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

D2.1 5G VICTORI Use case and requirements definition and reference architecture for vertical services

This project has received funding from the European Union's Framework Programme Horizon 2020 for research, technological development and demonstration

5G PPP Research and Validation of critical technologies and systems

Project Start Date: 1st June 2019

Duration: 36 months

Call: H2020-ICT-2019

Date of delivery: 2020-03-31

Topic: ICT-19-2019

Version 1.0

Project co-funded by the European Commission

Under the H2020 programme

Dissemination Level: **Public**

Grant Agreement Number:	857201
Project Name:	**V**ert**I**cal demos over **C**ommon large scale field **T**rials f**O**r **R**ail, energy and media **I**ndustries
Project Acronym:	5G-VICTORI
Document Number:	**D2.1**
Document Title:	5G VICTORI Use case and requirements definition and reference architecture for vertical services
Version:	1.0
Delivery Date:	2020-01-31 (**2020-03-31**)
Responsible:	**ORO**
Editor(s):	Carmen Patrascu (**ORO**)
Authors:	Marius Iordache (**ORO**), Cristian Patachia (**ORO**), Jean Ghenta (**ORO**), Bogdan Rusti (**ORO**), Carmen Patrascu (**ORO**), Martin Piovarci (**KCC**), Peter Lundh (**BT**), Miggi Zwicklbauer (**RBB**), Sven Glaser (**RBB**), Christoph Ziegler (**IRT**), Louay Bassbouss (**FhG**), Eric Troudt (**FhG**), Stefan Pham (**FhG**), Shadi Moazzeni (**UNIVBRIS**), Hamid Falaki (**UNIVBRIS**), Ben Thomas (**UNIVBRIS**), Markos Anastasopoulos (**UNIVBRIS**), Anna Tzanakaki (**UNIVBRIS**), Luke Kazanis (**MATI**), Athina Metridou (**MATI**), Joanna Tzima (**MATI**), Anthony Karydis (**MATI**), Robert Sugar (**UHA**), Erika Fucsok (**UHA**), Miguel Catalán (**I2CAT**), Adriana Fernández (**I2CAT**), Jorge Paracuellos (**ZN**), Azahar Machwe (**ZN**), Kostas Katsaros (**DCAT**), Tanya Politi (**UoP**), Panagiotis Papaioannou (**UoP**), Spyros Denazis (**UoP**), Nikolaos Tzanis (**ADMIE**), Paris Flegkas (**UTH**), Nikos Makris (**UTH**), Marievi Xezonaki (**ICOM**), Konstantinos Chartsias (**ICOM**), Dimitrios Kritharidis (**ICOM**), Sergios Soursos (**ICOM**), Kostas Stamatis (**ICOM**), Alexandros Dalkalitsis (**TRA**), Christian Schlehuber (**DBN**), George Tombras (**IASA**), Alexandros Manolopoulos (**IASA**), Ioanna Mesogiti (**COSM**), Fofy Setaki (**COSM**), Elina Theodoropoulou (**COSM**), Nebojsa Maletic (**IHP**), Jesús Gutiérrez (**IHP**).
Keywords:	5G Networks, Vertical Industries, 5G use-cases, 5G Network infrastructures, Communication Systems, 5G KPIs.
Status:	Draft
Dissemination Level	**Public**
Project URL:	https://www.5g-victori-project.eu/

Revision History

Rev.	Description	Author	Date
0.0	Draft Table of Contents (ToC)	Marius Iordache (ORO)	2019-08-14
0.1	Modified ToC according to feedback from ICOM, FhG, IHP.	Carmen Patrascu (ORO)	2019-09-13
0.2	Section 3.3 first content, with HW overview. Critical Service for Railways updated. Section 3.3 IxChariot info added.	Peter Lundh (BT), Martin Piovarci (KCC), Peter Lundh (BT)	2019-09-15 2019-10-04 2019-10-15
0.3	Section 3.3 figure updated, 5G CPE doppler subsection added. Modified ToC according to discussions from Bristol Technical Meeting.	Peter Lundh (BT), Marius Iordache (ORO)	2019-10-28
0.4	Section 3.3 populated again with the removed parts+ as of the modified ToC activity in rev 0.3. Section 3.3 updated: train test scenario and 4G.	Peter Lundh (BT)	2019-11-14 2019-11-18
0.5	Requirements added in section 3.3.	Peter Lundh (BT)	2019-11-26
0.6	Use Case 3 description in section 3.5	Miggi Zwicklbauer (RBB), Sven.Glaser (RBB), Christoph Ziegler (IRT), Louay Bassbouss (FhG), Stefan Pham (FhG)	2019-11-27
0.7	Sections 2.3.2, 2.4 & 2.4.1, 2.5 and 3.6.1 populated by ORO	Bogdan Rusti (ORO), Marius Iordache (ORO), Jean Ghenta (ORO), Silviu Rapuntean (ORO)	2019-12-10
0.8	KPIs to be measured added in section 3.5.4	Peter Lundh (BT)	2019-12-10
0.9	Update Section 3.8	Louay Bassbouss (FhG)	2019-12-11
0.10	Update on section 2 and insert contributions to section 3.6, 3.7, 3.8	Marius Iordache (ORO), Carmen Patrascu (ORO)	2019-12-19
0.11	Update on sections 2.5.1 and insert introduction to section 4	Marius Iordache (ORO), Jean Ghenta (ORO)	2019-12-23
0.12	Insert contribution to sections 4.2.1, 4.2.1.1, 3.2.1	Marius Iordache (ORO), Cristian Patachia (ORO)	2020-01-02
0.13	Insert contribution to Bristol cluster use case (sections 3.2, 4.3 with sub-sections)	Shadi Moazzeni (UNIVBRIS), Hamid Falaki (UNIVBRIS), Ben Thomas (UNIVBRIS), Luke Kazanis (MATI), Athina Metridou (MATI), Joanna Tzima (MATI), Anthony Karydis (MATI), Robert Sugar (UHA), Erika Fucsok (UHA), Miguel Catalán (I2CAT), Adriana Fernández (I2CAT), Azahar Machwe (ZN), Jorge Paracuellos (ZN), Kostas Katsaros (DCAT)	2020-01-14

0.14	Insert contribution for 5G-VINNI cluster use-cases (sections 3.1, 3.4, 3.5, 3.6, 4.1 with sub-sections)	Tanya Politi (UoP), Marievi Xezonaki (ICOM), Ioanna Mesogiti (COSM), Nikolaos Tzanis (ADMIE), Paris Flegkas (UTH), Nikos Makris (UTH), Konstantinos Chartsias (ICOM), Dimitrios Kritharidis (ICOM), Sergios Soursos (ICOM), Kostas Stamatis (ICOM), Alexandros Dalkalitsis (TRA)	2020-01-14
0.15	Update contribution for 5G-EVE cluster Use-cases (3.2, 3.4: Why 5G and requirements, 4.2.2); update on sections 3.2.1.1, 3.3.1, 3.3.2.4, 3.6.1.2, 3.6.3, 4.1, 4.4.2) Insert contribution to section 2.1, 2.2	Marius Iordache (ORO), Bogdan Rusti (ORO), Jean Ghenta (ORO), Shadi Moazzeni (UNIVBRIS), Marievi Xenozaki (ICOM), Christian Schlehuber (DBN), George Tombras (IASA), Alexandros Manolopoulos (IASA), Anna Tzanakaki (UNIVBRIS), Ioanna Mesogiti (COSM)	2020-01-20
0.16	Update contribution on sections: 3.5.1, 3.5.3, 3.4.1, 3.4.2, 3.4.3, 3.1.1, 3.1.2, 3.1.3, 4.1.1, 4.1.2, 4.1.3, 4.1.4, 4.1.5, 3.6.1.1, 3.6.3, 4.4	Tanya Politi (UoP), Elina Theodoropoulou (COSM), Fofy Setaki (COSM), Louay Bassbouss (FhG)	2020-01-23
0.17	Update contribution on sections: 3.3, 5; first review of the document	Marius Iordache (ORO), Bogdan Rusti (ORO), Jean Ghenta (ORO), Martin Piovarci (KCC)	2020-01-31
0.18	Review and document formatting	Marius Iordache (ORO), Bogdan Rusti (ORO), Jean Ghenta (ORO)	2020-02-03
0.19	Insert spiders into requirements and KPIs subsection of use cases	Carmen Patrascu (ORO)	2020-02-06
0.2	Additional contributions to the different KPIs' tables	Shadi Moazzeni (UNIVBRIS), Rober Sugar (UHA), Nikolaos Tzanis (ADMIE)	2020-02-13
0.25	Final revision of the document	Anna Tzanakaki (UNIVBRIS), Jesús Gutiérrez (IHP)	2020-02-29
1,0	Submission of the document	Jesús Gutiérrez (IHP)	2020-03-31

Table of Contents

List of Figures

List of Tables

Executive Summary

5G-VICTORI is focusing on conducting large scale trials for advanced vertical use case (UC) verification focusing on Transportation, Energy, Media and Factories of the Future and cross-vertical UCs over an integrated 5G platform. The project integrated 5G-platform exploits existing facilities interconnecting main sites of all ICT-17 infrastructures, i.e. 5G-VINNI (Patras, Greece), 5GENESIS (Berlin, Germany) and 5G-EVE (France/Romania), and the 5G UK testbed (Bristol, UK), in a Pan-European Infrastructure.

This deliverable delves into describing the proposed UCs and their specific requirements, as they are dictated by the associated vertical industries, in terms of Key Performance Indicators (KPIs) relating the delivered services as well as the network performance. These KPIs are also discussed and analysed considering also the overall 5G-PPP vision. In addition, this deliverable reports on the required enhancements and extensions of the existing infrastructures exploited by the project towards integration of a large variety of vertical and cross-vertical UCs.

An overview of the architectural proposals of the various 5G-PPP activities is provided. The UC and KPIs' analysis is translated into technical requirements used to define the 5G reference architecture of the project, which is also described. In this document this architecture aims at 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. These functions can be accessed and shared on demand, and they can be deployed to compose very diverse set of services in support of the variety of services and ecosystems that the project is focusing on.

This deliverable provides input to the upcoming project activities within Work Package 2 (**WP2**), including the preparation of deliverable D2.2 "Preliminary individual site facility planning", deliverable D2.3 "Final individual site facility planning", and 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".

1 Introduction

The overall 5G vision is going far beyond the evolution of mobile broadband, becoming an enabler of the future digital world that will support the transformation of all economic sectors and the growing consumer market demand. An important aspiration of 5G is to offer services to new industrial stakeholders (referred to as vertical industries), and to support new business models and opportunities. This vision introduces the need to transform traditionally closed, static and inelastic network infrastructures into open, scalable and elastic ecosystems that can support a large variety of dynamically varying applications and services.

In response to these needs, 5G platforms can play an instrumental role in bringing together technology players, vendors, operators and verticals orchestrating their interaction with the aim to open up new business models and opportunities for the ICT and vertical industries. Moreover, these platforms also enable cross-vertical collaborations and synergies to offer further enhancement in value propositions. As 5G targets to support a set of stringent requirements in terms of latency (below 5 ms), reliability and density (up to 100 devices/m^2), along with tight constraints on geographical and population coverage and high speed mobility capabilities (exceeding in some cases 500 km/h), it is clear that it can provide the most suitable framework in support of the greatly varying strict requirements of vertical industries. In view of this, it is expected that 5G can facilitate the cost levels required to meet the vertical customers' expectations and needs, satisfying at the same time the guaranteed level of Quality of Service (QoS) expected by end-users and the sustainability objectives demanded by society.

In this context, 5G networks aim to support a fully connected and mobile society involving different types of applications, both human-centric and machine-type, exploiting the notions of end-to-end (E2E) network slicing, Software Defined Networking (SDN), and adopting concepts such as service-based architecture and Network Function Virtualization (NFV). Therefore, the research being conducted by 5G Public Private Partnership (5G-PPP) collaborative projects along with standards development organizations (SDOs), is defining and developing the outline of the 5G architecture.

The 5G ecosystem requires the competence and cooperation of a variety of stakeholders such as manufacturers, solution integrators, network and service providers, and small and medium-sized enterprises (SMEs). The 5G-PPP collaborative research projects of Phase 1 and Phase 2 have extended the stakeholder roles that were defined from the 3GPP only for an operators aspect, to enable numerous customer-provider relationships between stakeholders [1], including:

- Service Customers.
- Service Providers.
- Network Operators.
- Virtualisation Infrastructure Service Providers.
- Data Centre (DC) Service Providers.

In view of this, the overall 5G ecosystem should enable manufacturers, solution integrators, network and service providers, and SMEs to efficiently and successfully interact taking advantage of technology advancements including virtualisation, standardised interfaces and protocols, or open application programming interfaces (APIs). These roles are more recently being extended to allow various possible customer-provider relationships between verticals, operators, and other stakeholders.

In this context, 5G-VICTORI aims at conducting large-scale trials for advanced use case (UC) verification in a commercially relevant 5G environment for a number of verticals, as well as some specific use cases (UCs) involving cross-vertical interaction. The project will exploit extensively the existing ICT-17 5G Testbed Infrastructures interconnecting main sites of the 5G-VINNI, 5GENESIS, 5G-EVE and the 5G UK testbed in a Pan-European Network Infrastructure. 5G-VICTORI will modify these existing infrastructures to extend their coverage towards the integration of commercially relevant, operational environments. This is key for the demonstration of the large variety of 5G-VICTORI vertical and cross-vertical UCs focusing on **Transportation**, **Energy**, **Media** and **Factories of the Future**.

This document is the first technical deliverable of the project and defines the specifications and requirements of the project's UCs needed to be satisfied in the 5G validation trials from both technical and business perspectives. The deliverable identifies the main 5G service requirements, KPIs and 5G network capabilities to support a fully connected and mobile society. The presentation of the KPIs is depicted in UC requirement templates and also visualised through graphical KPI charts.

This deliverable also provides a thorough analysis of the requirements for the 5G-VICTORI overall platform focusing on the following set of services: **Enhanced Mobile Broadband under High-Speed Mobility**, **Digital Mobility**, **Critical Services for Railway Systems**, **Smart Energy Metering**, **Digitization of Power Plants and CDN Services in Dense, Static and Mobile Environments**.

The deliverable introduces the 5G-VICTORI infrastructure requirements, including site facility requirements definition that are analysed per facility cluster (5G-VINNI, 5GENESIS, 5G-EVE and the 5G UK testbed). Each individual facility of the 5G-VICTORI platform is described from a 5G network perspective and the required extension to support integration of the facilities and the verticals are also discussed.

The UC and the KPI analysis are translated into technical requirements used to define the 5G reference architecture of the project. The preliminary 5G-VICTORI architecture is presented in the deliverable and is well aligned with the overall 5G vision and the 5G-PPP architectural definition, which is also summarised in this document.

Document structure

The document is structured in six (6) main sections:

- Section 2 presents an overview of the 5G Services and Verticals.
- In Section 3, the Vertical UCs defined in 5G-VICTORI are analysed and the KPIs associated with them are presented.
- Section 4 establishes a connection between the UCs defined in the previous section and the necessary requirements the 5G-VICTORI infrastructure features, indicating and highlighting the necessary extensions needed.
- Section 5 provides a preliminary proposal of the 5G-VICTORI architecture following a summary description of the 5G-PPP architectural approach with the aim to support the implementation of the Verticals UCs that the project is concentrating on.
- Finally, Section 6 concludes the deliverable.

2 5G Services and Verticals overview

2.1 The 5G-VICTORI Vertical Ecosystems

In all stages of development and commercialisation of legacy network technologies (from 2G to 4G), all activities ranging from technology specification/standardisation, solution/equipment development, network operation, service deployment and provisioning take into account generic, application- and customer-agnostic network requirements/characteristics, originated from the legacy monolithic network architectures. 5G changes these established principles taking into consideration a different set or requirements that are driven by the stakeholders, applications and services and tailor network services definition, provisioning and deployment not only to technical but also to operational requirements.

For this reason, the Vertical industry stakeholder analysis and its service requirements become of high importance, and it is driving 5G technical developments including research, demonstration and standardisation activities. In the context of 5G, Vertical industries are organised under a set of classes [2] [3] [4], each representing large service groups associated with various business stakeholders belonging to specific market and/or social environments. This classification is summarised below:

- Automotive, focusing on high mobility scenarios, IoT services, etc.,
- eHealth, focusing on remote health services with high latency and reliability requirements,
- Energy, focusing on IoT based energy monitoring, management, and network control services,
- Media & Entertainment, focusing on next generation UHD/VR/AR services, Crowdsourced/multi-user created content, highly interactive services, etc., and
- Factories of the Future, denoted as Industry 4.0 setups.

In addition to these, the 5G-PPP community has refined the vertical industries classification to include also the following classes [5]:

- Public safety, and
- Smart Cities.

5G-VICTORI aims at conducting large scale trials for advanced vertical UC verification focusing on Transportation – especially on Railways (represented by **TRA** and **DBN**), Energy (represented by **ADMIE** and **AIM**), Media – especially content delivery network (CDN) – represented by **ICOM**/**COSM**, **RBB**, etc. – and Factories of the Future –especially Digital Utilities (represented by **ADMIE**), as well as cross vertical UCs addressing the following service classes:

- **eMBB** (**enhanced Mobile Broadband**), including bandwidth intensive services/applications, i.e. with (very) high data speed requirements such as streaming, video conferencing, and virtual reality; reaching 100 Mbps per user and, in some cases, even 10 Gbps (also in [6]).
- **mMTC** (**massive Machine-Type Communications**), extending LTE IoT capabilities – for example, NB-IoT – to support huge numbers of devices with lower costs, enhanced coverage, and long battery life; reaching thousands of end-devices (also in [7]).
- **URLLC** (**Ultra-Reliable, Low-Latency Communications**), "mission-critical" (MC) communications, including latency-sensitive services such as industrial automation services, drone control, medical applications, autonomous vehicles, etc., requiring even <1 ms – 2 ms for the user plane (UP) and less than 10 ms for the control plane (CP), (also in [8]).

In this context, the set of services that will be demonstrated in 5G-VICTORI relate with the following services classes as summarised below:

- The Transportation (Railways) Vertical includes mainly eMBB, and URLLC services.
- The Media Vertical represents includes mainly eMBB services.
- The Energy Vertical includes mMTC and URLLC services.
- The Factories of the Future (Digital Utilities) Vertical includes URLLC, mMTC and eMBB services (in the case of CCTV applications).

Table 2-1 shows the generic cartography of the services and the verticals tackled in 5G-VICTORI. Figure 2-1 provides a more visual cartography of the different services and verticals addressed in 5G-VICTORI. A mapping between the 5G-VICTORI UCs and the Next Generation Mobile Network (NGMN) 5G Verticals is shown in Figure 2-2 and Figure 2-3.

Table 2-1 Generic cartography of the services and the verticals in the context of 5G-VICTORI

Vertical	Service	Description
Transportation 1 ***(UC # 1.1)***	eMBB	eMBB services under high speed mobility in Rail environments
Transportation 2 ***(UC # 1.2)***	Digital Mobility (mIoT, eMBB, URLLC)	A Mobility as a Service (MaaS) framework providing Door-to-Door services for passenger adopting sustainable transport modes. A Passenger followed pop-up network on-demand.
Transportation 3 ***(UC # 1.3)***	Critical Services (URLLC)	Critical services for railway systems
Factories of the Future ***(UC # 2)***	Digital Utilities (mIoT, URLLC)	Development of a fully automated Digital Utility Management system (Energy Utility)
Media ***(UC # 3)***	CDN services (eMBB)	CDN services in dense, static and mobile environments
Energy ***(UC # 4)***	Energy Metering HV/LV (URLLC, mIoT)	URLLC for HV: Realtime low latency mMTC for LV: high density distribution (e.g. 10k sensor / 10 km^2)

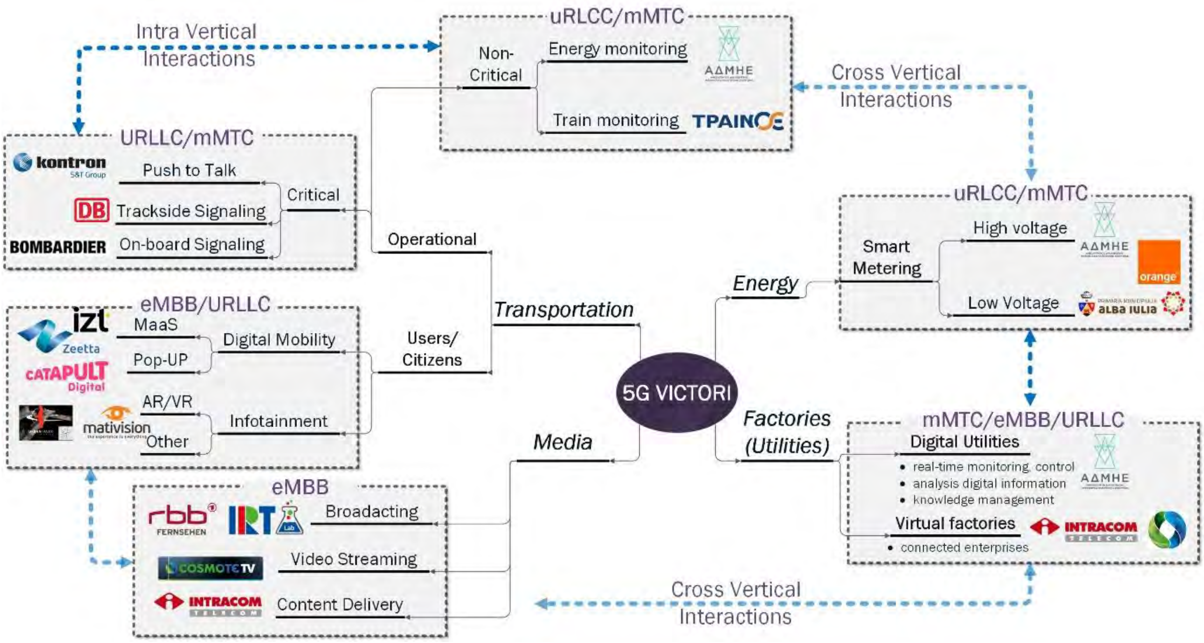


Figure 2-1 Generic cartography of the services and the verticals in the context of 5G-VICTORI

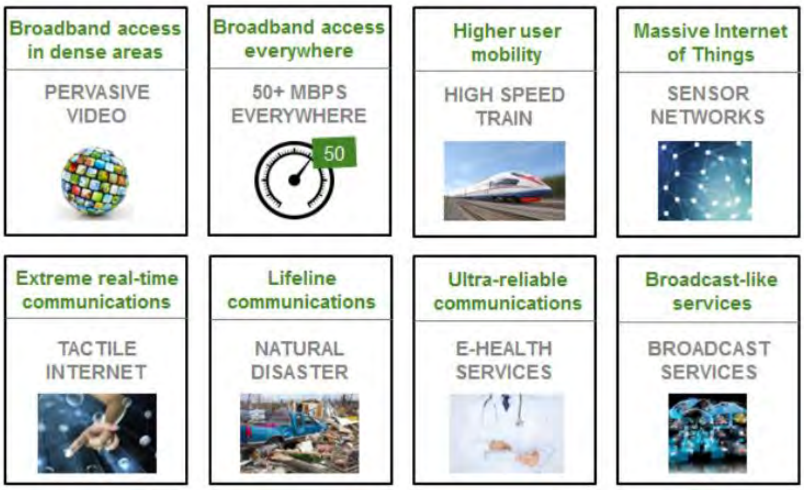


Figure 2-2 NGMN 5G UC families

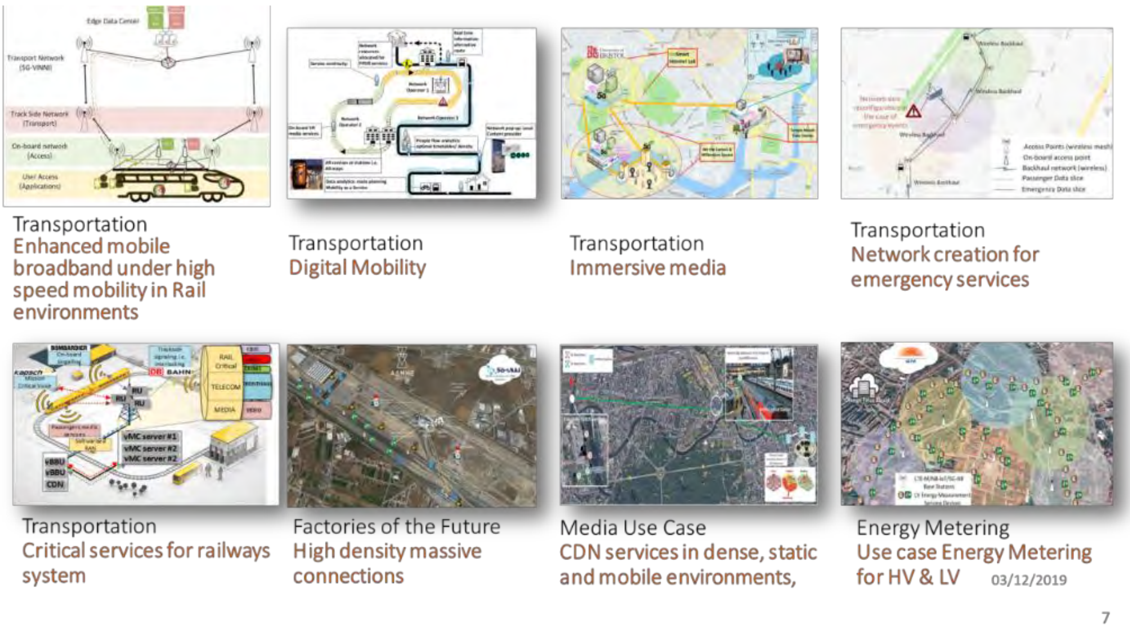


Figure 2-3 5G-VICTORI UCs map

2.2 5G Related Efforts and Activities

Deploying 5G solutions for vertical industries in Europe is a well-defined objective, there is a clear need to develop future proof 5G infrastructures to address a wide range of vertical applications adopting a flexible architecture, offering converged services across heterogeneous technology domains deploying unified software (SW) control. It is true to say that, despite the European strategy to support verticals through 5G solutions, verticals face the problem that they can only practically verify their UCs in small scales in commercially relevant environments before investing in large scale deployments. However, vertical industries are gaining great attention as they are expected to boost service innovation and contribute towards global digital transformation. Verticals that can benefit from 5G projects are of different types, size, market perspectives, including:

- Agriculture and farming (AGR).
- Automotive (AUTO).
- Energy (ENERGY).
- Health (HEALTH).
- Industry 4.0 (I4.0).
- Media & Entertainment (M&E).

- Public Safety & divide resorption (PS).
- Smart cities (SMART).
- Transport & Logistics (TRAN).

Table 2-2 shows the relation between Phase 2 projects and vertical industries.

The third and final phase of 5G-PPP projects, which includes 22 projects in total, is divided in four parts.

The first part of 5G-PPP Phase 3 includes three projects that are implementing and testing advanced 5G infrastructures in Europe. These three projects are shortly described below:

- **5G-EVE** [9] aims at a 5G E2E facility that will allow vertical industries to implement, test and validate their 5G-ready use-cases in a realistic environment. The project platform includes four 5G European facilities (in France, Greece, Italy and Spain) each supporting the full stack of capabilities physical infrastructure to orchestration. A homogeneous testing and validation framework is being developed on top of the interconnected facilities, to allow verticals define, plan, execute and validate their 5G-based applications.
- **5G-VINNI** [10] aims at building an E2E 5G infrastructure integrating networking, computing and storage resources as well as network softwarisation technologies offering increased flexibility, reliability and security across multiple administrative domains. The facility will play the role of an open experimental platform leveraging network slicing, to support independence of performance, management and security for different verticals.
- **5GENESIS** [11] aims to also offer an experimentation facility across five geographically distributed platforms (Athens, Malaga, Limassol, Berlin, and Surrey), each supporting diverse capabilities to verticals. In view of this, the overall reference architecture adopts a common view across the five platforms. The generic architectural approach enables interoperability between the platforms and common interfaces to experimenters to allow sharing of components across platforms. However, individual platforms are independent from an administrative perspective and maintain their platform specific capabilities.

Table 2-2 Verticals cartography for 5G-PPP Phase 2 projects [10]

5G-PPP Project	AGR	AUTO	ENRGY	HEALTH	I4.0	M&E	PS	SMART	TRAN
5GCAR		X							
5GCity						X		X	
5G ESSENCE						X			
5G-MEDIA						X			
5G-MoNArch								X	X
5G-PICTURE						X		X	X
5G-PHOS					X			X	
5G-TANGO					X	X			
5G-TRANSFORMER		X		X		X	X		
5G-XCast						X	X		
BlueSpace						X		X	
IoRL						X			
MATILDA		X			X	X	X	X	
METRO-HAUL						X	X		
NGPaaS							X		
NRG-5			X						
one5G	X	X			X	X		X	
SaT5G	X					X	X		X
SLICENET			X	X					

Moreover, three automotive projects have been selected for Part 2 of the 5G-PPP Phase 3. Those projects are:

- **5GCroco** (http://5gcroco.eu/) aims to demonstrate 5G technologies in a cross-border corridor environment along France, Germany and Luxembourg. Beyond its technical objectives the project also targets to define new business models for the relevant ecosystem and impact relevant telco and automotive standardisation bodies.
- **5GCarmen** (http://5gcarmen.eu) focuses on Cooperative, Connected, and Automated Mobility (CCAM) and aims to carry out trials across a cross-border corridor between Bologna and Munich, spanning 600km of roads across three countries. The cross-border UCs include cooperative maneuvering, situation awareness, video streaming and green driving.
- **5G-MOBIX** (www.5g-mobix.com) focuses also on CCAM trials along cross-border and urban corridors exploiting 5G technologies. The project aims at evaluating the benefits of 5G infrastructures in the CCAM environment and define relevant deployment scenarios and provide contributions to standards and spectrum gaps.

Additionally, eight research projects, including 5G-VICTORI, form the third part of 5G-PPP Phase 3, involving advanced 5G validation trials across multiple vertical industries. More specifically:

- **5G-SOLUTIONS** (https://www.5gsolutionsproject.eu) targets to verify that 5G will be able to support big industry verticals with wide access to a variety of forward-looking services. The project includes advanced field trials, related to end-users across five different countries focusing on the following vertical domains: Factories of the Future, Smart Energy, Smart Cities, Smart Ports, Media & Entertainment.
- **5G-TOURS** (https://5gtours.eu) main objective is to deploy full E2E trials that will put together 5G with real users. The trials involve thirteen close-to-commercial UCs related to tourists, citizens and patients.
- **5G!DRONES** (https://5gdrones.eu) aims to trial different Unmanned Aerial Vehicle (UAV) use-cases that range including eMBB, URLLC, and mMTC 5G services. 5G KPIs will be validated in order to support the relevant UCs.
- **5G-HEART** (https://5gheart.org) involves validation trials that focus on vertical use-cases related to healthcare, transport and aquaculture.
- **5G-GROWTH** (http://5growth.eu/) focuses on Industry 4.0, Transportation and Energy taking advantage of Artificial Intelligence (AI)-driven 5G E2E solutions with the aim to enable these verticals to achieve their key performance goals.
- **5G-SMART** (https://5gsmart.eu/) focuses on the smart manufacturing sector (Industry 4.0), by demonstrating, validating and evaluating its potential in real manufacturing circumstances.

The fourth part of 5G-PPP Phase 3 is focusing on the Long-Term Vision of 5G involving eight projects:

- **ARIADNE** (https://www.ict-ariadne.eu/) will develop new radio communication technologies using the above 100 GHz D-Band frequency ranges. It will exploit advanced connectivity technologies and employ Artificial Intelligence techniques to flexibly manage resources for high-frequency communications.
- **5G-CLARITY** (https://www.5gclarity.com) concentrates on beyond 5G systems for private networks integrating 5G, Wi-Fi, and LiFi technologies, and managed through AI based autonomic networking addressing the challenges in spectrum flexibility, delivery of critical services, and autonomic network management.
- **5G-COMPLETE** (https://5gcomplete.eu) vision is to transform the 5G architecture, as it will efficiently combine compute and storage resource functionality over a unified Radio Access Network (RAN) based on novel technologies and a flexible transport supporting both analogue and digital FH solutions.
- **INSPIRE-5GPLUS** (https://www.inspire-5gplus.eu) focuses on security of 5G and beyond networks in two aspects: a) by exploiting and extending existing assets and b) by developing pioneering methods that will exploit the potential of state-of-the-art technologies. The project

will be addressing security challenges concerning and efficient realization of 5G for a variety of vertical applications mainly related to Industry 4.0.

- **LOCUS** (https://www.locus-project.eu/) main objective is to improve the 5G infrastructure functionality in order to: a) provide precise location information as a network-native service and b) extract complex features and behavioral patterns from raw location and physical events, and offer them to applications by simple interfaces. Solutions and findings of the project will be showcased in three scenarios: a) Smart Network Management based on Location Information of 5G equipment, b) Network-assisted Self-driving Objects and c) People Mobility & Flow Monitoring, including emergency services.
- **MonB5G** (https://www.monb5g.eu) proposes a novel autonomic management and orchestration framework that will be able to support network slicing at a massive scale for 5G LTE and beyond, thus enabling the realization of new pervasive mobile services of vertical industries.
- **TERAWAY** (https://ict-teraway.eu/) aims at developing a new generation of THz transceivers that will deal with the limitations of the existing THz technology and will make way for its commercial uptake.
- **5GZORRO** (https://www.5gzorro.eu) will be focusing on network slicing in order to make feasible the production-level support of different vertical applications that will have to coexist on a highly pervasive shared network infrastructure.

Finally, two projects that are complementary to the 5G-PPP, are **5G-DRIVE** (https://5g-drive.eu), which operates in technical, regulatory and business areas, and **PriMO-5G** (https://primo-5g.eu/), which aims to demonstrate an E2E 5G system that will provide video services for moving objects.

2.3 5G-VICTORI User Requirements Analysis

5G aims to enable the evolution of current business models to support new and different types of customers, vertical industries. Figure 2-4 shows examples of models expected to be supported by 5G [12]. A summary of new 5G services requiring more complex networks and implementations is provided in Figure 2-5 below.

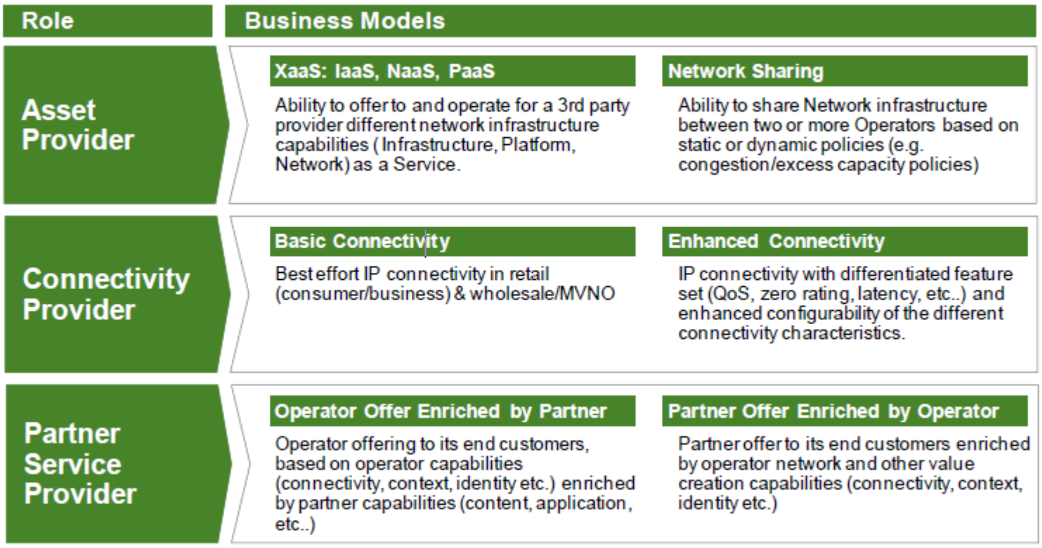


Figure 2-4 NGMN 5G Business Model example [12]

In this context, 5G-VICTORI aims at enabling new business models allowing vertical stakeholders to create infrastructure slices containing interconnected hardware (HW) and SW that will be accessed and used through new developed network functions (NFs). The collaborative approach will encourage and accelerate the level of adoption of 5G technologies on emerging markets and create new businesses for small enterprises and large industries. The main goal is the shift towards creating a network as a service model that will be realised by developing an open interoperable platform with the capability to support a large variety of verticals. It will integrate together networking, computing and storage resources into one programmable and unified infrastructure addressing business critical requirements of vertical industries including real time capabilities, latency, reliability, security and guaranteed QoS.

The envisioned infrastructure will be accessed on demand and will support the coexistence of multiple vertical services that share common resources. These resources will be able to be managed and accessed on demand by any service or application, enhancing resource utilisation efficiency and providing measurable benefits for the vertical industries in terms of cost, scalability, sustainability and management simplification.

In 5G-VICTORI there are six main UCs that will be implemented and demonstrated during the project lifetime, the specific UCs will be further detailed in section 3 and mapped in Table 2-3:

- "Enhanced Mobile broadband under high speed mobility", Vertical: Transportation – Rail.
- "Digital Mobility", Cross-Vertical - Transportation and Media.
- "Critical services for railway systems", Vertical: Rail.
- "Smart Energy Metering", Cross-Vertical: Energy and Rail.
- "Digitization of Power Plants", Vertical: Smart Factory.
- "CDN services in dense, static and mobile environments", Vertical: Media.

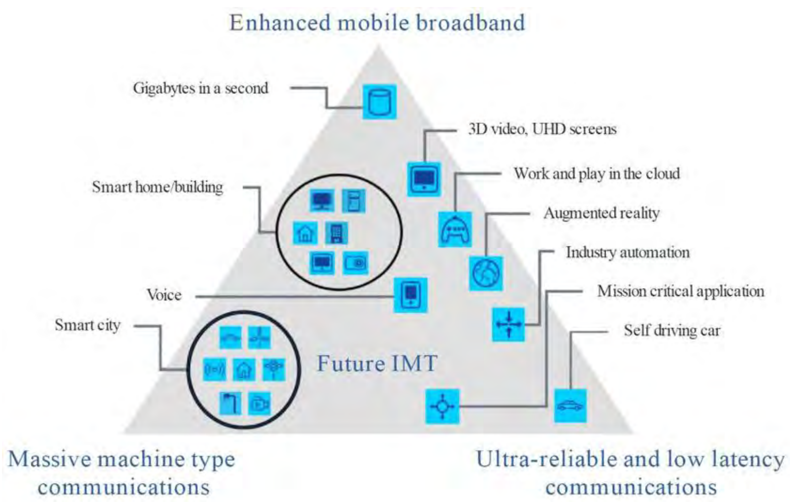


Figure 2-5 Main 5G family UC requirements

Table 2-3 5G-VICTORI verticals mapped to 5G requirements

Requirements	Transportation	Media	Energy	Factories of the Future
eMBB (Enhanced Mobile Broadband)	✓	✓		
URLCC (Ultra-Reliable Low Latency Communications)	✓		✓	✓
mMTC (Massive Machine Type Communications)	✓		✓	✓

3 Vertical use cases analysis and KPIs

This section describes the vertical UCs that 5G-VICTORI proposes together with their associated KPIs. We present, for each UC, a general definition of the requirements, a high-level architecture description and the targeted KPIs.

3.1 UC # 1.1 – Enhanced Mobile Broadband under High Speed Mobility

One of the main vertical industries that will be addresses by 5G-VICTORI is the rail transportation. This vertical imposes very strict communication requirements. The existing telecommunications infrastructure of the rail industry includes several versatile communication technologies used to provide versatile rail communication services. However, in practice, different networks are deployed for different communications services, leading to slow service deployment, low performance for premium services, and high Total Cost of Ownership (TCO) for all stakeholders. Meanwhile, in modern transport systems, there is a demand for a broad range of novel on-board applications for passengers including advanced guiding services, real time travel information, infotainment services, etc., pushing current 4G infrastructures to their capacity and QoS limits.

In 5G-VICTORI the overall architecture seeks to overcome the inefficiencies and inter-operation problems that stem from this versatility, while meeting all requirements of the various applications. It aims at serving all communication requirements of train operators and passengers adopting the 5G paradigm, even on-board high-speed trains. This is especially challenging under high-speed mobility due to challenges such as the requirement for fast handover for large numbers of end users.

