to ensure that the design phase of the Trials take into consideration all relevant requirements, parameters and constraints in order to deliver an innovative but also feasible solution that can support practical UCs in operational environments owned by vertical industries.

This deliverable reports on the planned extensions required at the different 5G-VICTORI facility sites for their individual operation and interconnection. In this context, each individual project facility reports on the planned activities towards integration of the verticals in accordance to the UCs planned to be demonstrated at the corresponding facilities as well as the planned cross-vertical and cross-domain experimentation. This includes description of specific materials, software and hardware elements to be purchased, developed and integrated as well as their interconnection requirements.

The work reported in this deliverable also focuses on the cross-vertical UCs that will be showcased at individual facility sites as well as on cross domain UCs, i.e. common UCs that may be demonstrated at more than one facility.

2.1 Objectives

This deliverable completes the planning work reported in deliverable D2.2 and takes into consideration the vertical industry requirements as well as the architecture blueprint for each facility sites i.e. Berlin, Bristol, France/Romania and Patras, in the delivery of the extensions required as part of the WP4 activities. In this context, the deliverable reports on the technical definition of the subsystems and their interconnection comprising the enhancements required per site with respect to:

- Planning of 5G facilities enhancements and vertical infrastructure integration per each site.
- Intra-, and Inter-field trial preparation and planning.
- Planning and integration of 5G and vertical technologies across all 5G/vertical ready facilities.

2.2 Approach and Methodology

As already mentioned, the deliverable reports on the final planning for each facility site and the 5G network extension and deployment therein and specifically reports on the activities that are listed below in Table 2-1, depending on the level of maturity per site and per UC. The description of each activity can be found in deliverable D2.2 [2].

Table 2-1 Activities carried out per facility

Activity
Network Requirement capture
Processing Requirement capture
Site Survey and report /Initial planning
Bill of Materials Listing HW/SW Equipment (additionally required to existing facilities infrastructure) Identifying the gaps between facilities and 5G-VICTORI test setups, e - aka Identifying Gaps with existing Test Network Capabilities
Network Slice Design for each UC
Lab testing and initial validation of services per UC
Second Site Survey and report
Procurement process

Furthermore, the deliverable initiated the planning of possible inter-cluster UCs to smoothly contribute to the definition of the end-to-end (E2E) reference architecture of 5G-VICTORI. This can contribute towards the instantiation and integration of the various verticals and corresponding infrastructures in the four selected facilities and across.

2.3 Purpose of the document

This is the final technical deliverable of 5G-VICTORI Task 2.2, "*Individual site facility planning and experimentation plan per facility*", which belongs to Work Package 2 (**WP2**) entitled "*Description – Use cases/ Specifications*". The dependencies with other 5G-VICTORI deliverables are highlighted in Table 2-2.

The purpose of this deliverable is to meet the following WP2 objectives:

- Final definition per site to fulfill the requirements of the UCs to be run in the different sites.
- Timeline and roadmap of the planned work.
- Description of the components and subsystems that will be part of all sites' upgrades.
- Initial planning of inter-cluster activities for the definition of the E2E 5G-VICTORI architecture.

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.
D2.2 [2]	Preliminary 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.

D4.1 [4]	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 [5] **D3.3 [6]** **D3.5 [7]**	**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 is taking place in deliverable D2.3.

2.4 Document Structure

This deliverable comprises four main sections, which follow a similar cluster-based structure content-wise: facility description, the components and the activity planning for the implementation of the UCs:

Section 3 focuses on the planning related to the Berlin Cluster Facility.

Section 4 details the planning activities related to the Bristol Cluster Facility.

Section 5 describes the France/Romania Cluster Facility.

Section 6 summarises the Patras Cluster Facility planning.

Section 7 provides an initial insight focusing on inter-cluster activities.

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

3 Berlin Cluster Facility Planning

The 5G-VICTORI Berlin facility is being developed to accommodate several UCs that have a common target operational facility, i.e. the Berlin main railway station. Three UCs were described in deliverable D2.1 [1], each involving different Vertical Industries and considering a variety of vertical services with different requirements:

- **UC #1.2**: Media & Transportation: Digital/Future Mobility (more information in Section 3.2).
- **UC #1.3**: Transportation: Rail Critical Services (more information in Section 3.3).
- **UC #3**: Media & Transportation: CDN services in dense, static and mobile environments (more information in Section 3.4).

These UCs do describe and bring together a set of vertical services, which were in the past served by purposely deployed legacy wired and wireless technologies. The advent of 5G and the availability of 5G equipment and state-of-the-art wireless and optical technologies, has led to the re-definition of the UCs and the associated services. To date, 5G is being rolled out on railway stations worldwide. This is one of the motivations to consider such venue to assess the performance of the services being supported by this technology.

Prior to 5G-VICTORI, the partners Fraunhofer FOKUS and IHP started equipping their premises with testbeds that allow testing the baseline functionality and infrastructure of a 5G capable environment. A 5G Platform is being built as part of the ICT-17 5GENESIS project, which integrates networking and computing devices. The specific 5G infrastructure deployed at these sites comprises a main data centre (hosting a 5G core) with an edge deployment that is interconnected with the 5G Radio Access Network (RAN) over a state-of-the-art wireless transport network.

The 5G-VICTORI Partners participating in the Berlin cluster are in charge of upgrading and extending the 5GENESIS Platform towards the Berlin Central Station, which is the target site for all trials and pilots stemming from the three UCs taking place in Berlin. 5G-VICTORI will ensure the deployment of 5G equipment and necessary extensions/upgrades of the infrastructure components to accommodate the UCs.

3.1 Final Facility commitment

The Berlin facility involves two sites where the final UC assessment will take place and both of them are located in West Berlin: Fraunhofer FOKUS and Berlin Central Station. Additionally, two test sites are considered, which are outside the city of Berlin: IHP in Frankfurt (Oder) and the Annaberg-Buchholz Testfield in Saxony (see Figure 3-1). Additional details of each of these sites are included in section 3.1.1.

The Fraunhofer FOKUS site represents the central control point for the interconnection of all the other sites, as it integrates all management components.

3.1.1 Network design and service delivery

The design of the Berlin facility network at the four sites outlined above is shown in Figure 3-1. In its current state, Fraunhofer's test network can provide 5G, LTE and Wi-Fi connectivity, and the IHP site is being upgraded to allow 5G connectivity with an outdoor deployment of mmWave backhaul targeted to be available on August 2021. Annaberg-Buchholz can make available a 5G-capable testfield that is being used for testing FRMCS features.

The Fraunhofer FOKUS and IHP sites are already interconnected via a Virtual Private Network (VPN) and tests are being carried out to assess the different infrastructure related KPIs, such as throughput and latency. The connectivity between the four sites will be set up by Fall 2021 and, in addition, a nomadic 5G edge deployment integrating compute and storage capabilities could be used in any of these sites.

The following subsections provide details of the current infrastructure available at each of the sites and expected upgrades that the infrastructures will undergo to ensure their readiness for preliminary UC tests.

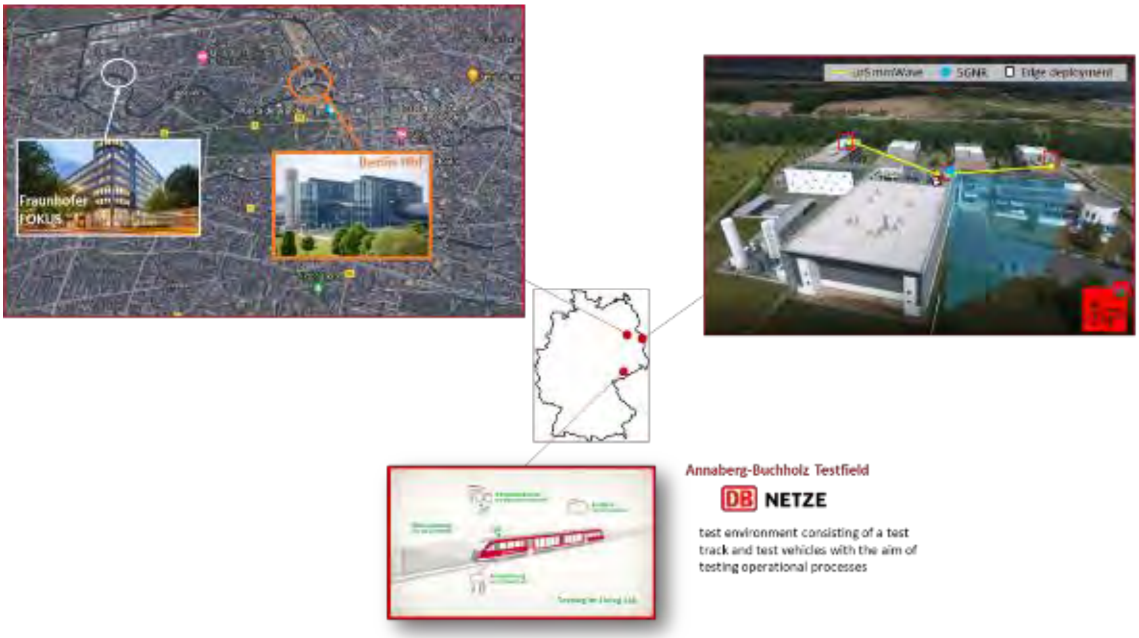


Figure 3-1 Facilities being considered for testing and demonstration purposes at the 5G-VICTORI Berlin facility

3.1.1.1 Fraunhofer (FhG) FOKUS

The Fraunhofer FOKUS site hosts all management components of the Berlin facility to serve as the central control point and data centre for seamlessly interconnecting the Berlin Central Station and IHP sites.

It provides centralized computing and storage capabilities and is integrated around the FOKUS Open5GCore and legacy 4G radio technologies. This site is also integrated with 5G New Radio (NR) standalone (SA) equipment and non-3GPP access technologies, such as WiFi6 and satellite links for interconnecting remote sites.

A more detailed list of the capabilities is indicated below:

- 5G NR Coverage in n78 band
  - Rooftop: one radio unit with one antenna covering the front of the building, and another covering the inner courtyard. (Only one antenna/coverage area can be used at a time, not simultaneously).
  - Parking garage: 4 small-form radio units with integrated antennas (from two different vendors).
  - 2x Indoor lab coverage, each provided by one small-form radio unit (RRU) with an integrated antenna.
  - Baseband units (BBUs) and/or radio head hubs to serve the RRUs.
- Networking infrastructure
  - Internal connectivity provided by Cisco Nexus 9000-series leaf switches.
  - External connectivity via Cisco Nexus 9000-series spine and DWDM connection to some external sites.

- Computing resources: VMWare hypervisor running on 6x Cisco UCS Mini servers B200-M5.
- Open5GCore Software – able to run on top of common hardware platforms and can be deployed with containers or virtual machines (VMs) on top of a large number of virtualization environments.
  - Deployed on a VM to manage the 5G NR radio deployment at FOKUS.
  - In-house implementation of the 3GPP-specified 5G SA Core Network, compatible with Release 15 and 16 for supporting the subset of base functionalities.
  - Lightweight and can be deployed in different flavors of Linux containers, VMs, or bare metal without restrictive hardware requirements.
  - Continued development of interfaces for external application functions.

Slicing for the private or campus networks ideally should be E2E from the user to the application server, separating resources and allowing for the definition of Quality of Service (QoS) parameters at the slice level. This aims at allowing scenarios such as rail critical services to run over the same infrastructure with less critical services such as media services without being compromised. At the **FhG** testbed, the focus is to realize slicing at the Protocol Data Unit (PDU) session level for UEs, and for this slicing to be E2E, it requires to be implemented in both the RAN and Core Network.

The Open5GCore Core Network can be configured to use separate instances of software User Plane Functions (UPFs) or separate Session Management Functions (SMFs) to serve each slice. Slice selection can be performed by the subscriber by provisioning slice identifiers in the subscriber data or by PDU session with an explicit session management request from the UE for a specific slice identifier. In cases where the UE does not allow configuration of the slice identifier in session management, a similar separation of resources on the core side can be achieved by configuring the requested Data Network (DN) where the PDU session should terminate. The exact realization of slicing in the RAN is dependent on hardware from external vendors. However, slice information and QoS parameters can be communicated to the RAN through the N2 interface from the Core Network.

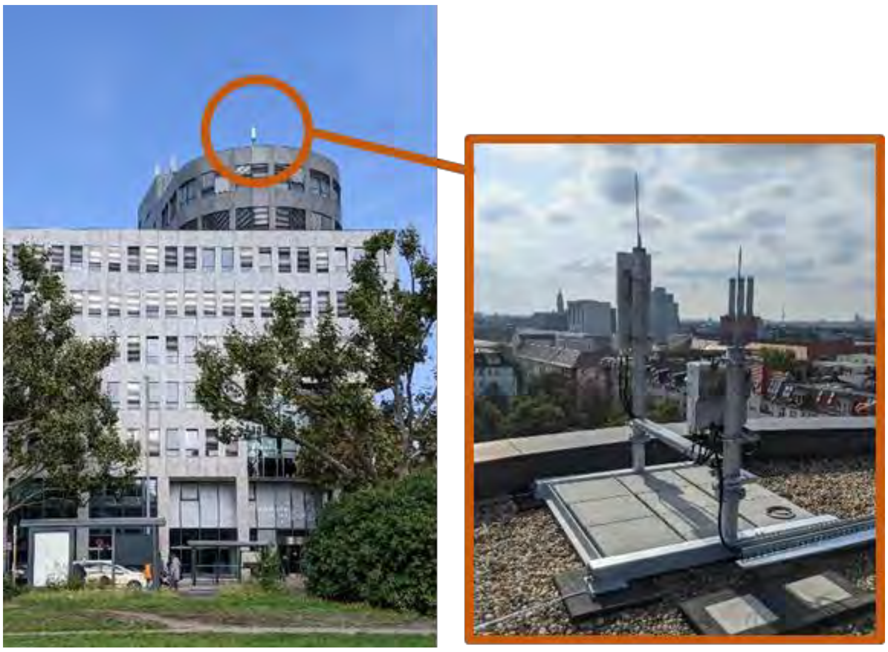


Figure 3-2 5GNR installation @ Fraunhofer FOKUS premises

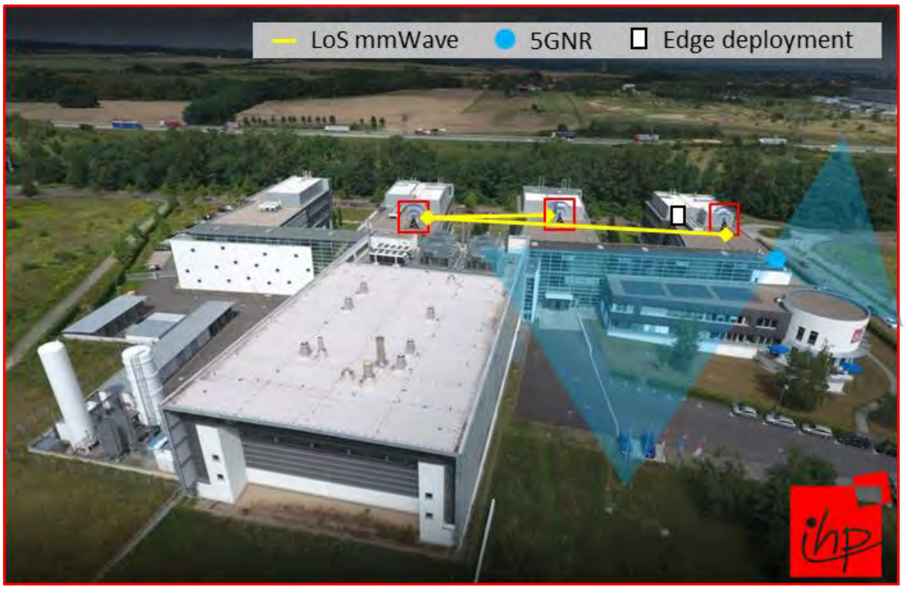


Figure 3-3 The IHP 5G-VICTORI site in Frankfurt (Oder)

3.1.1.2 IHP

The IHP site in Frankfurt (Oder), Germany, is a 5G-VICTORI test site that is connected to the main data centre residing at the Fraunhofer FOKUS site (via VPN), and it is used for mmWave outdoor testing purposes. IHP is the owner of the facility and its surroundings, making it attractive for outdoor demonstrations. The site will be featured in Q3 2021 with 5G NR equipment, together with several proprietary and COTS mmWave units. The IHP site will be the environment selected by the 5GENESIS Consortium to host the final 5GENESIS Berlin Platform demonstration.

The network can be accessed remotely from the Fraunhofer FOKUS site, while management components and monitoring tools can be instantiated at IHP. Once the IHP premises are equipped with 5GNR equipment and mmWave backhaul connectivity supporting beam steering, initial tests for a few of the 5G-VICTORI UCs can be performed.

Among the available COTS mmWave equipment in IHP, Figure 3-3 illustrates the units that will be installed on the rooftops of several of the IHP 'wings'. Apart from the mmWave units, IHP will also make high-end PCs for hosting monitoring probes available, e.g. several DELL Precision 5820 CPU Intel Core i9-7980XE @ 2.60GHz × 18 RAM 32 GB.

3.1.1.3 Berlin Central Station

The Berlin Central Station is the largest passing railway station in Europe, and it is operated by DB Station & Service, a subsidiary of Deutsche Bahn AG (**DB**), partner of the 5G-VICTORI project. The station forms a connecting point for converging and intersecting lines of different modes of public transport. It has railway tracks on two levels, which run perpendicular to each other. The upper level of the station comprises six tracks that are used by the Berlin S-Bahn (2) and regional/long-distance trains (4). These tracks are served by three island platforms.

In 5G-VICTORI, the upper level and a specific track was considered for running the trials. Figure 3-4 shows a representation of the station from the top, depicting the considered upper level, where the three island platforms can be observed.

This complex operational environment comes along with additional risks, security and installation constraints that must be considered well in advance. The risks associated to the utilization of this infrastructure are described in section 3.5.2.

3.1.1.3.1 Radio equipment installation

One of the most relevant tasks when performing the site visit at the station, and the one that determines the final position of the equipment at the Berlin Central Station office, is to find out exactly where the radio equipment for the trials (5GNR and mmWave equipment) can be installed in any of the light poles available in the platform(s). This decision is subject to the trials' needs and relies heavily on the internal assessment of several DB departments that are the ones granting the final approvals.

Different types of light poles exist, each of them serving a particular purpose in the station (hosting information panels and clocks with Wi-Fi APs; hosting surveillance cameras and speakers for providing audible information to the passengers). These poles are of different nature and subject to constraints, meaning that not all light poles could be used to install radio equipment on top of them.

Once the suitable points of attachment (light poles) and exact positions are fixed the next step is the planning of the cabling from these points to the server room within the station. Figure 3-5 shows an exemplary position of the radio equipment (5G NR and mmWave) in one of the selected poles at the platform. The idea with the 5G NR equipment is to cover the station platform and the railway track to provide 5G connectivity to the users walking around the platform and to the trains. For the mmWave equipment the interest only resides in providing connectivity using pencil beams to the mmWave unit installed at the train.

The specific installation of Figure 3-5 it the one that would fit the installation requirements at the poles in the platform. Some of its benefits and characteristics of this layout are:

- External antennas mounted on mini-vertical-pole mounts attached to horizontal support. This is a way to put most of the weight at the center part of the infrastructure.
- RRU + AC/DC can be mounted anywhere on the same structure as long as cabling is possible.
- Additional cabling between RRU and external antennas required.
- This arrangement grants the highest flexibility.

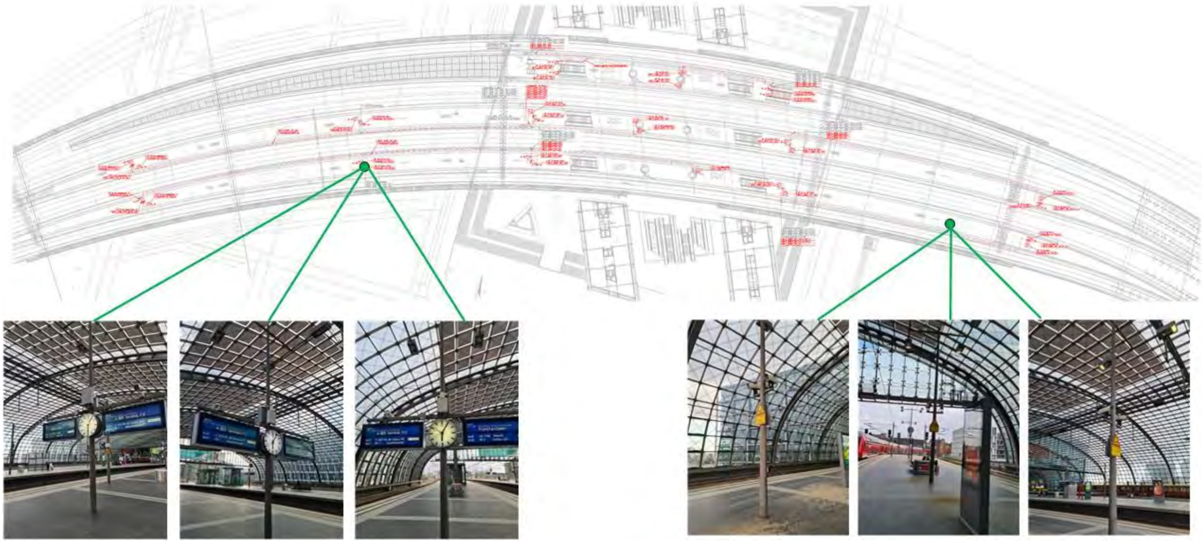
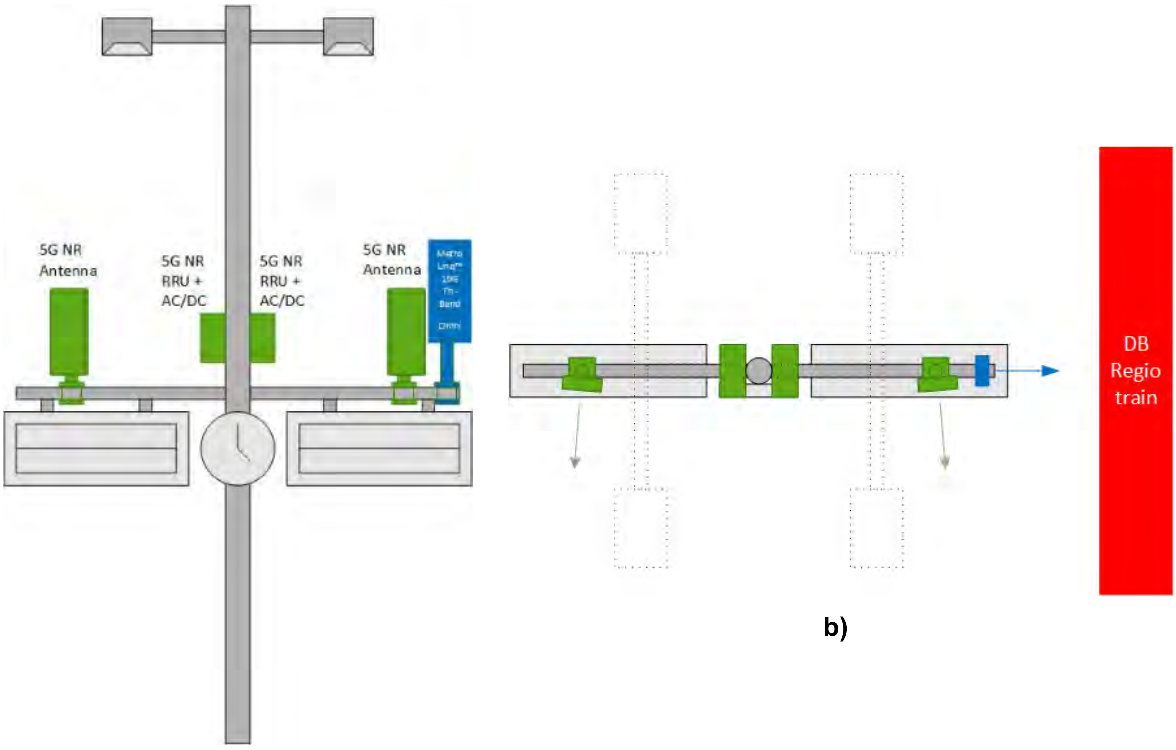


Figure 3-4 Light poles at the Berlin Central Station where radio equipment will be installed



b)

a)

Figure 3-5 Potential installation of 5GNR and mmWave equipment in a light pole, 5GNR in green and mmWave in blue. a) Front view, b) top view

3.1.1.3.2 Connectivity towards the Internet

Berlin Central Station will be interconnected with the Fraunhofer FOKUS site for conducting different remote tests before and during the final trial. This interconnection will be carried out over the *Deutsches Forschungsnetz* (DFN).

Particularly, **UC #3** (see section 3.4) will require this connection to the Internet, he optimal bitrate for the connection to the outside world is 10% of that reachable over the mmWave link. This would mean that a speed (download) of 800 Mbps would suffice.

3.1.1.3.3 Berlin Office (aka Equipment Room)

This part of the infrastructure will house the edge platform that is able to host the compute, switching and backend components. This edge platform will host e.g. the Open5GCore, the 5G NR BBUs, the GPUs, etc.

The room itself is located at the ground level of the Berlin Central station (see Figure 3-6) and will involve a cable run to the platform of ca. 500 m, having direct connectivity to all platforms of the station. From this room it is possible to have direct access to DFN for remote connectivity to any other Berlin site (e.g. VPN to Fraunhofer FOKUS), and to the Internet (for **UC #3**). There exists enough rack space to integrate the 5G-VICTORI equipment and remote access to this equipment will be granted.

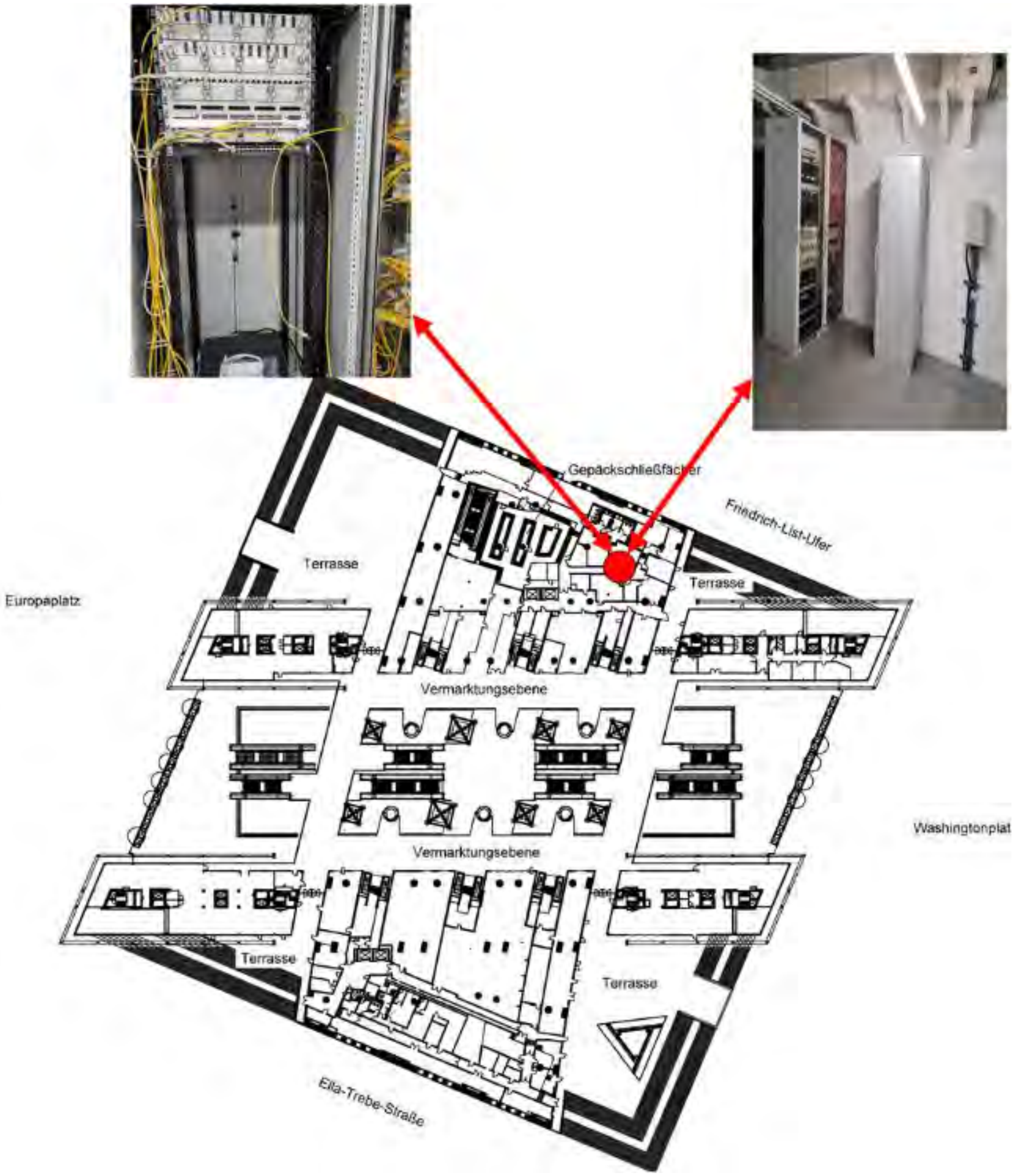


Figure 3-6 Equipment Office location at ground level, server room and rack space

3.1.1.3.4 Train part

Part of the infrastructure (equipment) coming from the technology providers will be also installed in a DB train. The train will pass by the station and connectivity from the units installed in the train will be made with those units installed at the platform (cf. section 3.1.1.3.1).

The connectivity options in the train regarding network equipment are GB Ethernet, where M12 coded connectors are required to connect to the existing components (e.g. WLAN AP).

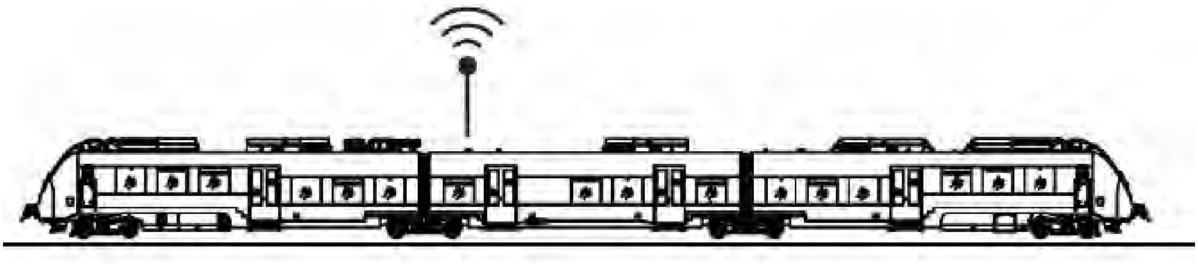


Figure 3-7 Sketch of a DB train and potential places where to install equipment

There is an onboard available switch, which is the CISCO IE 2000 Type 8T67P-G-E. The power is 24V DC via board power supply of the train.

Regarding the internal location where the equipment can be installed at the train, each vehicle of a train has a location where some rack space is available (the position is depending on the exact model). In this location the Infrastructure as well as Servers would be located. In the particular case of WLAN, the APs that already placed can be utilized. Additionally, there exists the possibility that these WLAN Aps are placed by the Colibri platform[1].

At the outer part of the train, external antennas will be located at the edge of each vehicle. The base system below the 5G-VICTORI implementation will be a Colibri-M train platform enhanced with Colibri-W (WLAN module). The former ensures the connection between train and land and enables broadband data exchange. The latter offers passengers Wi-Fi and free entertainment on board, and will be complemented by the *Rundfunk Berlin Brandenburg* (**RBB**) catalogue (see section 3.4.2).

Given the connectivity between the vehicles using the above-mentioned systems, as well as the allowance for placing outside antennas, this industrial communication platform within the train can be used to host 5G/mmWave equipment in support for the different services. Once the inspection of the trains is carried out, the final decision on the placement of the equipment will be made.

3.1.1.4 Annaberg-Buchholz

Annaberg-Buchholz forms the new Living-Lab of Deutsche Bahn, where DB is testing new and emerging technologies within the railway domain. Particularly, DB is interested in deploying and assessing the 5G technology, which is a key part of Future Railway Mobile Communication System (FRMCS).

Since 2020, a line section of approx. 24 km length between Annaberg-Buchholz and the town of Schwarzenberg in Erzgebirge, Germany, has been upgraded with federal funding to become a digital rail test field. DB is constructing 5G radio masts and traction units are being featured with the required equipment and will serve as test vehicles.

This site it is used as a potential test site for **UC #1.3**, as it allows more in-depth testing of features that entail security constraints and are easily realizable in field tests rather than in operational environments.

3.1.1.5 Overall network design for the UCs

The UCs running at the Berlin facility will be deployed using the two sites located in Berlin, i.e. Berlin Central Station and Fraunhofer FOKUS. As mentioned above, these two sites will be interconnected to allow hosting and instantiation of a few of the development tasks (e.g. 5G

[1]https://www.db-fzi.com/fahrzeuginstandhaltung-de/leistungsportfolio/produkte-und-innovationen/Colibri/colibri-3245138

Core, vertical service functions, etc.). These virtualized components may be instantiated at any computing/data centre locations present at any of these sites, and will be deployed at various points deployed across the Berlin facility for the final trials.

Figure 3-8 represents the different parts of the infrastructure that will play a role in the final Berlin facility trial. These parts include:

- **Fraunhofer FOKUS**: cf. 3.1.1.1.
  - Equipment Room (Office), with hosts all management components of the Berlin facility. These can be instantiated at the Equipment Room of Berlin Central Station.
- **DFN GÉANT**, is the German national research and education network (NREN) used for academic and research purposes. It will support the interconnection between Fraunhofer FOKUS and the Berlin Central Station.
- **Berlin Central Station**: cf. 3.1.1.3.
  - **Equipment Room (Office)**: this part of the infrastructure will host the edge compute/data centre, together with the 5G NR BBU, switching and backend components.
  - **Platform**: will host the radio equipment (5G NR and mmWave) and serve as the spot for **UC #1.2**.
  - **Wayside**: will involve the use of a point machine at this part of the infrastructure.
  - **Train**: will host the onboard computing and storage equipment tailored to the different UCs, together with the access network equipment of various technologies – 5G customer-premises equipment (CPE), Wi-Fi – to provide services within the train.

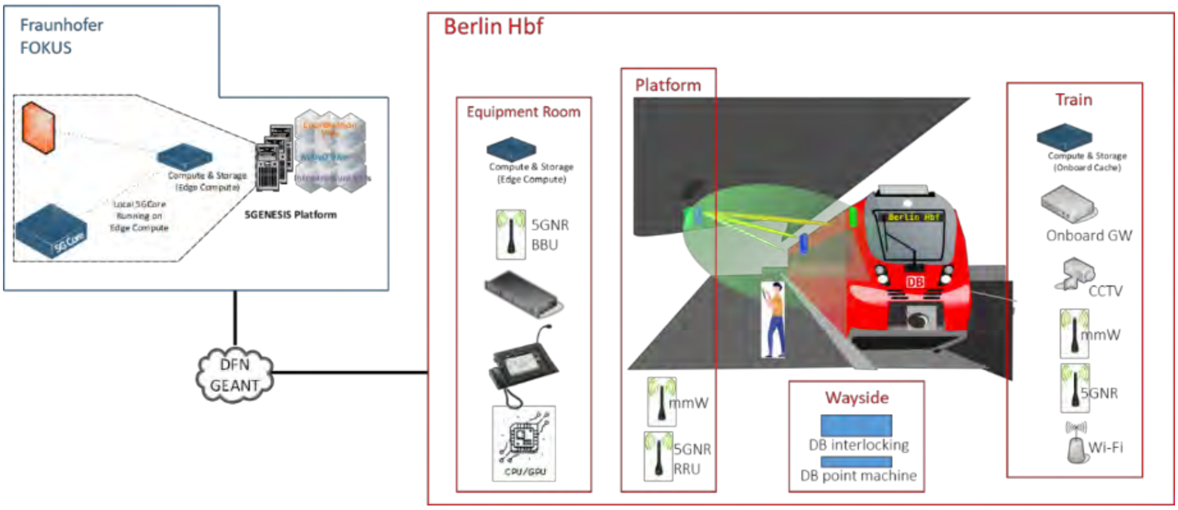


Figure 3-8 Final sites of demo activities (preliminary figure)

A more detailed representation of the connectivity between the different parts (hardware and software) of the infrastructure within the Berlin Central Station is shown in Figure 3-9.

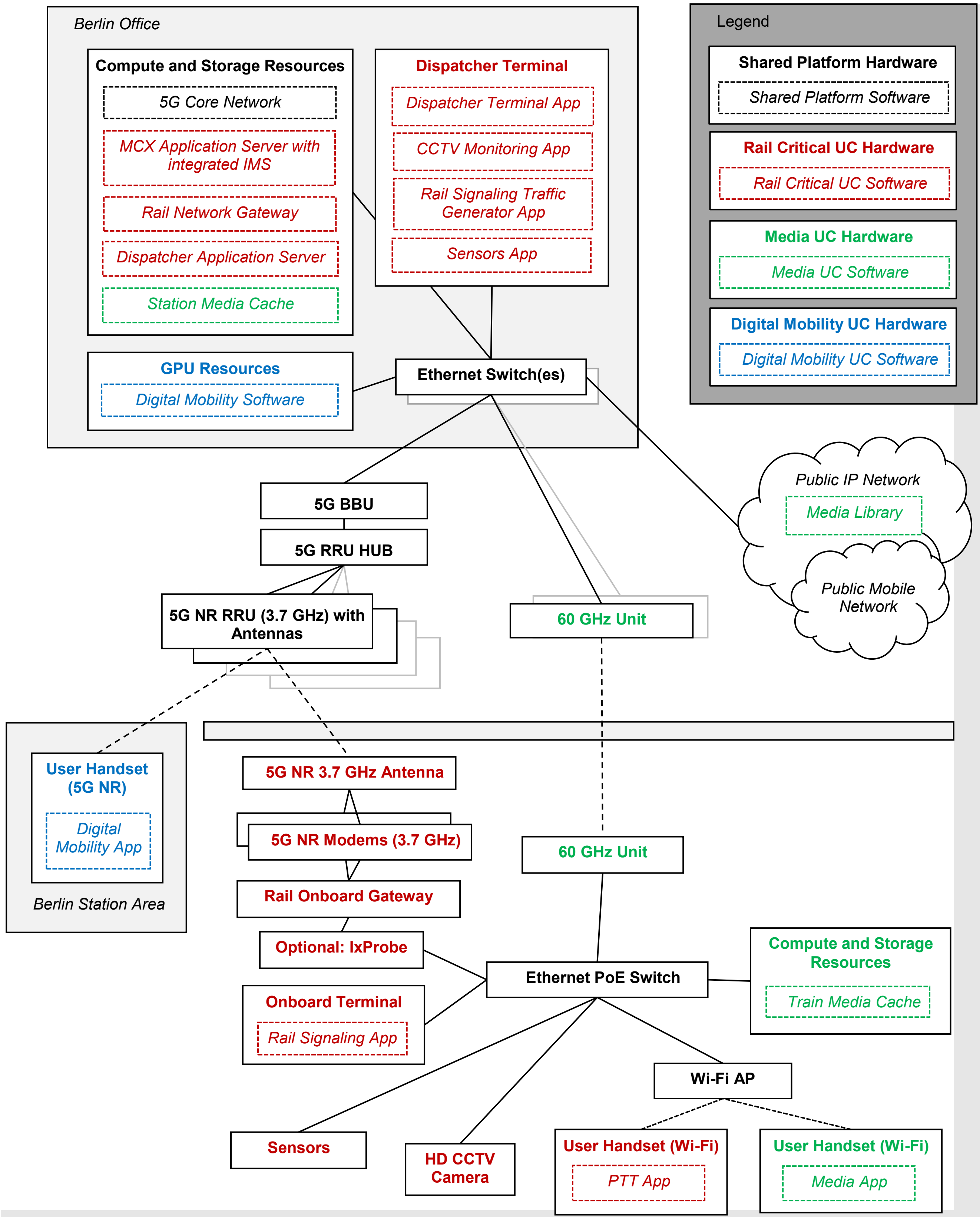


Figure 3-9 Overview: Berlin Central station equipment and applications

3.1.2 COTS & General Equipment

Table 3-1 presents the equipment that will be shared for two or more UCs.

Table 3-1 General equipment that will support all three UCs

Equipment	Item	Components	Quantity Total weight	Dimensions Rack-mount	Power supply / Consumption	Connectivity	Installation/ Attachment details
General Equipment for the UCs							
 (sample image)	5G NR BBU + PSU	Baseband Unit for running 5G radio units (plus power supply) located in station tech room.	1	19" rack form factor 3-4 U (BBU) + 1 U (PSU)	Most likely 100-240VAC to PSU	Dark fiber to each RRU Precision time server IP to 5G core network	If GPS used for time sync, connection to a GPS receiver required.
 (sample image)	5G NR RRU + PSU	Remote Radio Units (plus power supply) to be mounted on station platform.	1-4 ~10-20 kg per unit	~200-400mm x ~200-400mm x ~100-200mm	Most likely 100-240 VAC to PSU	Dark fiber to BBU RF cabling to antenna	-
	5G NR Antenna	Either integrated with RRU or external, to be mounted on station platform.	1-4 (1 per RRU)	(form factors vary widely)	(driven by RRU)	RF cabling to RRU	If directional antennas are used, placement and angling are critical to defining the 5G NR coverage area
	Station tech room Ethernet switch	Ethernet switch in station tech room for IP connectivity of BBU, use case equipment.	1	Most likely 19" rack solution	100..240VAC/50-60Hz	See 3.1.2.2	-
	Train equipment room Ethernet PoE Switch (or switch plus PoE injector)	Ethernet switch in train equipment room for IP connectivity. At least one PoE output for UC1.3 camera, either built-in or via injector	1	Wall mount - available	100..240VAC/50-60Hz (2x if additional if separate PoE injector used)	See 3.1.2.2	-
	Microsemi TimeProvider TP4100	IEEE 1588v2 Precision Time Protocol (PTP) grandmaster	1 3,6 kg	44 mm (H) x 438 mm (W) x 237 mm (D) 19-inch and 23-inch options	DC power models: dual-power feeds, –38.4 VDC to –72 VDC Power consumption: OCXO model with DC supply: 28 Watts (max), 20 Watts (typical)	Standard base unit with 8 Ethernet ports, 4 E1/T1 ports, 1 craft port, 2× 1PPS/ ToD ports, 2× 1 PPS/10 MHz ports	-

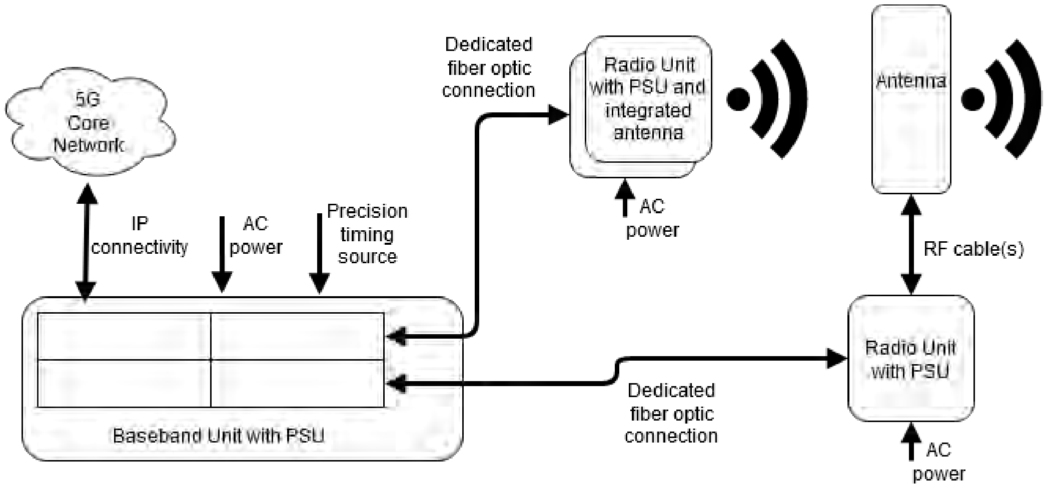


Figure 3-10 Outline of 5G NR RAN components and their interconnectivity

3.1.2.1 5G NR

Equipment for the 5G NR RAN deployment will operate in the 3.7-3.8 GHz range allocated for use by local campus networks and consist of the following components:

- 1x Baseband Unit (BBU): Server rack form factor, taking in approximately 4-5U with power supply. One unit is required for a site to support multiple radio units and requires dedicated fibre optic connections for each site. Additionally, it requires a precision timing source (PTP Grandmaster) and IP connectivity to the 5G Core Network and user plane resources.
- 1-4x Radio Units (RRU/RRH): Range in size, options are in the approximate range of 200-400 mm x 200-400 mm x 100-200 mm, including power supply. An integrated antenna can be used, which adds thickness to the unit but maintains form factor and reduces RF cabling length, or external antennas can be run. Each RRU requires a dedicated fiber optic connectivity (dark fibre) to the BBU.
- 1-4x Antennas: Wide range of sizes and form factors. The antennas can either be integrated with the RRU to reduce size and to share a mounting point, or externally, requiring a separate mounting point and RF cables to run to the RRU. As the antenna properties, mounting position and angle define the coverage area, the details to be refined through further site planning.

Selection of the manufacturer and the exact models of components will be done as the size and weight constraints allows, as well as the radio coverage planning details (e.g. exact positioning and required antenna types) for the site deployment are solidified.

3.1.2.2 Switches

The Ubiquiti EdgeSwitch 16-XG (Figure 3-11) is a 16-Port Managed Aggregation Switch that consists of sixteen 10G ports. For fiber connectivity, it consists of 12 SFP+ ports. For copper connectivity, the EdgeSwitch XG offers four RJ45 ports that support 10GBASE-T, the standard for 10 Gbps connections using Cat6 (or higher) cabling and RJ45 connectors.

It offers an extensive suite of advanced Layer-2 switching features and protocols, and also provides Layer-3 routing capability. Its dimensions are 443 x 221 x 43 mm.

Additionally, at the train part of the infrastructure, a CISCO switch IE 2000 Type 8T67P-G-E will be available, which is shown in Figure 3-12. It is a managed with 8 x GB Ethernet10/100 (PoE+) + 2 x 10/100/1000.

Figure 3-11 Ubiquiti EdgeSwitch 16-XG

Figure 3-12 CISCO switch IE 2000 Type 8T67P-G-E available at the train

Figure 3-13 Dell PowerEdge R640 Server

3.1.2.3 Compute & Storage

Computing and storage are supported by a Dell PowerEdge R640 (see Figure 3-13) with an Intel Xeon Gold 6146 3.2 GHz 12-core processor, 64 GB of RAM, and 5x 240GB SATA Solid State Drives (SSDs) – total of 1200 GB. A quad-port 10 Gbps SFP+ provides high throughput network connectivity to the switch. It is a standard rack form factor with a height of 1 U and a depth of 705 mm.

3.2 UC #1.2: Future Mobility service

This UC aims to optimize media streaming services in mobile environments enabled by 5G technologies, including Edge Computing. **UC #1.2** consist of an app that renders a 3D twin[2] overlayed on the passenger's smartphone's live camera feed, which will allow the user to navigate in and around the station.

The app is connected to a backend application instance running at the edge (located physically in a server room at the railway station) and downloads/updates the station's spatial digital twin (3D) from **UHA**'s cloud-based backend. For the trial, passengers will arrive at the station with the app pre-installed on their 5G UEs (or project partners with 5G UEs if not widely available).

Media standards such as Moving Picture Experts Group Server and Network Assisted DASH (MPEG-SAND) will also be used to monitor the entire workflow and ensure its reliability in terms of encoding, packaging, delivery, playback, etc. To deploy complex workflows in this UC, Network Based Media Processing (NBMP) will be used as the standard for Data Shower and multi-CDN applications.

[2] A digital twin is a virtual representation that serves as the real-time digital counterpart of a physical object or process. An example of digital twins is the use of 3D modelling to create digital companions for the physical objects.

3.2.1 Network Processing Requirements aspects

The spatial mapping can be based on spatial information processed prior to the end user using the app, or during the time the end user is using the app. This app relies on spatial mapping in order to provide a realistic 3D representation of the digital twin.

For prior-to-usage spatial mapping, no connectivity is required – the camera USB3 connects to a notebook GPU where the point-cloud is stored in its raw form, then injected into the Polaron engine once all capturing is complete.

Live spatial mapping is done from a Lidar-equipped smartphone (future Android alternative of a current iPhone 12), in which case the colour and depth camera image sequences are streamed to the backend for further processing and then become injected into the overall 3D twin (UHA's Polaron engine). Therefore, a live mapping would require fast connectivity capable of high-definition streaming.

Figure 3-14 illustrates a block diagram of all components and apps that will be used in **UC #1.2**. The diagram contains two (2) Edge nodes, which is in line with the high level concept of our user mobility in between nodes. However, during the trials a single node will be used likely.

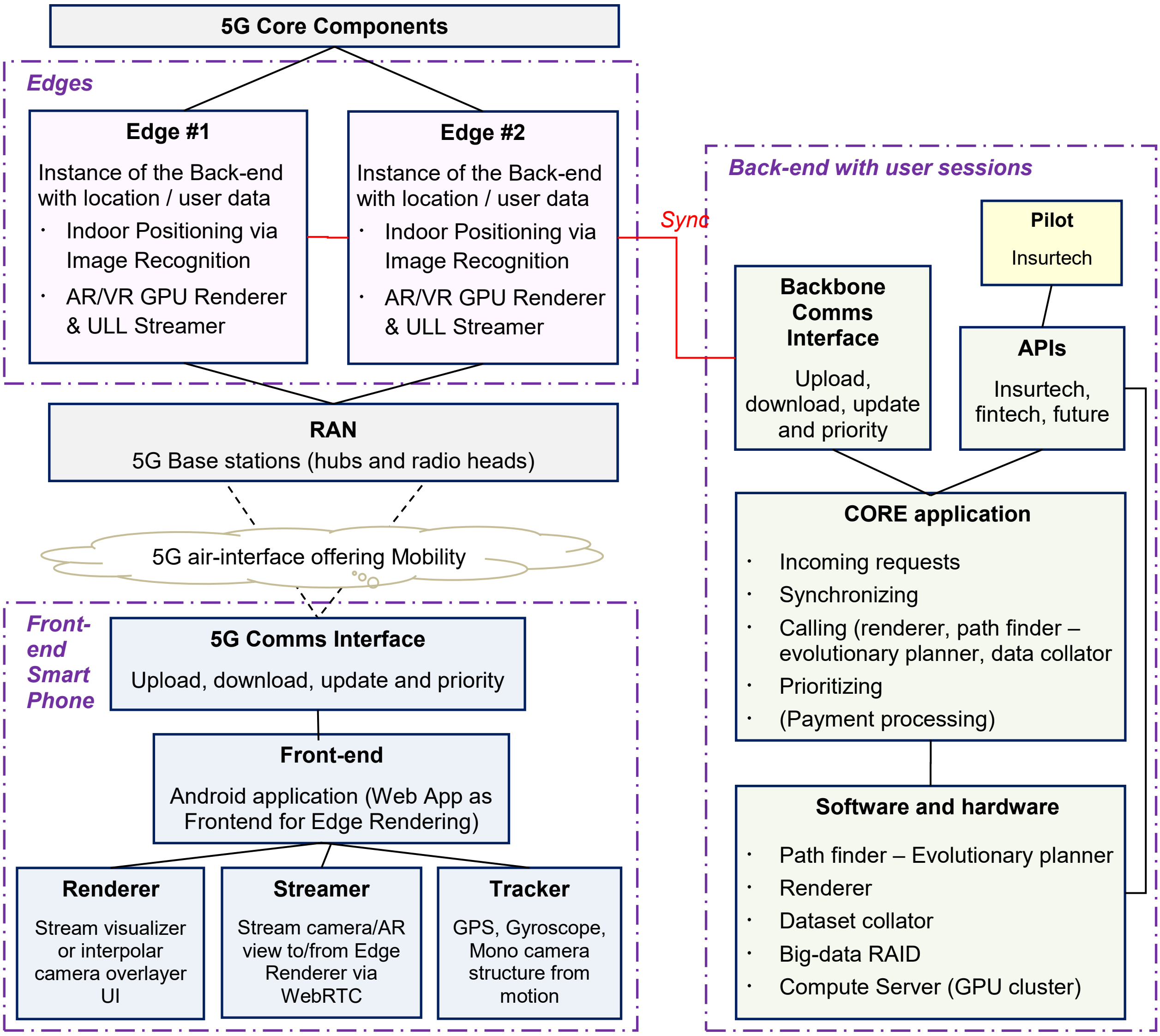


Figure 3-14 Block diagram: Apps and Components of UC #1.2

3.2.2 Site Survey and report /Final planning

Initially, an offline generation of spatial mapping was planned. This involved in advance the inspection of the entire train station without concerns about the processing time it will take. In this context, the planned site visit was intended to take a few samples, check the achievable quality and estimate the deviation in tracking precision over a later large-scale multi-hour scanning exercise. However, due to the COVID-19 restrictions, the plan could not be executed as planned.

Luckily, due to the continuous improvements of the Polaron engine in the backend, **UHA** is able to integrate live captured point-clouds (of decent resolution; 10 million points for example) into their spatial data grid (30-50x per second). This fact enables UHA to consider live capturing the transport infrastructure right before or during the field trial as the passengers carry around their cameras. This greatly mitigates any delays and facility access restrictions stemming from COVID-19.

Without the COVID-19 disruption, the partners could have surveyed Berlin Central Station and they could have taken a full Lidar scan by now, which could have been used in the Lab tests. Since that has not materialised, the idea is to use a mix of conventional 3D meshes of the station (in Wavefront OBJ format, so it can be imported into the Polaron engine and simulate the data as if generated through Lidar) that can be sourced and used in UHA's lab test runs. Field wise test scanning, as described above, will be performed close to the day of the trial.

3.2.3 Network Slice Co-Design

N/A

3.2.4 Design Review and Bill of Materials

Section 3.1.2 presented a list of equipment required and to be shared across all UCs. In this section, Table 3-2 and Table 3-3 list the HW equipment and SW components respectively, specifically required for **UC #1.2**.

Table 3-2 Specific HW equipment for UC #1.2

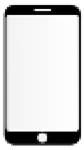
Equipment	Components	Dimensions Rack-mount	Quantity Power supply / Consumption	Connectivity
 **GPU**	To run the digital twin of the train station. Nvidia RTX 3090 with 24GB on board RAM.	It cannot be rack mounted due to its scale. Will be installed on an Intel I7 mother board with 16 GB RAM next to the network Edge infrastructure.	1 240V, 1200W	PCI/E
 **5G smartphone, Android**	The digital twin will receive user data from this device and send visualisations to such device that overlayed on top of the camera feed will produce the AR guidance experience.	N/A	N/A	5G with fallback to Wi-Fi

Table 3-3 Specific SW components for UC #1.2

Software Component	Runs where and on what hardware	Runs on OS	RAM	Memory usage	Cores	Additional Requirements
UHA's Polaron Engine Used for running the train station's digital twin.	Runs on the GPU at the back-end server.	Windows or Linux.	16 GB	8 GB+	CPU 1+ GPU 4000+	1200 W power supply

3.2.5 Description of Equipment

3.2.5.1 Fraunhofer FOKUS (FhG)

3.2.5.1.1 Open5GCore 5G Core Network

Details on 5G core (see 3.1.1.1).

3.2.5.1.2 WebRTC ULL Streamer for MEC

WebRTC ULL Streamer for MEC: The WebRTC Ultra Low Latency Streamer consist of client and server components for sending and receiving media streams such as Camera Stream or AR rendered view between UE and Edge using a variety of video codecs such as H264, VP8 and VP9. The WebRTC ULL client is available for web and mobile platforms such as Android and iOS. The WebRTC ULL Streaming Server is available as Docker container that can be deployed on the Edge or the Cloud. The WebRTC ULL Streaming Server will be integrated with the Digital Mobility Back-end Software for rendering the AR view for each video frame. The results will be encoded as a video and sent back to the UE again via WebRTC.

3.2.5.2 Urban Hawk (UHA)

3.2.5.2.1 Hardware

3D-Camera: for capturing facilities and providing 3D model ZED2 RGB + depth stereo USB camera connected to a GPU-equipped Notebook for mobility. The latter does camera location and orientation tracking with high accuracy and, as a result of that, the scanning becomes a walking and camera pointing exercise. The Lidar sensor is connected to the Notebook in the same way.

Compute, Storage, GPU in the cloud/edge: Nvidia RTX 3090 with 24GB on board RAM installed on an Intel I7 mother board with 16GB RAM next to the network Edge infrastructure.

3.2.5.2.2 Software

Digital Mobility Backend Software

This is **UHA**'s Polaron engine written in OpenCL/Cuda hybrid with C++ at CPU side.

We organise the scanned RGB + depth data in voxel alike spatial data grids. Lossless but very efficient packing accelerated with distance fields at the higher levels in the hierarchy for fast traversal. Optimal balance between compression ratios, memory access/manipulation, and traversal. Ready for volumetric Artificial Intelligence (AI).

- Point-clouds: The current pipeline injects up to 20 million points per second from depth sensors. While maintaining rendering at interactive rates on a single RTX 3090 GPU. We are not aware of any other technology being capable of this performance.
- Scene size: max 16k3 voxel grid on single GPU; max 256k3 on a GPU cluster (have not yet tested higher but in theory possible).
- Info stored with each voxel: Any custom data next to grey, rgb or rgba colour channels. Ready for physics (including fluid dynamics to run flood simulations and other natural disaster scenarios).
- Physical materials: reflection, refraction and light scattering.
- Rendering: Fully path traced (progressive spatio-temporal reprojection).
- Importing from conventional mesh formats: PCD, OBJ, elevation maps, shapefiles, and SVG are already supported.

Future Mobility Mobile Application

Currently implemented for Android phones only. Written in C++. Able to render streamed video via WebRTC and access the on board camera video stream for AR manipulation.

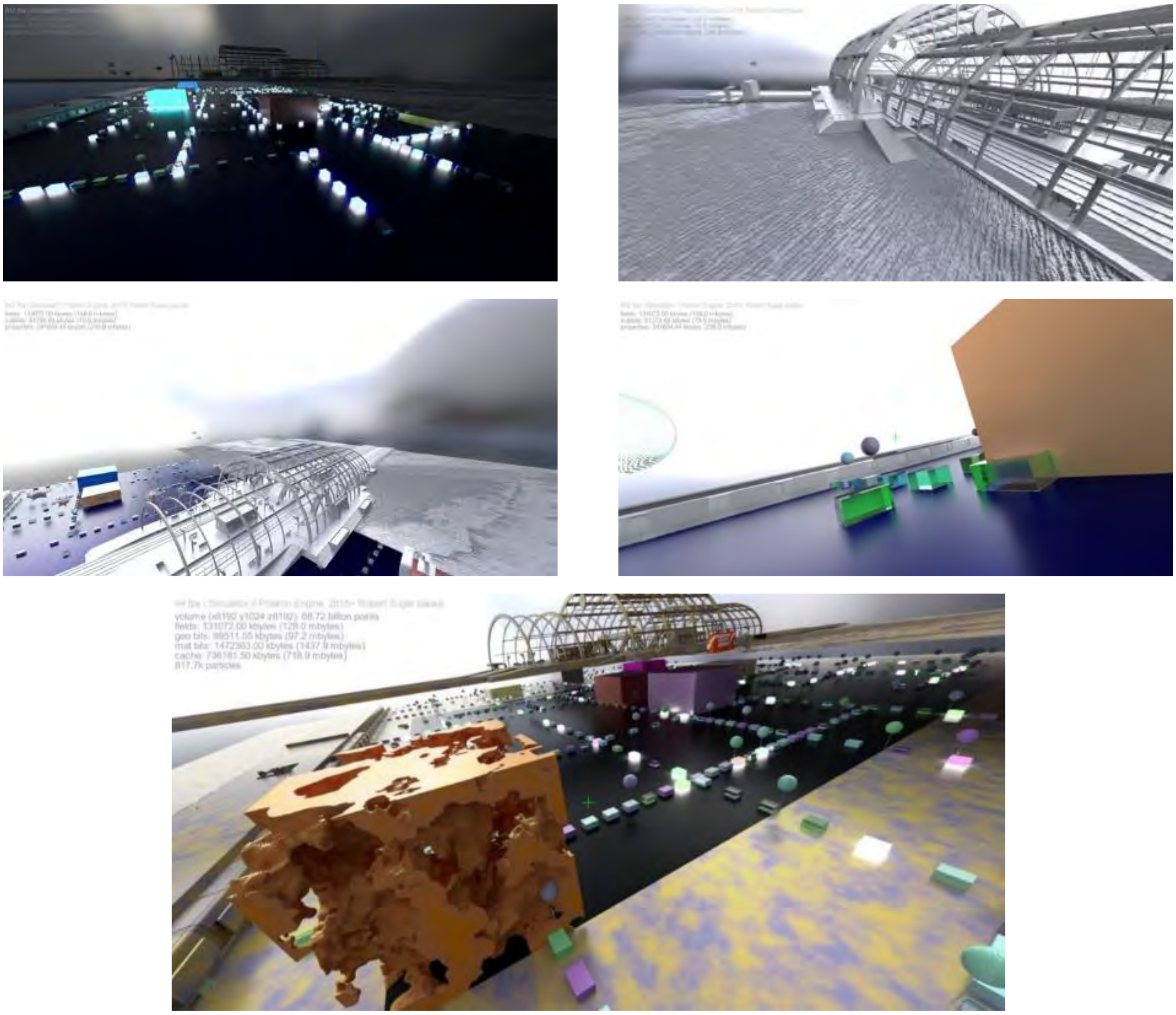


Figure 3-15 Screen captures of UHA's back-end visualisation of a train station

3.2.6 Identifying Gaps with existing Test Network Capabilities

In the existing requirements (processing, applications and UC), gaps have not been identified. Only 5G NR equipment and UEs required at Berlin Central Station.

3.2.7 Planning of Lab testing and initial validation of services per use case

While the original goal was to generate images at Berlin Central Station, this plan was not feasible and screen captures were created instead. The pictures in Figure 3-15 are screen captures of UHA's backend visualisation of a train station and other test elements that are put together in a scene. The spatial resolution is 8192 x 2048 x 8192 points (137 billion data points, voxelised). The scenes are fully editable (point by point) in real-time and can be injected with live data that is extracted from a stereo camera or Lidar, 30-50x per second.

For the field trial of **UC #1.2**, the whole Berlin Central Station will be scanned and the close surrounding outdoor areas. UHA's AI scheme will annotate/label the subsequent relevant features (see an example picture in Figure 3-16; ran on the Nvidia Synthia dataset):

- Remove the people from the dataset.
- Classify doors, exits.
- Classify stairs, escallators, lifts.
- Classify crossings and passage areas.

Figure 3-16 Example scan of an area including features, which ran on the Nvidia Synthia dataset

The transport features are labelled manually, such as platforms and platform numbers; ticket machines selling different types of tickets (long distance rail versus local metro and bus); difficult areas from disability and luggage point of view; bus stops with bus IDs outdoors; taxi waiting areas.

For the lab test prior to visiting the Berlin Central station, more or less the same procedure is followed except from:

- An imported traditional mesh is used to replace the Lidar station scan;
- The user movements are limited due to the fact that the space for moving around will be restricted to that of the Lab/officein the digital replica of the station. And the space/distances are much more limited in Lab/office.

Following labelling the transport operator's timetables and live train locations will be collated into the spatial data.

Once mapping is accomplished and the features are labelled the Edge side GPU node with the Polaron Engine on will be ready to communicate with the front-end user apps. The application relevant test cases (see detailed information in deliverable D3.1 [5]) can commence.

3.3 UC #1.3: Rail Critical Services in Berlin

The Rail Critical Services at the 5G-VICTORI facility in Berlin comprise five representative type of services. Four of them are related to communications between the Office and onboard a train, and the last one is offered as a wayside service [1]. These services are:

- Onboard services:
  - Rail signaling.
  - CCTV monitoring.
  - Telephony (Cab Voice and Emergency Calls).
  - Sensor data.
- Wayside services:
  - Wayside Point-machine Object controller signaling.

Rail Signalling, Critical Telephony and Sensor Data Transmission services will be provided as part of the Rail Critical Services taking place at the Berlin Central Station between the Berlin Office and onboard the train.

Rail Signalling is emulated using a traffic generator, which can be configured to send traffic in both directions. Rail Critical Telephony and Sensor Data transmission are performed live using a set of on-train, mobile and fixed terminals running rail applications (voice, emergency call, data app and sensor app), which are communicating with each other through rail critical, performance or business data sessions. Rail Critical applications requiring reliable IP level connectivity between onboard and ground systems use 3GPP MCData IPconn service to exchange arbitrary IP data.

The on-board mobile and fixed devices with applications are from Kontron Transportation (**KCC**), while the IxProbe performance endpoint is used to monitor specific KPIs is from Keysight. Measured results are displayed in the Keysight console.

The traffic generator consists of a Console, located at the office, with up to ten performance endpoints located in the office and onboard the train for different services. The Console consists of an Ixia Hawkeye server, which is reached via a web browser. Traffic is generated and monitored via the endpoints, and the result is communicated and presented as KPIs and statistics in the Console.

CCTV is streamed from the train to the office, using a CCTV network camera. The camera is mounted in front of the train and images are monitored from the Berlin office using a web browser that accesses the camera. The camera is not fitted with an SD memory card, as no recordings are planned.

A probe is used on the train for monitoring several types of traffic on different protocol abstraction layers. The probe is useful for CCTV streaming where a performance endpoint cannot easily be installed on the CCTV camera. The probe can both insert traffic as a performance endpoint and can monitor traffic, including rail signalling, CCTV streaming, and other service monitoring tasks. The IxProbe is managed via a separate Ethernet port, enabling in-line monitoring of traffic through its ports A and B.

The onboard Ethernet switch supports Power over Ethernet (PoE). The camera is powered using PoE, thus the IxProbe needs to sit in-line on the northbound side of the switch, as the probe is not PoE transparent.

Figure 3-17 provides an overview of the equipment used for Rail signalling and CCTV streaming over the 5G-VICTORI 5G network at Berlin Central station.

The main objectives of the UC related to the Rail Signalling and CCTV Streaming services are as follows:

- Demonstrate that **Rail Signalling** is conveyed over 5G with the required characteristics, regardless of other services and background traffic.
- Demonstrate that **CCTV Streaming** is conveyed over 5G with the required characteristics, regardless of other services and background traffic.

The main objectives of the UC related to the Rail Telephony and Rail Sensor Data services are as follows:

- Demonstrate that **Rail Telephony** is conveyed over 5G with the required characteristics, regardless of other services and background traffic.
- Demonstrate that **Rail Sensor Data** is conveyed over 5G with the required characteristics, regardless of other services and background traffic.