The objective of this UC is to demonstrate eMBB functionality through heterogeneous access technologies for on-board network connectivity in a railway setup leveraging the 5G-VINNI facility in Patras. Both business (e.g. infotainment services to passengers) and critical operations services – e.g. video streams from on board CCTV systems, Push-to-talk (PTT) from operations centre to cabin – as categorized by [13], will be showcased over a unified, orchestrated 5G infrastructure.

The specific objectives of this UC are summarised as follows:

- Demonstrate a disaggregated multi-technology 5G cellular network addressing the railway environment specific requirements and challenges.
- Explore multi-technology transport network connectivity through a variety of technologies, including both millimetre wave (mmWave) and Sub-6 GHz technologies.
- Instantiate slices of the network in an E2E fashion to allow different types of services with strict KPI requirements such as latency and/or throughput.
- Provide high-speed and low latency network connectivity on-board.

The main stakeholders involved are:

- *Railway infrastructure* and *Train* operators that require multiple/versatile network services for performing their own critical communication, performance and business services.
- *Telecom Operators/Carriers* (or other engineering companies) that deliver network infrastructure solutions and usually (depending on the agreements) also communication services to Railway and Transport operators.
- *Passengers* usually served directly by Telecom Operators/Carriers.

In the context of 5G-VICTORI, we consider a set of 5G technologies integrated, interoperating and deployed together to provide a holistic solution for railway communications addressing also the vision of Future Railway Mobile Communication System (FRMCS), where:

- Railway & Train operators, still require the same multiple/versatile network services.
- Telecom Operators/Carriers deliver a single network infrastructure/solution and/or services to Railway & Train operators.

- Railway & Train operators, may own the network deployment (and provide network resources/services) to multiple parties such as Service Providers, Telecom Operators, Content Providers, passengers, etc.
- End-users/passengers, and Railway & Transport operators are all served by the single network infrastructure.

In 5G-VICTORI UC # 1.1 will be primarily addressed by TRAINOSE (**TRA**). Specifically, in Greece, **TRA** operates a large fleet of passengers and freight trains. TRA connects the biggest cities in the Greek region and transfer more than 11 million passengers per year. The current UC will operate in Patras suburban area, which is one of the main railway routes of TRA and connects the centre of Patras with the city University. Main users of this route are mainly students, who will use this new technology. TRA will use the services for improving the railway systems that use this route in terms of safety and consistency. In this facility, diesel trains will be used with real passengers.

As the main scope is to deliver both eMBB and URLLC under high-speed mobility scenarios with handover requirements, the communications-based services that will be evaluated include;

- **Rail operation non-critical support services.** These can be sub-grouped into four categories: i) passenger information services, ii) location operation services, iii) security services and iv) maintenance infrastructure services. For the latter, a CCTV will be used capturing the rail track state live in order to monitor the track quality and provision maintenance for the tracks when needed. These cameras will be mounted on the front and rear part of the train capturing images that will be forwarded in real time to the Operations Center of TRA.
- **Communication services for passengers including Enhanced passenger experience:** Passengers embarking, travelling and disembarking from the trains daily, require broadband connectivity via various means. Based on the availability on board and at the stations, passengers consume infotainment services, seamlessly while travelling between stations. These services include "*Enhanced passenger experience*" associated with eMBB services provided to passengers, with no safety consequences thus not critical requirements. At train stations typically passengers utilise Wi-Fi access. While the train moves from one station to the next, boarded passengers can either use 5G or on-board Wi-Fi access to view content/services. Assuming versatile mobile broadband services, typical data rates required would be of 5-10 Mbps per passenger. For a total of 100-300 passengers in a station area (i.e. platforms and 1-2 trains), the maximum capacity needed would be in the range of 1-2 Gbps per cell.
- **Rail operation critical support services:** These services cover MC and safety related aspects of railway systems. Information generated in this type of services must be shared between different stakeholders, e.g. one infrastructure operator and several railway operators. This group of systems requires the maximum Safety Integrity Level to minimise the risk associated to the equipment failure. In the specific UC, a scenario providing services for MC Telephony and Data to Train Operators will be showcased. Details regarding this UC are provided in section 3.3.2.2, which will be also demonstrated in the Greek facility.

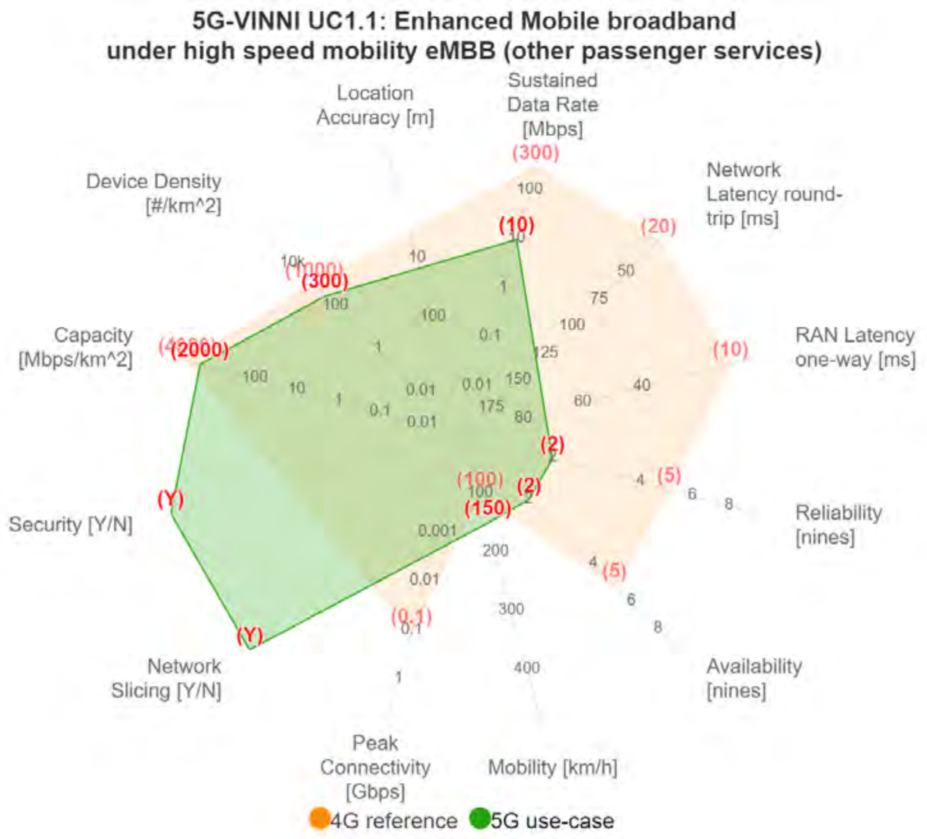
To provide these services, a number of challenges emerge from the harsh rail environment, considering the trains' and stations' construction specificities. These will be elaborated and investigated in the context of Work Package 3 (**WP3**).

3.1.1 UC # 1.1 Key UC Requirements and KPIs Addressed

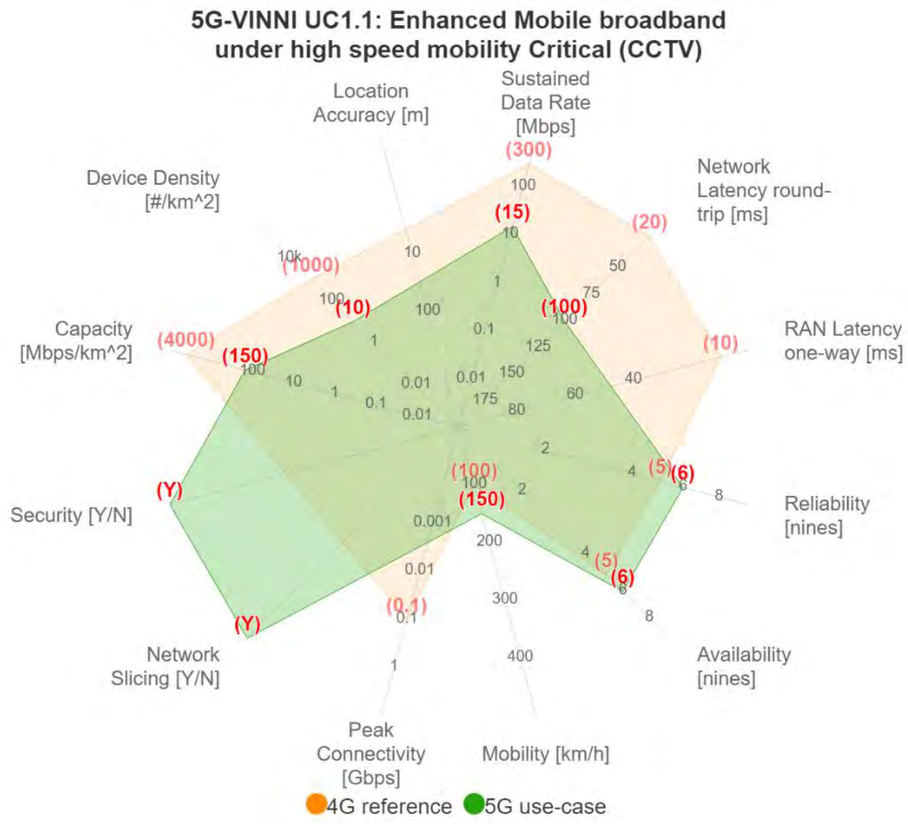
The requirements for the main communication services categories foreseen in the forthcoming FRMCS and 5G landscape are summarised in Table 3-1. Please note that these reflect the vertical (**TRA**) requirements considering not only the current (restricted to SW and network capabilities) services but the foreseen future ones, thus not all of them are subject to demonstration as already mentioned. Further refinement of these KPIs will be provided in the context of WP3, with the explicit definition of the applications to be demonstrated.

Table 3-1 UC # 1.1 Requirements foreseen in FRMCS and 5G landscape

UC # 1.1: Enhanced Mobile Broadband Under High Speed Mobility Vertical: Transportation – Rail			Services			
			Future Train operation services (URLLC)	Critical (CCTV)	Other Passenger Services (eMBB)	MCPTT
UC Requirement - KPI		Units				
1	Latency (min. between user service end-points)	ms	20-100 ms	100 ms	Non Critical	20 ms
2	User Datarate (Max.)	Mbps	100 kbps	10-15 Mbps (Uplink)	~10 Mbps / passenger	100 kbps
3	Reliability (%) - Min/MAX	%	99.9999% (SIL4)	99.9999% (SIL 4)	Not Critical	99.99% (SIL2)
4	Availability (%) - Min/MAX	%	99.9999% (SIL4)	99.9999% (SIL 4)	Not Critical	99.99% (SIL2)
5	Mobility	km/h	50-150 km/h	50-150 km/h	50-150 km/h	50-150 km/h
6	Traffic Density (Traffic demand per specific area)	Mbps / area surface	Non Critical	150 Mbps	max. 1-2 Gbps, assuming 5-10 Mbps/ passenger @ train or station, Total: 100-300 passengers in a cell coverage area, ~max. ave. 1-2 Gbps	Non Critical
7	Device Density (#Devices per specific area)	Devices/ area surface		(non-critical) 2CCTV cameras / train, 5 trains in area of coverage	100-300 passengers/ users per cell coverage area	5 trains in area of coverage
8	Location Accuracy	m	1 m			
Additional Requirements						
9	Packet Loss Ratio	Num	10^{-6}	0.005	Non Critical	10^{-6}
10	Bit Error Rate		Mission critical	Mission critical	Non Critical	Critical
11	Security (Y/N) ("Carrier Grade")	Y/N	Y	Y	Y	Y
12	Type of Device		IoT devices/ Cameras/ Gateways	CCTV Cameras	Smartphones	KCC clients/ UEs
13	Type of Connection (i.e. Ethernet, WLAN, Zigbee)		5G/NB-IoT/Wi-Fi	5G/Wi-Fi	5G/Wi-Fi	5G/Wi-Fi
14	Battery Lifetime		Non Critical	Non Critical	Non Critical	Non Critical

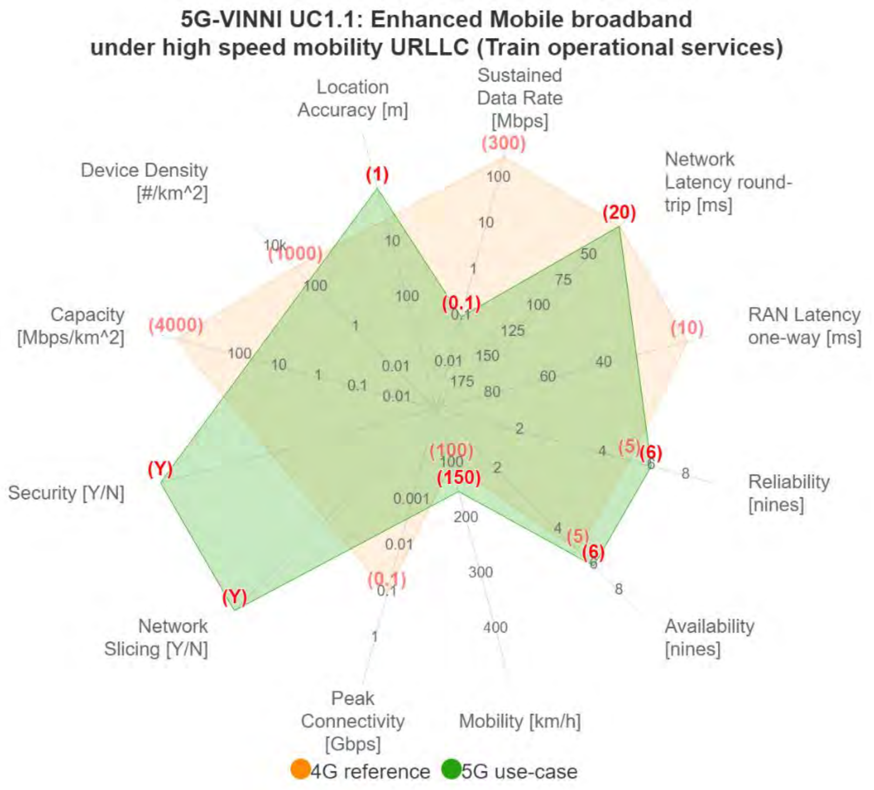


a)

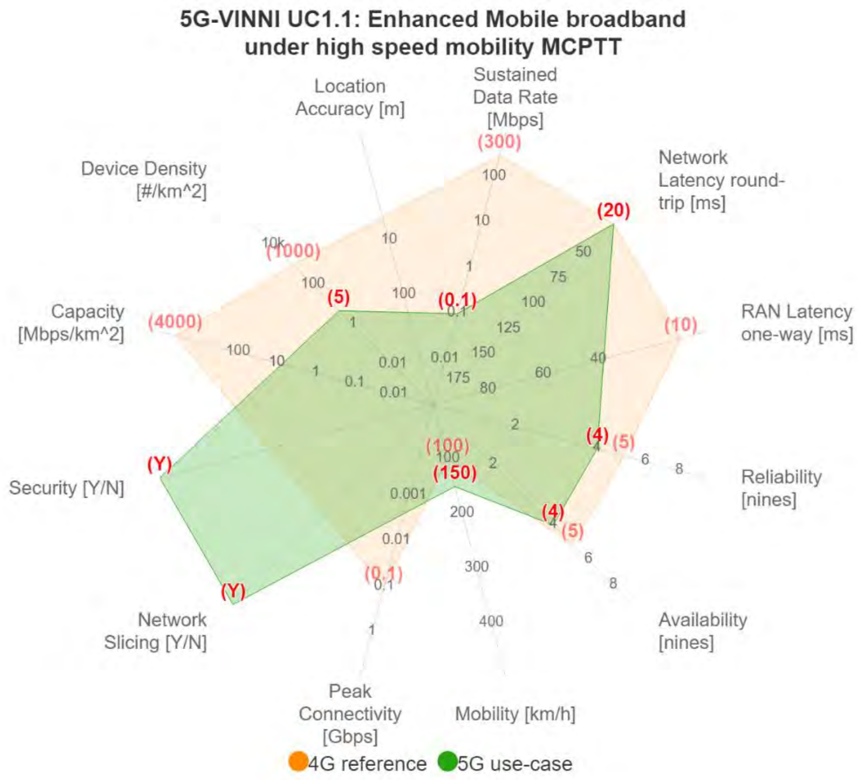


b)

Figure 3-1 a) UC # 1.1 eMBB, b) UC # 1.1 Critical CCTV



a)



b)

Figure 3-2 a) UC # 1.1 URLLC, b) UC # 1.1 MCPTT

3.1.2 UC # 1.1 Network Performance Requirements and KPIs

Table 3-2 presents the network performance requirements and KPIs associated to this UC.

Table 3-2 UC # 1.1 Network Performance Requirements and KPIs

Req.ID [U/F-Type-RQ#]	**Description** [Descriptive text]	**Priority** [H/M/L]	**KPIs and Parameters** [to be measured]
U-CA-1101	**High Traffic Density** High Traffic Density concentrated at the wagons of a train is expected assuming the aggregate traffic of services reaching up to 2 Gbps over a single wagon. It shall be noted that the aforementioned connection density is the expected one in the near future. Considering the all FRMCS services.	**H**	Total capacity offered to a single train / wagon is about 1-2 Gbps.
U-PE-1102	**Mobility** It is required that high QoS services are seamlessly provided to train wagons moving to speeds reaching even 150 km/h and 250 km/h in advanced technology trains.	**H**	Seamless service provision to wagons moving with speeds up to 50 km/h -250 km/h
U-PE-1103	**Latency** For specific applications, there are stringent requirements about E2E latency. For example push to talk applications should be not be more than 20 ms.	**H**	KPI: latency min. between UE and service end-points 20 ms
F-CA-1104	**Air Interface – Access/Transport Network Capacity** Towards delivering the required network capacity for the specific devices, it is needed to design and develop Access/Transport network nodes operating at wide spectrum thus at high frequency bands.	**H**	Antenna operation at high frequency bands delivering the required capacity
F-PE-1105	**Air Interface Characteristics** Towards delivering the required network capacity for the specific devices, it is needed to design and develop solutions the delivery of high-speed data rates inside the train wagons, despite their high penetration losses and mobility speed.	**H**	Delivering the required capacity inside the train wagons, even at high speeds.

3.1.3 UC # 1.1 Functional Requirements and KPIs

Table 3-3 presents the network performance requirements and KPIs associated to this UC.

Table 3-3 UC # 1.1 Functional Requirements and KPIs

Req.ID [U/F-Type-RQ#]	Description [Descriptive text]	Priority [H/M/L]	KPIs and Parameters [to be measured]
F-FU-1110	**Distributed Pools of (Compute/Network) Resources** Towards achieving the stringent QoS targets as well as efficient resource utilisation, it is necessary to enable instantiation of network, compute and storage resources optimally selected from a common resource pool that is physically distributed. This requires that the deployment is based on distributed (at different geographical locations, e.g. in the notion of edge computing) pools of resources (i.e. DCs) where the allocation is based on specific QoS and resources requirements.	H	• Capability for instantiation of network and compute resources for a specific service over geographically distributed pools of resources. It shall be possible to use various Edge and Core DCs to host different parts of the Power Plants Monitoring and Preventive Maintenance Applications. • Monitoring of distributed resources pools from a common platform.
F-FU-1111	**Multi-Tenancy** The 5G facility needs to support simultaneously multiple tenants and multiple services, with various QoS, requirements, etc., over a single infrastructure, in line with FRMCS requirements. Namely, there is a need to convey over a single infrastructure Critical communication services (MPTTC), business services (CCTV) and performance services (VoD).	H	• Delivery of services with the requested QoS to multiple tenants over a single network deployment.
F-FU-1112	**Slicing** Towards supporting multi-tenancy over the 5G facility, slicing is required in order to preserve security and isolation between tenants, and to maintain the QoS guarantees.	H	• On-demand instantiation/ deletion/ configuration of an E2E network slice and delivery of services over it. • QoS guarantees (e.g. latency, bandwidth, etc.) of a slice shall be met.
S-FU-1113	**Management & Orchestration of Distributed Pools of Resources** Towards delivering a solution capable to support efficient utilisation of network and compute resources through dynamic, flexible, on-demand instantiation of them, while meeting the 5G services stringent QoS requirements, it is necessary to have a flexible overacting management and orchestration platform, spanning across all distributed pools of resources. This Management and Orchestration platform shall be able to: • monitor and manage the physical and virtual resources (i.e. compute and network components) of distributed pools/DCs, • perform the orchestration of VNFs, and • support and perform the logic towards the optimal instantiation of resources for each tenant/slice/service.	H	• Monitoring of Network and Compute resources in terms of utilisation/availability/planned reservations. • Management, automated allocation of resources upon request taking into account optimisation of resource utilisation and required QoS. • Instantiation of VNFs.
S-FU-1114	**Mobility – Handovers (1)** Handover functionality is required between subsequent trackside nodes (access or transport network ones), so that services are seamlessly provided to moving train wagons.	H	Handover functionality between two subsequent (access or transport network ones) trackside nodes is supported.
S-FU-1115	**Mobility – Handovers (2)** Depending on the service, also handovers between (non-subsequent) access network nodes (e.g. when passengers are on-boarding or off-boarding the train) can be also required.	M	Handover functionality between two access network nodes is supported (possibly also between 4G & 5G nodes).

3.2 UC # 1.2 – Digital Mobility

3.2.1 Transportation and Media

The first part of the Digital Mobility UC will be developed and demonstrated by the 5G UK and 5GENESIS clusters. The main objective of this UC is to develop a common framework for innovative mobility applications and services. This includes:

a) *A Mobility as a Service (MaaS) framework* providing Door-to-Door services for passenger adopting sustainable transport modes.

b) *A Passenger followed pop-up network on-demand able to:*
- To create and deploy customised networks for a large group of passengers arriving at a station.
- To create an on-demand network that seamlessly converges with available networking technologies and devices at each station, e.g. IoT, various wireless access networks, edge computing.
- To create a network that can follow passengers seamlessly in all stations.
- To provide a robust, MC, interoperable public safety communication network.

c) *A Set of Innovative applications that will:*
- be installed on the pop-up networks to present interactive, user-controlled geolocated 360º content.
- provide Infotainment and data visualisation to rail passengers. Real time, in 3D mixed with location relevant maps, with potential AR elements.

In this UC, it will be demonstrated how the E2E 5G UK platform and the 5GENESIS platform (for App 3) can be on the fly configured to provide the following applications (Apps):

App 1	Immersive media services to travelers arriving at the Temple Meads station.
App 2	VR Live streaming application delivered at **UNIVBRIS** campus during a course.
App 3	Future Mobility application to collect and analyse people information including their location, their mobility and movement from train station towards the city centre. Furthermore, the application will provide passengers with station guidance and multi-modal transport journey planning beyond the train station.

App 1: Immersive media services to travelers arriving at the Temple Meads station.

App 1 will combine augmented reality and geolocation views of the service (commercial or non-commercial). When the passengers get off the train and move towards the city, i.e. Millennium Square, the service should be preserved. The mobility of the passenger from train station to the rest of the city has commercial and non-commercial aspects. At Millennium Square, a 360º VR application will be delivered during context of a large showcasing event (i.e. concert). In the path between the train station and the city, there will be several Multi-access Edge Computing (MEC) nodes and one backend computing node that will handle various parts of the App. The parts that are latency-sensitive must follow the route of the passenger at the edge.

The Mativision (**MATI**) 5G UC will provide a group of users arriving at Bristol a 360º VR tour guide of the route between Bristol Temple Meads, Millennium Square and the University of Bristol. The group of users will be directed to specific geolocation hotspots to watch a 360º VR video shot at that specific spot with a tour guide. The users watching the 360º video will perceive an experience of “replaced reality” as the 360º video is shot at the same exact spot but includes a tour guide pointing out anything that is interesting in that specific geolocation spot. The group of users will watch the 360º videos in full synchronicity to each other. This will provide a social VR experience of all users watching the same content at the same time.

As the group of users arrives at Bristol Temple Meads, one user of the group will be appointed as the group leader. This group leader will launch the Mativision 5G tour guide app and create a new group inside the app. The app will provide a small token, for example a 6-letter code, that the other user will input inside the app to be associated with the group leader. Once all users are linked to the group leader the app will provide a map overview of the first geolocation hotspot and the users will start walking towards it. Once all users are within a specific radius of the geolocation hotspot the group leader will be prompted to start the 360º video linked to that specific hotspot. Once the group leader taps start, the same video is started synchronously on all devices at the same time. The video rotated to match the magnetic north of the 360º video and that of the user's device. This makes sure that device matches the magnetic north of the video and thus the video and real location match up irrelevant of where each user device is pointed at. This matching makes the experience a "replaced reality" as reality and 360º video match up. Now the group watches the 360º video and rotate their devices to follow the tour guide inside the 360º video. Once the video has ended the group is pointed in the direction of the next geolocation hotspot.

While the group is moving from 360º video geolocation hotspot to another hotspot there are flat video hotspots of secondary interest that the group leader is prompted to start playing. These secondary flat video hotspots are shorter that the full 360º video hotspots and not require the group to stop moving while watching them. As these videos include voice over the group can listen in to the narration without the need to watch their device's screen.

As the group is walking from hotspot to hotspot around Bristol, the group leader gets real-time location updates of all the group members on his map. The same experience can be run by single users where they can follow the tour without a group leader in single user mode.

The Mativision 5G Tour app relies on two different services, the video streaming service and synchronization service. The video streaming service is a two-part application one running in the backend and one on the edge nodes. The backend streaming server has all videos stored that comprise the whole tour. These include both the 360º VR videos and flat videos. The second part is an edge node streaming server. When a user or group of users request a video from the edge node, the edge node connects to the backend streaming server and starts streaming the video. If the same video segments are requested from multiple users at the same time the edge server caches the video segments and provides them to all users. The edge server works as a multicast intermediator as each segments is requested once from the backend server is transferred once to the edge server which, in turn, transmits to each user that has requested it. This reduces the bandwidth load between the users and the backend streaming server as the video segment is only transferred once and is transmitted to any user requesting it. Without the edge node the video stream is unicast to each user from the backend server. This means that the same segments will travel most of the same routes to reach each. As users will be walking from hotspot location to another location the edge node streaming service will need to move with the users to provide uninterrupted streaming.

The synchronisation service is a two-part application, one running in the backend and one on the edge nodes. The edge node service handles all synchronicity messaging between all devices local to that edge node. Once a group leader connects to the service a new "room" is created and the group leader is attached to it. The service provides a unique ID of the room back to the group leader device. The group leader provides the unique id to all the users that are going to be associated to his device. As each non-leader user connects to the service it is added to the same room referenced by the unique id. The backend service will keep the states of all devices so that there is continuity when the edge service moves from node to node. Once the service is instantiated again, it will connect to the backend, retrieve all active rooms and user ids and reconnect all of the devices to each other.

The virtual tour will benefit from network slicing as synchronization and 360º video quality are critical to the whole experience. Considering a traffic-dense area while other data heavy applications are running in parallel, this could affect the performance of the virtual tour application increasing the latency between devices or reducing the video quality that users receive. Low latency messaging between the group leader and the rest of the devices is paramount for the group to have a concurrent "social" 360º VR experience. High quality video streaming is also essential for the group to be able to follow the tour and notice the details pointed out by the "replace reality" tour guide.

A key technology component for this application is synchronisation. The synchronisation edge service and video streaming edge service need to be close to the users providing low latency and high bandwidth videos, while the streaming server backend storing the videos and synchronisation server state machine can be put in the backend. The synchronisation edge service and video edge service will need to move with the passengers while from location to location.

App 2: VR Live streaming application delivered at UNIVBRIS campus during a course and providing remote visualisation.

This App will involve a training course hosted at the University of Bristol, using capabilities of **MATI**, **UHA**, and 5G-VICTORI. The users can take part in the class from anywhere in Bristol with access to the 5G network and attend the class via VR in real-time with low latency. One of the main objectives of this application would be reaching a large number of users rather than Mobility.

For the training course we will setup three 360º cameras in a **UNIVBRIS** class room that will stream to the **MATI** HTML5 multi-camera player. Each camera will send a high bandwidth stream (up to 50 Mbps) to the backend streaming server. The backend streaming server in turn will re encode the stream to multiple qualities and segment it to support HTTP live streaming. The segmentation will be optimized with low latency and quick start of the stream in mind. When each user requests a stream from the edge node, the edge server will open up a connection and request the packets from the origin server and relay them to the users requesting to watch the live stream. The users can be located anywhere in Bristol with 5G coverage or Wi-Fi AP connected to the 5G infrastructure.

The Mativision HTML5 player will be used to support multiple camera streaming where the user can select to watch a different 360º camera. Once this happens a new connection is opened to the edge server, if the stream segments are already cashed then they are relayed to the user, if not they are requested from the origin server, cached and served to the user. Each edge streaming service will play the role of multicast intermediator. The stream segments will only be requested once from the backend streaming server and will be cached locally on the edge. This segment will then be transmitted to any user requesting it via each edge streaming server service.

The application will benefit from network slicing, as video streaming will be delivered through a network slice making sure that users get the best video quality regardless of the rest of the traffic going through the network. 360º video requires large amount of data to be transferred to the end user devices and network slicing would guarantee the best QoS.

In comparison to the 5G Smart Tourism [14] [15], 5G-VICTORI will stream up to 50 Mbps to find the most common bitrate that devices can achieve during high concurrency sessions, while Smart Tourism was locked at 10 Mbps. The Smart Tourism project did not deploy any edge servers with all traffic routed to one streaming server, in 5G VICTORI we will deploy edge servers to cache the content close to the user with only the edge servers requesting content from the origin server.

For this application, edge servers will be deployed close to the users to provide better caching and lower latency. The origin streaming server need to be put in the backend for all edge nodes to connect to it and request / cache any content needed.

App 3: Future / Digital Mobility (5G UK Cluster and 5GENESIS)

App 3 will collect and analyse information from passengers and travelers including their location, their mobility and movement from train station towards the city centre. Furthermore, the application will provide passengers with station guidance and multi-modal transport journey planning beyond the train station. It can have commercial and non-commercial benefits as it can monetise the analysed data to organisations such as Bristol city council, and other commercial verticals such as train operators and insurers. Moreover, in emergency situations it can create and manage network slices. The collected data is ideal for Insurtech UCs and insurer verticals. Another big leap towards real-time insurance products and automated claim validation with instant payout.

Urban Hawk's (UHA) application will have a front-end and a back-end technical element. The front-end is a smart phone app, the back-end is a data collation and analytics and route planning service. The Insurtech layer will operate from the back-end and sync with the insurers through an API.

Passengers involved in the trial will arrive at the station by train with the front-end app pre-installed on their phones. The app will connect to the 5G Edge, where the back-end will run, and download Bristol Temple Meads or Berlin Central station's spatial digital twin (3D). At front-end (app) the 3D twin will be rendered and overlayed on the smart phone's live camera feed, and thereby help the passenger to orientate inside and around the station. Passengers will appoint travel goals through the app, where the back-end will build an optimal travel route, starting from the station, highlighting the appropriate exists to use, considering disability and other personal details such as the number of luggage bags, if traveling with children, if grabbing a coffee should be an intermediate goal. Live connecting transport data (other trains, buses), that is necessary for the further travel route planning, to be sourced and collated at the back-end. A full route/journey plan, which updates as the transport situation changes, will be visualised through the app, which shall be followed by the passenger with the help of the live guidance.

The goal is to provide a much improved guidance and planning service than existing solutions such as Google Maps, Google Maps AR, Citymapper, or Blippar. The solution contains near future (robust) extendibility both in technical and commercial aspects. Fintech (ticketing, booking, allocating) and Insurtech (travel, life, liability insurance) extended features as well as products to be introduced in the near future beyond the term of 5G-VICTORI.

3.2.2 Public safety and security

App 4: Safety and comfort for citizens

The second set of digital mobility UCs will be hosted in Alba Iulia Municipality (**AIM**) with the objective to increase safety and comfort for citizens. The Digital Mobility UC to be developed in Alba Iulia by the Municipality, together with the Public Transportation Company and with Orange Romania (**ORO**) support, is structured around two main components: infotainment services and public safety critical service (Figure 3-3). Various 5G based infotainment components (media streaming, social networks access, emails access, online shopping, municipality public services access for tourists and citizens) will be provided within the vehicles while on the move or in the stations.

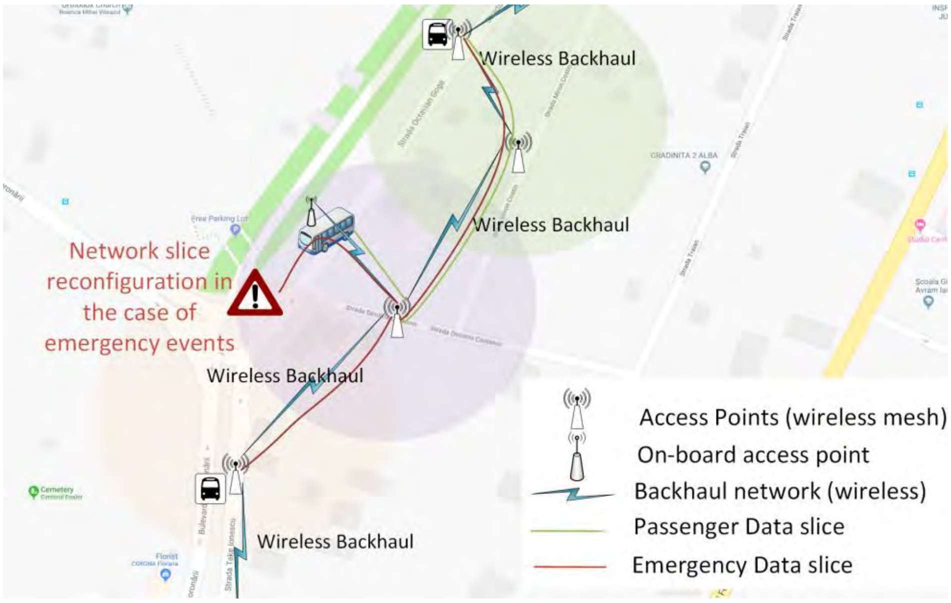


Figure 3-3 Network pop-up for emergency services at Alba Iulia Municipality

The **infotainment** component is carried out through a captive portal, in which the municipality frequently carries out surveys on issues of general interest. A captive portal is a powerful and flexible solution that allows real-time communication with users on the captive portal by displaying information considered by the city administration as important and public interest: surveys, alerts, tourist information. The new 5G infrastructure together with video cameras will connect to the Traffic Management centre of the private operator for public transportation and will be able to communicate with different stakeholders involved in providing interventions for public transportation passengers.

For the public safety critical service UC, the vehicle will be equipped with surveillance cameras linked to a Municipality Command & Control Centre (CCC), being able:

- to identify threats to the public, such as thefts and healthcare emergency or lost items that can represent potential terrorist dangerous, and
- to allocate on the spot the appropriate infrastructure resources requested for the emergency / interventions / first responders' teams in order to maximise the intervention efficiency.

When one such threat is identified by the system, the infotainment resources are backlogged and a high-quality live stream is established to the public safety critical service, on a case by case scenario. The 5G infrastructure will orchestrate the infotainment versus public safety resources' priorities according to the CCC.

Another aspect that will be also investigated is associated with **child transportation scenario**. Due to the lack of a dedicated child transportation services in **AIM**, today, children use their parents' car to reach school. This is going to change soon. Based on the contract between AIM and the private operator who runs the public transportation in the city, one dedicated bus will drive up to 160 children (of grade 2 to 8) to the *Mihai Eminescu* school and deliver them back home. The local police will take care of the safety of the children, especially when boarding and leaving the bus, and also during the journey when and where resources enable. To minimise the use of police resources throughout the daily operation (and, potentially, of school staff), web cameras will be installed on the bus, which will constantly monitor the interior with the help of a proposed automated video feed analytics service. The service will take most of the burden off the human resources whilst further enhance the safety and security of the children. Privacy concerns will be cleared by requiring parents' consent when subscribing to the bus service.

AIM is already trialling the first bus service, yet without on board smart intelligence, in March 2020. The children will be the beneficiaries of the trials and the future service. In medium term, a fleet of 13 electric buses will come in place, which are already being procured by the ministry. The main features of this UC are:

- face recognition in use to identify individual on board; thereby staff members and parents can be real time alerted when a child boards the bus, or fails to do so, and when gets off the bus (successful arrival at pickup point from where the child can be collected, or shall be expected to walk home imminently if agreed so);
- unusual or dangerous behavior to be spotted and alerted then actioned;
- the traffic management system of the private operator as well as the emergency services can get vital live intelligence in case of an accident or other emergency.

The proposed solution will be extended to other regions and countries considering taxis or private cars for transportation.

3.2.3 UC # 1.2 Key Requirements and KPIs Addressed

App 1: Immersive media services to travellers arriving at the Temple Meads station.

Some specific technical requirements of Digital Mobility UC-App1 including latency, bandwidth, and required resources are provided in the sequel. Table 3-4 summarises the whole list of Digital Mobility UC-App1 specific technical requirements. Furthermore, Figure 3-4 shows the spider diagram accounting on the KPIs related to this application.

- **Latency and bandwidth requirement**
  The maximum latency of the synchronisation server tolerance is 100 ms. The bandwidth requirements are to stream up to the maximum 50 Mbps bitrate of 360º VR videos to up to 20 users at the same time.
- **Resources required at the edge computing nodes and backend nodes**
  Edge nodes will need 2 CPUs and 4GB of ram and 5GB of space. The backend synchronisation server will need 2 CPUs and 8GB of ram and 5GB of space. The backend video streaming server will need 4 CPUs and 8GB of ram and 100GB of space. No GPU acceleration is needed.

Table 3-4 UC # 1.2 Application specific technical requirements (5G-UK)/App1

UC #1.2: Digital Mobility		Units	App1			Priority	Range	
	Vertical:		URLLC	mMTC	eMMB[10]		Min	Max
General Vertical/UC Requirement								
1	Latency (in ms) - round trip - Min/MAX	ms			✔	H	10	100
2	Speed (in Mbps) - Min/MAX - sustained demand	Mbps				H	10	50
3	Reliability (%) - Min/MAX	%	✔			H	> 99.99%	100
4	Availability (%) - Min/MAX	%	✔			H	> 99.99%	100
5	Mobility (in m/s or km/h) - Min/MAX	km/h			✔	H	0	5
6	Broadband Connectivity (peak demand)	Y/N or Mbps			✔	N		
7	Network Slicing (Y/N) - if Y deployment time (min)	Y/N			✔	Y	< 1	
8	Security (Y/N) - if Y grade i.e. "Carrier Grade"	Y/N			✔	N		
9	Capacity (Mbps/m^2 or km^2)	Mbps/m^2			✔	H	20 Mbps/m^2	60 Mbps/m^2
10	Device Density	Dev/km^2			✔	H	11	55
11	Location Accuracy	m			✔	M	1	10
Specific Vertical/UC Requirements								
Network	Number of End Points				✔	H	3	
1	Number (Range) of End Devices per End Point				✔	H	11	
2	Density of End Devices (per sq. meter)				✔	H	1	2
3	Bitrate needs per end point (kbps, Mbps, Gbps)				✔	H	1 Gbps	
4	End -to-end Latency (msecs)				✔	H	10	100
5	Highest Acceptable jitter (ms)				✔	M		15 ms
6	Number of Class of Service / QoS (1-8, more)				✔	M		1

End Devices	Type of Device (i.e. Smartphone, TV, VR)						Smartphone	
1	Bitrate required (Kbps / Mbps / Gbps)				✔	H	10	50
2	Max Latency Allowable (in ms)				✔	H		100
3	Max Moving Speed (km/h, 0 if stationary)				✔	M	0	5
4	IPv4 & IPv6 support (or both)				✔	M		IPv4
5	Connection of Device to End Point (Wired/Wireless)				✔	M		Wireless

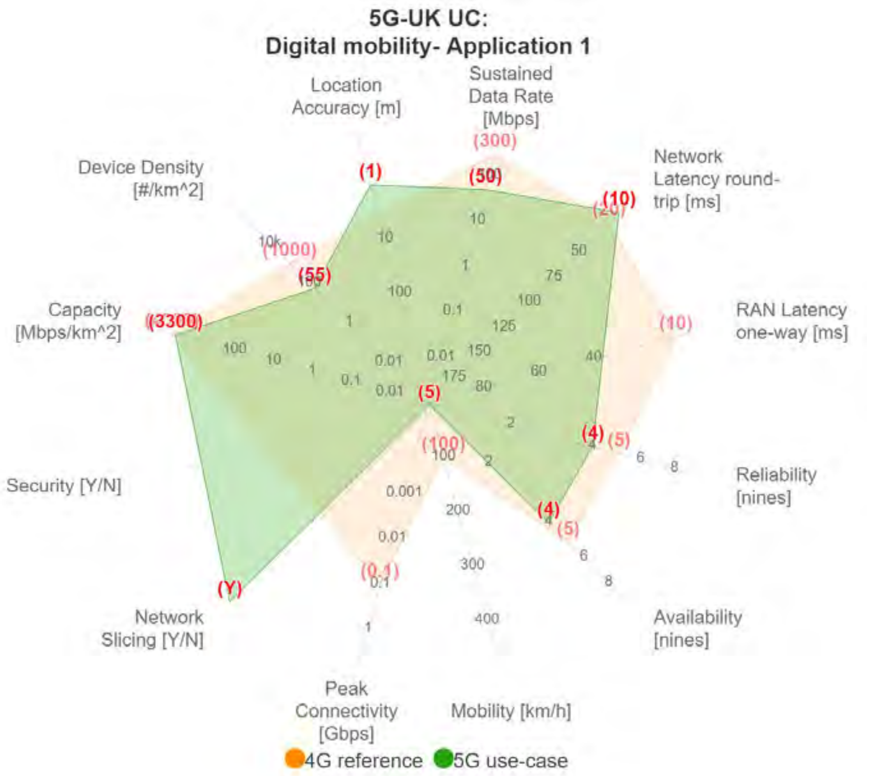


Figure 3-4 UC # 1.2 – App 1

App 2: VR Live streaming application delivered at UNIVBRIS campus during a course and providing remote visualizing.

Some specific technical requirements of Digital Mobility UC-App2 including latency, bandwidth, and required resources are provided in the sequel. Table 3-5 shows the list of Digital Mobility UC-App2 specific technical requirements. Moreover, Figure 3-5 shows the spider diagram accounting on the KPIs related to this application.

- **Latency and bandwidth requirement**

  Bandwidth requirements are n x bitrate of stream where n is the number of users. The bitrate of the stream can go up to 50 Mbps.

- **Resources required at the edge computing nodes and backend nodes**

  Edge nodes will need 2 CPUs and 4GB of ram and 5GB of space. The backend origin video streaming server will need 8 CPUs and 16GB of ram and 50GB of space. No GPU acceleration is needed.

Table 3-5 UC # 1.2 Application specific technical requirements (5G-UK)/App2

UC # 1.2 Digital Mobility		Units	App2			Priority	Range	
	Vertical:		URLLC	mMTC	eMMB[10]		Min	Max
General Vertical/UC Requirement								
1	Latency (in ms) - round trip - Min/MAX	ms			✔	M	10	100
2	Speed (in Mbps) - Min/MAX - sustained demand	Mbps			✔	H	10	50
3	Reliability (%) - Min/MAX	%	✔			H	> 99.99%?	100
4	Availability (%) - Min/MAX	%	✔			H	> 99.99%?	100
5	Mobility (in m/sec or km/h) - Min/MAX	km/h			✔	H	0	5
6	Broadband Connectivity (peak demand)	Y/N or Mbps				N		
7	Network Slicing (Y/N) - if Y deployment time (min)	Y/N			✔	Y	< 1	
8	Security (Y/N) - if Y grade i.e. "Carrier Grade"	Y/N				N		
9	Capacity ($Mbps/m^2$ or km^2)	$Mbps/m^2$			✔	H	20	60
10	Device Density	Dev/km^2			✔	H		200
11	Location Accuracy	m			✔	-		
Network	Number of End Points						2	
1	Number (Range) of End Devices per End Point				✔	H	10	
2	Density of End Devices (per sq. meter)				✔	H	1	2
3	Bitrate needs per end point (kbps,Mbps, Gbps)				✔	H	1 Gbps	
4	End -to-end Latency (ms)				✔	H	10	100
5	Highest Acceptable jitter (ms)				✔	M		15
6	Number of Class of Service / QoS (1-8, more)				✔	M		1
End Devices	Type of Device (i.e. Smartphone, TV, VR)					Smartphone, desktop, laptop		
1	Bitrate required (Kbps / Mbps / Gbps)				✔	H		50 Mbps
2	Max Latency Allowable (in ms)				✔	H		100
3	Max Moving Speed (km/h, 0 if stationary)				✔	M	0	5
4	IPv4 & IPv6 support (or both)				✔	M		Ipv4
5	Connection of Device to End Point (Wired/Wireless)				✔	M		Wireless

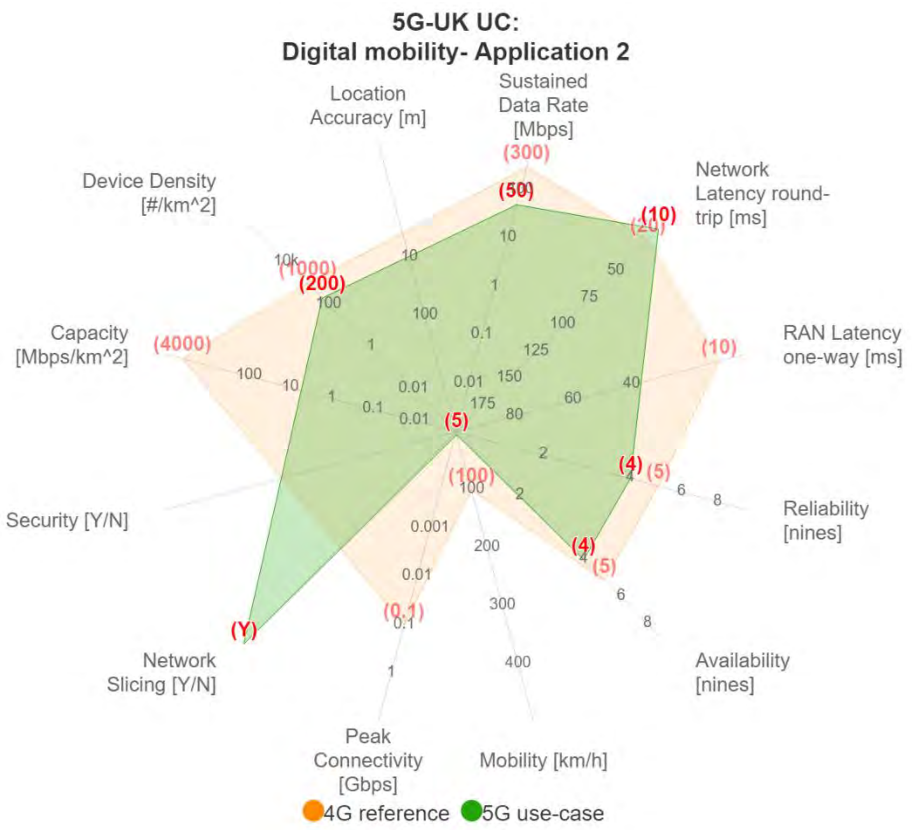


Figure 3-5 UC # 1.2 – App 2

App 3: Future / Digital Mobility (5G-UK Cluster and 5GENESIS)

Some specific technical requirements of Digital Mobility UC-App3 including latency, bandwidth, and required resources are provided in the following. Table 3-6 shows the list of Digital Mobility UC-App3 specific technical requirements. Moreover, Figure 3-6 demonstrates the spider diagram accounting on the KPIs related to this application.

- **Latency and bandwidth requirement**
  Latency is less critical than bandwidth. Latency will be mitigated by duplicating the local (location relevant) high resolution 3D spatial data over to the 5G Edge, and running a local copy of the route planning AI there. Smaller data sets will be synced from the cloud to the edge, per user, to feed the local copy of the AI with the most up to date information. Upload bandwidth of 10+ Mbps requested. Download bandwidth as high as possible, starting from 30 Mbps and tending toward the hundreds. Both for multiple concurrent users. Where no 5G Edge is available, the mechanism will fall back to cloud, which will end up in increased latency and longer loading times. To mitigate also that the spatial resolution can be decreased dynamically.
- **Resources required at the edge computing nodes and backend nodes**
  UHA's current back-end contains 4x Nvidia 1080, and 4x Nvidia 2080 cards. The demo can be certainly realised with less than this. 2x Nvidia 1080 cards on the Edge and/or back-end are sufficient. Plus CPU (4-6-8 cores) as not all processing goes massively parallel, due to the nature of algorithms (for example entropy compression, etc.).

Table 3-6 UC # 1.2 Application specific technical requirements (App3)

UC # 1.2 – Digital Mobility		Units	App3			Priority	Range	
	Vertical:		URLLC	mMTC	eMMB[10]		Min	Max
General Vertical/UC Requirement								
1	Latency (in ms) - round trip - Min/MAX	ms			✔	L	10	100
2	Speed (in Mbps) - Min/MAX - sustained demand	Mbps			✔	H	20	200
3	Reliability (%) - Min/MAX	%	✔			H	99.99 %	100%
4	Availability (%) - Min/MAX	%	✔			H	99.99 %	100%
5	Mobility (in km/h) - Min/MAX	km/h			✔	L	0	50
6	Broadband Connectivity (peak demand)	Mbps			✔	M	100	100
7	Network Slicing (Y/N) - if Y deployment time (min)	Y			✔	H	0	1
8	Security (Y/N) - if Y grade i.e. "Carrier Grade"	Y			✔	M	Carrier grade	
9	Capacity (Mbps/m^2 or km^2)	Mbps/m^2			✔	M	20	100
10	Device Density	Dev/km^2				L	1	200
11	Location Accuracy	m			✔	M	1	10
Network	Number of End Points							
1	Number (Range) of End Devices per End Point				✔	L	1	30
2	Density of End Devices (per sq. meter)				✔	L	1	2
3	Bitrate needs per end point (kbps, Mbps, Gbps)				✔	H	20	200
4	End -to-end Latency (ms)				✔	L	10	100
End Devices	Type of Device:					y	Smartphone with Android OS	
1	Bitrate required (Kbps / Mbps / Gbps)	Mbps			✔	H	0	100
2	Max Latency Allowable (in ms)				✔	L	0	100
3	Max Moving Speed (km/h, 0 if stationary)				✔	M	0	50
4	IPv4 & IPv6 support (or both)	IPv4			✔	L		
5	Connection of Device to End Point				✔	L	Wireless	
6	Type of Connection (i.e. Ethernet, WLAN, Zigbee)	Ethernet			✔	L		
7	Authentication method (i.e. SIM, eSIM, Key..)	Key			✔	H		
Other Vertical Specific (non-Network related Requirements)								
1	Insurtech relevant personal data encryption	SHA-2			✔	H		

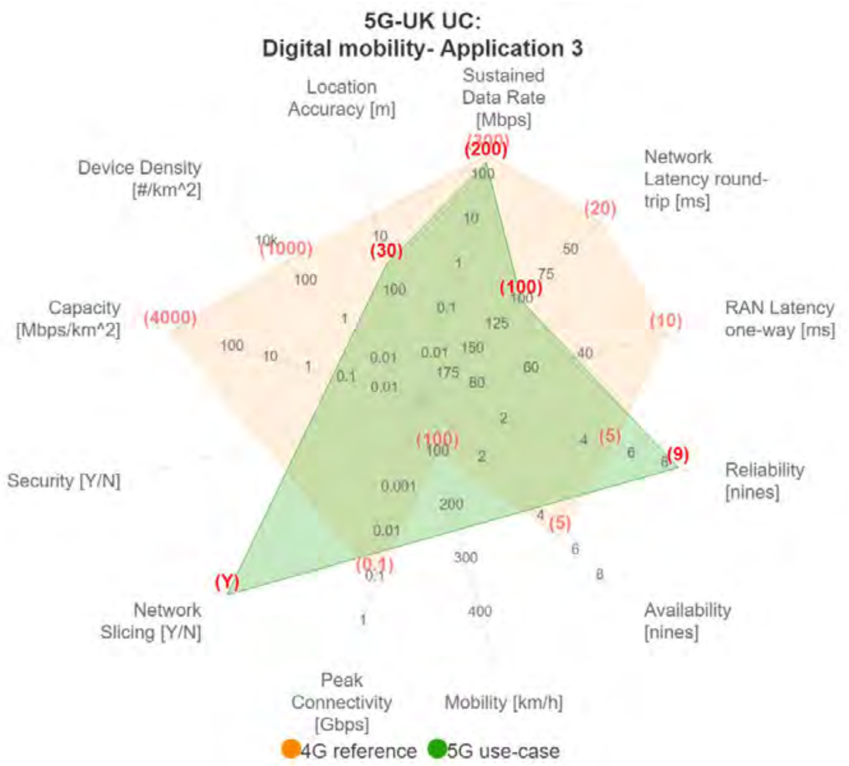


Figure 3-6 UC # 1.2 – App 3

App 4: Public safety and security

The public transportation UC is increasing the quality of the transportation by digital mobility, infotainment service and public safety critical service support; cameras are deployed in the transport vehicles and connected through 5G dedicated slice with the Municipality CCC. Specific requirements related to use case application KPIs as availability, reliability, mobility, connectivity, latency and coverage are provided in Table 3-7 for Infotainment and in Table 3-8 for Public Safety, summarising the list of technical requirements related to the KPIs that are described in details in Figure 3-7 with impact in latency and bandwidth requirement.

Immediate service triggered instantiation must be achieved, the latency being a critical metric for experimentation, the low latency will provide the proper traffic delivery to analytics processing at the 5G MEC, including also the needed device data rate to ensure the video quality to the C&C centre, at 20 Mbps per device.

Table 3-7 UC # 1.2 Infotainment Requirements and KPIs (AIM/App4)

Req.ID	Description	Priority	KPIs/Parameters to be measured
U-PE-2101	Infotainment app deployment time - Time to on-board and deploy the Infotainment application, for the first time.	M	90 minutes
U-PE-2102	Scaling time - time to start the Infotainment application and on-board the components	H	5 minutes
U-PE-2103	Browsing time (latency) – time to display the requested information	H	3 seconds
U-PE-2104	Service availability	H	99%
U-PE-2105	Service reliability	H	99%
U-PE-2106	Broadband connectivity	H	>20 Mbps
U-PE-2107	Incident (crash) application reporting accuracy	H	99%
U-PE-2108	Max simultaneous active users - Active users are who launch your app and perform actions in it	L	200

Table 3-8 UC # 1.2 Public safety Requirements and KPIs (AIM/App4)

Req.ID	Description	Priority	KPIs/Parameters to be measured
U-PE-2110	Public safety app deployment time - Time to on-board and deploy for the first time the Public safety service	M	90 minutes
U-PE-2111	Scaling time - time to start the Public safety service and on-board the components	H	1 minute
U-PE-2112	Application availability	H	99.9%
U-PE-2113	Application reliability	H	99.9%
U-PE-2114	E2E latency for public safety service (in ms)	H	< 5 ms
U-PE-2115	Mobility – high user mobility	H	< 50 km/h
U-PE-2116	Device (camera) data rate	H	> 20 Mbps
U-PE-2117	Location accuracy	H	< 10 m

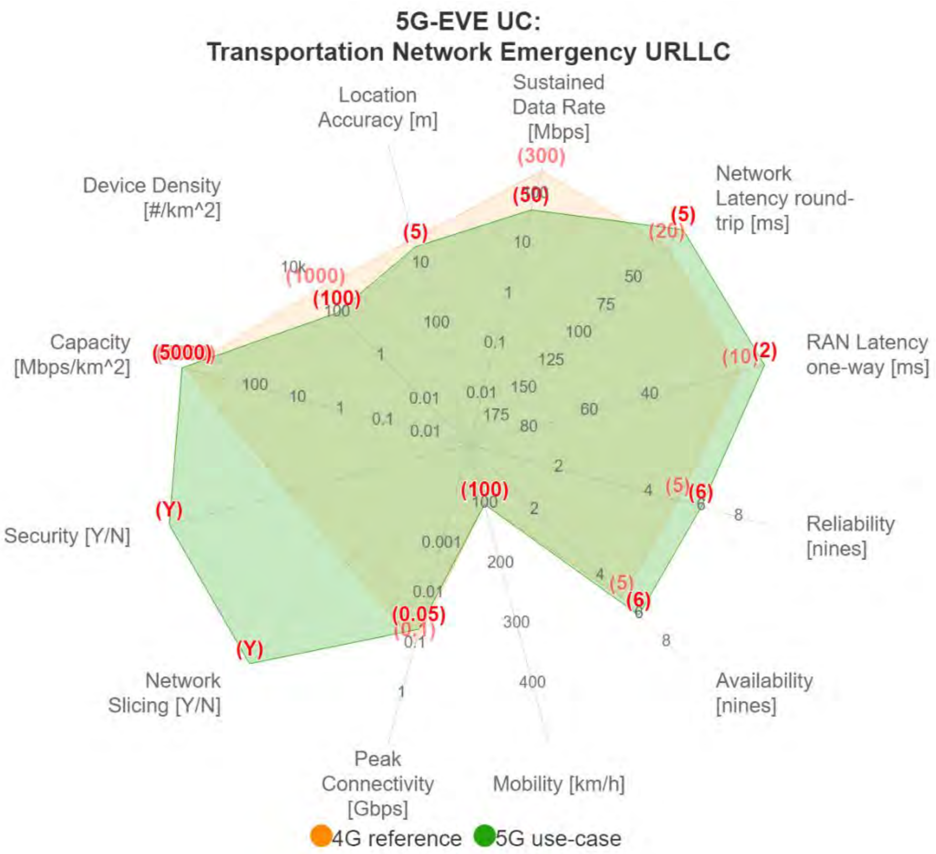


Figure 3-7 UC # 1.2 – URLLC

3.2.4 UC # 1.2 Network Performance Requirements and KPIs

Table 3-9 summarises the most important performance requirements of the Digital Mobility UC related to transportation and media hosted by the 5G UK cluster.

Table 3-9 Performance Requirements- Digital mobility for transportation and media

Req.ID	Description	Priority	KPIs/Parameters to be measured
U-PE-2201	Latency between devices in group mode	H	Time it takes a message from the master device to reach all end user devices
U-PE-2202	Latency when synchronisation service moves between edge nodes	H	Time it takes for devices to re-sync when the synchronisation service moves between edge nodes
U-PE-2203	Average bitrate during video playback in group mode	H	Bitrate of video streaming to the user devices and the most prominent bitrate when running in group mode
U-PE-2204	Average bitrate during video playback in standalone mode	H	Bitrate of video streaming to the user devices and the most prominent bitrate in standalone mode and during live streaming
U-PE-2205	Latency when switching cameras	M	Latency during camera switching between the user input, buffering and the stream playback rate reaching 1.
U-PE-2206 (Related to App3)	**Telecom:** We can take advantage of the increased 5G bandwidth and edge computing, and thereby create commercial incentive for telecom network carries so that they invest into building the next generation network.	M	Partnering intention of the telecom network carriers to distribute the product. Number of interested passengers who may become users of the solution in future.

The Network functional requirement of the digital mobility UC with emphasis on public safety and security that will be hosted at AIM including network KPIs, slicing capabilities, MEC are described in Table 3-10.

Table 3-10 Network Functional Requirements and KPIs (AIM)

Req.ID	Description	Priority	KPIs/Parameters to be measured
U-PE-2220	Network availability	H	99.9%
U-PE-2221	Network reliability	H	99.9%
U-PE-2222	Network slice capabilities/management	H	Yes
U-PE-2223	E2E latency for interactive service (in ms)	H	<30 ms
U-PE-2224	E2E latency for public safety service (in ms)	H	<5 ms
U-PE-2225	Mobility – high user mobility	M	<50 km/h
U-PE-2226	High bandwidth required for data intensive public safety applications and HD video streaming	H	>20 Mbps
U-PE-2227	Edge computing capabilities	H	99%
U-PE-2228	Jitter – Time critical communications should be stable and reliable. Timing variation must be minimal	H	<1 ms
U-PE-2229	Packet loss - Reliability and high availability of the services in extreme conditions is essential for emergency systems. Therefore, packet loss should be made as small as possible	H	0.01%

3.2.5 UC # 1.2 Functional Requirements and KPIs

Table 3-11 and Table 3-12 summarise the most important functional requirements of the Digital Mobility UCs and addressing the "Transportation and media" and "Public safety and security", respectively.

Table 3-11 Functional requirements Digital mobility for transportation and media

Req.ID	Description	Priority	KPIs/Parameters to be measured
U-PE-2301	Management & Orchestration of Distributed pools of Resources	Essential	Service Instantiation Time, Service Tear-down Time, Service Modification Time
U-PE-2302	Slicing	Essential	Slice Setup Time, Slice Tear-down Time, Slice Modification Time, Slice Resource Overhead
S-FU-2303 (Future Mobility application)	Download speed from 5G Edge	M	The amount of time it takes to download a spatial dataset. Tolerable up to 5 seconds.
S-FU-2304 (Future Mobility application)	Digitisation accuracy	M	The geospatial error in the digital twin, the 3D mapped replica of stations and other travel hubs. Tolerable up to 2 meters.
S-FU-2305 (Future Mobility application)	Guidance App location and orientation accuracy	H	The error in meters regarding location, and degrees concerning orientation. Tolerable up to 5 metres location wise, and up to 30 degrees orientation wise. Compare against Google Maps.
U-OTH-2306 (Future Mobility application)	Insurance: Use the accumulating data to realise real-time insurance solutions with automated claim validation.	L	Partnering intention of insurers to underwrite the product. Number of interested passengers who may become users of the insurance layer of the product in future.

Table 3-12 UC # 1.2 Functional requirements Digital mobility for public safety and security (AIM)

Req.ID	Description	Priority	KPIs/Parameters to be measured
U-FU-2320	Very high data rates for transfer of large volumes of information (4K)	H	E2E data rate, network slicing
U-FU-2321	Support for mobility of moving vehicle	H	Mobility, reliability, availability
U-FU-2322	Compute/storage/networking resource usage monitoring	M	Compute usage/storage
U-FU-2323	Management & Orchestration of Resources	H	Service Instantiation Time, Service Tear-down Time, Service Modification Time

3.3 UC # 1.3 – Critical services for railway systems (Vertical: Rail)

Constantly increasing traffic and the shift from the road to rail as a way-out of the climate change, made the rail transportation favourable environment-friendly transportation alternative. Since the beginning of the railway operations, the need and demand for MC communication and signalling has increased significantly. Managing increasing rail traffic would be unthinkable without the Global System for Mobile Communications for Railway (GSM-R).

GSM-R is a successful international wireless communication standard used by railways to support MC voice and data communication between trains moving up to 500 km/h and railway controllers, staff and other railway operational equipment with more than 100.000 km of railway tracks only in Europe. The EU legal framework CCS TSI defines GSM-R as the radio system for voice and signalling communication. The technology itself is based on 2G GSM with additional railway specific functional enhancements. Together with the European Train Control System (ETCS), GSM-R is part of the European Traffic Management System. Its aim is to replace different national train control and command systems in Europe and enable a seamless interconnected European railway system.

GSM-R delivers features such as group calls with PTT, voice broadcast, railway emergency calls, prioritisation, call pre-emption, functional and location-dependent addressing. An effective and punctual railway operations like rail traffic control, train control and dispatching or shunting in the rail yard would be impossible without them.

Though the GSM-R was able to accommodate all functional needs of railway industry so far and it can evolve to accommodate mid-term needs e.g. using ETCS over packet switched data GPRS/Edge in parallel to circuit-switched data to speed up ERTMS deployment in corridors and in stations with complex situation to overcome capacity issues [18], a successor to GSM-R is required primarily to minimize risks due to expected obsolescence of the GSM-R technology. Also, due to digitalization of railways and further evolution of the ERTMS towards autonomous train operation (GoA3 and GoA4), this was an argument to look for a GSM-R successor. Fist considerations and studies for a GSM-R successor were launched by the International Union of Railways (UIC) back in 2012. UIC project defined the new User Requirements Specifications (URS) [13], focusing mainly on rail communication needs and the EU Agency for Railways was tasked by the EU commission to introduce the new communication standard in the CCS TSI planned for 2022.

FRMCS is the future worldwide telecommunication standard and GSM-R successor as well as key enabler for rail transport digitalisation. The fundamental principles, which are considered for FRMCS from UIC perspective, are:

- Meeting capacity, reliability, availability, maintainability and quality of service characteristic for railways under various operational conditions including degraded and emergency conditions.
- Independence of railway applications of the used FRMCS network and Radio Access Technologies (RATs).
- Seamless transition between various FRMCS networks and different RAT without interruption in application usage.
- Ability to capitalise on true Commercial Off-The-Shelf (COTS) HW and SW products and use of open and standardised non-proprietary interfaces.
- Focus on automation in operation and maintenance as far as possible without the need for manual assistance of humans.
- Cybersecurity, encryption and authentication.

FRMCS shall be built upon and take advantage of 5G and 3GPP Mission Critical Communication Standard (MCX). While commercial broadband technology of public operators is driven by consumer needs, the MCX has been developed having global critical communication and railway industry and its requirements on mind. MCX over mobile broadband network offers combination of mobile broadband capabilities and MC features as emergency calling, group calls, PTT communication, security and encryption and meeting the high reliability and high availability requirements.

3GPP started to standardise MC PTT (MCPTT) voice communication with Rel.13 in 2016 to create a migration path for legacy narrowband public-safety users that transition to private, public safety mobile broadband networks. This technology was designed to ensure that the needs of critical communication industry, public-safety stakeholders, MC users are met and the interfaces between crucial components are open and standardised.

With recent enhancement in Rel.14, Rel.15 and Rel.16, improvements in MCPTT, MCData and MCVideo, MC interworking between LTE and non-LTE systems, MC system migration and interconnection as well as MBMS, MCX specification is moving to 5G & FRMCS future.

3.3.1 Reference Architecture - Rail Critical Services

The Railway System consists of several domains, namely Signaling, Fixed Installation and Rolling Stock, which have to interact with each other. Each of these domains contains several critical services, like the Braking System for trains or interlocking systems for Signaling. Several of these critical services are linked to each other and due to this have specific requirements on mission critical communication. A rough overview of the services and their criticality can be seen in Figure 3-8.

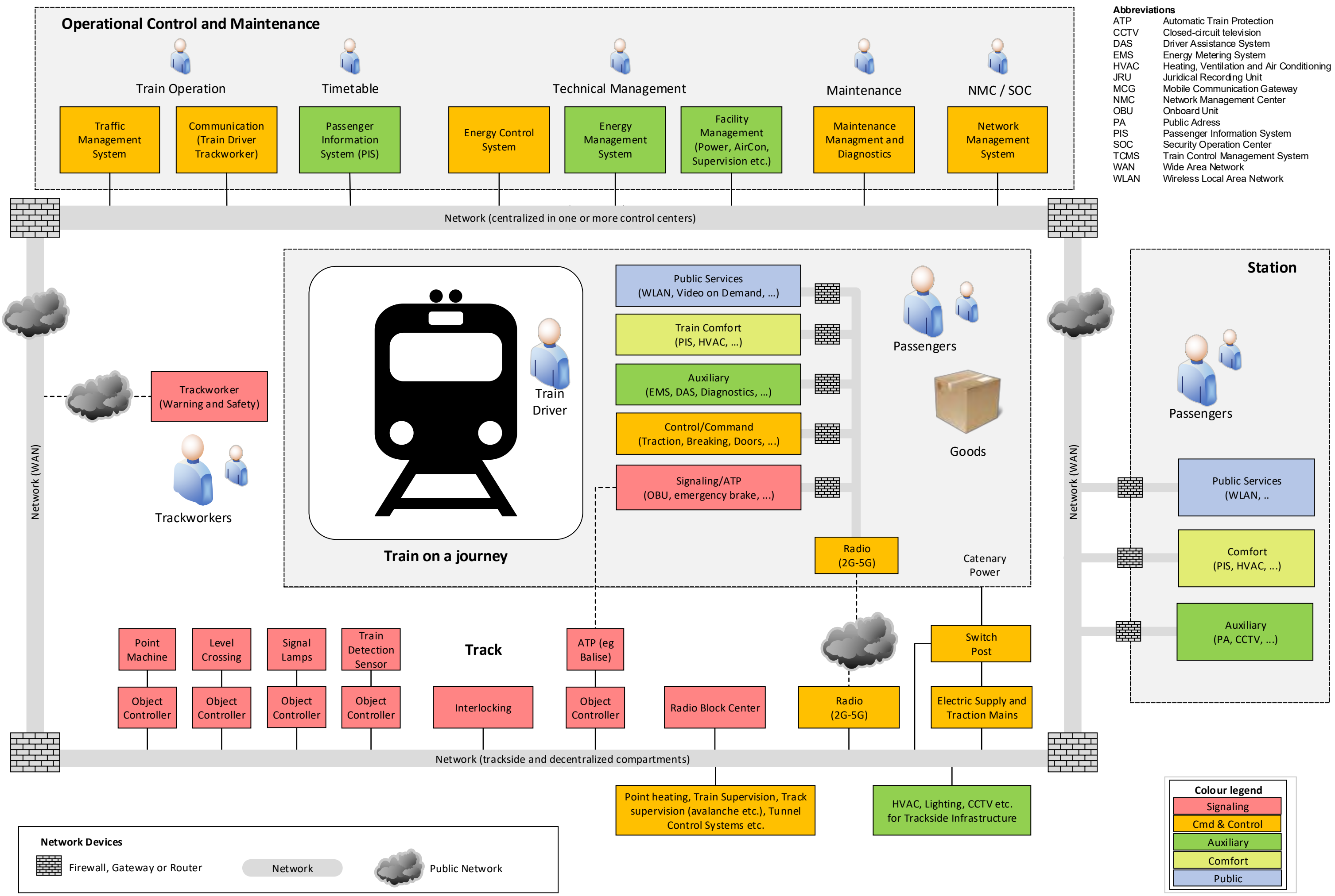


Figure 3-8 Railway Reference Architecture (Source: CEN prTS 50701 D6E4)

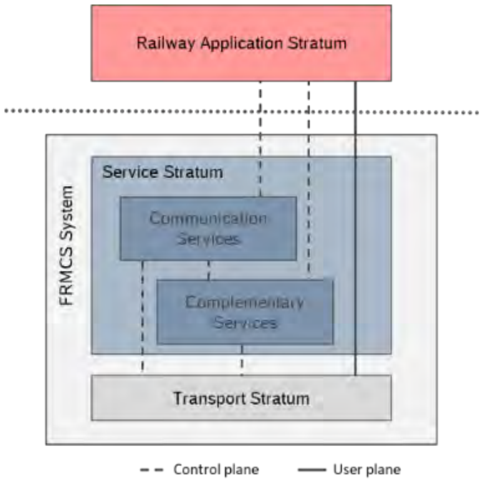


Figure 3-9 High-level FRMCS overview (ETSI TR 102 459)

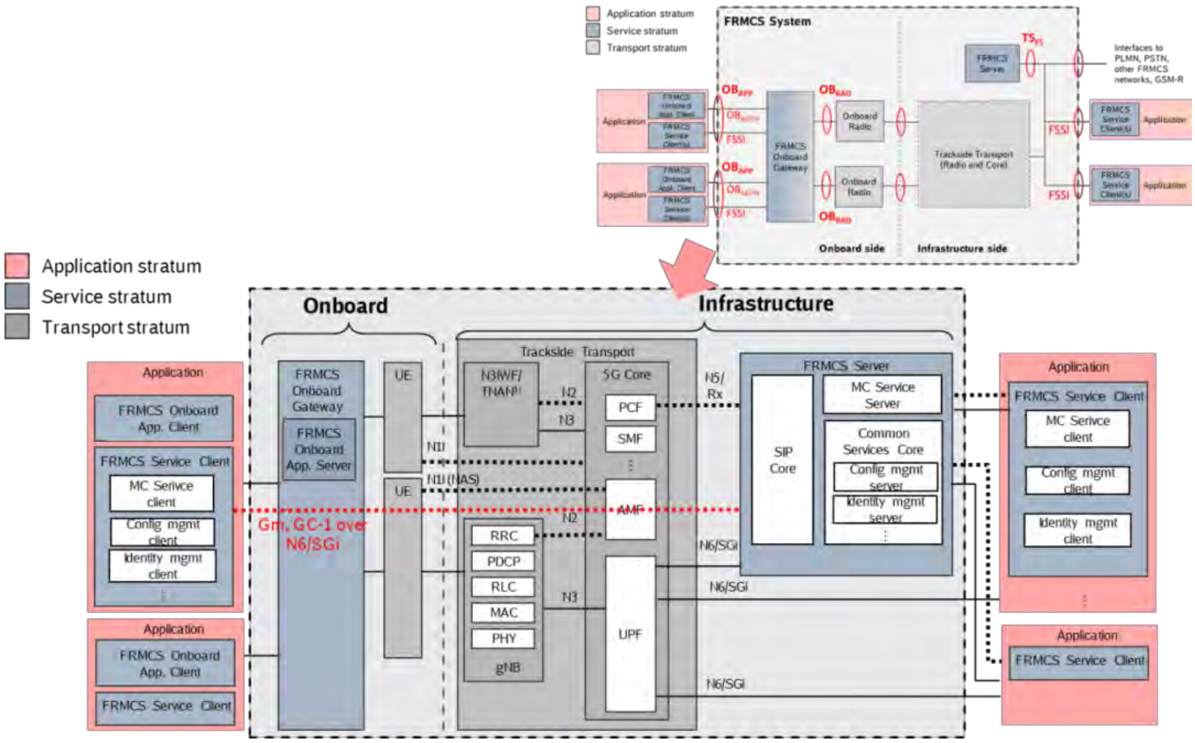


Figure 3-10 FRMCS system boundaries and high-level logical architecture (ETSI TR 103 459)

One key objective behind the FRMCS is allowing the railway applications to become independent. While the Railway Application Stratum provides railway-specific functionalities using communication and complementary services offered by Service stratum utilising both 5G's and 3GPP's MCX service-based architecture, the Transportation stratum comprises 5G NR access and 5GC core functions of the FRMCS system. Thus, there has to be clear separation between Railway Application stratum, Service and Transport stratum.

The FRMCS system boundaries and high-level logical architecture are depicted in Figure 3-10. The color-coding of different logical entities corresponds to the stratums introduced in Figure 3-9.

Each railway application is represented by FRMCS on-board application client, which is using service and transport capabilities of the FRMCS on-board gateway (OBG). In addition, there is instance of a FRMCS Service client for each tuple of FRMCS user, application and service type (e.g. critical voice, critical data), which logically interfaces to the FRMCS Server on the trackside.

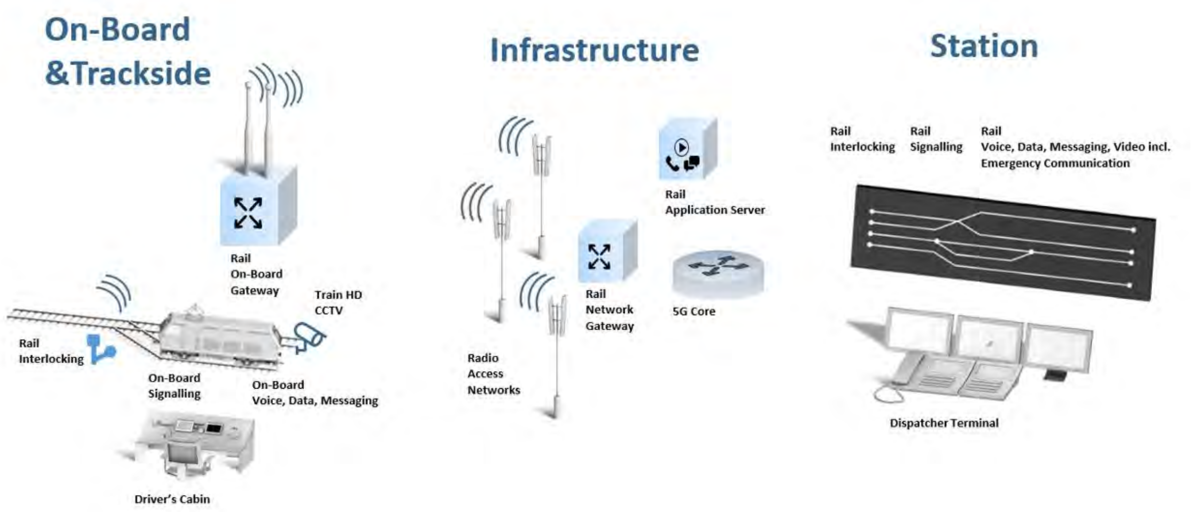


Figure 3-11 Critical rail services and entities at on-board, trackside and infrastructure side

The client enables authorisation of the railway application to the FRMCS OBG, granting it access to services provided by the OBG such as selecting initial or default FRMCS On-board Radio for particular application or providing bearer management. The FRMCS On-board Radio handles the functionality of a „UE" according to 3GPP definitions, which supports 5G access. One On-board Radio entity can explicitly cover multiple 3GPP or non-3GPP RATs. The trackside transport stratum corresponds to the 5GNR access and 5GC.

The FRMCS Server supports termination of the service-level relations to the FRMCS Service Clients and provides policy control, session management, interworking to legacy systems and interconnection between FRMCS systems in service stratum.

An example of the different logical entities is presented in Figure 3-11, where:

- FRMCS On-board Applications are:
  - On-board critical rail voice and emergency communication.
  - On-board signalling.
  - Train CCTV.
- FRMCS On-board Gateway is Rail OBG.
- On-board radios are 5G UEs, CPEs or 5G radio modules built in the FRMCS OBG, whereby the first 5G UE shall be dedicated to critical rail Vertical Service Instance (VSI aka slice) [1] and the other one(s) to performance/business VSI or other 5G network.
- Trackside transport (radio and core) is 5G network.
- FRMCS Applications on infrastructure side are:
  - endpoint for rail signaling.
  - endpoint for rail interlocking.
  - dispatcher terminal.
- FRMCS Server is Kontron's IMS based SIP-core and Rail (MCX/FRMCS) Application Server and Rail Network Gateway.

Figure 3-12 outlines a hardware block diagram for suggested Rail Critical Services in Task 2.1. The figure gives a simplified overview of the Rail Critical Services in the 5G-VICTORI project:

- Train Control Signaling.
- HD CCTV.
- Mission Critical Telephony and Data.
- Object Controller Signaling.

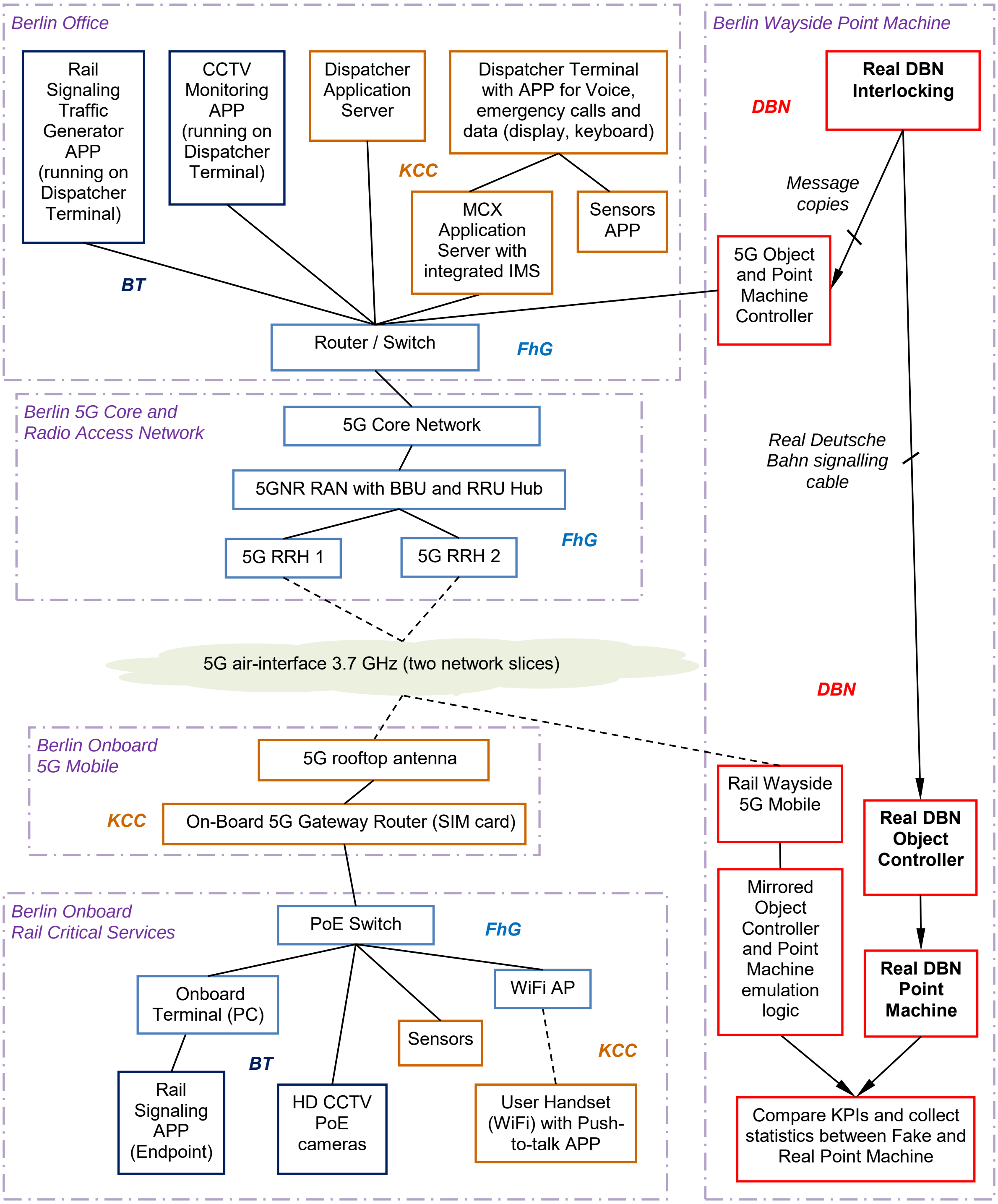


Figure 3-12 5G-VICTORI Rail Critical Services - Equipment Overview

Due to the strong Reliability, Availability, Maintainability, and Safety (RAMS) and certification requirements in the railway signaling domain, it is not possible to directly include the solution by 5G-VICTORI into operational networks. Instead of this, the original communication by the interlocking system is copied at the control center and, from there on, the copy is transferred via the 5G-VICTORI network to the trackside infrastructure.