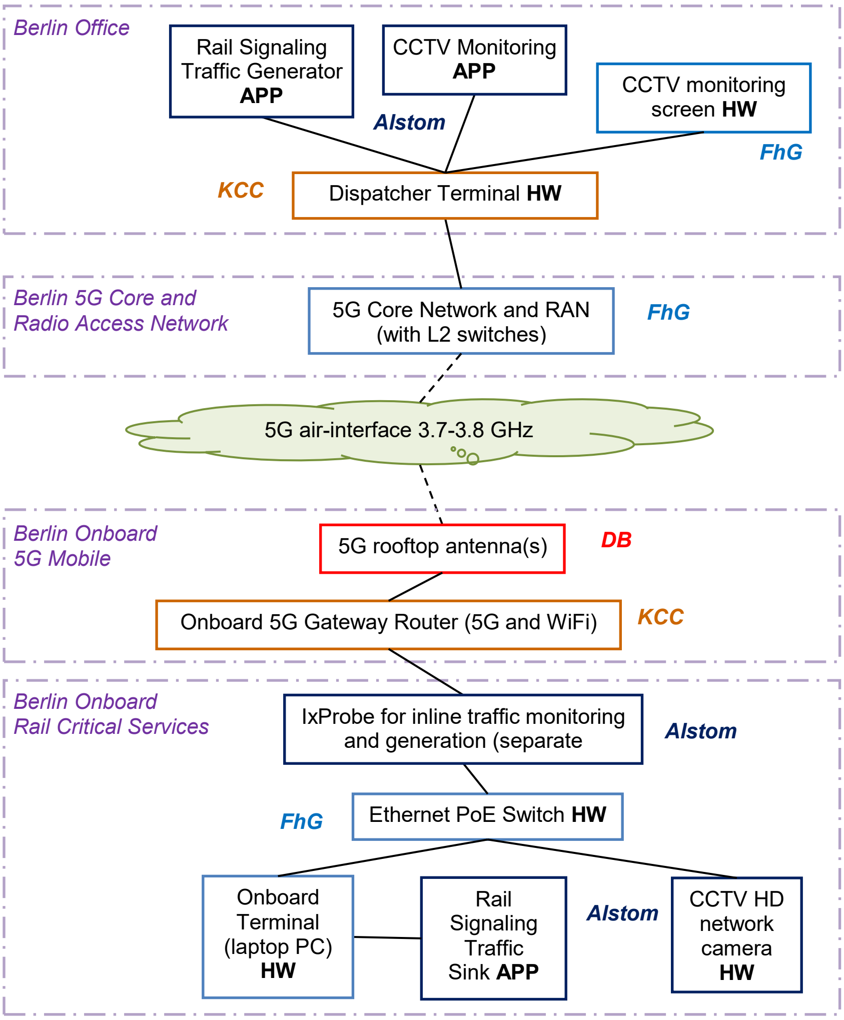


Figure 3-17 Rail Critical Services – Rail Signalling and CCTV Streaming – block diagram

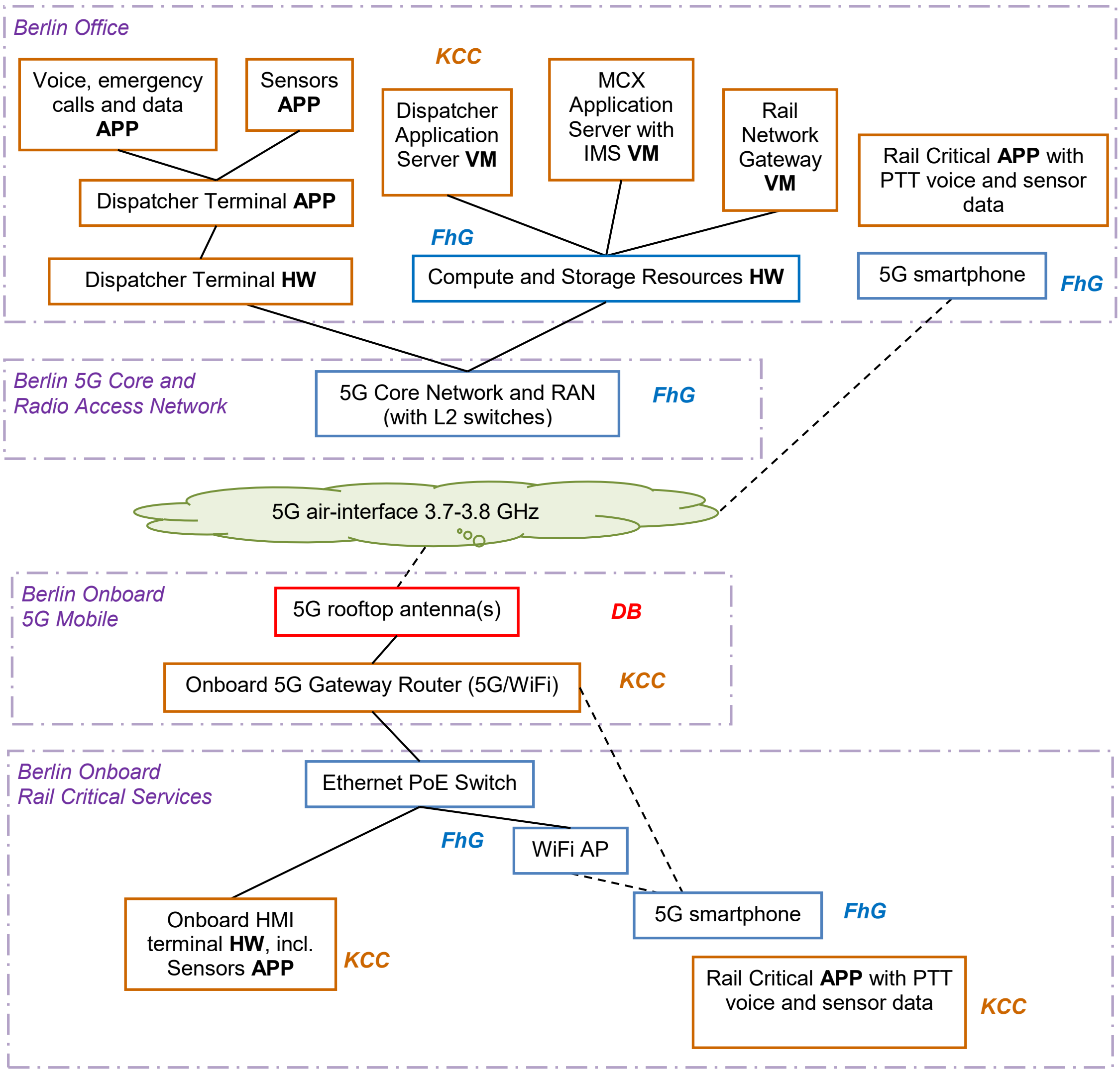


Figure 3-18 Rail Critical Services – Rail Telephony and Sensor Data – block diagram

Wayside services

For the Point-machine object controller signalling UC, the Rail Signalling traffic is extracted from a productive interlocking system via the usage of a network Test Access Point (TAP) – Siemens Data Capture Unit (DCU) – see Figure 3-19.

The purpose with this UC is to ensure, that specific timing KPIs of the communication can be met as well as different types of traffic can happen at the same time without influencing the signalling traffic.

The real signalling traffic from the *Deutsche Bahn* Interlocking is in this case transmitted via two parallel paths:

- Directly via a copper cable to the real point-machine controller and point machine in the field.
- The signaling traffic data is in parallel extracted (via a TAP), a Siemens DCU, which is prepared and processed to convey data over the 5G network and transmitted to an emulated point machine controller at the same site as the real point machine.

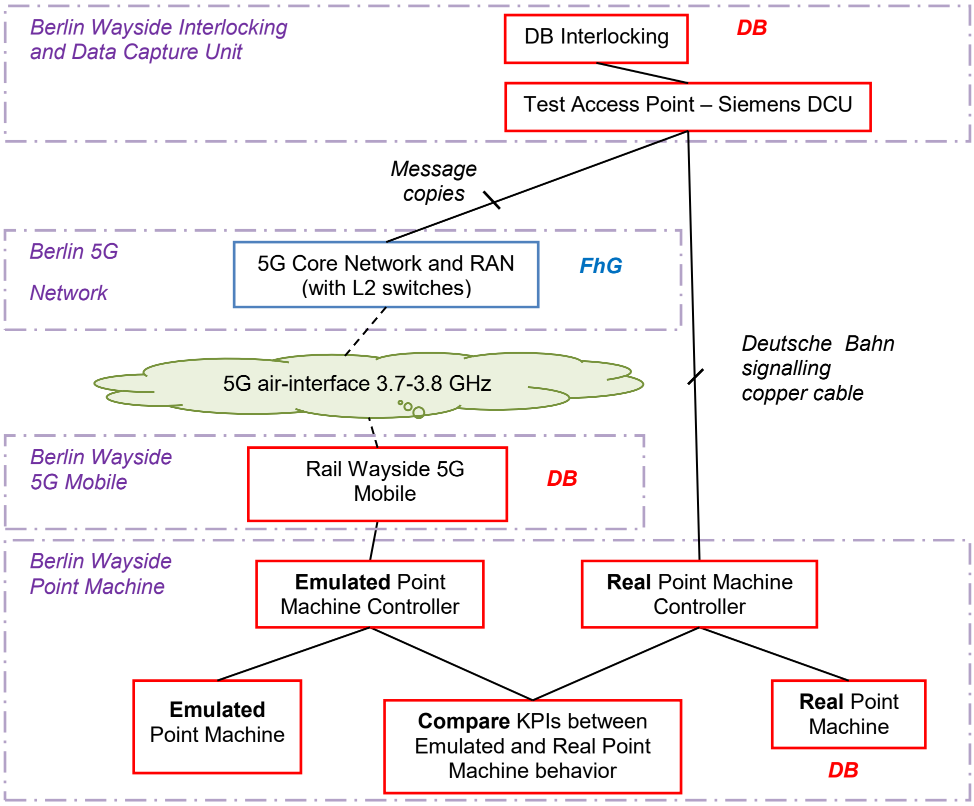


Figure 3-19 Rail Critical Services – Point Machine signaling over 5G

3.3.1 Network Requirement capture/ Processing Requirement capture

The Rail Critical services are based on the 3GPP IP Multimedia Subsystem (IMS) / Mobile Critical Service (MCS) architecture and are provided by KCC's MCX/FRMCS solution, which requires computing resources listed in Table 3-4 for proper operation of its virtualised software nodes.

To allow the IMS-based MCX Application Function to request the applying of corresponding 5G Policy and Charging Control Rules incl. delay critical ultra-Reliable Low Latency Communications (uRLLC) 5G QoS class und guaranteed flow bit rate for mission-critical applications, the 5GC's Policy Control Function (PCF) shall expose 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. To support the execution of mission-critical test scenarios, Fraunhofer's PCF shall be integrated with KCC's P-CSCF via Rx interface.

Detailed information on the required traffic model to be supported by 5G Core and 5G NR for Rail Critical Services can be found in deliverable D2.1 [Table 3-13 in section 3.3.1].

Table 3-4 Required compute resources for 3GPP MCS nodes (VMs)

VM / Function	CPU [#]	RAM [GB]	Disk Space [GB]
Gateway	4	8	50
Management Node	2	4	10
MCX AS, MRF	4	16	60
HSS	2	4	30
P-CSCF	4	8	30
S-CSCF	4	8	30
Dispatcher AS	2	4	50
SBA / MR / BBRC	4	8	150

Seamless transition between 5G networks is the desired capability of future FRMCS networks and FRMCS equipment, especially in cross-border scenarios, where no interruption of Rail Critical applications – such as Automatic Train Operation (ATO) – is allowed. The execution of seamless transition scenarios require propagation of at least two 5G network identifiers even over the same 5G-NR to be able to execute UCs such as the **U-FU-3165** requirement in D2.1 [Table 3-16 section 3.3.3], if supported by the infrastructure.

3.3.2 Site Survey and report /Final planning

The site survey of the Berlin Central station did involve the visit to the infrastructure of representatives of DB, FhG and IHP, given the travelling restrictions for people arriving to Berlin from abroad. It mainly focused on the analysis of the points where the 5G equipment (RRU & antennas) could be installed at the platform.

3.3.3 Network Slice Co-Design

When Rail Transportation and other type of services use the same 5G network, including air-interface, RAN and Core Network, different Network Slices can preferably be used for these services: A first uRLLC-optimised Network Slice for Rail Transportation Services, a second Network Slice for other types of services, etc. Slicing capabilities will be provided at the PDU session level for UEs, and for this slicing to be E2E, it requires to be implemented in both the RAN and Core Network.

With network slicing, it can be demonstrated that rail critical services like signalling and voice can be separated from other types of services, like predictive maintenance sensor data and other rail or non-rail related services[3]. An example using one network slice for all Rail Transportation Services (with a QoS ladder) is as follows:

- First Network slice
  1. Cab voice
  2. Rail signaling
  3. CCTV streaming
  4. Predictive maintenance with sensor data

Another example with two network slices for the Rail Transportation Services, each with a QoS ladder:

- First Network slice
  1. Cab voice
  2. Rail signaling
- Second Network slice
  1. CCTV streaming
  2. Predictive maintenance with sensor data

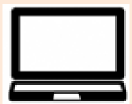
To support the execution of the requirement **U-FU-3164** in D2.1 [1] with multiple contending application categories within the rail vertical services, it is required to pre-configure and pre-establish three isolated slices for each category application:

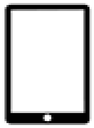
- A slice for rail signalling, critical telephony and data,
- A slice for performance applications using MCData, and
- A best-effort slice focused on high DL rates for business operations such as passenger Internet.

There is no need for on-demand instantiation of slices for execution of the mentioned UC. The 5G E2E slice can be addressed by the application using Data Network Name (DNN) in a network slice instance using Single – Network Slice Selection Assistance Information (S-NSSAI).

3.3.4 Design Review and Bill of Materials

[3] Note: the rail operators using a 5G network for FRMCS, with Network Slicing and/or QoS, need to agree on a common practice setting for configuration purposes.

Equipment	Item	Components	Quantity Total weight	Dimensions Rack-mount	Power supply / Consumption	Connectivity	Installation/ Attachment details
UC #1.3 Rail Critical Services							
	Dispatcher Terminal	The dispatcher terminal (computer) on which the Rail Dispatcher app, Sensor app, Console and the Office Performance Endpoint are running.	1	510 x 334 x 112mm 7.5kg	100..240VAC/50-60Hz, 35W	2x TJ45 10/100/1000 Base-T	Installation on desk
	AXIS P3935-LR Network Camera | Axis Communications	Camera P3935. RJ45 extension box provided. Note: mounting bracket in train cab for the camera with screws needed.	1 **Weight**: 0.42 kg	Camera mounted on a bracket in train front cabin. Camera outer diam: 110 [mm]. Camera height from mounting base: ~55.	Power supply only via PoE (Power over Ethernet), IEEE 802.3af/802.3at Type 1 Class 3. IR illumination on: typical 6.6 W, max 11.8 W.	The cameras has a short RJ45 Ethernet cable (male). Extension box with two female connectors is delivered with the camera.	Mounting plate diam: 107 mm. Drill circle: 91 mm. Mounting screws diameter: 4 mm. Front lid has two TR20 screws. A T20H screwdriver needed.
	IxProbe from Ixia Keysight	The probe is connected in line with the Gigabit Ethernet cable, not PoE transparent. The IxProbe supports Hardware Endpoints.	1 **Weight**: 0.33 kg	Height: 23 mm Depth: 148 mm Width: 83 mm	Transformer input: 100 to 240 VAC, 50 to 60 Hz, 0.5A Max. Transformer output: USB-C DC 5V 3A, with security screw. Power dissipation less than 10 W.	Network ports A and B for in-line measurements: RJ45, 8-pin connectors. Management port: RJ45, 8-pin connector. Console port: 1 micro-USB connector.	The IxProbe comes with a mounting bracket, with screw holes, mounted on rack shelf, or wall. IxProbe 3.0 User Guide in BSCW. Operating temperature: 0°C to 40°C.
 **(sample image)**	Onboard terminal (Laptop)	Generic 15inch Laptop running Rail Critical app and measurements end-points.	1	15 inch 2 kg	100..240VAC/50-60Hz, 70W	IEEE802.11ac/a/b/g/n	N/A

 **(sample image)**	Onboard HMI (Tablet)	Generic 10inch Tablet running Rail Critical app.	1	10 inch 0.5 kg	100..240VAC/50-60 Hz, 20 W	RJ45 100/1000Base-T IEEE802.11ac/a/b/g/n	N/A
	Onboard GW (Router) Kontron TRACe	EN50155 Mobile Fanless 5G / Wi-Fi / GNSS / ETH Router / Gateway for Smart Railway Applications	1	300 x 190 x 87 mm 4 kg	24..110 VDC (external 100..240 VAC adapter available)	2x M12 10/100/1000 Base-T IEEE802.11ac/a/b/g/n GNSS, 5G, Wi-Fi antenna connectors	N/A
	User Handset	5G smartphone	min. 2	-	-	-	-
	Ext. Antennas	OBG antennas (5G, GNSS, Wi-Fi)	3	-	-	-	-
	Cabling	-	-	-	-	-	-

Software Component	Runs where and on what hardware	Runs on OS	RAM	Disk Memory usage	Cores	Additional Requirements
Ixia Hawkeye Server and Console Traffic Generator and Monitoring (using HW or SW Endpoints).	The Hawkeye Server runs on a Berlin Office Windows computer. The Hawkeye Console is reached via a Google Chrome web browser, using the IP address of the Hawkeye Server.	The Hawkeye Server is a Linux based software. It runs over Linux VMware Player over MS Windows.	The Hawkeye Server deployment is recommended with a minimum of 8 GB RAM.	The application on VMware disk memory usage is probably less than 20 GB.	4 vCPU	See the Ixia document in BSCW "Hawkeye, Release 5.0, Getting Started Guide", for installation prerequisites and Activation etc. For License, contact Alstom.

Performance Endpoints Software Performance Endpoints are mainly used for rail signalling traffic between office and onboard (can also be used for other Rail Transportation Services, like voice). Note: Endpoints are available for downloading at http://www.ixiacom.com/support/endpoint_library.	Endpoints run on a train onboard computer, and on an office computer. Note: Hawkeye supports both software and hardware endpoints (the IxProbe is a hardware endpoint).	Windows, Linux, Mac OS, vmware, iOS, Android, available for 20 different OS/platforms.	The amount of RAM can be configured that suits the file sizes being sent, e.g. 10 MB or so.	The amount of hard disk memory usage can be configured between zero and upwards.	-	See the Ixia document in BSCW "Performance Endpoints User Guide", for installation of software Endpoints.
CCTV Monitoring A web browser is used in the Office for monitoring live pictures from the Axis network camera located on the rain. Note: Another option is to use the Axis Companion application, supporting several cameras, but we have only one camera.	The monitoring software runs on an office computer, with screen.	Same as used for the Web browser	With live streaming from the camera, the amount of RAM for the browser increases with around 600 MB.	A Web browser needs to be installed. No additional disk space needed.	-	The login user and pw for the network camera P3935 is found in the D3.1 document.
Next-Gen Dispatcher Solution Next-Gen Dispatcher solution provides mission-critical communication for railway's control room. Operating trains and other stuff are	Dispatcher client runs on terminal and Next-Gen Dispatcher Application Server runs	Windows embedded PC.	As provided by dedicated Dispatcher Terminal HW.	As provided by dedicated Dispatcher Terminal HW.	As provided by dedicated Dispatcher Terminal HW.	N/A
Rail Critical Application Onboard and mobile rail critical application for PTT voice and data communication incl. sensor data.	Runs on onboard terminal/DMI, mobile 5G smartphones and client VM.	Runs on Android 8,9,10, iOS, Linux OS.	As provided by onboard terminal HW and 5G smartphone.	As provided by onboard terminal HW and 5G smartphone.	As provided by onboard terminal HW and 5G smartphone	N/A
Railway Onboard Gateway FRMCS onboard gateway incl. adaptable communication system based on UIC/TOBA architecture.	Runs on dedicated onboard gateway HW (TRACe).	Runs on linux OS.	As provided by the dedicated onboard gateway HW.	As provided by the dedicated onboard gateway HW.	As provided by the dedicated onboard gateway HW.	N/A

3.3.5 Description of Equipment

3.3.5.1 Alstom

Hardware:

- Network camera Axis P3935, powered via the RJ45 connector, using Power over Ethernet (PoE).
- IxProbe, in-line probe for generating and monitoring traffic.

Software:

- Traffic generator Ixia Hawkeye Server, console
  - Hawkeye runs on Linux, VMware Player over Windows x64 needed.
  - License for one user and 10 end-points (license moved when changing computer).
- Ixia Performance Endpoints
  - Running over Windows, Linux, Android, etc.
  - These endpoints are downloaded from Ixia Internet and installed.
- CCTV monitoring of train live pictures in Berlin office.
  - Web browser, addressing the onboard camera (optionally Axis Companion SW can be used).
  - Running over MS Windows.

3.3.5.1.1 Rail Signaling – Traffic Generator

Rail Signalling traffic is generated with an Ixia **Hawkeye** traffic generator. The Hawkeye traffic generator consists of a Console to be placed at the Berlin office (see Figure 3-20) and uses up to ten active performance endpoints (which is supported by a minimal license).

The performance endpoints can be hardware (like the IxProbe) and/or software. The software performance endpoints are supported by different operating systems like Windows, Unix, Android.

The Ixia **Hawkeye Console** controls connections between the endpoints, sets up and monitors traffic, collects statistics, and generates reports and KPIs. Traffic can be scheduled and logged over a long period of time.

Hawkeye offers visibility in live networks with network throughput, class of service, QoE, QoS, etc.

Figure 3-20 Rail Critical Services – Rail Signaling Traffic Generator – Hawkeye Console

Figure 3-21 Rail Critical Services – Rail Signaling Traffic Generator – IxProbe

Figure 3-22 Rail Critical Services – CCTV Streaming – Network camera Axis P3935-LR – front side

The **IxProbe** (IXPR-CU3 from Ixia), shown in Figure 3-21, is connected in-line with the traffic that passes the box. The IxProbe is configured for Out Of Band management (OOB), which means that a separate MGMT Ethernet port is used for management, with its own IP address, making it possible to login to the inbuilt home page. Using OOB IxProbe management enables monitoring and inserting traffic in a different IP network (Port A and B, yellow and blue cable in figure) relative the management IP network (MGMT port, red cable in Figure 3-21), should that be required.

The IxProbe is located between the onboard 5G mobile and the PoE switch - Port A on network side, and Port B on client side. The IxProbe also supports a fail-to-wire, should the probe lose power. The IxProbe is powered with 230 VAC via a transformer to the screw secured USB-C connector, and consumed less than 10 W.

The IxProbe (hardware endpoint) monitors and generates traffic. Its network ports are RJ45 8-pin connectors and communicates with the Hawkeye Console for traffic and monitoring management. A full range of traffic statistics are available on the Hawkeye console and IxProbe GUI.

3.3.5.1.2 CCTV Streaming – Network Camera P39

The CCTV network cameras is of model P3935-LR from Axis. It is a transportation certified camera – rugged version for transportation usage – for trains, buses, subway, etc. Datasheet can be found here. The camera is:

- Vandal-resistant, metal casing.
- Complies with EN50155, EN45545, and NFPA 130.
- Lightfinder and Forensic WDR.
- Invisible IR LEDs, built-in microphone, and EIS.
- Enhanced security features.

The camera is pre-fitted with a thick cable, including:

- Ethernet (RJ45).
- Sound (3.5 mm).
- I/O pins pins.

For lab and onboard installation, the pre-fitted Ethernet cable needs an extension:

- Ethernet extension cable with male/female connectors.
- Standard Ethernet cable with a female/female box.

Figure 3-23 Rail Critical Services – CCTV Streaming – Network camera Axis P3935-LR – back side

A Torx tool T20H with a center hole (not a standard T20H) is needed in order to obtain access to the inside of the camera and mounting it on a place.

The camera has a built-in microphone, IR illumination and can support several configuration options. For example, the number of P-frames can be set to determine how often full frames are sent. With one P-frame in between, it generates bitrates of approximately 5 Mbps, H.264 encoded frames.

The camera has an outer diameter of 110 mm, where the mounting plate is 107 mm. The camera height from mounting base is ~55 mm. Weight: 425 gr (including the RJ45 metal box). Suitable fastening screws are M4, or 4 mm in diameter. The mounting drill circle has a diameter of 91 mm. The optimal cc line distance between the screw holes on each side is 40 mm.

3.3.5.2 Kontron

Hardware:

- Railway Onboard Gateway HW – TRACe.
- Onboard Terminal – generic PC.
- Onboard DMI – generic 10inch tablet.
- Dispatcher Terminal.

Software:

- Rail Critical Client for Linux as VM for lab deployment.
- Rail Critical App for Android supporting PTT voice, data and sensor data.
- Dispatcher Terminal Client.
- Rail Onboard Gateway SW.
- Dispatcher Application Server.
- MCX Application Server.
- IMS-based SIP core incl. HSS, P-CSCF, S-CSCF, etc.

3.3.5.2.1 Rail Critical Telephony and Sensor Data APP

Kontron's Rail Telephony and Sensor Data APP (see Figure 3-24) is a multi-platform capable rail communication client for Android, iOS, Linux and Windows, empowering users to communicate in a modern way in safe, relevant and mission-critical environments. Used as an Android APP and Linux VM in the Berlin cluster, the APP brings in emergency group communication, train-to-driver private communication, functional aliasing and mission-critical data, including IPconn for ATO, Short Data Service (SDS) and File Distribution and Location Services.

3.3.5.2.1 Next-Gen Dispatcher terminal client

Kontron's Next-Gen Dispatcher (see Figure 3-25) is a future-proof, standards-based dispatching solution for existing and future rail networks. It supports individual, user-tailored applications for rail operations. It combines point-to-point, group and broadcast call functions with message-based communication, such as chat with data transfer, SMS, SDS and emergency alarm and geographic information system (GIS) with geolocation services such as geofenced group call.

Figure 3-24 Rail Critical Telephony and Sensor Data APP showing communications and connectivity options with drivers.

Figure 3-25 Dispatcher Terminal

3.3.5.2.2 Railway Onboard Gateway

Kontron's Railway Onboard Gateway is a FRMCS onboard gateway prototype including adaptable communication system based on UIC/ Telecom On-Board Architecture (TOBA) architecture. It allows transparent, bearer independent usage of various Radio Access Types for railway applications, requiring seamless transition between various communication networks. See Figure 3-26 for the design and Figure 3-27 for the HW component itself.

Figure 3-26 FRMCS Railway Onboard Gateway design

Figure 3-27 Railway Onboard Gateway Hardware

3.3.5.3 Deutsche Bahn

3.3.5.3.1 Siemens DCU (network TAP)

With the Data Capture Unit (DCU), see Figure 3-28, Siemens has pursued a data diode approach based on purely passive network tap functionality. The DCU can be looped into the existing data connections of a safety-critical switched Ethernet network via the listening ports, for example at suitable switches or relevant control nodes. As a network tap, the DCU provides a connection which will not interfere with the monitored network. On the one hand, the DCU can act as a network tap (“tap mode”) and write network data to a local storage medium which is comparable to a “black box” data recorder. The data can then be analysed offline as required. This allows the evaluation of past events (a retrospective analysis), for example, when the cause of an incident needs to be investigated.

Figure 3-28 Siemens DCU

3.3.5.3.2 Controller for filtering

Controller that is attached to the DCU and is in charge of receiving the captured packets. It takes the information of these and sends them to the emulated point-machine controller.

3.3.5.3.3 Siemens EULYNX Object Controller

EULYNX[4] defines the next generation of railway signalling equipment. The controllers are built in a standardized way with communication interfaces according to their purpose (e.g. point-machine or signal). The interfaces of these object controllers are specified by the EULYNX consortium and are freely available. Due to the open interfaces it should be able to switch between suppliers quite easy as well as reducing the barrier for joining the railway market, as a supplier is able to provide small parts of a signalling system only.

The controllers (see example in Figure 3-29) are built with Reliability, Availability, Maintainability & Safety (RAMS) in mind, and due to this make use of safety communication protocols according to EN 50159 and redundancies.

[4] EULYNX is an European initiative by 13 Infrastructure Managers to standardise interfaces and elements of the signalling systems

3.3.5.3.4 Emulated point-machine controller and Emulated point-machine

For the emulated point-machine a model signal by Märklin is used and attached to a micro controller, which is able to speak the signalling safety protocol Rail Safe Transport Application (RaSTA) as well as the required signal communication protocol as specified by EULYNX. For this, a Raspberry Pi will be used, which is equipped with a DB-owned EULYNX communication stack. An emulated point machine example is shown in Figure 3-30.

3.3.6 Identifying Gaps with existing Test Network Capabilities

This UC requires the use of the 5G NR components and the slicing capabilities of the network.

3.3.7 Planning of Lab testing and initial validation of services per use case

3.3.7.1 Rail Signaling

First, the equipment should be installed at the lab without a 5G network. When the equipment is up and running, then a 5G network is included. After emulating one train, up to twelve trains can then be emulated. The bitrate between the office and onboard the train is changed to correspond to a demonstration test case, see deliverable D3.1 [5] for more details.

The lab equipment is located at:

1. Alstom & Kontron labs in Stockholm and Vienna (for pre-testing only), respectively, which serve for testing the traffic generator and monitoring equipment, suitable for lab activities.
2. Fraunhofer FOKUS lab in Berlin, which will host the 5G network together with the vertical-related equipment listed in section 3.3.5 and assessed previously in 1.
3. Berlin Central Station and Onboard during the field trial tests in Berlin, involving the equipment mentioned in 1 and 2.

Figure 3-29 EULYNX Object Controller

Figure 3-30 Emulated point-machine example

3.3.7.2 CCTV Streaming

In the first place, the equipment should be installed and tested at the lab without a 5G network. As soon as the setup is up and running, a 5G network will be included for additional testing purposes. Up to 12 trains can be emulated and the bitrate can be modified.

The lab equipment is located at:

1. Alstom & Kontron labs in Stockholm and Vienna, respectively (for pre-testing only).
2. Fraunhofer FOKUS lab in Berlin.
3. Berlin Central Station and Onboard field trial in Berlin.

3.3.7.3 Rail Critical Telephony and Sensor Data

The lab phase will begin with a deployment of the IMS-based SIP core, MCX Application Server and MCX client VM on **FhG**'s compute node in the Berlin cluster. Remote VPN access to the lab is required.

1st phase *– OTT, w/o RAN, no QCIs*

First, Over-The-Top scenarios without RAN will be executed. The deployed MCX client VM includes an interface, which can be remotely controlled so that test cases can be executed without the need of physical access to the lab.

2nd phase – w RAN, CPE, no QCIs

A 5G CPE will be introduced into the test setup. The MCX client VM will be reconfigured to use 5G CPE via Ethernet, so that all MCX/FRMCS communication runs through 5G-NR.

3rd phase – w RAN, OBG with CPE/mPCIe, smartphones, no QCIs

Rail Critical Telephony and Sensor Data APP will be ported by Kontron to a 5G smartphone device, selected by Fraunhofer for the testing. 5G smartphones running the Rail Critical Telephony and Sensor Data APP and Dispatcher terminal will be deployed in the Berlin lab. Both smartphone and dispatcher terminals will be remotely operated using "teamviewer"-like technology.

Railway Onboard Gateway will be deployed in the Berlin lab, first connected to 5G CPE from Fraunhofer, and then potentially integrated into the mPCIe 5G radio module as a next step. Scripts for automation of UCs and remote control will be updated.

4th phase – PCF/QCIs

As soon as Fraunhofer's Open5GCore is updated to release the provision of the PCF with a legacy Rx reference point, it will be integrated with Kontron's P-CSCF to control QCIs of sessions.

5th phase – User-controlled test/demo – On-site lab tests and demonstrators.

3.3.7.4 Point Machine

1st phase:

First the Siemens DCU will be applied to the existing signalling network at the interlocking location responsible for Berlin Central Station. After applying the DCU the captured traffic is verified and it is validated, that the EULYNX stack is compatible with the data.

2nd phase:

In a following step, the emulated point machine controller is attached to the data stream and it is checked, that the actions by the emulated controller and the productive controller are the same.

3rd phase:

The communication is now moved to 5G and general connectivity between the endpoints (emulated controller and filtering controller) is established. After this is validated, the emulated controller is attached and the data stream from the filtering controller to the emulated controller is enabled.

4th phase:

Finally also other communication is added to the 5G network, and it is checked that the required KPIs are met.

3.4 UC #3: CDN services in dense, static and mobile environments

This UC aims to optimize streaming services in mobile environments enabled by 5G technologies, including mmWave, edge computing and media streaming standards, i.e. NBMP and MPEG SAND. It follows the multi-CDN concept and extends the streaming service's CDN to trains by equipping them with caches. The caches are filled with content via mmWave high-speed links ("Data Showers") for uninterrupted connectivity.

Data showers will be installed at selected locations along the train route in order to transfer media content from the CDN cache (at the train station) into the train's cache with multi-Gbps data rates. For Video-on-Demand (VoD), content will be preloaded via a 5G data shower to the content cache on the train, which acts as an edge server of the content provider's CDN. For this scenario, it is assumed that viewers will use their personal mobile devices to connect to the train's on-board Wi-Fi to consume media streams.

3.4.1 Network Requirement capture/ Processing Requirement capture

Figure 3-32 shows a high-level block diagram of the software and hardware components and the interconnection between them. The network and processing requirements for this use case are divided into the following groups:

Compute and Storage:

- Content Aggregator VM (Cloud): 2+ CPU cores, 4+GB RAM, 20GB storage space.
- Station CDN Cache (Office): 4+CPU cores, 16+GB RAM, 1+TB storage space.
- Train CDN Cache (Onboard): 4+CPU cores, 16+GB RAM, 1+TB storage space.

Network (lab/field):

- Downlink station CDN Cache: 500 Mbps
- mmWave 60 GHz Link: 5+ Gbps with 5+ Gbps Ethernet
- Wi-Fi Access Point onboard

Other Equipment:

- iOS, Android Mobile devices with RBB Mediathek/ARD Player installed
- Laptops/Tablets with RBB Mediathek/ARD Player running in Browser
- Laptop with Browser for monitoring and logging

3.4.2 Site Survey and report /Final planning

The site survey revolved around suitable points of attachment of the radio equipment, i.e. the mmWave units, which need to be fixed to both light poles at the platform side and to the Regional Train that will be equipped with the equipment to support the UC (see Figure 3-31 for a mockup figure on how the mounting of the units could be made).

Having two nodes installed at the platform and 1 node installed at the train outer panels, it is assumed that the train will approach and connect to the Berlin Central station via mmWave to download streaming content in a "data shower" fashion. To validate this UC, the Mediathek catalog (offered by **RBB**) will provide VoD content.

To integrate with the Deutsche Bahn facility, the CDN platform will be enabled by NBMP and consist of three main network entities: workflow-manager, tasks and function repository.

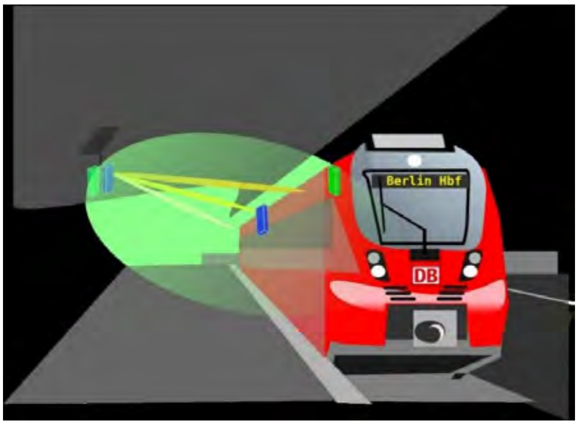


Figure 3-31 Sketch of the mmWave connectivity to the train from the platform

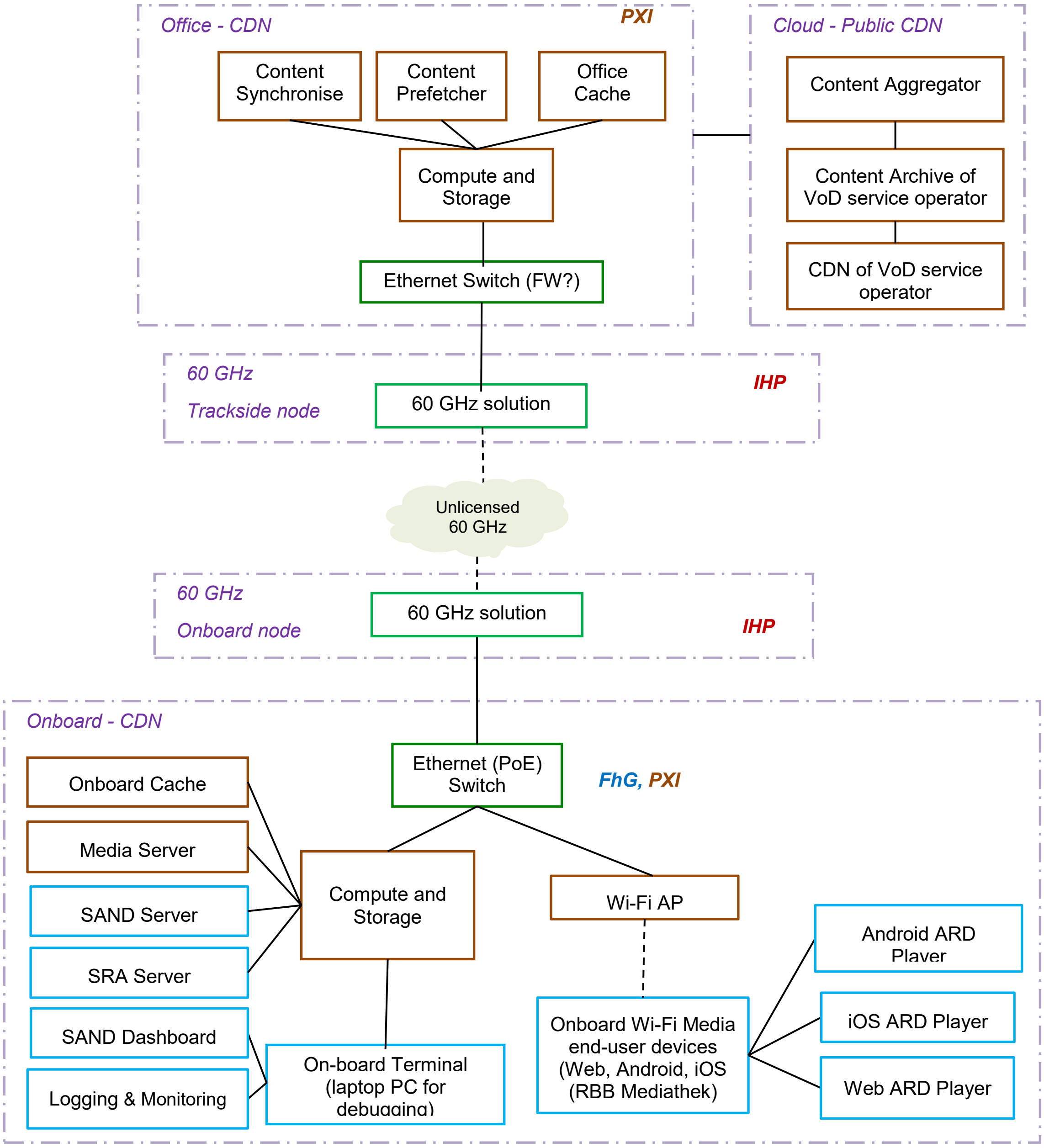


Figure 3-32 CDN services: SW/HW High Level Diagram

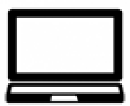
3.4.3 Network Slice Co-Design

N/A, since only mmWave data link is used in this UC.

3.4.4 Design Review and Bill of Materials

In this section, Table 3-5 and Table 3-6 list the HW equipment and SW components specifically required for **UC #3**, respectively.

Table 3-5 Specific HW equipment for UC # 3

Equipment	Item	Components	Quantity Total weight	Dimensions Rack-mount	Power supply / Consumption	Connectivity	Installation/ Attachment details
UC # 3 CDN services in dense, static and mobile environments							
	Nexcom aROK 5510 19" rail grade server	Train-mounted cache server	1 **Weight**: 8.5kg	Length: 400 Width: 483 Height: 95 (3U height required)	24/100 VDC <650 W power consumption	2x1 Gigabit Ethernet (M12 coded) 2x10 Gigabit SFP+	Server used for caching assets on the train has to be integrate into train Wi-Fi
	Generic server	Platform side server used to pre-cache/buffer assets to be pushed to train cache	1 **Weight**: < 10kg	TBD	100..240VAC/50-60Hz, < 400W	5+ Gigabit Ethernet (RJ-45) or SFP+	High throughput internet connection required to fill platform side caches
	Generic laptop for connection to onboard cache and platform cache	Generic laptop	2 < 2kg	< 15 inch < 2 kg	100..240VAC/50-60 Hz, 70 W	IEEE802.11ac/a/b/g/n	Used to monitor caches on train and platform
	Generic mobile device	Mobile device to consume the contents provided by the cache server/media provider	2	< 6 inch < 300 g	100..240VAC/50-60 Hz, 20 W	IEEE802.11ac/a/b/g/n	Android and iOS device needed. Native apps of media provider need to be installed.
	Wi-Fi LAN	Wi-Fi Access Point	2-3	590 x 287x 20 3 kg	12 V DC ,24 V DC, 48 V DC	1 x IN Gigabit-Ethernet-Port, M12 1 x OUT Gigabit-Ethernet-Port, M12	Already installed as part of the Colibri project
	MetroLinq™ 2.5G 60 Beamforming Sector	Train-mounted mmWave unit	1 **Weight**: 2.00 kg	Length: 190 mm Width: 190 mm Height: 60 mm	Power Supply: 24-48V/1A passive Gigabit PoE or DC	Network ports (2): 1x 2.5 Gigabit Ethernet Port (PoE IN 24-48v) 1x SFP Port Configuration (1):	Height of the DB Regio train to calculate the height at which the units must be mounted

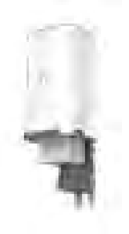
	(ML2.5-60-BF-18)				<24 W power consumption	1x USB 3.0 Port	
	MetroLinq™ 10G Tri-Band Omni (ML-60-10G-360)	Station-mounted mmWave unit	1 **Weight**: 4.06 kg	Length: 217 mm Width: 179 mm Height: 455 mm	Power Supply: 48 V Passive PoE IN or DC <60 W power consumption	Network ports (2): 1x 2.5Gbps nBase-T Ethernet Port (PoE IN) 1x SFP+ (10Gbps) Port	Height of the DB Regio train to calculate the height at which the units must be mounted *Note: can be replaced with a MetroLinq 2.5G if needed
	Mikrotik wAP 60Gx3 AP	****Reserve/ Back-up**** Train-mounted and Station-mounted mmWave unit	2 **Weight**: <1 kg	Length: 80 mm Width: 30 mm Height: 185 mm	Power Supply: 12-57 V PoE or DC Jack, <5 W power consumption	Network ports (1): 1x 1 Gigabit Ethernet Port (RJ-45)	Back-up option for the train and station mounted units that can replace the MetroLinq 2.5G and MetroLinq 10G. **Note: the data throughput is limited to 1 Gbps in this case.

Table 3-6 Specific SW components for UC #3

Software Component	Runs where and on what hardware	Runs on OS	RAM	Memory usage	Cores
Paxlife Innovations railSTACK Platform and edge side software used for manging the train and platform cache	Edge side components runs on train cache server, platform counterparts run at cloud provider	Linux	16GB+	1+ TB	4+
5GV platform Software system for the prefilling of media caches jointly developed by FhG/IRT/PXI	Pre-caching of media assets	Linux	8GB+	1+ TB	4+
SAND Server Media Streaming and Analytics SW	Onboard CDN	Linux	8GB+	100GB+	4+
SAND Dashboard Visualises Streaming Analytics and Monitoring	Monitoring Laptop	Browser	2GB+	-	2+
SRA Server Shared Resource Allocation (SRA) Server	Onboard CDN	Linux	8GB+	100GB+	4+
RBB Mediathek/ARD Player Mediathek for iOS, Android and Web. The Web Player integrates SAND Adapter	Mobile Devices	iOS, Android, Web	1GB+	16GB+	2+

3.4.5 Description of Equipment

The partners that participate in the Berlin cluster facility will provide HW and SW components necessary for running the trials. These partners are Fraunhofer FOKUS (**FhG**), **IHP**, PaxLife (**PXI**) and **RBB**.

3.4.5.1 FhG

Fraunhofer provides the core components for enabling efficient media delivery and playback over 5G. The software and hardware components provided by Fraunhofer within this UC are listed below.

Software:

- **Streaming Monitoring and Analytics / Server and Network Assisted DASH (SAND)**: SAND metric reporting is an important tool for content providers as it enables players to provide streaming performance information like average throughput, buffer level, representation switch events and initial playout delay (QoE metrics defined in ISO/IEC 23009-1). See Figure 3-33.

Figure 3-33: Streaming Monitoring Dashboard

SAND provides real-time metric reporting to monitor player performance information like average throughput, buffer level, representation switch events which are important metrics to monitor the QoE of individual sessions. The SAND Library will be integrated in the ARD Mediathek player (Web/Android/iOS) and the reported metrics will be reported on the SAND Server deployed in the train. The SAND Dashboard provides a powerful tool to visualize aggregation of different metrics in one place.

- **Shared Resource Allocation (SRA)**: shared resource allocation (SRA) utilizes SAND collected metrics and allows network components to control how much bandwidth a client should use. This is useful in scenarios in which multiple DASH/HLS clients share the same network and compete for the available bandwidth like in the train. SRA provide 3 different options to control how much bandwidth a client should use. 1) by passing SRA messages to each SAND client which include information about the target bandwidth, 2) by passing SRA messages to the CDN cache node in the train to only serve clients with video/audio segment with a bit rate below a specific threshold which is calculated based on collected SAND metrics and 3) to control the bandwidth of each client connection with the Wi-Fi AP. This option requires a Wi-Fi AP with dedicated interfaces to limit the bandwidth of each connection like OpenWRT enabled Wi-Fi APs.

- **FAMIUM DASH**: FAMIUM DASH is a fully standard-compliant DASH end-to-end solution. It also supports cutting-edge features on content creation side. These are complimented by the various features included in the HTML5-based FAMIUM player, which enables a wide range of use cases. With DASH, clients can seamlessly adapt to media representations (e.g. in terms of resolution, codec or bitrate) that best fit the user's device and network connection.

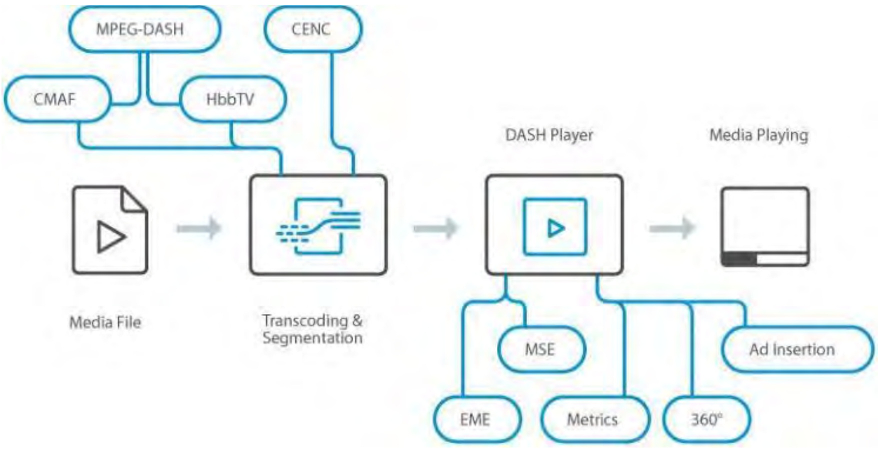


Figure 3-34 DASH Streaming Workflow

Hardware:

- *Compute and Storage*
    - For SAND and SRA Servers
- Mobile clients
    - Android/iOS devices with ARD Mediathek
    - Web Clients with ARD Mediathek in Browser
- Laptop
    - For SAND Monitoring via Dashboard
    - Logging & Monitoring

3.4.5.2 IHP's Hardware (platform & train)

Hardware: Two possible options are considered as mmWave units to be installed at both the platform and for onboard the train. These are MetroLinq™ 10G Tri-Band Omni and the MetroLinq™ 2.5Gb PTMP, shown in Figure 3-35. The nodes are available at IHP and are ready for (Remote) testing in a mobile environment in **IHP** by Fall 2021.

The former is able to provide up to 7.25 Gbps throughput if 3 nodes are used (e.g. 2 at the station, 1 inside the train). The latter can be interconnected with the former but it is limited to a data rate of 2.5 Gbps, although more units could be installed. The details are included in the Bill of Material (BoM) in Table 3-5.

Software: The SW includes the support of beam steering for connectivity to trains on the move, which is available and ready for testing (remote access also supported)

a) MetroLinq™ 10G Tri-Band Omni   b) MetroLinq™ 2.5Gb PTMP

Figure 3-35 mmWave units

3.4.5.3 PaxLife

Hardware (station): will involve COTS x86 Linux server with 10 Gbps network interface, sufficient storage (~5-10TB) and RAM disk for caching (64GB).

The station side server acts as intermediate cache. It will be connected to the public internet as well as to the high bandwidth mmWave setup. On the server the jointly developed platform will be running to download and process all selected media items from (public) CDN sources and provide the processed assets via mmWave to the server on the train. To facilitate maximal throughput the data will be served by a RAM disk which avoids I/O bottlenecks.

Hardware (train): The required HW in the train involves:

- **aROK 5510**, 19” EN-50155 compliant high-performance server with high-speed networking interfaces and easily accessible high-capacity storage.
- Fallback option (should installation of 19” be impossible):
    - **nROK 7251**
    - **aROK 8810**

The station side server has to confirm to the EN10155 requirements in order to be cleared for installation on a train. This limits the overall selection in particular as high speed (> 1 Gbps) network interfaces are required. It will be connected to the mmWave link to ingress data from the station side server as well as to the trains Wi-Fi network to provide the cached contents to the passengers. The software enabling data transfer from the train to the station, as well as serving content to the passengers is PXIs railSTACK (edge). Within railSTACK the jointly developed train cache will be hosted.

Hardware (portable):

Standard COTS notebooks are required to monitor and debug the train and station side servers (which will be running headless) and to run integration tests against the individual components as well as the whole software chain.

Software (train): The software running at the train comprises the following parts:

- PXI railSTACK (edge), remotely managed application hosting platform providing:
    - A consistent run time for applications on edge servers.
    - Automatic data synchronization between edge and cloud as well as arbitrary data sources/sinks.
    - Remote management using the railSTACK cloud platform.
    - Status: production.
- Train cache
    - Mirror of public broadcaster contents jointly developed by **IRT**, **FhG** and **PXI**
    - Status: PoC/work in progress

Software (station):

- 5gv platform
    - Software stack to pre-fetch media content jointly developed by **IRT**, **FhG** and **PXI**.
    - Responsible for data ingress and transformation to allow serving from on board.
    - Serves content to train caches (via 5G link).
- Status: PoC, work in progress

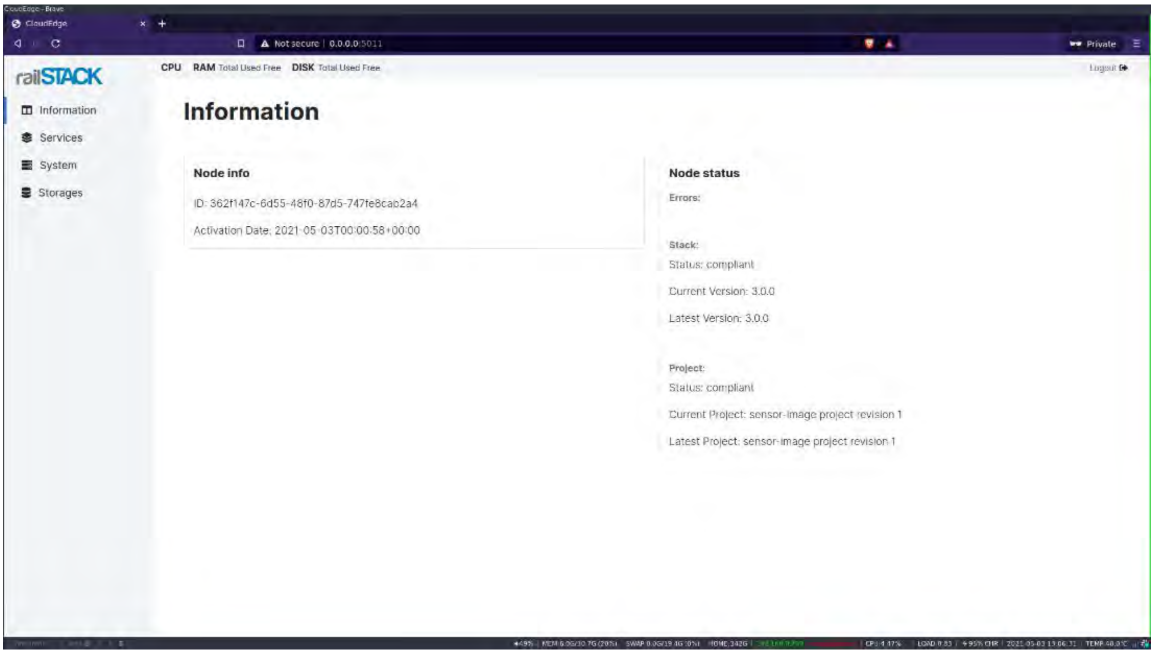


Figure 3-36 On-train management interface for monitoring onboard operations

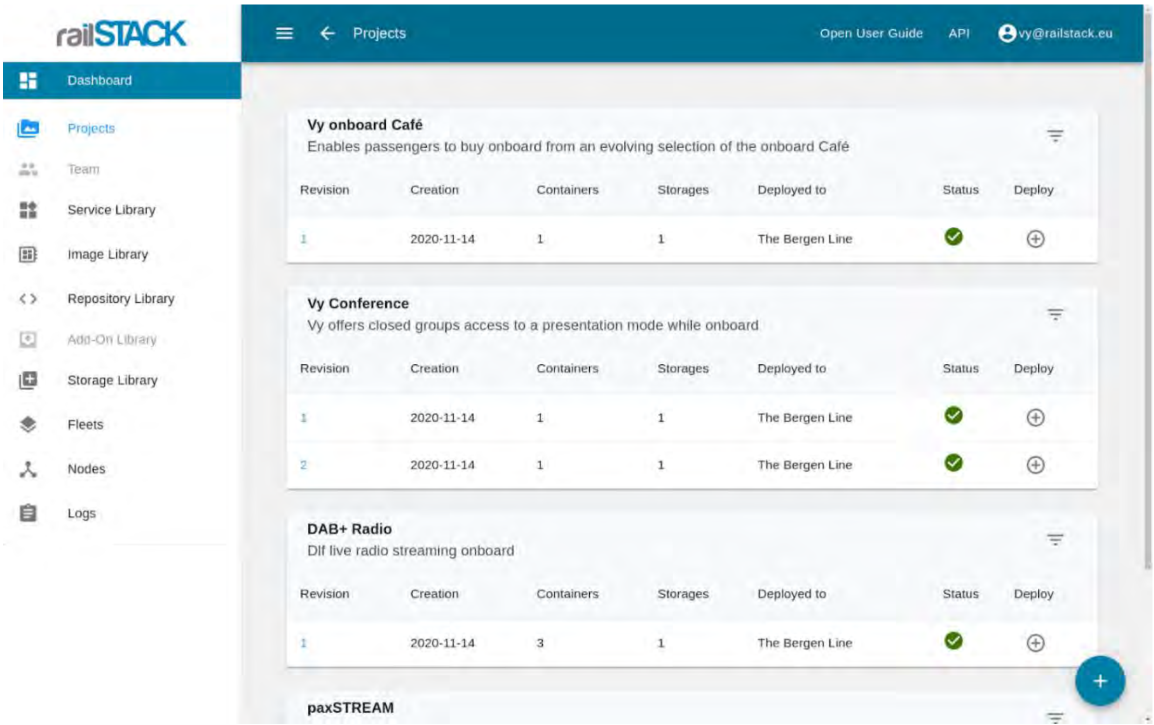


Figure 3-37 Cloud based interface to manage fleets, nodes and deployments

Software (cloud):

- PXI railSTACK (cloud), cloud-based remote management and deployment platform
  - for management and monitoring of fleets of edge servers
  - CI/CD capabilities to easily build and deploy software to edge servers
  - Automatic data synchronization between cloud and edge
- Status: production

3.4.5.4 Rundfunk Berlin Brandenburg (RBB)

Software:

- **RBB** Mediathek with ARD player for the platform Web, Android, iOS platforms: The RBB Mediathek is part of the ARD Mediathek which includes video catalogues for all ARD channels including RBB in a single App.
- Media Content: DASH and HLS media content of the RBB Mediathek available via public CDN Akamai.

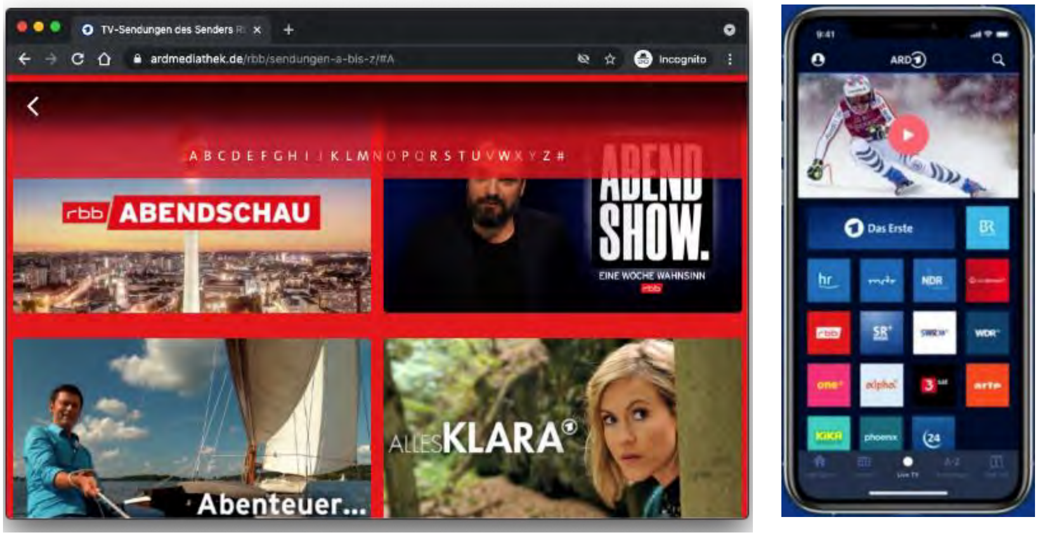


Figure 3-38 RBB Mediatheks for Web and mobile Platforms

3.4.6 Identifying Gaps with existing Test Network Capabilities

The network infrastructure in Berlin requires an upgrade of the mmWave capabilities allowing for beam steering for the connectivity from the trackside to the train on the move. This is supported by the installation a mmWave device onboard the train.

3.4.7 Planning of Lab testing and initial validation of services per use case

The testing and validation of this UC in the lab will be performed in two stages before going live to the Berlin Central Station. Two different facilities are involved in the testing and validation activities. Software and Hardware components required for these testing and validation activities will be made available in the labs of these two facilities:

- **Fraunhofer FOKUS Lab**: deployment of all software and hardware components for media caching (train and station) and media distribution in the train.
- **IHP Lab**: remote access to the mmWave equipment for testing static and mobile scenarios, which is supposed to be installed at the station and at the train.

The test and validation activities will be performed in 3 phases:

- **1st Phase – Static deployment**: In this phase, the station and train CDN caches will be deployed in Fraunhofer FOKUS Lab while the mmWave equipment is installed at IHP Lab. Both labs are connected via VPN using the existing connectivity between them that has been set up in the context of the 5GENESIS project. In this phase, the mmWave equipment nodes installed at fixed positions in the IHP facility are used to perform tests mimicking train stops.
- **2nd Phase – Dynamic deployment:** In this phase, the whole chain (all SW and HW components including the mmWave equipment provided by IHP) will be installed at the Fraunhofer FOKUS facility. In addition to the tests performed in the first phase, the focus in this phase will be on tests simulating train mobility entering and leaving the station. This will be achieved by installing the train equipment in a moving car at the parking deck.
- **3rd Phase – Test and validation at Berlin Central Station**:

Test and validation at Berlin Central Station: the local installation of the third phase at Fraunhofer is transferred to the main station, set up and tested. The entire End-to-End Data Shower workflow will be tested and validated under real conditions during a train stop or when train enters/leaves the station.

3.5 Final Facility assessment

3.5.1 Activities

Table 3-7 outlines the planned activities in the Berlin cluster starting from May 2021.

Table 3-7 Planning of activities in the Berlin cluster

Activity	Start / Finish[5]	Dependencies to other activities – Responsible Berlin partners
1. Procurement, Install and commission additional network entities	M24–M30	Activity 1 **FhG**, **Alstom**, **PXI**, **KCC**, **IHP**, **DB**
2. Final Site survey, cabling & equipment @ Berlin Central Station	M24–M30	Activity 2 **DB**
3. On-board network application a. 5G CN components b. MEC & analytics	M24–M30	Activity 3 **FhG**
4. Lab testing and initial validation of services per UC a. Component and functional tests b. Report on observed KPI	M24–M30	Activities 4, 5 **ALL**
5. Lab testing and initial validation of services per UC (incl. 5G) a. Component and functional tests b. **Report on observed KPI**	M30 – M36	**FhG**, **Alstom**, **KCC**, **PXI**, **UHA**
6. Configure and validate the network slices	M30 – M36	Activity 3, 4, 5 **FhG**, **Alstom**, **KCC**, **PXI**, **UHA**
7. Onboard each UC App to their appropriate network slices	M36 – M40	Activity 6 **FhG**, **KCC**, **Alstom**, **UHA**, **RBB**
8. Test and validation of the applications: a. Component and functional tests b. Report on observed KPIs	M24–M34	Activities 9, 10, 12 **FhG**, **Alstom**, **KCC**, **PXI**, **UHA**
9. **Testing in** the **operational environment** (Berlin Central Station)	M36 – M40	ALL
10. **Final trials**	M40 – M43	
11. Prepare for the experimentation for the Project Review and Official Deliveries	M44 – M45	Activities 10, 11, 12 **ALL**

3.5.2 Risks and Potential Delays

The risks related to Berlin Hbf are included in Table 3-8 and Table 3-9.

[5] Starting from May 2021, as it is the due date of the deliverable and M24.

Table 3-8 Risks that can stem from Berlin Central Station

Number	Description	WP No.	Chance (L/M/H)	Impact of the Risk (L/M/H)	Risk Mitigation Measures
1	Approval process by responsible stakeholders and authorities takes additional time	WP4	Low	High	Early engagement with the board of managers of DBH as well as with the responsible people managing Berlin Central Station Also a check with the authorities will be run in order to check if there are approvals required and schedule these.
2	Antenna position requires approval by authorities	WP4	Low	Low	The process is already started in Q2 2021 as the final position of the antennas need to be thoroughly evaluated by several departments within DB
3	Useable positions for antennas do not allow a good coverage	WP4	Low	Medium	Pre-assessment of the connectivity and network design via simulation prior to installation
4	Train gets reassigned to a new route	WP4	Low	Medium	Consideration of long term use of a train in a specific line OR use of a train not belonging to any line in particular

Table 3-9 Risks that can stem from the use of the technologies at the sites

Number	Description	WP No.	Chance (L/M/H)	Impact of the Risk (L/M/H)	Risk Mitigation Measures
1	Connectivity issues mmWave due to mobility	WP4	M	H	Provision of additional mmWave units at the train to connect to those installed at the platform.
2	No access to Berlin Central Station	WP2, WP3 D2.2, D2.3, D3.1, D3.2	M	L	As passengers we will be able to access the passenger dedicated areas of the station any time. Those are the interesting areas from the UC's point of view. No pre-organised access means we will have to map the station live. We will use Lidar equipped smartphones and transmit the live station scans to the Polaron engine running at the back-end at Fraunhofer. In a worst case scenario we will buy tickets and get our test passengers with the smartphones in hand into the station like that. In case UHA will have to purchase further equipment (ex. a fleet of Lidar equipped 5G smartphones for £2000 and above), additional budget will be assigned.

3	Our back-end technology is behind in progress	**WP3** D3.1, D3.2, D3.4	L	H	Unlikely as we are already working with pointclouds from live cameras (ex. https://youtu.be/d04YguqA_wk). Labelling features (exits, passenger areas, seats, toilets, escallators, platforms, etc.). And planning routes while considering multiple goals.
4	Our front-end technology is behind in progress	**WP3** D3.1, D3.2, D3.4	M	H	We accelerate development on the smartphone application. Remove video streaming in the lab tests and go with interpolated render snapshots between dense locations.
5	Liberal or Green activists surround Central Station on the day of the field trial	WP4	H	H	We do it another day when they are gone.
6	No access to relevant labs for collaboration	**WP3**, **WP4**	2021 (M) 2022 (L)	2021 (M) 2022 (H)	Relying on equipment receiving lab people and remote dealing
7	Travel restrictions that hinders lab collaboration	**WP3**, **WP4**	2021 (M) 2022 (L)	2021 (M) 2022 (H)	Relying on equipment receiving lab people and remote dealing
8	Equipment not working as intended	**WP3**, **WP4**	2021 (M) 2022 (L)	2021 (M) 2022 (H)	Relying on people with experience that can help solving the problem
9	5G modem and 5G network incompatibilities	**WP3**	M	H	Early tests and parameter exchange between 5G network and 5G modem responsible parties
10	Unforseen issues during installation of MCX Server components at the provided virtual infrastructure (network connectivity)	**WP3**	M	M	Installation as early as possible to test the setup
11	Remote connectivity issues for server components (for installation)	**WP3**	L	L	Local installation of server components
12	Chosen KPI measurement tool not fully suitable	**WP3**	L	M	Early tests of KPI measurement tool to check and to be able to find workarounds
13	Slicing and selection of slice	**WP3**	M	H	Early tests of slicing and slice selection

4 Bristol Cluster Facility Planning

The Bristol 5G-VICTORI facility will host the 5G-VICTORI Digital Mobility UC (**UC #1.2**), where a total of three applications will be showcased. These are referred to as **App 1**, **App 2** and **App 3**, and they are described in deliverable D2.1 [1], while the facility planning was preliminary described in deliverable D2.2 [2]. The target of the Bristol facility is to fulfil the requirements of these Apps, and to validate the vertical-related KPIs defined in D2.1 [1].

The Bristol cluster facility planning for these three Apps is detailed in this document in sections 4.2 to 4.4). Each App involves provisioning of a different service:

- Application 1 (**App 1**) will provide immersive media and AR/VR services to travelers.
- Application 2 (**App 2**) involves a 360° VR Multi-camera Live streaming and focuses mainly on large user connectivity and greater number of users
- Application 3 (**App 3**) involves an AR journey.

UC #1.2 has been tailored to the requirements set by the Bristol Cluster to implement the Digital Mobility UC, which challenges the capabilities of future 5G networks. For example, one of the most demanding UCs for future mobile networks is the emerge of AR/VR technologies, which do not only require high throughput but also very strict latency performance. It is essential for a network to stay within such strict performance requirements, even when a handover is taking place.

Prior to the extension of the infrastructure for hosting the Apps, and similarly to the role of ICT-17 platforms in the other clusters, the baseline functionality and available infrastructure is built as part of the 5GUK test network available through the Smart Internet Lab of the University of Bristol.

The network coverage is described in deliverable D2.2 [2], and the network entities are located at:

- Smart Internet Lab, used as the Cloud Core network,
- We The Curious (WTC), used as the primary edge node,
- MShed, used as the second edge node,
- Millennium Square (MSq) and Bristol Harbourside waterfront used for the Field trial,
- VIRTUS Data Centre in Slough is used as for inter-connectivity across a number of domains.

For the needs of 5G-VICTORI, the 5GUK Test Network coverage is extended towards the location of the SS Great Britain museum with an additional ‘Nomadic’ node that is deployed on a boat. Users follow a route that allows their devices to utilise various Radio Access Technologies (RATs) while moving around either on foot, or on a boat. The Bristol cluster partners’ solutions are integrated with the 5GUK Test Network.

The 5G Nomadic node will provide the required mobility services onboard the boat. It supports seamless service provisioning around SS Great Britain or at locations where the 5GUK Test Network’s coverage is not sufficient for the requirements of the UCs. MEC services will be provided through the compute resources available at the MSq, WTC and MShed network edges, as well as within the Nomadic Node.

4.1 Final Facility commitment

The 5G-VICTORI facility in Bristol extends the 5GUK Test Network, hosted/owned by the University of Bristol (UNIVBRIS), towards the implementation of the Digital Mobility related UCs. As described in D2.1 [1] and D2.2 [2], the 5GUK Test Network provides access to an urban dark fibre network, with configurable private cloud compute resources and wireless access, either at the edge or centralised in the Smart Internet Lab workspace. The Cloud Core Network is situated at the Smart Internet Lab supporting edge-computing, SDN switches, and access nodes deployed at selected locations like WTC, MSq, and MShed.

The UC demonstration (involving **App 1** and **App3**) initially assumed a tourist's journey starting outside of the Temple Meads Railway station towards the Bristol City Centre. The risks identified in D2.2 regarding the use of this station have materialized, hence the idea of including the Temple Meads Railway station as a potential site for the implementation of the UC has been finally discarded.

Instead, the UC demonstration for these apps (see section 4.2) takes place at various locations within Bristol city centre including the following key locations:

1. Outside the MShed Museum,
2. Boat trip at waterfront along the Bristol Harbourside; starting the boat trip at MShed towards and finishing at MSq, via SS G. Britain Steam Ship,
3. Millennium Square (MSq),
4. Smart Internet Lab, MVB.

To demonstrate the 5G-VICTORI **App 1**, various locations were selected in central Bristol (Spike Island and Harbourside area) and at the University of Bristol, HPN and Smart Internet Lab, MVB. Users will follow a route that will allow their devices to utilize various RATs while moving around either on foot, or on a boat. The planned route for the trial is marked in Figure 4-1, where four key locations are highlighted. These are the SS G. Britain Steam Ship Museum (outdoor area) at point ⑤, the MShed Museum (outdoor and indoor areas) at point ③, the MSq - MSq/WTC (outdoor area) at point ⑦, and the MVB (i.e., indoor area) at point ⑧. Most of the route includes open space walk paths with various obstacles along or on the sides of the route such as small buildings, trees, port cranes (in front of MShed), boats and boat masts (river), tourist information boards, etc. Generally speaking, the users' activity is summarized into a smart tourism activity scenario as below.

Delegates starting the journey from point ① to point ② through the Bristol Harbourside old train (in case of **App 3**), and follow a path (i.e., by walking) toward MShed at point ③. Then they board the boat at point ④ toward the Brunel's SS Great Britain at point ⑤, while they are still on boat, they follow the path towards point ⑥ (through a boat journey). Then, delegates get off the boat, and follow the path towards MSq at point ⑦ (i.e., by walking). Finally, they resume the journey through walking from point ⑦ towards point ⑧ at the University of Bristol, MVB.

4.1.1 Technical capabilities

The technical capabilities and geographical coverage of the 5GUK infrastructure that have been allocated for use in the 5G-VICTORI network are summarised below (Please refer to D2.2 [2] for more details.).

- 3GPP LTE-A cellular network (2.6 GHz licensed band B7).
- 3GPP 5GNR cellular network (3.7-3.8 GHz licensed band n78, and 3.8-3.9 GHz band n77).
- 802.11ac Wi-Fi (2.4 GHz / 5 GHz unlicensed band).
- Configurable backend data paths using routers & switches (i.e. IP networks & VLANs).
- Dark fibre mesh transport used as backhaul / midhaul / fronthaul networks.

In preparation of the UC demonstration, the 5GUK Test Network has adopted the following extensions to its network capabilities:

- Addition of an LTE macro cell at the MShed roof top, complementing an upgraded 5GNR M-MIMO radio operating in band n78.
- Addition of a 5GNR operation in Band n77 at WTC as well as equipping this location with an additional Massive MIMO 5GNR operating in n78 band.
- RAN optimisation & Site survey for mapping of the coverage area on the route of the journey for the UC.

- 5G Core SA and NSA deployment in the core network and further work still to be carried out to deploy UPF functions at the edge nodes.
- Addition of servers and upgrade of switching network within the WTC and MShed IT service racks.

Network slicing ensures that the different performance requirements for each application, i.e. **App 1 – App 3**, are met. Each network slice addresses the KPIs' requirements of each application, and includes multiple Radio Access Technologies (RATs). The details of each network slice are discussed in sections 4.2.3, 4.3.3, and 4.4.3, respectively.

More details are provided in the following subsection 4.1.

4.1.2 Network Design and Service Delivery

The high-level design of Bristol's 5GUK Test Network at the four key locations (outlined in the previous section) is shown in Figure 4-2. The 5GUK Test Network provides 5G, 4G LTE and Wi-Fi connectivity at three key locations: MShed, MSq and MVB.

For the needs of 5G-VICTORI, the 5GUK network coverage is extended towards the location of SS Great Britain museum with an additional, 'Nomadic' node that is deployed on a boat. To meet the requirements of all demonstration UCs, additional compute resources will be installed at all edges, including the Nomadic node. By doing so, the network can support seamless connectivity and mobility along the demonstration path for all users and for any UC, either on foot or inside the boat.

DCAT's 5GNR and **i2CAT**'s Wi-Fi solutions will be integrated with the 5GUK Test Network so that the 5G Nomadic node will provide the required mobility services onboard. It supports seamless 5G connectivity at the surrounding area of SS Great Britain, and at locations where the 5GUK Test Network's coverage is not sufficient for the requirements of the UCs. MEC services will be provided through the compute resources available at the MSq, WTC and MShed network edges.

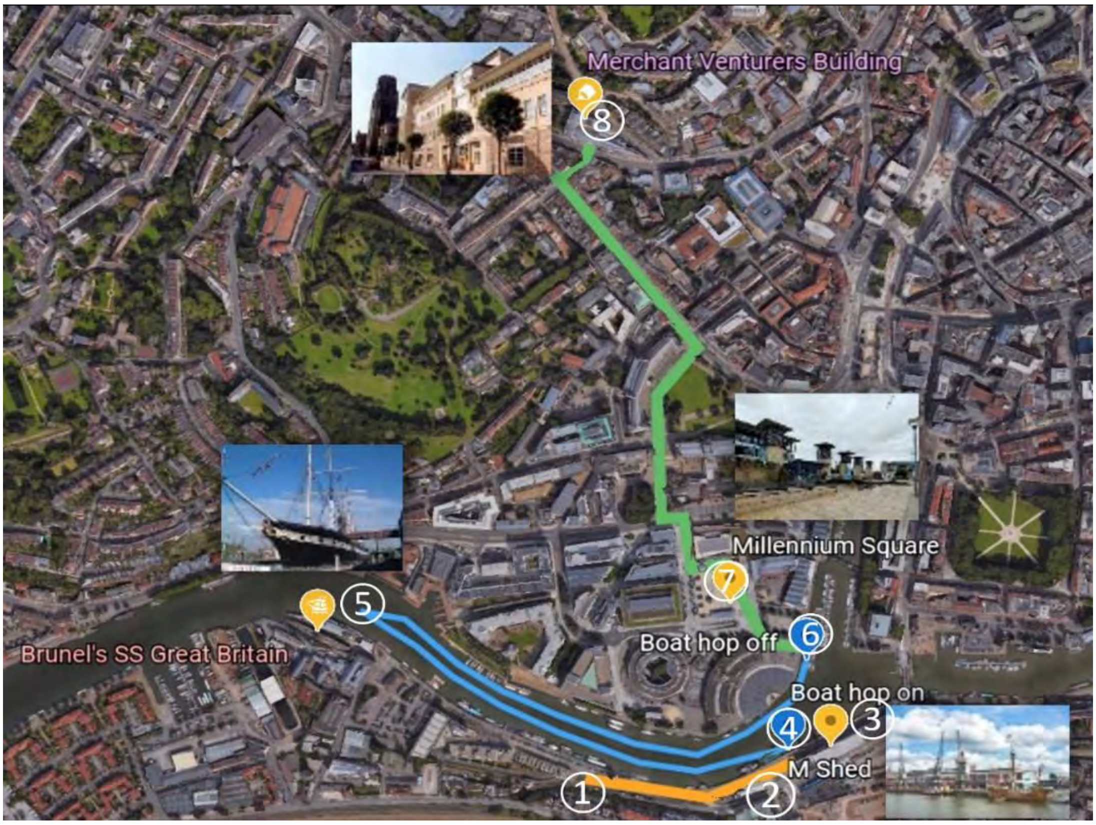


Figure 4-1 5G-VICTORI Bristol facility and sites involved in the trials. The orange and green paths denote the routes covered on foot while the blue path is covered by boat.

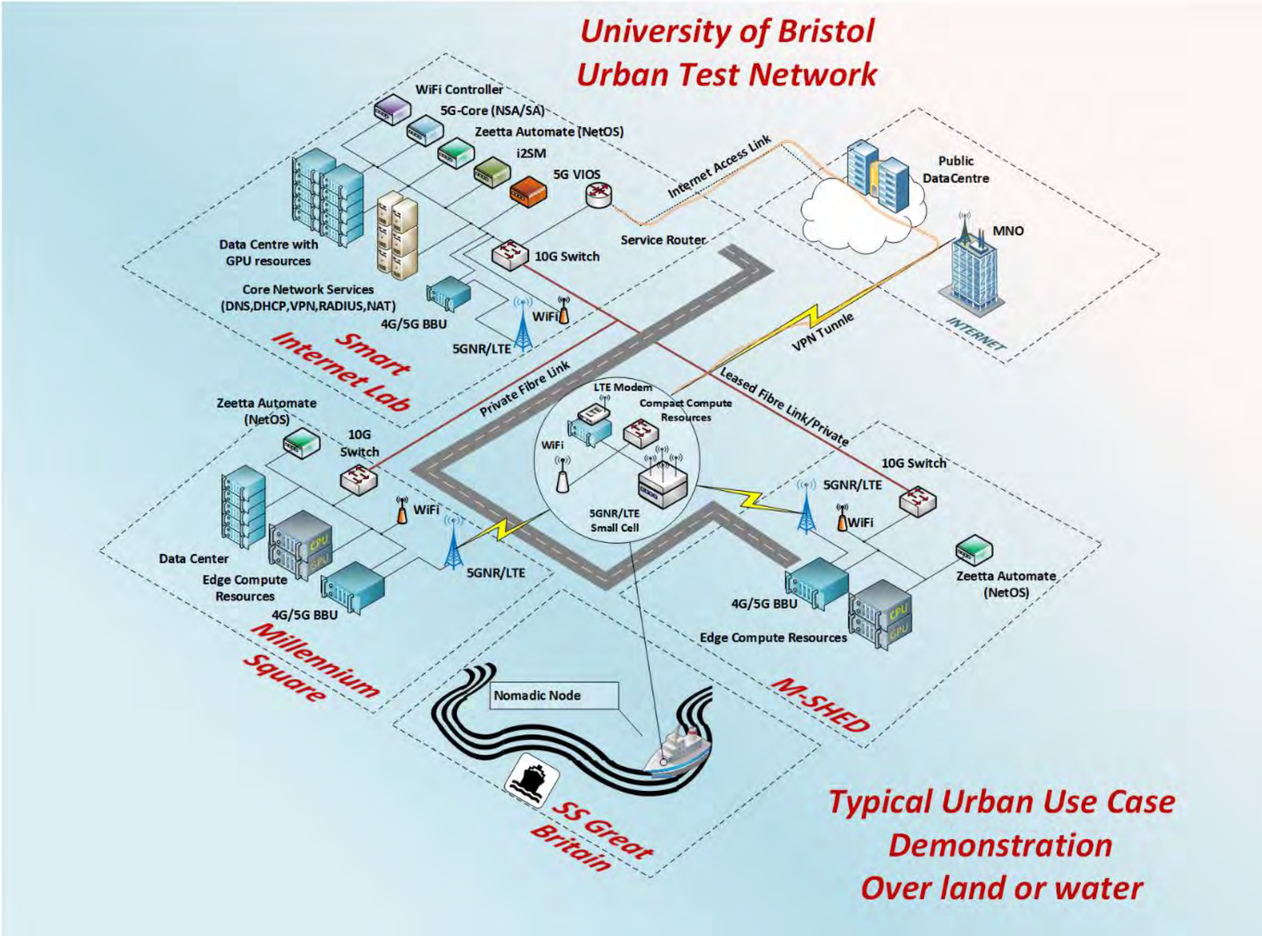


Figure 4-2 The high-level 5G-VICTORI Bristol facility network design – Physical and logical interconnections.

In addition, an instance of Zeetta Automate (Zeetta's slice management solution based on NetOS - 4.1.2.7) is instantiated at each network edge to configure the network slices on the 5GUK network Edgecore switches and manage local layer-2 traffic. A detailed description on the NetOS can be found in section 4.1.2.7. The 5G-VICTORI Operation System (5G-VIOS) Inter-Edge Connectivity Manager's SDN controller will call each instance of Zeetta Automate to create/modify/delete slices for each edge. Additional compute resources will be deployed within the Nomadic node on the boat. A detailed description of the current network setup and performance along the full route (foot path) can be found in the following sections.

4.1.2.1 MShed

The MShed building is one of the key locations within the Bristol city centre hosting some of the University of Bristol 5GUK Test Network infrastructure. A MEC facility, three 4G LTE pico-cells and Wi-Fi APs are located inside the building while more Wi-Fi APs and 5G RAT are installed on the building's rooftop.

4.1.2.1.1 Outdoor area

Connectivity to the outdoor area is provided by Rukus T710 Wi-Fi APs located at the East and West rooftops, and two Nokia RUs (4G LTE and 5G M-MIMO) located at the East rooftop (Figure 4-3). A fixed wireless (mmWave @26 GHz) mesh network is also installed on the East and West rooftops allowing gigabit connectivity between the MShed and MSq nodes. There is a good 4G LTE, 5G and Wi-Fi coverage outside the building.

4.1.2.1.1 *Indoor area*

Server Room

The MShed Server Room (Figure 4-4) is the location that hosts the Core of the network at this site. Fibre link is installed to connect the Server Room with other locations within the MShed where the equipment is deployed. There is plenty of space and power plugs to accommodate upgrades and new equipment. Recent network upgrades in this server room include the installation of a new 10G Edgecore switch and a 5G-ready Nokia AirScale, both providing the required throughput (backhaul and edge) and edge services.

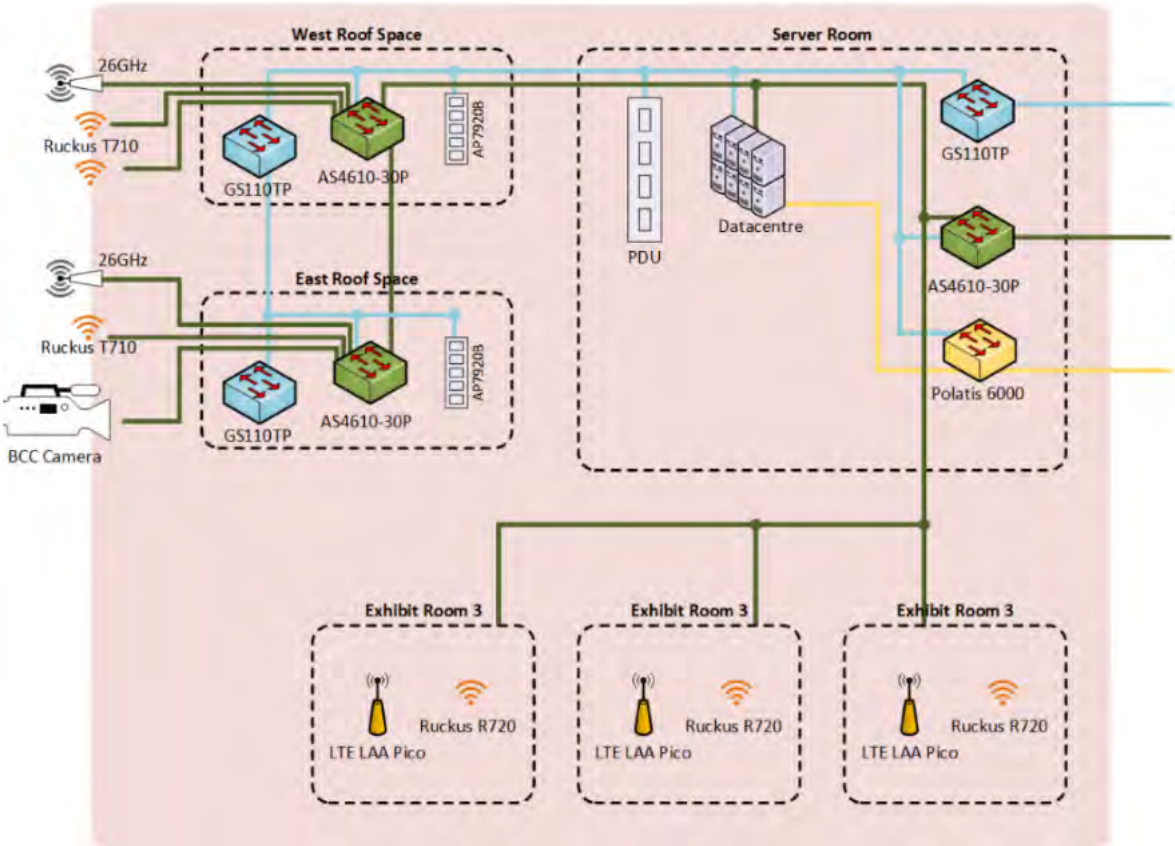


Figure 4-3 MShed network design

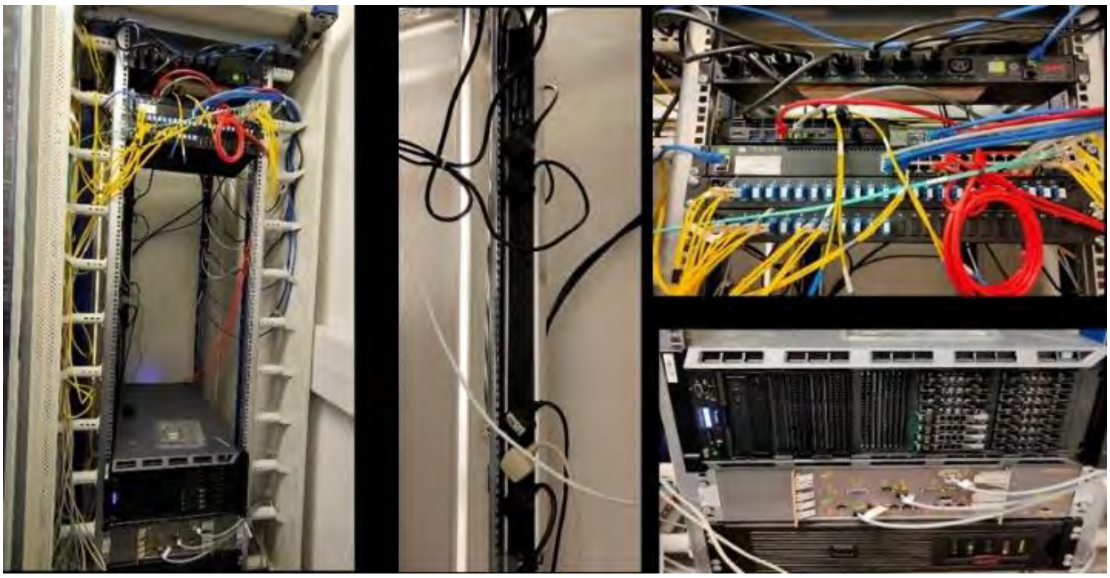


Figure 4-4 MShed Server room equipment

Exhibition Halls

There are three exhibition halls each covered by their own LTE Licensed-Assisted Access (LAA) pico and Ruckus R720 Wi-Fi AP:

- Bristol-People

  Located on the first floor of the MShed building (Figure 4-5), the Bristol People houses one Ruckus Wi-Fi access point and one Nokia Pico cell. The Wi-Fi AP links 2x UTP connections. The LTE Pico cell links 2x UTP connections and 1x single mode fibre connection LC-LC terminated. The Server Room provides power from switches to both devices through PoE.

Figure 4-5 Bristol People, 1st floor hall in MShed

- Bristol-Places

  Located on the ground floor of the Mshed building is the Bristol Life Exhibition Room. Linking the two APs (one Ruckus Wi-Fi and one Nokia Pico cell) at this location is 4x UTP connections and 1x single mode fibre connection.

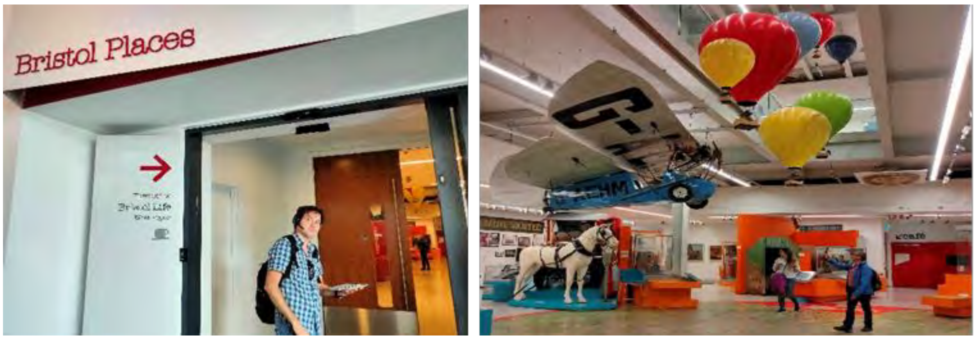


Figure 4-6 Measurements taken at Bristol Places, ground floor hall in MShed

- Bristol-Life

  Located on the first floor inside the Mshed building. The same access points (one Ruckus Wi-Fi and one Nokia Pico cell) in the two other Exhibition Rooms are also installed here, which requires the same connectivity (4x UTP connections and 1x single mode fibre connection).

Figure 4-7 Bristol Places, 1st floor hall in MShed

4.1.2.2 Bristol Harbour Railway

As illustrated in Figure 4-8 and Figure 4-9, the Bristol Harbour Railway is located across the river, from MShed to SS G. Britain. Along the Harbour Railway, network measurements showed an average 5G coverage. An additional 5G cell needs to be deployed across this path to ensure good 5G coverage and seamless connectivity. The high throughput and low latency requirements of future mobility services are incapable of providing seamless connectivity and service continuity through unstable links.

Figure 4-8 Bristol Harbour Railway (facing towards SS G. Britain)

Figure 4-9 Bristol Harbour Railway (facing towards MShed)

4.1.2.3 SS Great Britain

SS Great Britain (Figure 4-10) is a museum steamship known as the longest passenger ship in the world from 1845 to 1854. Being the furthest away from any of the 5GUK Test Network's RRUs, the signal reception at this location during our early testing was very poor – Received Strength Reference Power (RSRP) < -115 dBm. The Nokia 5G RRH located at the East rooftop of MShed was physically rotated towards the ship for better coverage. The outdoor area (Figure 4-10) is included in the boat demonstration. It is noted that currently, we have no hosting agreement with SS Great Britain.

4.1.2.4 Millennium square and WTC

The area outside WTC, i.e., MSq is also included in the demonstration. On the balcony area of WTC (Figure 4-11) multiple poles house three Nokia RRHs (4G LTE, 5G NR, M-MIMO 5G NR) and a Cambridge Communications Systems (CCS) Metnet node. This position allows LTE and 5G coverage in MSq (Figure 4-12) as well as the surrounding area. The CCS Metnet can form Line-of-Sight (LoS) links to other nodes in the mesh but not all of them.

Figure 4-10 SS G. Britain outside area

Figure 4-11 WTC balcony area

Figure 4-12 MSq Towers 4, 5 and 6

At MSq (Figure 4-13), six cooling Towers have been provided with connectivity (Figure 4-13). Each Tower is connected to the WTC Server Room via fibre. There is therefore a direct link from the top of each Tower to the WTC Server Room for MEC applications. The configuration for each tower is:

- 1 x Ruckus T710 outdoor Wi-Fi AP.
- 1 x Nokia AC400 outdoor Wi-Fi AP.
- 1 x CCS Metnet 26 GHz mmWave mesh node.
- 4 x fibre connection to WTC Server Room.
- 1 x two-way 230V AC switched mains outlet.

There is strong signal reception and a wide range of AP technologies in MSq and the surrounding areas (WTC). Along with the available MEC servers and facilities, all network services required by App1-3 can be provided.

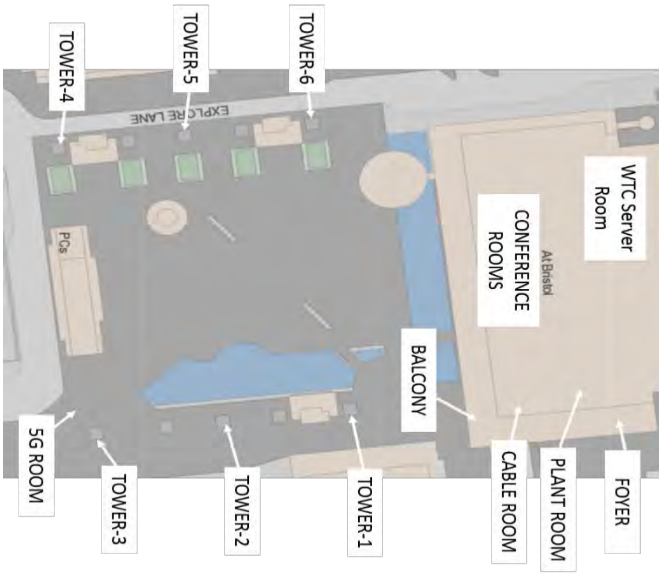


Figure 4-13 MSq network locations and tower naming

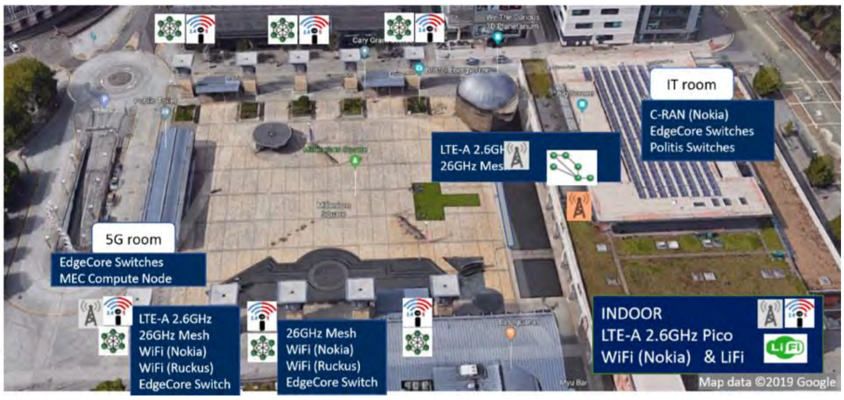


Figure 4-14 Available RATs at MSq

4.1.2.5 Smart Internet Lab

4.1.2.5.1 Office area and Meeting rooms

To set-up the online lecture for **App 2**, three cameras and an interactive whiteboard (Figure 4-15) shall be utilised. A Pico-cell shall also be deployed in the Smart Internet Lab office area (Figure 4-16) to enable video streaming by providing LTE connectivity to the devices.

4.1.2.5.1 Lab area

The cloud network at the Smart Internet Lab (Figure 4-17) hosts the central compute resource for control and operation of the test network nodes. High-capacity Dell servers have been deployed at datacentre providing virtualisation, management, and orchestration services. The naming convention of these nodes follow the popular TV show, The Simpsons: Homer (T630), Marge (T630), Lisa (T630), and Bart (T720).

4.1.2.5.2 Other Equipment

Several NUC (Next Unit of Computing) devices are currently available or being used as further compute resource at MEC nodes at the edge of the network (Figure 4-18). NUC devices can be connected to the Edgecore switches and therefore have direct access to the radio resources such as Wi-Fi APs. System specifications include an Intel i7 8th Gen. (4C/8T) CPU, 32 GB RAM and 2x Gigabit LAN. The high computation performance of NUCs make them ideal devices for MEC at the edges of network such as the remote satellite 5G node and MShed. Portable heavy-duty poles are also available for deployment anywhere along the demonstration route (Figure 4-19).

Figure 4-15 A Microsoft Surface Hub will be used as part of the online lecture for App2

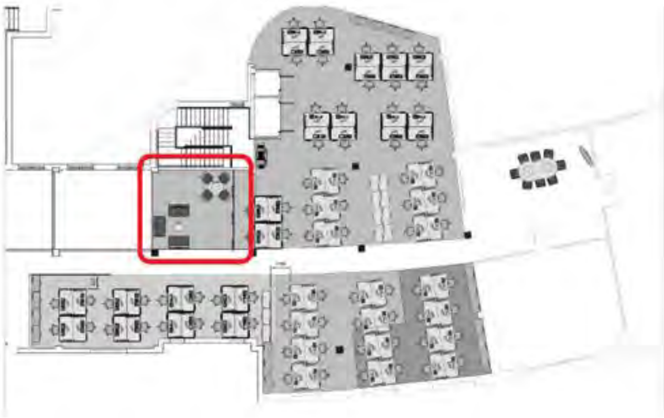


Figure 4-16 MVB Smart Internet Lab office area. The pico-cell along with the online lecture will be set-up at the marked location

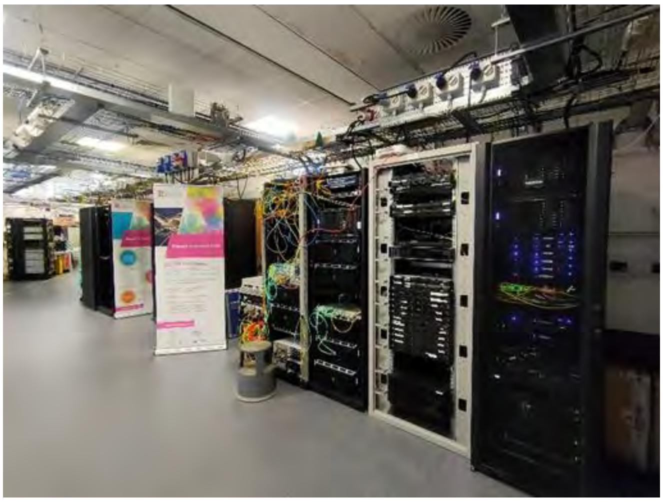


Figure 4-17 Smart Internet Lab, Cloud network

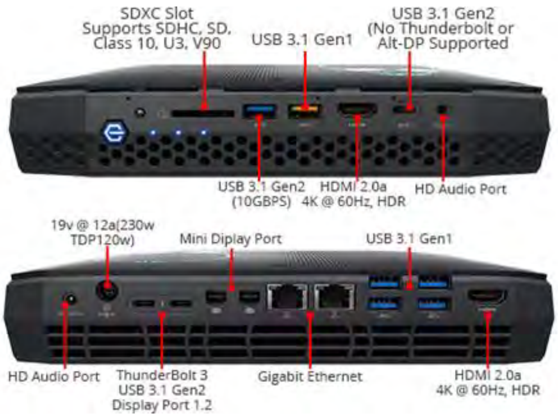


Figure 4-18 Intel NUC ports/connectivity

Figure 4-19 Portable heavy-duty posts available in the lab area

4.1.2.6 Nomadic Node

The Nomadic Node edge (Figure 4-20) will be installed on the boat to provide the required edge services during the boat trip. It comprises of an Amari Callbox Pro system with Software Defined Radios (SDRs) for Sub-6 GHz, designed to support high end LTE Categories providing up to 5 CC 4x4 MIMO with a total downlink throughput of 2 Gbps. It also comes with 5G NR SA capability, allowing early adopters to test their 5G NR user equipment. Wi-Fi access will be provided by Single Board Computers and their SDN Wi-Fi AP (based on Gateworks Ventana GW5410 or PC Engines APU2/APU4) with at least one ath10k Wi-Fi interface (802.11ac, Wave-2) and (2x) Gbps Ethernet ports. Each Wi-Fi interface can achieve DL throughput up to 400/500 Mbps. At the time of writing this document, the integration of Wi-Fi 6 technology is not envisioned, although it may happen during the realization of the project. Edge compute units (CPUs, GPUs) will provide the required resources at the Nomadic Node to support all VMs and services for Apps1-3. Specifically, for App3, the compute units (CPU and GPU) shall be provided by **UHA** and will be integrated to the 5G-UK test network for the demonstration purpose. Backhaul connectivity will be realized either using the University of Bristol 5GUK Test Network or via a VPN tunnel using a public network with good 5G coverage along the demonstration route.

The **i2CAT**'s Slicing Management (i2SM) solution will manage the available compute and radio resources of the nomadic node infrastructure, creating and grouping resource partitions or chunks to form E2E slices. In essence, this solution is composed of two main functional entities, namely the Slice Manager, which is responsible for breaking down the slice creation requests and delegating it to corresponding management modules; and the RAN Controller, which is responsible for managing and configuring the radio resources.

More in details, the RAN resources are managed by means of a NETCONF manager. It interacts with the different RAN elements (i.e., Wi-Fi APs and Amarisoft Callbox), being able to remotely configure them and to deploy RAN slices. In the case of the Wi-Fi RAN, the slices will be based on the deployment of virtual Access Points with different SSIDs; while in the case of the cellular RAN, slices will make use of different APNs (4GN Core) and S-NSSAI (5G core), being connected to a common Control Plane but an independent User Plane. Traffic forwarding between the wireless nodes and the vertical applications on the Nomadic node will be performed at layer 2, using VLAN tags to differentiate the data traffic from/to different slices. Figure 4-21 shows an example of the slicing architecture that will be applied in the Nomadic Node.

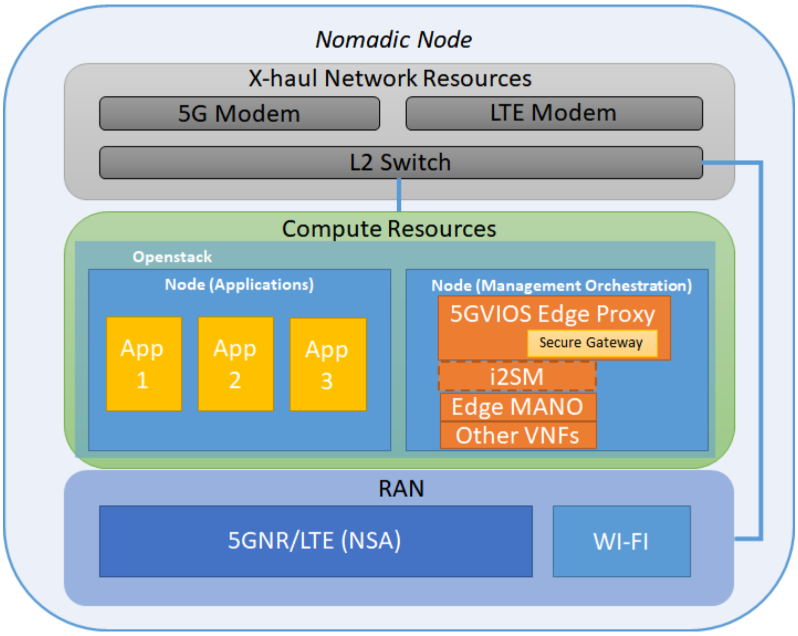


Figure 4-20 Nomadic node high-level architecture

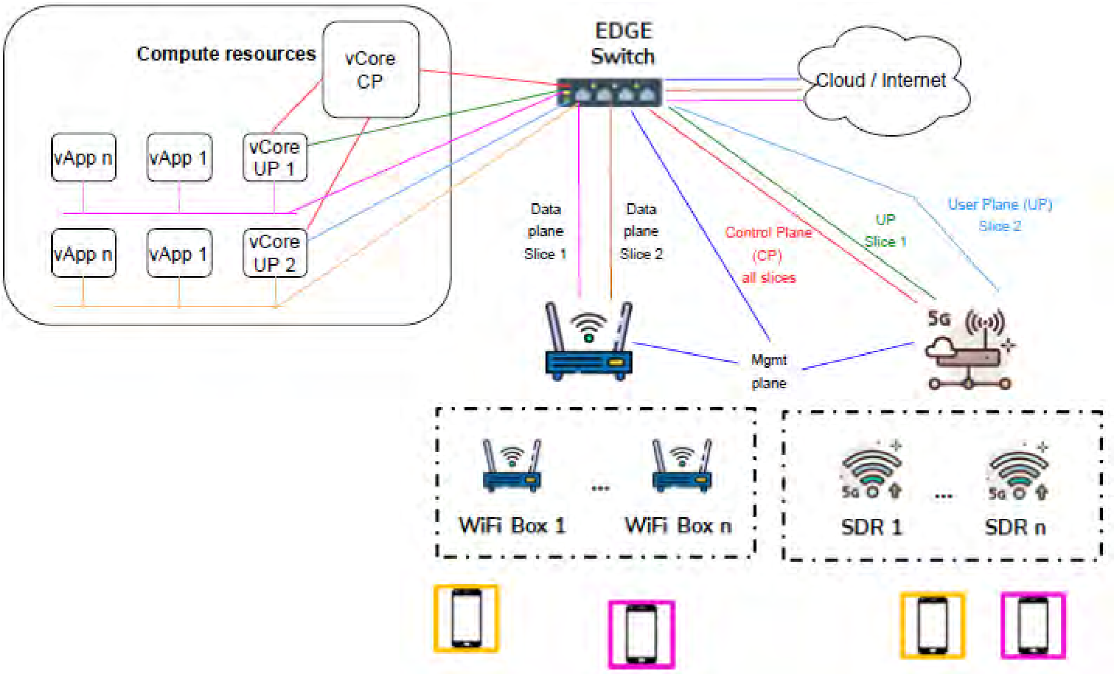


Figure 4-21 An example of the slicing architecture that will be applied in the Nomadic Node

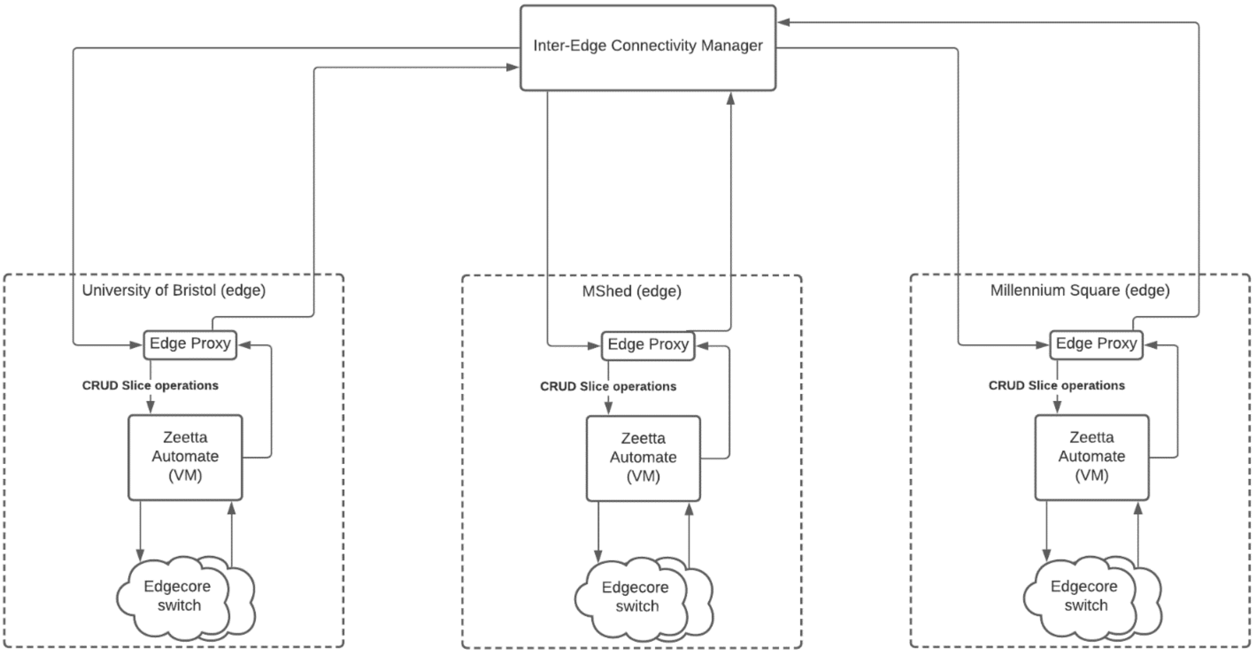


Figure 4-22 The slicing architecture with Zeetta Automate that will be applied to the edges (apart from Nomadic node)

4.1.2.7 Zeetta Automate (NetOS)

Zeetta Automate is responsible for managing the layer 2 slices at the edges by configuring network slices, it will allocate devices and a VLAN for each slice. Zeetta Automate will expose its APIs to create, modify and delete slices. This will allow the Edgecore switches per edge to be added to a slice for a given VLAN. There will be only one instance of Zeetta Automate per edge.

The workflow for using Zeetta Automate would be orchestrated by the 5G-VIOS Inter-Edge Connectivity Manager (Figure 4-22). This manager oversees delegating the provisioning of the network to the different edges in the Bristol cluster (apart from the nomadic edge) and at the same time takes care of the inter-connectivity between edges by configuring the Edgecore switch ports on the edges. Each edge has its own proxy to communicate directly with Zeetta Automate. The proxy will call through to the Zeetta Automate APIs to create, modify and delete the slices.

4.2 UC #1.2 Application 1

Application 1 (**App 1**) will provide immersive media and AR/VR services to travellers starting from MShed. A synchronous 360° tour guide at specific geolocations will be given to a group of users with 5G connectivity. One of the main focuses of **App 1** is user mobility. To support this capability, the Bristol facility will provide seamless connectivity to users when they are moving (even on the boat) from one location such as MShed to the other location such as MSq. In **App 1**, when moving from one location to another, the synchronization edge and streaming server services will need to move as well, staying as close to the users as possible. The services will notify the backhaul operating system to move the services to the new locations using geofences. This will provide users with a seamless service virtual tour guide throughout the route planned through the city of Bristol.

4.2.1 Network Requirement capture/ Processing Requirement capture

The requirements of **App 1** are classified into the following groups:

A. Hosting Requirements:
- Video Storage VM: 4 CPU cores, 8 GB RAM, 50 GB storage space.
- Video Caching VM: 2 CPU cores, 4 GB RAM, 10 GB storage space.
- Synchronization State Manager VM: 2 CPU cores, 4 GB RAM, 10 GB storage space.
- Synchronization Service VM: 2 CPU cores, 4 GB RAM, 10 GB storage space.

B. Network Requirements: (lab & field)
- Low latency for real-time message communication between devices.
- 10 Mbps or more per device for 360 video streaming.

C. 5G-VIOS API requirements:
- Instantiate edge services (lab & field).
- Initiate mobility events with new location (field).

D. Equipment Requirements: (lab & field)
- Multiple 5G-enabled android devices.
- Backhaul VM hosting server.
- Edge VM hosting server.

The following required equipment is provided by Mativision (**MATI**):
- 360 Video camera used to film the “360 video hotspots”.
- Non-360 video camera used to film.
- Video storage VM containing videos and application logic.
- Caching service VM containing application logic.
- Synchronization VM containing application logic.
- State Manager VM containing application logic.

The following items are required to be provided for the **nomadic node**:
- X-Haul Network Resources
  - 5G modem (**UNIVBRIS**).
  - L2 Switche(s) (**UNIVBRIS**).
- Compute resources
  - 2 x NUC high performance compute node (**UNIVBRIS**).
  - 1 x Virtual Server hosting the Application Videos.
  - 1 x Virtual Server hosting the Synchronization service state manager and 5G-VIOS communication.
  - 1 x Video caching service residing on MEC.

   - 1 x Synchronization service residing on MEC.
- Radio Access Technologies (RATs)
   - **DCAT's** 5GNR solution provides 5G cell coverage within the boat during the trip ensuring 5G connectivity from the Nomadic node at locations where there is a weak 5GUK Test Network coverage.
   - **I2CAT**'s Wi-Fi boxes comprise SDN Wi-Fi Single Board Computers based on Gateworks Ventana GW5410 or PC Engines APU2/APU4, with, at least, one ath10k Wi-Fi interface (802.11ac, Wave-2) and (2x) Gbps Ethernet ports. Each Wi-Fi interface can provide up to 400/500 Mbps (depending on UEs location and channel status). Each SBC will be packaged in an outdoor enclosure with external omnidirectional antennas.
- Network Functions
   - Secure gateway.
   - Island Proxy.
   - i2SM: **i2CAT**'s Slicing Management solution will configure and manage the radio (5G NR and Wi-Fi) and the compute resources (MEC) of the boat, integrating them in common slices serving the different applications. This solution will be deployed at the Smart Internet Lab Cloud and shall be connected to the boat infrastructure through a VPN (Slice Manager VM: 4 vCPU, 8 GB RAM, and 60 GB Storage; RAN Controller VM: 8 vCPU, 16 GB RAM and 80 GB Storage).

4.2.2 Site Survey and report /Final planning

4.2.2.1 Boat Path from MShed to surrounding area of SS Great Britain and from SS Great Britain to MSq

A boat will be hired for the purposes of **App 1** and **App 3**. Health and safety considerations will decide the boarding and disembarking locations of the boat. The most probable boarding and disembarking locations are in front of MShed (Spike Island) at point ③ in Figure 4-23, and the MSq waterfront).

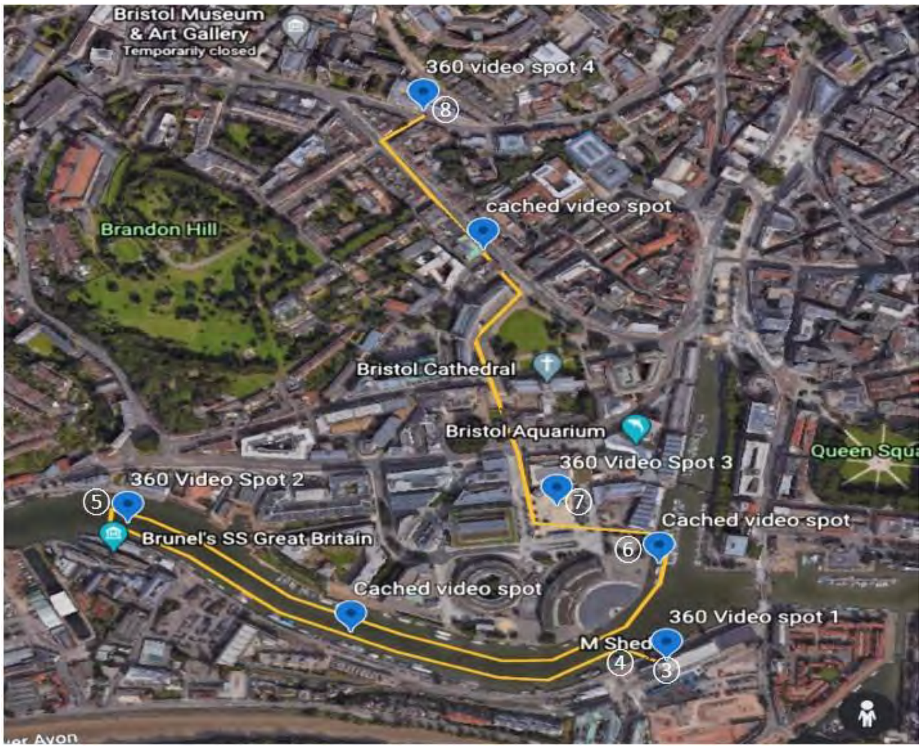


Figure 4-23 The journey related to App 1

Figure 4-24 Panoramic photo of the demonstration route from SS G. Britain (far left) to MShed (far right).

The boat follows a similar route as the one described in section 4.1.2.3, before reaching the SS G. Britain steamship at point ⑤, and heads back to MSq waterfront for disembarking. The signal coverage is very good and the Reference Signal Received Power (RSRP) is around -80 dBm around the MShed building, but it gets weaker as the boat moves towards SS G. Britain. To address this gap, as previously mentioned, a nomadic node with edge processing capabilities will be deployed on the boat providing 5G, LTE and Wi-Fi connectivity to the users on-board. Each Wi-Fi interface can provide up to 400/500 Mbps (depending on UEs location and channel status); the final number of Wi-Fi boxes and Wi-Fi interfaces per box will depend on the dimension of the boat and the channel availability (i.e. number of channels and bandwidth).

4.2.2.2 Path from Millennium square to Smart Internet Lab

Due to the lack of good LTE and 5G coverage between the MSq,(i.e., point ⑦ in Figure 4-23) and the Smart Internet Lab (at MVB) (i.e, point ⑧ in Figure 4-23), a simple offline video cached beforehand can be shown to the devices on the path from MSq to MVB. This video will be tied to the location through which the group will pass and will be tied to GPS location for accuracy.

4.2.3 Network Slice Co-Design

Figure 4-25 presents the video storage and state synchronization servers running on the backend. As depicted in the diagram, the synchronization server notifies the 5G-VIOS API of instantiation events to create the services on the edge and mobility events when users move between edge locations. The edge services cache the video content close to the user and provide synchronization services close to the users to reduce latency. **App 1** runs on a separate network slice to ensure the performance of video segments.

The flowchart in Figure 4-26 depicts the sequence of processes for **App1**. Specifically, Figure 4-26 shows the process of users requesting to connect to the edge service, the edge service being instantiated and users connecting to the synchronization service by using tokens. The chart presents how messages are transferred between devices and the edge service, and how videos are cached on the edge. The loop point signifies a mobility event. Once a mobility event is triggered, the edge service is moved to the new location and the application runs the logic for the beginning.

4.2.4 Design Review and Bill of Materials

The following items should be considered to build the demonstration infrastructure to support **App 1**, **App 2**, and **App 3** along the demonstration route and boat trip:

- Total Dimensions of nomadic node.
- Net weight of nomadic node.
- Power consumption consideration.
- Boat trip risk assessment.
- An Event manager seems to be required to manage the review the risks and manage the event.

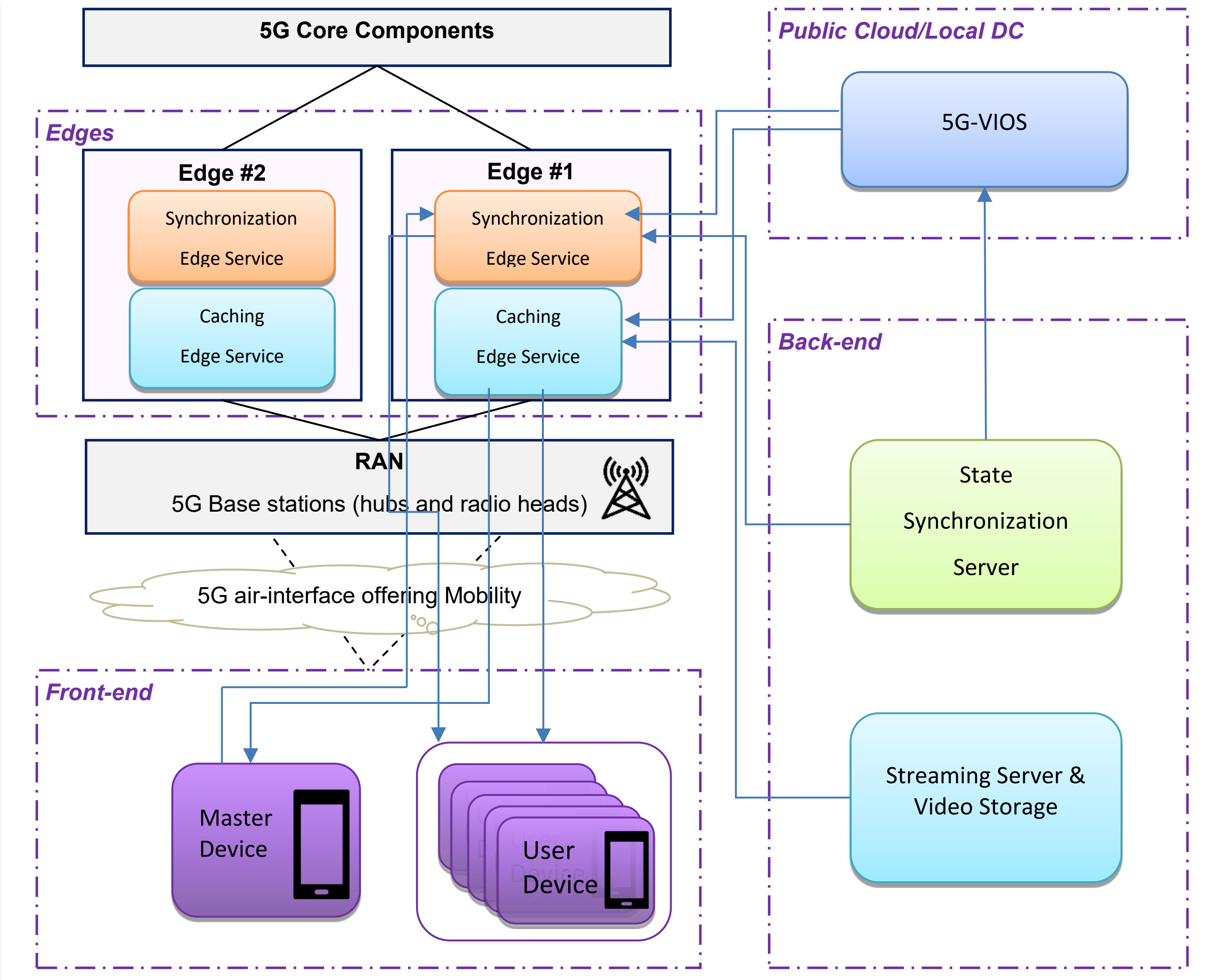


Figure 4-25 Digital Mobility in Bristol – App1: Mativision immersive media and AR/VR services to travellers –high-level block diagram

Table 4-1 details the BoM of all elements required to provide service for **App 1**:

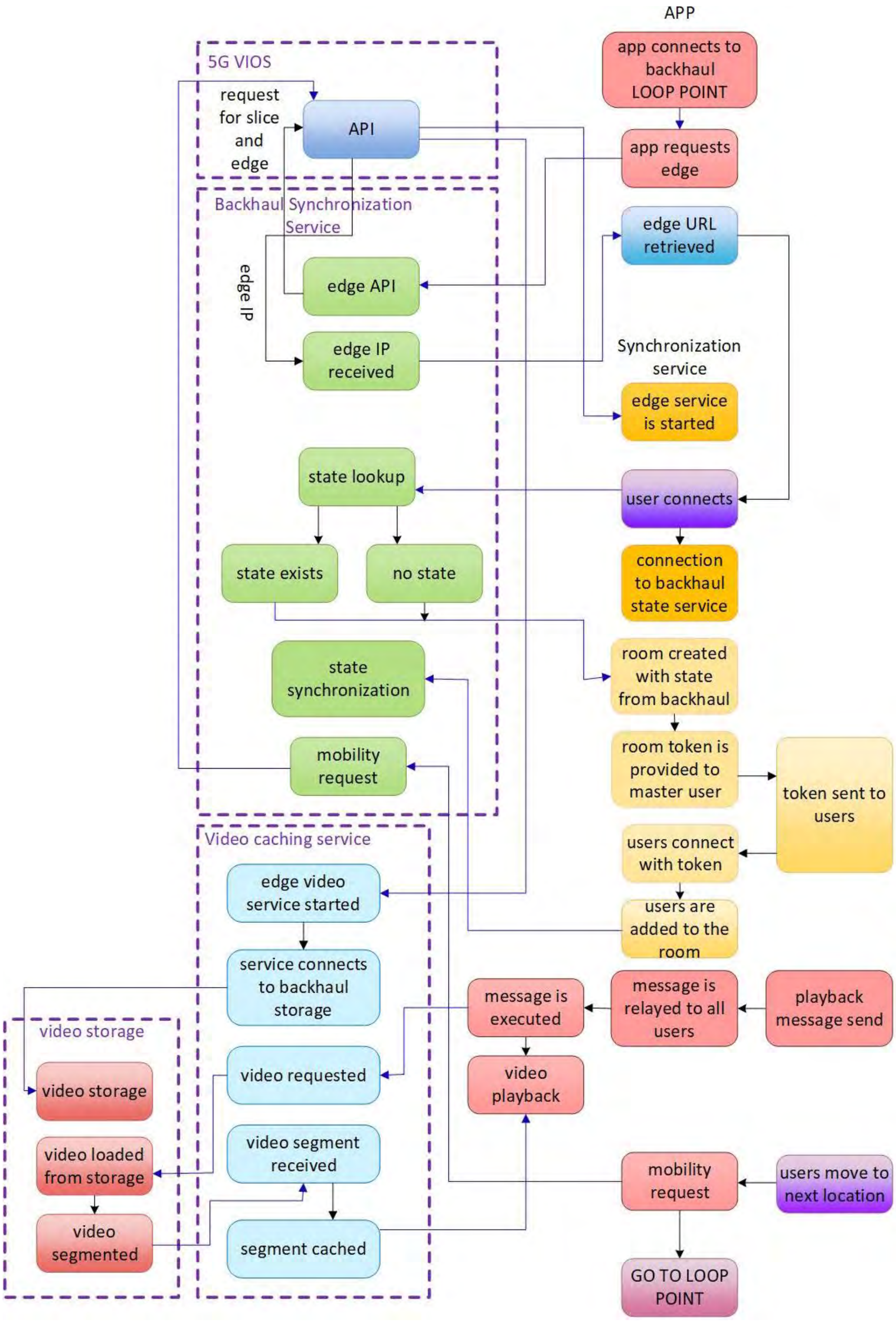


Figure 4-26 Digital Mobility Bristol – App 1 sequence diagram

Table 4-1 Bill of Material - Bristol cluster

Equipment	Item	Components	Quantity	Dimensions	Power supply
SDN Wi-Fi Single Board Computers 	Gateworks Ventana GW5410 or PC Engines APU2/APU4	- (1x/2x) ath10k Wi-Fi interface (802.11ac, Wave-2) - (2x) Gbps Ethernet ports. - Outdoor enclosure - External omnidirectional antennas	1x/2x (TBC according to the dimensions of the boat)	- (23 cm W, 18 cm H, 23 cm D) + antennas - 4-6 kg.	approx. 20-30W (peak), but can work with PoE (ideally).
5GNR Box 	Amarisoft Callbox Pro	PC unit - 6x PCIe SDR Cards with omni antennas - Optional Radio Frontend with up to 2 Watt output (tbc)	1x	- H × W × D 45,5 cm × 40 cm × 20,5 cm Power supply voltage 230 V AC input - 12 kg	- 230 V AC input
4G/5G CPE (Nomadic Node Backhaul)	Quectel RM500-QGL	- 3GPP Rel-15 - 5G SA/NSA (DL max. 2.5 Gbps, UL max. 650 Mbps) - 4G LTE (TDD/FDD) - Evaluation Board (M.2 interface)	1x/2x	- 5.2 x 3.0 x 0.2 cm (w/o evaluation board) - extra space for evaluation board and external antennas.	- USB 3.1 port
Nomadic Node Container	Container	Container to host Nomadic Node.	1x	t.b.d. when all equipment and corresponding hardware specifications have been finalized.	High power source required (Nomadic Node will host high-end compute units to support Apps1-3).
Nomadic Node Power Provider	Power Generator	Power Generator to fit the specifications of the Nomadic Node.	1x	-	t.b.d.
Compute Units (to host all required VMs at the edges)	Intel NUC	Intel core i7 CPU 32 GB RAM 2 TB Storage 2x 1GbE	6x	216 x 116 x 23mm	230 W

Compute Units (to host all required VMs in the core)	Dell Server	-	1x	-	-
L2 Switches	10G Edgecore switches	48x 10G Ports (optical)	3x	438.4 x 473 x 43.4 mm	400 W
UE 5G Android Devices	(At least) Samsung Galaxy S20/Note20	5G SA/NSA: n77, n78	10x	-	-
WiFi 6 APs	Ruckus T750	5 Gbps PoE Dual-band Wi-Fi (2.4/5 GHz) Supports up to IEEE 802.11ax	2x	-	PoE
4G LTE Radio + eNB	Nokia Airscale + FRHG	4G LTE: b7	2x	-	-
5G NR + gNB (WTC)	Nokia Airscale + AWHQM/AEQD	5G SA/NSA; n77, n78	1x	-	-
5G NR + gNB (MShed)	Nokia Airscale + AEQE	5G SA/NSA; n78	1x	-	-

During 2020, Mativision has proceeded in the procurement of some additional items which are being used for the purposes of **App 1** (& **App2**) of the 5G-VICTORI Project. The BoM in Table 4-2 shows the updated status.

Table 4-2 The BoMs related to MATI - App 1 (and App 2)

Equipment	Item	Components	Quantity	Interface	Dimensions	Power supply
360º Camera System (plus all peripherals)	Insta 360 Pro II	- Insta 360 PRO II camera heads. - 12V 5A adapter. - Farsight Wireless Remote control - 24 x MicroSD cards + 14 x Full SD cards	3 complete systems	Ethernet Port. WiFi specifications 802.11 b/g/n, 2.4GHz. Signal range is about 20 meters in open space. Max preview framerate of 30 FPS, supported in roughly 5-meter range	(each unit:) Diameter φ143mm, Weight ~1550 g	220/240V – 50HZ Standard Wall Domestic Power. Cameras & peripherals powered by own PSU or Batteries. 12V 5A adapter.
Digital Audio Field Recorder	Zoom H4nPro Digital Audio Field Recorder	Recorder Unit	3 units	Connects to host computer via audio cables. USB port for file transfer to and from computer. 2-in/2-out USB audio interface for Mac/PC	73X157X 37, 295g	Battery powered. Runs on 2 standard AA alkaline or NiMH rechargeable batteries
PC Accessory (system Upgrade)- Motherboard	ASUS Sabertooth X99 Motherboard	Single motherboard card	1	Internal connections to a host PC enclosure and other components. No external connections	Not relevant	Powered by the host PC which is connected to a standard wall power socket. 220/240V – 50HZ
Laptop Computers	Apple MacBookAir	Laptop computers and their power supplies	3	Two Thunderbolt / USB 4 ports	0.41X30 X21, 1.29kg	Internal battery powered as well as own charger/ power supply connected to a standard wall power socket. 220/240V – 50HZ
Laptop Computers	Razer Blade 15 Base Model (2020)	Laptop computers and their power supplies	2	USB 3.1 Gen 1 (USB-A) x 2, USB-C 3.2 Gen 2, Thunderbolt™ 3 (USB-C)	19.9 mm x 235 mm x 355 mm, 2kg	220/240V – 50Hz, standard wall power socket.
VR Headset	Pico G2 4K	VR Headset unit plus USB charger unit	1	Wireless, Wi-Fi	278g(w/o Band), 470g(total)	Battery powered. USB charger unit

4.2.5 Description of Equipment

4.2.5.1 Specifications and Interconnections

There are fibre inter-connections between MShed, MSq and the UNIVBRIS Smart Internet Lab supported by 10G Edgecore Switches. If higher throughput requirements arise, the number of 10G connections between edges and between edges and core can be increased. The Nomadic Node backhaul connectivity will be provided either through the 5GUK Test Network wherever possible or through a public mobile network operator where there is not sufficient coverage from the test network. The users will be handed 5G capable phones, with SIM cards registered to the 5GUK Test Network, through which they would be able to experience the application.

4.2.5.2 Interfaces with the Use Case specific Equipment

This UC will make use of the compute infrastructure at the edge and the core of the Bristol 5GUK Test Network, where MATI application services will be running. The end user would be accessing those services through a 5G capable phone, connected to the test network. No other special equipment would be required.

4.2.6 Identifying Gaps with existing Test Network Capabilities

5GUK Test Network outdoor coverage was initially provided by a single M-MIMO 5G NR radio located at MShed (physically directed towards MSq) and two 4G LTE Macro radios located at WTC - MSq. Based on the results of our first site survey, the 4G and 5G coverage along the demonstration route was very limited, especially towards the SS Great Britain Museum which was only covered by a weak LTE signal. Since then, the network has been upgraded with two additional 5G NR radios (1x M-MIMO, 1xMacro) and the locations and configuration of all radios have been optimized to improve not only the coverage along the demonstration route but also network performance. Specifically, one of two 4G LTE radios was re-located from WTC-MSq to MShed, two 5G NR radios were installed at WTC-MSq and the 5G NR radio at MShed was physically directed towards the SS Great Britain Museum. Further antenna beamforming optimizations will also be implemented during lab testing/field trials to decide on the trade-off between throughput and coverage.

Furthermore, to provide seamless connectivity to the UE devices on the boat a Nomadic Node will be deployed comprising 4G LTE, 5G NR, Wi-Fi and MEC capabilities. The Nomadic edge functionality will be provided by i2SM. In order to host the additional RAN and MEC equipment at the edges (MShed, WTC) and provision for the UC-specific performance requirements, additional network equipment and infrastructure were installed including multiple 10G Edgecore switches and power supplies as well as additional power and optical fibre wiring.

The Slices at the edges (except the Nomadic node edge) will be managed by Zeetta Automate (NetOs). Our network can utilise either, a 4G/5G NSA core provided by Nokia solutions or an open source 4G/5G SA core (open5gs). Both cores are fully operational and ready to host all future mobility UCs of 5G-VICTORI. NUCs will provide the required CPU processing at the edge. The cloud/core network resources are more than enough to host the required VMs and provide the required E2E functionality. VMs hosted on servers inside the lab will contain i2SM (handled by i2CAT only) as well as an instance of Zeetta Automate (NetOs).

4.2.7 Planning of Lab testing and initial validation of services per use case

The plan of Lab testing for Digital Mobility UC-Bristol cluster is shown in Figure 4-27. All different components and their functionality will be tested in the lab prior to the field test/demonstration. Lab testing will first start in M24 and will be completed by M30. As a first step, the functionality of each of the components will be checked inside the Smart Internet Lab premises. For every test case, all required VMs will be hosted on servers inside the lab and the required services will be instantiated. We plan to test **App 1** and measure the KPIs assuming a good integration of i2SM, DCAT 5GNR, and NetOS with Bristol's 5GUK Test Network. In the following, we provide a high-level view on the plan to measure **App 1** KPIs.

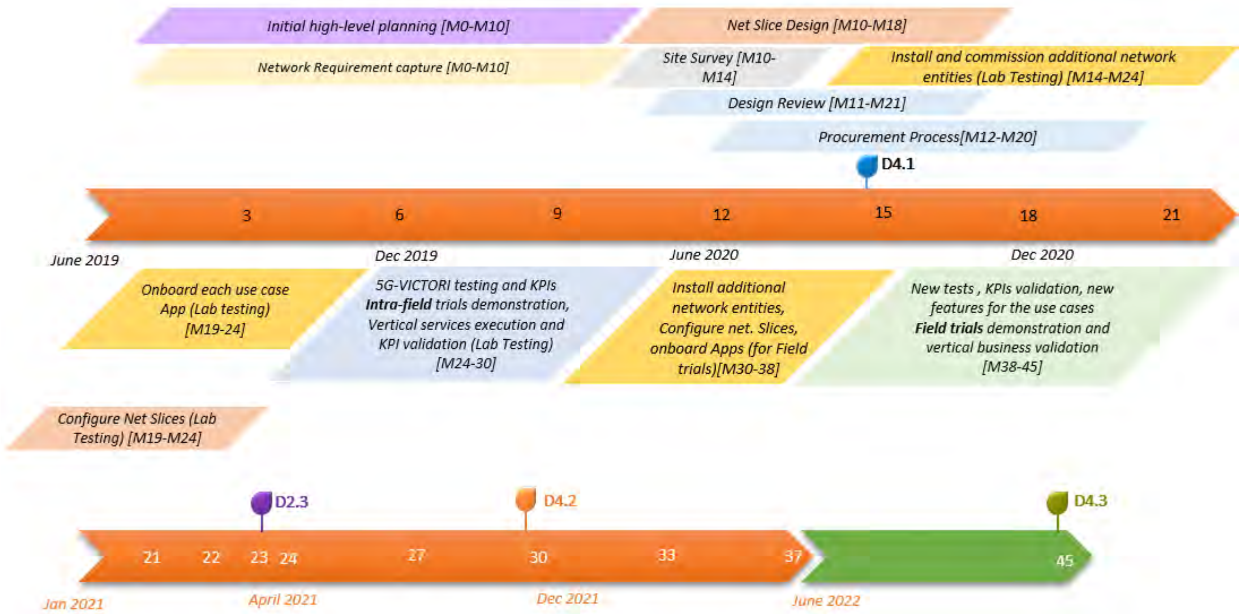


Figure 4-27 Planning of Lab testing and initial validation of UC #1.2 services in Bristol

To measure the Synchronisation latency of **App 1**, instances of i2SM, NetOS, 5G-VIOS as well as multiple Synchronization edge and MEC servers are required. The Amarisoft all-in-one box (if available) and 4G LTE radios inside the lab will be used to perform functionality tests of the required application that is installed on a number of pre-configured (APN) UE Android devices. At the end of this test, i2SM and NetOS should have created the E2E slices with the required vLAN and Public Land Mobile Network (PLMN) configuration while the application should have run successfully on all Master and corresponding Slave devices with the synchronisation latency values having sent and being available in the analytics package. After, doing a preliminary lab testing inside the Smart Internet Lab, the final lab test will be performed at the edges (MShed, MSq, SS G. Britain) to measure the required KPIs as well. Synchronization and MEC servers will be instantiated at MShed, WTC and Nomadic Node (if available). The same testing procedure will be followed with the UE devices connected to the 5G radios available at the demonstration sites.