The purpose with the 5G-VICTORI project is to show that all onboard vertical services can share the same air-interface by using different network slices and QoS. Therefore, all on-board vertical services shall use e.g. the 3.8 GHz band.

Table 3-13 outlines a traffic model for the suggested Rail Critical Services. The actual data content sent over the 5G network is not important, but the characteristics of the data sent, together with other vertical services are.

Table 3-13 UC # 1.3 Rail Critical Services – Traffic Model

Rail Critical Services	Protocol	Mobile / NW Slice [name]	5G QoS Class	3GPP QCI or 5QI (5G QoS Indicator)?	Bitrate UL [kbps]	Bitrate DL [kbps]	Frame size [bytes]	Round trip time [ms]	Maximum Packet Loss Ratio
Train Control Signaling	CBTC, ETCS, or FRMCS	Rail Onboard	uRLLC	5	160	160	300	100	0.5%
HD CCTV	MPEG4, H.264	Rail Onboard	uRLLC	2	4500	~0	1400	150	0.5%
Mission-Critical Telephony and Data (Staff and Emergency and other railway services)	3GPP MCX (MCPTT/ MCData), AMR-WB	Rail Onboard	uRLLC	65 (MCPTT) 70 (MCData) 9 (default bearer)	100	100	72	60 ms (MCPTT) 200 ms (MCData)	10^{-6}
Object Controller Signaling	Vendor specific	Rail Trackside	uRLLC	5	5	10	300	100	10^{-9}

Note: the PC software *Iperf* can probably be used in general to collect data traffic characteristics.

3.3.2 UC description –Train Control Signaling

Train Control Signaling in the project emulates generic train signaling using a traffic generator. The generic train signaling here represents any signaling system like:

- CBTC (Communication Based Train Control).
- ETCS (European Train Control System).
- FRMCS (Future Rail Management Control System).

The train signaling emulation could be implemented using an IXIA traffic generator, with an office PC for the Console for configuring and managing traffic between the endpoints. The bitrate is rather limited and only one train is emulated, therefore a PC with endpoints emulating software will do just fine (not needing dedicated physical box).

The content of the rail signaling packets are of not important, but the characteristics are, together with KPIs defined by the other vertical services. Another alternative is Spirent and *Spirent Test Center* software on PC. Assuming IxChariot: a Console software manages the traffic endpoints. Traffic can be configured in either or both directions. This traffic generator will be used to emulate Rail Signaling between end-points, where each end-point is given specific traffic instructions. These instructions are sent to the End-points, used when generating traffic between the End-points. End-points report and heart-beat to console, i.e. can be inside firewalls. The type of traffic is selected or configured between the End-points. Traffic can be either unidirectional or bidirectional. Performance KPIs that will be tested include: Throughput, Packet Loss, Jitter, One-way delay, MOS and Application latency.

3.3.2.1 HD CCTV

High Definition Closed Circuit Television (HD CCTV) will be also investigated, using real on-board CCTV cameras for demonstration purposes. This will allow to show real pictures from the train in the office and measure KPIs of interest. Two CCTV cameras are proposed to be used on the train:

- A first CCTV camera can be located in the driver's cab, pointing forward, looking towards track and signals, mounted just inside the window in a black box with sunshield.
- A second CCTV camera can be located in the driver's cab, looking towards the dashboard, showing train instruments like train speed, mounted close to the back wall and ceiling.

The CCTV pictures are conveyed via the train local PoE switch (the cameras use Power over Ethernet), the 5G CPE router, 5G air-interface, 5G RAN and core network to the monitoring software. Data from the on-board CCTV cameras are only sent in uplink. Bitrates from such a camera depend on movements in the pictures, compression degree, etc. However, an SD camera needs around 1 Mbps and an HD camera around 4.5 Mbps. The monitoring software could for example, be run on a PC, e.g. the same as the Dispatcher Terminal.

3.3.2.2 Railway Telephony and Data - Staff and Emergency

Essential services for safe railway operation are MC Railway Telephony, e.g. operational voice, private and group communication, emergency group communication; and MC Railway Data Service, e.g. alerting in case of railway emergency, enhanced location railway service and operational messaging. These services are provided by Kontron's FRMCS server over a 5G network. They are based on MC voice, data and video communication (MCX/FRMCS) used by MC applications running, e.g. on on-board terminals such as FRMCS cab radio or fixed terminal such as Kontron's FRMCS dispatcher.

An FRMCS OBG is designed to allow smooth migration from technologies of previous generations to 5G/FRMCS by introducing bearer independence. Kontron's OBG, which is an adaptable communication system supporting multiple packet switching technologies and Radio Access Types, will provide train-to-ground connectivity to on-board application and terminals, via 5G.

On-Board terminals, clients and applications will benefit from the independence of the underlying radio technology, data throughput, and connection reliability by flexible usage of multiple radio bearers by one or more networks or network slices.

The mission-critical railway voice and data communication between dispatcher terminal (NG Dispatcher) and on-board terminals, clients and applications (especially NG terminal, optional railway signaling and HD CCTV) will pass via OBG allowing high connection reliability using multiple 5G bearers and VSIs/NSI (vertical network instances (slices) and service continuity during outage of one network slice or 5G radio.

The required bitrate is rather limited and symmetrical in Uplink and Downlink for private voice calls without floor control and non-symmetrical in private and group calls with floor control (using PTT). MCPTT voice communication is using AMR-WB codec with max. 23.85 kbps data rate. The delay or round-trip-time should be low to offer good end-user perception.

3.3.2.3 Object Controller Signaling

The idea for this UC is to use 5G as a backup (or the unique) communication between an Interlocking and an Object Controller with its objects like a Point Machine or a Signal. The reasons for this are the increase in copper cable thefts as well as the accidental destruction of cables during construction work, which results in large delays due to increased capacity of the rail network. Besides the usage as primary communication could result in decrease of costs because digging down cables and maintaining them is expensive[1].

The outlined suggestion is to test how good a 5G-based communication between an Interlocking and an Object Controller/Point Machine is compared with the current cable-based solution and if RAMS requirements can be fulfilled.

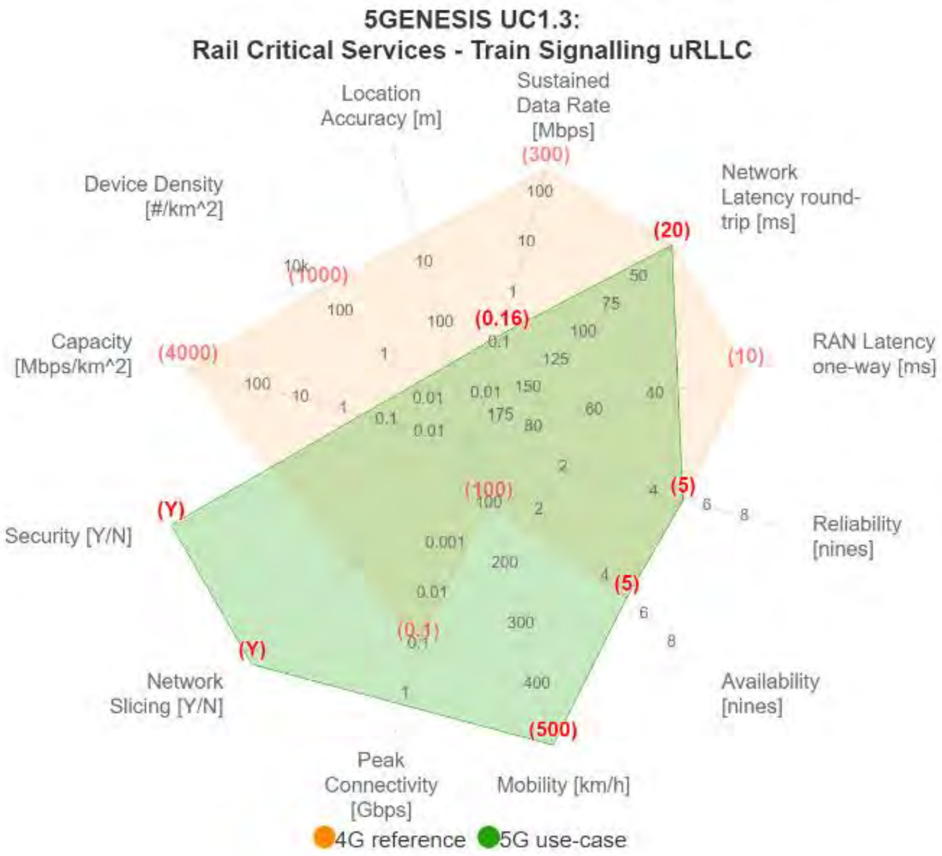
[1] Copper cables are still needed between the motor of a Point Machine for power feeding and status sensing and also for the power supply of the controllers, but the power supply is handled locally and an outage would only result in an outage of a few elements.

The procedure of implementing the UC would be:

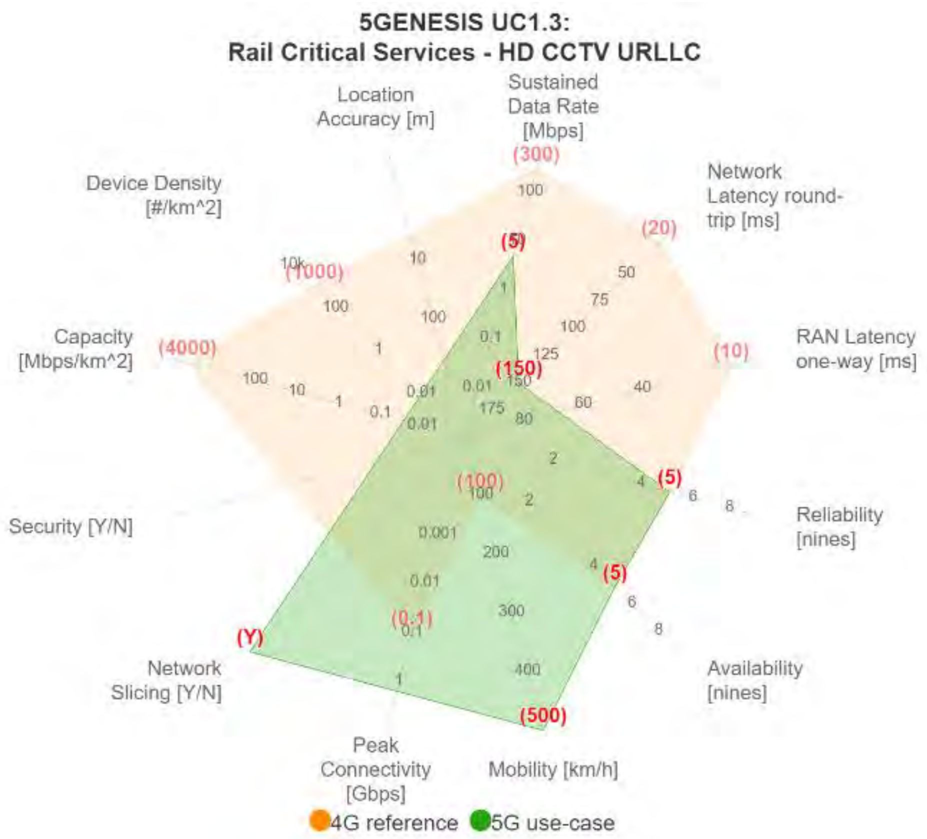
- A signal from a real *Deutsche Bahn* (**DBN**) interlocking, addressing a certain real Object Controller with a certain real Point Machine/Signal is copied, captured, and sent via 5G to a Fake Object Controller with a Fake Point Machine/Signal (indicating left/right, or red/green, etc.).
- The KPI characteristics are collected between the Fake and Real Point Machine/Signal, and statistics are built up in a database.
- A Point Machine/Signal that is rather active within one of DBN's maintenance and shunting yards will be chosen.

The required bitrate is very low, but the availability and reliability needed has to be very high. The protocol used over 5G should probably use Automatic Repeat Request (ARQ), like TCP/IP (or SCTP).

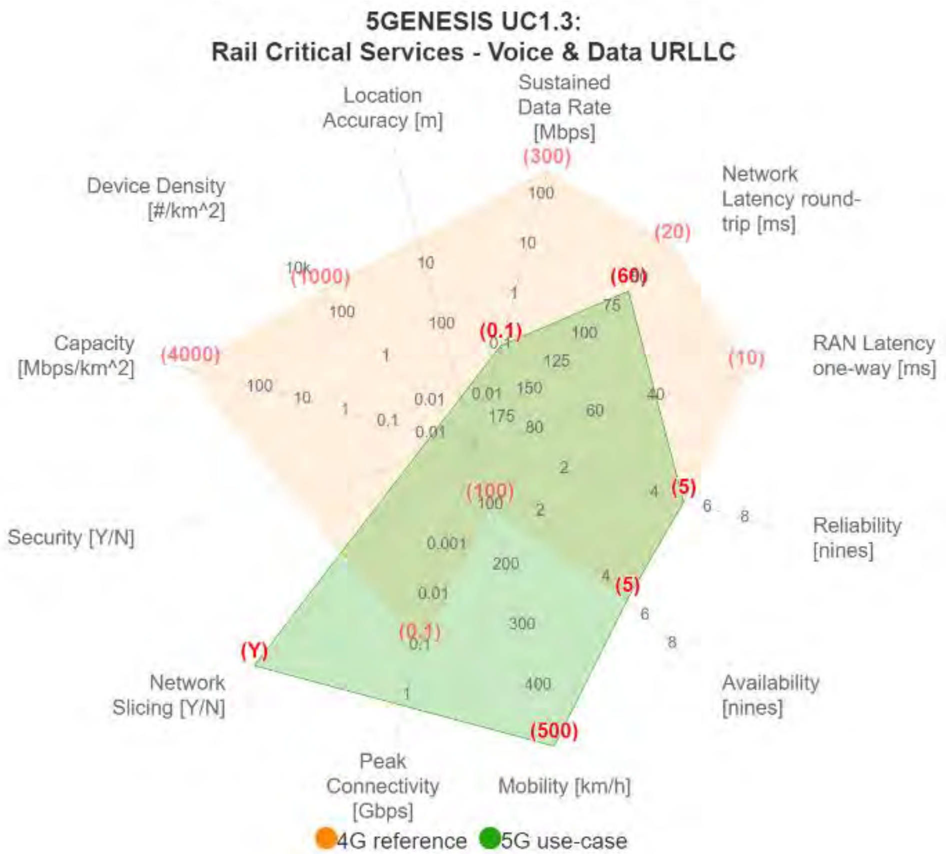
Figure 3-13 shows the spider diagrams accounting on the KPIs to be fulfilled for each of the services.



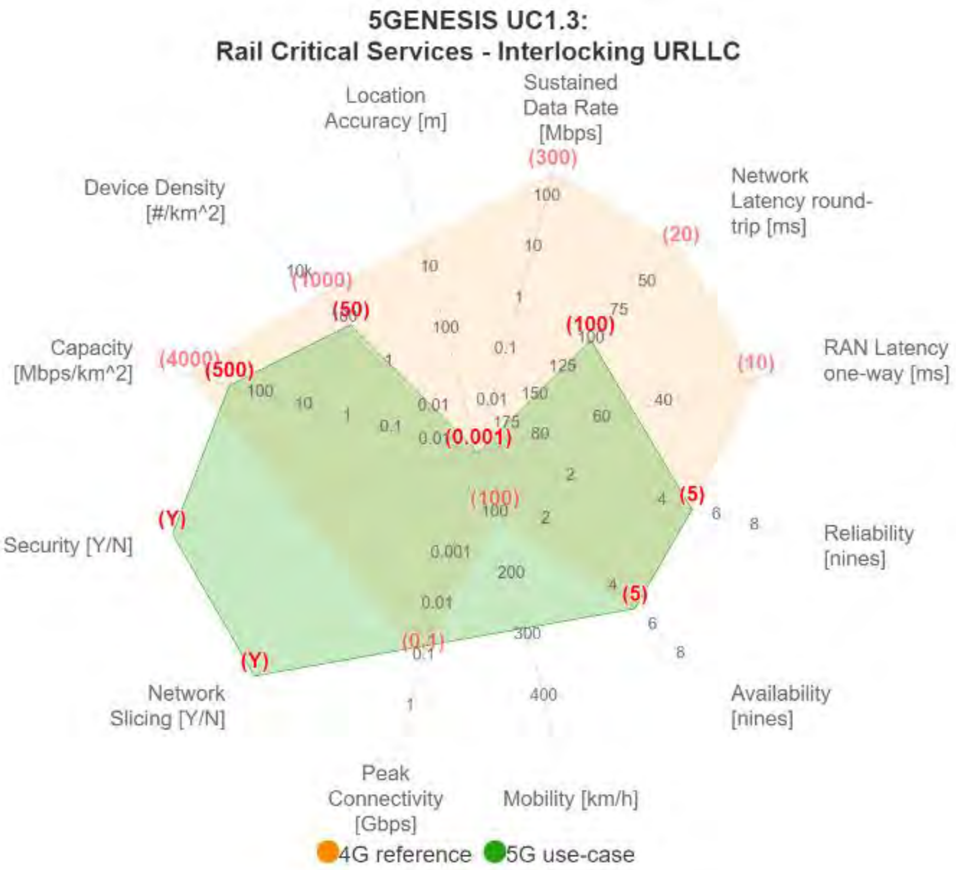
a)


5GENESIS UC1.3:
Rail Critical Services - HD CCTV URLLC
Location Accuracy [m]
Sustained Data Rate [Mbps]
(300)
Network Latency round-trip [ms]
(20)
Device Density [#/km^2]
(1000)
(5)
RAN Latency one-way [ms]
(10)
Capacity [Mbps/km^2]
(4000)
(150)
Reliability [nines]
(5)
Security [Y/N]
(100)
(5)
(0.1)
(Y)
Availability [nines]
Network Slicing [Y/N]
(500)
Peak Connectivity [Gbps]
Mobility [km/h]
4G reference
5G use-case

b)


5GENESIS UC1.3:
Rail Critical Services - Voice & Data URLLC
Location Accuracy [m]
Sustained Data Rate [Mbps]
(300)
Network Latency round-trip [ms]
(20)
Device Density [#/km^2]
(1000)
(60)
(0.1)
RAN Latency one-way [ms]
(10)
Capacity [Mbps/km^2]
(4000)
Reliability [nines]
(5)
Security [Y/N]
(100)
(5)
(0.1)
(Y)
Availability [nines]
Network Slicing [Y/N]
(500)
Peak Connectivity [Gbps]
Mobility [km/h]
4G reference
5G use-case

c)



d)

Figure 3-13 a) UC # 1.3 Voice&Data URLLC, b) Interlocking URLLC, c) UC # 1.3 Train Signalling URLLC, d) UC # 1.3 CCTV URLLC

This section lists specific Rail Critical Services and Berlin platform Network related requirements. The requirements' tables (Table 3-14, Table 3-15, Table 3-16, Table 3-17, Table 3-18, Table 3-19) contain four columns:

- Req ID uses format U/F-TYPE-RQ#, where:
  - U/F= U: User, the vertical service, F: Facilities, the network part.
  - TYPE of requirement = Functional (FU), Performance (PE), Capacity (CA), and Other (OTH).
  - Requirement Number is a unique serial number in this document*[2].
- Description is the textual part, which must contain the word "shall".
- Prio: High is a must; Medium is a standard solution, Low is a wish.
- KPIs and Parameters: Variables can be measured and KPIs calculated, parameters or often related to what one configures.

[2] This type of requirement tables is only found in headings level 3 in this document, in different headings on level 2, with different tables' headings on level 4. Therefore, it would be feasible to base a unique requirement ID Prefix based on headings level 2 and 4: 31xx, 32xx and 33xx, where xx is the local sequence number within each requirements table, e.g. 01, regardless of "U/F" or TYPE. For example, Req ID: U-FU-5101.

3.3.3 UC # 1.3 Key UC Requirements and KPIs Addressed

Table 3-14 summarizes the rail signaling requirements and KPIs that are of consideration in the 5G-VICTORI Project.

Table 3-14 UC # 1.3 Rail Critical Services – Rail Signaling Requirements and KPIs

Req ID [U/F-TYPE-RQ#]	**Description** [Descriptive text]	**Priority** [H/M/L]	**KPIs and Parameters** [to be measured]
U-FU-3101	The rail signaling part of the Rail Critical Services uses an IxChariot traffic generator which **shall** send traffic over a demo 5G cellular network between "Performance Endpoints" (Endpoints). The Endpoints are located both in the Office (train station) and on the Train, sending traffic in both downlink (office to train) and uplink (train to office).	H	Check that traffic can be sent between IxChariot Performance Endpoints.
U-FU-3102	The rail signaling traffic generator is based on one Console and up to 10 active Endpoints (the minimum license possible). The Console handles the IxChariot application with licenses, users and endpoints. The Console is a Windows application, which **shall** be installed and run on a computer in the Office.	H	Check that the IxChariot Console can be installed and run on an office Windows computer.
U-FU-3103	The rail signaling traffic generator is based on one Console and up to 10 active Endpoints. The Endpoints handle the IxChariot traffic generation and reception, with KPIs figures such as bitrate and latency. A first Performance Endpoint **shall** be installed and run on a computer in the office, a computer supporting a platform like Windows, Linux, Android tablets and phones, IoT HW like Raspberry Pi, and VMs.	H	Check that a first IxChariot Performance Endpoint can be installed and run on an onboard computer, using for example MS Windows.
U-FU-3104	The rail signaling traffic generator is based on one Console and up to 10 active Endpoints. The Endpoints handle the IxChariot traffic generation and reception, with KPIs figures such as bitrate and latency. A second Performance Endpoint **shall** be installed and run on a computer on the train, a computer supporting a platform like Windows, Linux, Android tablets and phones, IoT hardware like Raspberry Pi, and Virtual Machines.	H	Check that a second IxChariot Performance Endpoint can be installed and run on an office computer, using for example MS Windows.

U-FU-3105	The rail signaling traffic generator **shall** emulate a rail signaling system with a suitable bitrate, packet size, latency, etc., needed in a rail signaling system like CBTC, ETCS, or FRMCS. The content in the rail signaling packets is of no importance, but the characteristics of the packets are (among the other vertical services using the same demo 5G cellular network frequency band).	H	UDP and/or TCP Bitrate Packet size Packets per second Latency
U-FU-3106	The rail signaling traffic generator Endpoints **shall** use a first pair of IP addresses in the same IP network (common for office and train) for rail signaling traffic generation over the demo 5G cellular network.	H	Check IP address allocation and IP network connectivity between Endpoints.
U-FU-3107	The rail signaling traffic generator IxChariot with the Console application manages the Endpoints in the network. When the Endpoints are active and alive most of the time, with heartbeat supervision, the Endpoints can be used for both traffic and management over the same pair of IP addresses. When and if the non-connectivity time periods between an Endpoint and the Console becomes too long, the Console might consider the Endpoints dead. If there is a problem with dead Endpoints, then the Endpoints in the office and train **shall** be configured with two pairs of IP addresses: - First pair of IP addresses used for Endpoint rail signaling traffic over the demo 5G cellular network. - Second pair of IP addresses used for Endpoint management over a public 4G cellular network.	H	Check that the IxChariot Performance Endpoints can maintain traffic in between Onboard and Office, also after short and long non-5G cellular connectivity periods. If traffic cannot be maintained in between the Performance Endpoints after a non-connectivity period, check that a pair of management IP addresses over a 4G cellular network can be used.
U-FU-3108	It would be preferred and good if the rail signaling traffic generator with the IxChariot Console application could start a test either daily (early in the morning), or at each time the demo 5G connection comes up (for example six times per day). Everything that can be configured in the IxChariot software application in the console can be controlled via an automation interface called REST. The demo 5G equipment **shall** indicate to the rail signaling traffic generator to start the test, either daily or every time a demo 5G network connectivity comes up.	H	Check that the Rail Signaling traffic over IxChariot starts every time a 5G cellular connectivity comes up, or daily when the train is powered up.

Table 3-15 UC # 1.3 Rail Critical Services – CCTV Requirements and KPIs

Req ID [U/F-TYPE-RQ#]	**Description** [Descriptive text]	**Priority** [H/M/L]	**KPIs and Parameters** [to be measured]
U-FU-3141	A real onboard CCTV camera is good from a demonstration point of view, being able to show real pictures from the train on an application in the office. A first CCTV camera **shall** be put in the driver's cab, pointing forward, looking towards track and signals, mounted just inside the window in a black box with sunshield.	H	Check that a first CCTV camera is mounted in the driver's cab, pointing forward towards the track, and that the pictures look nice.
U-FU-3142	A real onboard CCTV camera is good from a demonstration point of view, being able to show real pictures from the train on an application in the office. A second CCTV camera **shall** be put in the driver's cab, looking towards the dashboard, showing train instruments like train speed, mounted close to the back wall and ceiling.	M	Check that a second CCTV camera is mounted in the driver's cab, pointing towards the dashboard, and that the pictures look nice.
U-FU-3143	The CCTV pictures that are shown on a monitoring software in the office **shall** run on a PC in the office. This PC could be the same as used for the Dispatcher Terminal, supplied by Kontron.	M	Check that an Axis monitoring software has been installed on an office computer.
U-FU-3144	The CCTV pictures **shall** use a monitoring software in the office for showing moving pictures from the train (when 5G connectivity is available). The train monitoring software could be either Axis Companion (which is a consumer software), or the more professional Axis Camera Station (ACS), needing a license.	M	Check that the Axis monitoring software delivers moving CCTV pictures when there is a 5G connection between office and onboard. Measure bitrate etc.

Table 3-16 UC # 1.3 Rail Critical Services – Voice and emergency calls Requirements and KPIs

Req ID [U/F-TYPE-RQ#]	**Description** [Descriptive text]	**Priority** [H/M/L]	**KPIs and Parameters** [to be measured]
U-FU-3161	On-train voice communication (bi-directional critical voice with PTT) between driver and responsible controller, initiated by driver or controller.	H	Low latency, Low bandwidth, High reliability, Normal setup, High speed *see Section 3 for details on KPIs/parameters

U-FU-3162	Railway emergency alert, voice and/or data (bi-directional critical voice/data) triggered by authorised users aware of a hazard, triggered within an automatically configured area or group, which is based upon originator's location, send to those users likely to be affected by the emergency.	H	Low latency, Low bandwidth, High reliability, Immediate setup, High speed
U-FU-3164	QoS class negotiation and efficient 5G resource management and arbitration in order to fulfill the level of communication quality required by different contending application categories within rail vertical service instance (VSI) and/or between multiple VNIs/NSIs, i.e. the critical (essential for safety), performance (improving railway operation such as train departure) and the business application category (supporting railway business operation such as passenger internet).	H	Critical category: Low latency Low/high bandwidth High reliability Immediate/Normal setup High speed Performance category: Low/normal latency Low/high bandwidth Normal reliability Normal setup High speed Business category: Normal/high latency Low/high bandwidth Best effort reliability Best effort setup High speed
U-FU-3165	Seamless transition between various 5G networks* without interruption in rail critical services and application usage. (*if infrastructure available).	M	Check continuity of rail critical services during transition of FRMCS network.
U-FU-3166	Critical data application (such as ATC, ATO, DSD, location services, critical advisory i.e. speed restrictions, overriding of stop point etc.) using reliable communication bearer (bi-directional critical data) in order to ensure efficient data transfer between on-board system and ground system.	H	Low latency, Low bandwidth, High reliability, Immediate setup, High speed
U-FU-3167	Monitoring and controlling of critical infrastructure such as vehicle sensors and alarms using data communication (bi-directional critical data) between infrastructure systems and ground or train based system.	M	Low latency, Low bandwidth, High reliability, Normal setup, Normal speed
U-FU-3168	Performance data application (such as train departure information, non-critical driver advisory) using data communication bearer (bi-directional data) in order to exchange test and/or voice messages or data files (images).	M	Normal latency, Low bandwidth, Normal reliability, Normal setup, High speed
U-FU-3169	Business data application (such as wireless internet and media services for passengers, passenger information) using data communication bearer (bi-directional data) in order to exchange test and/or voice messages or data files (images).	M	Normal latency, Low bandwidth, Normal reliability, Normal setup, Low speed

Table 3-17 UC # 1.3 Rail Critical Services – Point machine Requirements and KPIs

Req ID [U/F-TYPE-RQ#]	**Description** [Descriptive text]	**Priority** [H/M/L]	**KPIs and Parameters** [to be measured]
U-FU-3181	The signal from a real interlocking has to be copied in a way that does not interfere with existing admissions of the signaling system. For this a certified network test access point (TAP) shall be applied to the wired communication channel of the interlocking.	H	Check that the relevant signaling data is copied by the TAP.
U-FU-3182	The data stream copied by the TAP will contain lots of data that is not important for the Signal/Point Machine of 5G-VICTORI. A fake endpoint controller shall be implemented, which takes the raw data from the TAP, processes it and then transmits it to the 5G-VICTORI network. The endpoint shall also be capable of monitoring relevant data to measure other KPIs.	H	Check that the endpoint sends correct data to the 5G-VICTORI network. Check that KPIs are monitored.
U-FU-3183	The communication has to be passed from the fake endpoint controller near the interlocking system to the trackside fake object controller. The endpoint and the object controller shall use the 5G-VICTORI demo network for communication. In case of lost connectivity, the system shall log and report.	H	Check that communication can be passed from endpoint to object controller. Check that lost connectivity gets handled.
U-FU-3184	For controlling the signal and the point machine a fake object controller is required, which takes data from the 5G-VICTORI network and triggers the signal model or the point machine model. The device shall be able to communicate with the endpoint via the 5G demo network and trigger the signal/point machine accordingly. The device shall also be able to monitor relevant data to measure the KPIs for the 5G network.	H	Check that communication is processed by the object controller.
U-FU-3185	For demonstration of the correct function of the Rail Critical Service a Signal Model shall be implemented, which controls a small model signal according to the trigger sent by the controller.	M	Check that the signal model behaves as triggered by the controller.
U-FU-3186	For demonstration of the correct function of the Rail Critical Service a Point Machine Model shall be implemented, which controls a small model signal according to the trigger sent by the controller.	M	Check that the point machine behaves as triggered by the controller.
U-FU-3187	To provide evidence of the fulfilment of the KPIs a monitoring system for the communication is required, which also analyses the timings and other required indicators. A system for monitoring these shall be implemented.	H	Check that the monitored data is sufficient to check the KPIs.

3.3.4 UC # 1.3 Network Performance Requirements and KPIs

Table 3-18 UC # 1.3 Network Characteristics Requirements and KPIs

Req ID [U/F-TYPE-RQ#]	**Description** [Descriptive text]	**Priority** [H/M/L]	**KPIs and Parameters** [to be measured]
F-PE-3201	The Rail Critical Services and other on-board vertical services, using the same 5G air-interface frequency spectrum band 3.8 GHz and the same 5G CPE gateway, **shall** show good performance isolation between the different vertical services, using slicing and QoS.	H	Check isolation between different vertical services using the same 5G air-interface spectrum band.
F-PE-3202	The onboard 5G Customer Premises Equipment (CPE) modem **shall** supports doppler up to at least a train speed of 100 km/h. The reason is to make the 5G connectivity periods longer than what a non-doppler capable modem offers (5G connectivity only when the train stands still).	M	Check that the onboard CPE can connect to the 5G cellular network at a train speed of at least 100 km/h and convey data between onboard and office.
F-PE-3203	The Rail Signaling traffic that are used for the 5G demo purposes onboard the train **shall** have access to a 5G cellular network bitrate between the train and office of around 200 kbps.	M	Check that rail traffic signaling can use a bitrate of around 200 kbps over the 5G cellular network.
F-PE-3241	The HD CCTV cameras that are used for the 5G demo purposes onboard the train **shall** each have access to a 5G cellular network bitrate between the train and office of around 5 Mbps, i.e. 10 Mbps for two HD CCTV cameras.	M	Check that each onboard HD CCTV camera can use around 5 Mbps over the 5G cellular network.

3.3.5 UC # 1.3 Functional Requirements and KPIs

Table 3-19 UC # 1.3 Network Functional Requirements and KPIs

Req ID [U/F-TYPE-RQ#]	**Description** [Descriptive text]	**Priority** [H/M/L]	**KPIs and Parameters** [to be measured]
F-FU-3301	The Rail Critical Services and the other onboard vertical services that **shall** use the same 5G air-interface frequency spectrum band, e.g. the 3.8 GHz band. The reason is to comply with the purpose of the 5G-VICTORI project, i.e. to show isolation between vertical services using the same 5G network resources, being separated with network slices and QoS.	M	Check that all onboard Rail Critical services use the same 5G air-interface spectrum band (else the 5G-VICTORI project becomes useless).
F-FU-3302	It is assumed that the demo 5G cellular systems **shall** look like this: • 2 RRHs are put at the demo train station. • Each RRH with a directive antenna towards train. • Onboard demo active when train travels eastwards.	M	Check that the test scenario with the 5G radio heads at train station looks decent.

	• Train onboard 5G CPE modem in front of the train. • Distance between RRH at least 250 m. • At approach: train connects to RRH1, then RRH2. • Train approach coverage distance: at least 500 m. • Train stop with short LOS to RRH2.		
F-FU-3303	The onboard 5G demo equipment, or other equipment, **shall** indicate when the train has been powered up, a useful indicator for starting the daily demo 5G test.	M	Check that the rail signaling, and CCTV applications comes up and run after train power up.
F-FU-3304	The onboard 5G CPE modem, or other equipment, **shall** indicate when the 5G connectivity is up and running, a useful indicator for starting 5G sessions.	M	Check that the rail signaling, and CCTV applications comes up and convey traffic between onboard and office when there is 5G connectivity.
F-FU-3305	The onboard 5G demo equipment, or other equipment, **shall** indicate when the 5G connectivity is done for the day and the train is about to be powered down, a useful indicator for finishing the tests and uploading logs with KPIs for the day, over a 4G network.	M	Check that rail signaling and CCTV logs and KPIs are kept and preferably uploaded to office before train powers down each day.
F-FU-3341	The CCTV cameras are powered over Ethernet. The 5G demo equipment on the train **shall** support a PoE Ethernet Switch with cabling to the cameras, mounted in the driver's cab.	M	Check that the PoE switch works fine, powering the CCTV cameras.

3.4 UC # 2 – Digitization of Power Plants (Vertical: Smart Factory)

The goal of this UC is to demonstrate how different types of applications included in the concept of Smart Factory can be efficiently supported by the services provided by an underlying 5G ICT infrastructure. In the concept of Smart Factory, data from various sources (sensors, processed or historical data, etc.) are combined through a smart communication network to provide faster and more reliable monitoring of the system. The data provided can be fed to automated controllers and actuators, and lead to faster decision-making and action taking. Actions in a smart factory can be classified into three broad classes namely maintenance, security and operation.

From a network requirement point of view, the Smart Factory vertical can be split in different services or applications, presenting different requirements. 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. This UC will showcase how 5G technology can integrate and deliver services able to support these diverse applications simultaneously. More specifically, two 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 and eMBB applications for real time monitoring, security and automation in an industrial environment.

Within these scenarios, applications with different and strict KPIs will be demonstrated, such as latency, reliability, throughput, etc.). The trial will take place at the facilities of **ADMIE** in Rio and Antirio, where mmWave technology will be used for the connection of the two sites and the 5G-VINNI facility in Patras. The different services will be supported via different network slices, orchestrated by the 5G-VINNI platform. **ADMIE** facilities in Rio and Antirio are ideal for demonstrating various key aspects of 5G technology. Rio and Antirio sites are separated by sea and electrically connected via a submarine cable.

The protection and control of the overall system is achieved through continuous measurement and assessment of critical quantities such as temperature, pressure, voltage, current, speed, etc. These quantities are measured by high cost, energy inefficient, hard wired, legacy sensors in real time. The system produces thousands of measurements every minute, but only at local level, and provides information through indication leds. A unified monitoring system, able to process data from both sites and generate alerts or auto trip signals in case of major problems, will lead to great improvement in quality and cost / time reduction of maintenance activities. The objective of this UC is the monitoring and control of the facilities at both sites, including the submarine cable from a remote location in ADMIE premises. The underlying 5G ICT infrastructure should be able to meet the different requirements imposed by the different type of services.

3.4.1 UC # 2 Applications

App 1: Preventive maintenance

For the first scenario of this UC, a smart network of energy efficient sensors and the corresponding management system, able to support preventive maintenance techniques, will be demonstrated. Currently, inspection of equipment, buildings, etc., is performed by personnel and a set of legacy sensors providing limited information at local level. To achieve real-time / remote monitoring and inspection of the equipment, a great number of sensors and the underlying network architecture will be deployed.

Due to the enormous number of sensors that need to be used to cover every inch of the facilities and the difficulty to access many remote locations, low-cost and low-power devices must be used without strict latency requirements. This concept is directly related to the massive IoT (mMTC) concept, where small and infrequent data packets are transmitted from numerous standalone devices. The network technology providing connectivity to such devices must satisfy these requirements and support high capacity. In this context, Low-Power-Wide-Area Networks (LP-WANs), like NB-IoTs and Low Power

Wide Area Network (LoRaWAN), will be used for the establishment of multiple links from the sensing devices. In addition to this, preventive maintenance applications requiring high frequency timestamped sampling will be also considered. This includes power quality estimation through the identification of harmonic distortions, voltage sags, imbalances, etc.

To support the concept of preventive maintenance, data must be collected, monitored and processed in an efficient way. 5G NR will be used for the transmission of the collected data to the 5G-VINNI infrastructure, where a data management platform will be responsible for correlation and analysis of the collected time-stamped information. The platform will support a variety of services to facilitate optimal decision-making and preventive maintenance strategies. Real-time and historical data will be used to estimate the health of several critical components of the system and schedule maintenance activities.

App 2: Monitoring of critical infrastructures

The second scenario considers the development of a monitoring solution able to meet the real-time requirements imposed by the nature of application that must be supported (security / safety / operation). The transmission system is scattered in a very extended area of land, often difficult to reach and secure. ADMIE facilities have been the victim of copper cable theft and vandalism for several years.

An advanced security system consisting of a set of FHD cameras and motion control sensors will be deployed in the facilities. The deployed equipment should be able to stream high-quality data to be used complementary to the sensors generated data. An application will process the generated data, recognise un-authorised access to facilities and trigger corresponding alarms. In the same context, other type of safety critical sensors (temperature, oil pressure, etc.) will be employed at key locations of the facilities to ensure the safety of personnel and equipment.