To test the Mativision 360° VR Video Streaming, like in the previous case, functionality check and KPI test will be performed inside the lab and at the edges, respectively. The same procedure will be followed but additional servers will have to be instantiated such as a Backhaul, Linux Dummy ingest and Caching servers. A (360° VR) video stream will also have to be available for testing purposes. Each UE device inside the lab will have to successfully analyse traffic and switch to a better bitrate. Bitrate changes must be recorded and relayed to the analytics package. Different locations will be used for KPI measurements with throughput required to be at least 10 Mbps per device.

To test the Mativision mobility feature, the test will be performed at the edges only, as GPS information is required. The same services will be used as described in the previous paragraph. The handover functionality will be checked by moving UE devices from one 5G cell coverage to another maintaining service continuity on all devices. Mobility latency, i.e., latency between mobility start and communication with the sync server will be measured to ensure the service does not degrade during handover.

To test the 5GUK infrastructure (between Core and edges, and between edges), KPIs such as the latency, Jitter and DL/UL throughout between dummy VMs in the core and at the edge as well as between edges will be measured using Bristol's Measure and Monitoring tool along with iPerf and ping. The required KPIs include a latency value below 1 ms and at least 1 Gbps of DL/UL throughput. In addition, to test the 5GUK infrastructure (between Core and the Nomadic node), integration and functionality checks will be performed inside the lab premises with 4G LTE backhauling. KPI tests will follow a similar procedure to previous paragraph and will be performed at the SS G. Britain with 5G backhauling. The required KPIs are a latency value below 100 ms and at least 100 Mbps of DL/UL throughput.

Moreover, to test the 5GUK Infrastructure between UEs and Core, and between UEs and Edges, the E2E latency, jitter, DL/UL throughput between UEs and core as well as between UEs and edges will be monitored. KPIs will be measured using *iperf* and *ping* commands with the corresponding values required to be less than 100 ms latency and at least 100 Mbps DL/UL throughput.

An instance of Zeetta Automate will be available at each 5GUK Test Network edge (excluding the Nomadic Node) and will be responsible for the intra-edge slicing. Each slice is created on a different VLAN. The Zeetta Automate product provides a user interface and an API for interactive and programmatic control of the solution. For the purposes of this project the API is being extended for external system API call to create and manage network slices. Network slicing is an architecture that enables multiplex multiple virtualised networks to operate independently and isolated from each other on a common physical infrastructure. Zeetta Automate is a slice administrator. The operator needs only to specify the end points of the slice and Zeetta Automate computes the resources within the network required to implement connectivity. Each network slice is assigned to a single VLAN identity as part of its definition. Zeetta Automate uses a shortest-path algorithm when configuring a network slice through multiple devices. Where a network architecture is composed of multiple network domains, each domain will need a slice configuring to enable the forwarding of traffic across the network i.e. multiple Zeetta Automate solutions may be deployed to support each domain. In 5G-VICTORI there are multiple network domains and, consequently, multiple Zeetta Automate products deployed. The separate deployments are controlled from the central, remote, 5G-VIOS element by an API.

Furthermore, the performance of on-demand multi-RAT (5G NR, Wi-Fi) slice management will be tested in terms of network slice establishment and slice deployment time. 5G NR lab testing will depend on the availability of the Nomadic Node inside the lab premises. Wi-Fi APs inside the lab will be used to test the creation of new slices. Upon successful functionality check, the test will move to MShed and the WTC edges to test the 5GUK infrastructure. The time elapsed between a new slice request and the instance when the corresponding network services are all up and running will be measured. A minimum of 30 iterations will be required with the slice deployment time not exceeding 90 minutes.

4.3 UC #1.2 Application 2

App 2 involves a 360° VR Multi-camera Live streaming and focuses mainly on large user connectivity and greater number of users. A remote training class taking place at the University of Bristol (MVB) is attended by users via 360° VR in real-time from anywhere in Bristol with access to the 5GUK network. The key metric of **App 2** is number of concurrent users and the achieved bitrate.

4.3.1 Network Requirement capture/ Processing Requirement capture

The requirements of **App 2** were identified and divided into the following groups:

A. Hosting Requirements:
   - Streaming Server VM: 8 CPU cores, 16 GB RAM, 50 GB storage space.
   - Video Caching VM: 2 CPU cores, 4 GB RAM, 10 GB storage space.
B. Network Requirements: (lab & field).
   - 10 Mbps or more per device for 360 video streaming.
C. 5G-VIOS API requirements:
   - Instantiate edge services (lab & field).
D. Equipment Requirements: (lab & field).

- Multiple 5G-enabled android devices.
- Backhaul VM hosting server.
- Edge VM hosting server.
- Zeetta Automate University of Bristol hosting server (2 VMs NetOS and NetOS Statistics).
- Zeetta Automate MSquare hosting server (2 VMs NetOS and NetOS Statistics).
- Zeetta Automate MShed hosting server (2 VMs NetOS and NetOS Statistics).

The following required equipment is provided by **MATI**:

- 360 Video camera used to live stream.
- Streaming Server VM containing streaming server application.
- Streaming Server License Key used during testing period.

A 360° VR Multicamera Live stream will be delivered, focusing on large scale user connectivity, greater number of users and high bitrate videos. Mativision's **App 2** will involve a training course hosted at the **UNIVBRIS**, using capabilities of MATI, and the 5G-VICTORI 5G-UK test network. The users can take part in the class from anywhere in Bristol with access to the 5G-UK test network and attend the class via VR in real-time with low latency. Figure 4-28 illustrates the journey associated to Application 2. The selected locations for the journey are the Smart Internet Lab office area (i.e., at point ⑧), MShed (i.e., at point ③), and Millennium Square (i.e., at point ⑦).

4.3.2 Site Survey and report /Final planning

Streaming services for App2 will require MEC and backend servers as well as 5G, LTE or Wi-Fi connectivity. As mentioned in section 4.1.2.5, to set-up the online lecture, three cameras and an interactive whiteboard will be utilised at Smart Internet Lab office area. A Pico-cell will be also deployed at the Smart Internet Lab office area to enable video streaming by providing LTE connectivity to the devices. The Smart Internet Lab survey details were provided in Section 4.1.2.5. Also, users can take part in the event via 360° VR in real-time from anywhere in Bristol with access to the 5GUK network, such as Bristol Harbour Railway, MSq, and MShed which were detailed in sections 4.1.2.2, 4.1.2.4, and 4.1.2.1, respectively.

Figure 4-28 The journey related to App 2

4.3.3 Network Slice Co-Design

Figure 4-29 presents the 360º camera streaming infrastructure that connects to the streaming server located at the backend. As shown in the diagram, the backend notifies 5G-VIOS to create the edge services that cache the content close to the user. The stream is pulled from multiple users concurrently from the edge.

App 2 runs on a separate network slice to ensure the performance of video segments.

The flow chart in Figure 4-30 depicts the sequence of processes for **App 2**. Specifically, Figure 4-30 presents the process of the camera connecting to the streaming server, the server notifying 5G-VIOS, the edge service being created, and the stream being cached. On the end user browser, the stream is pulled from the edge service, decoded, and displayed on screen via a 3D graphic rendering engine.

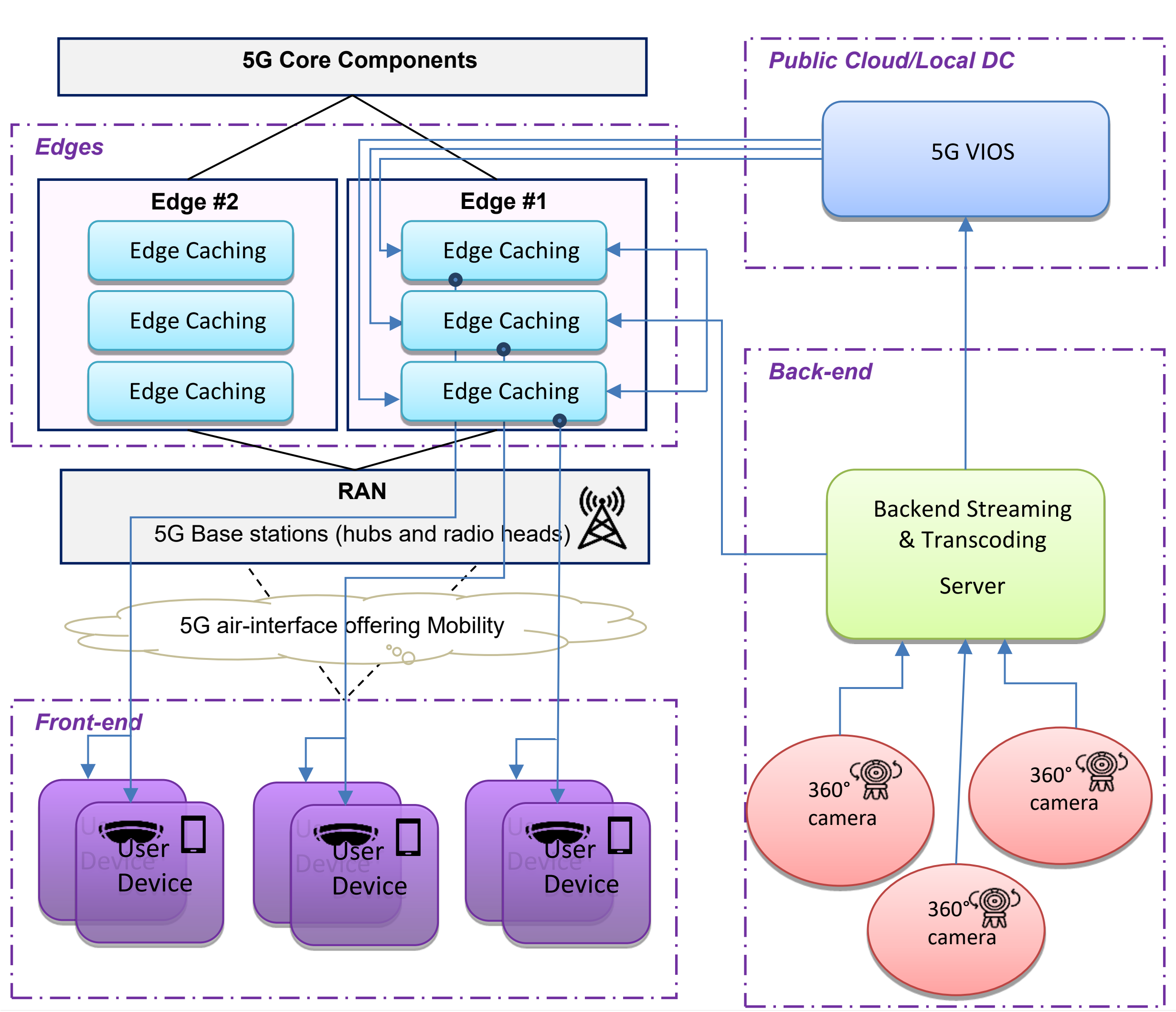


Figure 4-29 High-level block diagram of the Mativision VR Multicamera Live streaming at UNIVBRIS campus

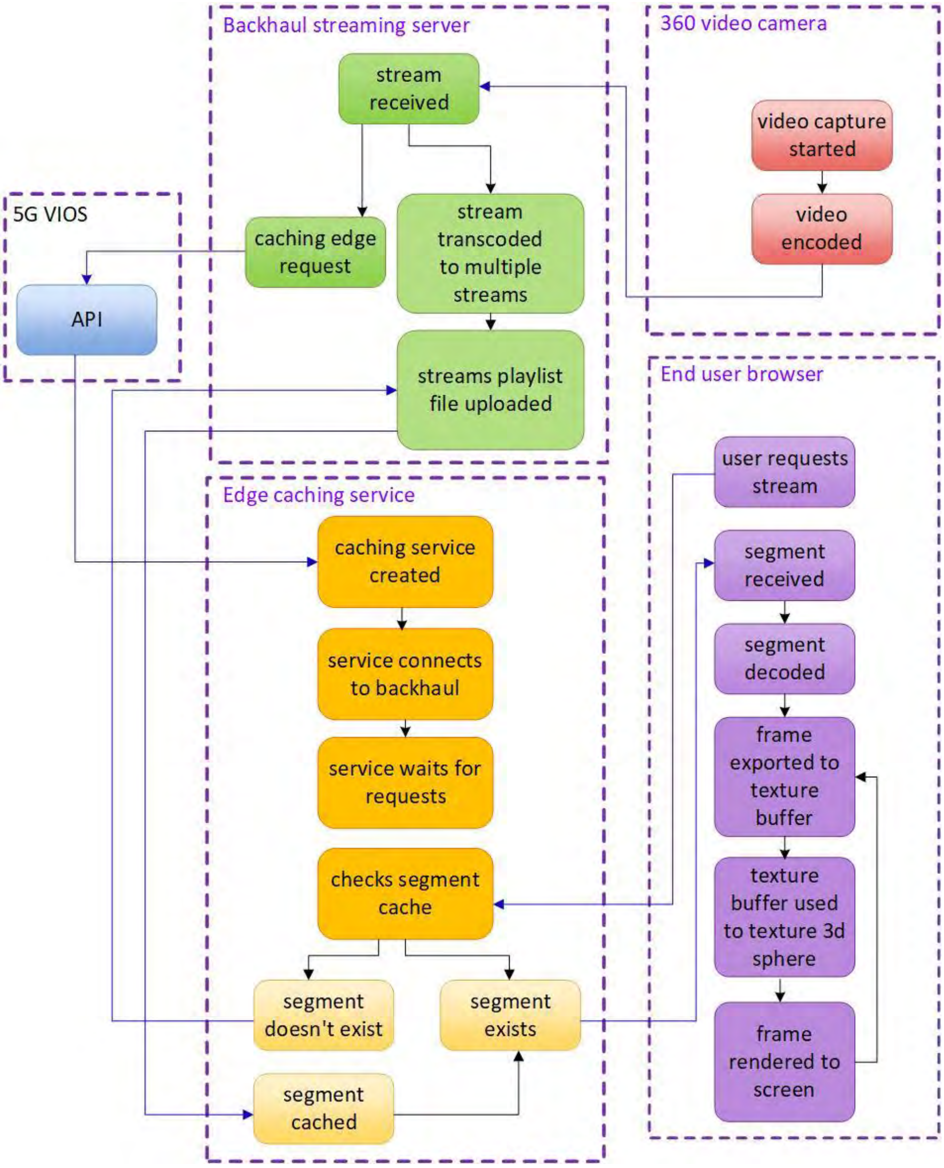


Figure 4-30 Digital Mobility Bristol – App 2 sequence diagram

4.3.4 Design Review and Bill of Materials

The general BoMs for the Bristol cluster are presented at the relevant section of Table 4-1. Please note that the BoM related to Mativision's **App 2** is already presented in Table 4-2, as it is the same for **App 1** and **App 2**.

4.3.5 Description of Equipment

4.3.5.1 Specifications and Interconnections

Like **App 1** in section 4.2, the connectivity will be provided by the Bristol 5GUK Test Network. The key locations for this UCs are University of Bristol that stream the content to other locations in Bristol.

4.3.5.2 Interfaces with the Use Case specific Equipment

The key equipment used for this application are 360° cameras that are connected through Ethernet connectivity to the Bristol 5GUK Test Network at the University of Bristol to capture the training class. The end users can watch the stream either through Wi-Fi VR headsets, or through 5G-capable phones mounted to headsets or hand-held.

4.3.6 Identifying Gaps with existing Test Network Capabilities

All gaps have been identified in previous sections and are the same as the ones described in **App 1**. The 360 video camera to be used for **App 2** supports Ethernet as well as Wi-Fi technologies. The Bristol cluster will enable the camera to stream content to the streaming server either through multiple Wi-Fi APs available inside the Smart Internet Lab premises or via a CPE device with an Ethernet port.

4.3.7 Planning of Lab testing and initial validation of services per use case

The plan of Lab testing for the Digital Mobility UC-Bristol cluster is shown in Figure 4-27. Like for **App 1**, functionality checks will be performed inside the lab premises (when possible) while KPI testing will involve the demonstration sites. To test the Mativision Live 360º VR Video Streaming, the same services as in App1 are required. Assuming the required servers have been instantiated inside the lab premises, functionality checks will ensure that the 360 VR video camera is connected to the network and configured correctly and that the UE devices that are connected to the 4G LTE radios inside the lab are receiving live feed. All UE devices must analyse the traffic and change the bitrate accordingly. KPI testing will require instantiation of the required services at the edges and the UE devices connected to the 5G network at MShed or WTC. Throughput at all tested locations must not drop below 10 Mbps per device.

Moreover, to test the Mativision Edge Instancing, Caching edge, Backhaul Streaming and MEC server VMs must all be instantiated and correctly configured. The 360º video camera connects to the network and streams to the streaming server. The UE Android devices have been correctly configured (APN) and the required app is opened. Upon successful realization of the test inside the Smart Internet Lab, the test will be conducted at MShed and WTC to determine the latency between the request for an edge service and the edge service being up and running. The obtained latency values should be stored in a .csv file and be less than 60 s.

4.4 UC #1.2 Application 3

As discussed in D2.1 [1] and D2.2 [2], in UHA's Future Mobility Application, referred to as **App 3**, travelers may use the old Bristol Harbourside train (i.e., point ① to point ② in Figure 4-1) to reach to a staring location, e.g., MShed (i.e., point ③ in Figure 4-1). Taking advantage of the 5G connectivity and the **UHA** Future Mobility App installed on their phones, an AR journey will take place through the river on a boat and by foot.

The boat trip will include a visit outside of SS Great Britain (i.e., point ⑤ in Figure 4-1) before ending at MSq (i.e., point ⑦ in Figure 4-1). Some network services such as the synchronisation service, spatial data renderer/visualiser, journey planner, and video streaming service will be deployed and run at edge and backend servers. People's information including their location, their mobility and movement will be collected and analysed. Furthermore, **App 3** will provide passengers with specific location guidance and multi-modal transport journey planning beyond the starting location using AI techniques. **UHA** plans to bring equipment such as the Stereo vision cameras and Lidar for initial 3D mapping, Backend GPU cluster (Nvidia platform) and, potentially, Nvidia GPUs for the Edge. The 2080 RTX Nvidia cards are PCI desktop, so UHA will also provide a motherboard and CPU with it.

4.4.1 Network Requirement capture/ Processing Requirement capture

The requirements for the Nomadic node and the general requirements are already described in section 4.1.2.6. Please refer to this section for additional information. Particularly for **App 3**, the requirements are:

- Network/nodes: **App 3** will require Front-end smartphones, Edge, and Back-end servers as well as 5G, LTE or Wi-Fi connectivity. Connectivity is essential for data flow between each node.
- Smartphone: Any 5G capable Android phone or tablet with built in GPS and accelerometer (most devices have these by default). Optionally with built in Lidar (if used then will be provided by UHA Provided by UHA for the time of lab testing and field experimentation).
- Edge, back-end compute capability: UHA will install GPU nodes next to the network's Edge nodes. Each GPU node will contain an Nvidia RTX-2080 or RTX-3090 card with an Intel or AMD CPU with at least 16 GB RAM.

4.4.2 Site Survey and report /Final planning

The mentioned services such as Synchronisation and Streaming will require MEC and Back-end servers with high processing power as well as low latency 5G, LTE or Wi-Fi connectivity. The site survey, including the path from MShed to MSq and the Mobility support is described for **App 1**, and is the same as the one for **App 3**. Please refer to section 4.2.2 for more details.

4.4.3 Network Slice Co-Design

Identical instances of UHA's Polaron engine (back-end) will be running at each 5G Edge node, dedicated to geo locations, as shown in Figure 4-31. The only difference is in the spatial data they process, which is location relevant within a short radius until the user moves to the next Edge. Mobility is handled by the network and 5G-VIOS. It is worth to mention that next to the network the Polaron engine also knows the user's location (transmitted and frequently updated via the front-end smart phones' GPS to the active Edge) as that is part of the route planning procedure.

Slicing and prioritising may be activated in a low bandwidth scenario (i.e. other services are loading the overall bandwidth simultaneously), and then the user's data gets priority (location, orientation, preferences) while the streamed visuals for AR guidance become secondary.

A cloud-based instance of the Polaron engine is also active and directs user data between the Edges during a handover. Can also take over in case of a network blackout or when the user physically leaves the array of available Edges (out of range/coverage area).

Many similarities exist with the Future Mobility UC in the Berlin cluster (section 3.2). The same Polaron engine is operating on the Edges and the cloud Back-end, just loaded with the cluster relevant data (spatial maps and users). The same Front-end/ and the same mapping methodology is deployed when scanning the surrounding physical infrastructure (instead of train station the M-Shed and its surroundings are captured). The same AI is used to label the relevant features.

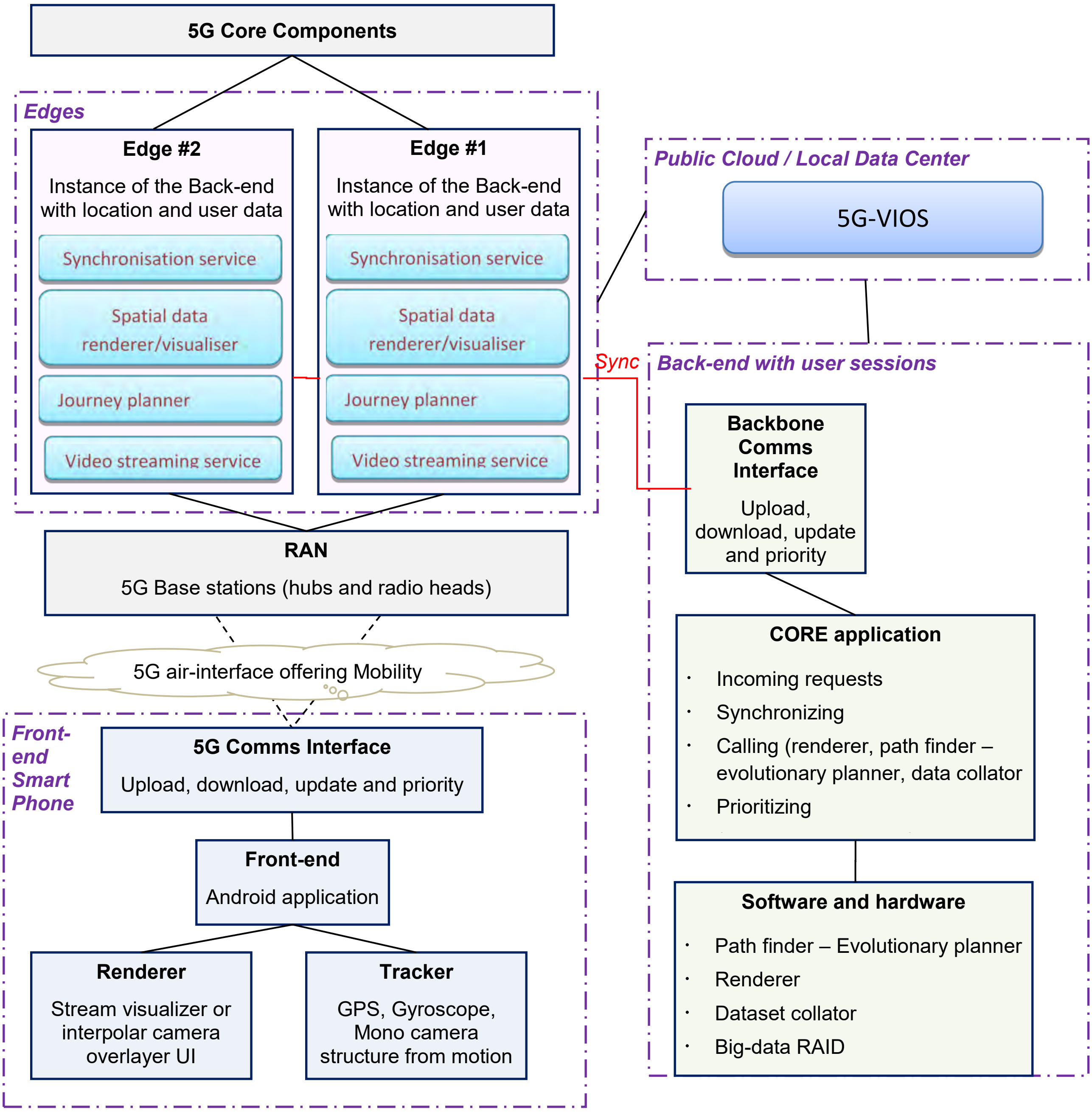


Figure 4-31 Digital Mobility in Bristol - App 3: Urban Hawk's Future Mobility Application- high-level block diagram

4.4.4 Design Review and Bill of Materials

The general items and specific items for demonstrating the boat trip and deploying the nomadic node on the boat are described in section 4.2.4. Please refer to this section for more information.

Table 4-3 details the BoM of specific elements that will be provided by **UHA** for **App 3**, for the duration of the lab and field trials:

Table 4-3 The Bill of Materials of the equipment that will be provided by UHA

Equipment	Item	Components	Quantity	Dimensions	Power supply
	Intel I7 CPU with 16GB RAM. Nvidia RTX-3090 GPU	Edge GPU compute node for running the digital twin.	1	-	240 V, 1200 W
	Intel I7 CPU with 16GB RAM. Nvidia RTX-2080 GPU	Edge GPU compute node for running the digital twin.	1 (optional to the number of Edge nodes used)	-	240 V, 1200 W
	Intel I7 CPU with 16GB RAM. Nvidia RTX-3090 GPU	Back-end server.	-	In UHA's server cabin.	240 V, 1200 W
	Lidar equipped Android 5G smartphone	Front-end. The digital twin will receive user data from this device and will send visualisations to such device that overlayed on top of the camera feed will produce the AR guidance experience.	3+	This item cannot be specified further as the market will be constantly changing until the 2022 field trials. Newer and cheaper phones will be available by then.	

4.4.5 Description of Equipment

4.4.5.1 Specifications and Interconnections

Like the previous two applications, **App 3** will make use of the Bristol 5GUK Test Network as described in section 4.2. The key equipment that this application would need in addition to the other applications, are the GPU-powered compute infrastructure at the core and/or the edge to run UHA application services.

4.4.5.2 Interfaces with the Use Case specific Equipment

As mentioned above, the only specific equipment for this UC are the GPU cards that would be available in the infrastructure (core/edge). The virtualisation infrastructure manager that will be running and managing those resources (OpenStack and/or Kubernetes), would make them available to the applications requiring them. The end users would use standard 5G-capable phones with SIM cards registered to that network (as mentioned in section 4.2.5.1) to access the services through the network.

4.4.6 Identifying Gaps with existing Test Network Capabilities

Most of the gaps have been identified in previous sections and are the same as the ones specified in **App 1**. For **App 3**, additional upgrades will be required to provide high-end GPU processing. Advanced compute (CPU/GPU) resources will be required at the edge and will be hosted in allocated space at the edges of the 5GUK Test network in Bristol. Even though GPU units can be physically installed at any of the edges, installing them inside the Smart Internet Lab premises at MVB (cloud/core network premises) is also under consideration.

UHA will provide high-end compute units consisting of nVIDIA RTX GPUs which will then be integrated to the required edges (MVB, MShed, MSq, Nomadic Node).

4.4.7 Planning of Lab testing and initial validation of services per use case

The plan for the lab testing of the Digital Mobility UC is shown in Figure 4-27. Like in **App 1** and **App 2**, the services of **App 3** will be lab tested by performing functionality checks and on-site KPI testing.

To test the UHA Future Mobility's spatial scanning/mapping feature, lab testing will be divided into two stages, one involving the 5GUK Test Network and the other involving the Nomadic Node. Both tests will require all services mentioned in **App 1** and **App 2** to be instantiated as well as the required applications running on the UE devices. For all edges (MShed, WTC, Nomadic Node), the required latency and throughput (DL/UL) values should be less than 20 ms and at least 10 Mbps per device, respectively. Seamless mobility/handover between edges should also be tested.

To test the communication between Backend, Frontend and Edge nodes, the same lab plan as described in **App 2** will be utilised. In addition, to test and measure the high bitrate data distribution between Backend and Edge feature, the lab test is required to investigate the spatial distribution of a large amount of data (>1GB) from the Backend to the Edges (MShed/WTC). This test will require the integration of **UHA**'s Compute Units, real-time 3D tile processing engine and communication module to the Bristol cluster. The previous tested VMs must be instantiated along with the Backend server (CPU). 5G UE devices will test the network and app functionality at the edges and obtain ensure small throughput fluctuation as well as excellent connection stability and reliability during handovers. The throughput between the edges and backend must never drop below 20 Mbps.

4.5 Final Facility assessment / Unforeseen risks and mitigation plan

4.5.1 Risks and Potential Delays

As in every multi-year project, several conditions imposing risks and potential delays have been identified and tabulated in Table 4-4.

Table 4-4 Bristol facility-Risks and Potential delays

Risk ID	Description	Impact	Mitigation Plan
UC #1.2-Bristol -R1	Lack of spectrum license for 5G – Expiring OFCOM license for band n78.	High	Should the n78 spectrum not be available, spectrum in the n77 band will be solely used and compatible 5G NR radios will have to be purchased.
UC #1.2-Bristol-R2	Radio units in band n77 won't be available on time for testing.	Low	RAN solutions from several vendors are already being consider for purchasing soon in case the band n78 is unavailable.
UC #1.2-Bristol-R2UC #1.2-Bristol-R3	Availability of devices in band n77 as a mitigation to operate in this band.	Low	The number of UE Android devices supporting band n77 is limited. Also, Bristol cluster RAN is not compatible with most of the phones tested by their engineering team in band n77. However, most current phone models from all manufacturers now support n77 so we should not be concerned about device availability. Samsung devices have been tested and are fully compatible.
UC #1.2-R2UC #1.2-Bristol-R4	Pandemic, COVID-19.	High	Potential lockdowns and social distancing due to COVID-19 will significantly affect the procurement process while limiting and slowing down most of

			engineering activities required for experimentation and demonstrations purposes. There will be limited access to the lab at least for the next few months. There will be limited access and restrictions at hosting sites and locations for use case demonstration. Limitations will also be imposed on the boat.
UC1.2-Bristol-R2UC1.2-Bristol-R5	Limited opportunities for trial tests on-boat.	Low	The boat won't be available on-demand for testing purposes before the demonstration. Lab testing will ensure that all equipment is fully functional but testing on the boat will probably 'reveal' new challenges.

5 France/Romania Cluster Facility Planning

The France/Romania (FR/RO) baseline infrastructure initially described in deliverable D2.2 [2] has been built extending the ICT-17 5G-EVE[6] facility in France. 5G-EVE involves four cluster facilities in France, Greece, Spain and Italy. For 5G-VICTORI, the French cluster capabilities are extended to Romania, interconnecting Paris – Sophia Antipolis sites, and providing 5G services and 5G functionality to the Romanian sites, i.e. the Bucharest and Alba Iulia Municipality (**AIM**) locations.

In this context, the 5G-VICTORI partners are in charge of upgrading and extending the 5G-EVE infrastructure towards the Romanian sites, offering an E2E 5G facility that comprises a virtualized infrastructure (compute nodes), control and orchestration capabilities (ONAP/Openshift) as well as 5G RAN and core components adopting the OpenAirInterface (OAI) platform. The 5G communication services are implemented at AIM with the support of the City Hall and are available for two major 5G vertical UCs, as described in D2.1 [1], which are **UC #1.2** and **UC #4.2**.

5.1 Final Facility commitment

The facility involves collaboration between the French sites (Paris and Sophia Antipolis) and two Romanian sites, one in Bucharest and one in AIM, to instantiate in the two former both 5G RAN and Core functions. The Bucharest site plays the role of IP interconnection point between France and Romania and also connects the AIM site to the cluster for service deployment. The Bucharest site is also the test site for the 5G network elements deployment.

The two Romanian sites, i.e. Bucharest and AIM, represent the extensions of the 5G-EVE infrastructure that are being adapted and developed to conform with the requirements of the French 5G-EVE infrastructures. The implemented 5G-VICTORI services need to be integrated in 5G-EVE (highly complex environment) and ready to be deployed within the resulting 5G-VICTORI infrastructure (Paris/Sophia-Antipolis/Bucharest/AIM) to support the UCs.

As described, the 5G-VICTORI Romanian facility is integrated within the 5G-EVE cluster solution framework to provide 5G services for the two UCs in AIM:

- **UC #1.2** Digital Mobility[7], and
- **UC #4.2** LV Energy metering.

These UCs were described in deliverables D2.1 and D2.2 and, in more detail, as the services and test cases are captured in WP3 deliverables (D3.3 [6] and D3.5 [7]). The demonstration is planned to take place in AIM's City Centre, where a dedicated 5G infrastructure will be deployed. This infrastructure represents a 5G-VICTORI extension and includes antennas, virtualization capabilities, RAN and Core functions, adding on top of the facility functionality Edge computing capabilities for UC #1.2 experimentation. In AIM, all 5G services will be mainly orchestrated by the French cluster tool (ONAP), as the cluster extension has been adapted to support all the entire UC requirements in terms of service KPIs and functionality as described in deliverables D3.3 [6] and D3.5 [7].

5.1.1 Network Design and Service Delivery

The demonstration will take place around the Orange Romania physical site, where the entire 5G infrastructure will be deployed. The high-level network design to support the planned services is highlighted in Figure 5-1, describing the main architectural cluster components for the UCs services instantiation and experimentation.

[6] www.5g-eve.eu

[7] Became in June 2021 one of the selected Trials and Pilots to appear in the 5G-PPP Brochure No3

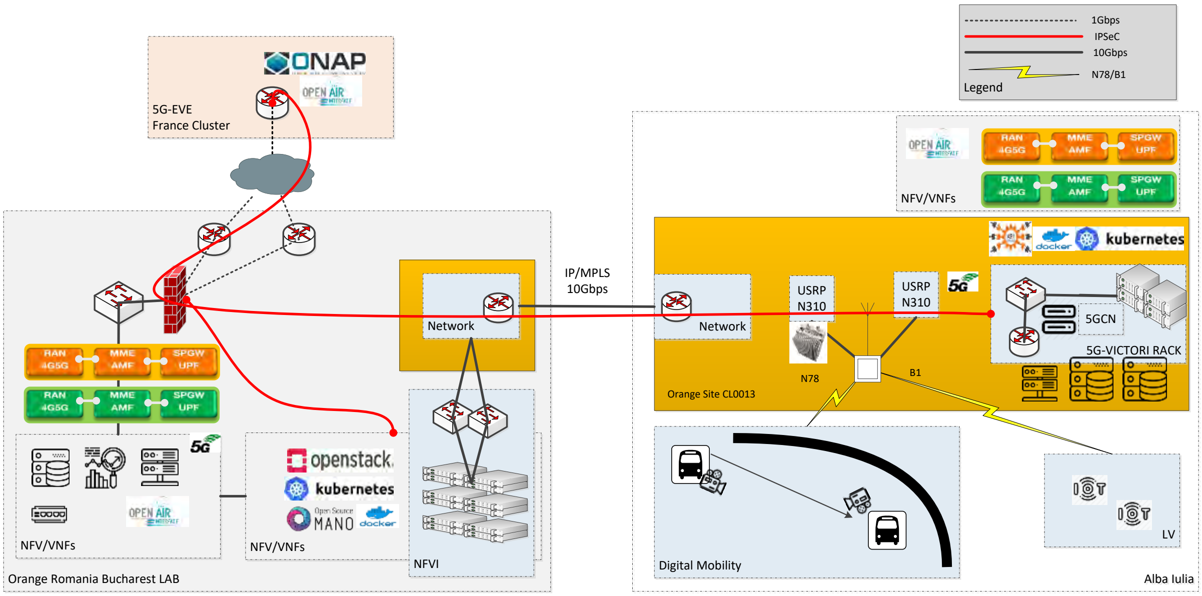


Figure 5-1 High level network design Romanian facility

5.1.2 FR/RO Facility

The FR/RO facility comprises several hardware and software elements as well as connectivity services. These are presented as the main components that must be physically deployed and integrated at the Romanian sites and then interconnected with the French cluster for automation of the service instantiation and orchestration:

- The entire experimental network infrastructure (RAN/Core and computing) is deployed in the Orange Romania site in AIM (CL0013).
- Hardware available: Outdoor Antennas, RAN USRP RRU, L2/L3 networking devices, Computes Nodes.
- Software: Virtualization environment (K8s/Docker), 5G RAN/Core OpenAirInterface (OAI).
- IP/MPLS connectivity with Bucharest cluster (10 Gbps connectivity).
- Orchestration tools (ONAP).

The field testing and UCs' experimentation activities are taking place only in AIM and the testing area is seen in Figure 5-2. A single Radio site (5G NSA) is deployed in the 5G-VICTORI FR/RO facility, covering the area around the proposed physical site facility where all the equipment will be deployed. The site is hosted at a secured physical location that includes an outdoor cabinet with power, rack space, network connectivity, where the infrastructure can be physically installed and configured.

AIM CL0013 site view

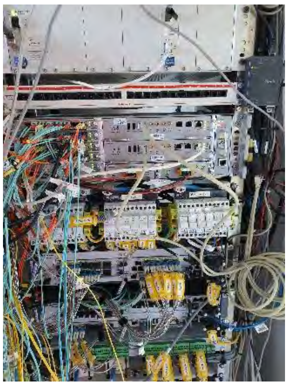
Experimentation area UC #4.2

Experimentation area UC #1.2

Figure 5-2 AIM UCs experimentation area

Outdoor cabinet

Rack space



Power and Networking

Radio antenna pylon

Figure 5-3 Orange physical site components

```
mdl-cl0013#ping mdl-bi0891 source loopback 0 repeat 1000 size 1000 -df
Type escape sequence to abort.
Sending 100, 100-byte ICMP Echos to 109.[redacted] timeout is 2 seconds:
Packet sent with a source address of 62.[redacted]
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!

Success rate is 100 percent (100/100), round-trip min/avg/max = 8/10/12 ms
```

Figure 5-4 AIM cluster connectivity with Bucharest

The AIM physical site is ready for infrastructure deployment and for equipment installation, as highlighted in Figure 5-3. As described in D2.1 [1] and D2.2 [2], the AIM site (md1-cl0013) is interconnected with the Bucharest site (md1-bi0891) using the Orange IP/MPLS VPNv4 network (see Figure 5-1), ensuring proper transport capacity in terms of allocated bandwidth and delay corresponding to 10 Gbps connectivity and less than 5 ms delay between the two Romanian sites. The IP connectivity has been ensured, tested and validated, and is able to support the needs in terms of management, control and orchestration capabilities. A snapshot that verifies the connectivity is shown in Figure 5-4.

The equipment available at the AIM site relates to both the infrastructure deployment (e.g. racks), and to connectivity needs. A summary of this equipment is presented in Figure 5-5.

IP network rack

N310 USRP family

(10 Gi interfaces)

Compute DL380 Servers

(4x10Gi Interfaces)

Cisco IP networking ASR9k

	Antennas	(10Gi Interfaces)
		
Rack space for compute and USRPs	Serma Remote Radio Head	Cisco IP networking Nx-OS

Figure 5-5 Orange AIM site room equipment

Figure 5-6 Orange 5G-VICTORI Antenna deployment

To deploy the network services supported by the 5G NSA implementation, an anchoring 4G layer (eNodeB RAN for signaling activities) and a data 5G layer (gNodeB RAN data traffic) are used. The radio spectrum should be allocated properly for this activity. Out of 10 MHz available in the B1 band, Orange Romania is using in AIM 5 MHz for commercial activities, and 5 MHz for project activities, with the purpose of avoiding radio interferences. In this particular case, the radio spectrum started to be cleared from commercial eNBs, from 10 MHz to 5 MHz in AIM at all Orange Romania sites in the city; and a 5 MHz bandwidth spectrum will be allocated in AIM for the 5G-VICTORI trials, as clean spectrum for the experimentation facility is required.

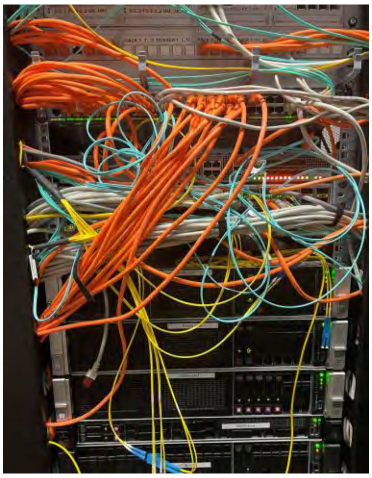
In summary, the radio spectrum analysis for the Orange site in AIM for 4G and 5G (5G NSA) would be:

- 4G: 5 MHz spectrum in B1 (from 10 MHz licensed spectrum available).
- 5G: N78; up to 50 MHz spectrum in N78 (licensed spectrum available).

5.1.3 Bucharest Facility, Orange Romania lab

5G-VICTORI Bucharest facility is the selected connectivity entry point in the Romanian cluster, securely connecting the 5G-EVE French cluster to AIM, as seen in Figure 5-1. The Bucharest facility is not only the connection point, but also the experimentation environment for the activities that take place in AIM, acting as testing and validation laboratory for OAI RAN and Core instantiation. The laboratory in Bucharest is able to support all technical needs and AIM UC requirements, as described below:

- The entire L2/L3 connectivity infrastructure, IPSec VPN aggregator.
- IPSec VPN between Orange France to Orange Romania.
- Hardware available: Antennas, RAN USRP RRU, L2/L3 networking devices, Computes Nodes.
- Software: Virtualization environment (K8s/Docker/OpenStack), 5G RAN/Core OAI.



Compute Rack servers

USRP N310 & Antennas

IP Networking Rack

Figure 5-7 Orange 5G-VICTORI LAB Infrastructure in Bucharest

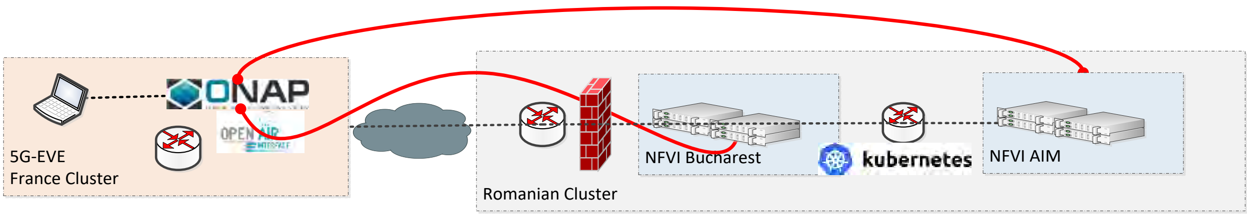


Figure 5-8 5G-VICTORI leveraging the French cluster orchestration capabilities

In the Bucharest Orange laboratory, ORO with the support of EUR, has been experimenting the OAI RAN and Core network deployment and service instantiation. The entire infrastructure deployed in Bucharest and the UCs experimentation framework are being tested and they will be progressively migrated to AIM in order to support the 5G-VICTORI trials running at AIM.

5.1.4 Paris Chatillon Facility, 5G-EVE cluster

The Paris facility main component provided by 5G-EVE is the orchestration tool, ONAP, which will be exploited in 5G-VICTORI to perform network service deployment. The 5G-VICTORI Romanian facility will take advantage of the network functions onboarding and automated 5G service deployment achieved in 5G-EVE (see Figure 5-8), with support for:

- L2/L3 connectivity infrastructure, IPSec concentrator.
- IPSec VPN between Orange France and Orange Romania.
- 5G-EVE Orchestrator, ONAP (5G-EVE blueprints for OAI deployment).

As already discussed, the Romanian facility is orchestrated through the 5G-EVE Open Network Automation Platform (ONAP), which is deployed in Chatillon and it is currently connected to the 5G-VICTORI infrastructure deployed in Romania. The orchestration functions and capabilities that will be later used to deploy the 5G-VICTORI services at the AIM site are depicted in Figure 5-1.

Due to the ONAP complexity, for both platform instantiation and platform maintenance, the existing ONAP platform hosted in France will be used to act as an orchestration solution for the experiments in Romania. For this purpose, an IPSec tunnel has been established between France and Romania, in order to provide the required connectivity between the 5G-EVE ONAP and the Romanian Virtualized Infrastructure Manager (VIM) cluster, which will support 5G network function deployment for the OAI RAN and Core.

```
h2020@h2020-server7:~$ ping 10.192.133.3 -c 3
PING 10.192.133.3 (10.192.133.3) 56(84) bytes of data.
64 bytes from 10.192.133.3: icmp_seq=1 ttl=61 time=37.2 ms
64 bytes from 10.192.133.3: icmp_seq=2 ttl=61 time=37.0 ms
64 bytes from 10.192.133.3: icmp_seq=3 ttl=61 time=36.9 ms

--- 10.192.133.3 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss
rtt min/avg/max/mdev = 36.984/37.089/37.255/0.196 ms
```

Figure 5-9 5G-EVE ONAP cluster connectivity with Romanian cluster

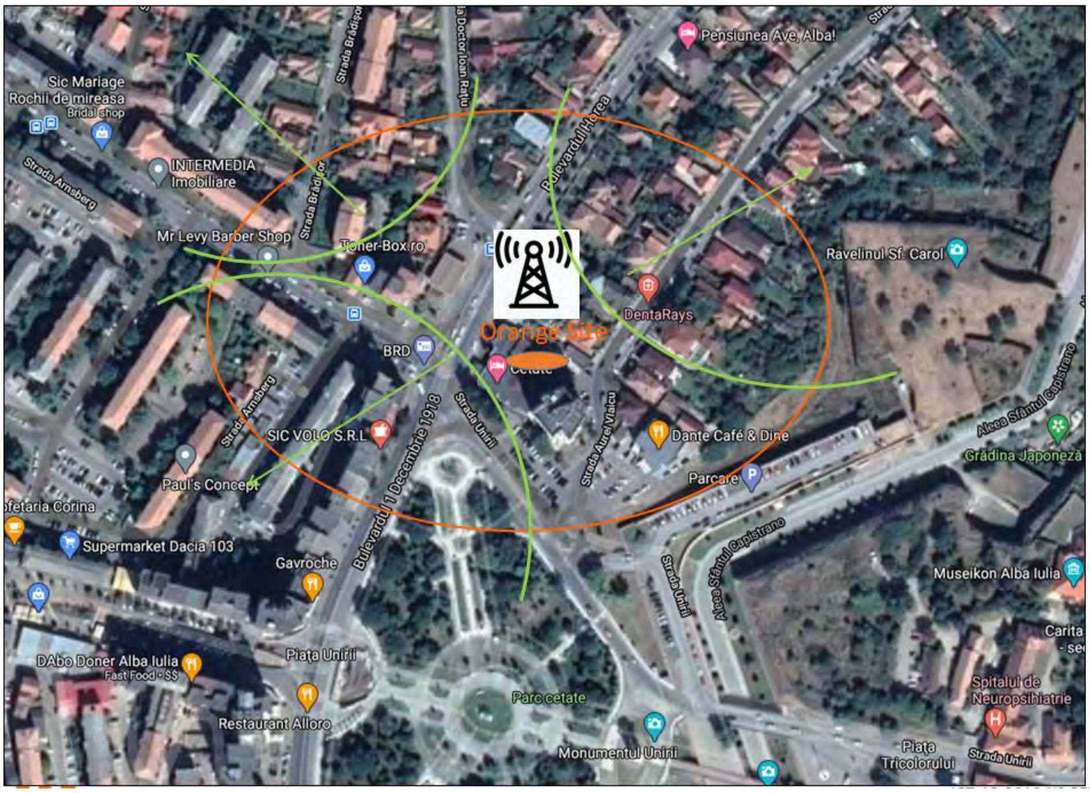


Figure 5-10 5G-VICTORI demonstration coverage area Romanian facility

As described in section 5.1.4, the preliminary experiments are taking place in Bucharest infrastructure (facility compute node h2020-server-7), as seen in Figure 5-7. Relevant results on the connectivity between the two facilities, the Bucharest and Chatillon cluster, are shown in Figure 5-9.

5.1.5 Demonstration and experimentation areas

The trials area comprises experimentation in accordance with the two UCs described in detail in **WP3**, i.e. LV energy metering and mobility that involve several physical locations across AIM. More specifically, for the LV metering UC, these include fixed points across the city (where the LTE-M devices have been installed and are collecting the energy data), while for the mobility UC, a larger area is supported, under the coverage provided by a single radio site, where City Hall buses travel on the city streets as seen in Figure 5-10.

The initial demonstration area proposed initially in D2.2 [2] is further evaluated from radio perspective using internal radio simulation tools. A real coverage map is depicted in Figure 5-11, with the orange footprint highlighting the area where connectivity will be supported through 5G coverage, which spans 500 m around (see more details in section 5.2.2). In the centre of the image the single radio site installed at the Orange physical site is illustrated. However, due to possible radio propagation tools estimation errors and the OAI RAN capabilities, the estimated radio covered area may be in practice reduced. However, this will be accurately evaluated in the field through experimental measurements.

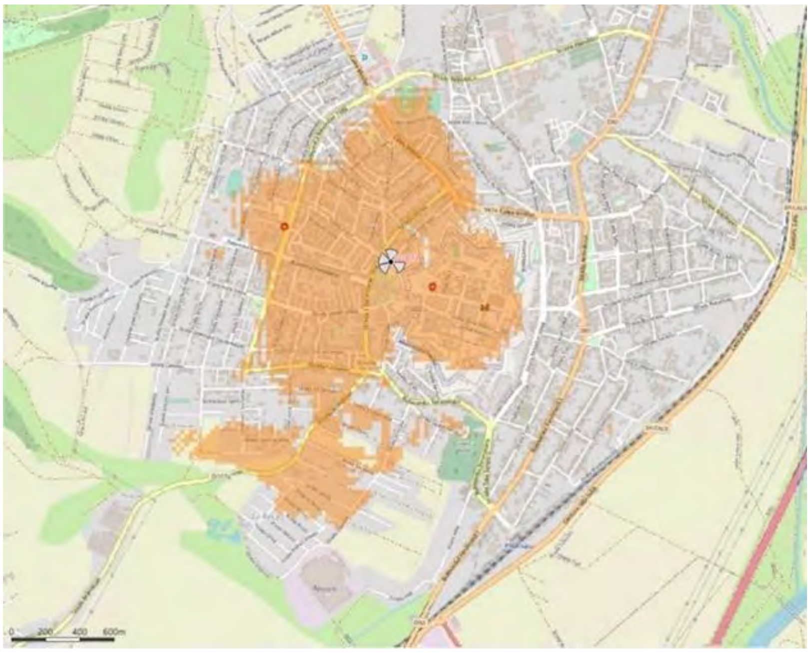


Figure 5-11 5G-VICTORI Alba Iulia experimentation areas

5.1.6 Others equipment

For the experimentation of the UCs there is a need for specific equipment, which will provide the required applications connectivity to the infrastructure, as follows:

- **UC #1.2** Digital Mobility, see section 5.2
- **UC #4.2** LV Energy metering, see section 5.3.

5.2 UC #1.2 Digital Mobility

UC #1.2 focuses on real time media service delivery and prioritized communication to the Command and Control Centre (C&CC) in case of emergency situations triggered when detected by AI recognition and identification mechanisms. The required information is transmitted over 5G dedicated slices assuring real time management, E2E orchestration and QoS control.

The entire UC experimentation is taking place inside an AIM bus, as presented in Figure 5-12.

General Bus view

Bus with passengers

Video analytics camera installation proposed position

Figure 5-12 5G-VICTORI UC #1.2 bus view

The UC is designed to offer the following vertical's capabilities:

- Infotainment/video services in dense, static and mobile environment
  - real time infotainment services will be delivered displaying municipality information and public interest information including: surveys, alerts, tourist information.
  - the captive portal will be connected through the 5G infrastructure to the AIM public traffic management centre for real-time communication.
- AI recognition and identification of emergency situation. The predefined emergency situations (passenger's fall, violence, health issue) are triggered by the AI algorithm that identifies and tracks human bodies throughout camera frames and also correlates with other data as head's coordinates and velocity. More details about the data collection and analysing and the triggering of the emergency situations are comprised in D3.3 [6], section 4.4.
  - in depth assisted pose estimation through different convolutional neural network models, and training data sets for recognition and identification of emergency situation.
- Prioritized communication to C&CC
  - public safety critical service – identifying public threats (thefts / healthcare emergency / lost items) and allocating on the spot appropriate resources.
  - E2E slice over 5G infrastructure, the emergency situation detected through the AI scheme addressing various emergency scenarios (thefts/healthcare emergency/lost items).

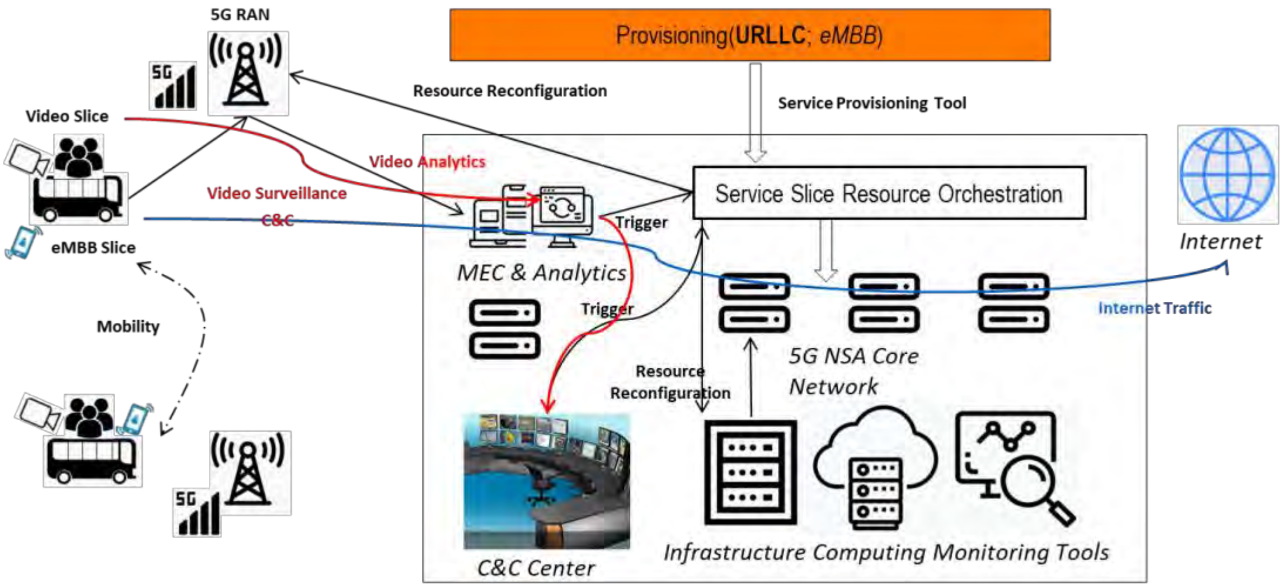


Figure 5-13 UC #1.2 experimentation design for facility requirements

The UC experimentation design is presented in Figure 5-13 and involves the creation of two network slices. The blue slice provides internet access in the Bus (Wi-Fi) by using a 5G compatible device connected to the network. The red slice corresponds to a prioritized connectivity slice between the video camera installed inside the vehicle and the computing entity for further Machine Learning (ML)/AI analysis.

For the network requirements, the specific UC communication characteristics are already evaluated, as described in D2.1 [1] and the experiments are included in deliverable D3.3 [6]. Preliminary images are taken from inside the bus to start the algorithms training phases:

- the blue slice is providing Internet connectivity to the bus passengers for browsing, Downlink capacity 20 Mbps and Uplink capacity 1 Mbps.
- the prioritized red slice is providing cameras connectivity to the compute area installed in Orange AIM site, Downlink capacity 1 Mbps and Uplink capacity 10 Mbps for good video resolution (1080p).

5.2.1 Network Requirement capture/ Processing Requirement capture

As described in section 5.1, the design of the Romanian facility consists of three key locations at which the network is able to provide LTE, LTE-M, 5G NSA, Wi-Fi connectivity and mobile data services within the cells site deployed. These locations are:

- Alba Iulia Facility, Orange site.
- Bucharest Facility, Orange laboratory.
- Paris Chatillon Facility, 5G-EVE cluster.

The details of the UC are described in section 5.3 and require the definition of two network slices, a single core deployment and RAN slice separation as described in deliverable D2.2 [2] and presented in Figure 5-13:

- Slice#1 – the eMBB slice offers up to 20 Mbps, downlink traffic, low traffic prioritization.
- Slice#2 – the URLCC slice offers 10 Mbps, uplink traffic, high traffic prioritization and treated as low latency in 5G RAN.

The list of the network equipment and accessories used for the UC experimentation, as presented in Figure 5-5, include:

- 2 network racks and power supply, dimensioned at 220V/32A for the entire environment.
- 2 USRPs N310, 2 TenGi Interface/USRP and management interface.
  - o USRPs are integrated with DL380 servers through 10Gi interfaces.
  - o Management interface will be integrated separately.
- 2 DL380 servers for OAI/RAN and Core software applications.
- Cisco ASR9k router with 10Gi Interfaces, aggregating all interfaces and providing
- Management switch
- Remote Head Units

Both 5G SA and NSA deployment scenarios will be considered in this UC, as illustrated in Figure 5-14. It consists of 4G and 5G core networks (CN) and radio access networks (RAN) based on the OAI software components. The 4G and 5G RAN is based on NI USRP B2xx or N3xx family products coupled with Antenna and power amplifier. Such scenarios require a private cloud consisting of 2 or more interconnected high-performance servers with orchestrated containers depending on the use-case requirements. The OAI gNB could be deployed in two flavour: monolithic or disaggregated consisting of CU and DU (F1 interface based on 3GPP option 2 split).

5G UDR (unified data repository) makes use of mysql database and 4G HSS software package make use of Cassandra, delivered as a docker images, as a database. Both offers a number of APIs to provision the database as shown in Figure 5-15.

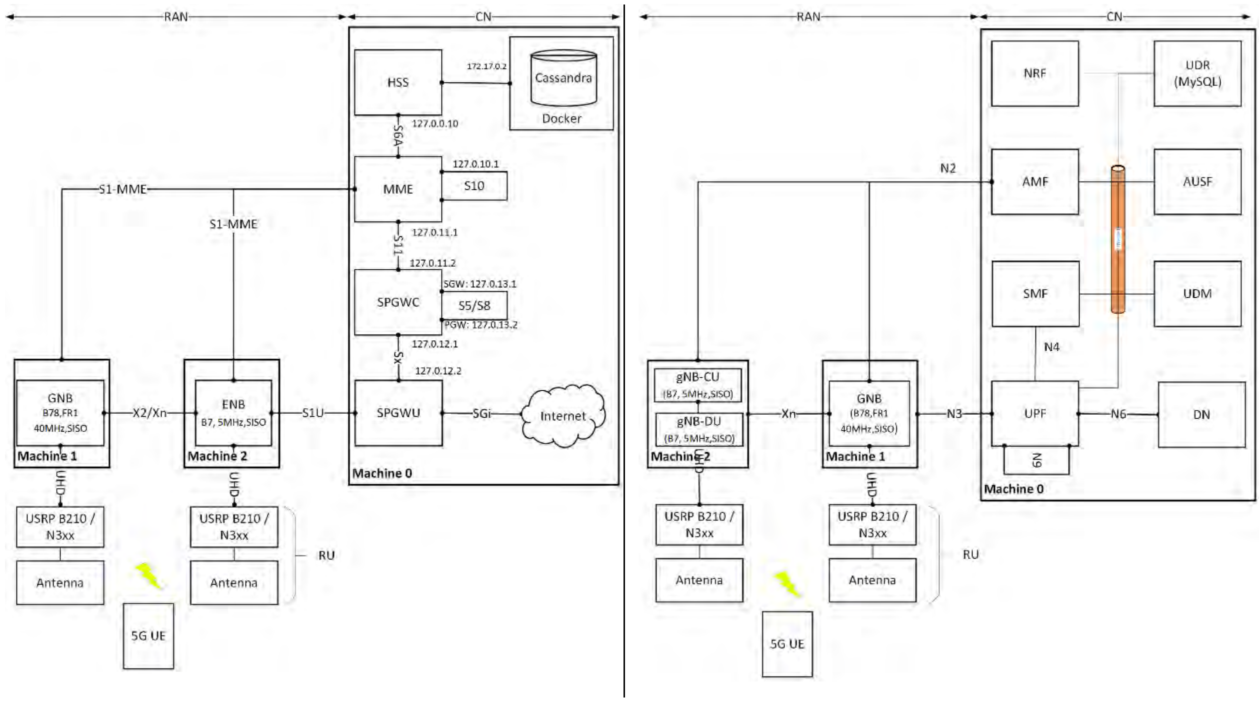


Figure 5-14 RAN/CN capture for NSA (left) and SA (right) deployment scenarios

> *add-users* *[options] Add one or multiple user(s) identfied by an IMSI*
> *dump-users* *[options] dump the current user DB. Use -h for more options.*
> *add-mme* *[options] Add an MME identified by its FQDN. Use -h for more options.*
> *dump-mmes:* *[options] dump the current authenticated mme hosts..*
> *dump-vars:* *Dump internal OAI-HSS vars*
> *reset-users:* *reset to default user entires in the cassandra DB*
> *clean-users:* *clean all user entires in the cassandra DB*
> *reset-mmes:* *rest to default MME entires in the cassandra DB*
> *clean-mmes:* *clean all MME entires in the cassandra DB*

Figure 5-15 APIs to provision the database

5.2.2 Site Survey and report /Final planning

The **UC #1.2** site surveys have been completed and the require locations have been identified. An equipped bus will move around the Orange site facility in AIM to support the mobility UC. The bus journey is near the installed antennas system (described as the ORO site) up to 500 m from the site, covering 2 bus stations. The average bus speed for this scenario is 10 km/h, taking into consideration the traffic conditions in the city, and during experimentation (3 min in average) the bus will remain within the coverage area provided by the 5G gNB.

For video processing and analytics functions a dedicated Edge server is installed at the AIM site, connected to the network. Within this architectural design framework low latency communication can be provided taking less than 1 ms for communication between the core network servers and the edge computing infrastructure.

5.2.3 Network Slice Co-Design

The network service design and slice implementation are described in WP3 [6] and it is implemented as illustrated in Figure 5-16. Based on the already described hardware components and network elements for the RAN and the Core, a first service network slice (uRLLC) is instantiated for the specific media UC, video analytics scenario. A second service network slice (eMBB) is implemented for the Internet service offered in the bus, where no prioritization is required for this service.

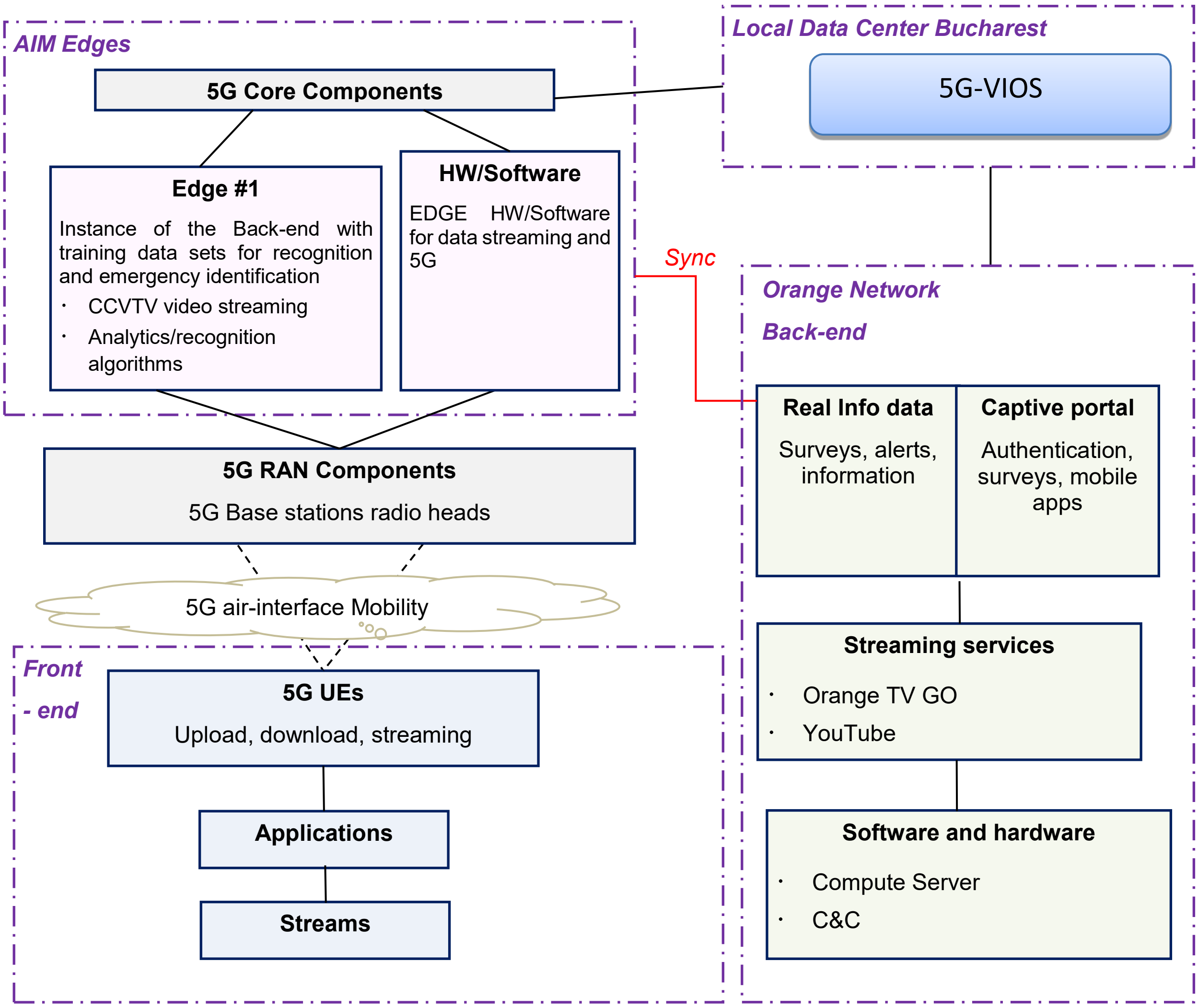


Figure 5-16 5G-VICTORI UC #1.2 framework implementation

Following the flows in the figures, several 5G UEs/Devices are connected to the 5G network deployed at AIM, for both use cases and scenarios, providing video streaming and Internet data access for the C&C Centre and customers that are in the bus. The main components that have to be automatically deployed are the 5G RAN and 5G Core, configuring an E2E solution for service experimentation. The video streaming analytics and traffic flow is sent through the Gi interface to the processing server and further the video content is forwarded to C&C, as seen in Figure 5-13.

The network slice co-design for the UC is based on the two data streams, as described in D3.3 [6]. The first slice, which is dedicated to video streaming analytics, assures 5G connectivity for UL/DL traffic using 5G RAN and 5G Core components and includes Edge Application processing. The second slice is dedicated to the Internet traffic flow providing access to Real Info data, Captive Portal and Orange streaming services.

With network slicing, a logical (E2E) network is dynamically created tailored to particular service / business applications. Such slicing may include the 5G Core Network both Control Plane (CP) and User Plane (UP), the 5G Radio Access Network or any interworking Functions to non-3GPP Access Networks.

New UEs entering the base station need to be associated to a certain slice. Typically, UEs deliver hints on preferred slices, such as the NSSAI in 5G or simply the International Mobile Subscriber Identity (IMSI) or selected PLMN in 4G or 5G NSA deployments. In 5G-VICTORI, slicing is dynamically performed by means of an agent application that auto-associates UEs to slices based on NSSAI, or the IMSI or selected PLMN to offload the controller from control decisions and reduce network load. In 4G and 5G NSA, the association will be based on a prefix-match (e.g., IMSIs starting on a pattern) to choose the correct slice, which assumes that every UE actually sends its IMSI. Such slicing creates a logical BS with specific service types and SLAs. In 5G, a UE may connect to a max of 8 slices in parallel using NSSAI, with the limitation of one common AMF per UE across all slices. It has to be noted that single network slice selection assistance information (S-NSSAI) comprises the Slice Type (SST) describing the expected network behaviour, and the slice differentiator (SD) and it is optional to describe further differentiation. For eMBB, URLLC and MIoT standardized SST values exist. The UE sends the NSSAI – based on the related slice(s) to be selected.

Figure 5-18 illustrates the building blocks for the RAN and CN slicing for this UC. It consists of an O-RAN-compliant flexible RAN intelligent controller (RIC) allowing to perform slicing in the RAN domain, and a flexible CN controller to slice the CN. With RAN slicing, the requested bandwidth is released and the required radio resources are allocated to the slice ensuring the required QoS. With the CN slicing, the UPF may be dedicated to a particular slice.

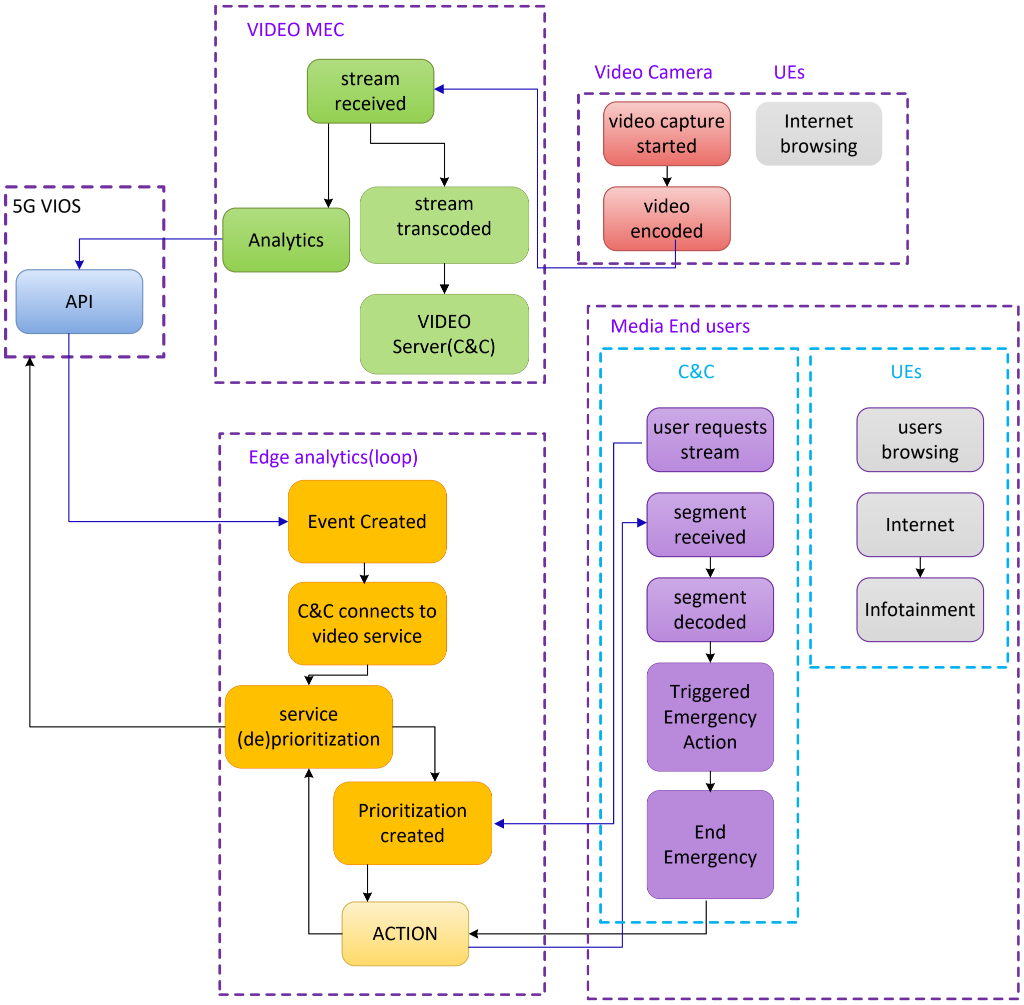


Figure 5-17 UC #1.2 Sequence Diagram

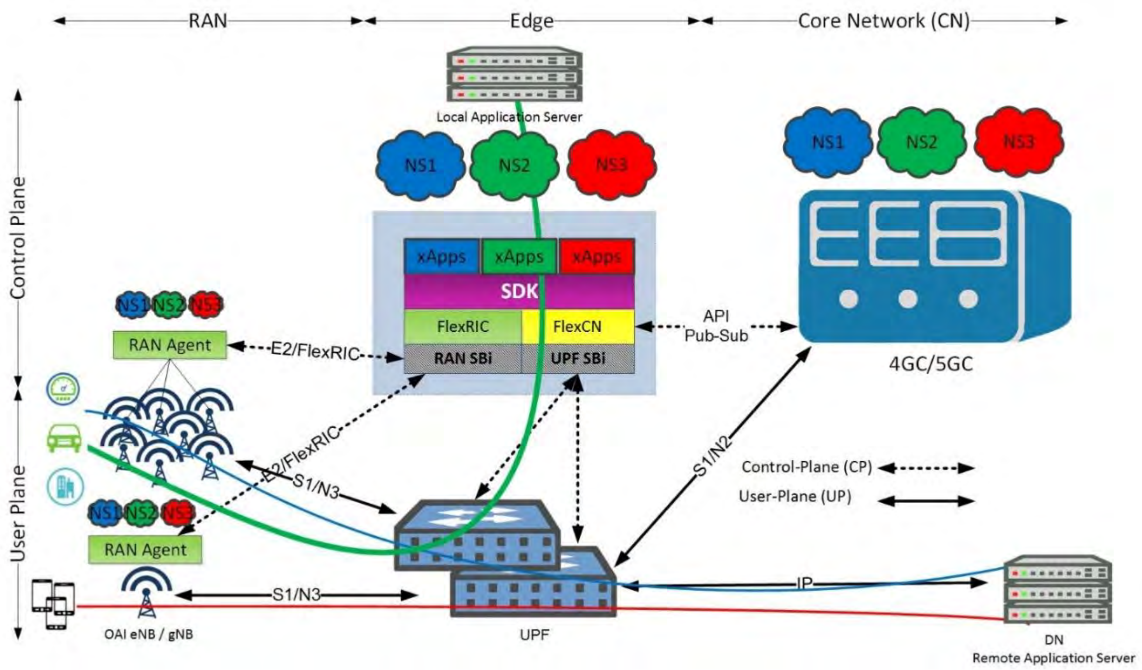


Figure 5-18 RAN and CN slicing system design for the Media use-case

5.2.4 Design Review and Bill of Materials

The network items indicated in Table 5-1 (software and hardware) are considered relevant for demonstrating the Media UC in AIM.

Table 5-1 BoM for the Media UC

Equipment	Item	Components	Quantity	Dimensions	Power supply
Router **IP connectivity** 	Cisco ASR9k	N x 10 Gbps Interfaces	4	132.6 x 443 x 234.2 mm)- 40.7 kg	550 W input power. Up to 2 power supplies (AC or DC)
L2 switches 	Cisco NX-OS	48 x 1Gbps 4 x 10 Gbps	3 4	**Dimensions**: 4.5 x 36.8 x 44.5 **Weight**: 6 kg	PWR-250 W AC
Compute servers **Control Servers** 	HPE DL360	2 x 24 Cores 4 x 10 Gbps Interfaces 4 x 1Gbps	2	4.29 x 43.46 x 70.7 cm	2 x 500 W
4G/5G **Networked SDR** 	USRP N310	SDR	2		
Antennas	Kathrein		2		
 **o Amplifier**	Remote Radio Head	High Power MIMO 2x2 RRH	1		
UE 5G Devices	Samsung S205G	5G SA/NSA: N78	5		
5G Router 	Sierra Wireless	5G High Performance Multi-Network Vehicle Routers	4	272 mm x 220 mm x 60 mm	
NVIDIA GeForce RTX 2080 	GeForce RTX 2080	GPU: TU104/ TU104-400A-A1	2		
Wi-Fi Routers	AirLink® MG90/MG90 Sierra Wireless	dual concurrent 3x3 MIMO 802.11 b/g/n/ac, Dual Band 2.4/5 GHz	4		

Camera 	Hikvision 5MP	4			
4G LTE Radio + eNB	Huawei SRAN 16	4G LTE: B1	1		
5G NR	Huawei SRAN 16	5G SA/NSA; n78	1		

During 2020 Orange Romania has proceeded in the procurement of almost all network items to be used in the planed demonstration activities at AIM.

In terms of software components, Table 5-2 shows the BoM.

Table 5-2: BoM Software components

SW Component	Vendor	Environment	Quantity	Testbed	HW Requirements
gNB (Monolithic)	OAI Amarisoft	Bare Metal Container(OAI)	2	EUR Pre-trial ORO (OAI)	Intel Xeon Gold, i9 > 12 Cores, > 3 GHz base frequency RAM < 64 GB 2 x 25 Gbps (PCI-e) Ubuntu/Centos/Fedora
eNB (Monolithic)	OAI Amarisoft	Bare Metal Container(OAI)	2	EUR Pre-trial ORO (OAI)	Intel Xeon Gold, i9, > 4 Cores, >3 GHz base frequency RAM < 32GB 2 x 10 Gbps (PCI-e) Ubuntu/Centos/Fedora
5GC	OAI Nokia Amarisoft	Bare Metal Container(OAI)	1	EUR Pre-trial ORO (OAI)	Intel Xeon Gold, i9, > 4 Cores, > 2.7 GHz base frequency RAM < 32 GB 2 x 10 Gbps (PCI-e) Ubuntu/Centos/Fedora
4GC	OAI Nokia Amarisoft	Bare Metal Container(OAI)	1	EUR Pre-trial ORO (OAI)	Intel Xeon Gold, i9, > 4 Cores, > 2.7 GHz base frequency RAM < 32 GB 2 x 10 Gbps (PCI-e) Ubuntu/Centos/Fedora
FlexRIC	OAI	Bare Metal Container	1	EUR Pre-trial ORO (OAI)	Intel Xeon Gold, i9, 4 Cores, >3 GHz base frequency RAM < 32 GB 1 x 10 Gbps (PCI-e) Ubuntu/Centos/Fedora

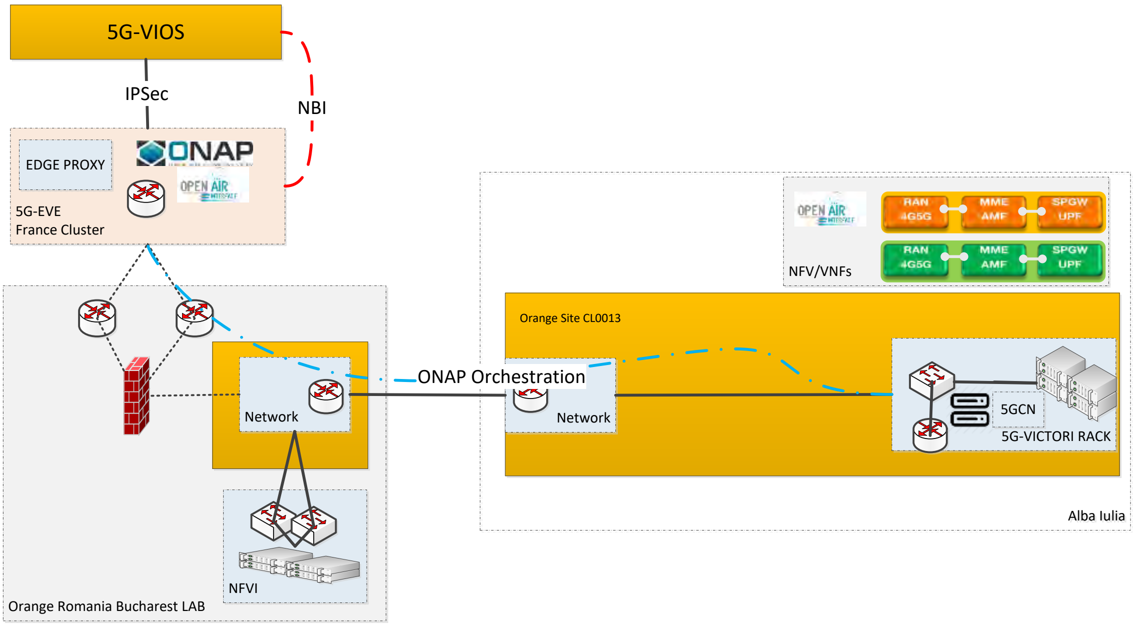


Figure 5-19: 5G-VICTORI required network interconnection

5.2.5 Description of Equipment

5.2.5.1 Specifications and Interconnections (ORO)//ONAP

As presented previously, the design of the 5G-VICTORI Romanian facility consists of two main sites in Bucharest and AIM. To support connectivity across these sites two major platforms have been identified:

- The 5G-VIOS Platform with the 5G-EVE French Cluster Orchestrator (ONAP)
    - Further interface details will be provided in deliverable D2.6 "5G-VICTORI Infrastructure Operating System – Final Design Specifications".
- The 5G-EVE French Cluster Orchestrator (ONAP).

The two locations in Romania are connected through the Orange IP/MPLS network using 10 Gbps interfaces, all the RAN/Core and servers installed at **AIM** are connected through 10G interfaces, as already described. The design permits both broadband connectivity and low latency UCs implementation, presented in Figure 5-19.

5.2.5.2 Interfaces with the Use Case specific Equipment

The UC will make use of the compute infrastructure at the edge and core at AIM and Bucharest, where the experiments will take place. The UC/end users services (eMBB, video streaming) will access the network through 5G capable devices (modems/routers/Smartphones). Wi-Fi services will be offered also on the moving Bus.

The network instances required for UC experimentation are using ONAP for service deployment in the network infrastructure for OAI RAN and Core instantiation. They use preconfigured APNs for the E2E network slicing creation, with the possibility of extending the deployment of the services to the edge of the infrastructure for analytics services. Part of the transport network between Bucharest and AIM will be pre-configured for the UC testing and validation, KPIs measurements will be performed as described in WP3 D3.1 [5].

5.2.6 Identifying Gaps with existing Test Network Capabilities

The UC KPIs and application requirements for the network implementation, as described in WP3 deliverable D3.1 [5] and in section 4.2, require suitable radio coverage around the Orange Site, mobility capabilities and an expected data throughput for both UL and DL traffic. The outdoor coverage was initially considered to be provided by a single M-MIMO 5G NR unit. However, based on the use case requirements in terms of coverage and capacity/throughputs, due to the limitation of the USRP Radio power, we have identified the necessity of 5G power amplifier, using a Radio Remote Unit in N78 band. This was further evaluated in relation with the OAI capabilities, described as a remote radio head product.

- High Power MIMO 2x2 RRH.
- Up to 2x40 W RF output RRH.
- MIMO 2x2.
- CPRI/eCPRI input.
- Supporting all standard bands TDD / FDD.

The identified product is the RRH JAGUAR equipment 2x2 MIMO N78 (3400-3600 GHz), 48V 2x20W, RRU 2x2 pole mouting kit, RRU 2x2 power supply cable and RRH eCPRI option. This product will optimize the radio performance for the use case applications.

5.2.7 Planning of Lab testing and initial validation of services per use case

In terms of feature and functionalities of OAI RAN, the first target is to develop and provide 5G Non-Stand Alone (NSA) RAN software and enable connection and traffic flow with a NSA-capable 5G commercial UE. In the NSA setting the gNB is supplemented by the LTE eNB that carries the control plane of the 5G signalling, while the data bearer is set up on the gNB. A NSA capable 3GPP Rel-15 4G EPC is connected through the S1 interface to the eNB and the X2-C interface enables connection between the eNB and gNB for routing and managing the flow of IP traffic. The NSA mode is also referred to as the E-UTRAN New Radio – Dual Connectivity (ENDC) mode and is shown here in figure. The 5G RAN project consists of the following phases over the course of the two year timeplan for the development of the use case starting in summer 2020:

- **Phase-I**: The first phase of the development consists of a no-S1 mode which is an intermediate phase already implemented with a preconfigured eNB and UEs that is configured to work without the existence of the core network.
- **Phase-II**: Phase-2 which includes the full NSA solution under 3GPP deployment option 3.x with the EPC supporting core network functionality.
- **Phase-III**: The second target is the development of the 5G Stand-alone (SA) RAN software. The packet network is based on the 5G SA core including AMF, SMF and UPF elements as the main components of the 5G SA core to which the 5G gNB is connected through the Next Generation (NG) control (C-) and user (U-) plane interfaces.

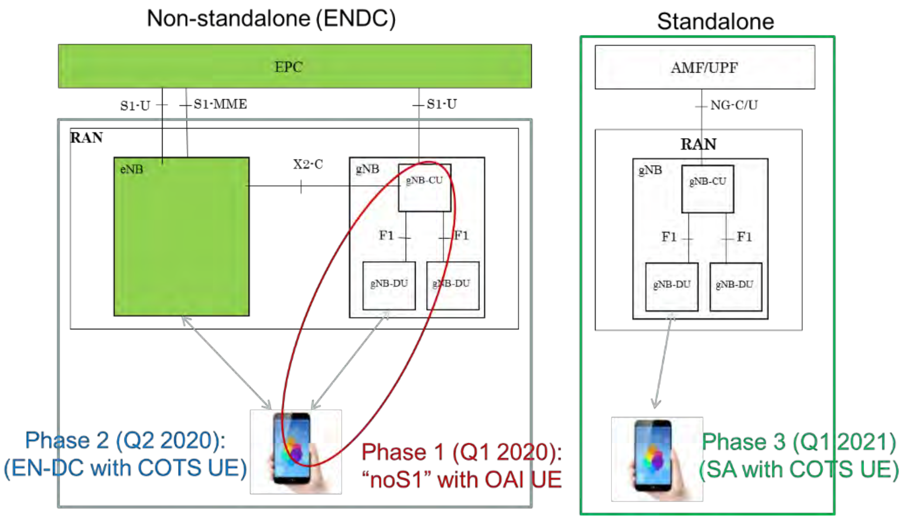


Figure 5-20: Development phase of OAI 5G RAN

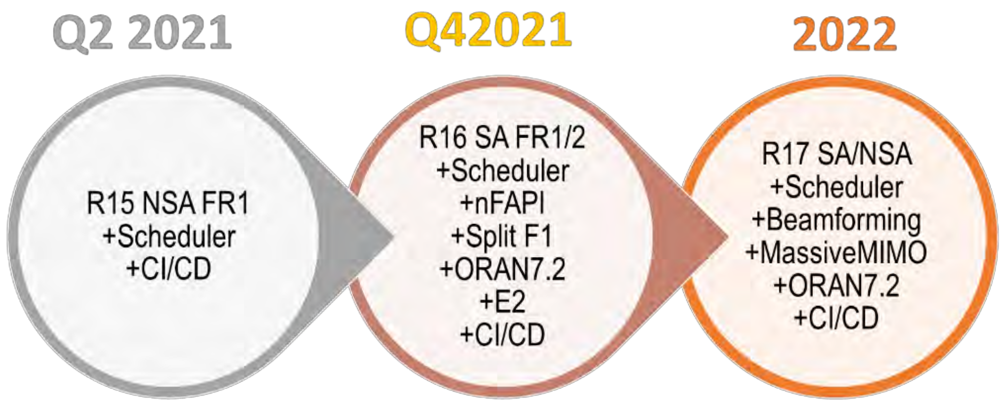


Figure 5-21: Timelines of OAI 5G RAN

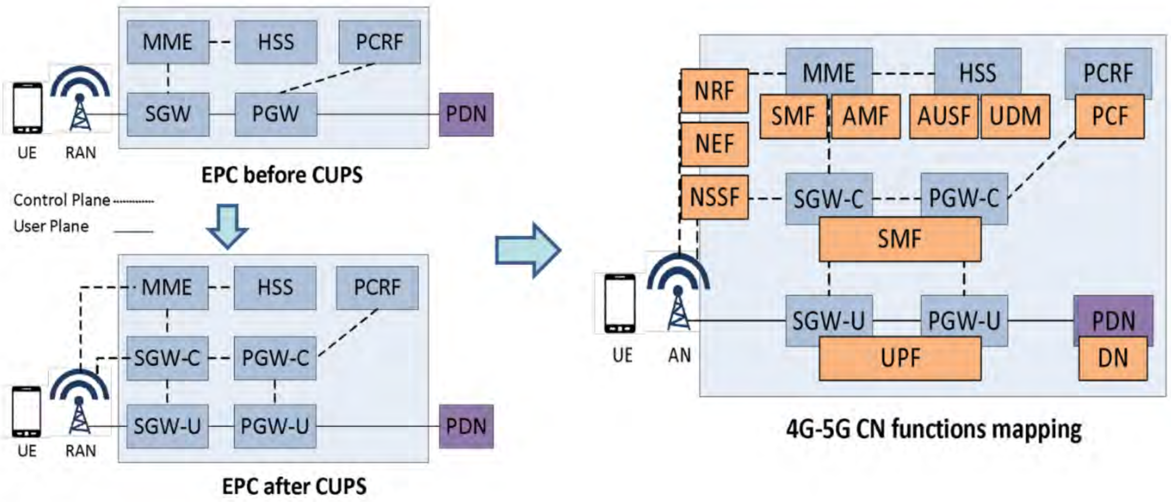


Figure 5-22: Development phase of OAI 5G CN

Figure 5-21 gives the status of current 5G RAN implementations in the OAI codebase and the roadmap of future implementations.[8]

The scope of 5G CN project developments is to deliver a 3GPP compliant 5G Core. The 3GPP 5G system architecture, based on correspondence between the 5G core and 4G LTE-EPC is shown in Figure 5-22. The developments in the framework of this project cover all parts of the 5G core coloured in orange. The project will consist of the following phases over the course of the two years starting in summer 2020:

- Phase-I: Basic deployment of AMF, SMF and UPF in docker containers based on the Ubuntu bionic with basic call flow and traffic tests;
- Phase-II: Continuous implementation of features as added updates for the existing network components (AMF, SMF and UPF) with addition of extra network components like UDM and Authentication Server Function (AUSF);
- Phase-III: Full stand-alone 5G core implementation and complete deployment framework for a microservices-based architecture.

Figure 5-23 gives the status of current 5G CN implementations in the OAI codebase and the roadmap of future implementations.[9]

[8] https://openairinterface.org/oai-5g-ran-project/

[9] https://openairinterface.org/oai-5g-core-network-project/

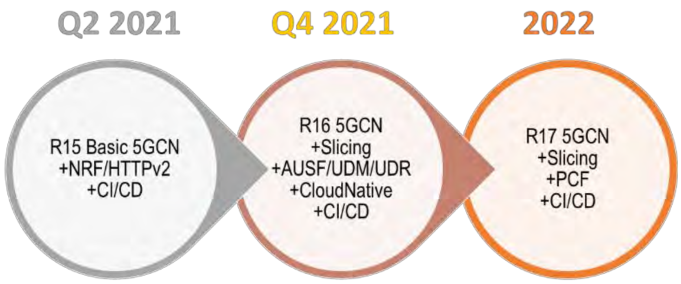


Figure 5-23 Timelines of OAI 5G CN

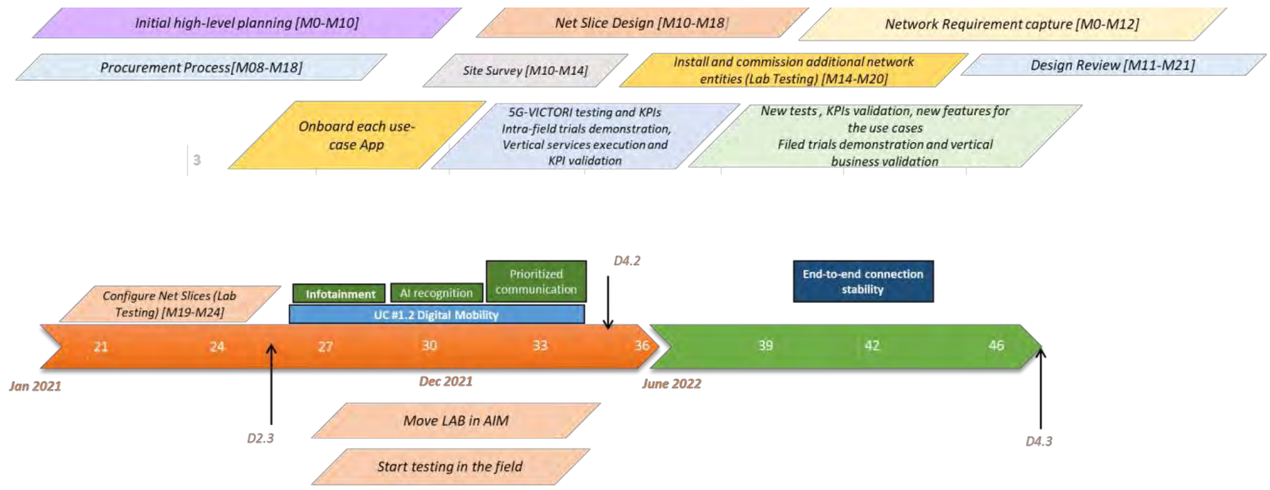


Figure 5-24 UC #1.2 lab testing planning

The testing plan for the UC is shown in Figure 5-24, and all different components and functionalities are priority tested in the LAB in Bucharest before final testing and experimentation at AIM. For all the tests the VMs and applications will be hosted at the Bucharest LAB and then the applications will be tested in AIM.

5.3 UC #4.2 LV Energy metering

UC #4.2 LV Energy metering is the 2nd UC for experimentation in the Romania facility of the 5G-VICTORI FR/RO cluster. This will concentrate on E2E LV metering and Energy analytics services over the 5G infrastructure assuring real time management and orchestration, as described in deliverable D2.1 [1] and in D3.5 [7], and more specifically:

- Real-time LV energy metering services for the AIM infrastructure.
- Energy Analytics for predictive and proactive maintenance for the AIM LV infrastructure.

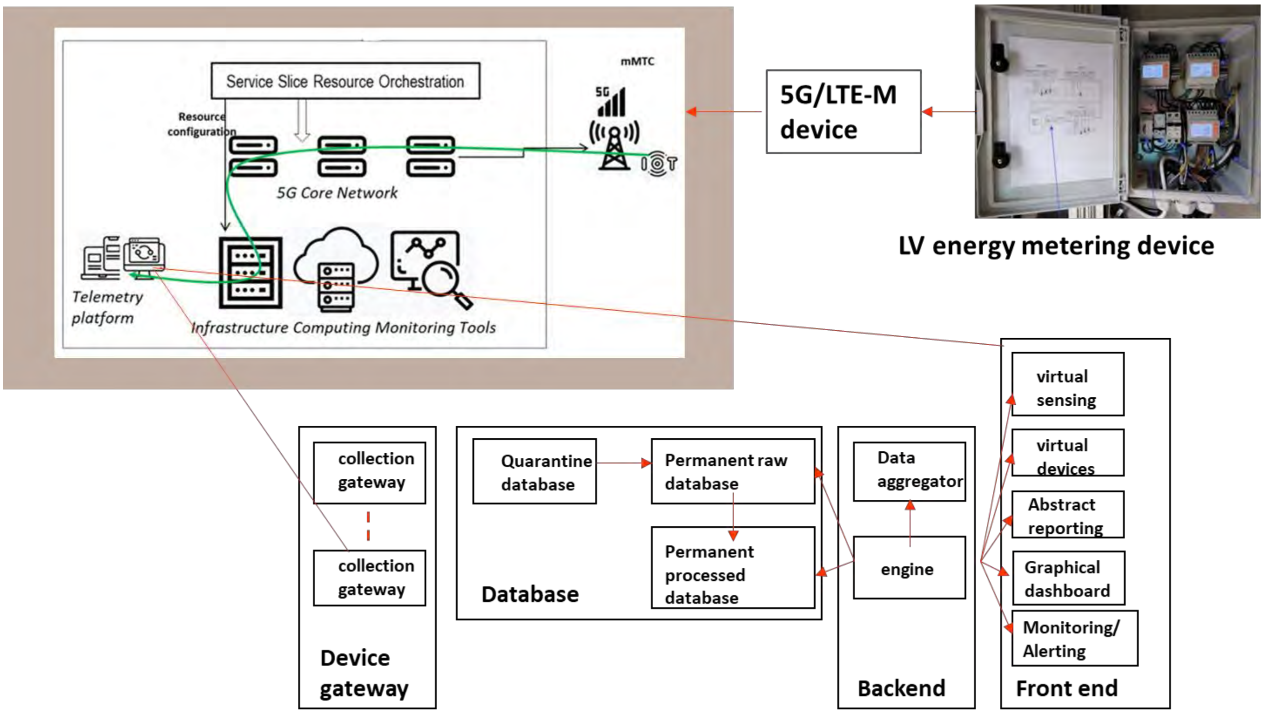
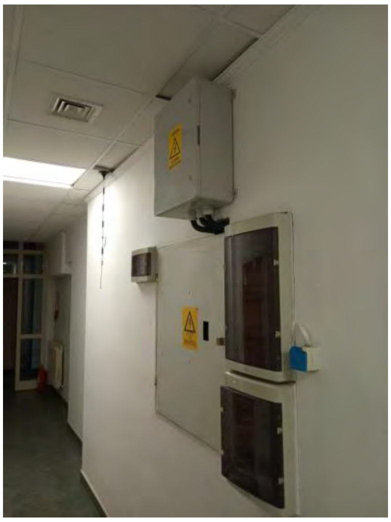


Figure 5-25 5G-VICTORI UC #4.2 Architecture and experimentation overview

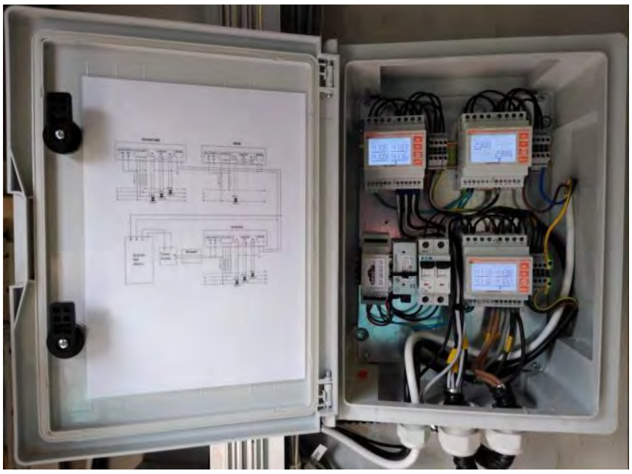
The UC is designed to provide:

- Real-time LV energy metering
    - metering data collection from endpoints deployed at the AIM locations.
    - collected measurements will be transferred to the 5G-VICTORI central cloud facilities to be stored, processed and analysed by the telemetry platform.
    - UC's will be demonstrated over the 5G-EVE infrastructure providing energy metering services for energy consumers like public buildings and street lighting in AIM.
- Energy Analytics for predictive and proactive maintenance for AIM LV infrastructure
    - energy analytics application development for real time & historical view as well as reporting of status and parameters.
    - advanced reports focusing on usage, running cycles & times, operational status for AIM LV devices will be developed.
    - QoS graphical visualization and reporting based on LV energy sensor collected data.
    - alerting events and incidents provoking real time triggers, based on measured parameters and predefined threshold.



LV Power units

LV in buildings



LV generic cabinet

LV generic cabinet

Figure 5-26 Examples of LV related infrastructure at AIM

5.3.1 Network Requirement capture/ Processing Requirement capture

As described in section 5.1, the design of the Romanian network testbed is able to provide LTE, LTE-M, 5G NSA, Wi-Fi connectivity and mobile data services within the cells site deployed and is composed by three key locations:

- Alba Iulia Facility, Orange site
- Bucharest Facility, Orange laboratory
- Paris Chatillon Facility, 5G-EVE cluster

The UC described requires the definition of a single network slice and single core deployment, as described in deliverable D2.2 [2]: Slice#1 – the mMTC slice offering 1 Mbps, UL/DL

The list of equipment presented in Figure 5-5, involve:

- 2 network racks and power supply, dimensioned at 220V/32A for the entire environment.
- 2 USRPs N310, 2 TenGi Interface/USRP and management interface.
- 2 DL380 servers for OAI/RAN and Core software applications.
- Cisco ASR9k router with 10Gi Interfaces, aggregating all interfaces and providing.
- Management switch.

5.3.2 Site Survey and report /Final planning

The UC#4.1 site survey has been completed and the relevant location has been identified. This UC does not require mobility or high bandwidth capacity in AIM, but corresponds to the mMTC-IoT communication services:

- Bandwidth ≈128 kbps/device.
- RTT ≈ 30 ms.
- applicable up to 30 devices in AIM area.

The surveys reports are split in two parts:

- network surveys, as described in Section 5.1.
- AIM surveys, as described in the Annexes (in the annex to add the list of points of presence for the IoT identified locations).

The RAN and Core deployment scenario is the same as the one described for **UC #1.2** with mMTC slice configuration to support the UC requirements. Such a slice configuration will be performed by the RAN and CN controllers.

5.3.3 Network Slice Co-Design

The network service design and slicing implementation are described in WP3, deliverable D3.5 [7], and the E2E service is implemented as in Figure 5-25, based on the already described hardware network components, RAN and Core Elements. A single simple network slice is instantiated, providing connectivity from the IoT devices through the deployed infrastructure to the IoT Application hosted in the Cloud.

The network co-design for this UC is based on a single data stream for the related LV application, LTE-M connectivity and Cloud application for data collection and analysis.

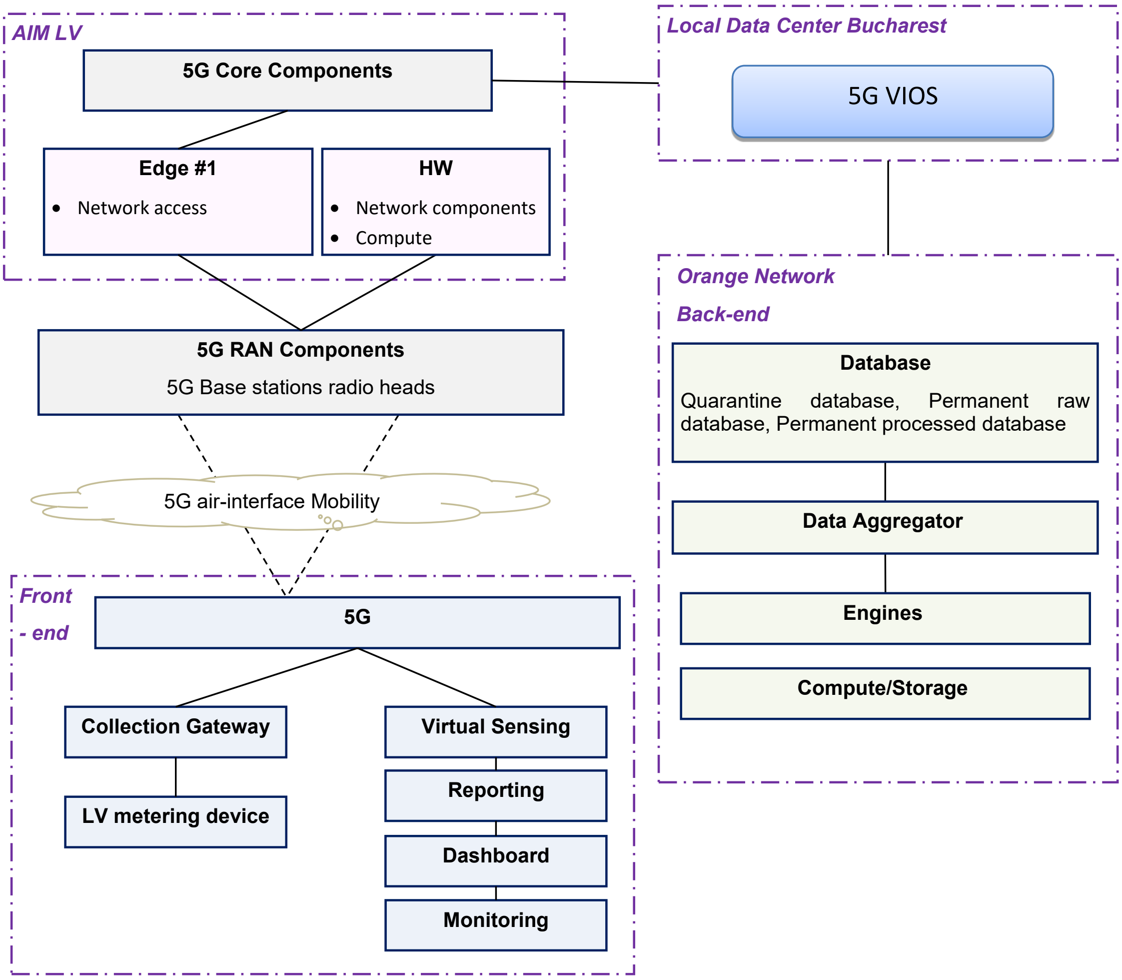


Figure 5-27 5G-VICTORI UC #4.2 framework implementation

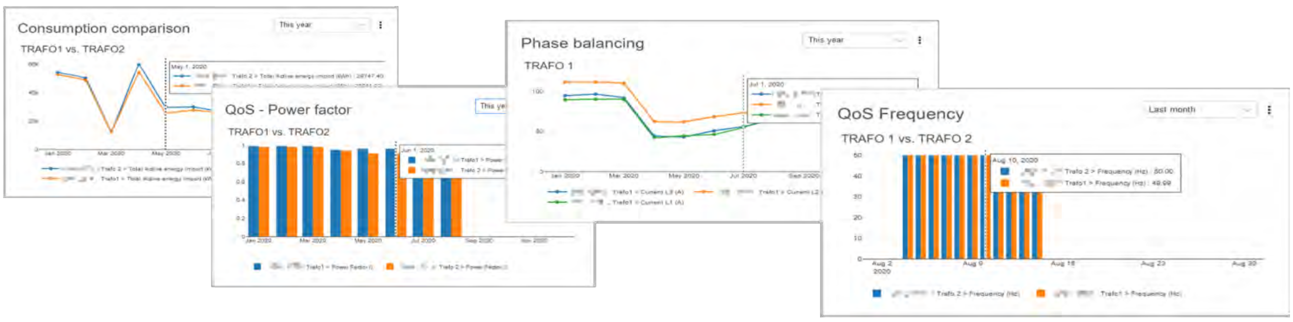


Figure 5-28 UC #4.2 energy analytics predictive/proactive maintenance

5.3.4 Design Review and Bill of Materials

The following network items (software and hardware) are considered relevant for the demonstration of the LV media UC at AIM, as the network and core components required are similar to that of **UC #1.2**.

Table 5-3 BoM for UC #4.2

Equipment	Photo	Item	Components	Quantity	Dimensions	Power supply
Router **IP connectivity**		Cisco ASR9k	N x 10 Gbps Interfaces	4	132.6 x 443 x 234.2 mm - 40.7 kg	550 Watt input power. Up to 2 power supplies (AC or DC)
L2 switches		Cisco NX-OS	48 x 1 Gbps 4x10 Gbps	3 4	4.5 x 36.8 x 44.5 6 kg	PWR-250WAC
Compute servers **Control Servers**		HPE DL360	2x24 Cores 4x10 Gbps Interfaces 4x1 Gbps	2	4.29 x 43.46 x 70.7 cm	2 x 500W
4G/5G **Networked software defined radio**		USRP N310	SDR	2		
Antennas		Kathrein		2		
Metering device and compact split core		Lovato Electric		>10		
Metering Split Core		Lovato Electric		>10		
IoT Control Telemetry Device(NB-IoT/LTE-M)		Industrial IoT Device	GPU: TU104/ TU104-400A-A1	2		

Power Supply		Mean Well RS15	-	-	-	-
Breaker		EATON 2A	4	-	-	-
Cabinet		Measurements Cabinet	-	-	-	-
4G LTE Radio + eNB		Huawei SRAN 16	4G LTE-M B1	1	-	-

During 2020 Orange Romania has proceeded in the procurement of almost all network items required for the application demonstration at AIM.

5.3.5 Description of Equipment

The UC will make use of the compute infrastructure at AIM and Bucharest, where experimentation will take place. The UC/end users (mMTC) will access the network and the services through 4G-LTE-M capable devices, the IoT connectors.

5.3.6 Identifying Gaps with existing Test Network Capabilities

The planning and timelines of the OAI software components remain the same as in **UC #1.2**.

5.3.7 Planning of Lab testing and initial validation of services per use case

The plan of testing for this UC is shown in Figure 5-29:

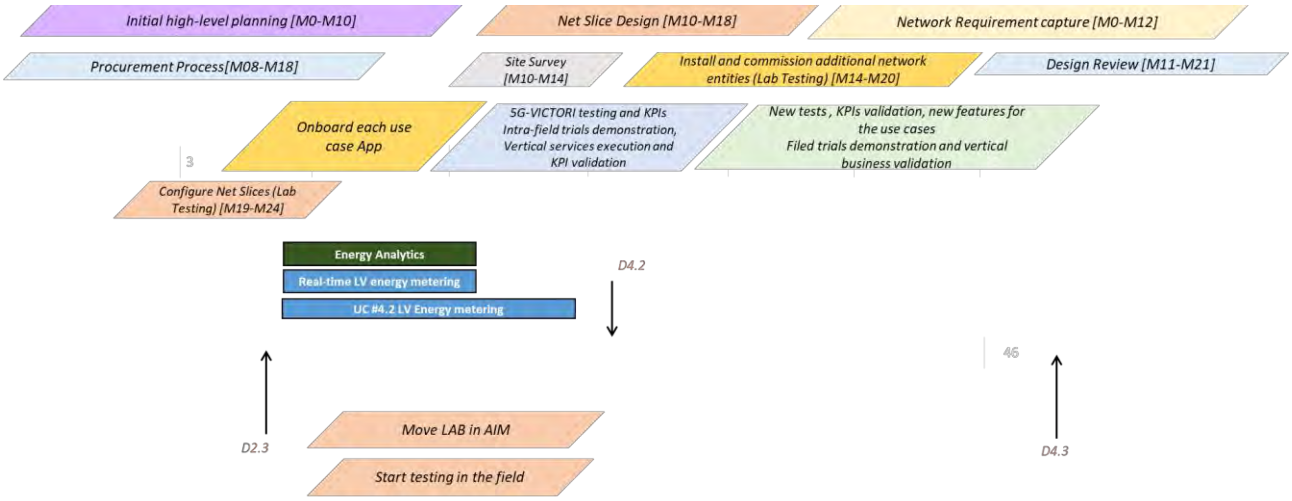


Figure 5-29 UC #4.2 experimentation planning

5.4 Final Facility assessment / Unforeseen risks and mitigation plan

Several conditions are imposing risks and potential delays, as described in Table 5-4:

Table 5-4 Risks and Mitigation plan

Risk ID	Description	Impact	Mitigation Plan
UC #1.2-FR/RO-R1	5G N78 Radio coverage in AIM	Medium	• Radio Head Unit to be installed in AIM
UC #1.2-FR/RO-R2	ORO B1 and N78 spectrum	Medium	• Spectrum available in N78, B1 will have to be cleared in AIM
UC #1.2-FR/RO-R3	Device availability and interoperability	Medium	• To be used devices tested and validated in LAB
UC #4.2-FR/RO-R5	IoT LV interoperability	Low	• mIoT Devices to be tested in LAB for OAI interoperability

6 Patras Cluster Facility Planning

The baseline implementation of the Patras 5G experimental platform is being developed within the ICT-17 5G-VINNI [8] project. The plan in 5G-VICTORI is to upgrade this platform with additional functionalities and to extend it towards several operational facilities owned by Greek vertical industries [2]. This will allow the implementation of the 5G-VICTORI UCs running in Patras [1], and will be able to also support cross-vertical and cross-facility experimentation and KPIs validation. In this regard, different 5G service classes will be supported, i.e. eMBB, uRLLC and mMTC.

The Patras 5G-VICTORI facility is designed to facilitate a variety of UCs that span from **Transportation** to **Energy**, **Media** and **Industry 4.0** application areas. Early identification of all requirements associated with each UC in terms of system functionality, network performance as well as definition of the infrastructure components, has led to accurate design of the facility extensions. This was also facilitated through several site surveys that helped in the definition of placement and deployment of Hardware and Software components required for support of the UCs. These UCs include:

- **UC #1.1** Enhanced Mobile Broadband under High Speed Mobility (see section 6.4 for the full facility planning related to this UC).
- **UC #2** Digitization of Power Plants (see section 6.5 for the full facility planning related to this UC).
- **UC #3** CDN services in dense, static and mobile environments (see section 6.7 for the full facility planning related to this UC).
- **UC #4.1** Smart Energy Metering – Energy Metering for HV (see section 6.6 for the full facility planning related to this UC).

6.1 5G-VICTORI planning phase challenges

The Patras 5G-VICTORI facility is extended to two sites in the Patras area and to another facility close to the city of Corinth, where the Energy UC (**UC #4.1**) will be showcased.

This facility initially included Patras and Rio sites. However, due to main reconstruction of the railway network in Patras during the COVID-19 lockdown, a relocation of the major UCs was decided and re-planning of the work described in D2.2 [2] was performed to ensure that all UCs will be supported in the newly designed network extension and all services and applications will be validated as planned.

6.1.1 UC #1.1 challenges

Different public and private network deployments in railway environments are currently providing a variety of services with different target end-users. 5G-VICTORI addresses this type of environments and proposes the use of 5G technology in legacy multi-technology environments.

UC #1.1 in D2.2 [2] proposed a multi-technology infrastructure to provide connectivity to a train as it moves along a railway track. Three to four points along the tracks around the city of Patras had to be chosen to guarantee the coverage required to ensure seamless connectivity for the demonstrated services. The target distance was more than 1 km for a back and forth rail journey. This part of the track was chosen in order to ensure connectivity to the main 5G-VINNI infrastructure at the UoP premises. On the other hand, this connection requires LoS for the backhaul network from UoP to the track. Additionally, LoS is mandatory to ensure strict alignment for the track to train connectivity.

6.1.2 UC #3 challenges

The Media UC offers an innovative solution, where a multi-layer CDN technology integrates high definition media content delivery onboard a train, as a TRAINOSE train approaches a railway station.

The solution benefits from the fact that the train remains for some time at, e.g. platforms, train depots, etc. In this UC, "data shower" techniques will be used supporting data rates of 1-1.5 Gbps.

Here the planning exercise took place together with **UC #1.1**, as the same onboard Network deployment and the vertical facility (**TRAINOSE**) is considered. As a result, the outcome of this planning phase led to the placement of a gNodeB at the railway station that is located at the end of the route planned for **UC #1.1**. Here the planning work explained below combined the **ICOM** CDN solution enabled by MEC and high capacity network coverage at the train station.

6.1.3 UC #4.1 challenges

(**UC #4.1**) involves two vertical industries Energy and Rail. Here **ADMIE**, the Greek Independent Power Transmission Operator (IPTO), identified the requirement of real time collection of energy consumption and load data and granular energy data manipulation for development of services for high consuming customers.

The planning phase of the specific UC mainly concerned site surveys at the combined TRAINOSE/ADMIE sites, UC equipment planning and placement at the vertical facilities, orchestration of various platforms and test cases design and planning. The major outcomes of the planning work are reported in section 6.6.

6.1.4 UC #2 challenges

Furthermore, **ADMIE** is leading the Smart Factory UC (**UC #2**), which uses the 5G-VICTORI pilot for the digital transformation of the ADMIE facilities. Facility planning at the ADMIE facilities involved several challenges including two high voltage (HV) facilities that at located 4 km apart and separated by a sea canal requiring strict data synchronization. This makes wireless connectivity between them not suitable. An additional challenge has to do with the in-house developed equipment that has to be used for the support of the UC. From the various options considered in deliverable D2.1 [1], interconnecting the two sites with a direct fibre link was decided as the most suitable option. At the network and processing design level, MEC capabilities had to be incorporated to ensure that the network design meets the UC requirements. Furthermore, both sites are considered to be High Voltage (HV) sites imposing strict synchronization requirements of civil works during power cuts and on the suitable BoM. More information is provided in section 6.5.

6.2 Final Facility commitment

6.2.1 TRAINOSE SA rail facility

TRAINOSE SA is at the moment the main and only provider of rail transportation for passengers and freight in Greece. The Company provides rail services using the network and the railway infrastructure owned by OSE. In Patras TRAINOSE runs the urban train services and will use the specific site identified by the project as a pilot for demonstrating demanding services and applications supported by 5G technology.

The facility is shown in Figure 6-1. It differs to that reported in deliverable D2.2 [2] due to the major reconstruction work happening at the rail tracks in the region. Fortunately, a facility near the city centre of Patras, where all services can be showcased, is already committed. It spans from the Patras Central station (near to D4 in Figure 6-1) to the Depot, which is close to D1. The 5G-VICTORI network extension lies along the main TRAINOSE railtrack. The transport network interconnects the main 5G-VINNI facility (at UoP premises) through the backhaul network and ensures the execution of the services related to **UC #1.1** and **UC #4**. At the Depot (D1) the train is connected to the gNodeB of the Depot Station, which allows the execution of the CDN UC (**UC #3**). The train continues the journey in a part of the rail track where no 5G connectivity nor 5G-VICTORI network coverage exists. On the way back the train can again traverse the 5G-VICTORI extension along the rail track.

Figure 6-1 Network diagram for UC #1.1 over Patras satellite map

6.2.2 ADMIE Rio-Antirio Facility

The Rio-Antirio facilities of **ADMIE** are chosen as the 5G-VICTORI site for the demonstration of the Energy and Factories of the Future services in the context of **UC #2** "Digitization of Power Plants". Both facilities lie at each side of the Rio-Antirio canal and they are separated by approximately 4 km of sea. The facility manages the Rio-Antirio submarine energy interconnection via a HV submarine cable, which passes along the Rio-Antirio bridge, with special requirements (cf. section 6.1.2).

The Rio ADMIE site and terminal station lies in a large area of land (see Figure 6-2). Here a Control room is used to monitor the health of the cable plus a set of legacy devices with no internet connection, and a set of LEDs that inform the personnel about the health of the cable. Furthermore CCTV cameras and sensor devices are used for the ADMIE service.

The Antirio site resides at the Antirio village (right part of Figure 6-2). For the trial, the 5G-VINNI facility in Patras is extended to connect the two isolated sites of **UoP** and **ADMIE** facilities. For that purpose, a mmWave link is deployed across the two sites, whereas a submarine fibre optic link is used for the interconnection of the two ADMIE facilities.

The network brings in data from both sides (Rio and Antirio) to the processing units that exist at the Rio edge data center. To ensure high degree of synchronization and data correlation, the integrated 5G-VINNI / 5G-VICTORI facility utilizes a submarine fibre cable as access transport solution. To that end, the data from the Antirio area will be transported to the edge data centre together with the data gathered from Rio for synchronization and correlation.

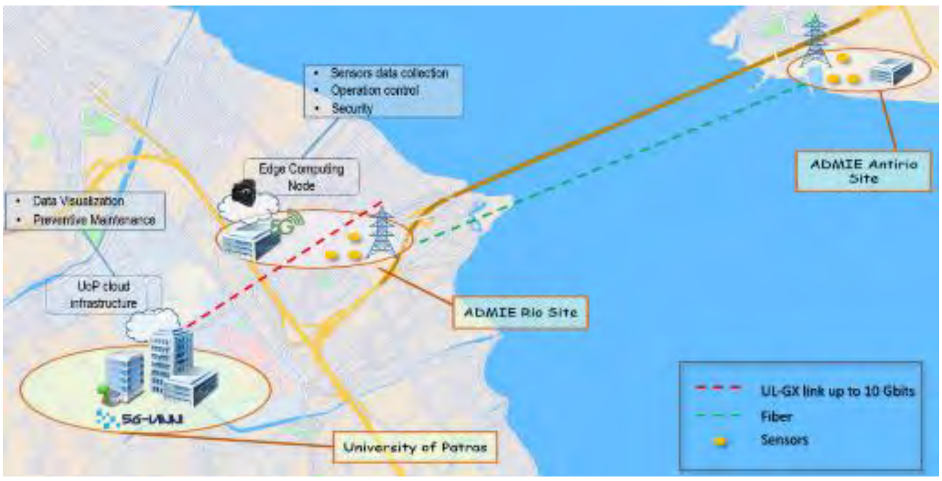


Figure 6-2 High-level network design Rio-Antirio site

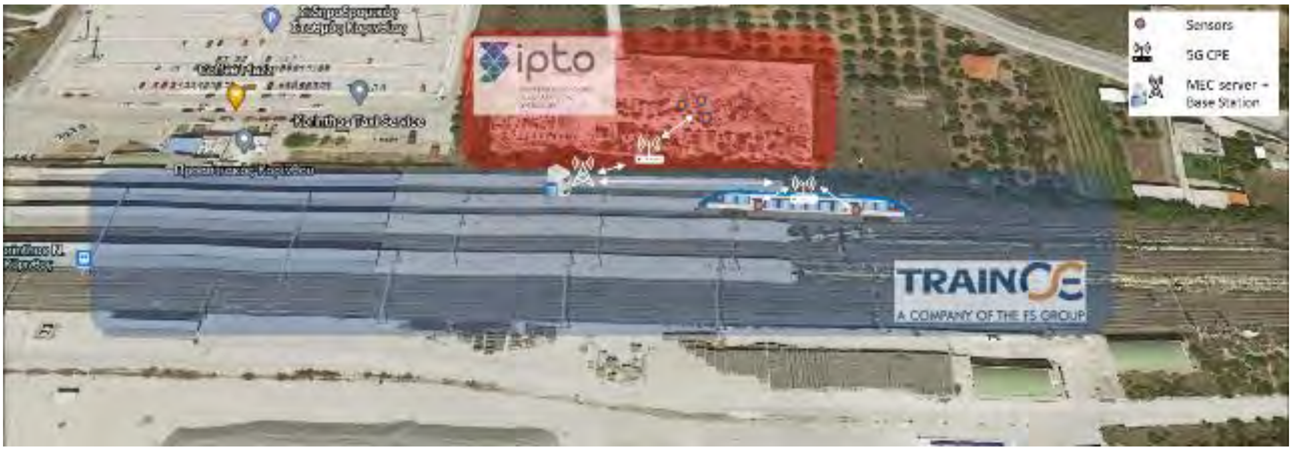


Figure 6-3: Corinthos High-level Facility plan

6.2.3 Corinthos Facility

The Corinthos site is chosen as the suitable site for the demonstration of the Energy and Factories of the Future services in the context of **UC # 4** "Smart Energy Metering", specifically **UC # 4.1** "Energy Metering for HV". Initially in deliverable D2.2 [2], the site of Loutropyrgos was considered. Due to the proximity of the TRAINOSE and ADMIE facilities, the former site was considered to be more suitable with respect to the latter.

In **UC #4** the aim is to bridge the energy digital utilities and the transportation-rail sectors in the process of HV electrical energy monitoring (see Figure 6-3:). The former is represented by an Energy Transmission System Operator (TSO), i.e. **ADMIE**, and the latter by a Railway Operator, i.e. **TRAINOSE**.

The deployment architecture comprises a 5G gNB (access), which will be installed close to the Corinthos substation to better provide the required coverage to the train; the measuring devices already installed at the ADMIE substation while the sensors will be installed onboard the electric train.

6.3 Network Extension

As seen in the map shown in Figure 6-4, the Patras 5G-VICTORI facility is spread across various sites located around the city of Patras to support the 5G-VICTORI UCs.

A block diagram that maps the available technologies to the different sites, together with their interconnection is shown in Figure 6-5. Construction works have been performed in some of the places and the status of the works is shown in the figures below. Specifically, in Figure 6-6 and Figure 6-7 the initial civil and construction works for points A and point B of Figure 6-5 are shown. The site surveys as well as the design and equipment mounting work per UC are described in the respective UC sections.

Figure 6-4 Patras Facility area and sites. The area between points TRAINOSE_1 and TRAINOSE_2 is enlarged in Figure 6-1

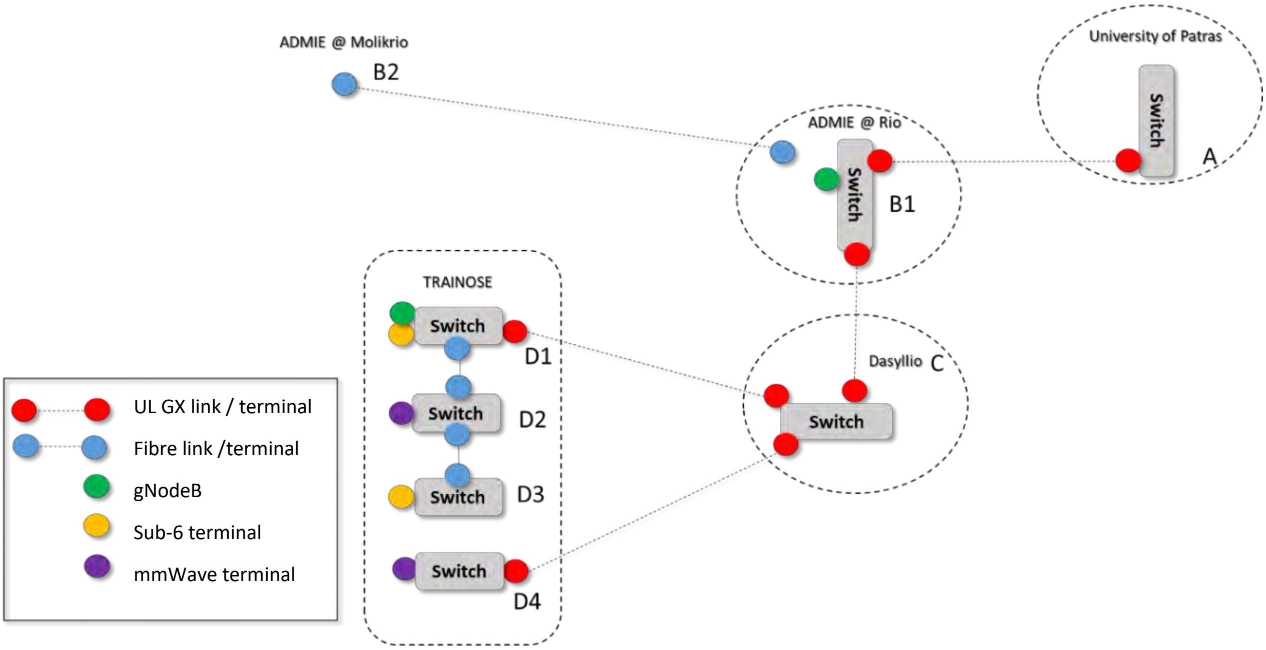


Figure 6-5 Patras Facility site interconnection and planned technology deployment per site

Figure 6-6 Deployments at UoP (see point A in map above)

Figure 6-7 Deployments at the ADMIE facility (see point B1 in map above)

Figure 6-8 Part of the UoP data centre (see point A in the maps above)

6.3.1 5G-VINNI facility

In the Patras 5G-VINNI facility, Network Function Virtualization (NFV) and experimentation enabled services, like Openslice and Open Source MANO (OSM), facilitate the E2E automated deployment of multiple customized-slices over the whole network, i.e. access, transport and core. This further includes slicing IoT devices in groups at the edge of the network. The facility is equipped with a cloud platform, able to host core network components, as well as NFV and MEC deployments. The cloud platform offers a total computing power of 300 CPUs and 1TB of RAM and 50 TB of storage. 10GbE NICs Data Plane Development Kit (DPDK)-enabled are also available (Figure 6-8).

Patras 5G provides 5G standard-conformant components and Core Network infrastructure and Integration of 5G Core and 5G RAN with the open source-based NFV platform. It supports various flavors and installations of the 5G System, which are both NSA and SA depending on the scenarios the customer demands. This facility features:

- 5G Core and EPC solutions that are available and can be orchestrated in the facility: Fraunhofer FOKUS (**FhG**) Open5GCore, Amarisoft EPC, SRS EPC, NextEPC.
- 5G and 4G RAN: Amarisoft 5G RAN (Classic boxes), 5G RAN open source radio (Lime, SRS)-700-800MHz, 3.5.-3.8 GHz, 4G NB-IoT, LTE-M (FhG NB-IoT core) based on Amarisoft, Various SDR equipment (Ettus).
- UEs based on Limemicro's SDR and SRS software, as well as commercial UEs: Mobile phones LG and Samsung, Huawei CPE, Various SDR equipment.
- Monitoring is available through: Grafana, Prometheus, Netdata that can be configured via OSM with VNF telemetry support.

− GÉANT connectivity is also available for the interfacility UC described in section 7.1.

6.3.2 Access Network /gNodeB

To enable network slicing and UC validation in the Patras/Greece facility, there are three (3) outdoor 5G base stations (gNBs) planned to be installed together with MEC installation(s), at properly selected places to support the vertical UCs' experimentation with at least six (6) UEs and CPEs. Currently, in UoP premises there are 5G SA devices available that are being tested in a lab environment together with a 4G capable device. Furthermore, other solutions with SDRs and open source 4G/5G implementations can be deployed. All available radio technologies and use equipment available at the Patras facility can be found at https://wiki.patras5g.eu/radio-equipment. Table 6-1 provides an overview of the BoMs required to extend the 5G-VINNI facility.

For the 5G network deployment (see Table 6-2), UoP will use a 5G SA with 100 MHz BW in order to set up a single cell (5G SA N78. The radio platform for N78 band is operating in a 4x4 configuration, N78 3400-3800 MHz capability and TDD mode of operation and is configurable to that respect. For each antenna the power is expected to be >2 W and 48 V is required for power supply. The RRU unit are connected through fibre (CPRI) to 1 gNodeB composed of an X86 server, an AW2S PCIe to CPRI interface board, AW2S Drivers for RRU Control and management and Amarisoft 5G stack software and Core.

Table 6-1 Bill of Materials required to supplement the 5G-VINNI facility

Equipment	Components	Quantity	Size and Weight	Power supply
Huawei CPE	5G/Wi-Fi CPE	1 Or 2	- H × W × D 20 cm × 5 cm × 5 cm	- 230 V AC input
UEs	Mobile phones (Huawei P40 Pro OnePlus NORD N10)	4-6	Depending on type	

Table 6-2 Bill of Material 5G equipment

Equipment	Components	Quantity	Size and Weight	Power supply
	Antenna	1 or 2	**Dimensions**: - H × W × D 45,5 cm × 40 cm × 20,5 cm **Weight**: 12 kg	230 V AC input
Remote Radio Head unit 	RRH + Omni antennae With - 1x omni antennas	1 or 2	**Dimensions**:H × W × D 20 cm × 10 cm × 5 cm **Weight**: 5 kg	2 x20 Watts
	gNodeB Amarisoft Callbox Pro - 4x PCIe SDR Cards with omni antennas	1	**Dimensions**:H × W × D 40 cm × 20 cm × 5 cm **Weight**: 5 kg	230 V AC input

6.3.3 Transport Network (Backhaul)

ICOM will provide to the Greek facility state-of-the-art mmWave backhaul. The UltraLink™-GX80 all-outdoor mmWave PtP Ethernet radio at 70/80 GHz (E-Band), which provides a 10 Gbps backhaul capacity, will be used to interconnect the g/eNBs and the APs used in **UC #1.1** and **UC #2** with the core network and the data centre at UoP premises, leveraging and extending the 5G-VINNI infrastructure. ICOM will provide support for SDN-based network slicing through the wireless backhaul.

For **UC #1.1** and **UC #4**, UltraLink™- GX80 systems will be used, installed at D1 and D4 poles offering up to 10 Gbps capacity, as they are depicted in Figure 6-1 and Figure 6-4. The other 2 UltraLink™- GX80 systems, which are required for the link establishment, will be installed at Dasylio's pole and will serve as an intermediate node between the ADMIE and TRAINOSE facilities. Moreover, industrial high capacity switches, PLANET IGS-6325-8T8S4X, will be used in order to provide up to 10 Gbps connectivity between D1 - D2 and D2 - D3 via optical fiber cables and also to aggregate Ethernet traffic from partners' equipment at each stanchion.

IHP will bring to the Greek facility a V-Band (60 GHz) solution with beam steering capabilities for the train-to-track connectivity in **UC #1.1**. The solution provides around 1 Gbps data rate. UTH will enhance the train-to-track connectivity in **UC #1.1** with Sub-6 technologies. These are discussed in a multi-connectivity framework of **UC #1.1** and the BoMs is there below.

In Table 6-3 only the material that is used across UCs is listed, i.e. the ICOM technology.

Table 6-3 Bill of Material (backhaul)

Equipment	Components	Quantity	Size and Weight	Power supply
 ICOM **UltraLink™- GX80**	FDD, E-Band, ultra-high capacity radio system **Frequencies**: 71,000 to 76,000 / 81,000 to 86,000 MHz **Throughput**: Up to 10 Gbps. **Ethernet interfaces**: 1 x 10GbE (SFP+) 2 x 1 GbE (SFP) 1 x 1 GbE RJ-45	**Total**: 5 2 for stanchions D1 and D4, 2 for Dasylio	**Dimensions of the Device:** (H x W x D) mm: 335 x 238 x 120 **Dimensions of the antenna** (30 cm): (H x W x D) mm: 385 x 546 x 153 **Weight** (device + antenna): 6.5 + 9 = 15.5 kg, without the mounting kit	Around 100 W Power supply options: 1) Direct DC: -48Volt 2) Power over Ethernet (PoE)
 **PLANET IGS-6325-8T8S4X**	Industrial Ethernet switch **Interfaces**: - 8 X GbE RJ-45 - 8 X GbE (SFP) - 4 X 10GbE (SFP+) - One RJ45-to-RS232 console interface for basic management and setup	**Total**: 5 4 for stanchions D1 – D4, 1 for Dasylio	DIN-rail mounted **Dimensions** (W X D X H): 76.8 x 107.3 x 152 mm **Weight**: 1.25 kg	Max 38.4 watts (Full loading) DC 12~48V, 4A max. An AC/DC power supply will be installed.

6.3.4 MEC

UoP together with ICOM will implement and integrate MEC and Edge Computing functionality, and also will provide the virtualization of edge IoT devices, i.e., IoT Slicing, as a VIM component.

6.3.5 Patras 5G Autonomous Edge

To allow the creation and management of 5G private networks on demand, the 5G-VINNI facility can deploy outdoor MEC units capable of supporting both cloud computing and 5G or other wireless connections. The main MEC unit of the facility is the “5G Autonomous Edge" [20], a mobile box, built for on-demand 5G deployments depending on the verticals' UC requirements.

The Autonomous Edge is based on 3 INTEL Xeon based servers giving in total 16 cores, 128 Gigabytes of RAM and 1 TB of storage.

- XEON D1518 @2.2 4 64 512 GB NVMe 6x1 GB + 2 x10 GB
- XEON D2146NT @ 2.3 GHz 8 64 512 GB NVMe 6x1 GB + 2 x10 GB
- XEON D2146NT @ 2.3 GHz 8 64 512 GB NVMe 6x1 GB + 2 x10 GB

Software wise, both core and MEC platforms support the ETSI NFV architecture. A basic element of this architecture is the Management and orchestration (MANO), which is the framework that coordinates the network resources and the management of VNFs. OSM [21] is the MANO used, while the virtualized environment is based on OpenStack [22].

Additionally, depending on the configuration required by the verticals’ UCs various 5G NR devices can be deployed and supported, relying either on commercial or open source SDR-based solutions. If required, the 5G core can be also deployed on the virtualized infrastructure of the Autonomous Edge to fully support 5G connectivity.

Figure 6-9 Patras/Greece Autonomous Edge

Table 6-4 Bill of Material Autonomous Edge

Equipment	Components	Quantity	Size and Weight	Power supply
5GNR Box 	Amarisoft Callbox classic - 4x PCIe SDR Cards with omni antennas	1 or 2	**Dimensions**: H × W × D 45,5 cm × 40 cm × 20,5 cm **Weight**: 12 kg	230 V AC input
	gNodeB	1	**Dimensions**: H × W × D 40 cm × 20 cm × 5 cm **Weight**: 5 kg	230 V AC input

6.4 UC #1.1 Enhanced Mobile Broadband under High Speed Mobility

This UC will provide a prototype network and deployment to facilitate train operations and services considering the FRMCS service definition (as detailed in [19]). 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 a heterogeneous wireless deployment.