Security- and safety-oriented applications are time critical services, as the delay between the incident and the reception of the relevant notification should be minimum. As such E2E latency should be a very important KPI to be measured. It should be highlighted that, from the application perspective, E2E latency should be measured from the moment that the incident occurs until the alarm triggering, including the time for data transmission, processing and actuation.

As a power transmission operator, **ADMIE** is responsible for the reliable and cost-effective transmission of electrical energy from a generating site to the distribution network. For efficient control of the network, improved monitoring is required. Legacy monitoring devices provide limited information regarding the system state and only at a local level. In this UC, data regarding the health status of the submarine cable, received from sensors at the Antirio side, are not known to the operator of the Rio site in real time. With no full view of the cable health status, the operator is not capable to identify faults in real time or perform optimal control techniques on the grid.

With the proposed solution, data from both sides will be gathered and correlated in real-time, giving the operator, or a future automated controller, the full view of operational status. Legacy sensors, providing alarm type information (e.g. maximum oil pressure indication, main power supply malfunction), will be enhanced with new type of sensors (humidity, temperature, etc.), and act as a unified information system.

The nature of electricity dictates strict latency and reliability requirements for the operational status. In order to meet the strict latency requirements, collection and processing of operational data might not be performed at the 5G-VINNI infrastructure but at an edge DC on site.

It should be highlighted that both scenarios must be supported simultaneously by the developed ICT infrastructure and this is yet a characteristic that must considered. Finally, yet importantly, since electrical grid is always a strong candidate for cyber-attack, information security is a strong KPI applying to all different scenarios.

3.4.2 UC # 2 Key UC Requirements and KPIs Addressed

The service performance requirements for the main communication services categories foreseen in the forthcoming smart factory/ digital utilities and 5G landscape are summarised in Table 3-20.

Table 3-20 UC # 2 Key UCs requirements and KPIs

Vertical: Smart Factory			UC # 2 – Digitization of Power Plants		
			Monitoring & Alerting Services (URLLC)	Maintenance Services (mMTC)	CCTV(as eMBB type of service)
UC Requirement - KPI		Units			
1	Latency (min. between user service end-points)	ms	10 ms	Not Critical	100-150 ms
2	User Datarate (Max.)	Mbps	0.1 Mbps (per device)	1-100 kbps (per sensor)	10-15 Mbps (Uplink, per HD/4k camera)
3	Reliability (%) - Min/MAX	%	> 99.9999999% (SIL 7)	>99%	99.9999 % (SIL 4)
4	Availability (%) - Min/MAX	%	> 99.9999999% (SIL 7)	>99%	99.9999 % (SIL 4)
5	Mobility	km/h	0 km/h	0 km/h	0 km/h
6	Traffic Density (Traffic demand per specific area)	Mbps/ area surface	Low, not critical 1000 Mbps/ 2000 m^2	Low, not critical 1000 Mbps/ 2000 m^2	20-100 Mbps / 2000 m^2
7	Device Density (#Devices per specific area)	Devices/ area surface	Low, not critical 100 Dev over 2000 m^2	100 Dev over 2000 m^2	Low, not critical 20 cameras/ 2000 m^2
8	Location Accuracy	m	non critical because the deployment is static thus the sensors' location is already known	non critical because the deployment is static thus the sensors' location is already known	non critical because the deployment is static thus the sensors' location is already known
Additional Requirements					
9	Packet Loss Ratio	Num	10^{-9}	10^{-6}	0.005
10	Bit Error Rate		Mission critical		Mission critical
11	Security (Y/N) ("Carrier Grade")	Y/N	Y	Y	Y
12	Type of Device		IoT devices/ Cameras/ Gateways	IoT devices/ Gateways	CCTV Cameras (possibly FHD/4K)
13	Type of Connection (i.e. Ethernet, WLAN, Zigbee)		5G/NB-IoT/Wi-Fi	5G/NB-IoT/Wi-Fi	5G/Wi-Fi
14	Battery Lifetime		Non Critical	up to 10 years	Non Critical
15	User Datarate (Max.)	Mbps/ samplin g point	Non Critical	2-10 Mbps	Non Critical

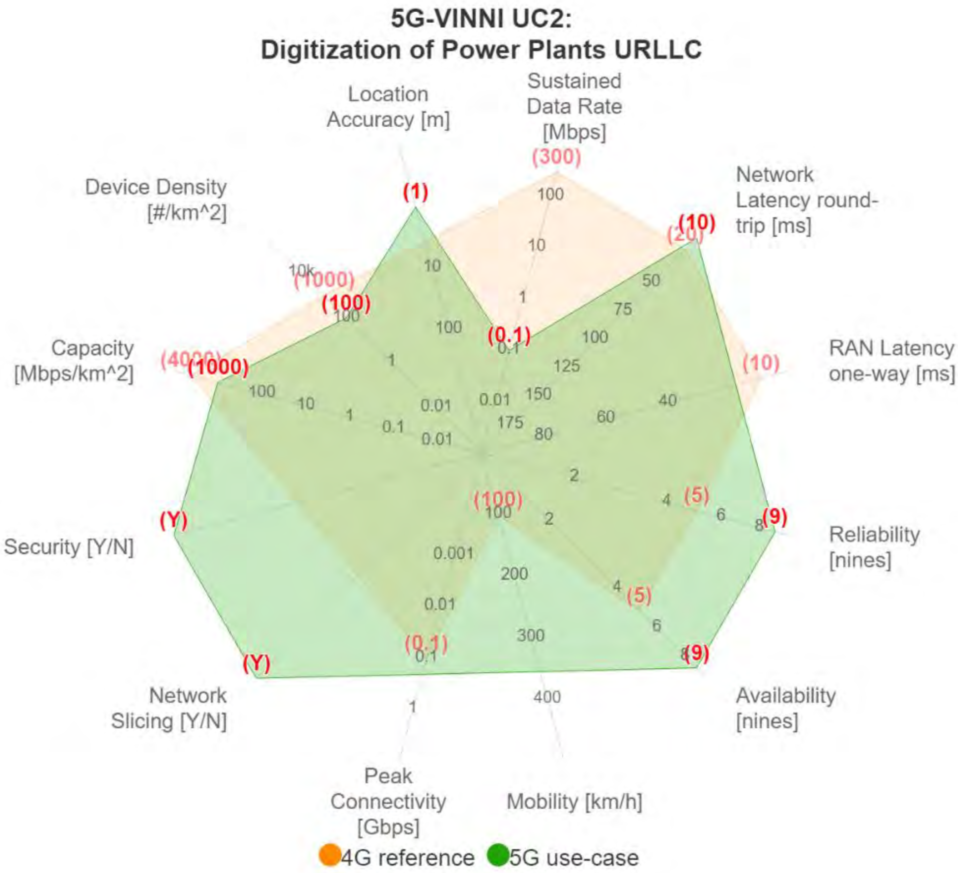


Figure 3-14 UC # 2 Digitization of Power Plants URLLC

Figure 3-14, Figure 3-15 and Figure 3-16 show the spider diagram accounting on the KPIs to be fullfilled. As already mentioned, note that these reflect the vertical (ADMIE/ digital utilities – energy) requirements considering not only the current (restricted to SW and network capabilities) services but the foreseen future ones, thus not all of them are subject to demonstration. Further refinement of these KPIs will be provided in the context of WP3, with the explicit definition of the applications to be demonstrated.

As initial estimation, for the demonstration of UC # 2, cameras (2 Full HD /4K cameras) will be considered for the Rio-Antirio facility premises, and 50 sensors of different types (motion control, humidity, temperature etc.) will be spread in the ADMIE facility of 2000 m^2. For KPI measurement purposes sensors will be distributed across the facility in different density configurations.

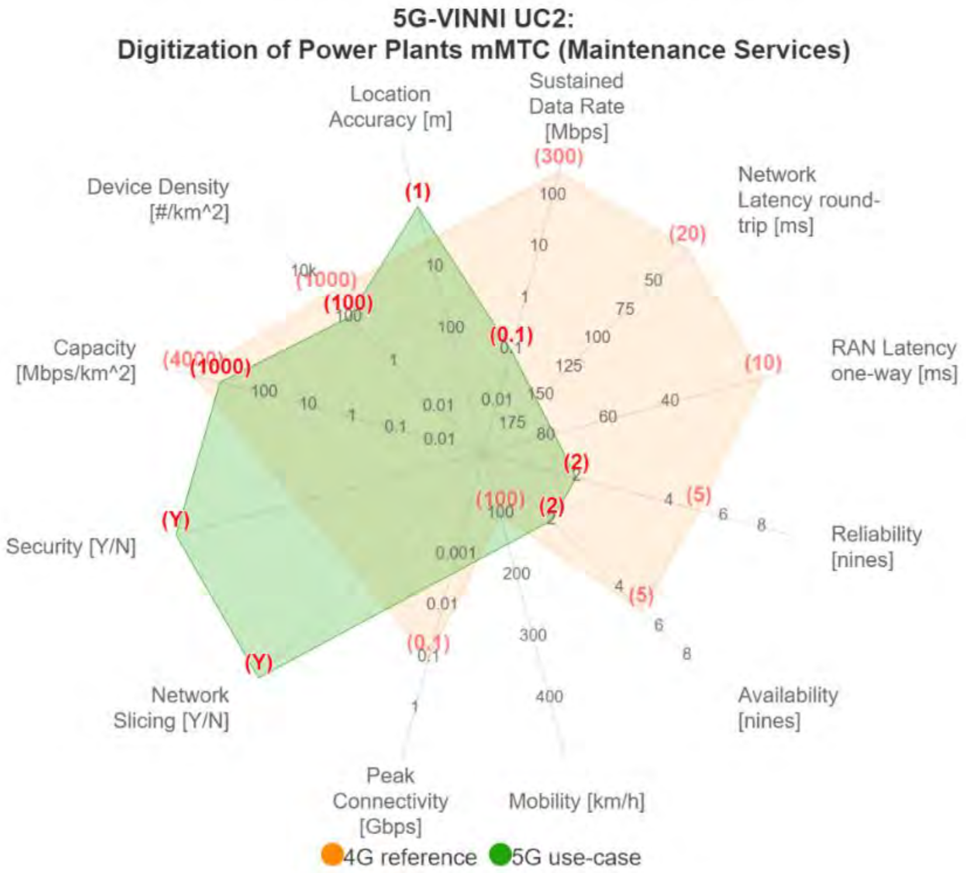


Figure 3-15 UC # 2 Digitization of Power Plants mMTC

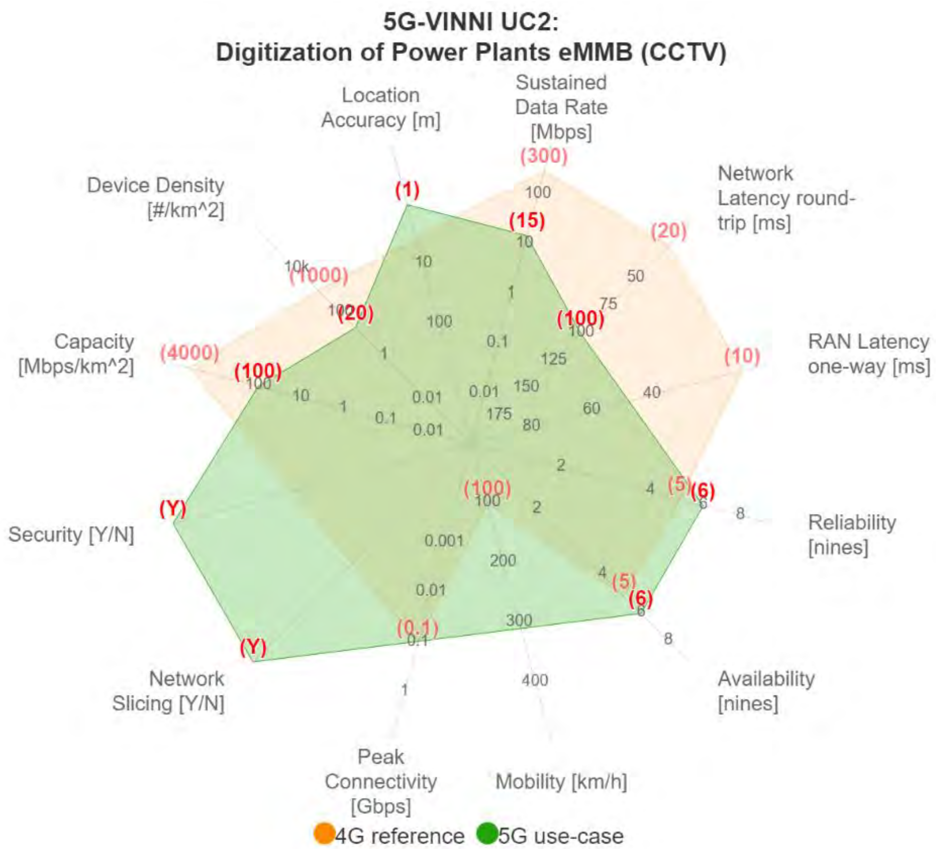


Figure 3-16 UC # 2 Digitization of Power Plants eMBB

3.4.3 UC # 2 Network Performance Requirements and KPIs

Table 3-21 UC # 2 network performance requirements and KPIs

Req.ID [U/F-Type-RQ#]	Description [Descriptive text]	Priority [H/M/L]	KPIs and Parameters [to be measured]
U-CA-5201	**High Connection Density** High Connection Density needs to be supported without compromise on the perceived QoS (Latency/Throughput). The targeted density depends on the scenario. It shall be noted that the aforementioned connection density is the expected one in the near future.	H	• Number of devices to be supported from a single access node • Number of devices to be supported from the 5G core NFs
U-CA-5202	High Traffic Density is expected assuming the aggregate traffic of ADMIE smart factory services reaching up to 1 Gbps over an area of 2000 m^2. It shall be noted that the aforementioned connection density is the expected one in the near future.	H	• Total capacity offered (by a number of access network nodes) over a specific area
S- OTH-5203	**Scalability** The network solution shall be scalable in terms of having the capability to accommodate connections in the order of 100 devices	H	• The solution shall be scalable so as to be able to accommodate (100) connections over the ADMIE facility.

3.4.4 UC # 2 Functional Requirements and KPIs

Table 3-22 UC # 2 network functional requirements and KPIs

Req.ID [U/F-Type-RQ#]	Description [Descriptive text]	Priority [H/M/L]	KPIs and Parameters [to be measured]
S-FU-5301	**Air Interface – Access Network** Towards delivering the required network coverage for the specific devices, it is needed to design and develop antennas operating at 5G/ Wi-Fi & NB-IoT frequency bands.	H	• Antenna operation at 5G, Wi-Fi and/or NB-IoT support.
S-FU-5302	**Distributed Pools of (Compute/Network) Resources** Towards achieving the stringent QoS targets as well as efficient resource utilisation, it is necessary to enable instantiation of network, compute and storage resources optimally selected from a common resource pool that is physically distributed. This requires that the deployment is based on distributed (at different geographical locations, e.g. in the notion of edge computing) pools of resources (i.e. DCs) where the allocation is based on specific QoS and resources requirements.	H	• Capability for instantiation of network and compute resources for a specific service over geographically distributed pools of resources. It shall be possible to use various Edge and Core DCs to host different parts of the Power Plants Monitoring and Preventive Maintenance Applications. • Monitoring of distributed resources pools from a common platform.
S-FU-5303	**Multi-Tenancy** The 5G facility needs to support simultaneously multiple tenants and multiple services, with various QoS, requirements, etc., over a single infrastructure. Since it can be possible that different departments make use and have access rights to different monitoring and maintenance applications/ information over the same ADMIE facility (e.g. one department can control the CCTV cameras, and another one can be in charge of monitoring the cable status), it shall be possible from the 5G facility to allow the creation of multiple tenants for this scenario.	H	• Delivery of services with the requested QoS to multiple tenants over a single network deployment.

S-FU-5304	**Slicing** Towards supporting multi-tenancy over the 5G facility, slicing is required in order to preserve security and isolation between tenants, and to maintain the QoS guarantees.	H	• On-demand instantiation/ deletion/ configuration of an E2E network slice and delivery of services over it. • QoS guarantees (e.g. latency, bandwidth, etc.) of a slice shall be met.
S-FU-5305	**Converged Optical – Wireless transport** Due to space constraints at the Energy utilities facilities, there are (sub)locations where wireless technologies are the only solution for last mile transport or access network, whereas there are others where optical network connectivity at last mile transport network is mandatory.	H	• KPI: Converged Optical-Wireless transport is available with high performance characteristics
S-FU-5306	**Synchronisation** Synchronisation is required across heterogeneous access (based on different wireless technologies.) networks. Therefore, existing synchronisation protocols based on packet round trip time measurements are inefficient (e.g IEEE TSN).	H	• KPI: Synchronisation is performed across two heterogeneous networks and two different sites.
S-FU-5307	**On Demand deployment of network services** There is a stringent requirement for instantiation and deployment of network services at specific areas of the facility on demand, specifically deployment of CCTV cameras on demand in case of alarm/fault detection.	H	• KPI: Show on demand eMBB service deployment
S-FU-5308	**Management & Orchestration of Distributed Pools of Resources** Towards delivering a solution capable to support efficient utilisation of network and compute resources through dynamic, flexible, on-demand instantiation of them, while meeting the 5G services stringent QoS requirements, it is necessary to have a flexible overacting management and orchestration platform, spanning across all distributed pools of resources. This platform shall be able to: • monitor and manage the physical and virtual resources (i.e. compute and network components) of distributed pools/DCs, and • perform the orchestration of VNFs, and support and perform the logic towards the optimal instantiation of resources for each tenant / slice / service.	H	• Monitoring of Network and Compute resources in terms of utilisation/availability/planned reservations. • Management, automated allocation of resources upon request taking into account optimisation of resource utilisation and required QoS. • Instantiation of VNFs.

3.5 UC # 3 – CDN services in dense, static and mobile environments (Vertical: Media)

Watching video is a common pastime among rail travellers, especially in long journeys. Like other rail-service providers across Europe do, Deutsche Bahn (**DBN**) offers free Internet access via on-board Wi-Fi networks on their long-distance services. However, this Internet access is only suitable for video streaming to a very limited extent. As the Internet connection via the Wi-Fi access point relies on mobile broadband connection, users experience service discontinuity when the train passes remote areas with limited network coverage.

In cooperation with the video-on-demand (VoD) provider Maxdome, DBN offers a VoD catalogue to their passengers through a DBN-branded portal application, which is accessible via the on-board Wi-Fi. The content is hosted on a storage device on the train, which is manually replaced on a regular basis. This approach has two disadvantages. First, it is not suitable for content that is only of interest to viewers for a short period of time and that should also be available shortly after publication, such as programmes related to current events, for example the news. Second, the distribution via a third-party platform requires separate licensing agreements for the content. Beyond that, delivery of Live-event coverage is not possible.

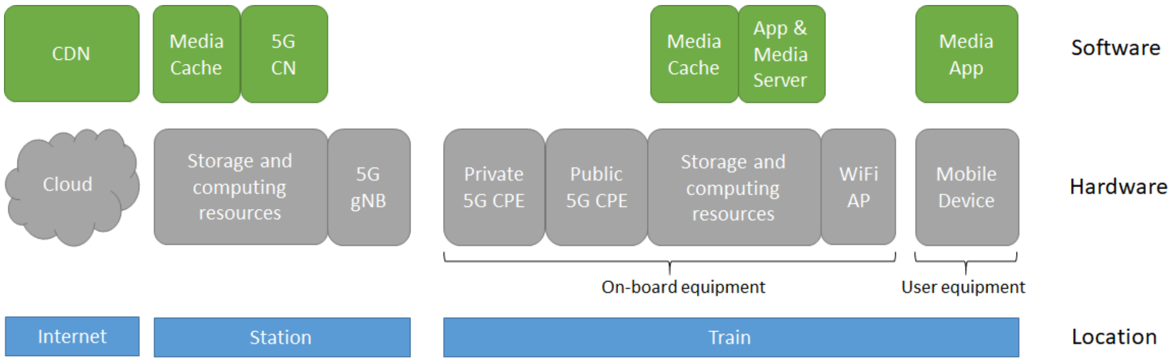


Figure 3-17 High-level architecture of the media-delivery platform 5G-VICTORI will develop and test on the Berlin Cluster

In 5G-VICTORI we are developing a solution that integrates seamlessly into the CDN infrastructure of content providers. This has the advantage for the users that they can use the conventional apps of the content providers, which they potentially have already installed on their devices. For the content providers, it has the advantage that the distribution model does not deviate from the conventional one and that the licenses already granted are valid. Our development work focuses on two usage scenarios: the consumption of linear live content and the viewing of VoD content. VoD content will be preloaded via a 5G data shower to a content cache on the train which acts as an edge server of the content providers CDN. For live content we will develop a mechanism for seamless handover between private 5G networks, potentially installed in coverage gaps of provider networks, and public 5G.

Figure 3-17 shows a high-level architecture diagram of the technical infrastructure used to implement the above mentioned UC. For both scenarios it is assumed that viewers use their personal mobile devices (such as smartphones, tablets, laptops) to consume media streams. The personal devices are connected to the trains on-board Wi-Fi. The sub-sections below describe how the UCs make use of the individual components in the diagram.

3.5.1 UC # 3 Applications

App 1: Data shower

Data shower refers to a network connection that can only be established at a specific geographical location and over which a high data rate (> 1 Gbps) network connectivity can be provided. We use data showers in train stations to push media items, which are predicted to be relevant to the passengers to a media cache on the train. The data shower consists of a data source, data transmission system and the data sink. The data source is a media cache in the train station. The media cache in the station preloads the relevant media items from the content providers' CDN before the train enters the station. The purpose of the cache in the station is to compensate data-transmission bottlenecks in the CDN, which might prevent the data rate of the data shower from being exploited. The transmission system comprises the 5G Core Network (5G CN), a 5G base station (5G gNB) and a 5G modem (5G CPE). The 5G CN is running on computing resources in the train station which are located close to the 5G gNB. 5G CN and 5G gNB open up a private 5G network to which a dedicated 5G CPE in the train connects, when it enters the train station. On the radio level, 3.5 GHz or 60 GHz mmWave are used for transmission, depending on which band is able to provide superior service.

Once the media items are transmitted to the media cache on the train, they can be accessed by the passengers through a media application on their personal devices. The media application requests media items from the App & Media Server, which is hosted in the physical infrastructure on the train. When many users on the train stream videos at the same time, they compete for bandwidth that a common Wi-Fi access point can provide. During playback, this can lead to unwanted behaviour, such as playback discontinuities or fluctuations of the video quality, when streaming with adaptive bit rates, for example with streaming solutions like "Dynamic Adaptive Streaming over HTTP" (DASH). In their specification "Server and Network Assisted DASH" (SAND), the Moving Pictures Expert Group (MPEG) specified messages and exchange protocols to enhance streaming experience and network bandwidth utilisation in multi-user scenarios. By means of the "Shared Resource Allocation" feature within SAND, the App & Media Server manages the assignment of network bandwidth to clients (traffic shaping) such that the average QoS is maximised. Also, the App & Media Server can initiate transition of transmission via multicast QUIC in situations where this is more efficient, for example if many users connected to the same Wi-Fi Access Point (AP) watch the same stream (see Figure 3-18).

App 2: Smooth live streams on trains

With the data shower we can potentially upload all VoD content that all passengers will be interested in during their train rides. However, as we cannot look into the future, we cannot achieve this for live content. Moreover, mobile network coverage along the railway tracks is not reliable.

Our solution for delivery of live content to trains is based on two approaches:

- measurement and prediction of network coverage, and
- seamless handover between private and public 5G networks (see Figure 3-19).

With measurement systems in trains, network coverage can be measured along the rails. Since individual tracks are frequently used, the quality of the measurements can be improved. As trains always move along known routes, this information can be used to create predictive models of connection quality. The predictions can be used, for example, in the planning of private 5G infrastructure to estimate where supply gaps in public infrastructure need to be covered in order to guarantee the necessary QoS parameters. At the application level, the prediction model can be used to decide how much a media stream has to be delayed, potentially even depending on the booked itinerary of an individual viewer, so that a media stream can be played without interruption.

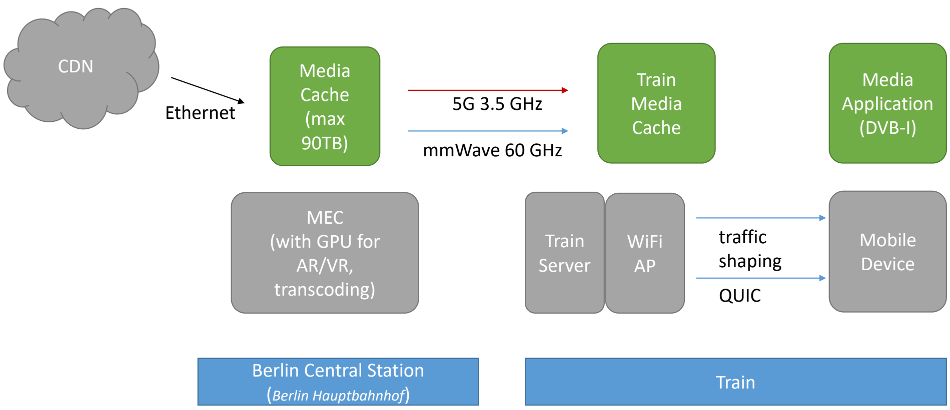


Figure 3-18 VoD Data Shower

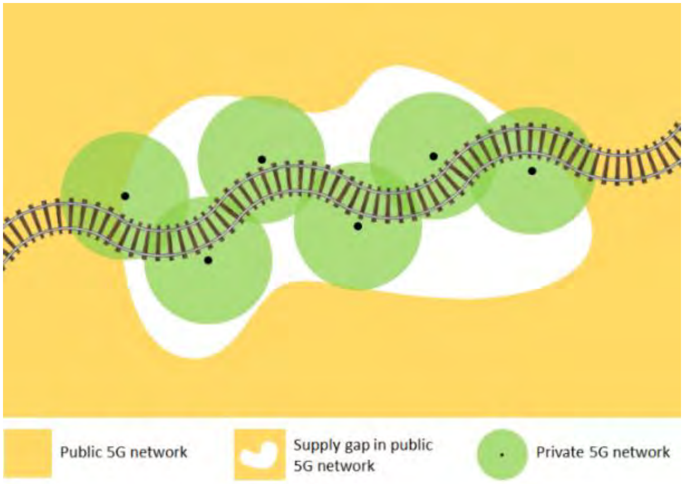


Figure 3-19 Coverage gap in a provider network which is filled by private 5G infrastructure along a railway line

For the live streaming the scenarios that are going to be demonstrated in 5G-VICTORI's Media UC are:

- The delivery of eMBB down-stream VoD or streaming TV services in a railway environment, with the content being distributed through an Edge on-board CDN server.
- The support of eMBB/URLLC up-stream of video from a 360º degree surveillance camera in the railway environment.

The **first scenario** of this UC (eMBB content down-stream) considers the delivery *of high quality on-demand video content* (e.g. from **ICOM**'s fs|CDN), similarly a streaming TV service on demand (e.g. COSMOTE TV content), where train transportation is involved. More specifically, the UC involves end users who board on a high-speed train and want to watch on-demand content on-board on their 4G user equipment (UE), due to the absence of 5G UEs at the moment. In such situation, high quality (e.g. 4K) content cannot be effectively delivered through the existing 4G networks due to the high bitrate requirements. Also the connection with the serving Points of Presence (PoPs) will weaken or even get lost at some points due the high speed of the train, and consequently the content's quality will not be able to be constantly preserved at high levels. In 5G-VICTORI we will leverage 5G technology at the transport network as well as the virtualisation concept introduced in 5G networks to deploy a vCDN solution to proactively bring the target content on-board, so as to achieve video continuity and high quality maintenance at all times of the subscriber's journey on the moving train over 5G.

The solution that will be showcased will be based on the 5G-VINNI existing infrastructure deployment, while allowing efficient dynamic reconfiguration of the communication network in terms of slice provisioning/activating towards achieving efficient utilization of resources, complemented by MEC infrastructure capabilities, and train station surveillance equipment. More specifically, the UC scenarios will be deployed on the infrastructure described in Section 3.6, meaning that the train station of Rio will participate in this UC and will be equipped with a 5G base station.

Based on this setup, a three-level hierarchical design vCDN solution will be realised. On top, there will be central CDN Cloud premises, mainly responsible for receiving and processing the content to be delivered. At the MEC level, appropriate Virtual Network Functions (VNFs) will be deployed and provide the necessary functionalities and elements to support the content delivery (storage and streaming) to end users. Also, an additional Edge server will be deployed on-board for serving the passengers even during disconnection periods, containing a subset of the MEC's vCDN functionalities and connected to the station's MEC server through a 5G modem. The overview of this scenario is illustrated in Figure 3-20.

The scenario of the content down-streaming will support video streaming service continuity in mobile scenarios with 5G network coverage through prefetching of large volumes of content for the disconnected operation of high quality (e.g. 4K) streaming services. The main idea is that the MEC server prefetches the most popular content locally at a high speed and quality using the 5G connectivity available at the station. Then, as a train enters the station, the prefetched content is pushed to the Edge server of the train. This happens for any train entering the station, resulting in multiple "data showers". When the end user enters the train she/he connects automatically through her/his mobile app to an on-train Wi-Fi, which is in turn connected to the on-board server. Therefore, the content starts being streamed from the on-board Edge server and presented on the user's device. This local caching of the content enables video continuity between train stations for the user, even at periods without 5G connectivity.

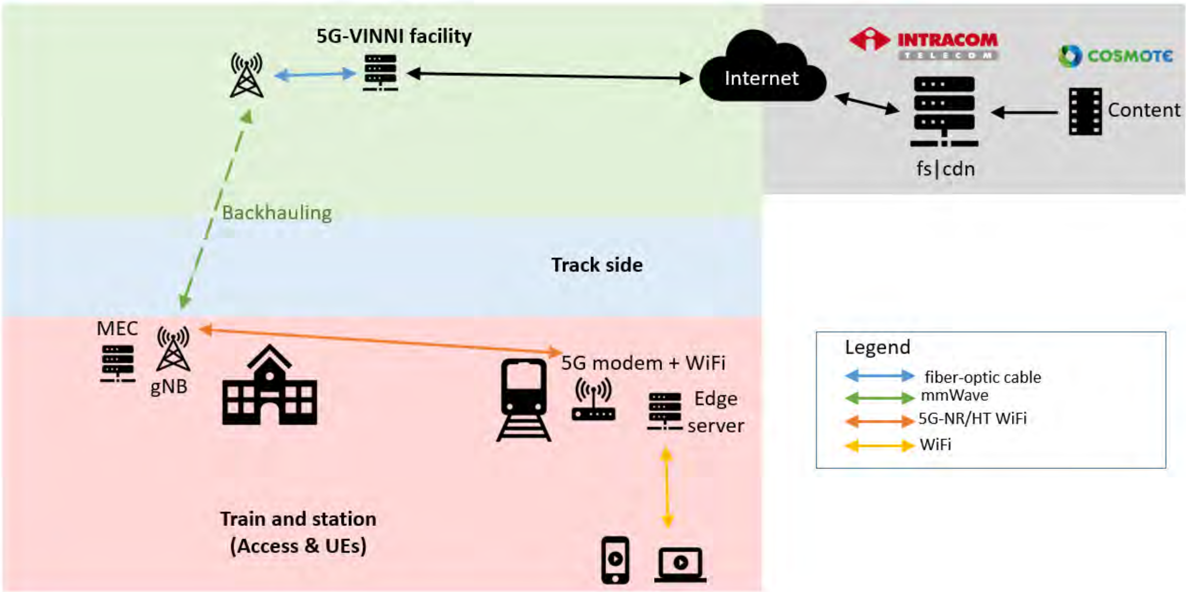


Figure 3-20 High level depiction of the UC # 3's first scenario

A possible future extension would be to assume that an end user is already watching specific on demand video content over 4G before arriving at the train station, and wants to continue viewing the same content on-board. As the user enters the train station, the MEC server at the station detects him through location-based features of the mobile CDN app and notifies the central CDN servers about him and the content that he is watching. Based on this, the MEC server is able to prefetch his on-demand content locally at a high speed and quality using 5G connectivity. Then, as trains enters the station, if an accurate positioning service is available on trains, the prefetched content and the user information are pushed to the Edge server of the specific train the user has boarded. The user is then able to watch his/her content, streamed from the on-board Edge server, by connecting to the on-train dedicated Wi-Fi. Finally, while the train is moving along the tracks, users' on demand content is periodically prefetched or updated in the on-board cache from each MEC station located along the route.

The **second scenario** of the UC emerges from the increasing need of various service operators coming from several vertical industries to monitor remotely the activity in more than one facilities that they operate. Selecting the railway vertical as the case examined in this UC, the security staff of a train operator, located at a remote operations centre, needs to monitor the train stations through VR/360º cameras deployed on site and control the field-of-view to receive the security footage in high-quality with ultra-low latency.

A similar setup to the previous scenario is envisioned for the case of the VR/360° 4K camera surveillance up-streaming system application, targeting both the eMBB and the uRLLC classes of services. A VR/360º 4K video camera will be installed at the train station of Rio, which remains equipped with a 5G base station, and also components of the distributed vCDN solution can be optionally used again as an inverted version of the previous scenario, in the sense that now high resolution video transmission will be uplink. The video streaming and optimisation processes will be supported at the MEC level or another option is to locally process and optimise the video streams and deliver them to the 5G network. The overview of the scenario is depicted in Figure 3-21:

The scenario workflow assumes, as a first step, that video streams from the 360º camera are optimised either locally or optionally at the MEC level, so that the current field-of-view is delivered through a 5G modem to the 5G network at high resolution (eMBB network slice) and the out-of-sight streams at a lower resolution – but adequate for unobstructed and fast changes of field-of-view (uRLLC network slice). Any changes in the field-of-view by the end user during head motion will be translated to quick adjustment of the active stream to one of the lower resolution ones until the new field-of-view is delivered at high resolution. At the receiving end, appropriate vCDN components can be used for the delivery of the video content.

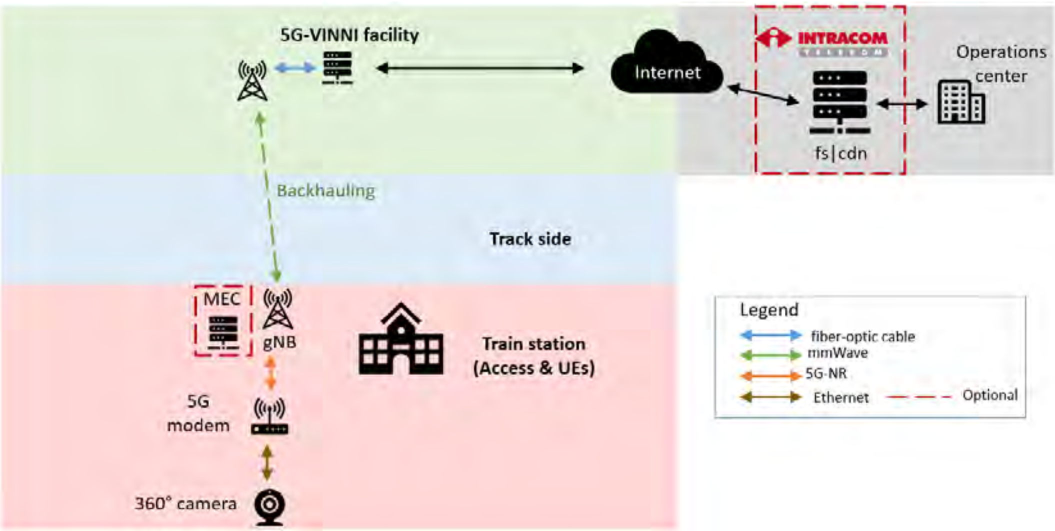


Figure 3-21 High level depiction of the UC # 3's second scenario

The scenarios of the UC impose a number of challenges to be faced, such as the provisioning of high data rates at high-speed mobility scenarios and the provisioning for eMBB content delivery to support high quality video (4K). Also, the efficient utilisation of network and caching resources is an issue that needs to be addressed.

The participation of various stakeholders is assumed for the realisation of the UC. Specifically, the following roles can be identified:

- A **railway operator** will provide the necessary railway infrastructure and trains where the service offered by the UC will be deployed. He will acquire network connectivity through a network operator as well as the CDN service through a service provider. Moreover, he will make the deployed service available to the end users.
- A **network operator** will provide connectivity to the railway operator's trains and will deploy the 5G components (base stations, MECs) that will support the UC. He will also provide virtual infrastructure slices of the deployed 5G network to the CDN service provider.
- A **content provider** will provide to the CDN service provider the VoD (or the on-demand streaming TV) content which will be transferred to the train and offered to the passengers.
- A **service provider** will lease virtual network infrastructure (network slices) from the network operator and will offer to the railway operator the CDN solution, which will deliver the VoD (or the on-demand streaming TV) content to the end users or the 360º camera security footage to a remote operations centre.
- The **end users**, i.e. the train passengers will participate in the first scenario of the UC by consuming the offered content streaming service.

3.5.2 UC # 3 Requirements and KPIs Addressed

The volume of assets in the ARD Mediathek is currently estimated, the calculation will be solidified later. The media library contains currently a pool of approx. 100,000 video clips. We assume an average clip length of 10 minutes. In the ARD-Web-L profile (960x540 pixels), which is available for all clips despite decentralised production, approx. 15 MByte is required per minute. Therefore, our calculation is 100.000 clips * 10 minutes * 15 MByte = 15 TByte. If we save complete HLS-ready sets, about 2.5 times the memory space is required, i.e. 37.5 TByte. When we assume that we store HLS sets including the ARD-Web-XL profile (HD720) we need about 4 times more, 60 TByte for the complete video pool. Each channel in the ARD network is uploading approximately 8 GByte of video to the pool daily. For the Web-

L profile this calculates to 63 GByte that would need to be transferred in a daily update of the cache or proxy server.

For the ARD range of radio programmes, the audio streams have a bitrate between 128 and 256 kbps, in summary 61 streams. This adds up to a maximum of 15.25 Mbps for the complete set of streams. As this consists of HLS and Icecast streaming options, we would need in the train a) an Icecast relay or b) an Icecast-to-HLS trans-multiplexing functionality. Also, RBB and Bayerischer Rundfunk (BR) are offering in summary 14 DAB-over-IP live streams (149 kbps each), which adds up to 1.9 Mbps bandwidth. As the currently mainly used DAB-over-IP client (HRADIO project) is supporting a time shift functionality, we would also need bidirectional network communication between client and DAB-over-IP server, having minimum latency.

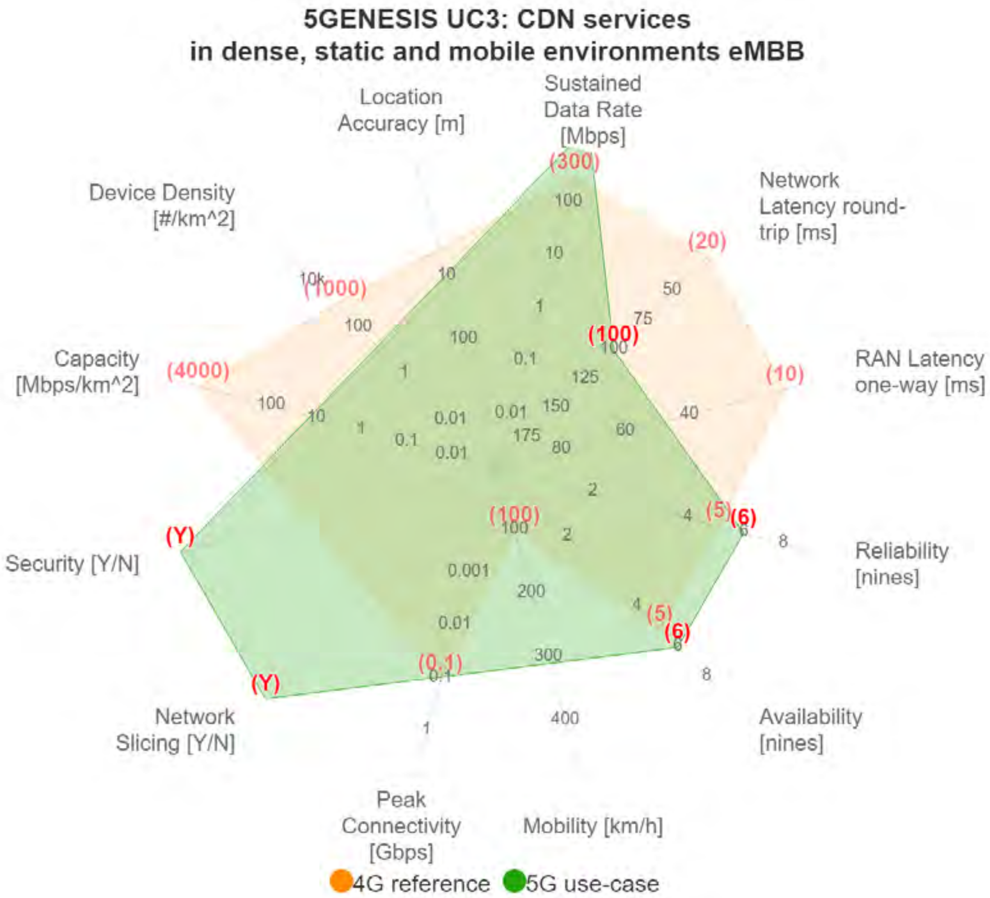


Figure 3-22 UC # 3 – VoD eMBB

IP-based TV live streams are also part of the offering and do count up to 18 programmes, having an average data rate of 3.5 Mbps each for the ARD-Web-XL profile only (here we would need to locally manipulate the M3U8 playlists). This adds up to 63 Mbps. If we would use the complete HLS set of profiles, we would need a maximum of 162 Mbps. In general, segments from any live stream should be loaded from the origin, not until a local demand is called.