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

The track-to-train communication scheme addressed by this UC is shown in Figure 6-10. The train moves along the rail track whose stanchions feature various wireless technologies (either Sub-6 or mmWave nodes). The exact number of units depends on the directionality of the antennas and will be defined after the lab testing. The proposed deployment comprises mmWave units (at D2 and D4 provided by **IHP**), and Sub-6 track-side APs (provided by **UTH**) at points D1 and D3.

At the train side, to maximize connectivity and minimize 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. Hence the train incorporates two Sub-6 nodes and two mmWave nodes at the train roof.

Only three stanchions are illustrated in Figure 6-10 to demonstrate the capability of the train to interconnect to the stanchions using various technologies as the train moves along the track [19].

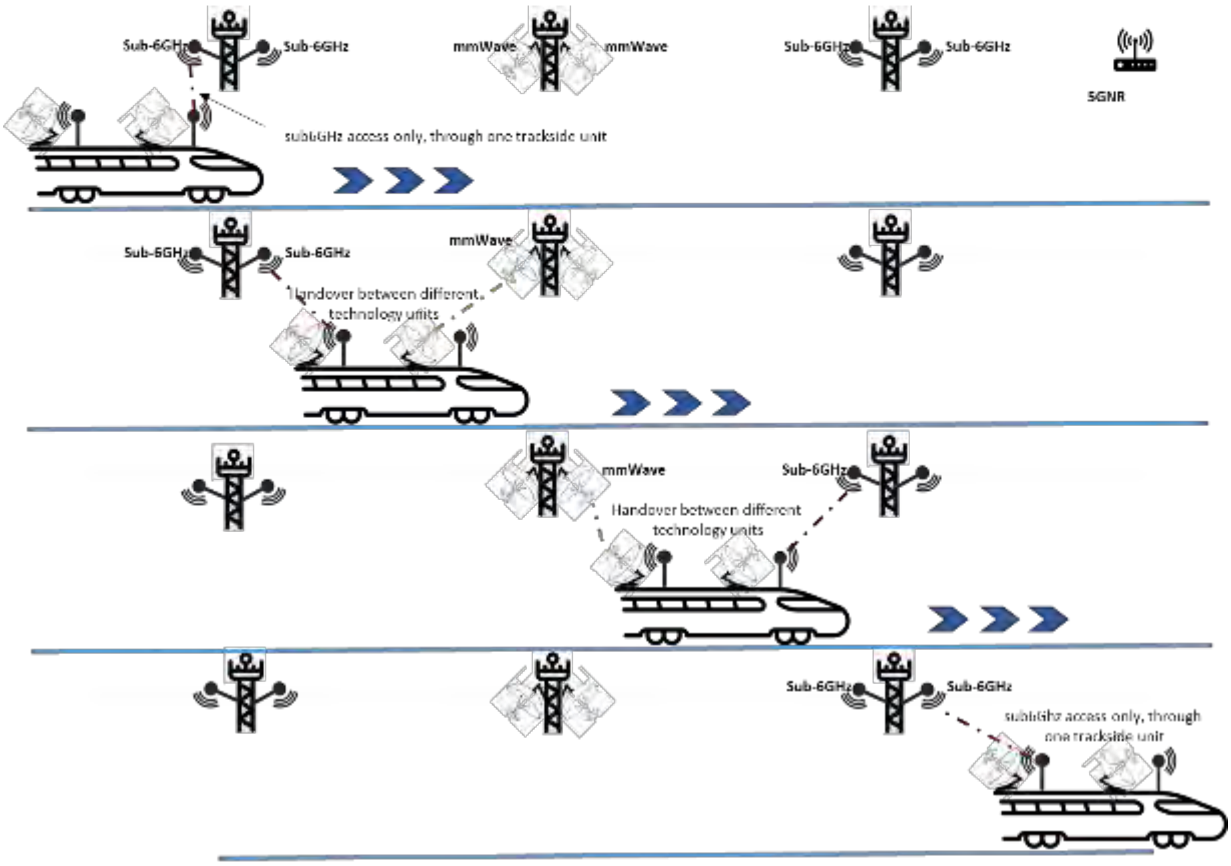


Figure 6-10 Patras/Greece network diagram for UC #1.1 demonstrating how multi technology handover will be ensured

To address the above-mentioned requirements, this deployment solution is based on a backhaul (BH) network realized over heterogeneous wireless technologies, to support dedicated disaggregated virtualized access nodes on top of high-speed moving trains. The cell disaggregation is based on the 3GPP Option-2 split [23], which splits the base station stack to the Central Unit (CU), implementing the PDCP and above layers, and the Distributed Unit (DU) integrating the RLC, MAC and PHY layers. The proposed work builds upon the prior contributions of the 5G-PICTURE project [24] in demonstrating seamless end-to-end connections from a moving train through track-to-train communication links [25]. At the same time, the 5G-VICTORI UC highly differentiates from the prior demonstrated setup through the following contributions on the network side: 1) On-board network connectivity is provided jointly from a disaggregated 5G cell and a Wi-Fi Access Point, instead of just Wi-Fi access in the 5G-PICTURE case. The new network elements pose different requirements and limitations for the transport network that is backhauling the elements to the core cloud. 2) The 5G-VICTORI track-to-train communication is using a heterogeneous wireless network, consisting of sub-6GHz technologies, through IEEE 802.11ax devices, and V-Band 60 GHz mmWave links. The equivalent 5G-PICTURE demonstration used single-technology track-to-train links, using the mmWave frequencies. The resource heterogeneity will assist in exploring the diversity that accessing different spectrum provides, allowing the setup of robust track-to-train communication links. 3) Handover management for train and the heterogeneous track-to-train links is realized using the P4 programming abstractions. P4-based switching allows the programmable configuration of the flows in the network, regardless of the technology that is connecting the train at any time point. Moreover, through the deployment of telemetry tools, managed directly from the network controller managing the different sides of the communication (train and cloud), the handovers can take place in a seamless manner and without replicating traffic over different links. The 5G-PICTURE equivalent used an FPGA based implementation for switching (FlowBlaze [26]) and was replicating traffic over different links that was restricting the scalability of the system.

The onboard network architecture is shown in Figure 6-11. Here a fibre network deployed on board interconnects access points, compute nodes and UC specific components (cameras, etc.) required for the execution of the UC.

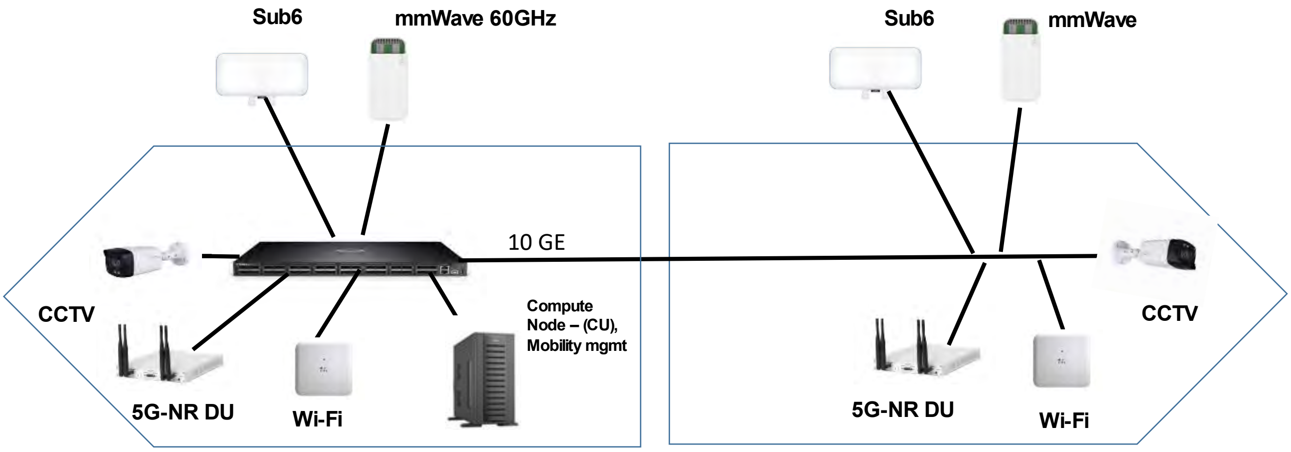


Figure 6-11 High-level Onboard network architecture for 5G-VICTORI's UC #1.1

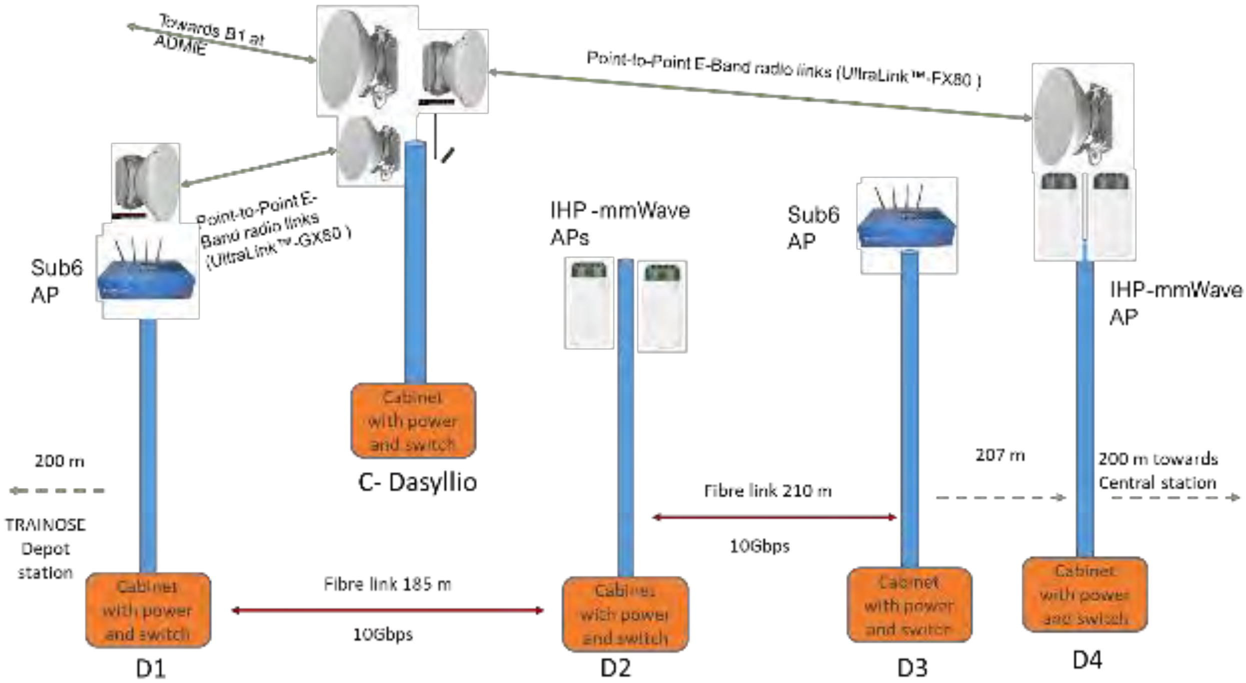


Figure 6-12 5G-VICTORI deployment along the trackside for UC #1.1

6.4.1 Transportation services and applications

In modern railway transportation facilities, there is a demand for a broad range of novel services addressing various end-users and rail related operational services. Detailed information on the railway environment requirements and vertical applications is provided in [18] and [19], along with their typical categorization into "Business", "Performance" and "Critical" services.

In particular, "**Business services**" refer to communication and broadband connectivity services provided to passengers present at railway facilities, i.e. at the train stations/ platforms, on-board. These services include infotainment, digital mobility, travel information services, etc. Indicatively wireless internet, and linear TV services – a customised solution of COSMOTE Mobile TV over Internet will be used for the demonstrating the context of this UC.

The "**Performance services**" category includes non-critical services related to train operation, including infrastructure monitoring and maintenance services. Usually, these services are deployed and consumed inside the railway facilities environment, so the service deployment considers this. In the context of this UC, CCTV - assisted supervision of the rail tracks health and maintenance provisioning is the main performance services to be tested. Cameras mounted on the train are capturing images/video of the tracks, viewed in real time at an emulated Railway Operations/Monitoring Centre – or peer viewer.

"**Critical services**" are related to train operation/movement, railway automation and operation control systems, trackside maintenance, emergency and safety services, etc., and involve information exchange between various users/stakeholders, e.g. railway infrastructure operators, train operators, railway staff, railway first responders, etc. Usually, these services are deployed and consumed inside the railway facilities environment. Therefore, in this case, the service deployment also takes this aspect into consideration. Mission-Critical Push-to-Talk (MCPTT) and Mission Critical Data (e.g. between the controller(s) at the train/ operations centre and the driver/ on-board staff, etc.) are used as indicative applications of this type in the context of this UC. The deployment of all services over the heterogeneous wireless and disaggregated mobile infrastructure is presented in Figure 6-13.

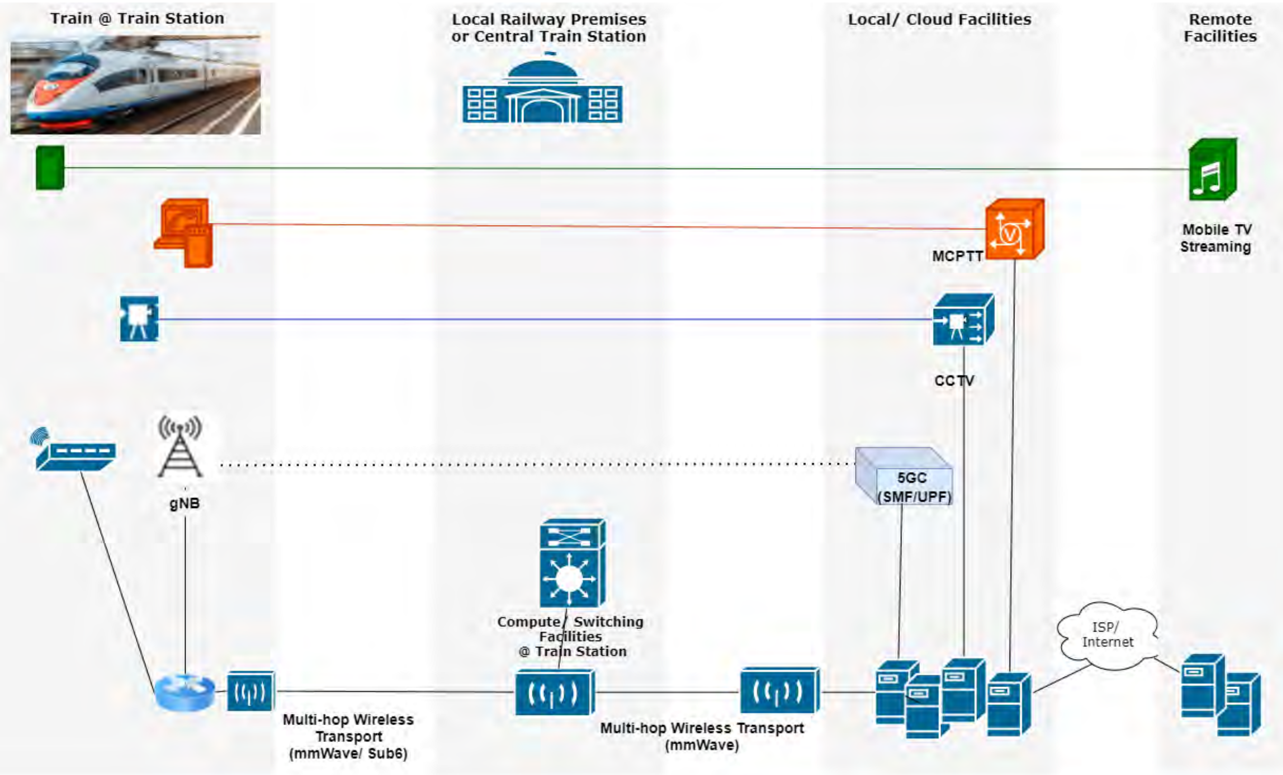


Figure 6-13 5G-VICTORI Service Deployment for UC #1.1

6.4.2 Network Requirement capture/ Processing Requirement capture

Due to the re-planning of the UC facility from Rio to the Patras City center, the number of stanchions that are needed to mount train-to-track connectivity equipment were finally defined to be 4, and some of the capture network and processing activities were re-designed. These activities are listed below in Table 6-5.

Table 6-5 Network and Processing Capture

Network coverage	• Coverage to be provided over ~2 km distance (two-way) from Patras Central station all the way Trainose Depot station (for the demo a train will travel this distance forth and back).	• A number of wireless links are deployed along the track providing full coverage according to the design • Depending on the technology and in order to support high-speed mobility, each direction needs to be covered by different access network nodes/ links.
	• Coverage to be provided on board	• One gNB will be deployed on Board
Network Mobility/ Handover and other service specifications	• Mobility/Handover support to be provided while train travels along the track.	• Wireless (access/transport) Track-to-Train connectivity is performed over two links simultaneously according to the design
UC network dimensioning	• At least 1 Gbps per access network node (onboard network) is required	Each stanchion must have up to 2 Gbps transport connectivity to the data center,

	• At least 1 Gbps per wireless (access/ transport) Track-to-Train link is required	• The maximum Track-to-Train distance is under investigation
	• Track-to-data center Transport Aggregation connectivity of more than 2 Gbps is required	• The transport aggregation links has capacity up to 10 Gbps
MEC/EC Applications' compute requirements	• MEC/Edge Applications deployed on board the train with various requirements	• On-board the train a server is deployed in order to host MEC/EC functionality and applications, with the following minimum characteristics: Intel Core i9 7980EX (18 cores) 16GB DDR, 480GB SSD.
	• On-board CU of disaggregated RAN nodes requirements: 1VM, 2 vcpus, 4GB RAM	
MEC/EC Compute requirements	• gNodeB and 5G core at UoP • UoPs' MEC solution requirements: 1VM (2vcpus), 4 GB RAM, for MEC functionality	• At UoP DC a server is deployed in order to host MEC functionality and applications and/or 5G core, with the following characteristics: (2-20) vCPUs,(4- 50 GB RAM, 1 Gbps Ethernet interfaces and1 and 10 GB Ethernet interfaces Autonomous Edge, to use as required by the test case

6.4.1 Site Survey and report / Final planning

The 5G-VINNI and-5G VICTORI integration activities take place at four levels. This was discussed in D2.1 [1] and updated in D2.2 [2].

The on-board network architecture lies at the lower level, as shown in Figure 6-11. This consists of several compute and network elements, all interconnected by fibre network. The proposed on-board network comprises a 10 GB Ethernet LAN with SDN-capable switches, connecting Sub-6 and mmWave antenna modules to be installed on the roof of the train, and software-based 5G-NR and Wi-Fi APs to be placed inside the train. The train-internal wireless part of the on-board segment comprises of SW-based solutions for 5G NR and Wi-Fi, provided over an aggregation environment augmenting the overall capacity of the network, and controlled through a single Centralized Unit (CU).

We consider disaggregation of the base stations at a high-layer Packet Data Convergence Protocol (PDCP) that can be used for aggregating heterogeneous access technologies. The CU can be instantiated as a VNF on an (edge) data centre – such as the data centre of **UoP** – and manage multiple heterogeneous Distributed Units (DUs) that integrate the radio-level characteristics of the base stations. At this point, a compute node is also necessary to deal with the handover management, while it can also act as a potential CU of the 5G-NR cell. Moreover, cameras are placed at the front and at the rear of the train realizing the critical service to be transported from the train to the Control Center located in the 5G-VINNI Patras facility.

At the second level, for the track-to-train connections, a heterogeneous wireless network is deployed operating in the Sub-6 GHz frequency band provided by **UTH** (e.g. 5G NR access, high-throughput Wi-Fi), and mmWave units featuring beam tracking capabilities provided by **IHP**.

At the third level, the interconnection of the track side APs to the core network is achieved through multiple Point-to-Point E-Band radio links with the UltraLink™-GX80 from **ICOM**, that provide up to 10 Gbps capacity, as shown in the map of Figure 6-4 but also through fibre links. Figure 6-12 illustrates the exact design for each of the deployed technologies.

Finally, a full 5G Base station unit with MEC capabilities (provided by 5G-VINNI) located at the TRAINOSE Depot station is also connected through mmWave BH to 5G-VINNI Patras facility. To demonstrate multi-technology track-to-train communication, the proposed setup comprises both mmWave (at D1 and D3 provided by **IHP**) and Sub-6 track-side APs to be deployed along the track between the two stations (at D2 and D4).

Various points along the trackside have been thoroughly investigated but the specific ones that are shown on the map (D1-D4) have been chosen as they simultaneously cover the requirements for power supply, line of sight with the main point C and distance between them that were set in deliverable D2.1 [1]. Alongside two train stations in Patras, the Central Station and the TRAINOSE Depot station which is going to be the central hub of the facility (~2,+ km two-way, considering that for the demo a train travels from Central station all the way to **TRAINOSE** Depot station and back). As shown in Figure 6-12 there are 2 mmWave units (provided by **ICOM**) at points D1 and D4. Site survey and design phases have been performed. The design of each node has already taken place (Figure 6-13). Construction and infrastructure works that are planned to be performed at each point of the facility are described in Appendix (10.2) and are briefly summarized into pre-conditions, network equipment installations and power supply checks and installations. As authorizations to mount equipment may be delayed, two different plans with alternative solutions have been developed for the deployment of each stanchion and antenna/equipment mounting.

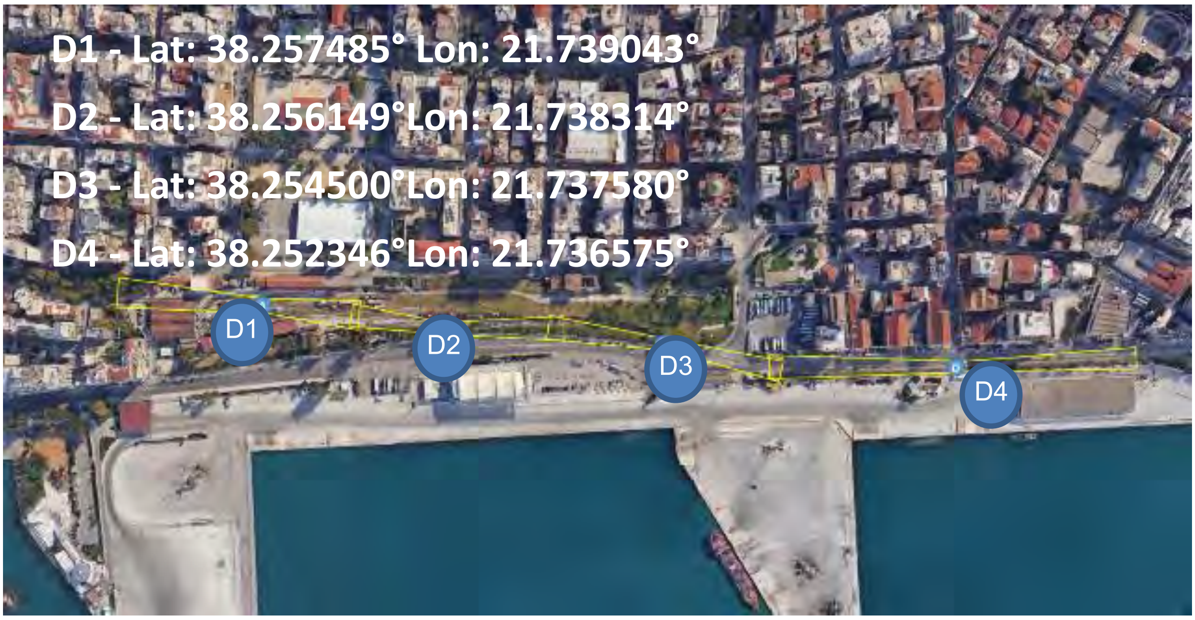


Figure 6-14 5G-VICTORI deployment map for UC #1.1

6.4.2 Network Slice Design

The on-board hosted services correspond to three different slices, which are instantiated concurrently for providing the required network substrate to the hosted services:

1) an eMBB slice, for providing on-board users with high-speed Internet connectivity and video streaming services,
2) a slice for providing a low-latency and high-bandwidth connection for the track-monitoring service to the cloud, and
3) a slice for providing low-latency communications for a MCPTT service needed for the operation control of the railway system.

Regarding the first slice instantiation, it spans the entire network, from the UoP cloud to the train on-board, across several of the deployed components. It focuses on providing seamless connection as the train crosses the different track-side stanchions, facilitated by a mobility management solution, provided by **UTH**, and on providing high-speed network connectivity to the cloud. The UoP cloud premises, where the Core Network is deployed, is also the gateway to the Internet. Figure 6-15 illustrates the components across which the eMBB slice is instantiated.

Regarding the second slice instantiation, it relies on high-speed and low-latency communications for transmitting the track video footage in real time to the rail Operation Control Center (OCC). As the OCC is instantiated in the UoP cloud premises, the slice spans the entire network as well (on-board, track-to-train, track-to-cloud) and may adopt characteristics of both eMBB and uRLLC. The components comprising the slice for the second service are illustrated in Figure 6-16.

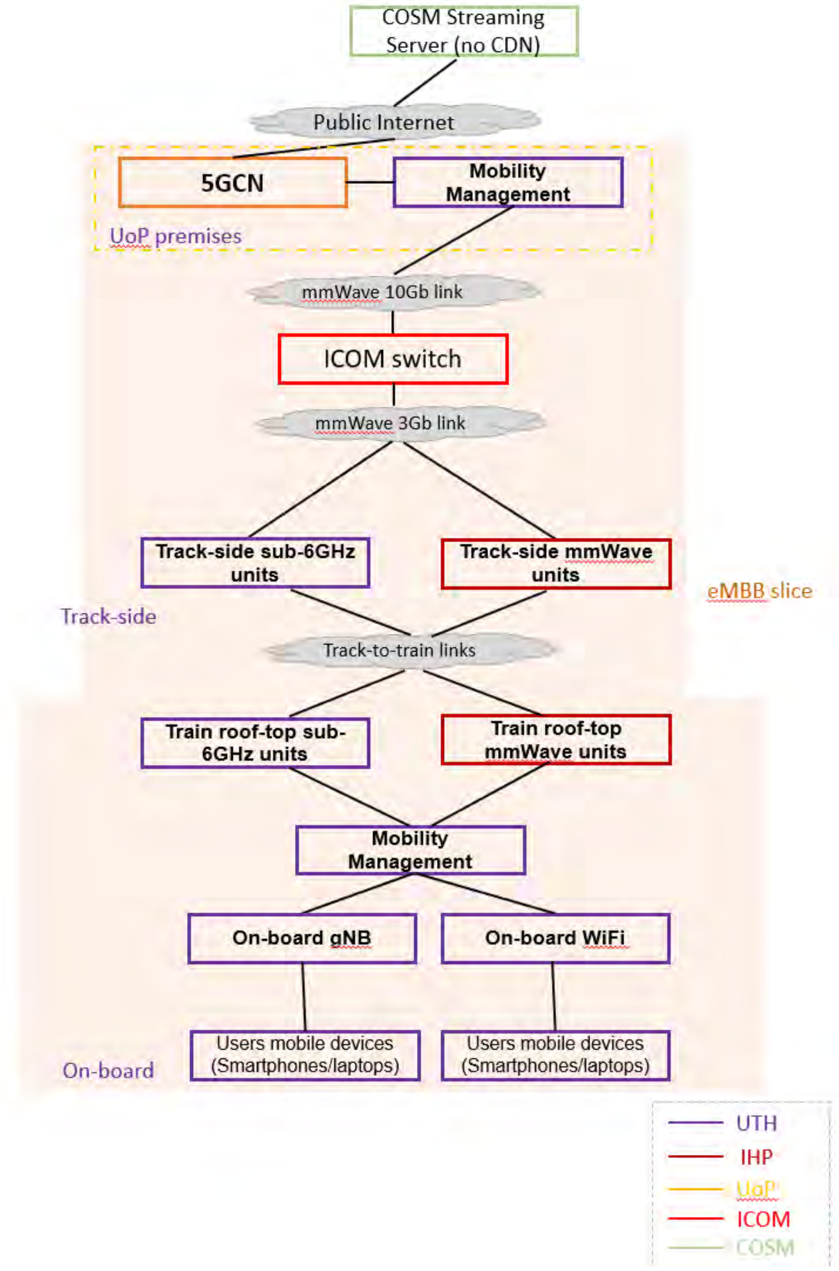


Figure 6-15 eMBB slice instantiation for providing high-speed data connection to train passengers

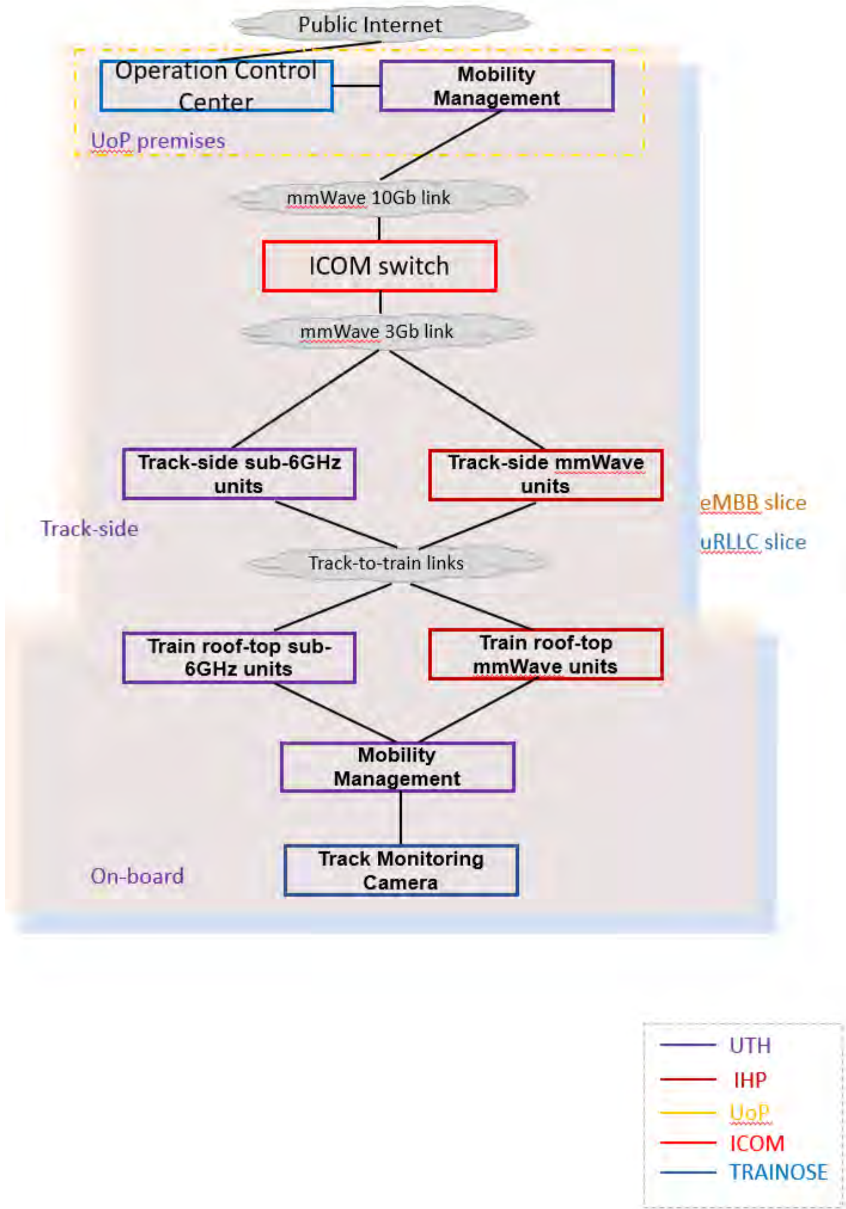


Figure 6-16 Track-monitoring service slices

Finally, for the MCPTT service that is running on-board, the network may be requested to provide another slice. The **KCC** MCPTT service that is used does not have stringent requirements in terms of throughput, but relies on low-latency connections that ensure the smooth operation of the system. As MCPTT relies on a server instantiation for managing the connections among terminals, the server will be instantiated in the UoP cloud. Therefore, this slice spans the entire network from the cloud to on-board train. Figure 6-17 illustrates the slice components for this service.

6.4.3 Design Review and Bill of Materials

For the Patras train demo, a maximum of six (6) mmWave devices (as those included in Table 6-6) are used for track-to-train connectivity. Two devices are placed on the train roof at the front and rear side, each device having a 180-degree field of view. One or two mmWave devices will be mounted per stanchion (D2 and D4) of the network's trackside part. The number of nodes per stanchion is still under analysis.

The following components enable the track-to-train communication for the Sub-6 GHz connectivity (Table 6-7).

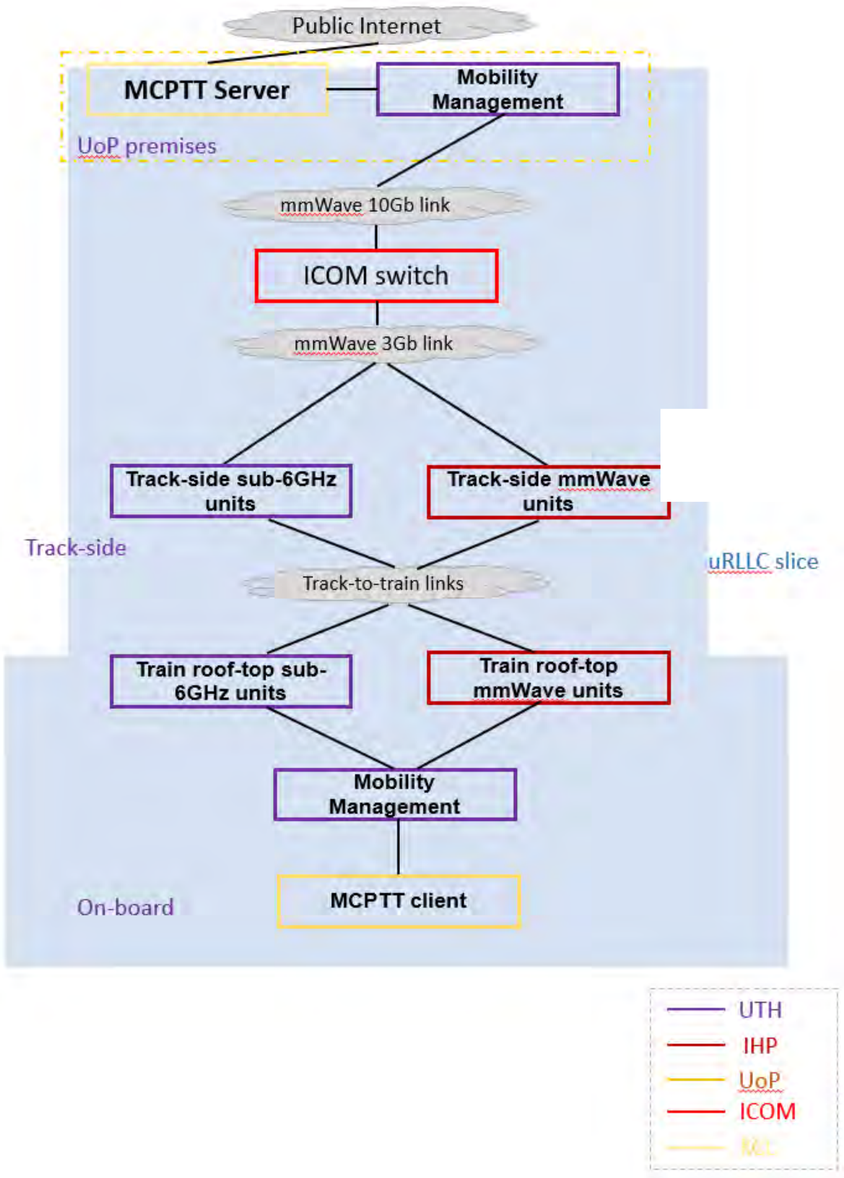


Figure 6-17 MCPTT slice

Table 6-6 Bill of material for UC #1.1 (mmWave)

Equipment	Components	Quantity	Size and Weight	Power supply
Mikrotik Wigig/802.11ad wAP60x3 	- Built-in 60 GHz 802.11ad chipset - Integrated phased-array with 96 antennas and 180-degree Field of View (FoV) - RouterOS - 1G Ethernet port	- 2 for train - 2-4 for track (stanchions D2 and D4)	**Dimensions**: (H x W x D) 18.5 cm, 8 cm, 3 cm **Weight**:< 1 kg	Around 11 W. It can be powered via direct-input power jack 12-57 V DC or PoE 12-57 V (802.3af/at). A power adapter or PoE is available.

Table 6-7 Bill of material for UC #1.1 (Sub-6)

Equipment	Item	Components	Quantity	Dimensions	Power supply

NITOS Icarus Nodes 	Custom made UTH node for track-to-train communication with high-speed Sub-6-GHz links	- 1x ath11k Wi-Fi interface (802.11ax, 4x4 MIMO) - (2x) 10 Gbps SFP+ ports. - Outdoor enclosure - External omni antennas	3 for deploying one on the train rooftop and two at different stanchions	- (35 cm W, 9 cm H, 22 cm D) + antennas - 4-6 kg.	approx. 350 W (peak)
NITOS Icarus Node 	Custom made UTH node for on-train compute and Wi-Fi AP provisioning	- 1x ath10K Wi-Fi interface (802.11ac) - (2x) Gbps Ethernet ports - External Omni antennas	2 for deploying in the train for provisioning Wi-Fi access to passengers and used as the compute node running the DU software	- (35 cm width, 4.73 cm height, 21.11 cm depth) + antennas - 3.13 kg	approx. 350 W (peak)
NITOS Icarus Node 	Custom made UTH node for on-train mobility management solution using P4 language	- 1x ath10K Wi-Fi interface (802.11ac) - (2x) Gbps Ethernet ports - External Omni antennas	2 for deploying in the train for provisioning Wi-Fi access to passengers and used as the compute node running the DU software	- (35 cm width, 4.73 cm height, 21.11 cm depth) + antennas - 3.13 kg	approx. 350 W (peak)
ETTUS USRP N310 	Ettus Research USRP N310 Software Defined Radio	- Xilinx Zynq-7100 SoC - Dual-core ARM Cortex-A9 800 MHz CPU - 10 MHz to 6 GHz frequency range - Up to 100 MHz of instantaneous bandwidth per channel - 4 RX, 4TX in - 2x SFP+ ports (1 Gigabit Ethernet, 10 Gigabit Ethernet, Aurora)	SDR for creating the 5G cell on board	- (35.71 cm width, 9 cm height, 22 cm depth) + antennas - 4-6 kg.	50-80 W

6.4.4 Description of Equipment

One of the nodes interfaces the USRP N310 Software Defined Radio (SDR) platform that enables the creation of the 5G cell on board. The node hosts the software for executing the DU side of the network. One more node is used as the local compute infrastructure, hosting the CU side of the network, and providing the NGAP interface towards the 5G Core network. The same node is used as a Wi-Fi AP to provide supplementary sub-6GHz connectivity for the passengers on-board. Additionally, a third node is used for running the “mobility management” solution, which ensures the seamless connectivity with the core network located at the UoP cloud. The different components communicate through a switch deployed on board. The same switch using VLAN tagging, or possibly a second one is deployed for interconnecting the on-board devices with the roof-top devices (mmWave and Sub-6 GHz nodes). Figure 6-18 shows the logical and physical interconnection for the on-board devices.

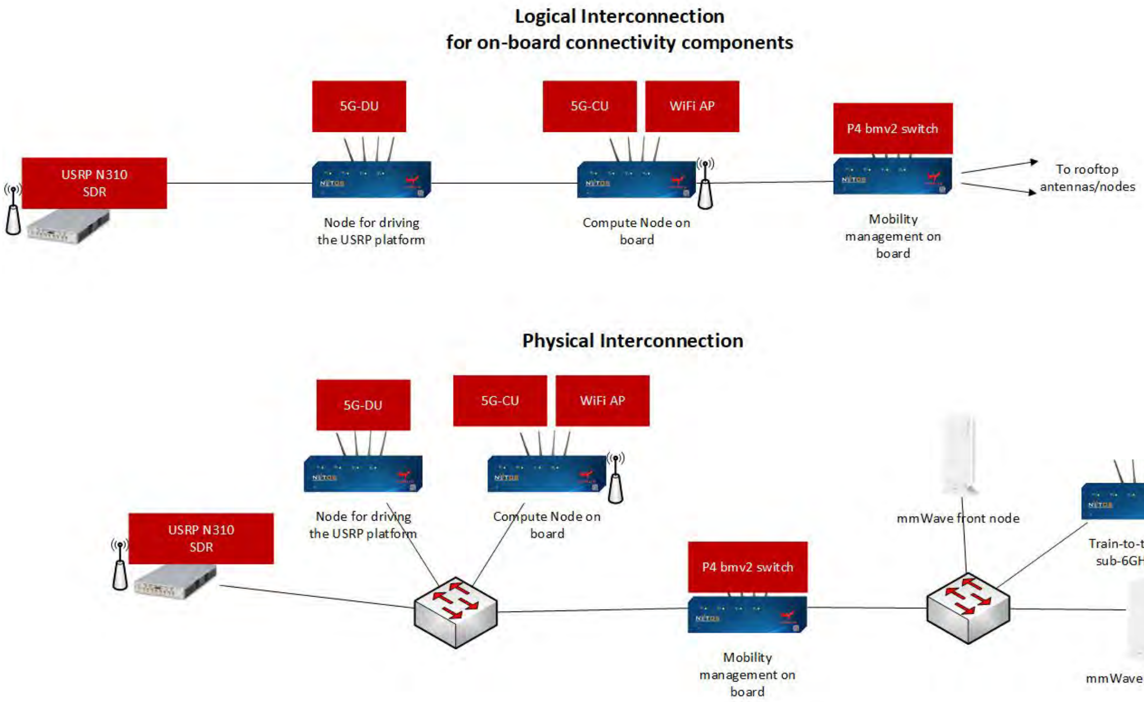


Figure 6-18 Logical and physical interconnection of the onboard components

6.4.4.1 Track to Train connectivity

To connect the train components with the rest of the network, four different stanchions with the respective track-side units are deployed. The track-to-train communication are realized using either Sub-6 GHz nodes or mmWave nodes. As the train moves, all the different cases of heterogeneous handovers are demonstrated. The stanchions D1 and D4 will be interconnected through mmWave links (**ICOM**) with the UoP cloud. From the cloud side, two software solutions are used for the UC. The first one is a software switch, which works in parallel with the one deployed on board, used to ensure E2E seamless connectivity (cloud to train). On top of the switch, the 5G Core network instance is deployed, allowing on-board users to access the Internet. Figure 6-19 illustrates the interconnection between the track-side units and the UoP cloud.

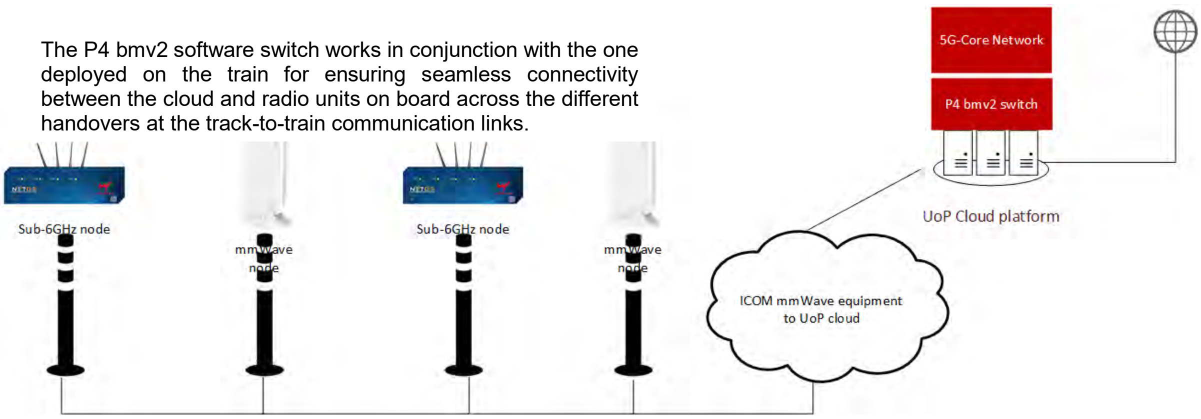


Figure 6-19 Interconnection between the track-side units and the UoP cloud

Figure 6-20 Three antenna arrays with a total of 96 antennas for 180-degree FoV

Millimetre wave (mmWave) devices that are used for track-to-train connectivity are commercial-of-the-shelf (COTS) Wigig/IEEE 802.11ad-based devices from Mikrotik. The devices operate in the 60-GHz band (i.e., V-Band 57-66 GHz). The channel bandwidth is 2-GHz, and there are four non-overlapping channels (centre frequencies are 58.32, 60.48, 62.64, and 64.8 GHz). Any of the four channels is selectable, typically, with the second channel being available in all countries. The devices support beamforming through three antenna arrays (each with 32 antennas – see Figure 6-20) arranged in such a constellation to have a 180-degree field of view (FoV). Both azimuth and elevation beamforming are supported.

The devices have a maximum EIRP of 30.5 dBm, with the maximum transmit power around 15 dBm and an antenna gain of approx. 15 dBi. They support point-to-multipoint connectivity up to 8 client devices per access point. The specified range is 200 metres, and the maximum net data rate is around 1 Gbps. The devices are equipped with a 1-Gb Ethernet connection. They can be powered on using an adapter 12-57 V DC or via power-over-Ethernet (PoE) 12-57 V. The device's maximum power consumption is 11 W. Also, they are of low weight and small size (18.5 cm x 8.5 cm).

6.4.4.2 Equipment power supply

Outdoor telecom cabinets will be installed at all railway stanchions. The cabinets store the PLANET IGS-6325-8T8S4X switches and the power supplies of all the telecom equipment. Moreover, each cabinet houses different number of 230 Volt AC power outlets, depending on the requirements of the equipment installed at each spot as shown in Table 6-8 and Table 6-9.

Table 6-8 Power supplies requirements at D1-D4

Power supplies in D1 Cabinet	Power supplies in D2 Cabinet	Power supplies in D3 Cabinet	Power supplies in D4 Cabinet
1 X power supply for PLANET IGS-6325-8T8S4X	1 X power supply for PLANET IGS-6325-8T8S4X	1 X power supply for PLANET IGS-6325-8T8S4X	1 x power supply for PLANET IGS-6325-8T8S4X
1 X PoE injector for UltraLink™- GX80	2 X for the 2 PoE injectors for WiGig	1 X Power Supply for sub-6GHz	1 x PoE injector for UltraLink™- GX80
1 X Power supply for Sub-6 GHz	2 X for laptops	2 X for laptops	2 x PoE injectors for WiGig
1 X PoE injector for the camera			2 x for laptops
1 X Power supply for gNodeB			
1 X PoE for HUAWEI CPE			
2 X for laptops			

Also, around 185 m of optical fiber will be used for the interconnection between the D1 and D2 switches and around 210 m for the interconnection of D2 and D3 switches.

6.4.4.3 Interfaces with the UC specific Equipment

The Ethernet interfaces of PLANET IGS-6325-8T8S4X switches that are used for the interconnection of different systems at TRAINOSE's stanchions are as follows at Table 6-9 and Table 6-10.

Table 6-9 Switch interfaces at D1 and D2

Switch at D1	Switch at D2
1 x SFP+ 10Gbps for UltraLink™- GX80	1 x SFP+ 10 Gbps for PLANET IGS-6325-8T8S4X at D1
1 x SFP+ 10 Gbps for PLANET IGS-6325-8T8S4X at D2	1 x SFP+ 10 Gbps for for PLANET IGS-6325-8T8S4X at D3

1 x SFP+ for Sub-6 GHz (Uth)	2 x RJ45 1 Gbps for 2 x WiGig
1 x SFP 1 Gbps for gnodeB (see CDN UC below)	
1 x RJ45 1Gbps for IP Camera (see CDN UC below)	

Table 6-10 Switch interfaces at D3 and D4

Switch at D3	Switch at D4
1 x SFP+ 10 Gbps for for PLANET IGS-6325-8T8S4X at D2	1 x SFP+ for UltraLink™- GX80
1 x SFP+ 10 Gbps for Sub-6 GHz	2 x RJ45 1Gbps for 2 x WiGig

6.4.5 Identifying Gaps with existing Test Network Capabilities

In order to determine the proper orientation and mounting of IHP's mmWave nodes for optimal coverage from stanchion D2 and D4 to the train nodes, a preliminary analysis is presented by simulating the movement of the train along the track. For this purpose, a physical model of the track is devised by extrapolating its GPS coordinates into a piece-wise linear Cartesian 3D model with 1m resolution, as shown in Figure 6-21 a), with the stanchion coordinates marked corresponding to their GPS locations. The goal of the analysis is to evaluate the angle of view between the train and stanchion mmWave nodes across the complete track, both in the azimuth and elevation plane (see Figure 6-21 b)). The parameters used for the object modelling are initially set as follows: train modelled as a 35 m long segment, height of the train antenna set to 4.2 m, height of the stanchion AP antenna set to 5 m and train speed assumed to be 15 km/h.

For the azimuth angle analysis, the path between stanchions D1 and D3 is taken as a range of interest, with a total length of 360 m. The azimuth angle of both the front and rear antenna to stanchion D2 is presented in Figure 6-22, and depends mainly on the vicinity of the train nodes to the stanchion. It can be observed that the azimuth angle is relatively low in the range of (-15:5) degrees when the train is near the stanchions D1 and D3. However, in the transition through stanchion D2 the azimuth angle changes rapidly, which needs to be taken into consideration for the beam-steering capabilities of the nodes. The advantage of having two nodes mounted on the train is that during the transition zone at least one of the nodes will maintain coverage under a low azimuth angle to the stanchion AP, as can be concluded from the diagram.

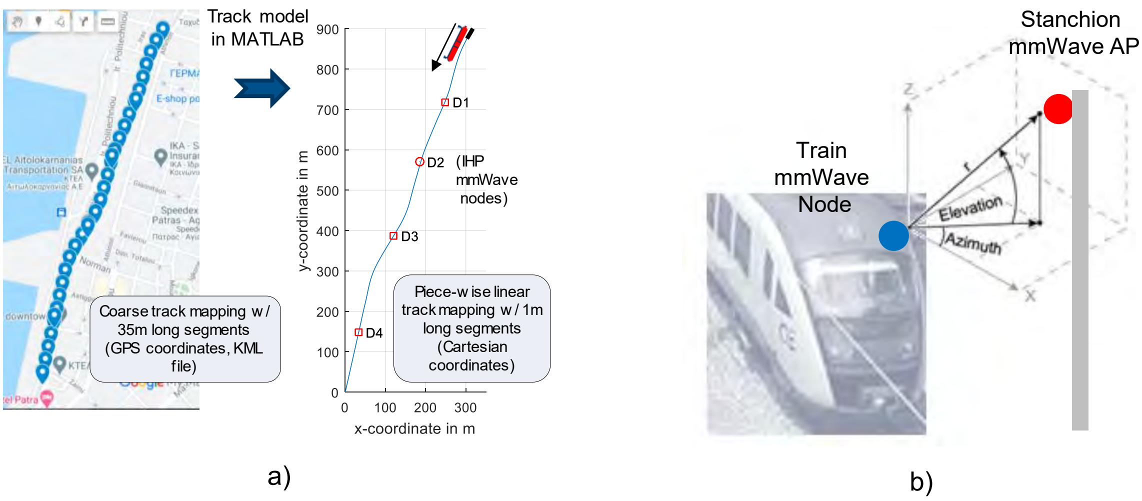


Figure 6-21 a) Physical model of the Patras train track, b) the angle of view between the train-mounted (front/rear) and the stanchion mmWave node

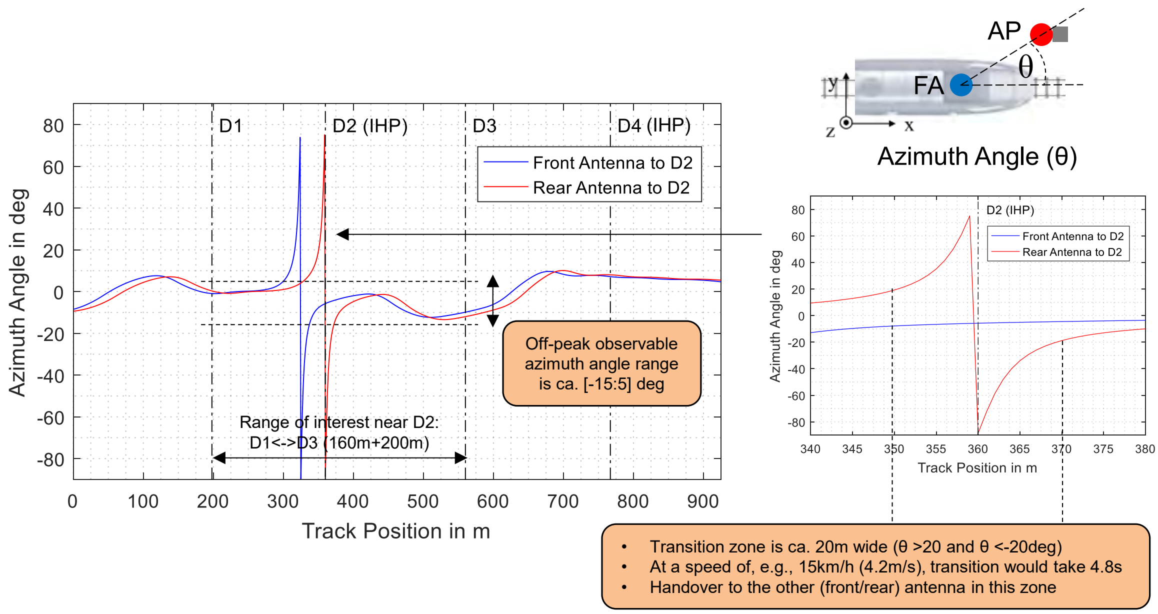


Figure 6-22 Azimuth angle analysis between the train-mounted and stanchion-mounted mmWave nodes

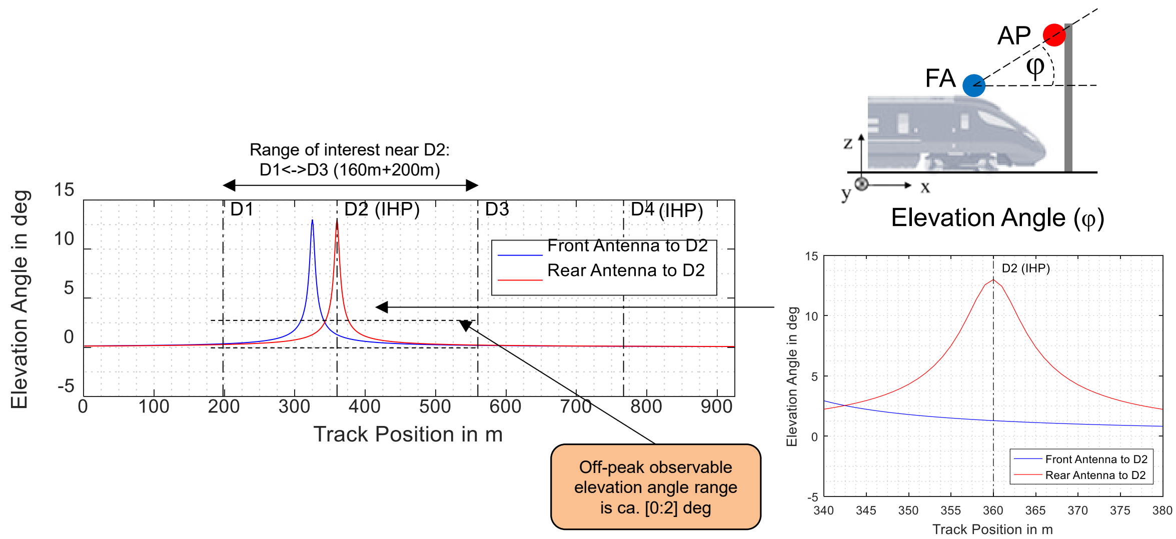


Figure 6-23 Elevation angle analysis between the train-mounted and stanchion-mounted mmWave nodes

Similar conclusions can be drawn for the elevation angle in the same range of interest, which mainly depends on the difference in height of the train and stanchion antennas (see Figure 6-23). Outside the D2 transition zone the elevation angle is stable and relatively low in the range (0:2) degrees, whereas at the peak when crossing D2 it amounts to approx.13 degrees. This suggests the elevation plane is less critical for the beam-steering and can maintain coverage across the complete range of interest.

Finally, another aspect that can be analyzed is the rate of change of the azimuth and elevation angles, as it needs to be assessed whether the beam-steering can be performed continuously under these conditions. In Figure 6-24 the rate of change of the azimuth (a) and elevation (b) angles is presented, focusing on the 2 0m transition zone centred at the stanchion D2. It can be observed that the peak rates are approx. 16 degrees/second for the azimuth and 1.5 degrees/second for the elevation angle. In the next iteration of the analysis, the association and beam adaptation time of the mmWave nodes need to be cross-compared with these findings to ensure a continuous train-to-track connection can be maintained across the range of interest.

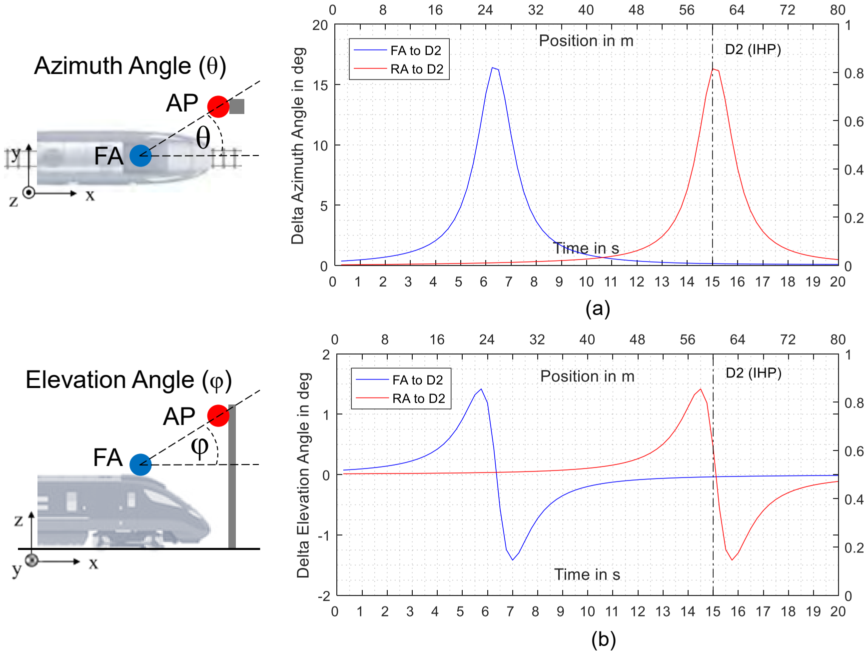


Figure 6-24 Angular rate of change in the azimuth (a) and elevation (b) planes

6.4.6 Planning of Lab testing and initial validation of services per use case

Regarding the evaluation of the UC, a concrete plan has been devised and presented in D3.1 [5]. The functionality of the different networking components will be evaluated initially in a lab environment, with an initial testing of each individual component. A different set of KPIs has been set for indicating the successful functionality of each component.

Special focus is being put on the mobility management tool, to assess it in practice in both static and mobile environments. Regarding the services that run on top of the equipment, a similar plan is presented in D3.1. Following this initial evaluation, the E2E functionality is evaluated by integrating gradually the different components in the architecture.

The updated roadmap for **UC #1.1** that combines both planning and execution phases is shown in Figure 6-25.

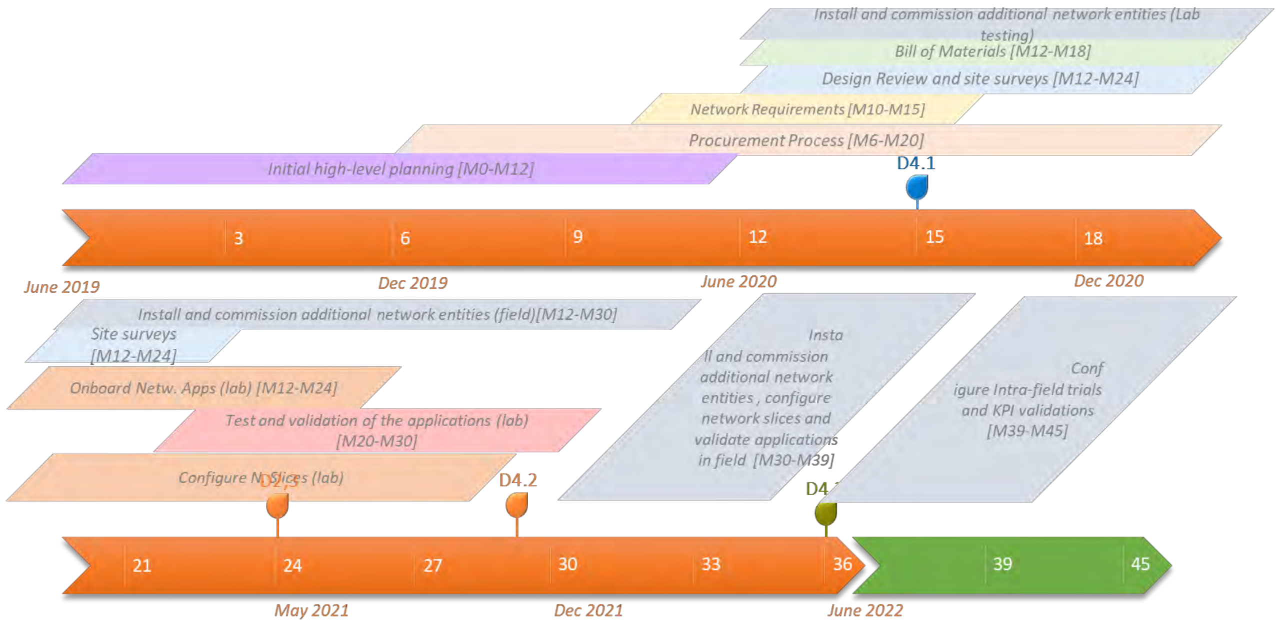


Figure 6-25 Updated roadmap for UC #1.1

6.5 UC #2 - Factories of the Future

The main objective of this UC is to automate the monitoring process and improve inspection methods and maintenance procedures of energy utilities as Factories of the Future, both for cost/time reduction and quality improvement [7]. The idea is to showcase how 5G technology can integrate and deliver services able to support these diverse applications simultaneously. An initial identification of the high level requirements of these services has been provided in [1]. Aggregating the service requirements, the network deployment requirements have been derived initially in [1], and are further refined in an iterative fashion.

These services are mainly grouped into three classes: maintenance, security and operation services. Maintenance activities require support of low cost, energy efficient sensors, planted in a distributed and heterogeneous infrastructure. Security and operation services ask for low latency trip signals and high bandwidth for CCTV. More specifically, three different scenarios will be demonstrated:

- The application of mMTC-banded IoT architectures for preventive maintenance and monitoring of the factory assets.
- The support of uRLLC-type applications for real time monitoring and automation in an industrial environment.
- The provision of eMBB services for smart CCTV surveillance applications.

6.5.1 Smart factory platform

For the needs of the UC, a data management platform (UiTOP), provided by **ICOM** is used. UiTOP is a cloud-hosted multi-tenant IoT solution that is developed in a containerized micro-services based architecture. It is divided into a core functionality and optional modules, which can be customized on demand to satisfy the specific needs of each application. Core and optional modules can be executed on the cloud or at the edge, providing capabilities of distributed processing and storage. It includes a rich and customizable dashboard for the monitoring of the infrastructure by the operator, and a northbound API for easy information exchange with third party applications, allowing a flexible integration of a variety of user applications and services in order to facilitate optimal decision making and preventive maintenance strategies.

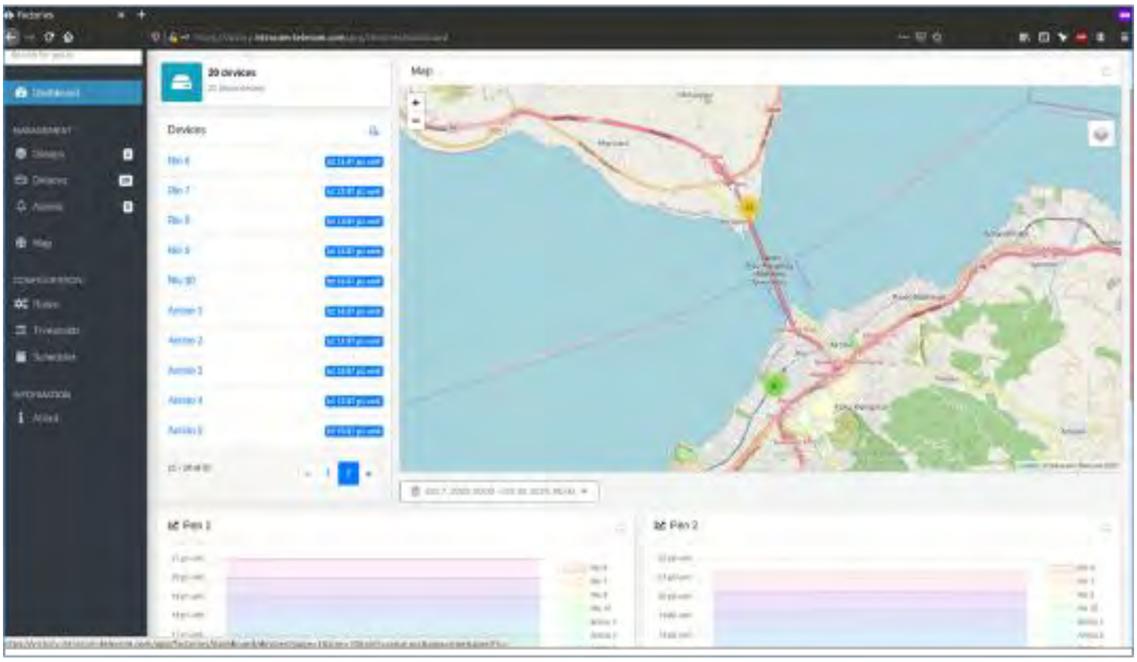


Figure 6-26 UiTOP dashboard presenting Rio (green circles) and Antirio (yellow circles) on the map

Two UiTOP modules are being developed/customized for the collection of measurements: A Modbus TCP module, responsible for the collection of measurements originating from the legacy sensors of the infrastructure, and a MQTT module for the collection of measurements from the newly established NB-IoT sensors. Modules responsible for real time data collection and processing are deployed at the edge (hosted on the Autonomous Edge), to take advantage of the low latency local processing, while permanent storage, post-processing and visualization are be executed on the UoP cloud.

Figure 6-26 depicts the customized UiTOP dashboard for **UC #2**. All connected devices are listed in the Devices menu of the software platform, where they can be selected for detailed reports. Their location at the facilities is shown in the map, where devices located at Rio are marked with green circles and devices at Antirio site with yellow circles.

6.5.2 Network Requirement capture/ Processing Requirement capture

At this stage, the requirements that are further elaborated are those affecting the facility planning and demo deployments, namely:

Deployment-related Aspect	Facility Requirement (Refined)	Deployment Solution & Dependencies
Network coverage	• Network coverage is needed over ~2,000 m^2 at Rio ADMIE premises, in order to complement the 1st level connectivity of the site.	• One NB-IoT Evolved Node B (eNB) and off-the-shelf LoRaWAN Gateway modules to be deployed for sensor connectivity
UC network dimensioning	• At least 1 Gbps per facility network node (B1) is required	• At B1 a gNodeB guarantees the high volume/high sample rate data from the ADMIE facility, At B2 this is not necessary as the data volume does not justify this • Each node will have up to 1 Gbps transport connectivity to the data center,
	• Low Latency required between the various sensors	• Connectivity among the two sites is required (preferred scenario is to connect B1-B2 other than both B1 and B2 connect to UoP) • Data processing in MEC/ Edge is incorporated hence two level architecture
MEC/EC Applications' compute requirements	• 1st level processing requirements (1-2(v)cpus), 2GB RAM). Central Processing requirements: 1-4VM, (2-8 (v)cpus), 4-16 GB RAM and 1 GB of space each).	• Edge server will be deployed at Rio/Antirio site, with the following minimum characteristics: The autonomous Edge if deployed at the field can provide 20 vCPUs, 50 GB RAM, 1 and 10 Gbps Ethernet interface. • Central Processing will be provided at UoP DC site, with the following minimum characteristics: 200 vCPUs, 256 GB RAM, 1 Gbps Ethernet interface.

6.5.3 Site Survey and report /Final planning

The deployment of the new infrastructure brought by the 5G-VICTORI project involves installation of sensing devices at the predefined locations and powered through either battery/solar cells or connected to the power supplies provided by **ADMIE** (Figure 6-27). The cells providing the gateway of the collected data are installed (software defined NB-IoT cell, COTS LoRaWAN gateway, Wi-Fi AP) along with the edge data centre and the remote connection to the 5G-VINNI facility.

Figure 6-27 shows the placement area that was selected for the demo following initial site surveys between the Rio (B1) and Antirio (B2) terminal stations. Indoor installations have already been performed in B1, however a major power cut need to be planned in order to perform the outdoor installations of the antennas.

Figure 6-28 shows the final network deployment and network installations equipment that is needed to ensure that the UC can be executed and that the KPIs are guaranteed. The two sites are directly interconnected via a fibre link, which is terminated at B1, where both the gNodeB and the edge processing units are based. At B2 gNodeB is not necessarily installed as the data volume and the trails discussed do not justify 5G radio, however architecturally the design can support an extra gNodeB at B2 if necessary. Both AP shown in the figure are considered Wi-Fi and gateways are interconnected via these AP. Also CPEs (see introduction) are used for the collection of data from the various sensors. The fibre link terminates at the edge processing unit where part of the two layer architecture is deployed and part of the platform is hosted. Then backhauling is performed via the mmWave links to the UoP premises.

Figure 6-27 UC facility plan and configuration at ADMIE facilities

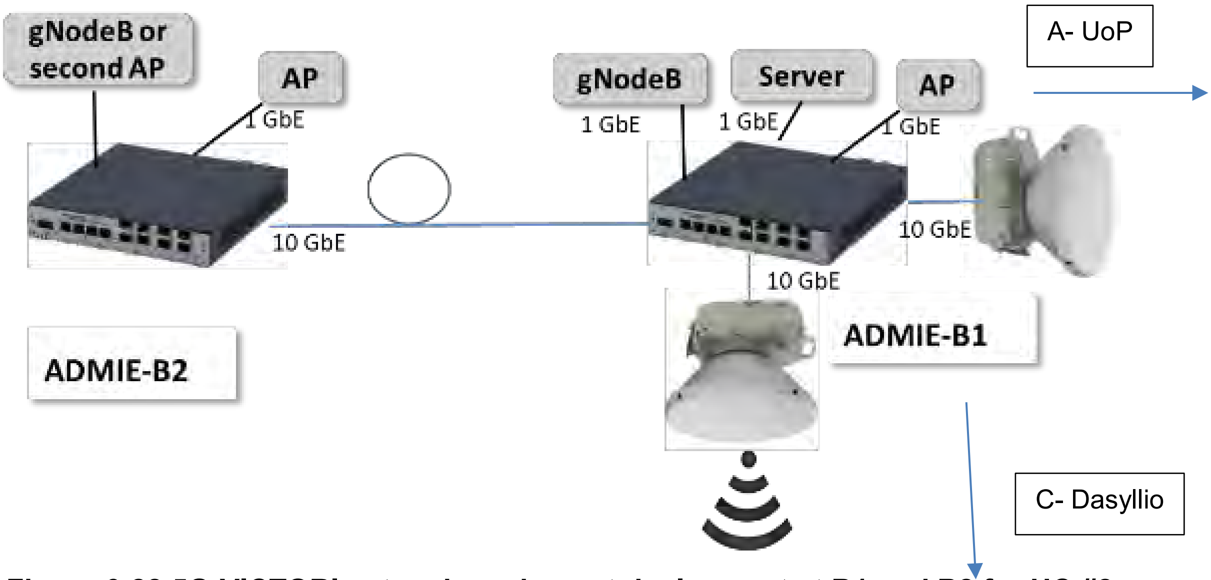


Figure 6-28 5G-VICTORI network equipment deployment at B1 and B2 for UC #2

Figure 6-29 5G-VICTORI Installation works at B1

6.5.4 Installation planning at B1

Figure 6-29 shows an overview of the ADMIE Rio Facilities (B1), where the main workload is performed. The Rio site serves as a terminal point for the HV submarine cable and it comprises numerous legacy sensors for monitoring of the HV submarine cable, power tower and a control room where the sensors' measurements are collected.

6.5.5 Outdoor installations

Rio site serves as a connection point between 5G-VINNI and 5G-VICTORI facilities. In this sense, two mmWave antennas, provided by **ICOM,** will be installed at the ADMIE premises, one for the interconnection with the University of Patras (A in Figure 6-5) and one with Dasylio (C in Figure 6-5). To achieve LoS with points A and B, the two antennas are mounted on the power tower of the facility at a height of 25 m, as depicted in Figure 6-29. Two mounting brackets, able to support the overall weight of the equipment, are installed on the power tower.

For the interconnection with the switch, placed indoor, and the provision of DC power supply, an underground channel (red line in Figure 6-29) is used. Two pairs of DC power cable and fibre link (one per antenna) is driven through the underground channel towards the base of the power tower. At the base of the tower, an external waterproof cabinet is used for the secure disunion of the pairs that follow different routes on the power tower (on-tower channels shown with green and yellow lines). The on-tower channels are attached in the interior side of the power tower according to the safety guidelines and reach each antenna separately. The works related to the underground channel have been completed. Moreover, DC power cables, and auxiliary flexible industrial channels have been purchased. For the completion of the outdoor installation, the two antennas must be mounted, secured and calibrated on the power tower.

6.5.6 Indoor installations

For the network equipment installations, a rack hosting the network switch and the needed DC power supplies has been already installed. Power and grounding requirements for each node have been documented. The network architecture that will be deployed is shown in Figure 6-28. Two fibre connections will be deployed for the interconnection with the mmWave antennas, and a third one for the interconnection with the Antirio site (point B2), providing backhaul connectivity. All necessary equipment interconnections and power supplies are described in detail in the sections below.

6.5.7 Network Slice Co-Design

To support the Smart Factory services, where each one of them imposes a substantially different set of KPIs, QoS mechanisms and schemes to the overall architecture, three dedicated slices are going to be instantiated concurrently on the network. Each slice corresponds to a different service; 1) a slice responsible for the timely collection of HV power cable sensor data from the two ADMIE sites at Rio and Antirio, 2) an eMBB slice for providing high-bandwidth communications to address sensor data collection, fusion and storage to the cloud and 3) an eMBB slice for providing high-quality live video streaming dedicated to smart facility monitoring and inspection.

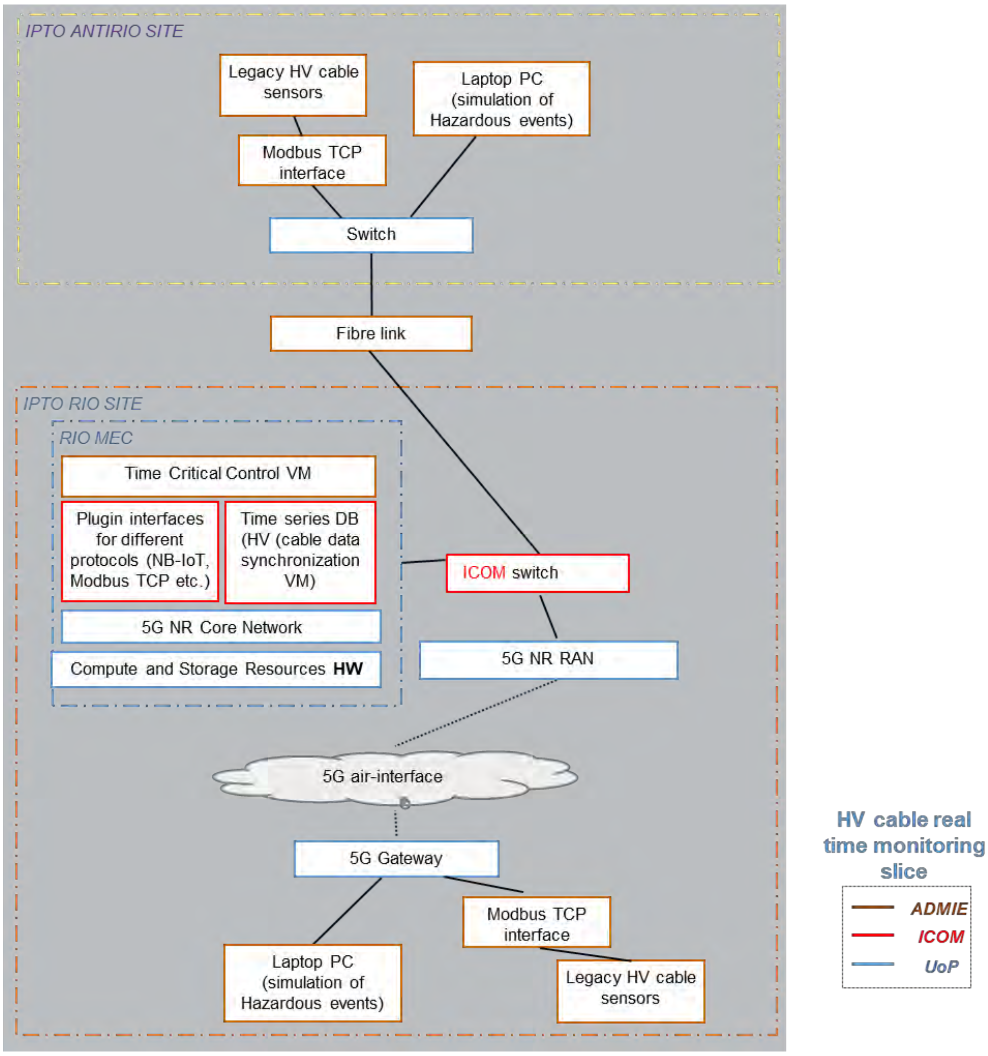


Figure 6-30: Slice for the Real-time monitoring of HV power cable service

Regarding the first slice instantiation (**Real-time monitoring of HV power cable service**), it spans the entire network which comprises the two **ADMIE** sites. It provides low-latency communications between the HV power cable sensing devices and the MEC server deployed at Rio. The two sites interconnected via a fibre optic link provided by ADMIE create a private network. Figure 6-30 illustrates the components across which the real time monitoring slice can be instantiated.

Regarding the second slice instantiation (**Preventive maintenance slice**), which is deployed over the whole network starting from **ADMIE** facility at Rio and extending up to the **UoP** premises. It provides high-bandwidth communications for supporting the collection of various sensor data at the MEC server deployed at Rio and their transmission at the UoP data centre. The two sites are interconnected via a mmWave link, which is installed and configured by ICOM, thus extending 5G-VINNI facility towards ADMIE facilities and the city centre. The components comprising the slice for the second service are illustrated in .

Finally, for the Facility **CCTV monitoring service**, the network is requested to provide an eMBB slice. The service relies on high throughput connections to ensure high-quality live video feed transmitted from the UHD cameras installed at ADMIE facility at Rio, to the MEC server. After an initial processing of the CCTV data frames at the MEC, the data frames is sent to UoP premises only when an interesting event is captured (e.g. technical personnel at the HV power cable control room). Therefore, the eMBB slice spans the entire network from the cloud to the ADMIE facility. Figure 6-32 illustrates the slice components for this service.

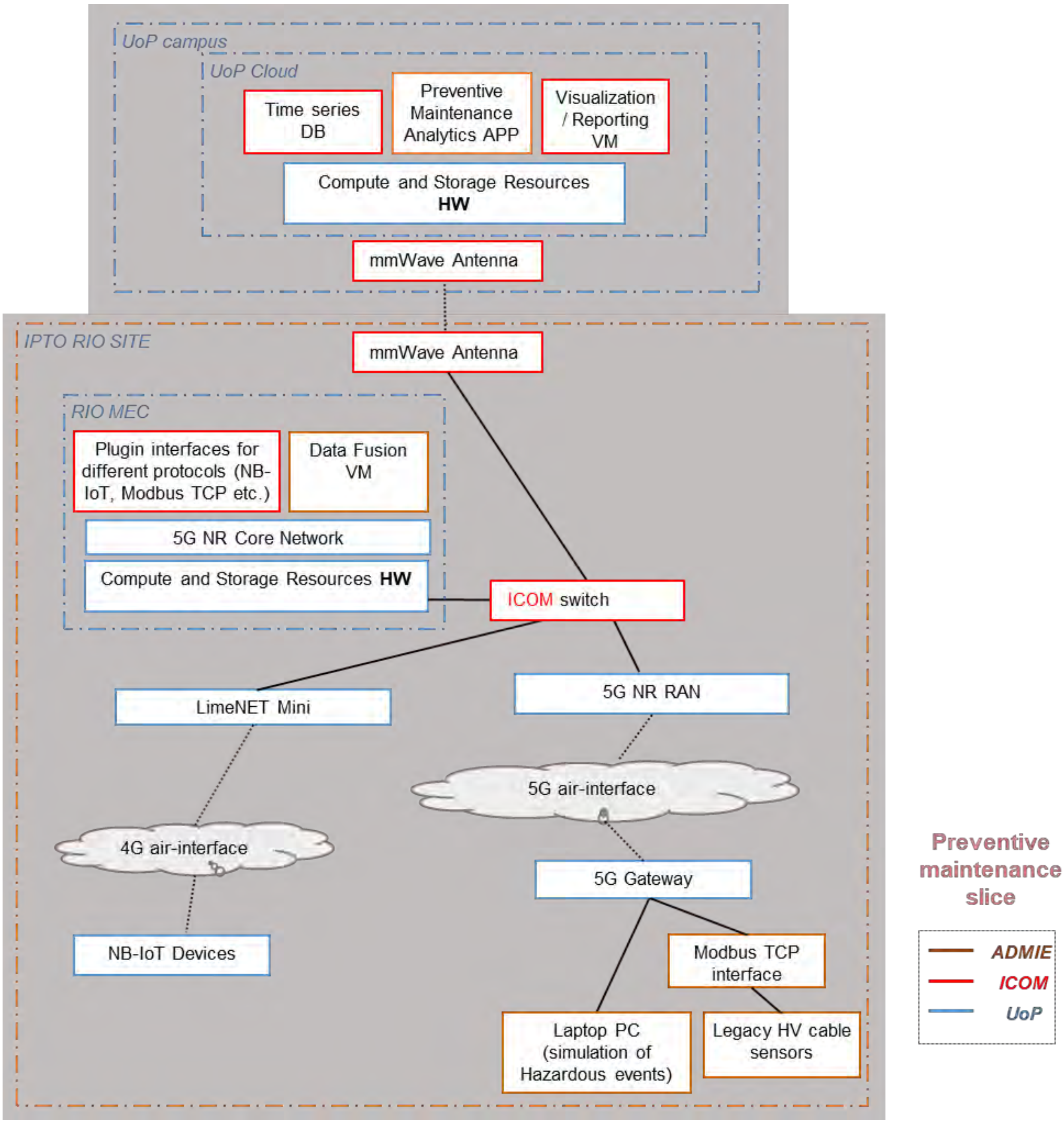


Figure 6-31 Preventive maintenance slice

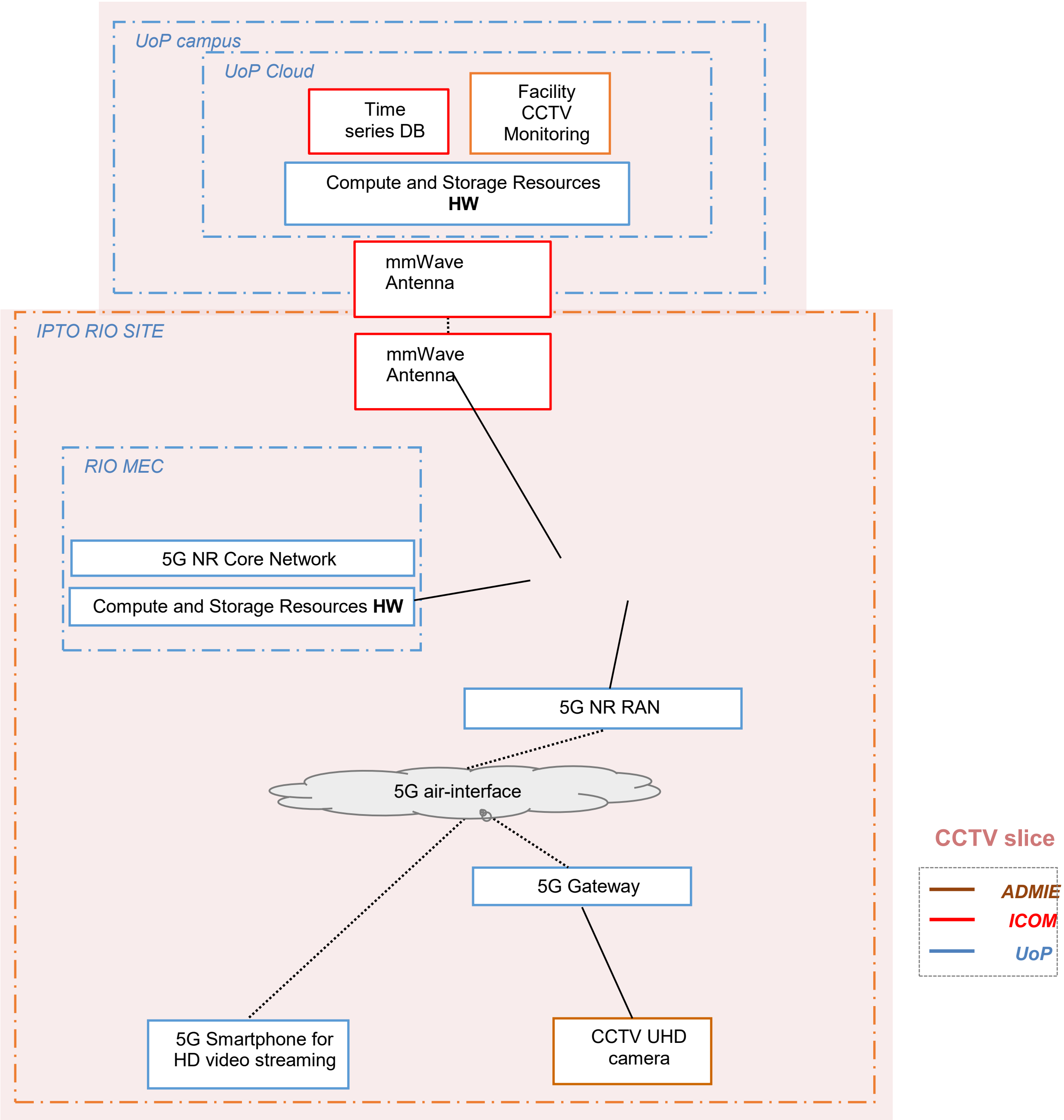


Figure 6-32 CCTV Monitoring slice

In Table 6-11, the components that drive the Digitization of Power Plants services are summarized:

6.5.8 Design Review and Bill of Materials

Table 6-11 Bill of Material UC #2

Equipment	Item	Components	Quantity	Dimensions	Power supply
HIKVISION DS-2CD2041G1-IDW1 2.8 camera	CCTV UHD camera for surveillance	- Resolution 3280 × 2464 (per camera) - 1 RJ45 10M/100M self-adaptive Ethernet port - Wi-Fi support (max transfer rate 150 Mbps)	1 for deploying inside the HV power cable control room	- (69.7 mm width, 67.9 mm height, 171.4 mm depth) - 372 g.	6 W (peak)

Waveshare IMX219-83 Stereo Camera 	Binocular camera module suitable for AI vision applications	- Max Resolution 2560 × 1440 at 60Hz, 20 fps - Compatible with Jetson nano Developer Kit (B01)	1 for deploying inside the HV power cable control room	- (85 mm width, 24 mm height) - 23 g.	
NVIDIA Jetson Nano Developer Kit (B01) 	Small, powerful computer able to run multiple neural networks for applications like image classification, object detection, segmentation, and speech processing	- Gigabit Ethernet port:10/100/1000Base-T auto-negotiation - 4x USB 3.0 port - 2x MIPI CSI camera connector	1 for deploying inside the HV power cable control room	- (69 mm width, 45 mm height) - 238 g.	10 W (peak)
RS485 IO Slim Module MOD-ETH 	ETH Module allows converting packets from Modbus TCP into Modbus RTU/ASCII format. Suitable for usage as a Modbus TCP gateway.	- 10/100 Mbps Ethernet port - RS485 interface - Mini USB interface for configuration	1 for deploying inside the HV power cable control room	- (22.5 mm width, 120 mm height, 110 mm length)	7.2 W (peak)
RS485 MODBUS Module 16I 	16I Module allows a simple and cost-effective extension of the number of lines of input in popular PLCs. Values are read via RS485 (Modbus).	- RS485 interface - Mini USB interface for configuration	2 for deploying inside the HV power cable control room	- (22.5 mm width, 120 mm height, 101 mm length)	0.96W (peak)
Mini Modbus 1AI 	1AI Module allows analog voltage or current measurement. Values are read via RS485 (Modbus). Can be easily integrated with popular PLCs, HMI or PC equipped with the appropriate adapter	- RS485 interface - Mini USB interface for configuration	1 for deploying inside the HV power cable control room	- (17 mm width, 90 mm height, 56 mm length)	0.912W (peak)

Table 6-12 Supplementary Bill of Materials for the interconnection to the backhaul

Equipment	Components	Quantity	Size and Weight	Power supply
 **ICOM OmniBAS™-10P**	Ethernet switch **Interfaces**: - 4 χ GbE RJ-45 - 4 χ GbE (SFP) - 1 χ FE (RJ-45) for Outband management 2 x 10GbE (SFP+)	1	**Dimensions** (H x W x D): 42 x 215 x 250 mm **Weight**: 2.06 kg	Around 30 W Nominal -48 V (tested at -40.5 to -60) An AC/DC power supply will be installed.

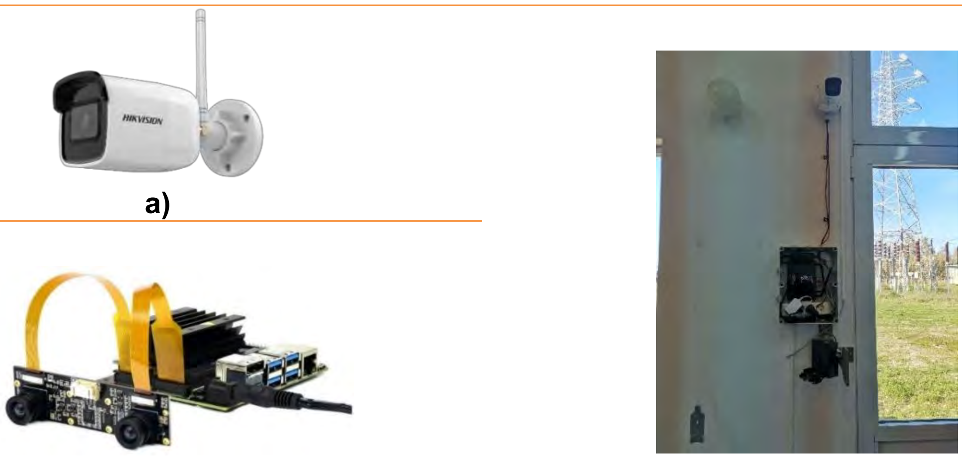
An ultra-high capacity switch, the OmniBAS™-10P (**ICOM**), provides local connectivity to LoRaWAN gateways, Wi-Fi APs and gNodeBs, while at the same time it is serving as an aggregation point and provides up to 10 Gbps connectivity to the UoP datacenter via the ADMIE-UoP wireless link based on UltraLink™- GX80 (see backhaul network description in section 6.3.3). The switch aggregates up to 10 Gbps traffic from ADMIE – DASYLIO wireless link, also based on the aforementioned ICOM's product, which serves as an intermediate link between ADMIE's and TRAINOSE's facilities. This way, not only different slices of the same vertical are served concurrently, but also multiple verticals are served, leveraging the same infrastructure.

6.5.9 Description of Equipment

6.5.9.1 Use Case specific Equipment Interfaces

For the provision of CCTV facility security services, as well as advanced monitoring applications, two cameras have been installed at the Rio site. Specifically:

- one HIKVISION DS-2CD2041G1-IDW1 2.8 camera (link), such as that in Figure 6-33 a), and
- one Waveshare IMX219-83 Stereo Camera (link), as depicted in Figure 6-33 b), with the support of
- one NVIDIA Jetson Nano Developer Kit (link).



a) b) c)

Figure 6-33 a) HIKVISION DS-2CD2041G1-IDW1 2.8 camera, b) Waveshare IMX219-83 Stereo Camera connected to an NVIDIA Jetson Nano Developer Kit, c) Setup of both cameras at Rio facility site

Figure 6-34 Modbus Modules (featuring the RS485 Expansion Module 1AI & the RS485 IO Slim Module MOD-ETH).

The first camera supports the CCTV service scenarios by providing UHD video livestreaming from the interior of the HV cable control room located at the Rio site. This specific camera can wirelessly transmit high-quality CCTV video with a maximum transfer rate of 150 Mbps, thus making it ideal for the demonstration of demanding CCTV applications in an industrial environment. The second camera, along with the Jetson Nano Developer Kit, serves as an advanced monitoring solution, providing AI capabilities in the premises of the facility. By leveraging Jetson's capabilities, legacy equipment of the control room with no network connectivity is supervised while alarm signals are generated in real-time through local processing, thus ensuring uninterrupted operation and health for the critical ADMIE infrastructure.

The two cameras are wired to a switch through which they are connected wirelessly to the Huawei 5G CPE brought from **UoP** through Wi-Fi

For the provision of advanced monitoring services over legacy equipment with no previous connectivity, dedicated Modbus modules (depicted in Figure 6-34) have been installed at the ADMIE facilities (as shown in Figure 6-35). This includes:

- RS485 MODBUS Module 16I (Expansion module – 16 digital inputs).
- Mini Modbus 1AI (Expansion module – 1 analog input, 1 digital output).
- RS485 IO Slim Module MOD-ETH (Expansion module – Modbus TCP gateway).

The first two devices are used for the collection of signals generated by legacy equipment and their transport over the network through an RS485 interface. These devices are connected to a Modbus TCP gateway that is responsible for enabling sensor data transmission over the Wide Area Network (WAN). By supporting Modbus TCP, the gateway device ensures secure and timely transfer of sensor data in real-time.

The gateway module connect to the Huawei 5G CPE provided by UoP via Ethernet connection.

Figure 6-35 Setup of Modbus devices at Rio facility site

Figure 6-36 Autonomous Edge (left), Limenet Mini and Sara R410 (right) during lab testing

6.5.9.2 Specifications and Interconnections of gateways and gNodeB

Furthermore, for the integration of new types of LPWAN sensors, NarrowBand-IoT (NB-IoT) cells are deployed to the facility through a Limenet Mini. Limenet Mini is a high performance mini PC with an integrated and shielded internal LimeSDR USB micro Type-B, U.FL cables, and antennas. Sara R410 NB-IoT developer boards serve as NB-IoT devices, able to collect and transmit measurements from different types of sensors (location, humidity, temperature sensors etc.). Figure 6-36 depicts Limenet Mini and Sara R410 and Autonomous Edge during lab testing.

6.5.9.3 Specifications and Interconnections of network switches

A telecom cabinet has already been installed inside the ADMIE's building which house the OmniBAS™-10P switch. Also, due to the specifities and limitations of the installation of telecom equipment near high voltage environment, the BoM has to meet stringent specifications. With regards to the outdoor installation, for the power supply and data/management traffic of the UltraLink™- GX80, 150 meters of DC shielded cables and 150 meters of outdoor optical fibres can be used respectively. Furthermore, in order to guarantee maximum availability and reliability in the power supply, 2 AC/DC power supplies in parallel operation (redundancy) are used inside the cabinet, each one of them capable to provide the maximum needed load for the OmniBAS™-10P switch and the UltraLink™- GX80 elements. Moreover, indoor and outdoor Surge Protection Devices (SPDs) are used for the DC cables, in order to provide additional protection against transient overvoltages.

6.5.9.4 Interfaces with the Use Case specific Equipment

The Ethernet interfaces of ICOM's OmniBAS™-10P switches that are used for the interconnection of different systems in ADMIE's facility are as in Table 6-13:

Table 6-13 Interfaces of the interconnecting switch

Switch at ADMIE
1 x SFP+ 10Gbps for UltraLink™- GX80 (ADMIE – UoP link)
1 x SFP+ 10 Gbps for UltraLink™- GX80 (ADMIE – DASYLIO link)
1 x RJ45 1Gbps for WiFi AP
1 x RJ45 1Gbps for NB-IoT BS (LimeNet mini)
1 x RJ45 100 Mbps for HIKVISION DS-2CD2041G1-IDW1 2.8
1 x RJ45 1Gbps for NVIDIA Jetson Nano Developer Kit
1 x SFP 1 Gbps to optical link terminal
1 x SFP 1 Gbps for gnodeB

6.5.10 Identifying Gaps with existing Test Network Capabilities

1st Phase: Establishment of mmWave connectivity between 5G-VINNI facilities and ADMIE facility in Rio.

In order to extend the 5G-VINNI infrastructure to reach ADMIE's facility in Rio, a mmWave link is going to be deployed across the two sites. A mmWave antenna is already installed at the University of Patras with clear LoS to the Rio facility. The mmWave antenna installation at Rio is still pending due to necessary safety procedures that must be followed from both ADMIE and ICOM, to ensure that the installation activities comply with international safety standards. The installation of the antenna will take place during summer 2021, when the procedures will be finalized and the required 5G spectrum license are ready, so as to be able to configure the antennas during installation.

2nd Phase: Rio-Antirio fibre optic link access permission.

After careful assessment of the mmWave link for the interconnection of two ADMIE sites and due to the peculiar terrain, the possibility of fibre link is being investigated. A submarine fibre optic link that interconnects the two ADMIE sites in Rio and Antirio is under construction and will be ready for use this summer. This link, as well as any other fibre link installed across ADMIE's power transmission network, is managed by Grid Telecom S.A., a subsidiary company of ADMIE. It is agreed that this link to be available for use to facilitate the interconnection of the two sites in the scope of 5G-VICTORI.

6.5.11 Planning of Lab testing and initial validation of services per use case

For the specific UC, the evaluation and testing plan is explained D3.2 [7]. The interconnection and network capabilities will be tested separately. Then the services that run on top of the equipment, will be tested in the lab as explained in [7]. Following this initial evaluation, the end-to-end functionality will be evaluated by integrating gradually the different components in the architecture.

The updated roadmap that combines both planning and execution phases is shown in Figure 6-37. Based on the planning that has been performed. Here the installation of UC specific equipment has already started is expected to be completed by month 30.

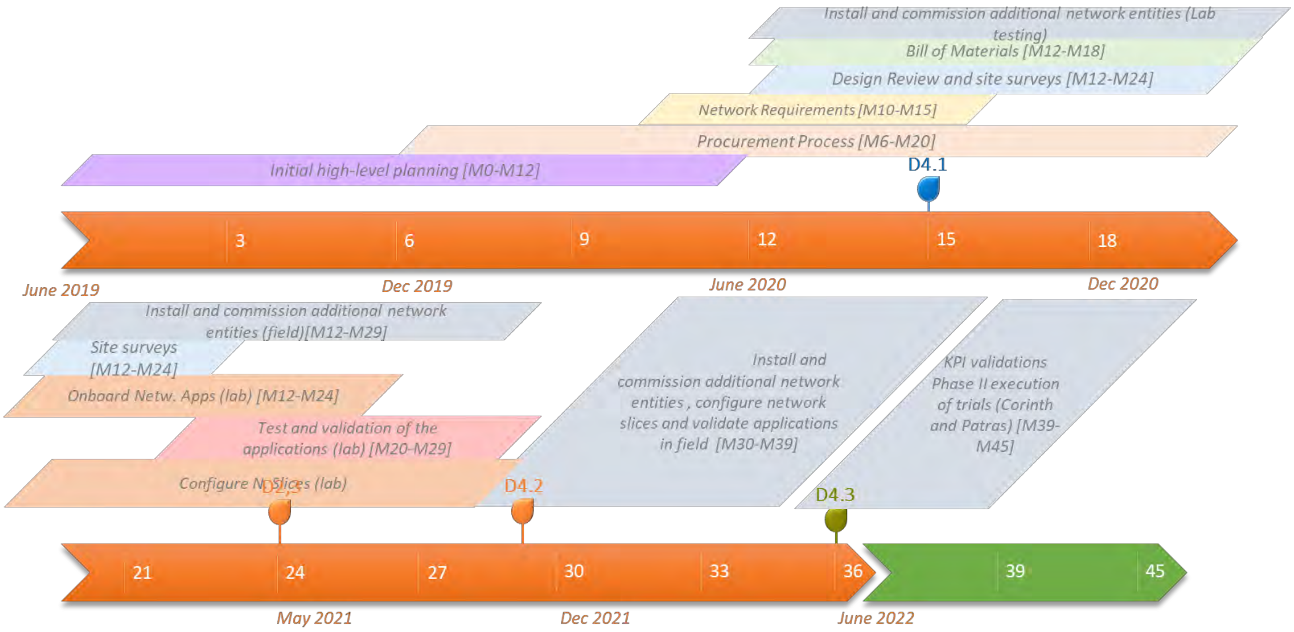


Figure 6-37 Updated roadmap for UC #2

6.6 UC #4.1 – Energy HV UC

This UC focuses on future Energy services/applications related to real time gathering of energy consumption and load data (recovery of energy fed back during braking) in the RMS and EMS platforms. The former aims to assist infrastructure managers and railway operators to select optimal strategies and resources in a cost-effective and energy-efficient manner (i.e., by synchronizing breaking and tractive effort in the rolling stock). The objective of the latter is to assist substation operators to perform smart energy techniques such as demand-respond, peak management, substation stress avoidance, load balancing, efficient HV grid interaction and cost savings in the EMS platform below [1].

In view of these services, the trial focuses on the monitoring and analysis of the energy flows for the railway system considering jointly the power electrification system and the rolling stock. The trial aims at analyzing the interactions between the train and the substations during acceleration/breaking periods of the trains. The final HV trial is expected to take place at Corinthos (Greece), where **ADMIE** feeds a range of primary substations. One of these primary substations (150kV/25kV), at *Corinthos*, is used for **TRAINOSE** suburban trains traction (TPSS).

To achieve the correlation and synchronization of the data sets and showcase the capability to make decisions and perform operation for the UC, a set of power metering devices installed on-board transmitting measurements to the trackside. Train-to-trackside connectivity is implemented through a private 5G network installed at the Corinthos train station to provide the required coverage to the train. The private 5G network connected to 5G-VINNI/UoPs Autonomous Edge/core solution is deployed (on VMs) at a local data centre. On-board power consumption measurements are correlated with measurements collected from devices at the ADMIE power station that is used to electrify the railway line. The required access network node (gNB) capacity will be of >1-2 Gbps to provide the required user data rates (~1 Gbps). The required latency requirements will be satisfied through incorporating/ basing the solution on MEC.

6.6.1 Energy related services and applications

The data management platform supporting the trial is deployed on the Autonomous Edge and orchestrates the collection and synchronization of measurements originating from the train and HV substation. The core functionality of the platform is based on UiTOP, which has been already presented in section 6.5, taking advantage, of two key features of UiTOP, multi-tenancy and on demand module configuration.

This is a cross-vertical UC where two different operators use the same infrastructure, thus it is a precondition to ensure data privacy. The Railway Management System (RMS) and the Energy Management System (EMS) are executed as two completely isolated applications (instances of UiTOP). Information exchange between the two systems is permitted only for specific datasets, as agreed.

For the real-time monitoring of the HV substation, Honeywell recorders are utilized, which use Modbus TCP communication protocol. For the collection of HV substation measurements by UiTOP, a custom Modbus TCP module and the needed time-series database have been developed.

The train monitoring system relies on a high performing data acquisition platform collecting measurements from a variety of sensors (i.e., power consumption, speed, position, 3-axial accelerometers, vibration sensors, frame grabbers monitoring the status of the electrification lines, etc.) installed on board. The monitoring system collects measurements with rates exceeding 50 KSamples/Channel/Sec. Fully synchronized/timestamped measurements should be transmitted to the trackside adopting standard IoT messaging protocols (i.e., MQTT) over the private 5G network that will be deployed at the Corinthos station.

6.6.2 Network Requirement capture/ Processing Requirement capture

An initial identification of the high-level requirements of these services has been provided in [1]. Aggregating the service requirements, the network deployment requirements have been derived initially in [1], and will be further refined in an iterative fashion. At this stage, the requirements that are further elaborated are those affecting the facility planning and demo deployments, and are shown in Table 6-14:

Table 6-14 Requirements that have impact in the facility planning and demo deployments

Deployment-related Aspect	Facility Requirement (Refined)	Deployment Solution & Dependencies
Network coverage	Network coverage is needed over ~1,000 m^2 at Corinthos TRAINOSE & ADMIE premises. For the train line, a network coverage in the order of 1000 m (500 m at each direction) is needed to capture the energy flows during breaking acceleration periods as the train arrives and departs from the train station.	Autonomous Edge w deployed, maximum coverage is still under investigation

Backhauling	N/A	N/A
Use Case network dimensioning	Low Latency required	Data processing at MEC/ Edge site will be incorporated.
	Access network node capacity of 1-2 Gbps is required. This capacity is necessary to support high frequency data collection process from the train to the ground.	The gNB provides min 1 Gbps.
MEC/EC Applications' compute requirements	5-10 VMs (2-4vCPUs, 2-8 GB RAM, 20-100 MB of space).	The autonomous Edge can provide 20 vCPUs, 50 GB RAM, 1 and 10 Gbps Ethernet interface.
MEC/EC compute requirements	UoPs' MEC solution requirements: 1VM (2vcpus), xGB RAM, for MEC functionality	

6.6.3 Site Survey and report /Final planning

6.6.3.1 Energy HV Use Case at Corinthos 5G-VICTORI trial.

A 5G base station (access) will be installed at the Corinthos TRAINOSE train substation connected to a local data center (VM). This UC is served through the 5G-Patras autonomous edge (section 6.3.5).

The ADMIE power station at Corinthos is located next to TRAINOSE Corinthos train-station (Figure 6-38). ADMIE high voltage facility is an area with security and surveillance systems. There various on-site metering devices (e.g. Honeywell metering devices) that are installed in a small building (point A in Figure 6-38). TRAINOSE facility is an open space, 4-platform station. One of the platforms lies along the ADMIE facility (point B in Figure 6-38)

According to the first design outcomes the Autonomous Edge will be mounted close to the platform 1 (see point B in Figure 6-38 . The distance between A and B is ~ 50 m. As the train arrives (departs) to (from) the Station, real time power consumption measurements are transmitted in real time to data management platform hosted at the Autonomous Edge. ADMIE will be equipped with CPE to be connected to AE at all times.

a)

b)

c)

Figure 6-38 (a) 5G-VICTORI dedicated facility for UC #4.1. The combined deployment for ADMIE (point A)/TRAINOSE (point B) facility will be integrated as shown here (b) view of point B from ADMIE facility and (c) view of point A from TRAINOSE

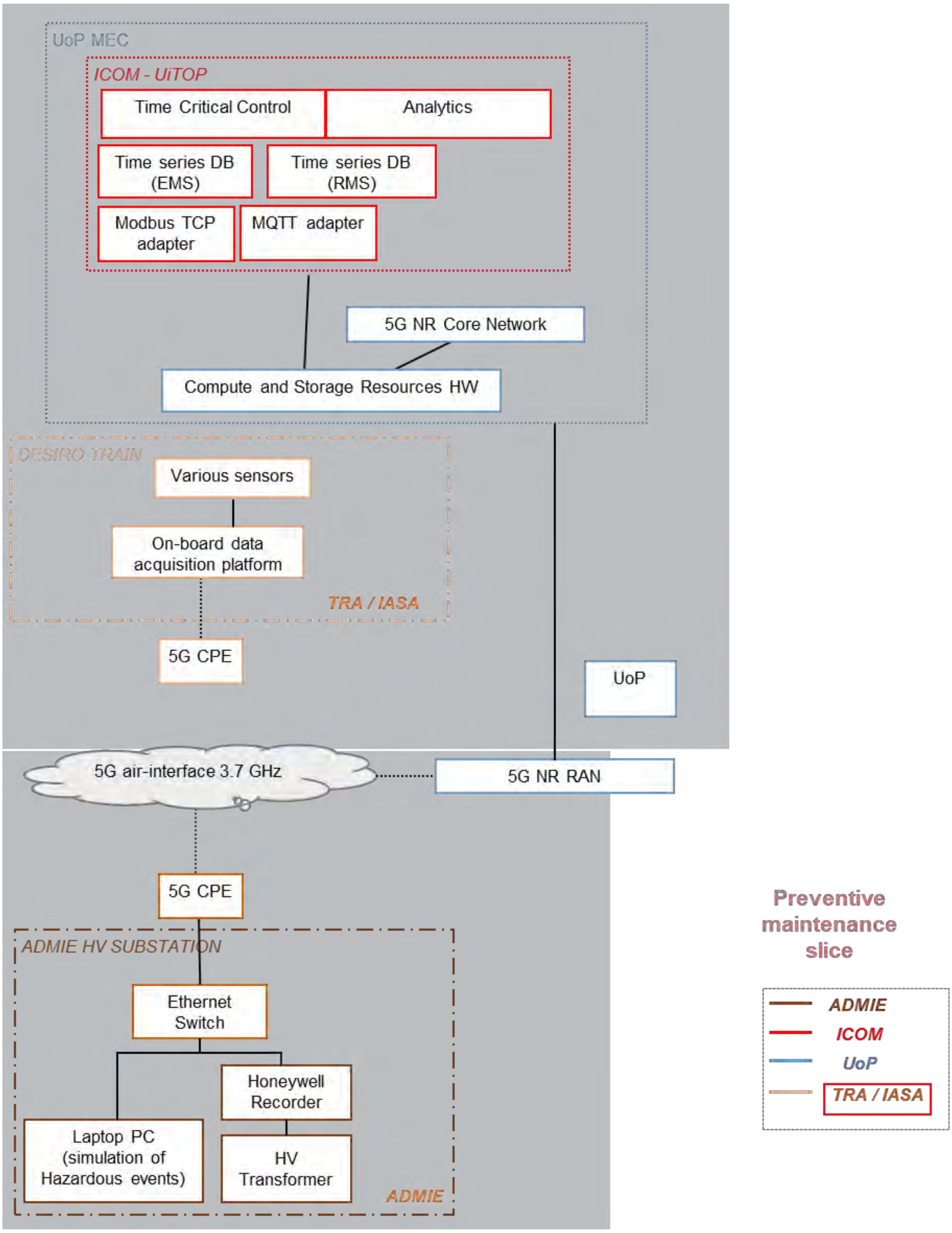


Figure 6-39 Preventive maintenance slice

6.6.4 Design Review and Bill of Materials

In Table 6-15, the components that drive the Smart Energy Metering services of the HV scenario are summarized:

Table 6-15 Bill of Materials for the Energy UC

Equipment	Item	Components	Quantity	Dimensions	Power supply
Honeywell QX Recorder 	Paperless recorder with16 analog inputs, Ethernet communications, up to 16 discrete inputs/outputs, totalization, math, retransmission outputs and transmitter power. Supports 20 ms scan rates and storage capacities up to 2 gigabyte.	- ETH 10/100 base - T with RJ45 connector supporting Modbus/TCP, FTP, Internet, DHCP or fixed IP address. - RS485 Modbus RTU (up to 115200 Baud Rate). - Input Resolution: 0.0015% (16 Bit ADC)	1 for deploying on the HV substatio n	- (144 cm W, 144 cm H, 200 cm D) - 2.7 kg.	40 W (peak)
High performing smart energy metering data acquisition devices installed on-board	Data acquisition devices with16 analog inputs ports. Supports acquisition rates up to 100Ksample/channel/sec . Aggregated sampling rate 4MS/sec. Protocol: MQTT (already installed)	1GbE connectivity/device	1 device to be installed on-board	30x30 cm	15 W (peak)
	Split core transformer (passive) +-20 ma (already installed)	Connected to the metering devices	4		
Accelerometer 	PCB 3-axial accelerometer +-500G (already installed)	Connected to the metering devices	1		
GPS RUT 955 	Teltonika RUT955 based GPS device (RUT-OS) Acts also as an MQTT broker (already installed)	4-1GbE connectivity	1	80x10 mm	7W (peak)
Vibration sensor MTN1185c 	General purpose, top-entry velocity transducer with a 4-20mA output of the RMS velocity values	Connected to the metering devices	t.b.d.		
Camera for line monitoring **Basler ACA1920-40gm** 	Industrial camera GigE	Connected to the metering devices	1	29.3 mm x 29 mm x 29 mm (with custom made enclosure constructed by TRAINOSE)	2.2 W (PoE)

6.6.5 Description of Equipment

6.6.5.1 ADMIE HV facility network deployment

To monitor the power consumption information of the electrical train, as well as enable the development of advanced services for the management of critical events between the power transmission system and the train power supply system, appropriate recording devices are installed at the HV substation close to the train station at Corinthos. Specifically one Honeywell QX Recorder (see Figure 6-40).

Figure 6-40 Honeywell QX Recorders

The recorder is connected directly to the measuring equipment of the substation and supports Modbus TCP connection over Ethernet. Modbus TCP protocol enables real-time communication of the Honeywell recorder over WAN, thus fulfilling the strict latency requirements of UC #3.

The recorder connects directly to the Huawei 5G CPE provided by UoP via Ethernet connection.

TRAINOSE has already installed and tested in the field an on-board metering system able to collect measurements from a variety of sensors monitoring energy, kinematic and structural parameters of the train including the catenaries (overhead power lines), the pantograph, the speed and position. The system has been installed in a Siemens DESIRO train, is non-intrusive and operates in parallel with its existing subsystems. The proposed metering that has been already installed and tested in the field collects timestamped, fully synchronized measurements from a variety of sensors which are then transmitted to the trackside using the MQTT protocol. During this first set of field trials, measurements are transmitted at IASA's MEC node using LTE connectivity (provided through Teltonika RUT955 router). This will be upgraded in the next set of field trials with a 5G CPE node that will be installed on-board. Through this set of measurements, kinematic and power consumption measurements from the train and the substations are correlated in order to identify the optimal policies that can optimize the performance of the entire railway system.

6.6.6 Identifying Gaps with existing Test Network Capabilities

Existing field trials have been carried out using a commercially available LTE Gateway providing the necessary connectivity between sensors installed on-board and the ground. The current gateway supports up to 150 Mbps throughput while the relevant tests have been carried out in a railway line connecting TRAINOSE's Depot located in Athens with Corinthos Station. So far, the system collects measurements from the train whereas correlation with substation measurements has not been tested yet. During the second set of field trials the objective is to test the performance of the system using a 5G CPE device installed on-board which will be connected with the private 5G network that is provided by UoP and will be installed at Corinthos station

6.6.7 Planning of Lab testing and initial validation of services per use case

In Figure 6-41 the roadmap for testing and integration activities for Energy UC are defined. All testing of UC related equipment and services on top are performed according to [7] and will then be integrated for the Trials. Initial validation of the capabilities of the Autonomous Edge have been performed in the lab.

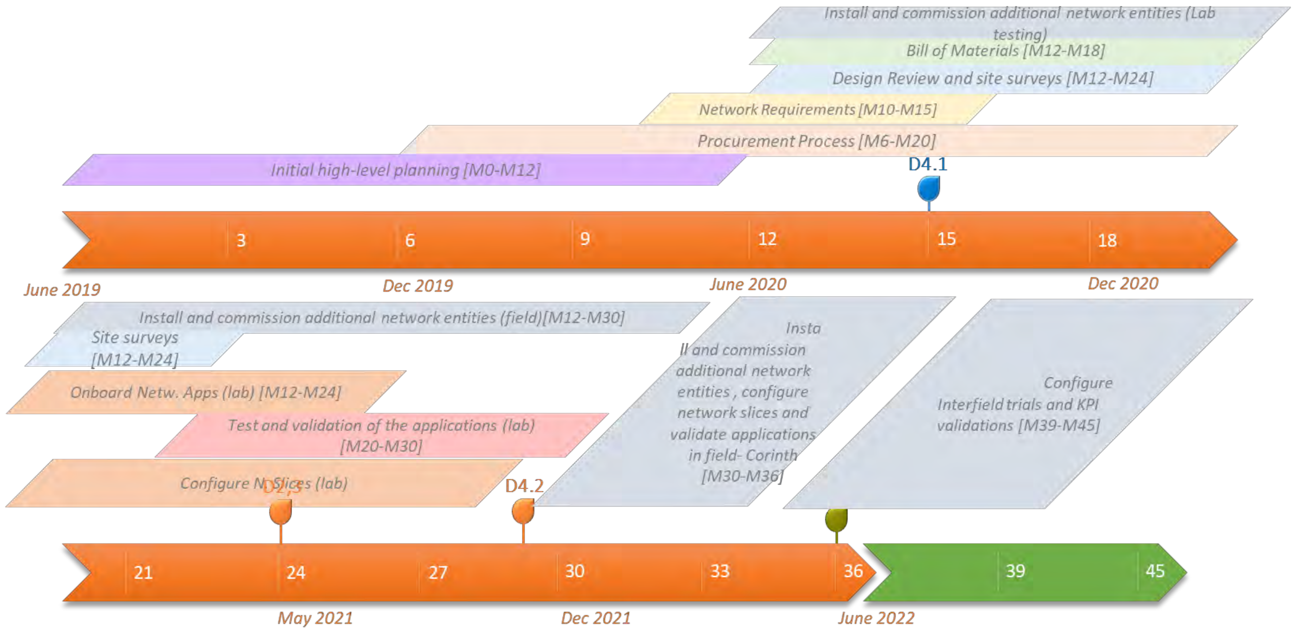


Figure 6-41 Updated roadmap for UC # 4

6.7 UC #3 Media

The main objective of this UC is to demonstrate efficient provisioning of eMBB-type, downstream services in trains for infotainment purposes, as well as delivery of upstream surveillance and safety services. An initial identification of the high-level requirements of these services has been provided in [1], and further refined in [6]. Aggregating the service requirements, the network deployment requirements have been derived initially in [2] and refined below.

6.7.1 ICOM multilayer CDN platform

ICOM provides a commercial CDN solution for the support of Live TV & multi-play services, namely fs|cdn™ Anywhere (Full Service Content Delivery Network) in the context of 5G-VICTORI project. The fs|cdn™ Anywhere solution is a full-fledged platform that incorporates components/features required for the acquisition, encryption, distribution, caching and reception of digital content, with support for Set-Top-Boxes (STBs) as well as Smart TV, Smart Phone (iOS and Android) and Tablet devices (iOS and Android). A variety of management tools and back-office interfaces are also included, supported by business and technical consulting and customization services.

The centralized CDN components, such as video head-end and management platforms are typically deployed on the mobile core. On the contrary, caching and streaming server components can also be deployed at MEC level, acting as edge streaming proxies and offering the benefits of not only disaggregation of core network traffic, but also low latency communication to end users and reliable and stable streaming rates. ICOM is building upon the associated technical expertise to support a CDN-oriented use case in 5G-VICTORI, deploying the customized fs|cdn™ Anywhere solution over distributed infrastructure.

6.7.2 Network Requirement capture/ Processing Requirement capture

A set of tests are going to be performed in order to verify that the functionality and the requirements/KPIs for both scenarios of this UC are met. Specifically, all steps of each scenario are individually tested. At this stage, the requirements that are further elaborated are those affecting the facility planning and demo deployments, as captured in Table 6-16.

Table 6-16 Network Requirement capture/ Processing Requirement capture

Deployment-related Aspect	Facility Requirement (Refined)	Deployment Solution & Dependencies
Network Coverage	• Network coverage to be provided at train station.	• One gNB w deployed at the selected train station site.
UC network dimensioning	• Considering a realistic scenario that: (a) one Video Streaming Service Provider supports the delivery of 10-20 channels of 8Mbps each, (b) the duration between two stations occupied with 5G coverage and MEC capabilities is approximately 15min, (c) the mean time that a train remains at a train station is approximately 3-4 min, then approximately 10GB of content will need to be prefetched during the train stop, thus posing the requirement for ~ 450Mbps-1Gbps datarates to the on-board caching point. • For the demonstration 3 channels (of ~8Mbps) will be available, posing the requirement for ~120 Mbps with the aforementioned timing conditions, OR for ~360Mbps or more for extended viewing times of 45min or more.	• The gNB (access network node) shall support at least 0.5 Gbps at the stopping point of the train on the platform.
Transport Access network	• The gNB shall be backhauled so as to be capable to provide at least 0.5 Gbps data rate at access network interface. • The above values effectively cover the surveillance scenario requirements as well.	• The gNB isbackhauled accordingly ,taking into account the relevant installation restrictions
Core/Backbone network Connectivity	• The 5GCore shall be connected to a central CDN point. • The 5GCore shall be connected to the internet for miscellaneous content services. • The 5GCore shall be connected to a camera client receiving the 360° camera footage. • The central CDN point shall be connected: o to a content origin in order to pull and cache content at various CDN points.	• The 5GCore is connected to: o Central CDN server(s), locally deployed (at UoP) o to the public internet for provisioning additional business services. o to the camera client of the surveillance setup, receiving the security footage. • The central CDN point shall be connected to a niche content origin that provides content in the format required by the CDN platform. The niche content origin isdeployed at COSMOTE premises and connected to CDN through ISP connection central point.
Applications' compute requirements	• At the MEC/Cloud compute resources, applications will be deployed for content prefetching and transfer. • At the train level, applications will be deployed on an onboard server (Edge server) for content reception, caching and distribution • At the train station level, applications will be deployed on a local server for 360° camera footage streaming in more than	• UoP's central cloud facilities used. • MEC server provided at D1, with the following minimum characteristics: 8 cores CPU, 16GB RAM, 2TB HDD, 2 Gbps NIC • Onboard (Edge) server deployed on the train in order to host EC functionality and

	one qualities (and optionally for streams optimizations).	applications, with the following minimum characteristics: 8 cores CPU, 16GB RAM, 2TB HDD, 2 Gbps NIC ● Local server deployed at D1 point for streams reception from the camera and forwarding to the 5G network.
Content Origin points deployment/ emulation	● Local VoD Content Origin point (s) shall be emulated and connected to CDN. ● Remote CDN Content Origin point shall be emulated and connected to CDN.	● A local VoD Content Origin will be emulated using a HD/4K videos (COSMOTE TV VoD content) server deployed on UoP premises. ● A Remote niche (CDN) Content Origin platform deployed at COSMOTE premises in Athens providing in terms of content: o COSMOTE TV streaming content (live (delayed) streaming) The niche Content Origjn platformcomprises a headend unit, an OTT encoder and an Origin. The platform will tailor COSMOTE TV live streams to the ICOM CDN requirements. It lso provides segmentation functionalities so that the CDN and Content Origin parts can be deployed at different places, while delivering a realistic deployment scenario.

6.7.3 Site Survey and report /Final planning

More specifically, the proposed deployment scenarios for the specific use case assume that a train approaches the TRAINOSE station (D1 in previous maps) and connects to the station through 5G NR in order to download streaming content in a "data shower" fashion, with the aid of ICOM's CDN multi-level solution. The content includes COSMOTE TV 4K Video on Demand content and COSMOTE TV linear services. Moreover, the train station is monitored through a 360° camera of high quality video. For this functionality at the end-user side:

- A 5G CPE will be on board the train along with an Edge server (on board).
- A 360° camera will be deployed at the D1 for uploading content to a remote Operations Center (through the gNB at D1).

For the integration with the 5G-VINNI facility, the CDN platform is based on a three-level hierarchical design. On top, there will be ICOM's central CDN Server (deployed at UoP premises), mainly responsible for receiving the (CDN) Source Content and preparing it to be delivered. The Content Origin point(s) is located on premises, (i.e. as a video streaming server at UoP premises hosting VoD COSMOTE TV content) to emulate local streaming services, and/or remotely to emulate a Content Origin point of a real CDN network deployment. The latter is placed at the COSMOTE (OTE Megaron building) premises in Athens, where a niche COSMOTE TV Content Origin platform is deployed for the purposes of the 5G-VICTORI project, available for direct connectivity to ICOM CDN providing access to a number of COSMOTE TV linear channels. The COSMOTE Content Origin platform comprises an Origin, an OTT Encoder and Headend equipment with interfaces tailored to ICOM CDN requirements. It shall be noted that the network design and COSMOTE Content Origin platform functionalities have been re-worked compared to the proposal made in Deliverable D2.2 so that the COSMOTE TV platform will also provide segmentation functionalities allowing for distributed deployment of the CDN Main Cache and the Content Origin point– the collocation of which two part was necessary in the previous design in deliverable D2.2 [2]. This will allow the clear definition and implementation of slicing between the three CDN caching stages (considered as the “Vertical Application”) excluding the Source point, thus providing a realistic environment for testing the complete deployment with streaming service coming from various CDN platforms – i.e. a CDN environment open to services of the outside world. From the vertical business services perspective, the deployment provides the means for testing two types of “business” services: a) CDN/streaming content services provided by the railway operator (asynchronous/VoD services) and hosted in the infrastructure deployed at the railway premises, b) CDN/streaming live content services provided by various 3rd parties outside the railway deployment, provided with the required high QoS by being processed by the CDN platform.

At the second level of the hierarchy, the MEC level, ICOM’s Main Cache component is deployed as VNF, constituting the MEC vCDN server and will provide the necessary functionalities and elements to support the content delivery (storage and streaming) to the lower level. At the third level, ICOM’s Edge Cache component is deployed at an additional Edge server located on board for serving the passengers even during disconnection periods. The Edge server contains a similar set of storage and delivery functionalities and connects to the Main Cache on the station’s MEC server through a 5G modem whenever the train reaches the station. This Edge server will be responsible to serve the train passengers, who will connect to the server through an on-board Wi-Fi.

For a specific channels number and bitrate per channel, and assuming that the train stop duration at a train station is fixed, the target data rate for the data shower functionality depends on the viewing time that we target to support on board. The volume of the data that will need to be transferred on the train occurs from the combination of the channels number, their bitrate and the target viewing time onboard. Then the data rate is computed by taking into account both the data volume and the duration of the train stop at the station. Indicatively, a data rate of approximately 500 Mbps is required to support 20 minutes of viewing time on board, having 10 channels with 7 Mbps bitrate and 3 minutes stop at the station.

A similar setup is envisioned for the case of the second scenario of the UC (video surveillance application), targeting both high data rate and low latency services. In this scenario, the 5G capabilities will be used to facilitate the monitoring of railway infrastructures by the railway security staff, located in a remote control center. A VR/360° 4K video camera will be installed at D1 train station, which remains equipped with a 5G base station. The video streams produced by the camera will be locally processed and optimized, and then delivered to the remote control center through the 5G network. The camera client (operator) is served with high quality video footage for as long as his field-of-view is stable, and with lower quality footage but with low latency during field-of-view movement. In this way, the new fields-of-view will arrive in time to the operator’s screen and no motion sickness will be faced during the transition to the new field-of-view.

The D1 train station area that was selected for the demo after some initial site surveys is depicted in Figure 6-42. Figure 6-42 shows the deployment at D1 for the Media UC. Various points in the area have been thoroughly investigated but the specific one has been chosen as it meets the requirement for access to 5G base station enabled with MEC capabilities.

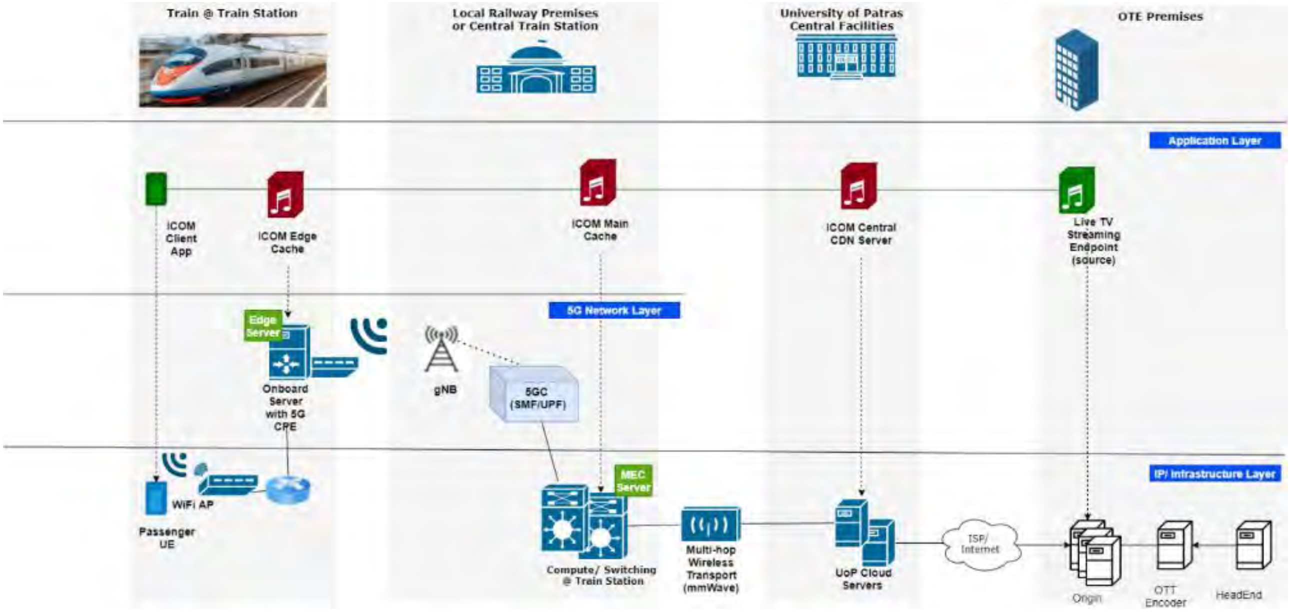


Figure 6-42 5G-VICTORI deployment at D1 for UC #4 (including equipment needed for UC #1-3)

6.7.4 Network Slice Co-Design

The total components that will be used in the context of the CDN scenario as well as the network slices are depicted in Figure 6-43.

An eMBB slice is formed in this scenario to support the data shower functionality. In this use case, the Edge server onboard serves as a UE in 5G terms, therefore the slice extends from the onboard 5G Gateway Router to ICOM's Central CDN Server at UoP. The slice contains all the necessary 5G network components and facilitates the fast transfer of content on board by providing high data rates. The slice is created and handled by the local orchestration framework.

Regarding the 360° camera scenario, the total components that is used as well as the network slices that is formed are depicted in Figure 6-42. In this case, two concurrent slices are formed to support the smooth FoV transition using high quality 360° cameras, one eMBB and one uRLLC. Both slices extend from the 5G Device/Switch located at the train station to the 5G connectivity at UoP, which enable the camera client to receive the footage. The slices contain all the necessary 5G network components and support both high quality video and low latency for lower quality video. Specifically, the first slice accommodates the high quality video streaming, whereas the second slice (see Figure 6-44) accommodates the lower quality video streaming as well as the camera control. The slices are created and handled by the local orchestration framework.

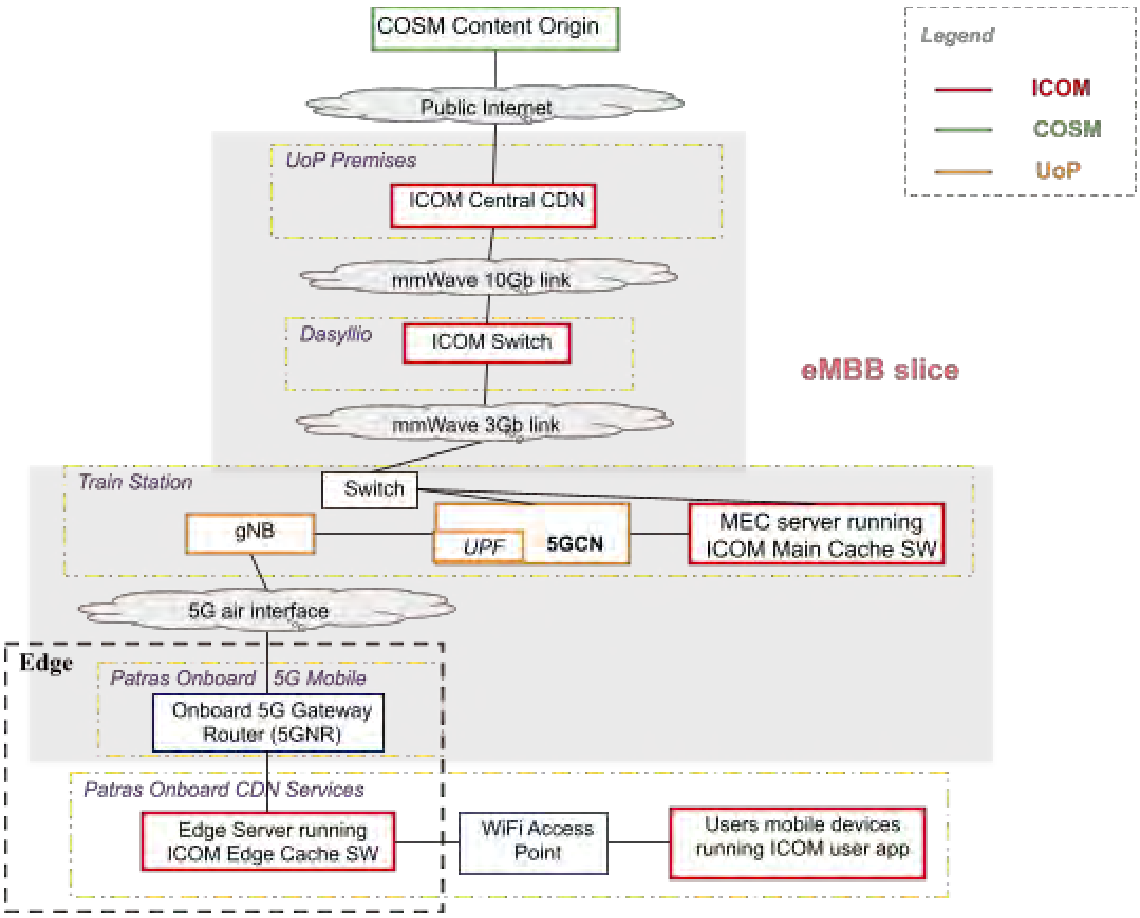


Figure 6-43 Architectural deployment for 5G-VICTORI CDN Data Shower Scenario

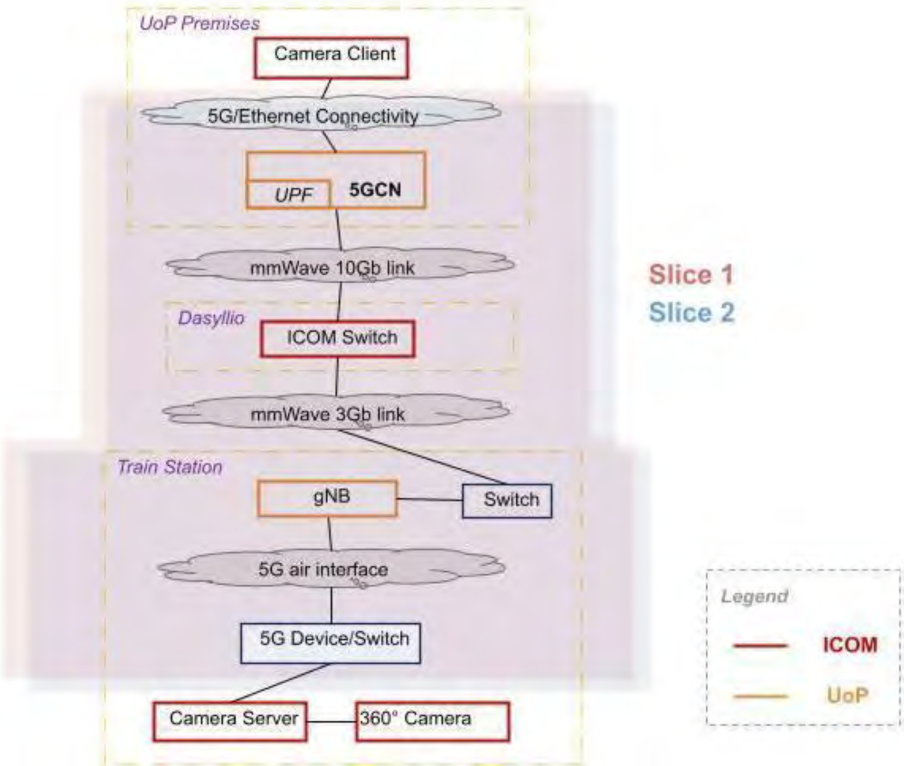


Figure 6-44 Architectural deployment for 5G-VICTORI CDN Surveillance Scenario

6.7.5 Design Review and Bill of Materials

The architectural design of the Media UC and the required components are summarized in the following BoM table (Table 6-17).