The requirements for the main communication services categories foreseen in the forthcoming Media and 5G landscape are summarised in Table 3-23. Please note that these reflect the requirements considering not only the current (restricted to SW and network capabilities) services but the foreseen future ones, thus not all of them are subject to demonstration. Further refinement of these KPIs will be provided in the context of WP3, with the specification of the applications and the system to be demonstrated. Figure 3-23 and Figure 3-24 show the spider diagrams accounting on the KPIs presented in Table 3-24.

Table 3-23 UC # 3 specific requirements (eMBB)

5G-VICTORI UC # 3 specific requirements						
Cluster: Cluster *5G-VINNI* -ICT-17 *5G-VICTORI*						
Vertical: Media			UC # 3 – CDN Services in dense, static and mobile environments			
			URLLC	mMTC	eMBB	Assumptions
1	Latency (min. between user service end-points)	ms			10-20 ms	10-20 ms needed for 4K video streaming
2	User Datarate (Max.)	Mbps			500-700 Mbps	~15 GB of content must be transferred to the Edge server in the 3-4 mins of the train's stop in the station
3	Reliability (%) - Min/MAX	%			99.9999	
4	Availability (%) - Min/MAX	%			99.9999	
5	Mobility	km/h			50-150	
6	Traffic Density (Traffic demand per specific area)	Mbps/ area surface			1-1.4 Gbps	~15 GB of content must be transferred to the Edge server in the 3-4 mins of the train's stop in the station, and there can be 2 trains in each train station
7	Device Density (#Devices per specific area)	Device s/ area surface			2 Edge servers / train station	2 trains will be at the train station each moment, one to each direction
8	Location Accuracy	m			-	
Additional Requirements						
9	Packet Loss Ratio	Num			0.00005 - 0.0005	
10	Bit Error Rate				MC	
11	Security (Y/N) ("Carrier Grade")	Y/N			Y	
12	Type of Device				Edge CDN Server	
13	Type of Connection (i.e. Ethernet, WLAN, Zigbee)				5G (5G modem)	
14	Battery Lifetime				-	

Table 3-24 UC # 3 specific requirements (URLLC)

5G-VICTORI UC # 3 Specific Requirements						
Cluster: Cluster *5G-VINNI* -ICT-17 *5G-VICTORI*						
Vertical:Media			UC # 3 – CDN Services in dense, static and mobile environments			
			URLLC	mMTC	eMBB	Assumptions
1	Latency (min. between user service end-points)	ms	7-10 ms		10-20 ms	10-20 ms needed for 4K video streaming, and according to ITU-R M.2083, the spec for the latency KPI for uRLLC is ~ half of eMBB.
2	User Datarate (Max.)	Mbps	5-8 Mbps		15-50 Mbps	eMBB slice will transfer 4K video, uRLLC slice will transfer lower resolution (FHD) video
3	Reliability (%) - Min/MAX	%	99.9999		99.9999	
4	Availability (%) - in/MAX	%	99.9999		99.9999	
5	Mobility	km/h	0		0	
6	Traffic Density (Traffic demand per specific area)	Mbps/ area surface	5-8 Mbps		15-50 Mbps	The specific area will involve one 360° camera which will send FHD/4K video

7	Device Density (#Devices per specific area)	Devices/ area surface	1 camera/train station		1 camera/train station	360° camera max night vision ~ 33 ft (~10 m), so covers ~314 m^2. Assuming that the train station is ~200 m^2, 1 camera is needed.
8	Location Accuracy	m	-		-	
Additional Requirements						
9	Packet Loss Ratio	Num			< 0.00005	
10	Bit Error Rate				Mission critical	
11	Security (Y/N) ("Carrier Grade")	Y/N			Y	
12	Type of Device				VR/360° camera	
13	Type of Connection (i.e. Ethernet, WLAN, Zigbee)				5G (5G modem)	
14	Battery Lifetime				-	

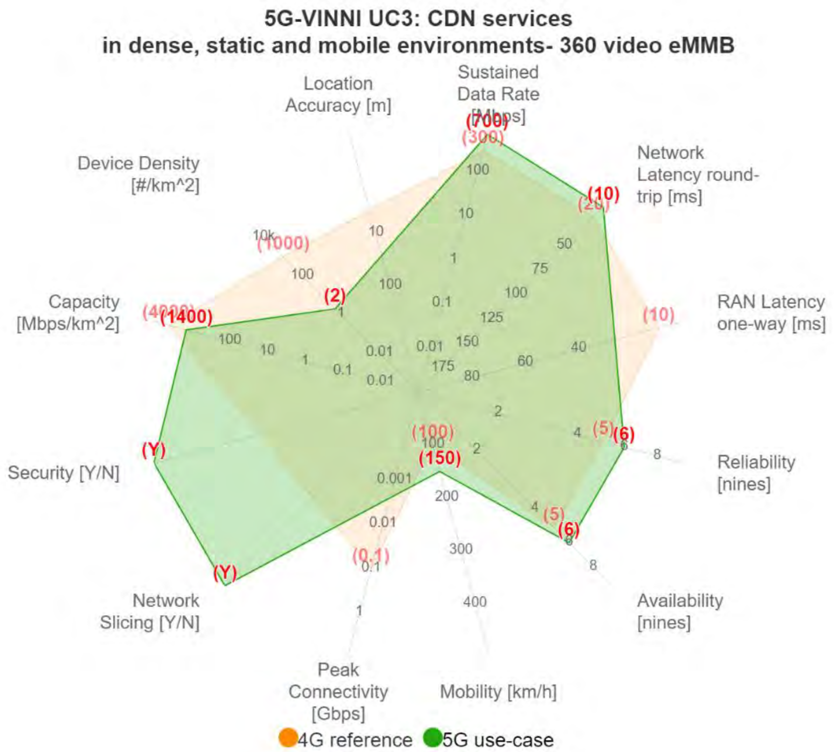


Figure 3-23 UC # 3 – 360º video eMBB

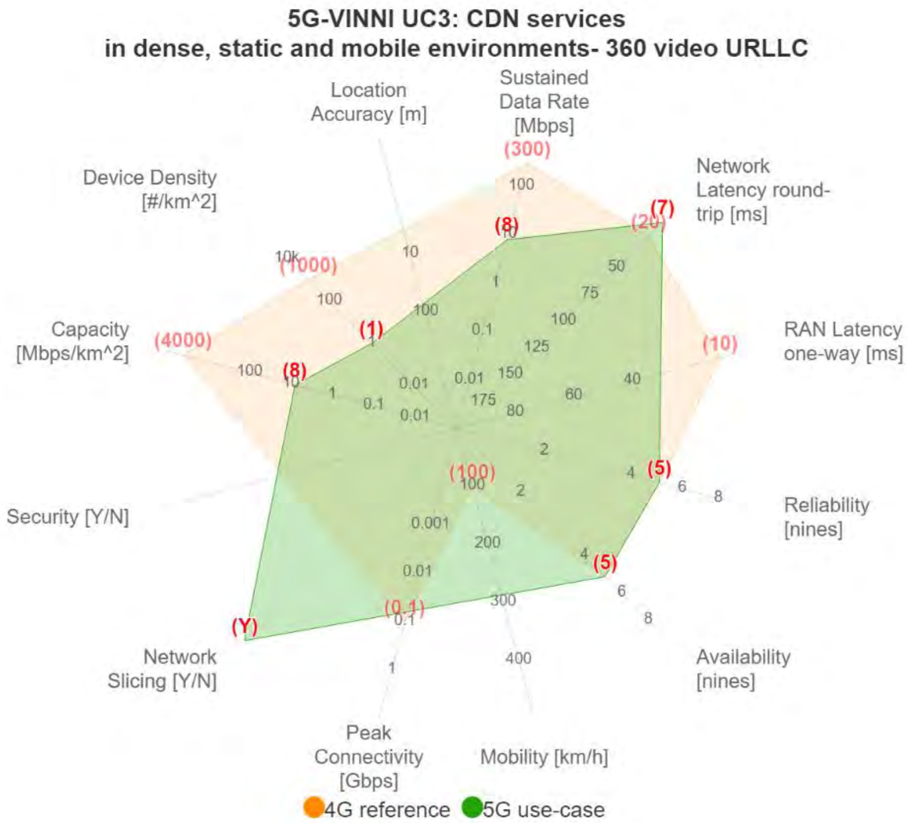


Figure 3-24 UC # 3 – 360º video URLLC

3.5.3 UC # 3 Network Performance Requirements and KPIs

Table 3-25 UC # 3 Berlin cluster network performance requirements and KPIs

Req ID [U/F-TYPE-RQ#]	**Description** [Descriptive text]	**Priority** [H/M/L]	**KPIs and Parameters** [to be measured]
U-PE-6201	The station's private 5G network, comprising of a 5G base station and a 5G core network should be able to support a ~1 Gbps downlink throughput for a single UE.	M	E2E data rate
U-PE-6202	The 5G UE used on the train for the connection to the private 5G network should also support a ~1 Gbps downlink throughput.	M	E2E data rate

Table 3-26 UC # 3 Patras cluster network performance requirements and KPIs

Req ID [U/F-TYPE-RQ#]	**Description** [Descriptive text]	**Priority** [H/M/L]	**KPIs and Parameters** [to be measured]
U-PE-6210	Very high data rates for proactive transfer of large volumes of high quality (e.g. 4K) VoD or TV streaming content from central CDN servers to local MEC host	High	(CDN-to-MEC) Data rate
U-PE-6211	Very high data rates for proactive transfer of prefetched high quality VoD or TV streaming content from MEC host to on-train Edge server	High	RAN data rate, transferred data volume
U-PE-6212	Uninterrupted streaming of high quality videos or TV streaming to train passengers	High	Wi-Fi data rate, Wi-Fi latency, Wi-Fi jitter
U-PE-6213	Very high data rates at low latency for high resolution video transmission from 360° camera to MEC host	High	RAN data rate, RAN latency, jitter
U-PE-6214	Very high data rates at low latency for high resolution video transmission from MEC host to the receiving control center	High	(MEC-to-ControlCenter) data rate, (MEC-to-ControlCenter) latency, (MEC-to-Control Center) jitter
U-PE-6215	Very low latency for lower resolution video streams transmission from 360° camera to MEC host	High	RAN latency
U-PE-6216	Very low latency for lower resolution video streams transmission from MEC host to the receiving control centre	High	(MEC-to-ControlCenter) latency, (MEC-to-ControlCenter) jitter
U-PE-6217	Low deployment time of CDN's VNFs is required for both scenarios	High	CDN VNFs deployment time
U-OTH-6218	Secure transmission and content encryption through all phases of both scenarios	High	Security

3.5.4 UC # 3 Functional Requirements and KPIs

The functional requirements and KPIs in the Berlin cluster are presented in Table 3-27. The functional requirements and KPIs in the Patras cluster are presented in Table 3-28.

Table 3-27 UC # 3 Berlin cluster Functional requirements and KPIs

Req ID [U/F-TYPE-RQ#]	Description [Descriptive text]	Priority [H/M/L]	KPIs and Parameters [to be measured]
U-FU-6301	User shall use the ARD Mediathek downloaded from the iOS App store or Android Playstore or the Web Application to access media content as usual. The application shall automatically connect to the local CDN cache in the train.	M	Service functionality
U-FU-6302	When the user is connected to the local network in the train, he/she shall only see the VoD content VoD cached in the train CDN.	M	Service functionality
U-FU-6303	The user shall be able to watch Live content with variable delay from the live edge depending on the 5G connectivity of the train in certain region during a trip. Through Link Prediction, the delay time can be estimated to avoid interruption in the playback	M	Delay between playback time and real time, duration of rebuffering events, frequency of rebuffering events
U-FU-6304	For linear streams, the media server in the train shall switch between multicast and unicast streaming depending on the access load of the stream.	M	Network traffic measurements
U-FU-6305	The media player of the ARD application shall be able to report media playback metrics following the MPEG-DASH SAND Standard to a SAND Server in the train.	M	Service functionality

Table 3-28 UC # 3 Patras cluster functional requirements and KPIs

Req.ID [U/F-TYPE-RQ#]	Description [Descriptive text]	Priority [H/M/L]	KPIs/Parameters [to be measured]
U-FU-6310	Very high data rates for proactive transfer of large volumes of high quality (e.g . 4K) VoD or TV streaming content from central CDN servers to local MEC host	High	Network slicing
U-FU-6311	Very high data rates for proactive transfer of prefetched 4K VoD content from MEC host to on-train Edge server	High	Network slicing
U-FU-6312	Support for very high mobility of moving train	High	Mobility, reliability, availability
U-FU-6313	The number of users able to be served must be at least equal to the total train capacity	Medium	Wi-Fi capacity
U-FU-6314	Very high data rates at low latency for high resolution video transmission from 360° camera to MEC host	High	Network slicing
U-FU-6315	Very high data rates at low latency for high resolution video transmission from MEC host to the receiving control center	High	Network slicing
U-FU-6316	Very low latency for lower resolution video streams transmission from 360° camera to MEC host	High	Network slicing
U-FU-6317	Very low latency for lower resolution video streams transmission from MEC host to the receiving control centre	High	Network slicing
U-FU-6318	Video continuity when switching to a new FoV during head motion, for smooth and seamless transition from high to lower resolution video and vice versa	High	Slices synchronisation latency

3.6 UC # 4 – Smart Energy Metering (Cross-Vertical: Rail and Smart City)

The objective of this UC is to demonstrate how smart energy operation is enabled from the use of advanced ICT infrastructures relying on 5G technology. Particularly, it focuses on how 5G technologies can be used to bridge industries, in terms of operations, that have been traditionally separated even when operating across a common infrastructure, providing benefits in cross-vertical scenarios.

In the context of this UC two cross-vertical scenarios are considered:

- **The High Voltage (HV)** scenario (to be supported at the 5G-VINNI facility), bridging the transportation-rail and the energy digital utilities sectors in the process of HV electrical energy monitoring. The former is represented by an Energy Transmission System Operator (TSO), being the partner **ADMIE**, and the latter by a Railway Operator (**TRAINOSE**).
- **The Low Voltage (LV)** scenario (to be supported at the 5G-EVE facility), bridging the smart city and possibly the energy digital utilities sectors, in the process of LV energy monitoring and LV devices actuation. In the context of 5G-VICTORI, Alba Julia Municipality (**AIM**) will be used as indicative smart city case.

3.6.1 UC # 4.1 Energy Metering for HV

Electric rail transit systems are large consumers of electrical energy and so they are directly fed by the TSO. Increasing the overall efficiency of electric rail transit systems is critical to achieve energy saving. One of the solutions to increase the energy utilization efficiency in railway transportation is the use of Regenerative Braking Energy (RBE). During braking, the motors of a train act as generators converting mechanical energy to electrical. This energy can be re-used in different ways:

- Synchronising trains operation. When a train is braking and feeding regenerative energy back to the traction power supply, another train is simultaneously accelerating and absorbing this energy from the traction power supply.
- Providing a path for regenerative energy to flow back and feed power to the main AC grid.

From the TSO point of view, an advanced rail energy system, leveraging regenerative energy, can be beneficial for system stability, reliability and power quality. Electricity power trains consume great amounts of energy in short periods of time during acceleration mode, while the energy required is significantly reduced during deceleration. If railing stocks are not optimally synchronized, this intermittent power consumption leads to voltage fluctuations and possible spikes at the HV substation, putting utility transformers and lines in great stress. With an optimal coordination between accelerating and decelerating railing stocks, power fluctuation can be minimised, leading to improved power quality and health of the infrastructure.

The real time information of power consumption of each railing stock, in accordance to the information of other valuable values such as: speed, location, time, acceleration, etc., can lead to better synchronization of trains, achieving a cost-effective operation of the system. It will also be beneficial for the TSO as it will give the TSO a clear view of the cause of potential voltage fluctuations and power imbalances, and the ability to reveal them, and monetise them. On the other hand, the rail operator can profit with the provision of ancillary services for system balancing by time-shifting its loads. This implies extended data exchange, enhanced observability, and a communication mechanism between the TSO and the Railway Operator in order to send congestion signals and ancillary services requests.

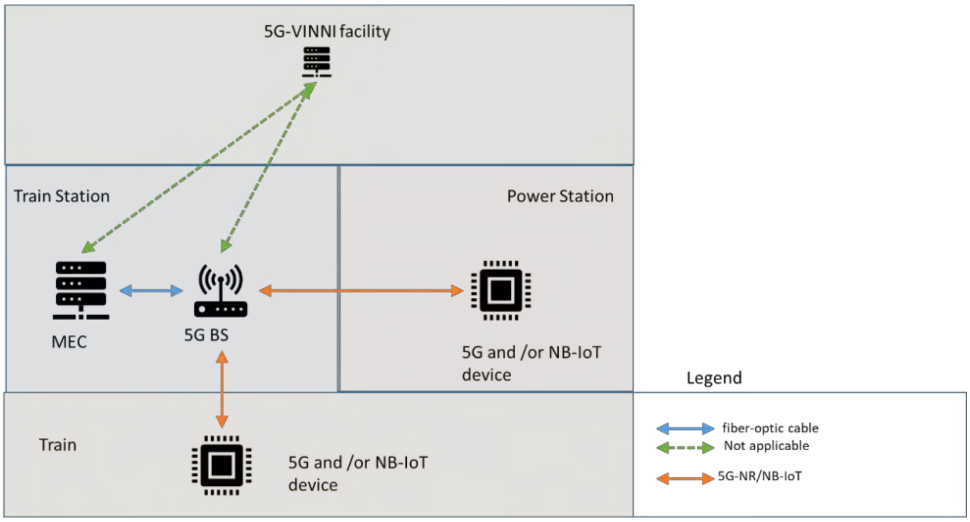


Figure 3-25 UC # 4.1 HV scenario involving the Train and the Energy management system

In this scenario, a set of live data will be gathered from the railing stocks and transmitted through the communication network to a data management platform. To achieve real-time monitoring of the system, information from the railing stock must be transmitted even when the train travels with high-speed, accelerates or decelerates, so the communication network must provide uninterrupted coverage. A 5G base station (access) will be installed at the substation connected to a local DC (virtual machine). A sketch of the scenario is shown in Figure 3-25.

Railing stock data will be timestamped and synchronised in real time with HV substation data. The data management platform will be responsible for correlation and analysis of the collected time-stamped information. When analysis is finished, informative and control signals will be sent back to the Energy and Railway Operator.

Both industries operate on strict real-time dynamic systems, hence latency and reliability are the most important KPIs that must be addressed. From the application perspective, E2E latency should be measured from the moment of data measurement until the output control signal is sent to the operator, including the time for data transmission, processing and actuation. Railway and Energy sector information is sensitive and both industries are strong candidates for cyber-attacks. The underlying ICT facility, meaning both the communication network and the data management platform, must meet strong security requirements (data encryption, use of isolated communication network, etc.)

3.6.2 UC # 4.2 Energy Metering for LV

The purpose for this UC is to show how 5G mMTC services can successfully support advanced energy metering deployments. The scenario to be demonstrated is metering data collection from relevant end-points scattered across a city. Alba Iulia will be the Romanian physical facility where the project will demonstrate the benefits of the 5G-VICTORI platform (mainly eMBB and uRLLC) for the connected mobility verticals. The new 5G infrastructure interconnected with dedicated servers will measure the energy efficiency, energy metering will provide real time data on energy consumption and CO_2 emissions in public transportation.

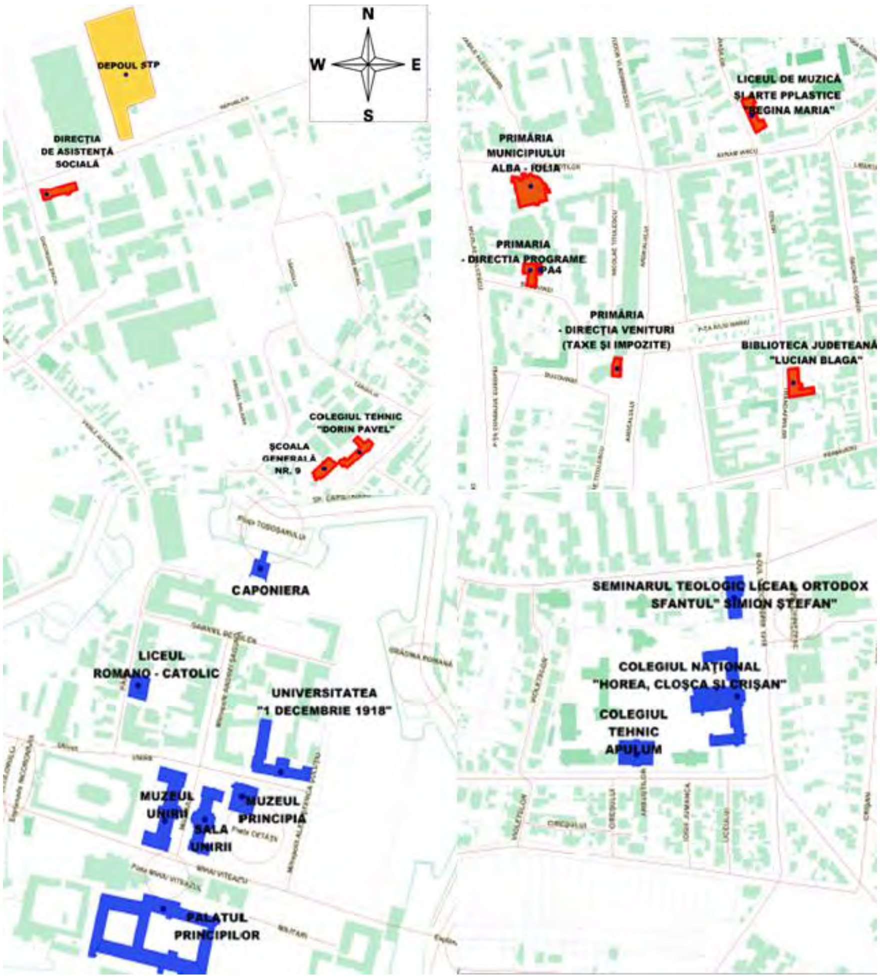


Figure 3-26 Energy Metering UC # 4.2 – Alba Iulia smart city locations

The LV UC will be demonstrated in the 5G-EVE infrastructure to provide energy metering services for public buildings and street lighting in the Alba Iulia Smart City environment in Romania. To achieve this, low cost/low energy consuming devices will be installed across the city that will operate through LTE-M / 5G-NR access layers. The collected measurements will be transferred to the 5G-EVE central cloud facilities that will be responsible for hosting, processing and analysing the collected measurements. Advanced analytics will be developed to predict future demands and create incentives for citizens to reduce overall power consumption. More than 20 public institution buildings have been selected for energy metering UC. To identify the weakest points in the energy consumption, the first step is to have a clear picture of the situation. Energy metering is therefore a key measure in the process of energy consumption reduction.

The scenario for this UC benefits from the mMTC capabilities that 5G has developed given that in real-life deployments, smart meter density requires high scalability from the get-go. The UC targets the small-scale representation of distributed electricity consumption and generation in smart grids, with actual distributed energy consumption and generation points as well as smart meters. It comprises the following elements, which represent the high-level architecture depicted in Figure 3-27:

- Energy sources (mostly sources from the national grid, but photovoltaic panels as well).
- Energy consumers (ignition points for public lighting, various single-phase and three-phase circuits of interest).
- Energy metering.
- LTE-M and/or 5G-NR MTC for data transmission.
- 5G EVE infrastructure.
- Telemetry platform.

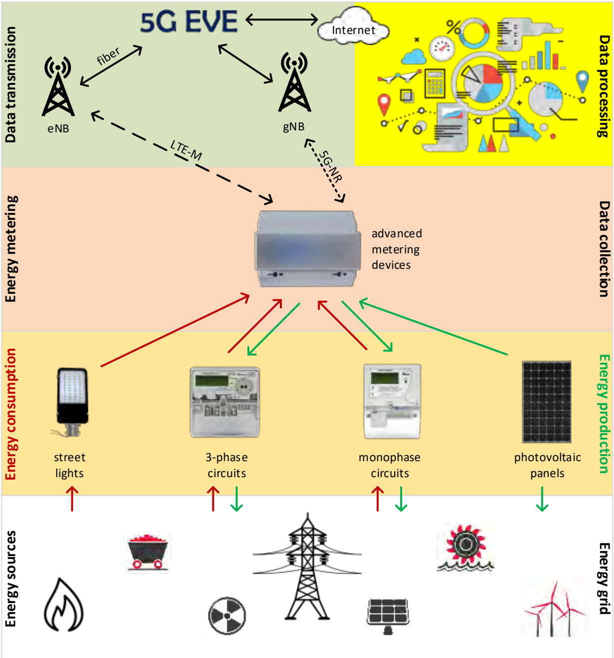


Figure 3-27 Overview of the Smart Energy Metering scenario in UC # 4.2

The problems this UC addresses are:

- On-the-fly reporting and analysis for both consumption and generation.
- Electric power quality monitoring for fault management and SLA infringement.
- Predictive and proactive maintenance.

Advanced metering devices available today monitor electrical infrastructures through innovative concepts and non-invasive installation. They serve as an alternative to standard, rigid, closed, costly and vendor-dependent solutions for measuring and monitoring the parameters of energy infrastructures, shedding light on energy management through advanced reporting (carbon footprint, consumption, quality, comparisons) and predictions for energy consumption and proactive maintenance. They perform multiple functions, including transmission over legacy or non MTC specific technologies like GPRS, UMTS, LTE and over newer LPWA technologies like LTE-M or NB-IoT. 5G access networks will be supported as well, as soon as such communication modules will be made available on the market. The data being collected in a telemetry platform can serve both as a front-end making information readily available to relevant personnel, or as a middleware for further manipulation of raw data or information in other platforms.

Besides leveraging the 5G EVE infrastructure, at least three cell towers in Alba Iulia will be equipped with 5G base stations and will service about fifty relevant end-points (ignition points for public lighting, various single-phase and three-phase circuits of interest and photovoltaic panels). The end-points will be scattered around the city, being either administrative buildings or schools with high energy budget impact, or tourist attractions managed by the municipality.

3.6.3 UC # 4 Requirements and KPIs Addressed

The service performance requirements for the communication service to support these services in the forthcoming cross vertical (transportation-Rail and digital utilities) and 5G landscape are summarised in Table 3-29. Figure 3-28 shows the spider diagram accounting on the KPIs to be fulfilled.

Table 3-29 UC # 4.1 HV scenario specific Requirements and KPIs

Vertical: Transportation – Rail & Digital Utilities (Energy Sector)			UC 4.1: Energy Metering for HV
			URLLC (rail operations)
UC Requirement - KPI		Units	
1	Latency (min. between user service end-points)	ms	Maximum latency of 20 ms (preferably <10 ms) to achieve overall CBTC performance (between on-board equipment and radio block centre / access point / 5G equivalent node)
2	User Datarate (Max.)	Mbps	1Mbps
3	Reliability (%) - Min/MAX	%	99.9999 % (SIL 4)
4	Availability (%) - Min/MAX	%	99.9999 % (SIL 4)
5	Mobility	km/h	50-150 km/h
6	Traffic Density (Traffic demand per specific area)	Mbps/ area surface	maximum 1 Mbps per train * number of functions (100) * 2 trains per track*trains per station maximum 100 kbps per power station * number of functions (2) * number of power stations (1)
7	Device Density (#Devices per specific area)	Devices/ area surface	Non Critical
8	Location Accuracy	m	Significant but Non Critical
Additional Requirements			
9	Packet Loss Ratio	Num	10^{-6}
10	Bit Error Rate		Mission critical
11	Data Rate for high frequency sampling measurements	Mbps/measurement point	5 Mbps
12	Type of Device		Devices/ Gateways
13	Type of Connection (i.e. Ethernet, WLAN, Zigbee)		5G/Wi-Fi
14	Battery Lifetime		Non Critical

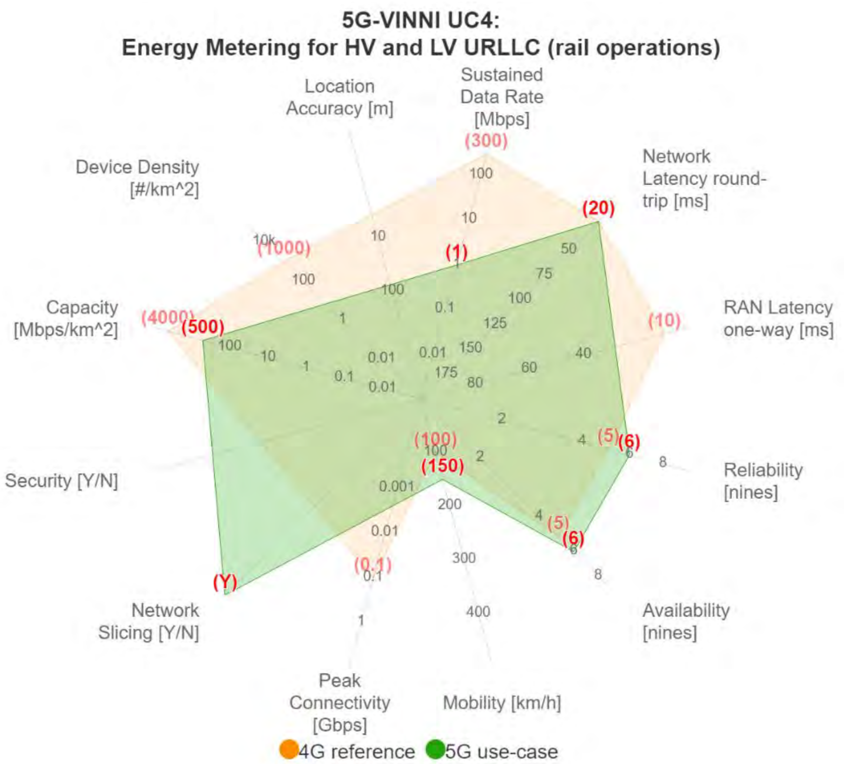


Figure 3-28 UC # 4.1 HV Energy Metering URLLC

Please note that these requirements reflect those considering not only the current (restricted to SW and network capabilities) services but also the foreseen future ones. Therefore, not all of them are subject to demonstration as already aforementioned. Further refinement of these KPIs will be provided in the context of WP3, with the specification of the applications and the system to be demonstrated. For the demonstration a train with two measuring devices will be connected to the data correlation and management platform with ultra-high frequency measuring rate. Data correlation with one power station will be performed.

Table 3-30 presents the service performance requirements for the LV UC. Figure 3-29 shows the spider diagram accounting on the KPIs to be fulfilled in the LV scenario.

Table 3-30 UC # 4.2 LV scenario requirements and KPIs

Req.ID	Description	Priority	KPIs/Parameters to be measured
U-PE-4101	Smart Energy Metering service deployment time – Time to on-board and deploy for the first time the Infotainment application.	M	90 min
U-PE-4102	Scaling time – time to start the Smart Energy Metering service and on-board the components	H	5 min
U-PE-4103	Service availability – Calculated as service down time/total time, reflects in percentage the availability/stability performance of Smart Energy Metering service	H	99.9%
U-PE-4104	Device status – evaluates the number of smart light sensors deployed on testbed platform	H	100 Smart Light sensors
U-PE-4105	Service reliability	H	99%
U-PE-4106	Incident (crash) service reporting accuracy	H	99%
U-PE-4107	Max simultaneous sensors devices supported	L	Up to 1000

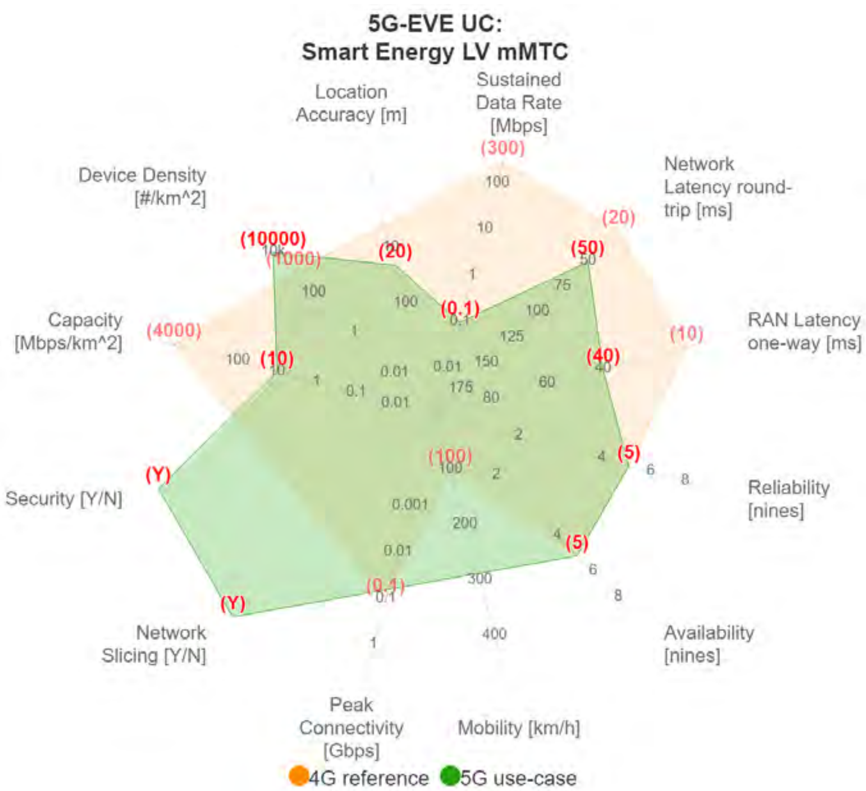


Figure 3-29 UC # 4.2 – LV Energy Metering (mMTC)

3.6.4 UC # 4 Network Performance Requirements and KPIs

Table 3-31 and Table 3-32 present the UC # 4 network performance requirements for the HV and LV scenarios, respectively.

Table 3-31 UC # 4.1 HV scenario network performance requirements and KPIs

Req.ID	Description	Priority [H/M/L]	KPIs/Parameters to be measured
U-PE-4201	E2E latency for HV Energy Metering service (in ms) - measures packet round trip time from IoT platform to device sensor.	H	<20 ms
U-PE-4202	Packet loss – shows the percentage of packets lost during transfer between sensors and IoT platform.	H	<0.1%

Table 3-32 UC # 4.2 LV scenario network performance requirements and KPIs

Req.ID	Description	Priority [H/M/L]	KPIs/Parameters to be measured
U-PE-4219	Network availability	H	99.9%
U-PE-4220	Network reliability	H	99.9%
U-PE-4221	Network slice capabilities/management	H	Yes
U-PE-4222	E2E latency for Smart Energy Metering service (in ms) – measures packet round trip time from IoT platform to device sensor.	H	<100 ms
U-PE-4225	Evaluates the transfer capacity volume of aggregated information from sensors to IoT platform. Calculated as (device number) x (bandwidth/device) (helpful for VNFs system parametrization)	M	100 Mbps
U-PE-4226	Edge computing capabilities	H	99%
U-PE-4228	Jitter – Evaluates packet delay variation in latency between IoT platform and device sensor.	H	<100 ms
U-PE-4229	Packet loss – shows the percentage of packets lost during transfer between sensors and IoT platform. The Smart Metering service is not critical, therefore retransmission is being allowed, without affecting E2E application functionality.	H	<0.1%

3.6.5 UC # 4 Functional Requirements and KPIs

Table 3-33 and Table 3-34 present the UC # 4 functional requirements for the HV and LV scenarios, respectively.

Table 3-33 UC # 4.1 HV scenario functional requirements and KPIs

Req.ID [U/F-Type-RQ#]	Description [Descriptive text]	Priority [H/M/L]	KPIs and Parameters [to be measured]
S-FU-4301	**Distributed Pools of (Compute/Network) Resources** Towards achieving the stringent QoS targets as well as efficient resource utilisation, it is necessary to enable instantiation of network, compute and storage resources optimally selected from a common resource pool that is physically distributed. This requires that the deployment is based on distributed (at different geographical locations, e.g. in the notion of edge computing) pools of resources (i.e. DC) where the allocation is based on specific QoS and resources requirements.	H	• Capability for instantiation of network and compute resources for a specific service over geographically distributed pools of resources. It shall be possible to use various Edge and Core DCs to host different parts of the Train Monitoring and Interventions Applications. • Monitoring of distributed resources pools from a common platform.
S-FU-4302	**Mobile Edge Computing Capabilities** Towards benefiting from the distributed pools of compute resources Mobile Edge Computing functionalities shall be incorporated to optimise also network resources utilisation.	M	• Mobile Edge computing capabilities and functionalities are available. • It shall be possible to deploy part of the Train monitoring and Interventions functions at MEC.

S-FU-4303	**Multi-Tenancy** The 5G facility needs to support simultaneously multiple tenants and multiple services, with various QoS, requirements, etc., over a single infrastructure. Since it can be possible that different departments make use and have access rights to different monitoring and maintenance applications/ information over the same – it shall be possible from the 5G facility to allow the creation of multiple tenants (e.g. ADMIE and TRAINOSE) for this scenario; also in line with FRMCS.	H	• Delivery of services with the requested QoS to multiple tenants over a single network deployment.
S-FU-4304	**Slicing** Towards supporting multi-tenancy over the 5G facility, slicing is required in order to preserve security and isolation between tenants, and to maintain the QoS guarantees.	H	• On-demand instantiation/ deletion/ configuration of an E2E network slice and delivery of services over it. • QoS guarantees (e.g. latency, bandwidth, etc.) of a slice shall be met.
S- OTH-4305	**Interoperability with Various Network Technologies** It is necessary that the solution is interoperable with various access network technologies 4G/5G/ Wi-Fi.	H	Showcase the interoperability with Wi-Fi and/or 4G connected measuring devices.
S-FU-4306	**On Demand deployment of network services** There is a stringent requirement for instantiation and deployment of network services at specific areas of the facility on demand, specifically on setting up a stand-alone 5G service	H	KPI: Show on demand service deployment
S-FU-4307	**Synchronisation** Synchronisation is required across heterogeneous and mobile access (based on different wireless technologies.) networks. Therefore, existing synchronisation protocols based on packet round trip time measurements are inefficient (e.g IEEE TSN, etc.).	H	KPI: Synchronisation is performed across two heterogeneous networks and two different nodes, one of them is with mobility.

Table 3-34 UC # 4.2 LV scenario functional requirements and KPIs

Req.ID [U/F-Type-RQ#]	Description [Descriptive text]	Priority [H/M/L]	KPIs/Parameters [to be measured]
U-FU-4320	High data rates for transfer simultaneously of large volumes of information	H	E2E data rate, network slicing
U-FU-4321	A set of test sequences was developed to evaluate the functionality of the slices: component unit test, integration test, functionality test, Interoperability test - to verify if a particular functionalities respond as expected.	H	Availability, functionality
U-FU-4322	Compute/storage/networking resource usage monitoring	M	Compute usage/storage
U-FU-4323	Management & Orchestration of Resources	H	Service Instantiation Time, Service Tear-down Time, Service Modification Time

4 5G-VICTORI Infrastructure Requirements

The 5G-VICTORI infrastructure being developed is addressing a wide range of applications that are adopting flexible architectures for converged services taking advantage of existing ICT-17 5G infrastructures including 5G-VINNI (Patras, Greece) , 5GENESIS (Berlin, Germany) , 5G-EVE (France/Romania) and the 5G UK testbed. Extensions and enhancements to the existing infrastructures will allow the execution of the planned vertical and cross-vertical UC (see Figure 4-1) that were described in detail in section 3.