Table 6-17 BoM for UC #3

SEGMENT	TYPE/connection	Intended Use	No of Items	Responsible
USER	User devices (Laptop/ Smartphone) with Wi-Fi connectivity	See **UC #1.1**	At least 2	Everybody
ON BOARD Network	5G SDR (e.g USRP) or 5G CPE Huawei	5G Connectivity between Train andTrain station	1	**UoP**
ON BOARD Network	Wi-Fi	For passenger to train connectivity	1	**UTH**
ON BOARD Network	Compute Node (part of CDN server)	Onboard content caching and delivery to end users	1	**UTH**
Station↔ Train	5G BS (see Network extension section)	Base station at train station	1	**UoP**
Station	Compute Node (part of CDN server) (see Network extension section)	MEC-enabled host for content prefetching and transfer to onboard server	1	**UoP**
Station	360° 4K camera	For the up-stream train station surveillance services of the second scenario	1	**ICOM**
Station	Laptop/Server	360° 4K camera streams optimization	1	**ICOM**
Station	5G CPE (see Network extension section)	5G connectivity between 360° camera server and gNB @station	1	**UoP**
UoP	Laptop (Camera Client)	Remote operator watching 360° security footage	1	**ICOM**
UoP	gNB	5G connectivity between 5G core @ UoP and gNB @ UoP	1	**UoP**
UoP	5G modem	5G connectivity between gNB @ UoP and camera client	1	**UoP**
UoP/COSM premises	Central CDN Server	Receive content from COSM and stream to MEC-level component (Main Cache)	1	**ICOM**
COSM premises	Origin	Origin receives content from Encoder and forwards it to Central CDN Server	1	**COSM**
	OTT Encoder	Encodes streams	1	**COSM**
	Headend	Interfaces COSMOTE TV live network deployment, and constitutes the borderline of the niche deployment	1	**COSM**
MH/BH	See **UC #1.1**			

6.7.6 Design Review and Bill of Materials

6.7.6.1 gNodeB Specifications and Interconnections

The gNodeB that will be used for this UC is described at the Network Extension Section 6.3.2.

6.7.6.2 Interfaces with the Use Case specific Equipment – CDN multi-layer platform

There are certain specifications that must be met so that the hardware requirements for each component are covered. For the CDN scenario, the servers that host both ICOM's Main Cache and ICOM's Edge Cache need to be compliant with the following:

- 8 cores CPU
- 2 TB HDD
- 12 Gbps NIC
- 16 GB RAM

The three layers of ICOM's fs|CDN will be connected through the internal mechanisms of the software, over IP.

The 4K 360° camera model that will be used for the surveillance scenario is Dahua IPC-EBW81230. It is a 12MP panoramic fisheye camera with the following main characteristics:

- Supports frame rate of 25 fps for quality of 12M (4000x3000).
- The camera can output three streams. The Main output stream is available at 12MP (25fps) or at 8MP (25/30fps), whereas the Sub Stream at D1 (25/30fps) and the Third Stream at 1.3MP (25/30fps)
- H.265/H.264 encoding
- Compliant with Open Network Video Interface Forum (ONVIF) standards regarding the communication between video surveillance IP products.
- Requires DC12V power supply but is also Power-over-Ethernet (PoE)-enabled
- The supported Infrared Radiation (IR) distance, translating to the distance that the camera can cover, is up to 10 m.
- Ingress Protection of level IP67 is supported by the camera, which makes it weatherproof and suitable for outdoor environments.
- IK10 compliance enables the camera to sustain the equivalent of 55 kg (120 lbs) force.
- Net Weight 0.58 kg / Gross Weight 1.0 kg.

Apart from the 360° camera for this scenario two laptops/servers will be needed, one for hosting the camera server software and one for hosting the camera client software. The plan is to use laptops of up to 2.5 kg and 16", requiring approximately a 20V power supply. The camera server laptop will connect to the 5G network via the gNB that will be placed at the train station, whereas the camera client laptop will connect to 5G Core via a gNB that will be available at UoP premises. At the station a 5G CPE (Network extension section) acting as a gateway between the laptop and the gNodeB will be used.

6.7.6.3 Specifications and Interconnections

As aforementioned, content source/origin will be placed at the **COSM** (OTE Megaron building) premises in Athens, where a niche COSMOTE TV source will be deployed for the purposes of the 5G-VICTORI project, available for over ISP connectivity to ICOM's HLS-enabled CDN system central server, which will be located at the UoP premises. The niche deployment will provide access to a number of COSMOTE TV linear channels. The COSMOTE source point will comprise an Origin, an OTT Encoder and Headend equipment with interfaces tailored to ICOM CDN requirements. In particular, as far as the Source-CDN interface specifications are concerned, these are summarized as follows:

- Container type: Fragmented mp4 (fmp4) streaming media format.
- Pull-based communication between COSMOTE TV source and ICOM central CDN server.
- HLS or DASH Stream packaging.
- HLS manifest will provide the capability to use 3 image qualities (3 renditions in ABR ladder) and one sound quality per channel.
- Chunks will be created based on ICOM CDN requirements.
- Various DRM techniques can be used – for initial testing unencrypted channels will be used.
- Segmentation will be performed at niche COSMOTE TV side. In this way, the requirement to co-locate ICOM central CDN server with COSMOTE TV origin is overcome, to better define slices at Patras facilities while having a realistic deployment of this UC.
- Specific delay will be inserted to the linear content at CDN side to apply the data shower concept properly.

6.7.7 Identifying Gaps with existing Test Network Capabilities

A local testbed in ICOM's premises has been created by ICOM's fs|CDN commercial team in order to facilitate the first implementation and validation of the solution that will be used in the CDN scenario. In parallel, the 360° camera has been already purchased and development and local lab testing are also taking place at ICOM for the realization of the 360° camera scenario. The integration on the 5G-VINNI/5G VICTORI testbed at Patras will be able to take place once the testbed setup is finalized.

6.7.8 Planning of Lab testing and initial validation of services per use case

To ensure that testing and integration activities between the three technology, network and content providers (UoP, COSM and ICOM) will be tested in various a testing plan has been developed and reported in [6]. The roadmap of all activities for the specific UC is depicted in Figure 6-45.

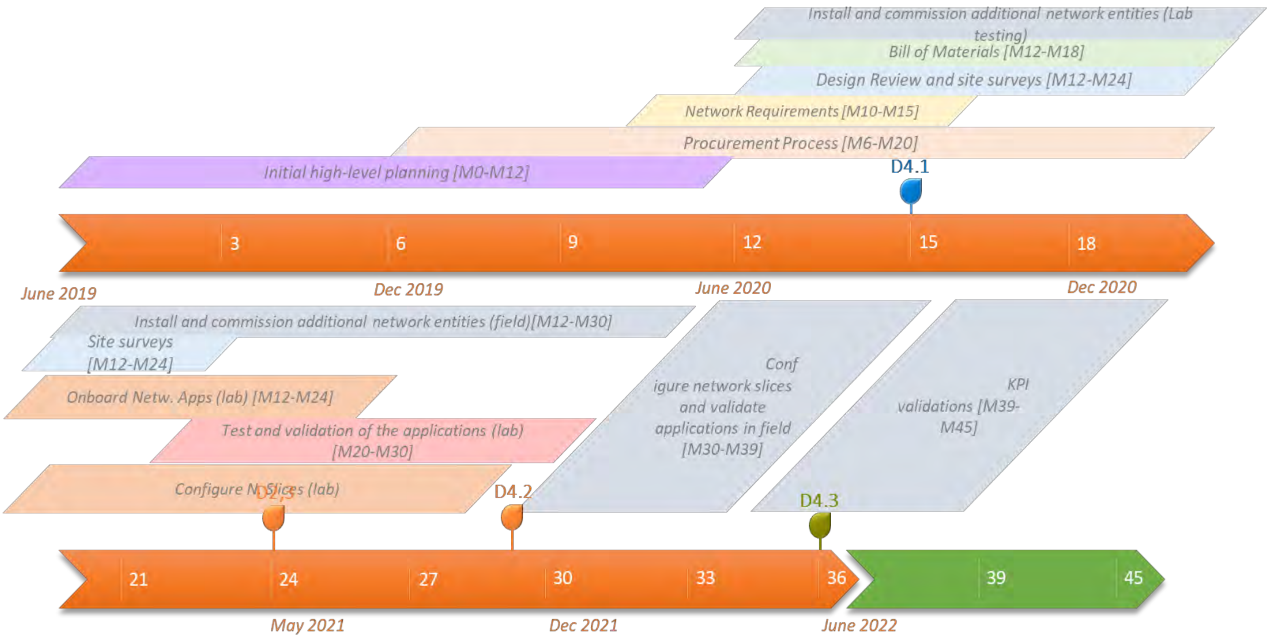


Figure 6-45 Updated roadmap for UC #3

6.8 Final Facility assessment / Unforeseen risks and mitigation plan

During the preparation of deliverable D2.3, and due to COVID-19, a major lockdown took place at all Greek Cluster site facilities. This includes the University of Patras, where 5G technologies are being developed and most of the sites where the vertical industry facilities reside. Although testing and development was not discontinued and was performed remotely it is expected that the procurement of some of the required components/equipment, lab tests, integration work and demonstrations will be delayed with respect to the initial plans.

With respect to the facilities involved in the Greek cluster UCs, currently all facilities were reachable for the planned site surveys. The roadmaps provided in this document have taken under consideration possible delays and facility changes up to 2021-05-01.

6.8.1 Spectrum and Licenses

As far as the mmWave is concerned from the track to UoP comprises merely **ICOM** (E-Band) technology and, according to the Greek legislation, the frequency license will be provided as soon as the exact points of antenna placement and specifications are declared to the EETT [https://www.eett.gr/opencms/opencms/EETT_EN/index.html].

As far as access technologies and especially for Wi-Fi technology are concerned, unlicensed bands are used for 802.11 in 5 GHz and 2.4 GHz across all facility sites and UC sites. Furthermore, technologies like LTE-A and 5G NR will be used to provide access to the 5G-enabled UE devices. Currently (status April 2021) all indoor and outdoor lab tests and experiments are performed through non-stand-alone 5G while the SA mode is also available. The application for using all the required spectrum (E-Band, 5G NR, etc.) has been filed to the appropriate Ministry.

Additional potential risks that have been identified and their corresponding contingency plans are presented in Table 6-18.

Table 6-18 Risk and contingency plan in the Patras facility

Risk type	Chance of risk (H/M/L)	Impact (H/M/L)	Contingency plan
Delays due to COVID-19 lockdown on equipment procurements	M	H	Roadmap of demonstrations and trials was reevaluated in March 2021 and all equipment delivery expected to be finalized by June 2021
Spectrum availability and licensing is not in time due to market instabilities	M	H	At the moment of D2.3 delivery legislation is in place, and UoP has submitted application for using the 5G spectrum available for research The Greek regulation concerns only 10 MHz bandwidth and the Greek cluster will need to apply for an extension to this
Delays due to COVID-19 lockdown on lab tests and integrations	M	M	Roadmap of demonstrations and trials will be reevaluated in September 2021
Delays due to COVID-19 lockdown on lab tests and software development	L	L	Roadmap of demonstrations and trials will be reevaluated in September 2021
Permissions on mounting equipment not available at the time of constructions (**UC #1.1**)	H	H	The plan of constructions and civil work is presented in Appendix At the moment the Greek cluster are already working on two alternative plans in order to ensure that a feasible plan can replace the specific one.
Changes on facility commitment (**UC #1.1**)	M	M	Alternative facilities will be sought planning will be performed again within the cluster
Power cut not performed by 2022 (**UC #4.1**)	L	L	Alternative pole will be sought, in the ADMIE facility

7 Inter-facility planning

This deliverable focuses on the description of the planning work for the facility extensions and upgrades that are required per 5G-VICTORI demonstration. This provides input to the detailed description of the 5G-VICTORI E2E architecture (deliverable D2.4).

As explained in deliverables D2.5 [3] and D4.1 [4], the inter-facility orchestration platform exists on top of each facility. This inter-facility orchestration is able to broker network services across multiple domains and facilities that comprise the 5G-VICTORI Platform. 5G-VIOS provides interconnection and interworking, creating a common infrastructure of integrated network and compute/storage resources.

In support of the 5G-VICTORI vision, to offer a Pan-European Infrastructure transforming current closed, purposely developed and dedicated infrastructures into open environments where resources and functions are exposed to ICT and vertical industries through common vertical and non-vertical specific repositories part of the facility planning work focused on inter-cluster activities. In this context, planning of cross-facility (inter) field trials is enabled by 5G-VIOS (Task 2.4) installed at each platform. 5G-VIOS is enhanced with multi domain resource management and cross domain orchestration capabilities.

These inter-cluster cross-facility activities will be executed in the framework of **WP4**. This requires harmonization and integration of all 5G enabled facilities across data, control and management planes. Therefore, more intensive relevant activities will follow in the next project phase.

Two inter-cluster UCs are described in the following section together with the associated facility planning. Also, a discussion on the common 5G-VICTORI functions repository is initiated with the aim to investigate the possibility of accessing common VNFs for cross facility service instantiation.

7.1 Patras-Bristol

A 360° VR Multi-camera Live stream will be delivered, focusing on large scale user connectivity, greater number of users and high bitrate videos. Mativision's inter-cluster proposed application will involve a training course hosted at the University of Bristol, using capabilities of **MATI**, and 5GUK test network. The users can take part in the class from anywhere in Bristol, with access to the 5G-UK test network, and attend the class via VR in real-time with low latency. Also users/students located at the **UoP** campus, will be able to concurrently participate to the same classes, by connecting to the UoP 5G network, and taking advantage of the 5G-VICTORI Inter-facility connectivity.

7.1.1 Network Requirement capture/ Processing Requirement capture

The requirements of Interfacility App Bristol-Patras were identified and divided into the following groups:

Hosting Requirements:

- Streaming Server VM: 8 CPU cores, 16 GB Ram, 50 GB storage space.
- Video Caching VM: 2 CPU cores, 4 GB Ram, 10 GB storage space.

Network Requirements: (lab & field)

- 10 Mbps or more per device for 360 video streaming

5G-VIOS API requirements:

- Instantiate edge services (lab & field)

Equipment Requirements: (lab & field)

- Multiple 5G Enabled android devices
- Backhaul VM hosting server

- Edge VM hosting server

The following required equipment will be provided by Mativision:

- 360 Video camera used to live stream
- Streaming Server VM containing streaming server application
- Streaming Server License Key used during testing period
- Caching service VM containing application logic

7.1.2 Network Slice Co-Design

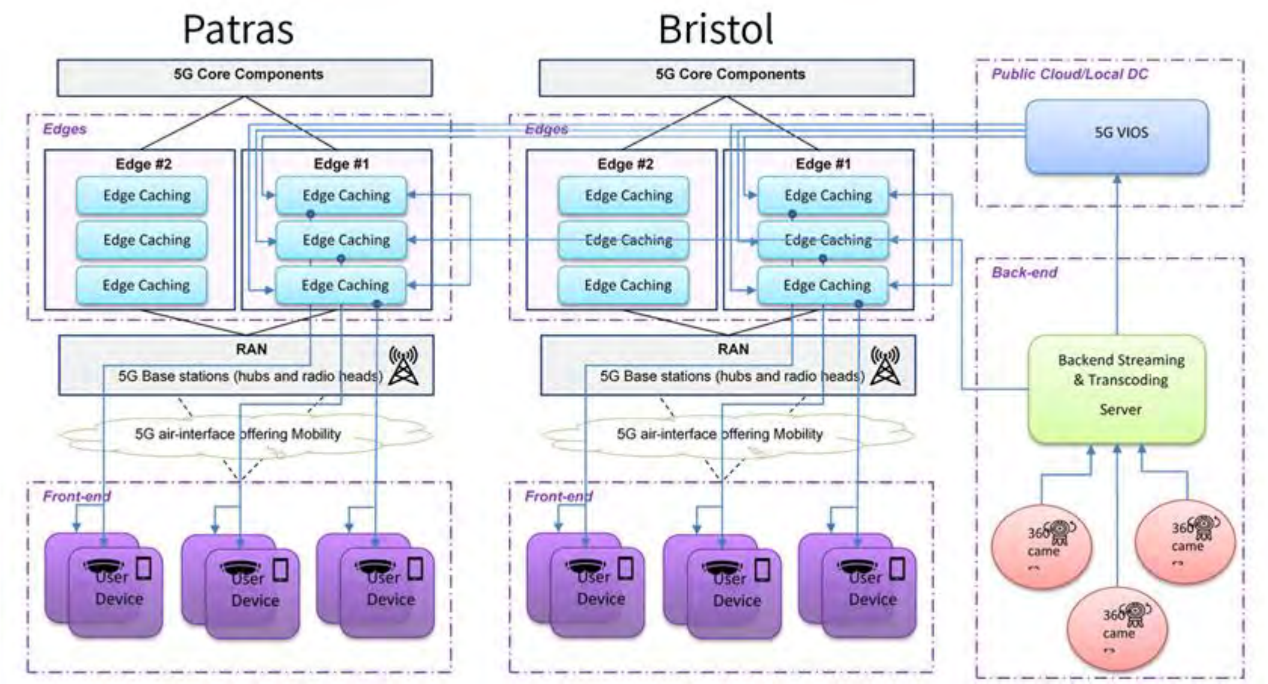


Figure 7-1 Interfacility App Bristol- Patras: MATIVISION VR Multicamera Live streaming from UNIVBRIS to Bristol locations and the University of Patras - high-level block diagram

7.1.3 Description of Equipment

Similar to **App 2** in section 4.3, the connectivity at Bristol will be provided by the Bristol 5GUK test network. The key locations of the Bristol side for this UC are University of Bristol campus, which streams the content to other locations in Bristol. Simultaneously, at **UoP** premises, the Autonomous Edge will be used as the AP at the University of Patras building. There, specific UEs will be distributed to students (UE as described in section 6.3.5) and will be used to attend lectures and events that take place at University of Bristol.

The key equipment used for this application are 360' cameras that are connected through Ethernet to the Bristol 5GUK test network at the University of Bristol to capture the training class. The end users can watch the stream either through Wi-Fi VR headsets, or through 5G-capable phones mounted to headsets or hand-held from Bristol 5GUK test network (specific edges) or UoP.

7.1.4 Identifying Gaps with existing Test Network Capabilities

For the caching and streaming to be able to work in an Inter-Cluster manner, the caching server will need to be able to connect to the streaming server VM and get the 360-video content. Connectivity will need to be established physically and logically between the two clusters and KPIs (throughput, latency, etc.) will need to be defined and measured. The physical interconnection could be provided by GÉANT but further discussion and connectivity details must be obtained before making a final decision.

7.2 Berlin-Bristol

UHA's future mobility insurtech API is put under scrutiny during the inter-cluster exercise. International travel from Berlin to Bristol will be played through, part real, part emulated. The aim is to demonstrate continued data capturing and forwarding between two international clusters. A scheme that shows how a passenger travels from these two cities is shown in Figure 7-2:.

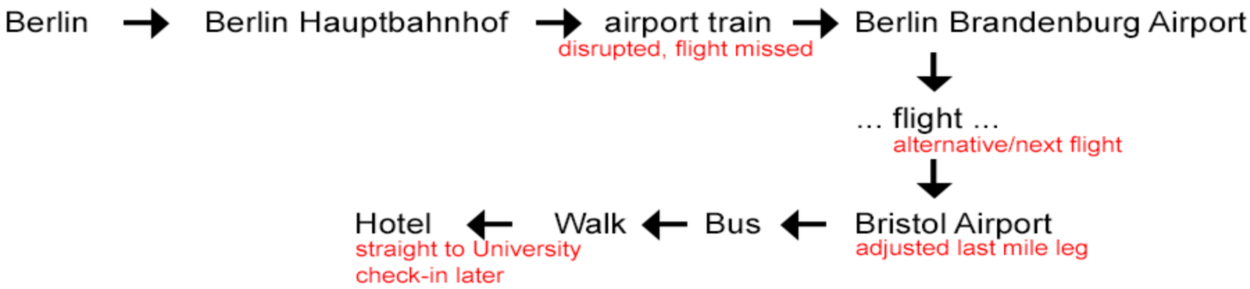


Figure 7-2: Scheme for a trip from Berlin to Bristol

Our passenger will physically start from Berlin, somewhere outside of Berlin Central Station. We envision the **UHA** future mobility front-end app is pre-installed on the passenger smartphone.

Our passenger will manually enter a Berlin-Bristol flight and a Bristol hotel booking through the front-end (flight number; hotel's address and contact with earliest and latest check in time). The app checks if sufficient time is available to get to the airport. (From Berlin Central Station to the Berlin Brandenburg Airport (BER); 30 minutes journey). The flight is in 95 minutes. Then plans the first and last mile leg of the international journey: via train from Berlin Central Station to the Airport, then flight, then a pre-paid bus from Bristol Airport to the hotel. It sends the relevant data through the insurtech API. Then offers an estimated travel insurance cover (no underwriter is yet connected therefore our estimate). Higher priced, due to the short remaining time (i.e., higher risk) until the flight. Finally passenger accepts the journey and the travel insurance product activates.

Delay: The Berlin Central Station to Airport journey is disrupted due to a fatal incident along the tracks (naturally we just emulate that in the data). Passenger is assumed to sit on the train half way with no chance of getting off or arranging alternative transport. As a result, the passenger misses the flight. In practice our passenger will depart only a few meters from the station and that data will be used to emulate the Berlin Central Station to Airport journey.

Blackout: no connection while stuck on the airport train. The cloud back-end waits until the passenger front-end reconnects. That happens when the passenger gets to the airport with a 2 hour delay. This part is also emulated. All relevant data is output through the insurtech API.

Our passenger is about to purchase a new flight ticket. The cloud back-end collates passenger's journey data (so far) with the rail operator's data stream. The Berlin Central Station to Airport disruption checks out as a valid insurance claim. Followed by an assumed instant payout our passenger has funds to buy a new flight ticket. And does so. Journey continued: once ticket re-purchased (in data) the passenger enters the new flight number through UHA's app.

UHA's cloud back-end re-plans the Bristol side last mile since the arrival time is different. Alerts passenger that the pre-booked Bristol airport bus is no longer valid. Also, an email about the delayed arrival at the hotel will be sent from the back-end to the hotel's email address.

Passenger is assumed to arrive at Bristol Airport. We will use a different test person and a different smartphone but with the Berlin data forwarded as if it was a continuous journey. From the airport with the help of the bus service our passenger gets to M-Shed (emulated). From here on every move is physical again. Once connectivity is regained at the Bristol side the cloud back-end registers the successful arrival. From M-Shed, instead of going to the hotel, our passenger edits the journey and aims Bristol University. Then follows the same route of the other Bristol cluster future mobility test cases. Another email about the later check-in at the hotel is sent from the back-end to the hotel's email address (has been entered manually in Berlin prior to departure).

7.2.1 Network requirement capture

Our cloud based back-end will jump from the German Edge node and Front-end app to the Bristol Edge and app once the emulated flight part of the journey takes place in the way depicted in Figure 7-3.

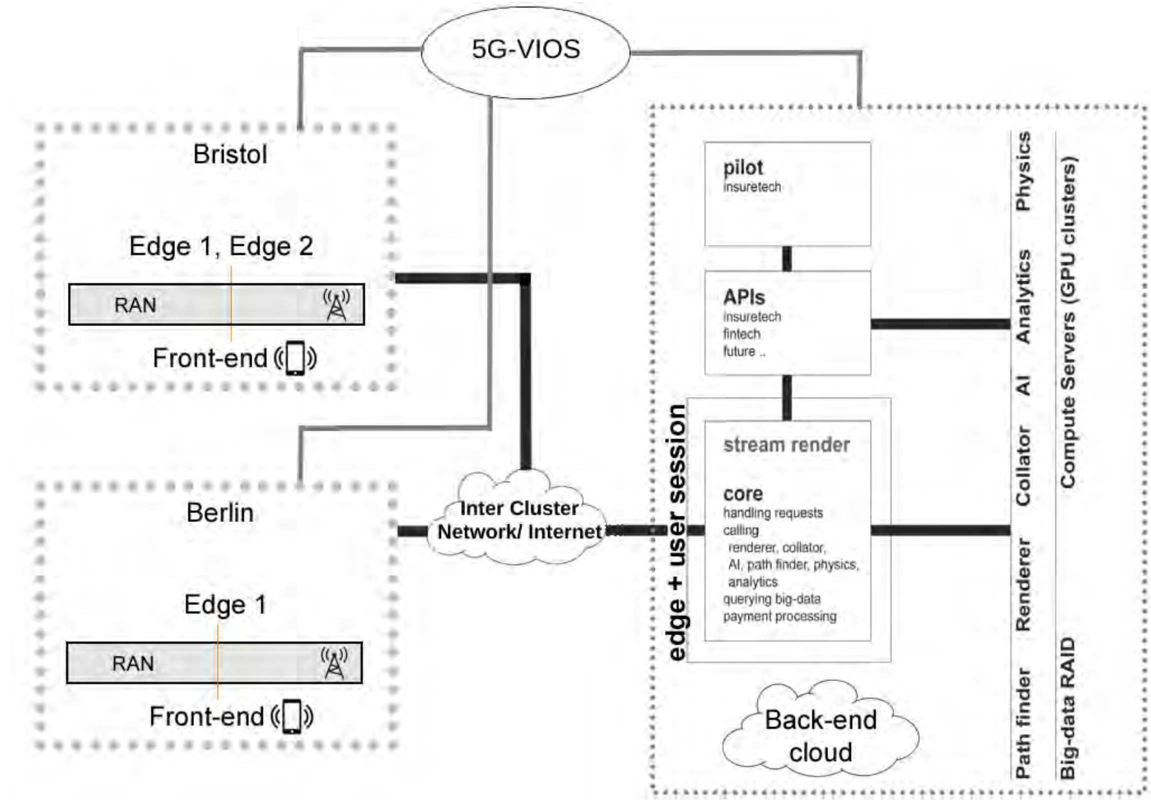


Figure 7-3 Interconnection of the two sites via 5G-VIOS and back-end instantiation

7.2.2 Description of Equipment

Same equipment will be used as in the other UCs. Please note that for the lack of space and reducing the complexity, services have not been mentioned at each edge. If interested, these services are provided in UHA's Network Slice Co-Design (section 4.4).

7.2.3 Identifying Gaps with existing Test Network Capabilities

From the network perspective the only new aspect is the loss and regain of connectivity (that is likely happening throughout a long journey). Connectivity will need to be established physically and logically between the two clusters and KPIs (throughput, latency, etc.) will need to be defined and measured. The physical interconnection could be provided by GÉANT but further discussion and link details must be obtained before coming to a decision.

8 Conclusions

This deliverable reports on the final facility planning of the individual 5G-VICTORI sites. Deliverable D2.1 defined and described the proposed UCs and their specific requirements, as they are dictated by the associated vertical industries, D2.2 described the initial phase per facility and UC and the final deliverable D2.3 described the overall co-design phase and the roadmap towards the Trials. It also describes how the requirements per cluster (5GENESIS in section 3, the 5GUK testbed in section 4, 5G-EVE in section 5, and 5G-VINNI in section 6) are taken into consideration to identify and design the per facility extensions imposed by the specific UCs planned to be demonstrated and the integration of the relevant verticals to the corresponding facility cites. This deliverable corresponds to the final plan for both network and facility extensions and it comprises all elements and their interconnection as required on a per site basis.

According to the methodology described in section 2.2, the partners of each cluster work together to ensure that the network and processing requirements are captured in the network design phase. After reporting the initial plan and list of hardware and software components, preliminary site surveys were performed to report on initial space, power, and cabling issues. This enabled the identification of the required 5G VICTORI facility extensions tailored to the UCs. Depending on the UC equipment and the installations that are needed per site, this specific planning phase took place several times, until the final bill of materials for software and hardware components was defined.

Based on the final bill of materials, final site surveys that resolve issues regarding demo equipment, safety issues, space, weight, power dissipation and cooling, took place at each site. Following this process a more realistic timeplan has been established that takes into consideration all required installation times and procurement of devices and software elements. Furthermore, installation permissions are being processed.

During this stage, the design of slices and the interconnection of equipment is designed in detail together with initial lab tests for equipment interconnection. To that respect network slices are designed in detail so that initial validation of services is planned on top of the designed networks at each site and in association with the planned UCs. In some cases, more than one concurrent infrastructure slices will be demonstrated over the same facility.

Expectedly, there have been some gaps between the required network design in order to demonstrate the trials per UC, and the network design that stemmed from this work. The identification of gaps has been part of this planning work. In this context, this deliverable also highlights alternative solutions with respect to the initial plan and the updated timeline and progress per site towards the completion of the sites' works and deployments. This deliverable provides input to the upcoming project activities such as deliverable D2.4 "5G-VICTORI end-to-end reference architecture", as well as activities of **WP3** "Vertical Services to be demonstrated", and **WP4** "Trials of Coexisting Vertical Services, validation and KPI evaluation".

All the planned work and facility enhancements that is described in this report concerns assets and resources that will be deployed in the physical locations. The latter is necessary for reaching out the main vertical sites and provide them with 5G coverage and interconnectivity with the ICT-17 facilities for the execution of testing (**WP3**) and Trials in **WP4** where will be executed and validated.

We summarize the achievements of each cluster up to May 2021.

8.1 Berlin Cluster facility

In this deliverable, the Berlin facility is presented after the site survey held at Berlin Central Station in May 2021. All the findings captured in this deliverable stem from the close interaction of the cluster leaders (FhG and IHP) with the vertical industries (Alstom, Kontron, PaxLife Innovations, RBB) and with the operational facility owner, which is Deutsche Bahn. Connectivity between the main data center at FhG and IHP has already been established for testing 5G and mmWave equipment. Prior to the integration efforts at Berlin Central station, several lab activities will be held at Alstom Labs, Kontron Labs, FhG Labs and IHP labs. These labs will involve both indoor and outdoor activities for testing the feasibility of the solutions in static and mobile environments, with the purpose to replicate experiences that will be of key importance when migrating the technical developments to a demanding operational facility such as Berlin Central Station.

The installation of the equipment at Berlin Central Station starts in Fall 2021, and will involve many interactions and activities with several departments of Deutsche Bahn, who are in charge of providing the necessary cabling (power and network), manpower to support the installation of the radio parts at the platform from DB Stations, manpower to support the installation of the equipment in a DB Train from DB System Technik, etc.

8.2 Bristol Cluster facility

In this deliverable, the Bristol facility presents the final Site Survey Report and provides a more detailed description of the updated Network Architecture. In addition, it provides a Network slice design for each application of the Digital Mobility UC in Bristol and a report on the deployed network technologies, equipment and services. The demonstration of the Digital Mobility UC dictates the configuration of a future-proof mobile network, capable of providing seamless functionality to services with strict performance requirements. The 5GUK Test Network was brought up to speed according to the performance requirements identified in 5G-VICTORI UCs, mainly focusing on Edge-to-Edge/Core-to-Edge/Inter-Node throughput and latency performance, edge computational resources, intra-edge slicing, and multi-RAT coverage and performance among others. Site survey report and final planning, network slicing and orchestration, lab and field testing along with an initial validation of services, and the final facility assessment (i.e., unforeseen risks and mitigation plan) were also discussed. Besides, the 5G-VICTORI facility in Bristol presents the installation of additional network entities and solutions from Bristol Partners (ZN, i2CAT, DCAT) including Amarisoft's 5G in-a-box and slicing products to be integrated into the 5GUK Test Network. The Bristol cluster plans to configure and validate the network slices, onboard each UC application to their appropriate network slices, then test and validate each UC, and finally Prepare for the experimentation for the Project Review and Official Deliveries.

8.3 FR/RO Cluster facility

In this deliverable the FR/RO facility is evaluated after the final surveys held in AIM, all survey outputs and information presented in this deliverable for the Romanian cluster is capturing the verticals UCs (LV Metering and Media UCs), in collaboration with the Alba Iulia City Hall. The activities describe the facilities 5G extensions and are based on the FR/RO E2E architecture and network functions integration. 5G support for service deployment is achieved through the extension of the 5G network to AIM. One of the main technical achievements is the integration of the RAN and Core functions in the facility, the 5G-EVE extension in Romania, was implemented through several labs activities and deployment actions. The testing and validation of the 5G proposed solution (in lab environment) has been implemented, while virtualized network function instantiation and network resources availability for the UCs validation has been also performed. Also, this deliverable confirms the availability of all required hardware and software components needed for the facility implementation and the UCs experiments, end-users devices, physical environment preparation, power supply and network connectivity. The equipment installation in AIM will be performed in the next period, involving interaction between the FR/RO partners in charge, as all required permissions have been granted.

8.4 Patras Cluster facility

For the design of Patras facility extension there was a close interaction between the Patras 5G facility leaders and vertical industry leaders, to ensure that the output 5G E2E infrastructure, will be suitable for the co-existence of various vertical industries and services. Due to the variety of vertical industries that will demonstrate 5G-enabled services and the nature of the cross-vertical services that will be demonstrated over the Greek 5G-facility there were numerous parameters and specifications that had to be considered. Hence the planning phase was detailed and thorough and involved a lot of iterations.

The aim of the Greek cluster is to develop a 5G-enabled digital infrastructure that is extended over the committed critical infrastructure of vertical industries. This extension concerns both the network and the services that are associated with this. To that respect the Greek cluster is developing new solutions for the mobility management schemes for the Transportation UC integrated with the advanced multi technology network. For the Smart Factory UC, all UC related equipment has been installed and related applications are further developed. For the Media UC, an innovative solution for the multi- layer CDN is integrated with the 5G network in order to investigate the data shower solution. For the Energy UC, an innovative solution that combines high sampling rate measurement data from the train with data from the power station over the Autonomous Edge is being developed.

Overall the Greek cluster is finalizing the co-design phase and entering the lab testing phase. This co-design phase has been long and various plans have been produced. Currently the plans that have been developed and reported in this deliverable are finalized together with alternative designs in case permissions to mount antennas and devices are delayed with respect to the Trials plan. At the moment of reporting all permissions are on the way and the commitment of the facilities and the vertical industries has been verified.

8.5 Overall Risk assessment

The impact of COVID-19, and the associated risks this pandemic entails, cannot be fully estimated yet for each of the clusters. The impact for our project does not only come from the above mentioned internal restrictions, but also from delays incurred by the associated ICT-17 Projects (5GENESIS, 5G-EVE and 5G-VINNI). This is why the situation for the different 5G-VICTORI clusters may vary depending on the specific cluster situation. The risks that have been captured in this deliverable will be implemented in the Participant Portal as unforeseen risks, each with a likelihood of occurrence. A detailed report on this matter has been already made available to the European Commission for evaluation.

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10 Appendix

10.1 Bristol Cluster - General Equipment Considerations

The integration of the test equipment (as defined in the bill of material in earlier sections) between partners requires the following considerations for the logistics of exchanging equipment in transport between laboratories or defining the interface between the equipment in preparation before the shipment. This activity will be a sub-project activity between the partners part of the integration task.

1. Demo equipment safety issues, Building, space, weight, power dissipation and cooling
2. Demo equipment power source, distribution, and on/off, Cabling, EMI, Grounding
3. Maintenance PC and work environment, Installation time, location, tools, schematics
4. Pre-testing of demo equipment in a safe environment for visiting partners

10.1.1 Raw data (Measurements)

Following is the part of one of 90 measured raw data in JSON Format, in this sample the repeated data in different time slots has been removed to reduce the complexity.

The “Device” category contains all the parameters related to the UE specially the radio part and the “Network” category contains the measured network performance related parameters.


```
{
    "Device": {
        "TimeStamp": "2020-07-23 12:16:02",
        "Device_MAC": "A8:DB:03:E1:E3:63",
        "Connection_Type": "Cellular",
        "Network_Type": "NR (5G)",
        "SDK_version": "29",
        "Cell_Operator": "00105",
        "Cell_RSRP": -80,
        "Cell_RSRQ": "Not Available for 5G",
        "Cell_RSSNR": 0,
        "Cell_ASU": 60,
        "Cell_PCI": 5,
        "Cell_Number": "70198821102xxxx"
    },
    "Location": {
        "lat": "51.4497246",
        "lon": "-2.5993094"
    },
    "Network": {
        "ping_time": "11.3"
    },
    "start": {
        "connected": [
            {
                "socket": 5,
                "local_host": "10.67.120.3",
                "local_port": 56528,
                "remote_host": "10.68.25.6",
                "remote_port": 5201
            }
        ],
        "version": "iperf 3.7",
        "system_info": "Linux localhost 4.14.113-18731944 #1 SMP PREEMPT Thu Jul
2 14:35:03 KST 2020 aarch64",
        "timestamp": {
            "time": "Thu, 23 Jul 2020 11:16:33 GMT",
            "timesecs": 1595502993
        },
```

```
        "connecting_to": {
            "host": "10.68.25.6",
            "port": 5201
.
.
.
.

    "end": {
        "streams": [
            {
                "sender": {
                    "socket": 5,
                    "start": 0,
                    "end": 10.000159,
                    "seconds": 10.000159,
                    "bytes": 205427488,
                    "bits_per_second": 164339377.40389928,
                    "retransmits": 205,
                    "max_snd_cwnd": 0,
                    "max_rtt": 0,
                    "min_rtt": 0,
                    "mean_rtt": 0,
                    "sender": false
                },
                "receiver": {
                    "socket": 5,
                    "start": 0,
                    "end": 10.000159,
                    "seconds": 10.000159,
                    "bytes": 202754752,
                    "bits_per_second": 162201222.60056067,
                    "sender": false
                }
            }
        ],
        "sum_sent": {
            "start": 0,
            "end": 10.000159,
            "seconds": 10.000159,
            "bytes": 205427488,
            "bits_per_second": 164339377.40389928,
            "retransmits": 205,
            "sender": false
        },
        "sum_received": {
            "start": 0,
            "end": 10.000159,
            "seconds": 10.000159,
            "bytes": 202754752,
            "bits_per_second": 162201222.60056067,
            "sender": false
        },
        "cpu_utilization_percent": {
            "host_total": 19.619783614867988,
            "host_user": 0.2478667016593042,
            "host_system": 19.371907076447766,
            "remote_total": 0.257254,
            "remote_user": 0.015792,
            "remote_system": 0.241465
        },
        "receiver_tcp_congestion": "bic"
```

10.1.2 Measurements

As it can be seen in Figure 10-1, the 5GUK testbed uses its own developed tool for measuring and monitoring the capacity of designed network on different RATs, especially for 5G and LTE.

This tool has two main parts. The first one is the Command-and-Control Centre application that manage all the procedures and an android application which is acting as a probe on a UE for recording all the parameters and send them back to the Database.

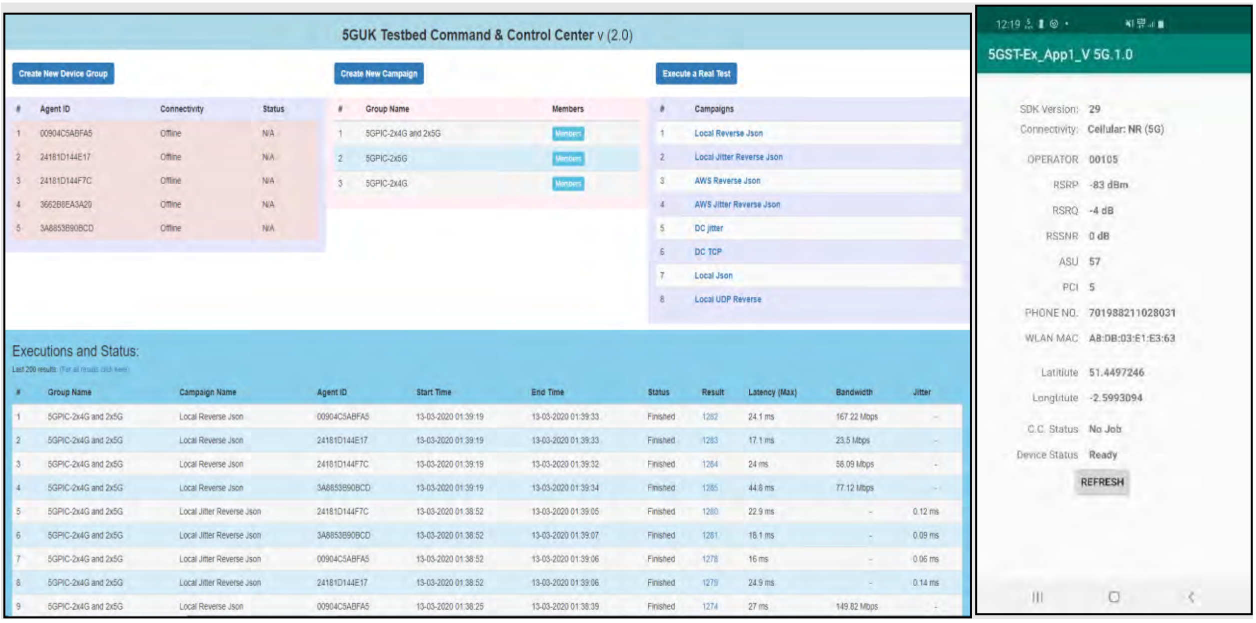


Figure 10-1: 5GUK Measurements and Monitoring Tools

During the site survey, 2 x Samsung Galaxy S20+ 5G and 2 x Google Pixel 5 phones were used. A network and UE performance capturing app was used on the phones to obtain all required metrics while driving the Nokia RAN to its limits by running TCP/UDP tests of unlimited bitrate along the demonstration route. At any given test instance, there were either: 1. two phones, one of them running UDP DL and the other UDP UL tests, or, 2. One phone running a TCP DL, or a TCP UL test. Results were then analysed by extracting the measured values and processing them accordingly either using Elasticsearch or other tools capable of performing the required statistical analysis.

10.1.2.1.1 Analysed Data

The following graphs were created using Elasticsearch and contain the coverage map of 5GUK 4G and 5G networks as well as some useful information related to throughput measurements.

Figure 10-2 shows the approximate outdoor coverage of 5GNR signals based on the measurement points. This figure extracted based on the RSRP level of the received signal by the UE, the warmer color in Figure 10-2 indicates the higher RSRP and the cold color in Figure 10-2 indicates the lower one (scope is between -75 to -120 dBm). The small circles are the location of measurements and in each location several measurements were happened.

Figure 10-4 shows the <u>indoor</u> 4G signal coverage inside MShed and MVB buildings.

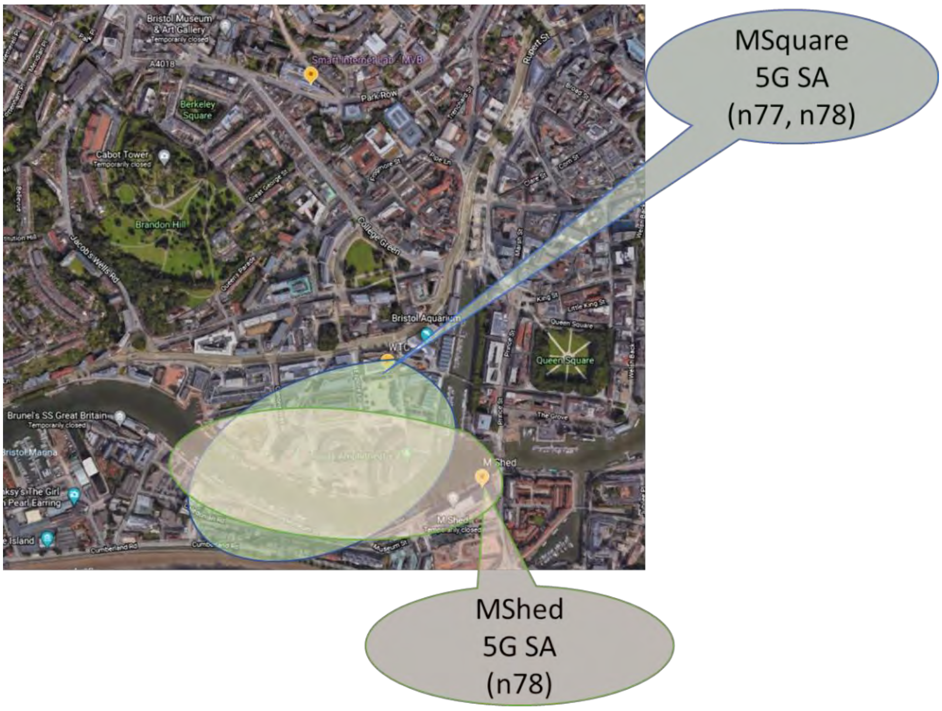


Figure 10-2: 5GUK testbed 5GNR coverage in Bristol harbour side

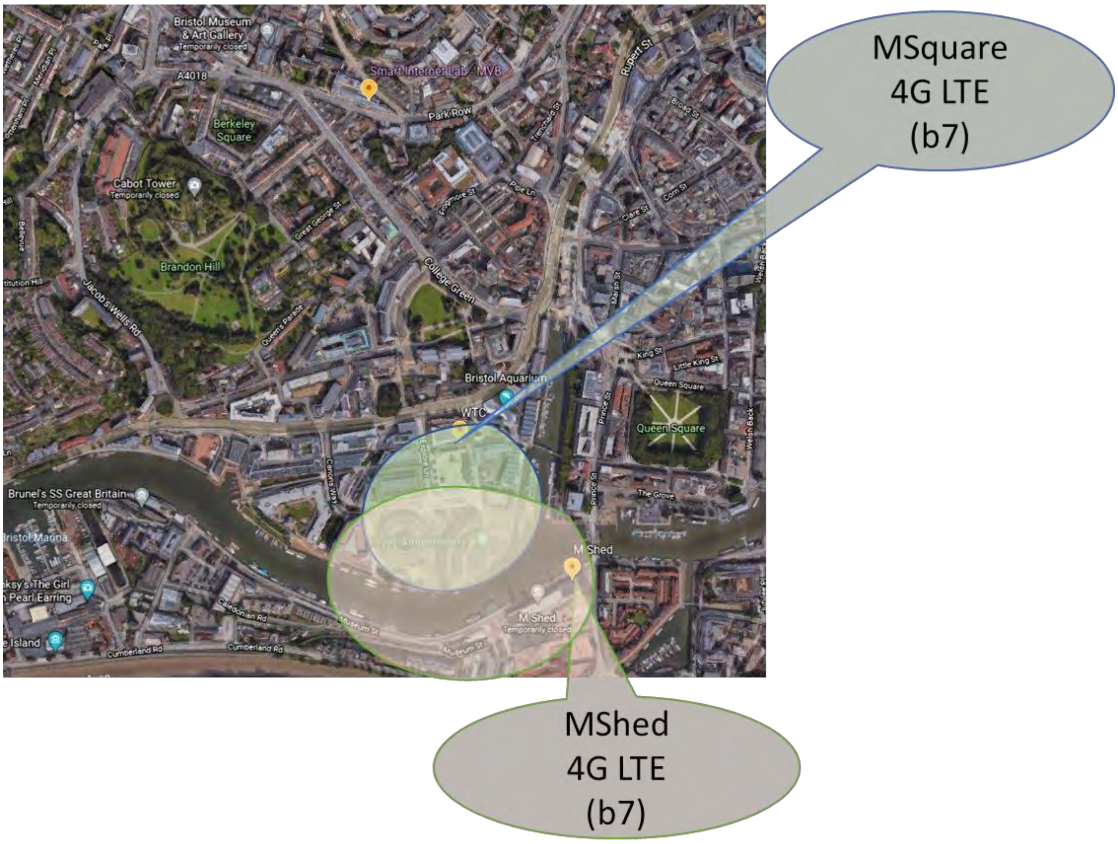


Figure 10-3: 5GUK testbed 4G coverage in Bristol harbour side

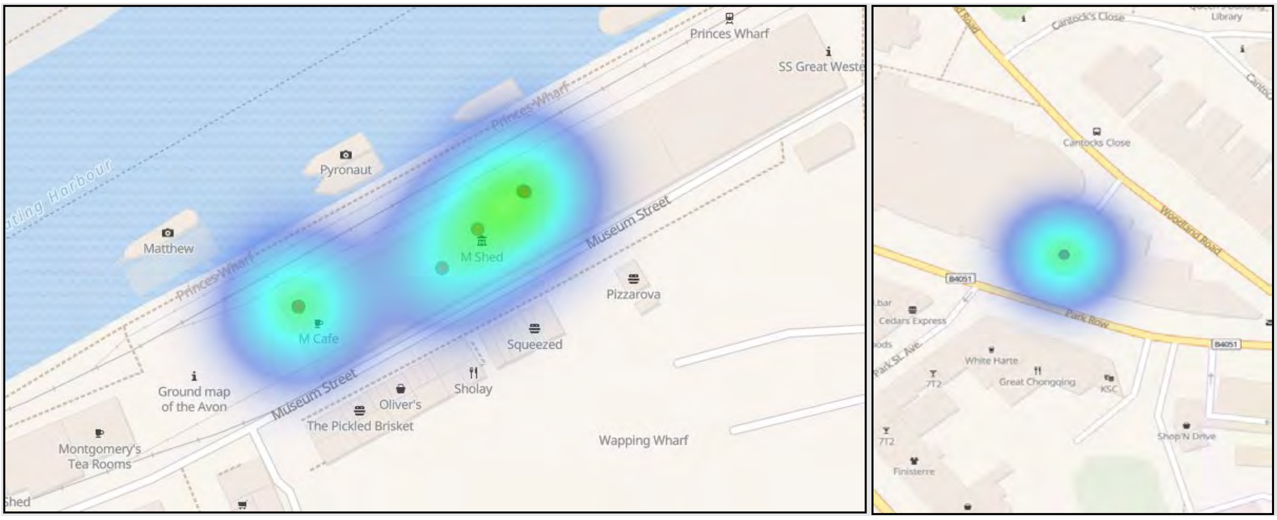


Figure 10-4- 5GUK testbed Indoor signal coverage map for the MShed (left) and the MVB (right)

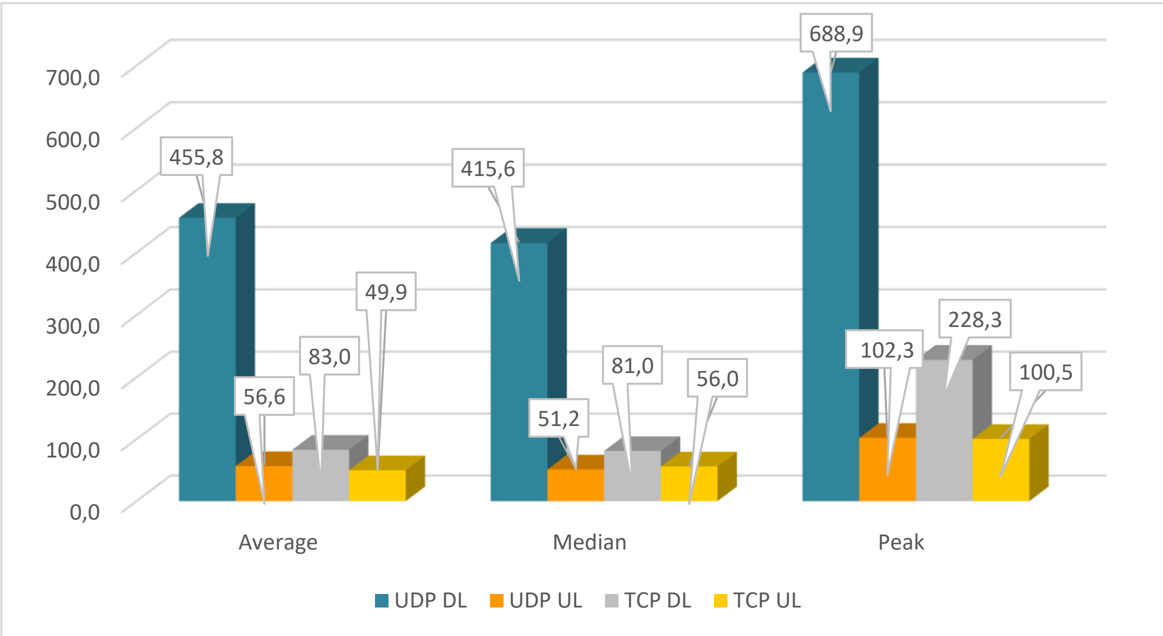


Figure 10-5: 5GUK Test Network 5G Download and Upload throughput (Mbps) along the demonstration route, from MSq to SS Great Britain

Figure 10-5 shows the 5G SA throughput of the 5GUK Test Network along the demonstration route. Handsets with 5G SA capability were used and throughput measurements were taken every 1s while walking along the route at an average/normal pace.

The 5GUK coverage at the cell edge, i.e., the area covering from Bristol Harbour Rail to SS Great Britain, is not as strong as the rest of the path. Even though there is a good DL performance, the limited power of portable devices such as the UE handsets cannot perform well in terms of UL performance. So, the Nomadic Node is providing all the required 5G connectivity to this area. Its connectivity with the backend network can be realized through 5GUK Test Network by using high-performance outdoor 5G-CPE equipped with high gain antennas or a VPN tunnel using one or multiple 3rd party networks. The 5G performance of an example 3rd party network around SS Great Britain is shown in Figure 10-6 and Figure 10-7.

Figure 10-6 5G Demonstration locations with lower signal coverage of the 5GUK Test Network (from Bristol Harbour Railway to SS Great Britain)

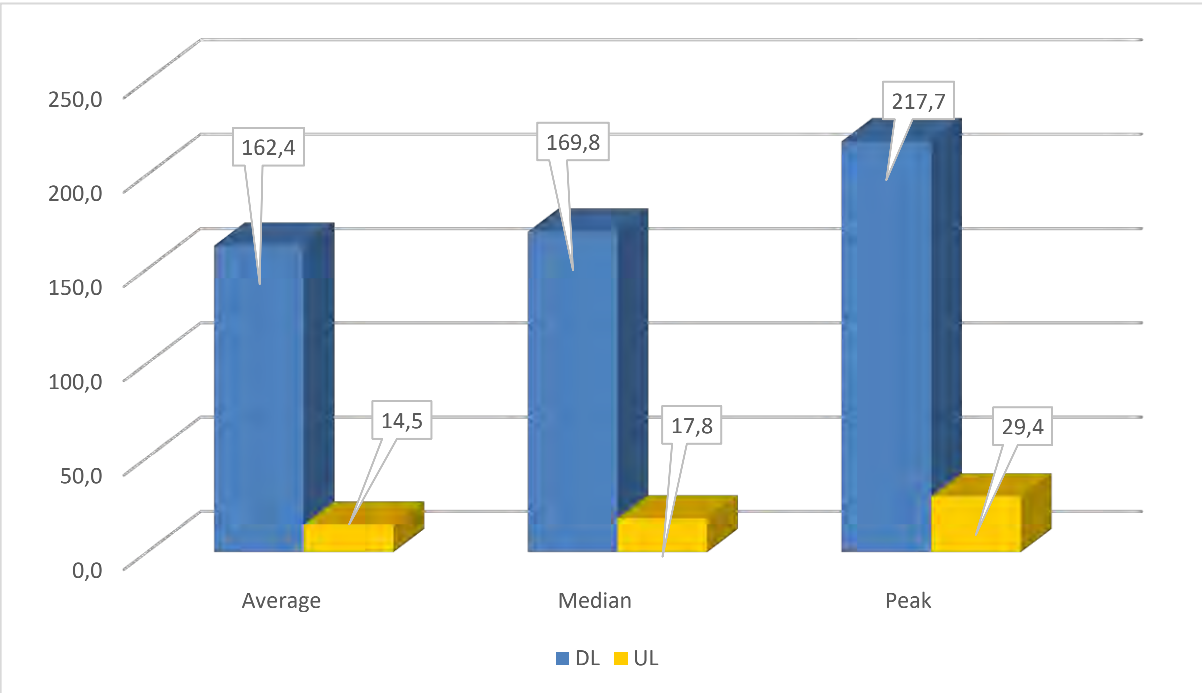


Figure 10-7 3rd Party MNO 5G Download (DL) and Upload (UL) speeds (Mbps) along the demonstration route from Bristol Harbour Railway to SS Great Britain.

10.2 Patras Cluster - General Equipment Placement Design and Considerations

10.2.1 Point D1

In brief the following installations are required for point D1: wireless node for backhaul link, optical node for fibre link with D2 and access point of 1or 2 sub-6 devices.

The prerequisite tasks pre-conditions for the implementation of construction work at D1 are summarized here: Security and safety check, structural check of structural design calculations for the wooden lamppost on which the stanchion will be supported, calibration and support of structural support reinforcement wherever it is required to existing poles/ in order to support the overall weight of equipment, structural support wherever it is required. In case the structural support is not suffice sufficient, an alternative pole will is planned to be built to mount the equipment.,

For the network equipment installations, an extension to the stanchion needs to be installed (**Figure 10-8**). Specifically for the wireless link with Dasyllio, the (wooden) light poles will be mounted with an extensions for to support the ICOM equipment. For the installation of the extension will be securely mounted on the light pole with appropriate fasteners, all necessary bases, poles and dedicated constructions will be mounted and secured. Furthermore an external cabinet will be installed close to the stanchion base which will accommodate AC sockets, power supplies, switches, etc. Ideally, a concrete base could be constructed for the installation of the external cabinet.

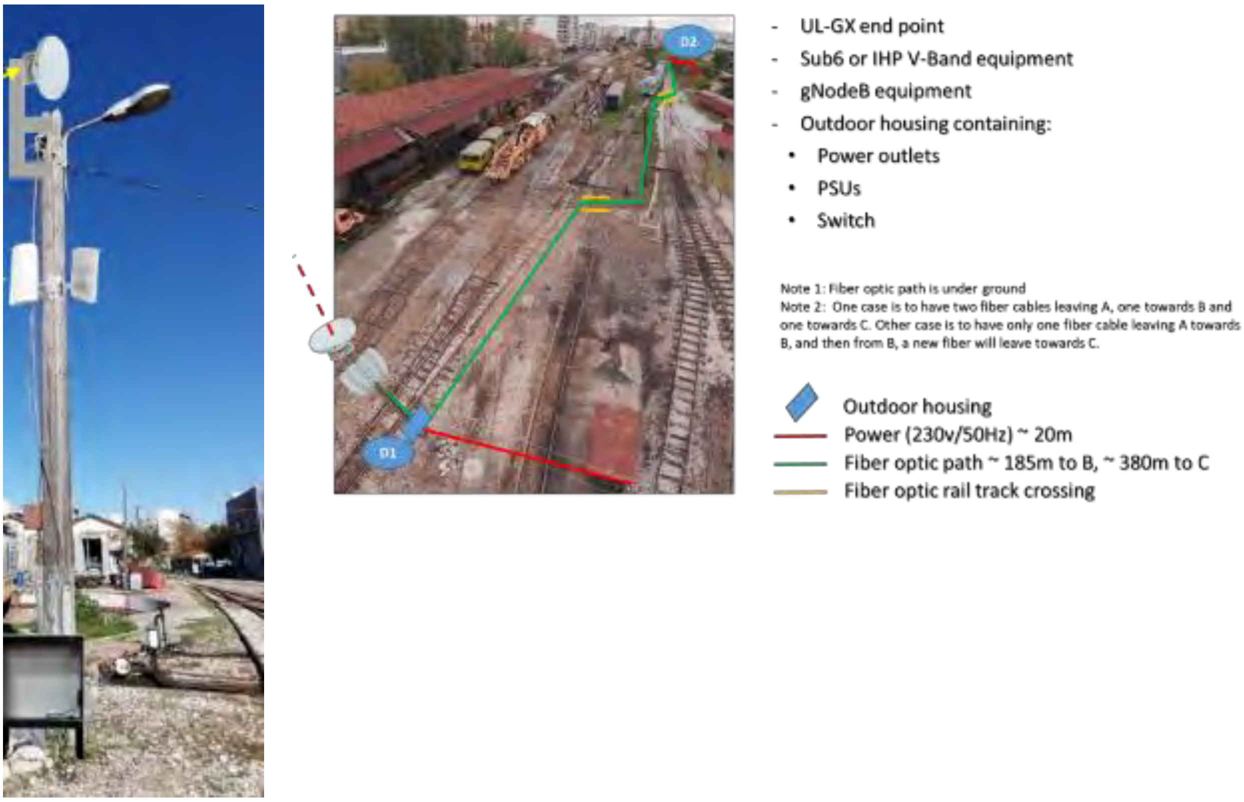


Figure 10-8 Design work at point D1

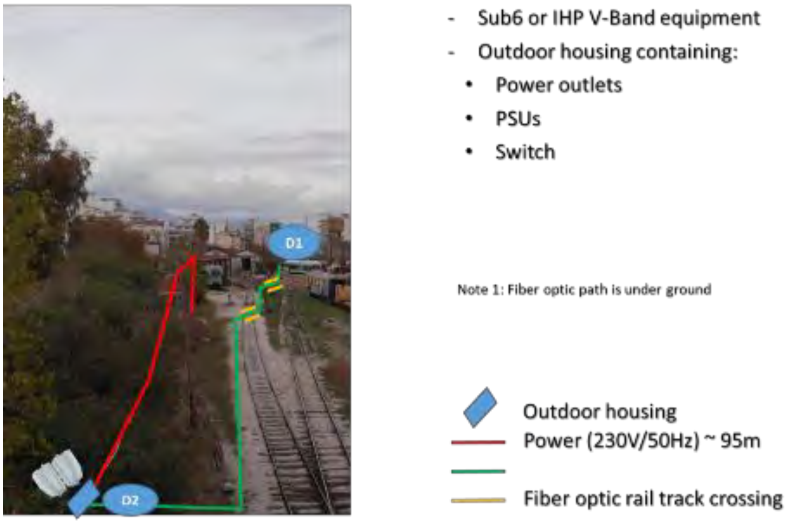
10.2.2 Point D2

The following installations are required for point D2: wireless node for backhaul link, optical node for fibre link and access point of 2 mmWave antennae access points provided by IHP. The optical layout of fibre cables between D1 and D2 may be performed either via an underground fibre cable, and is shown as a green line in **Figure 10-9**, or via an aerial fibre cable.

The prerequisite tasks pre-conditions for the implementation of construction work at D2 are similar to the ones summarized for D1; Fibre cables should be installed ensuring safety and with minimal disruption of the operational railway. For the network equipment installations, again in a cabinet will be installed at the base of the stanchion, which will accommodate AC sockets, power supplies, switches, etc., similarly to D1. Supplying point D2 with power will be realized via existing overhead poles, from a cabinet small building near point D2 (see yellow line in Figure and also red line in Figure). An alternative stand- alone battery-based power supply, if necessary, is also considered part of the design for the power supply of D2.

a)

b)



c)

Figure 10-9 Design work at point D2

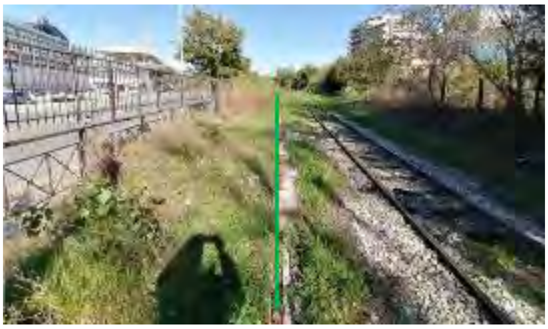
10.2.3 Point D3

The following installations are required for point D3: optical node for fibre link and access point of 2 S-ub6 antennas. The optical link between D2 and D3 will be provided either via an underground or an aerial fibre cable and is shown as a green line in Figure 10-10. All prerequisite tasks for the installation are similar to D1 and D2.

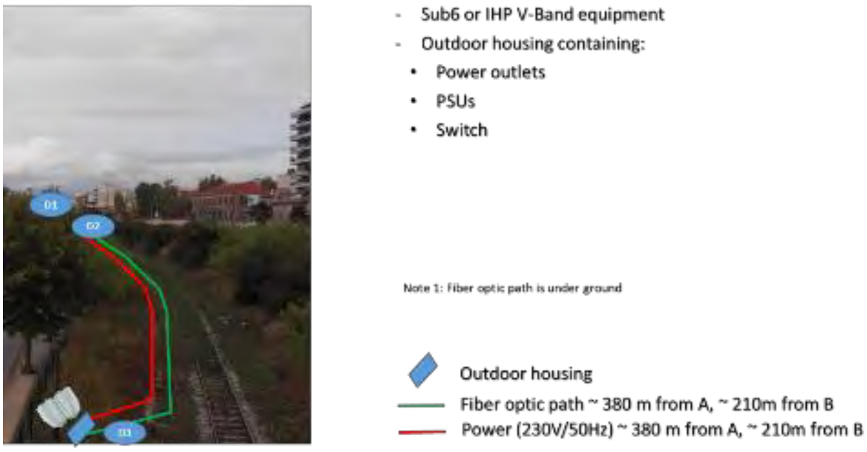
For the network equipment installations, again a cabinet will be installed at the base of the stanchion, which will accommodate AC sockets, power supplies, switches, etc., similarly to D1. Supplying point D2 with power will be realized via existing overhead poles, from a small building near point D2 (see yellow line in Figure 10-9 and also red line in Figure 10-9) In the event of failing to ensure power supply to the cabinet, an alternative stand-alone battery-based power supply, is also considered.

10.2.1 Point D4

The following installations are required for Point D4: wireless node for backhaul link and access point of 2 mmWave antennae provided by IHP. The prerequisite tasks for the implementation of construction work at D4 are similar to D1. The main difference concerns the installation of a new stanchion. The height of the stanchion should be 5 m. Civil works will be required to build a concrete base on which the new pole will be installed. For the network equipment installations, again a cabinet will be installed at the base of the stanchion, which will accommodate AC sockets, power supplies, switches, etc., similarly to D1-D3. In the event of failing to ensure power supply to the cabinet, an alternative stand-alone battery-based power supply, is also considered.



a)



b)

c)

Figure 10-10 Design work at point D3

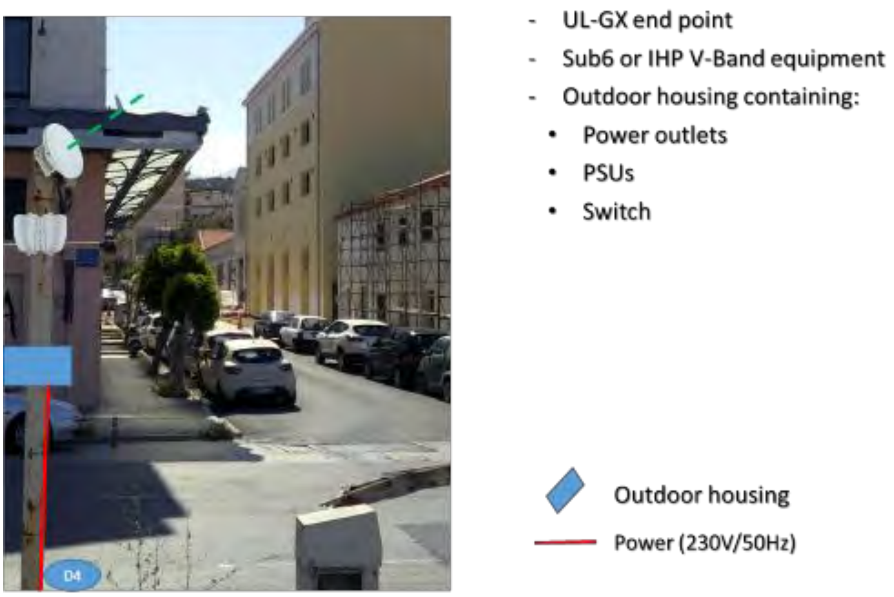


Figure 10-11 Design work at point D4