5G-VICTORI aims to transform the available 5G infrastructures into an environment where resources and 5G functions are exposed to verticals industries, capable to address diverse communication service's needs. This section describes the infrastructure available in 5G-VICTORI through the 5G-VINNI, 5GENESIS, 5G-EVE and 5G-UK infrastructures and the required extensions for the implementation of the planned UCs.

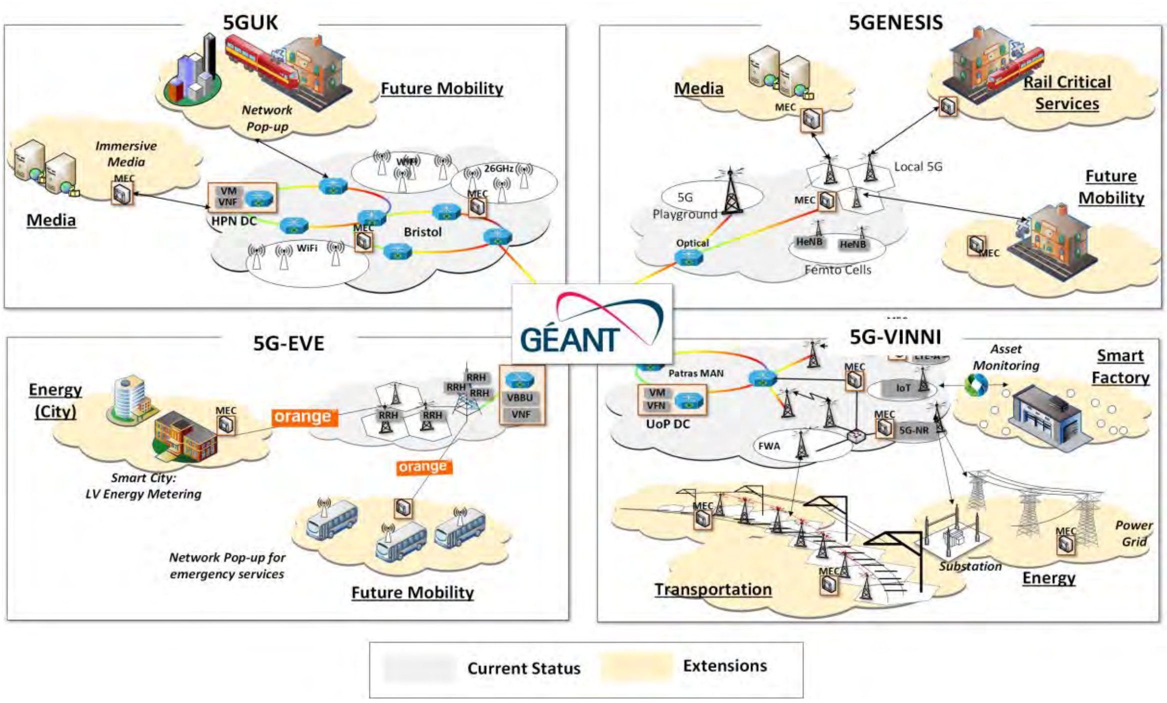


Figure 4-1 ICT-17 5G infrastructures supporting 5G-VICTORI

4.1 5G-VINNI Cluster

4.1.1 Patras/Greece 5G VINNI facility description

4.1.1.1 Cloud/MANO services

Currently, the Patras/Greece facility (see Figure 4-2) is equipped with a cloud platform offered by the University of Patras (**UoP**), able to host core network components, as well as NFV and MEC deployments. The cloud platform offers a total computing power of 212 CPUs and 768 Gigabytes of RAM and 30 TB of storage. Two servers with 4x10GbE NICs DPDK enabled are available.

On top of our cloud HW, a rich set of state-of-the-art SW tools is already available, which comprises an experimentation platform referred to as Cloudville. These include OpenStack as the cloud operating system, while OSM will be available to allow NSD/VNF deployments. Prometheus alongside with Grafana are installed for monitoring purposes. At the same time, Elastic search and Kibana are installed and being used to collect and visualise data extracted from IoT devices and sensors.

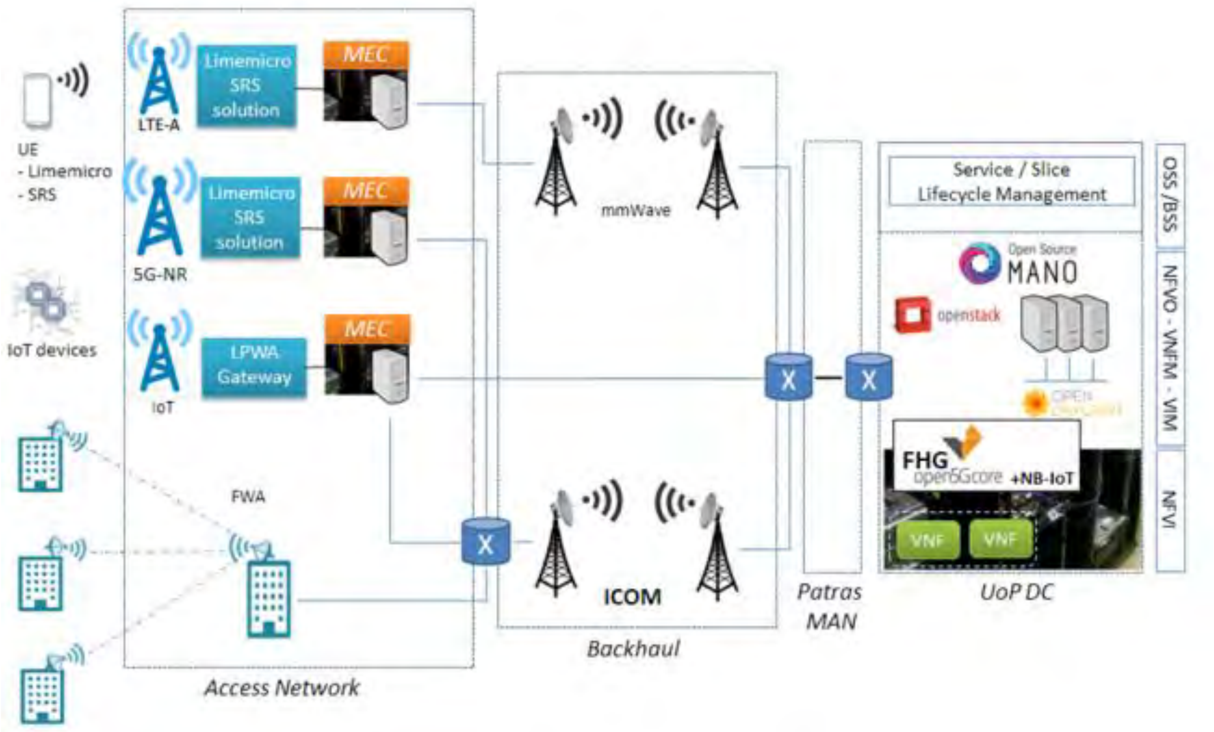


Figure 4-2 Patras/Greece 5G-VINNI facility

4.1.1.2 Access Network, MEC devices and UE

The Patras/Greece facility will include three (3) outdoor base stations together with MEC devices at the Patras campus and at the City of Patras placed at properly selected places to facilitate the execution of test plans together with around six (6) UEs. UoP together with ICOM will implement and integrate any standardised APIs and services to provide MEC functionality, including the virtualisation of edge IoT devices, i.e., IoT Slicing, as a Virtualized Infrastructure Management (VIM) component.

4.1.1.3 Backhaul

ICOM will provide state-of-the-art mmWave BH to the Greek facility. The UltraLink™-GX80 all-outdoor mmWave PtP Ethernet radio at 70/80 GHz (E-Band), that provides a 10 Gbps BH capacity, will be used to interconnect the g/eNBs with the core network and the DC at the UoP premises. Within 5G-VINNI, ICOM will add support for SDN-based network slicing to the wireless BH.

4.1.1.4 Core 5G/IoT services

Apart from Service Slice life-cycle management services and OSM, the Fraunhofer (FhG) Open5GCore will be installed. The Open5GCore implementation is a 5G oriented implementation of the core network (currently 3GPP Release 14 and 15, whilst Release 16 is planned in future releases). The Open5GCore enables the connectivity service as requested within the 5G networks. To support NB-IoT, the Patras/Greece facility will host the Open5GCore NB-IoT extension, which is the first implementation of the essential 3GPP NB-IoT features (Release 13 - TS 23.682) enabling the demonstration of low energy IoT communication. It addresses the current stringent needs of the 5G UCs to provide low power, low cost efficient communication for a massive number of devices. On the NBIoT, LTE-M radio side there will be both commercial licenced as well as open source solution available.

4.1.1.5 MEC

The Patras/Greece facility will provide support for MEC on two fronts:

- **IoT Slicing:** A VIM (sub-)component will be designed, implemented and integrated within the overall MANO architecture, to enable the virtualisation of the available edge IoT resources (sensors/actuators) for access within individual network slices.

- **Mobile streaming applications support:** The facility will support MANO mechanisms for the realization of high throughput, low latency, mobile types of applications (e.g., gaming, AR/VR) and corresponding test cases. Such mechanisms will include DNS and traffic flow management (on Mp1 ETSI MEC interface) for baseline service orchestration, as well as mobility support mechanisms, i.e., mobility management events such as application context transfer, user redirection network/application level), and a subset of the Location Service (ETSI GS MEC 013) for triggering mobility management events.

4.1.2 UC # 1.1 – Enhanced Mobile Broadband under High Speed Mobility

4.1.2.1 Integration capabilities

For this UC, we consider an application of a joint FH/BH network realised over wireless heterogeneous technologies. We consider the deployment of dedicated disaggregated virtualised cells on top of high-speed moving trains, in order to support the train operations through the creation of two separate infrastructure slices that will concurrently: 1) provide data services to train passengers using dedicated disaggregated heterogeneous femtocells deployed on-board and, 2) support time critical rail services. For the former, high capacity links are needed to provide high-quality infotainment services to passengers, whereas for the latter low latency / ultra-reliable connections are needed to transmit data obtained from various sources (e.g. train status monitoring devices) in real-time to the train operations and control center (OCC) for processing.

As shown in Figure 4-3, the 5G VINNI and 5G VICTORI integration will take place through four levels of network segments. The lower level is the on-board network. This consists of several HW and SW elements, all interconnected by a fibre network. The wireless domain for the on-board segment comprises a SW-based solutions for 5G NR and Wi-Fi, provided in an aggregation environment for augmenting the overall capacity of the network, controlled through a single Centralized Unit (CU). At the second level, for the track-to-train connections, a heterogeneous network will be deployed operating in the Sub-6 GHz frequency band (e.g. 5G NR access provided from 5G-VINNI, high-throughput Wi-Fi, and mmWave units supporting beam tracking). At the third level, the interconnection of the track side APs to the core network will be achieved through multiple Point-to-Point E-Band radio links with the UltraLink™-FX80 from ICOM, that provide up to 3 Gbps capacity. These will be aggregated at the central BH hub at Rio. At this hub, convergence of the 5G-VICTORI to the 5G-VINNI main facility network will be achieved at the fourth level of connectivity, as the hub will be connected to the core network at UoP premises through the 5G-VINNI E-Band PtP link with the UltraLink™-GX80, able to BH up to 10 Gbps.

Finally, a full 5G Base station (RAN + MEC) node from 5G-VINNI facilities will be located at the Rio train station also connected through mmWave BH to 5G-VINNI Patras facility. Figure 4-3 presents a high-level UC setup for the 5G-VINNI deployment in the Greek Cluster and also shows a high-level diagram of the network configuration.

Figure 4-4 shows the area that was selected for the demo after some initial site surveys between the Rio and *Kastelokampos* train stations as well as the railbus provided by **TRA** for the purposes of the demo.

To demonstrate multi-technology track-to-train communication, the proposed setup comprises both mmWave (provided by **IHP**) and Sub-6 track-side APs to be deployed along the track between the two stations as shown in Figure 4-5. Each stanchion has a pair of mmWave and/or Sub-6 APs, each one facing at the opposite direction of the track. To maximise connectivity and minimise the disconnection times between handovers from the train to the track APs, the proposed scheme requires antenna modules to be installed both at the front as well as at the rear of the train.

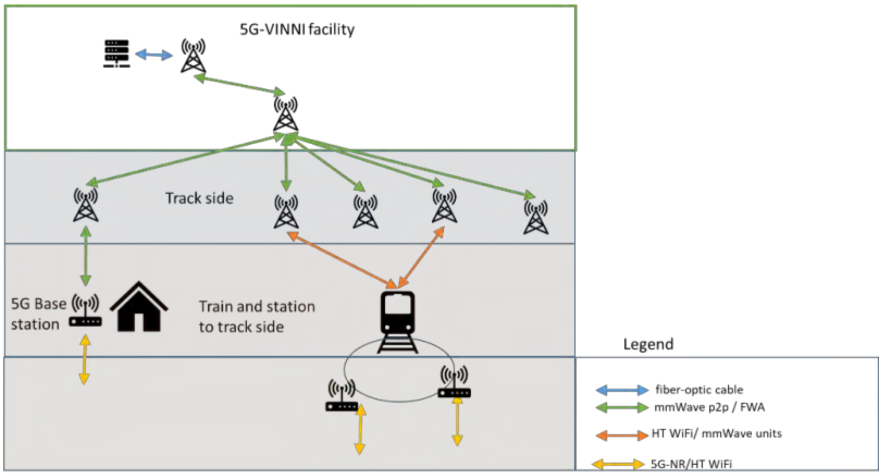


Figure 4-3 UC # 1.1 5G-VICTORI and 5G-VINNI facility integration

Figure 4-4 Site and Railbus to be used in the demonstration of the UC # 1.1

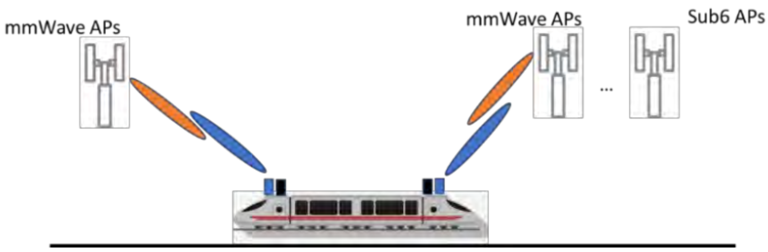


Figure 4-5 Track-side to train communication

Due to the movement of the train, the connection between the on-board units and the trackside units will continuously change over time. This represents a challenge since it is not possible to preserve network sessions if no handover management functions are implemented.

The proposed on-board architecture comprises a 10GB Ethernet LAN with SDN-capable switches, connecting the antenna modules to be installed on the roof of the train i.e. Sub-6 and mmWave and the software-based 5G-NR and Wi-Fi APs to be placed inside the train. Moreover, cameras will be placed at the front and at the rear of the train realizing the critical service to be transported from the train to the OCC located in the 5G-VINNI Patras facility. Finally, a compute node is also necessary to deal with the handover management, and also act as a potential CU of the disaggregated 5G-NR cell.

As mentioned above, the wireless domain for the on-board segment comprises SW-based solutions for 5G-NR and Wi-Fi, provided in an aggregation environment for augmenting the overall capacity of the network [64], controlled through a single CU. We consider the disaggregation of the base stations at a high-layer Packet Data Convergence Protocol (PDCP) that can be used for aggregating heterogeneous access technologies, according to the 5G-NR Rel. 15 specifications. The CU can be instantiated as a VNF on an (edge) DC – in this case the DC of UoP, and manage multiple heterogeneous Distributed Units (DUs) that integrate the radio-level characteristics of the base stations.

For the transport network, mmWave BH connections provided by ICOM will be used to integrate the deployed infrastructure along the track with the 5G-VINNI infrastructure offering throughput up to 10 Gbps. The exact number of mmWave links will be decided at the first phase of WP4. Figure 4-6 presents a proposed UC configuration for the 5G-VICTORI/5G-VINNI combined deployment in Patras.

Figure 4-6 5G-VINNI/5G-VINNI combined deployment for moving train UC

4.1.2.2 Facility-specific requirements

As the proposed setup consists of highly complex and heterogeneous infrastructure elements, we plan to make use of SDN/NFV principles for the orchestration and management of the infrastructure. Slices will be created to support business as well as critical services and meet their performance requirements. By making use of NFV, the execution of network functions on computational or network resources by leveraging SW virtualisation techniques is feasible. We plan to make use of a fully softwarised control and data plane – CUs and DUs based on the OpenAirInterface (OAI) stack implementation, forwarding elements, passenger infotainment and operational services running. Therefore, all the needed functionality for executing the UC will be running as VNFs. SDN network elements can be treated as VNFs, since they can be implemented as SW running on general-purpose platforms in virtualised environments.

Finally, VNFs for supporting either infotainment services for passengers or operational services for trains will be supported through this UC. The VNFs comprise different modules, able to manage cross-technology components, in order to prioritise traffic, isolate different slices of traffic and setup new paths in case of cross-technology handovers (e.g. switching from mmWave to Sub-6 GHz technologies for communicating with the trackside network).

4.1.3 UC # 2 – Digitization of Power Plants

4.1.3.1 Integration capabilities

The proposed UC will take place at the ADMIE facilities in Rio-Antirio, near Patras, Greece. The ADMIE complex includes terminal for containers, freight centre, storehouses as well as all the necessary installations for facilitating the ADMIE activities. As described in the UC, the monitoring, security and operation should be performed through the same digital infrastructure. Data from various sources (sensors, processed or historical data, etc.) are combined through the 5G network to provide faster and more reliable monitoring of the system. Both facilities lie at each side of the Rio-Antirio canal and they are separated by approximately 4 km of sea. The facility is an excellent candidate for demonstrating advanced monitoring solutions that the project will deploy, mainly regarding the awareness of the operations taking place, the equipment fault awareness, the analysis of the collected data, and the decision-making and information process of the first responders. Also, the facility manages the Rio-Antirio submarine interconnection via a high voltage submarine cable with the special requirements that were described above. The cable lies along the Rio-Antirio bridge.

The Rio ADMIE site and power station lies in a large area of land close to the Rio Rail station. Here a Control room is used to monitor the oil pressure of the cable. A set of legacy devices are used with no internet connection, and a set of LEDs, which inform the personnel about the health of the cable. The Antirio site, resides at the Antirio village (Greece).

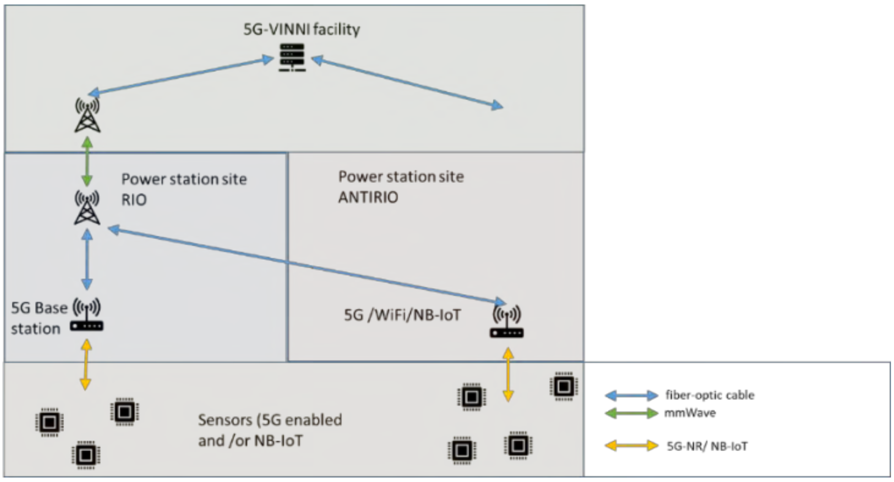


Figure 4-7 Smart Factory UC. Rio / Antirio sites submarine fibre interconnection

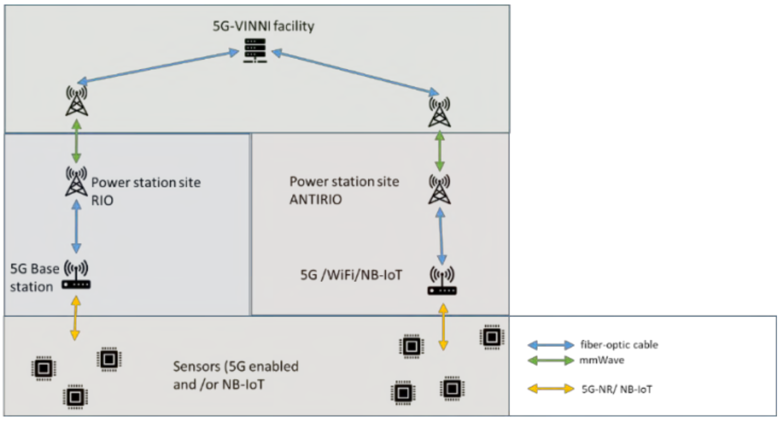


Figure 4-8 Smart Factory UC. 5G-VINNI / Antirio sites extra mmWave interconnection

Figure 4-9 Two proposed alternative UC configurations at ADMIE facilities

Figure 4-10 Two proposed alternative UC configurations at ADMIE facilities

The two scenarios differ with regards to the backhauling architecture and the edge DC site. The first assumes availability of submarine fibre cable among the two sites. The second will serve as contingency plan with mmWave backhauling.

The main objective of this UC is to automate the monitoring process and improve the inspection methods and maintenance procedures for both reductions in costs/ time and improvement in quality. Figure 4-9 and Figure 4-10 show the proposed trial setup. The following components will be deployed:

- An open wireless access communication system offering connectivity services for a massive number of low-powered sensing devices used for monitoring the critical components of the utility. This platform will be based on software-defined radio based NB-IoT Evolved Node B (eNB) and off-the-shelf LoRaWAN Gateway modules. CCTV data will be collected using off-the-shelf Wi-Fi equipment, tailored to the wireless environment of the area to support at least FHD streaming.
- Several monitoring devices deployed at key locations of the facility, consisting of oil pressure, tension, vibration, temperature, humidity, human presence and harmful chemicals sensors. These sensors will be interconnected wirelessly through at least two redundant links (NB-IoT and LoRaWAN).
- A data management platform allowing scalable data collection, aggregation and processing of the collected information. This platform will be able to operate both at the edge (deployed at the edge DC) and the central cloud (located at the 5G-VINNI facilities in Patras) allowing data and functionalities to migrate from one site to the other
- A processing platform supporting a variety of user applications and services to facilitate optimal decision-making and preventive maintenance strategies, as well as other possible enhancements including i) new inspection methods to allow faster and more accurate inspection of the facility; ii) develop new repairing, strengthening and upgrading methods; iii) novel data sampling techniques taking into account battery lifetime of the sensing devices.
- A data visualization platform able to combine input from sensing devices, aerial and ground imaging and 3D maps to provide faster decision making.

In this case also backhauling will be performed through a three-level aggregation network. The network brings in data from both sides to the processing units that exist at the Rio edge DC. To ensure high degree of synchronisation and data correlation, the 5G VINNI and 5G VICTORI integration will utilise a submarine fibre cable, as shown in the Figure 4-7. To that respect, the data from the Antirio area will be transported to the edge DC together with the data gathered from Rio for synchronisation and correlation. Then further processing and visualization will take place at the 5G VINNI premises at UoP. To address a possible risk of lack of available optical fibre at the time of the first phase of installations, a contingency plan is described where both facility sites are directly connected to the 5G-VINNI DC through mmWave BH.

Initially, the deployment of the new infrastructure brought by the 5G-VICTORI project will take place. This infrastructure involves the installation of the sensing devices at the predefined locations (see Figure 4-7 and Figure 4-8) and powered on through either battery/solar cells or connected to the power supplies provided by **ADMIE**. The cells providing the gateway of the collected data will be installed (software defined NB-IoT cell, COTS LoRaWAN gateway, Wi-Fi AP) along with the edge DC and the remote connection to the 5G-VINNI facility.

4.1.3.2 Facility Specific Requirements

Upon the initial equipment setup phase and testing, the trial will be carried out, including consistent and high-resolution retrieval of measurements from the sensors, collection and processing either on the edge or the remote DC. In-network software modules will be deployed for applying data analytics locally or at the edge, in order to reduce the load on the BH network (connection to the 5G-VINNI facility). The collected data will be visualized using advanced data visualization tools, and SW applications will be deployed for the information of first responders in case of critical events.

For the execution of the UC there is a requirement for extensive deployment, installation and configuration of the sensing devices. Two different base stations will be deployed, a 5G and a COTS LoRaWAN gateway. An edge server will be installed on site and interconnected to the network. In terms of SW, the following elements will be provided:

- VNFs for data analytics on the collected data.
- VNFs for decision-making based on reasoning on the analysis of the data.

Applications for visualising the measurements of the devices. All the provided VNFs will be integrated within the network OS that the project will leverage, and will support live migration between the edge and the core cloud system.

4.1.4 UC # 3 – CDN services in mobile environments

4.1.4.1 Integration capabilities

The 5G-VICTORI ICT system that will be showcased will be based on the 5G-VINNI existing infrastructure deployment. It will allow an efficient dynamic reconfiguration of the communication network in terms of slice provisioning/activating towards achieving efficient utilisation of resources, complemented by MEC infrastructure capabilities, and on-board train surveillance equipment.

To control and operate the 5G-VICTORI communications platform in a centralised manner based on an open source control plane solution, the SDN/NFV paradigm will be adopted based on the local facility's provided solutions (e.g. OSM). The established MANO framework will be used to manage and orchestrate the envisioned services, incorporating MEC-enabled locations.

For the specific trial, the UC # 3.1 facility described in section 4.1.2.1 will be deployed. The top part will be deployed at the 5G-VINNI cloud, while the management platform will be deployed at the Rio MEC.

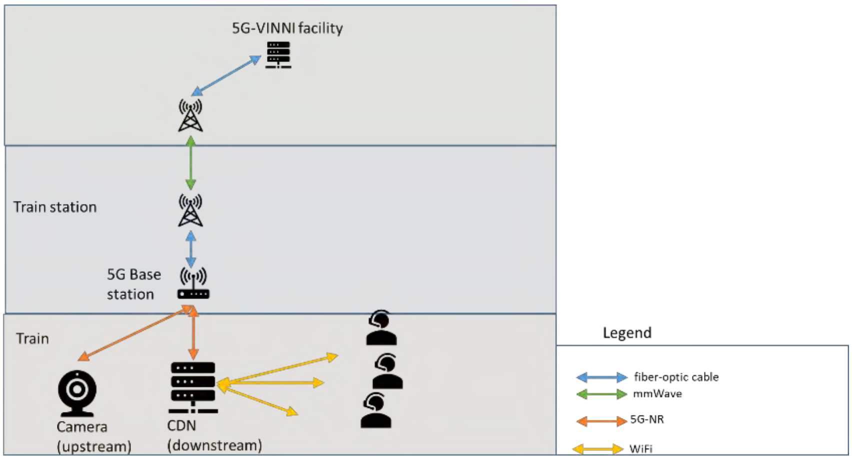


Figure 4-11 UC # 3 – Media, 5G VICTORI and 5G-VINNI facility integration

4.1.4.2 Facility-specific requirements

Based on the infrastructure described above, a vCDN solution will be realised for the support of the first scenario (Infotainment application). For the integration with the 5G-VINNI facility, the CDN platform will be based on a three-level hierarchical design. On top, there will be central CDN Cloud premises, mainly responsible for receiving and processing the content to be delivered.

At the MEC level, appropriate VNFs will be deployed and provide the necessary functionalities and elements to support content delivery (storage and streaming) to end users. Furthermore, an additional Edge server will be deployed on board for serving the passengers even during disconnection periods, containing a subset of the MEC's vCDN functionalities and connected to the station's MEC server through a 5G modem. In Figure 4-12, the part of the CDN server is located on-board and can be connected to integrate to the network while the train is at the station.

A similar setup is envisioned for the case of the second scenario of the UC (video surveillance application), targeting both the eMBB and the URLLC class of services. A VR/360° 4K video camera will be installed at the train station of Rio, which remains equipped with a 5G base station, and also the distributed vCDN solution can be optionally used again at the MEC level as an inverted version of the previous scenario, in the sense that now high-quality video transmission will be uplink. In this case, the video streaming and optimisation processes will be supported at the MEC level. Another option is to locally process and optimise the video streams and deliver them to the 5G network through a 5G modem. Therefore, the video streams from a VR/360° 4K video camera deployed in the area of the train station are either delivered to Rio MEC-enabled host where they are optimised and dispatched by the appropriate vCDN components, or directly to the 5G network after local optimisations. The overview of the deployment is depicted in Figure 4-11.

4.1.5 UC # 4.1 – Energy metering for HV

4.1.5.1 Integration capabilities

The objective of this UC is gathering of energy consumption and load data (recovery of energy fed back during braking) in the Remote Metering Solution (RMS) and Energy Management System (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 synchronising decelerating and accelerating 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.

The objective of the trial is to gather and compare energy consumption and load data from both the decelerating/accelerating trains and power substations. The HV trial is expected to take place at Corinth (Greece), where ADMIE feeds a range of primary substations. One of these primary substations (150kV/25kV), at Loutropyrgos, is used for TRA suburban trains traction (TPSS). As shown in the UC will be delivered upon an 5G facility that interconnects the Power consumption measuring devices on the train and the corresponding devices at the power station.

4.1.5.2 Facility-specific requirements

To achieve the correlation and synchronization of the data sets and showcase the capability to make decisions and perform operation for the UC, the trials will be executed in two phases:

1. **Energy HV UC emulation at the Rio/Kastellokampos 5G VICTORI trial.**
   The first part of the trial will be based on historical data taken from the electrical trains that operate at *Loutropyrgos* and the power station there. For proof of concept, the data measurement and/or gathering part will be emulated. The previously collected data will be used for emulating real time, high frequency sampling transmission from both the train and the power station. In order to pipeline trials and since there are no connected measuring devices on the trains that can feed the system with live data at the moment, the PoC should be implemented as phase 1. To that respect the data management platform will be developed and real time synchronisation between data from the train and power station will be showcased. This trial will

utilize the infrastructure and facility available for the Rail and Media UC, offering great advantage as far as the number of antennas and (emulated) measurement points is concerned. The first phase of the trial will be able to emulate the stringent KPIs with respect to device density and capacity density. The PoC scenario can be implemented on the Rio site (where other UCs will be showcased). In such case, the 5G-VICTORI facility at Rio will be utilised as a platform where many verticals can use separate slices of the same infrastructure concurrently for a variety of 5G network services with versatile KPIs.

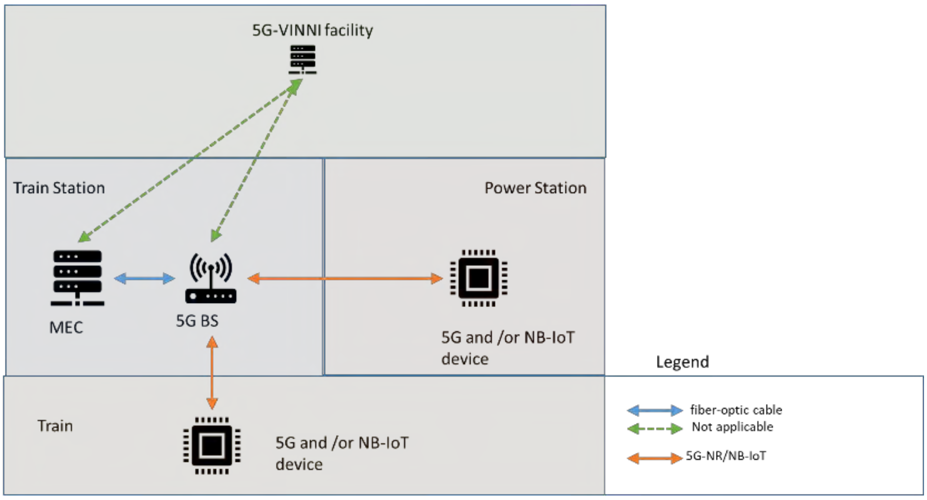


Figure 4-12 UC # 4.1 – 5G VICTORI and 5G-VINNI facility integration

2. **Energy HV private 5G trial.**
   Upon availability of devices on-board in the *Loutropyrgos* trains, phase 2 of the trials will take place. Now the data management platform and the synchronisation platform will be available. A 5G base station (access) will be installed at the *Loutropyrgos* substation connected to a local DC (VM). This UC will be served through one the 5G-Patras autonomous edge. The 5G-Patras Autonomous Edge is a mobile/portable box containing all SW and HW of a 5G private network, including but not limited to: the 5G NR and 5G Core, and Network and Service Orchestrations, including a virtualised environment based on OpenStack. Finally, the digital infrastructure comprises also a cloud facility that hosts OSM together with major open source projects like OpenStack, Kubernetes, etc., for VI management. In this context, the Patras platform is actually portable and can be installed in any facility in order to host instances of UCs that will be used for testing and validation purposes. The specific phase is shown in Figure 4-12.

4.2 5G-EVE Cluster

4.2.1 5G-EVE Facility description

ICT-17 5G-EVE is the European 5G validation platform for extensive trials, composed by a cluster of four nodes located at different cities, Nice, Paris Saclay, Paris *Châtillon*, and Rennes. The French facility capabilities will further support the verticals' UCs proposed by the Romanian cluster, including OAI, Mosaic-5G, Open Networking Automation Platform (ONAP) and infrastructure (see Figure 4-14).

The scenarios that will be validated in Alba Iulia Municipality (**AIM**) are based on open source developments:

- RAN OAI, the set of functional entities for LTE/NR eNodeB/gNodeB and UE.
- Core OAI, the set of functional entities for a 4G EPC and 5GC.

A functional view of the 5G-EVE cluster is shown in Figure 4-13.

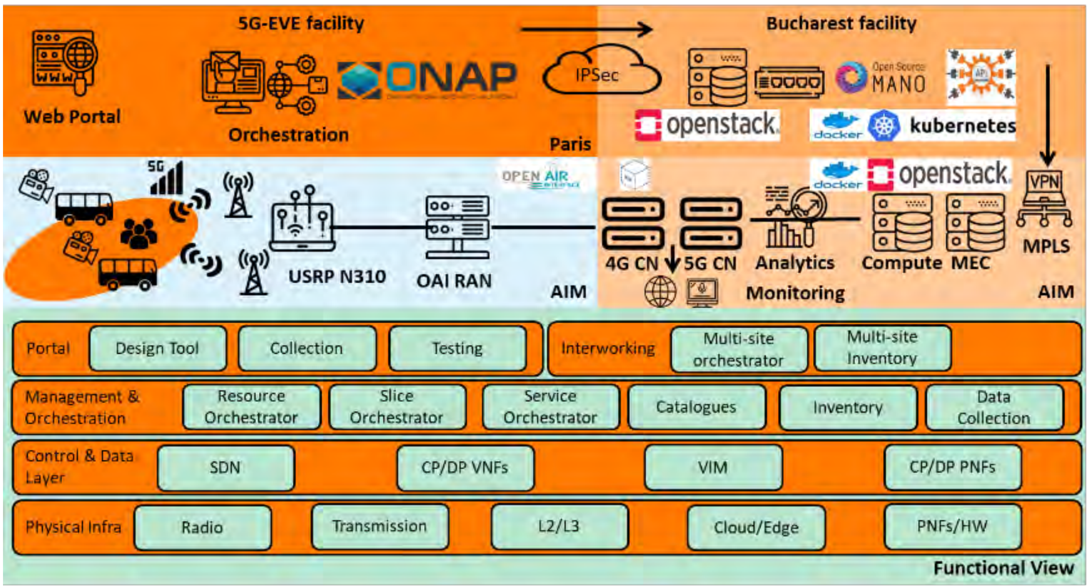


Figure 4-13 5G-EVE cluster functional view

4.2.2 UC # 1.2 – Digital Mobility (*Public safety and security)*

This UC proposes a critical service application that addresses URLLC feature requirements and pop-up network on-demand creation capabilities. Deployed for a low density scenario to provide services in passenger's buses, the App can be reconfigured on the fly for emergency services, combining different capabilities for the App demonstration in line with URLLC and eMBB scenarios. For the UC demonstration and validation, from the vertical perspective, KPIs described in section 3 should be achieved.

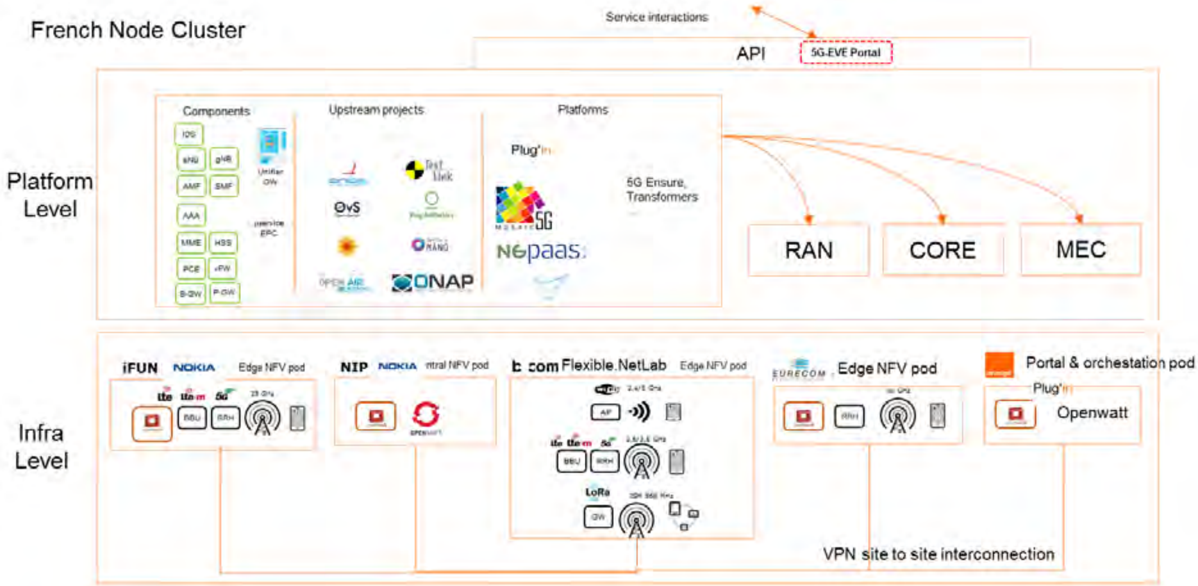


Figure 4-14 5G-EVE facility capabilities

4.2.2.1 Integration capabilities

The transportation UC, as described in section 3 is composed by a network service slice, real time for video data traffic from the bus, data traffic transported to the video analytics component (MEC capabilities) and a network slice for regular eMBB UE/passengers data traffic, mobility enabled for the services. Under an emergency situation, a MC network slice is created, based on a trigger and the MC service traffic will be provided to the CCC, while the network capacity dedicated to regular passenger will be decreased. The UC is requiring URLLC communication and is enabled by the following integration capabilities list (see also Figure 4-15):

- Network infrastructure elements integration and specific configuration for service assurance
  - Virtualisation capabilities, orchestration and service instantiation.
  - Network and service monitoring tools.
  - Servers and servers' management.
- Communication Service Design (Web tool capabilities).
- 5G network availability to support UC service requirements:
  - 5G RAN, 5G CN, MEC.
  - SDM/HSS or UDM and SIMs provisioning for the service.
  - MEC availability for low latency communication.
  - Specific VNFs availability and VNF integration requirements.
- 4G/5G Radio spectrum and radio resource allocation.
- Cloud Application and analytic system for video traffic: Data Analytics solution and algorithms.
- UE Equipment integration for basic activities and performance testing for video streaming
- Perimeter of service availability, mobility, service instantiation and service continuity
  - Indoor (inside bus)/outdoor network availability and performance.
  - Network handovers.
- 4G/5G network handovers respecting KPIs requirements.
- UE/camera devices density under integration purpose.
- Service security and proper data protection.
- E2E service provisioning, network slicing capabilities:
  - Video data traffic inside bus network slice.
  - eMBB data traffic for user's network slice.
  - Emergency network slice for C&C.
- E2E connectivity integration, for infrastructure's servers, UC applications and tools.
- Network capacity monitoring, resource provisioning, monitoring and resource assurance.
- Network Provisioning in two phases:
  - Phase 1: 4G LTE, 5G NSA network provisioning.
  - Phase 2: 5G SA network provisioning.

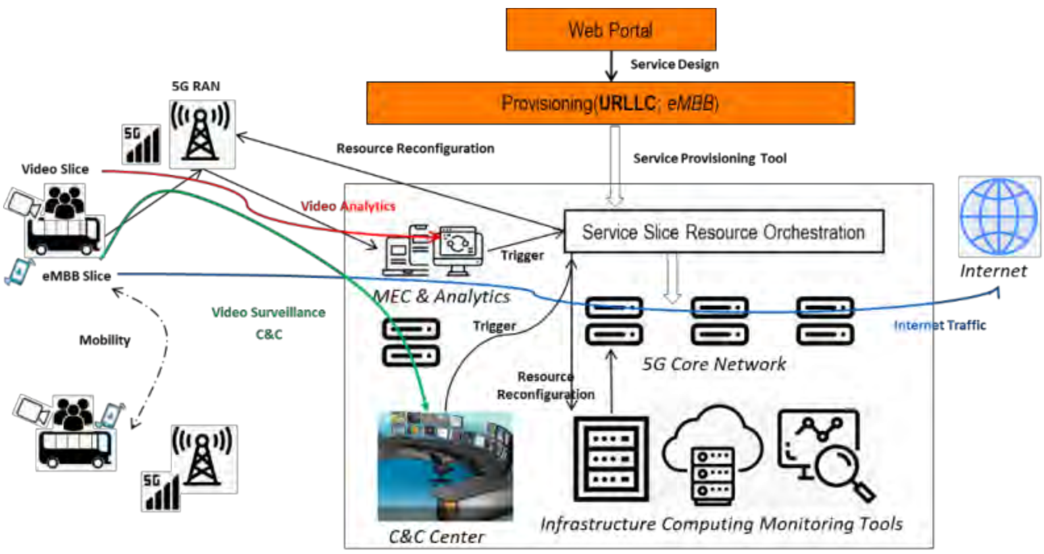


Figure 4-15 5G-EVE cluster - Integration capabilities

4.2.2.2 Facility specific requirements

UC implementation and validation requires facility capabilities for service, slice and communication network delivery, components developed and deployed through the 5G-EVE project and specific extension to the Romanian cluster, deployed in Bucharest and Alba Iulia. The requirements are listed following a bottom up approach, starting from physical requirements to service communication design and delivery:

- Physical infrastructure deployment, including:
  - Radio network.
  - Transmission network between components.
  - L2/L3 network elements.
  - Servers and MEC.
  - Hardware for functions that can't be virtualised (OAI RAN).
- Secured connectivity link between 5G-EVE Paris Cluster and Romanian facility.
- Virtualised infrastructure for CP and data plane layer, for VNFs and PNFs, including VIM and SDN controller.
- Virtualised infrastructure deployment in Alba Iulia, compute nodes integrated with Bucharest already existing site, ETSI MANO level.
- Management and orchestration capabilities for resources, service and slice orchestration
  - Infrastructure monitoring tools.
  - MEC functions for emergency service.
  - Service configuration and execution.
  - Life Cycle Management and slicing life cycle management.
  - Scalability.
  - Closed loop functions.
  - Monitoring.
- Network Slicing as dedicated network for UC communication
  - QoS and service prioritisation
- Service web portal:
  - Service design and creation tool.
  - VNFs onboarding, service composition and service deployment.
  - Service Operation and experimentation.
  - Monitoring tool.
  - Data collection tool.
  - 5G testing tool.
  - KPI analytics & performance tool.
  - Service catalogue.
- Interworking framework:
  - (multi)-site network service orchestrator.
  - (multi)-site catalogue and site inventory.
  - Run-time configurator.
  - Data collection.

As a site specificity, as the cluster is based on 5G-EVE pillars, will use OAI (OpenAir4G/5G) and Mosaic-5G Software Alliance broadly focuses on the evolution of 3GPP Cellular stack.

- Radio network Elements:
  - OAI 4G5G RAN platform, implementing several RAN entities, including 5G capabilities
  - USRP N310: performance RRU equipment, suitable for implementing 5G NR, proposes high processing bandwidth.
  - 4G/5G BBU, MAC, RLC and RRC are based on SW processing.
  - 4-Port panel antenna(N78 TDD band).
  - Frequency bands 4G/5G:

  - Technology supporting slice (NR/LTE):FlexRAN.
- Core network elements
  - OAI core network, 3GPP EPC & 5G CN.
  - MEC instantiation.
- Orchestration and automation
  - ONAP.
  - OSMv5 or OSMv6.
- Virtualisation capabilities: OpenStack, K8S.
- OAI CI/CD framework: Git.
- OAI testing tool.
- 4G5G Interfaces
  - S1, F1, X2, N, FlexRAN.
- Compute servers for CN and MEC deployment in AIM, including analytics capabilities.
- Monitoring tools, such as Prometheus and Grafana.
- Interconnection
  - IPsec to French cluster.
  - MPLS/VPN between Bucharest Cluster and AIM site.

4.2.3 UC # 4.2 – Energy metering for LV

The LV energy metering UC is depicted in section 3 as a service application, addressing mMTC capabilities of the network from the 5G-PPP perspective, with a high density of users/devices, consuming a low volume of data at low bit rate per device, with no mobility required. For the UC demonstration and validation from the vertical view, the KPIs described in aforementioned section should be achieved.

4.2.3.1 Integration capabilities

The energy metering UC, as described in section 3.6.2, consists of a network service slice having mMTC capabilities without mobility. The radio modules embedded in metering devices have different access capabilities, according to the relevant technology footprint. All metering devices, from generation or consumption endpoints, are connected to a telemetry platform. Even if there are 10k devices per 10 km^2, the application is built on algorithms, which avoid the connectivity with all of them at the same time. The network slice is deployed from the get-go, with the possibility to scale-out in case of further development of the energy grid. The UC is requiring mMTC communication, high availability and KPIs as described in Table 3-30 and is enabled by the following integration capabilities list:

- Network infrastructure elements integration and specific configuration for service assurance
  - Virtualisation capabilities, orchestration and service instantiation.
  - Network and service monitoring tools.
  - Servers and servers management.
- Communication Service Design (Web tool capabilities).
- 5G network availability to support UC service requirements.
  - 5G RAN, 5G CN.
  - SDM/HSS or UDM and SIMs provisioning for the service.
  - Specific VNFs availability and VNF integration requirements.
- 4G/5G Radio spectrum and radio resource allocation.
- Cloud Application and analytic system for data traffic.
  - Data Analytics solution and algorithms.
- UE Equipment integration for basic activities
- Perimeter of service instantiation and service availability
  - Outdoor network availability and performance.

- Service security and proper data protection
- E2E service provisioning, network slicing capabilities, e.g. mMTC network slice.
- E2E connectivity integration, for infrastructure's servers, UC applications and tools
- Network capacity monitoring, resource provisioning, monitoring and resource assurance
- Network Provisioning in two phases:
  - Phase 1: 4G LTE, 5G NSA network provisioning.
  - Phase 2: 5G SA network provisioning.

4.2.3.2 Facility-specific requirements

The UC implementation and validation requires facility capabilities for service, slice and communication network delivery, components developed and deployed through the 5G-EVE project and the specific extension to the Romanian cluster, deployed in Bucharest and Alba Iulia. The requirements are listed following a bottom up approach, starting from physical requirements to service communication design and delivery:

- Physical infrastructure deployment, including:
  - Radio network.
  - transmission network between components.
  - L2/L3 network elements.
  - Servers.
  - HW for functions that can't be virtualized (OAI RAN).
- Secured connectivity link between 5G-EVE Paris Cluster and Romanian facility.
- Virtualised infrastructure for the CP and data plane layer, for VNFs and PNFs, including VIM and SDN controller.
- Virtualised infrastructure deployment in Alba Iulia, compute nodes integrated with Bucharest already existing site, ETSI MANO level.
- Management and orchestration capabilities for resources, service and slice orchestration
  - Infrastructure monitoring tools.
  - Service configuration and execution.
  - Life Cycle Management and slicing life cycle management.
  - Scalability.
  - Closed loop functions.
  - Monitoring.
- Network Slicing as dedicated network for UC communication
  - QoS and service prioritisation.

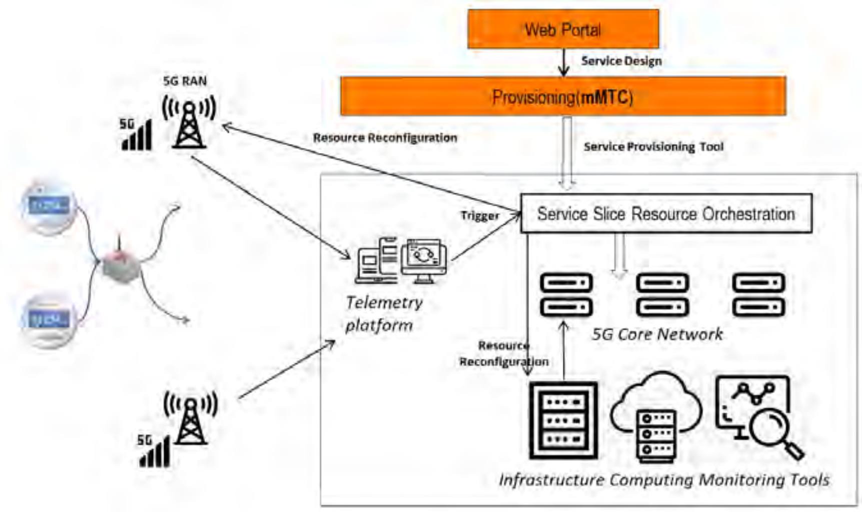


Figure 4-16 Energy 5G-EVE – Integration capabilities

- Service web portal
  - Service design and creation tool.
  - VNFs onboarding, service composition and service deployment.
  - Service Operation and experimentation.
  - Monitoring tool.
  - Data collection tool.
  - 5G testing tool.
  - KPI analytics & performance tool.
  - Service catalogue.
- Interworking framework:
  - (multi)-site network service orchestrator.
  - (multi)-site catalogue and site inventory.
  - Run-time configurator.
  - Data collection.

As a site specificity, as the cluster is based on 5G-EVE pillars, will use OAI (OpenAir4G/5G) and Mosaic-5G Software Alliance broadly focuses on the evolution of 3GPP Cellular stack.

- Radio network Elements
  - OAI 4G5G RAN platform, implementing several RAN entities, including 5G capabilities.
  - USRP N310: performance RRU equipment, suitable for implementing 5G NR, proposes high processing bandwidth.
  - 4G/5G BBU, MAC, RLC and RRC are based on software processing.
  - 4-Port panel antenna (N78 TDD band).
  - Frequency bands 4G/5G.
  - Technology supporting slice (NR/LTE).
    - FlexRAN.
- Core network elements
  - OAI core network, 3GPP EPC & 5G CN
- Orchestration and automation
  - ONAP.
  - OSMv5 or OSMv6.
- Virtualization capabilities
  - OpenStack, K8S.
- OAI CI/CD framework
  - Git.
- OAI testing tool
- 4G5G Interfaces
  - S1, F1, X2, N, FlexRAN.
- Compute servers for CN deployment in AIM
  - Including analytics capabilities.
- Monitoring tools
  - Prometheus, Grafana.
- Interconnection
  - IPsec to French cluster.
  - MPLS/VPN between Bucharest Cluster and AIM site.

4.3 5G-UK Cluster

4.3.1 UC # 1.2 – Future Digital Mobility (Transportation and Media)

In this UC, three PoPs will be considered for the evaluation including the Temple Meads Train Station, the Millennium Square – located at the city centre of Bristol – as well as at University of Bristol (**UNIVBRIS**). These locations have been selected to validate the proposed concept over scenarios with varying degrees of mobility, density and service requirements. These PoPs will be enhanced with purposely developed CDN platforms supporting AR/VR applications and are available to 5G-VICTORI through **MATI** and **UHA**. These applications were described in previous sections.

It is important to mention that considering a railway station as part of the demonstration in Bristol introduces a project risk. At this point in time in the project, we are starting the dialogue with Network Rail and the GWR railway operator to obtain a hosting and data sharing agreement so that we could include a railway station such as Bristol Temple Meads. Until we obtain the hosting agreement with a railway operator, this activity entails some level of risk. Meanwhile, our mitigation plan is to provide the mobility between MShed to Millennium Square which requires some network roll-out/expansion instead of the route between the Temple Meads railway station and Millennium Square.Integration capabilities

- ***UNIVBRIS Integration capabilities***

The University of Bristol's Smart Internet Lab owns and operates a wide range of network and telecommunication infrastructure in the Bristol urban area. This infrastructure has been used successfully for numerous UK and Horizon 2020 projects and will contribute to 5G-VICTORI. The technical capabilities and geographical coverage of the infrastructure can be summarised as follows:

- Smart Internet Lab office.
- Millennium Square public precinct.
- M-Shed museum.
- Temple Meads train station (Will be extended).
- VR Lab and Watershed development centres.

The technical capabilities of each site vary. However, in general, the equipment distributed around the network can be adjusted and the university can support:

- 3GPP LTE-A cellular network (2.6 GHz licensed band).
- 3GPP 5G cellular network (3.5 GHz licensed band).
- 802.11ac Wi-Fi (2.4 GHz / 5 GHz unlicensed band).
- Configurable backend data paths using routers & switches (i.e. IP networks & VLANs).
- Fibre & Wireless (26 GHz licensed band) mesh transport BH network.

In short, this network provides access to wide reaching urban dark fibre network, with configurable private cloud compute resources and wireless access, either at the edge or centralised in the Smart Internet Lab office.

Figure 4-17 Map overview of the sites in Bristol

The Smart Internet Lab office is the central node of the **UNIVBRIS** infrastructure network. It is the main termination point of the lab's urban fibre network, which extends to a wide range of sites across the city and continues to expand with new projects. The lab hosts a small datacentre of privately operated compute sources, capable of hosting VNFs along with onward Internet connectivity. This is the location for our central cloud network solution. The lab space has further access capability to a range of different fixed Wi-Fi access points (configurable as a part of the testbed), backend SDN-capable Ethernet switches, and small-cell LTE-A eNBs. This space is used to validate applications before trials in the open space at other locations.

Millennium Square is a public precinct operated by the We The Curious science museum. The museum serves as a partner to the university by offering physical colocation services within their building, and telecoms easements for our fibre network distributed across their estate. The museum has also proven itself to be an invaluable meeting/conference/demo location.

This location provides several IT racks spaces for connectivity back to the Cloud Core Network and reach to each of the many installed access points around the Millennium Square. The public square contains large ventilation towers, which six of them are used by the lab for hosting various radio air-interface equipment such as Wi-Fi access points, 26 GHz mesh radios and LTE eNBs. Depending on the radio interface, coverage generally covers the entire public square area.

The M-Shed is local council-run history museum. It is located approximately opposite the We The Curious Millennium Square precinct. Bristol harbour exists directly between the sites. However, pedestrian footpath routes are available in-between. Outside the museum is a former dockyard railway space, which is suitable for simple outdoor activities.

This site houses our 5G NR radio for outdoor coverage towards the harbour and the Millennium Square. It also houses Outdoor LTE and Wi-Fi Access along the waterfront and indoor LTE and Wi-Fi Access coverage for indoor services used to evaluate business solution as part of Smart Tourism projects.

VR Lab and Watershed are development sites used to located edge computing and possible access nodes per research project. A default capability for this site is:

- Dark fibre connectivity to the network in Mesh formation.
- L2 optical switch plus a router.
- Local server as a compute node.
- Radio access per project demand.

Temple Meads is the primary railway hub for the city of Bristol. It is located approximately 1 km away from the previously mentioned museums. Directly next to the station is the under-construction site of the new University of Bristol Temple Quarter campus, which will host a wide array of technical research centres including the Smart Internet Lab.

As of Q4 2019 the technical capability of the overall testbed includes:

- NFV Hosting: NFV has been a main line of research of the lab and, as such, it possesses a wide range of servers as compute nodes. These compute nodes are readily configurable, and able to support services such as OpenStack, OSM and other platforms according to the requirements. The hosting infrastructure is split across numerous high-powered 'generic' servers in the central lab office, to more 'edge-focused' nodes that can be deployed for low-latency applications.
- Fibre & Wireless (26 GHz licensed band) Mesh transport BH network: The lab owns and operates a dark fibre, which (in addition to other sites not mentioned here) connects the lab's central office with the We The Curious & M-Shed museums. These fibre runs are generally over-provisioned, so capacity planning is relatively simple and available. Furthermore, the length of these runs is sufficiently short that signal attenuation is not generally a concern and repeaters are not required.
- Configurable back-end data paths using routers & switches (i.e. IP networks & VLANs): Beyond optical connectivity, the testbed utilizes a network of SDN-capable switches from Edgecore and Corsa running PicOS. These switches support OpenFlow configuration as required and can

provide simple point-to-point connectivity or more advanced SDN features. For more advanced IP requirements, a centralised Nokia Service Router 7750 exists in the lab office.

- Radio/Air Interface Modes: The lab's central office and museum sites all provide access to 3GPP LTE-A cellular network (2.6 GHz licensed band), 3GPP 5G cellular network (3.5 GHz licensed band) and 802.11ac Wi-Fi (2.4 GHz / 5 GHz unlicensed band).

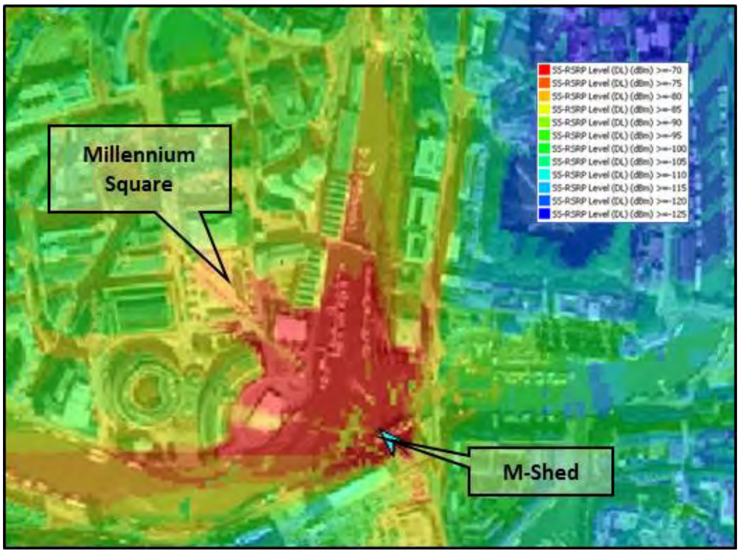


Figure 4-18 Outdoor coverage for 5GNR cellular network around M-Shed and Millennium Square

The precise configuration of these access networks depends on the UC requirements. These highly flexible networks are centrally managed and integrated, allowing varying degrees of mobility between APs and access-modes.

In addition to these network modes, the lab has deployed a prototype 5G non-standalone single-cell network at M-Shed, which is still undergoing testing and integration. This 5G NR cell coverage is shown in Figure 4-18 indicating seamless coverage of the service between the two museums around Millennium Square and the MShed.

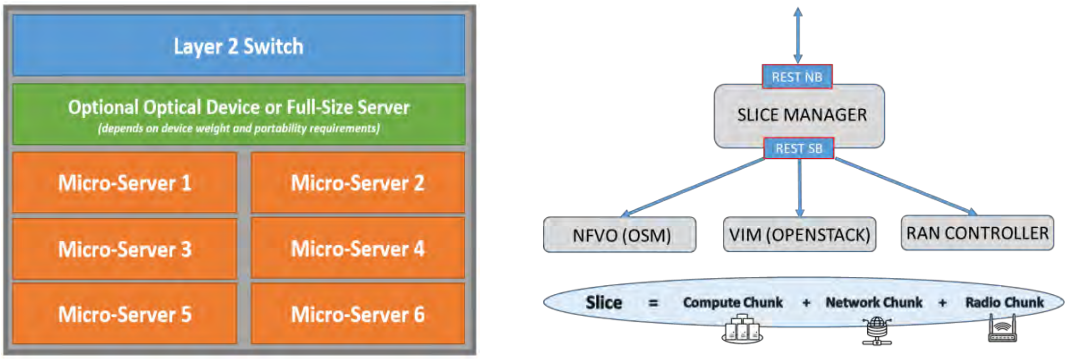
- ***Zeetta's Integration Capabilities***

The UC will demonstrate on-demand composition and operation of short-lived application specific networks (or pop-up 'network on-demand'). With pop-up network on-demand, a network can be instantiated for a short time period in order to provide specific services to passengers specific to that time and geolocation. Zeetta Networks (**ZN**) will provide three (3) Rapide platforms to be deployed at various locations in Bristol (as required for the demos). Power and connectivity requirements are to be clarified as is the specific Rapide platform configuration. It is envisaged that the platform will contain a combination of wired connectivity (via a Layer-2 Switch) and compute infrastructure (multiple servers), this is shown in Figure 4-19a.

The pop-up network has the capability to integrate with infrastructure around stations such as IoT, Information Systems and wireless infrastructures.

- ***Digital Catapult's Integration Capabilities***

Digital Catapult's (**DCAT**) 5G Testbed is a three-site facility, geographically distributed across Brighton and London, technologically complete E2E, equipped with commercial and open source protocol stacks, offering open access and technical support to third party companies that want to test and develop 5G-enabled services and applications. The three sites are interconnected with 1 Gbps links. In addition, the London node is interconnected with 5G UK through the 5G UK Exchange. DCAT will be offering a pop-up network/network-in-a-box based on Amarisoft, a SDR platform, to provide 5G-NR connectivity on demand in one of the three locations identified. This will be connected with one of the Rapid boxes that would provide the edge computing capabilities required by the UCs.



a) b)

Figure 4-19 a) Outline of the Zeetta Rapide platform with suggested layout, b) i2CAT's Neutral Host Platform

- ***i2CAT's Integration Capabilities***

i2CAT's Neutral Host platform enables the on-demand instantiation of network slices, including the management of radio and compute resources and the orchestration of services. Figure 4-19b depicts the logical architecture of the platform.

At the radio part, the centralised SDN RAN controller can actually handle the deployment and control of Wi-Fi (access and mesh BH) and LTE (Accelleran Small Cells) technologies, by means of the NETCONF protocol. Also, during the execution of 5G-VICTORI, it is planned to integrate 5G NR RAN using Amarisoft's SDR solution. In the case of the Wi-Fi RAN, the centralized CP can deploy different virtual Access Points over a single physical interface and manage their available wireless channel consumption, thus enabling slicing and multi-tenancy features. In addition, SDN controlled data paths through the mesh BH can be established in order to route traffic to specific nodes (i.e. gateways to the Internet or to MEC devices). Finally, it implements a cRRM solution, which allows to control the UE assignment among the deployed Wi-Fi APs, thus enabling seamless mobility according to service performance (e.g. mobility based on the performance or the location of the demanded content). On the other hand, in the case of the LTE RAN, slicing is accomplished by dynamically instantiating up to 5 different PLMNIDs in a single Small Cell, each of them attached to a vEPC deployed in edge or cloud compute nodes by means of the slice manager.

The compute part is based on a single OpenStack VIM, which manages compute nodes distributed through availability zones, and OSM as the service orchestrator. VNF mobility can be accomplished by moving VNFs between compute resources managed by the same VIM.

Finally, both the RAN and the computing parts can export telemetry data using Prometheus framework. Thus, their metrics can be integrated into the 5G UK Cluster (e.g. by means of federation).

4.3.1.1 Control Plane and Orchestration Integration

With regards to the software components, SDN Network Operating Systems (e.g., ZN NetOS™, OpenDayLight, ONOS, etc.) control the network elements to forward and steer network traffic and NFV VIMs (e.g., OpenStack, OpenVIM, AWS, VMware vCloud Director, etc.), manage the compute resources in the access and core networks. The orchestration of the network and compute resources and the life-cycle management of the services in each edge (access or core) is handled by edge orchestrators. The edge orchestrators can coordinate with the Multi-edge orchestrator to provide E2E services across the access and core networks. 5G-UK Exchange as a multi-domain orchestrator may be integrated and upgraded to support multi edge orchestration and mobility.

5GUK Exchange (5GUKEx) is a novel hierarchical architecture to enable E2E orchestration among multiple network administrative domains with minimum overhead in complexity and performance. 5GUK Exchange allows operators to plug-in their ETSI NFV standards compliant NFV Management and Network Orchestration (MANO) systems.

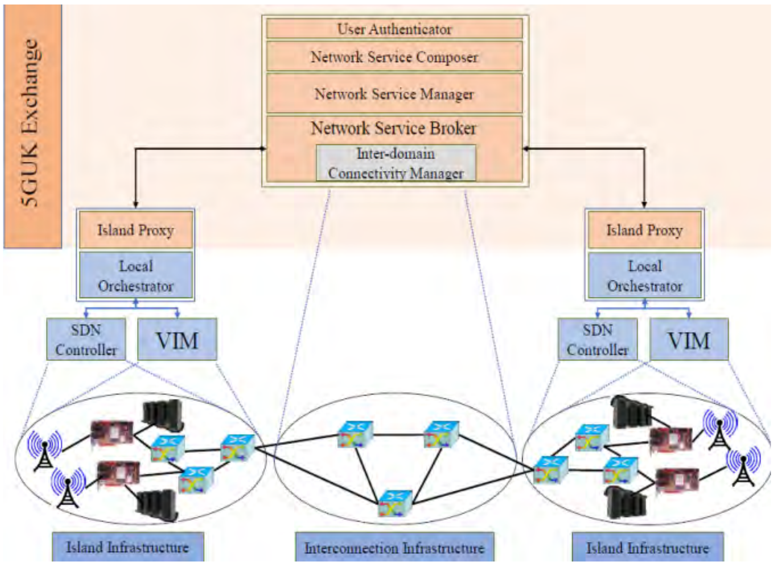


Figure 4-20 5G UK Exchange Architecture

Figure 4-20 shows the architecture of 5GUKEx involving multiple components on top of MANO systems at each test network site. *Island Proxy* uses the NBIs of the MANO system to communicate with the *Network Service Broker (NSB)*.

On deployment of NS on each test network, the endpoints are shared with the *NSB.* The Inter-Domain Connectivity Manager (*IDCM*), uses the endpoints to establish the network connectivity between the participating test networks.

The current design of 5GUKEx is based on the earlier version of ETSI NFV MANO systems and would potentially be upgraded to the latest ETSI NFV standards. In addition to this, for 5G-VICTORI project, the APIs of 5GUKEx will be extended to include an NFV slicing and mobility manager, multi-edge monitoring system and further components as required for the use-case deployments. The upgraded and newly added components will be defined in deliverables D2.5 and D2.6.

4.3.1.2 Facility-specific requirements

- ***UNIVBRIS Facility-specific requirements***

The current Test Network provides a highly flexible cloud network compute resources that can be configured at the centre or edge of the network. This flexible configuration capability is delivered using a range of SDN enabled switched supported along with a high-end service router 7750 solution. The access networks created at various location are only created as temporary network slices per project using commercial grade radio solutions and on certain projects, we use the prototype solutions in the field to validate a technology. The test Network technology refresh programme is currently looking to supplement the outdoor 5G NR + LTE coverage around Millennium Square and M-Shed with similar indoor access capability at the Smart Internet Lab. Subject to 5G-VICTORI project requirements, this lab is also planning to extend its outdoor radio access coverage and reach into the Temple Meads railway station. This extension intends to provide the same sort of technologies as the existing sites will grow from an existing University of Bristol connection in the Engine Shed business incubator site adjacent to the station. The timeline for this expansion is dependent on project demand. However, a rough estimate would be for work to begin the second quarter of 2020, with completion possible by early 2021.

- ***I2CAT's facility-specific requirements***

As was done in 5G-XHaul and 5G-PICTURE, the SDN Wi-Fi solution of i2CAT can be integrated into 5G-UK Cluster in order to cover the Wi-Fi access of a specific zone. Also, a Wi-Fi mesh BH can be deployed in order to connect radio nodes (i.e. Wi-Fi or cellular) without a wired connection to the cloud or edge resources. This can be especially useful in the case of pop-up or MC networks where the RAN

HW is deployed on-demand in an ephemeral and unplanned way. In particular, I2CAT can provide 4 to 6 multi-radio single board computers (SBCs) to be integrated into the Bristol infrastructure.

Regarding the cellular RAN, LTE and 5G NR nodes are more difficult to deploy on-demand due to regulations (e.g. available spectrum) or physical limitations. In any case, the Accelleran SCs already deployed in Bristol can be integrated in the neutral host platform by means of a firmware upgrade to enable centralized management via NETCONF protocol.

Finally, the acquisition of MEC devices and its integration into the 5G-UK Cluster is also foreseen; the concrete specifications of these compute nodes will depend on the requirements of the services to be deployed in the different UCs.

4.4 5GENESIS Cluster

The 5GENESIS architecture of the Berlin platform is shown in Figure 4-21[3]. It shows the components of the main three layers at the different phases. The 5GENESIS Platform integrates HW and SW prototypes, and provides customised, sliced network services to verticals based on 100 Gbps optic fibre backbone. It features interconnected macro-base stations with the macro-nodes edge DCs collocated with micro-base stations. It also targets ultra-dense areas covered by various network deployments like the Berlin Central station facility (also denoted as *Berlin Hbf*). The KPIs for the various UCs discussed in Section 3 will be validated within a large-scale, dense environment. Within that scope, the main focus will be put on the following KPIs: User density, Reliability, Service creation time, and Data rate.

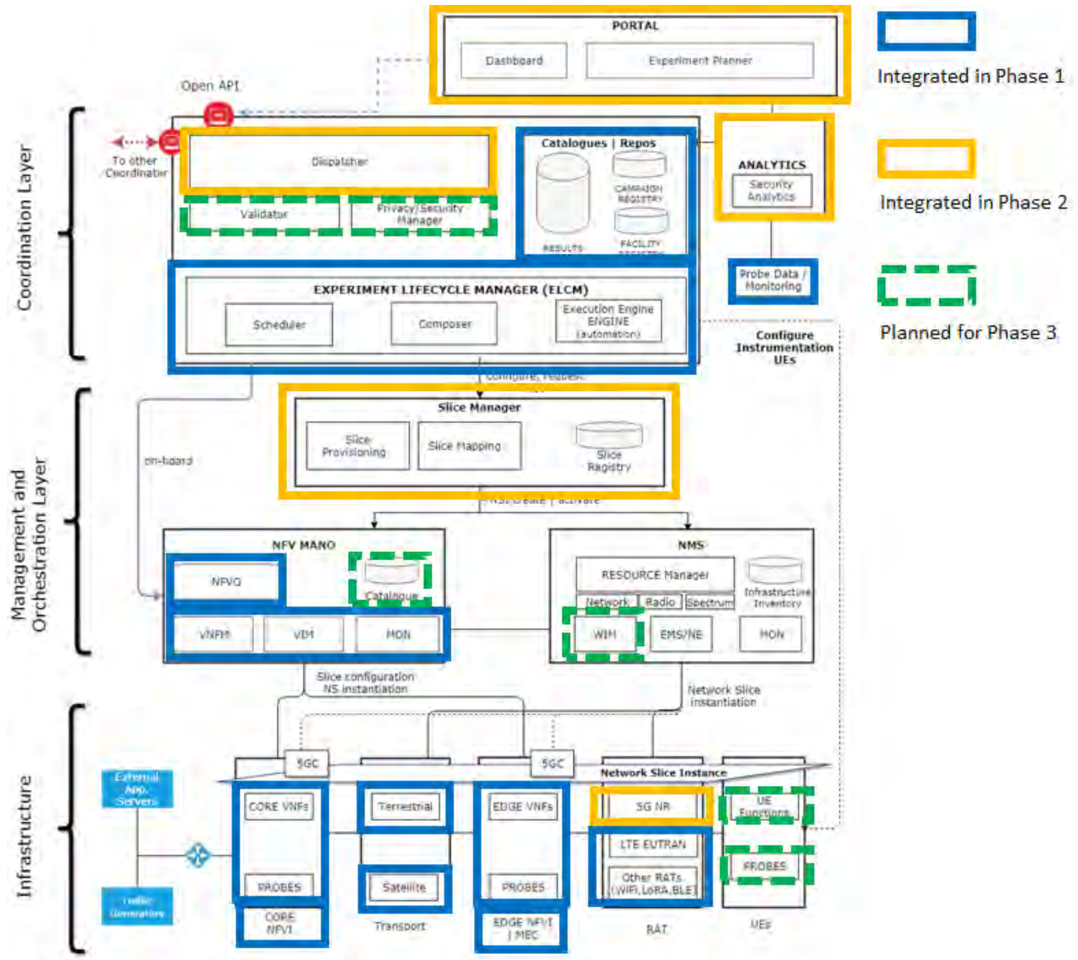


Figure 4-21 Instantiation of the 5GENESIS Architecture for the Berlin Platform [16]

[3] As of the current status at the time this deliverable was written, i.e. as captured in 5GENESIS deliverable D4.14 [16].

Figure 4-21 shows the instantiation of the 5GENESIS architecture from the perspective of the Fraunhofer FOKUS (**FhG**) side, representing the central hub of the Berlin Platform, where most of the central components such as Open5GCore, Slice Manager, and Coordination Layer components will be deployed. The Fraunhofer FOKUS site is equipped with state-of-the-art technologies consisting of sophisticated and high performance DCs, indoor and outdoor deployment of the components for internal testing and validation.

The 5GENESIS Platform Architecture consists of the three layers:

- **Coordination Layer**: this is a common layer for all Berlin 5G-VICTORI Cluster facilities. The corresponding software components are solely instantiated at each facility. The Experiment Lifecycle Manager (ELCM) provides the common agreed layer in each UC interfacing project-wide, common coordination layer components and site-specific realizations of the lower layers.
- **Management and Orchestration Layer**: The MANO Layer of the 5GENESIS architecture comprises three main components, namely: NFV MANO, Network Management System (NMS), Slice Manager. The NFV MANO functionally is realised via OSM and OpenStack. The VIM is provided by OpenStack, the standard de-facto VIM in the one conformant to ETSI NFV specification. The NMS is a platform-specific NMS with direct access to physical resources as well as configuration interfaces. In the Berlin platform, the NMS will provide the overview of the physical resources and an interface to man-age them.
- **Infrastructure Layer:** The Infrastructure Layer covers the core infrastructure components, the transport network components, as well as those belonging to the RAT. It summarises as well the devices and networking elements that encompass the core infrastructure used for experimentation.

Figure 4-22 Fraunhofer FOKUS site, where the core infrastructure is deployed

4.4.1 UC # 1.2 – Future Digital Mobility

The proposed application will provide passengers with indoor and outdoor station guidance and multi-modal transport journey planning beyond train stations. The aim is to efficiently connect stations with the rest of the urban transport network, boost on efficiency, potentially cut from journey time and cost, and help to reduce emissions. Information on passengers' location, movement, destinations and personal preferences will be collected.

Unlike in the UK, where next generation alternative urban transport options (see electric scooters) are not yet allowed, Germany offers an ideal environment for development and trialling with potential partnering opportunities with such transport operators and existing datasets.

The proposed solution will offer benefits of both commercial and non-commercial nature. The analysed data in regards to user location and mobility can be sold to organisations such as municipalities, and other commercial verticals like train operators, alternative urban transport operators, and also insurers. In emergency situations the solution can create and manage network slices.

Passengers involved in the trial will arrive at *Berlin Hbf* by train with the front-end app pre-installed on their phones. The app will connect to the 5G Edge, where the back-end will run, and download the station's spatial digital twin (3D). At front-end (app) the 3D twin will be rendered and overlayed on the smart phone's live camera feed, and thereby help the passenger to orientate inside and around the station.

Passengers will appoint travel goals through the app, where the back-end will build an optimal travel route, starting from the station, highlighting the appropriate exists to use, considering disability and other personal details such as the number of luggage bags, if traveling with children, if grabbing a coffee should be an intermediate goal. Live connecting transport data (other trains, buses), that is necessary for the further travel route planning, to be sourced and collated at the backend. A full route/journey plan, which updates as the transport situation changes, will be visualised through the App, which shall be followed by the passenger with the help of the live guidance.

The application will consider the environmental footprint of each connecting transport option beyond rail, and propagate such (with priority) towards the passengers.

4.4.1.1 Integration capabilities

- ***FhG FOKUS's integration capabilities***

FhG FOKUS's Open5GCore is a SW platform that implements 5G Stand-alone Core Network (5GCN) functions as standardised by 3GPP. By deploying and configuring the Open5GCore 5GCN along with a 5G RAN (NG-RAN) and by provisioning 5G-capable UEs in the network, E2E connectivity can be enabled between a UE and a data network. Applications enabling the digital mobility UC can be run with the client side on the UE and the server side in a local data network.

- ***IHP's integration capabilities***

IHP facilities allow the assessment of wireless communication systems in different scenarios within the IHP premises. Moreover, it is currently an "island" of the 5GENESIS Berlin Platform, where experiments can be carried out both indoors and outdoors for the evaluation of these systems in real conditions.

The connectivity between FhG FOKUS and IHP allow the deployment of virtual instruments for the remote characterization of wireless systems and, hence, for the evaluation of KPIs. For this specific UC, IHP can provide access technologies (Sub-6 and mmWave) to be attached to the edge deployment at the railway station.

- ***UHA's integration capabilities***

UHA's cloud backend is a multi-node GPU server, up to 8 nodes (4 Nvidia RTX 2080 + 4 GTX 1080) that as a whole or in part is movable to the locations of the 5G-VICTORI demonstrators. Such backend can be linked to the 5G edge computing to make the spatial and transport data synchronisation happen. Connectivity either through FhG FOKUS premises or a DBN dedicated server room.

- ***DBN's integration capabilities***

DBN is the operator of a large railway system and for integration will provide access to some of their stations in the Berlin area and set up test equipment for the 5G-VICTORI demonstrators. Besides equipping the stations there will also be some trains of DB Regio equipped with the test systems that run on the area of the Berlin cluster demonstrator. Within the trains some rack space and mounting possibilities will be offered. Within the Central Station a set-up for the antennas has to be planned which does not interfere with the current homologations of the German Railway Authority (*Eisenbahnbundesamt*). The servers and other technical equipment will be placed in one of the server rooms available at the station.

For all UCs, a first integration test could be performed at the Advanced Train Lab and the Living Lab close to *Annaberg-Buchholz*, where DB operates a large scale testing facility for infrastructure and on-board systems that can be placed on an ICE train.

4.4.1.2 Facility-specific requirements

The following would be required to enable the UC at the *Berlin Hbf* site. Depending on space concerns as well as available network infrastructure between sites, CPU (or GPU) resources could be located at the Berlin Hbf site or at the FhG FOKUS site:

- One or more 5G-capable smartphone UEs for the client side of the UC application.
- NG-RAN deployment at Berlin Hbf with coverage of the area relevant to the UC application.
- Compute resources at Berlin Hbf (if space allows) or FOKUS (if network connectivity allows) to host Open5GCore 5GCN with IP connectivity to NG-RAN.

CPU and potentially GPU resources at *Berlin Hbf* (if the 5GCN is also there) or FOKUS to host server side of UC application with IP connectivity to the 5GCN.

4.4.2 UC # 1.3 – Rail Critical Services

4.4.2.1 Integration capabilities

- ***FhG FOKUS's integration capabilities***

FhG FOKUS's Open5GCore is a SW platform that implements 5GCN functions as standardised by 3GPP. By deploying and configuring the Open5GCore 5GCN along with an NG-RAN and by provisioning 5G-capable UEs in the network, E2E connectivity can be enabled between a UE and a data network. In the rail critical services UC, this connectivity would support the client-server communication of the MC applications provided by Kontron.

- ***KCC's Integration capabilities***

The implementation of Rail Critical UCs requires specific facility capabilities to enable MC Railway Telephony, like operational voice, private and group communication with PTT, emergency group communication and other MC Railway Data Service like alerting in case of railway emergency, enhanced location railway service and operational messaging, essential for safe railway operation. These services are based on MC voice, data and video communication (MCX/pre-FRMCS) used by MC on-board applications such as train signaling or on-board cab radio. These services need to be provided to the applications by the facility over a 5G network. Enabling these capabilities in the facility requires the integration of MCX/pre-FRMCS Kontron's solution, including MCX Application Server and IMS-based SIP core with the 5GC. The execution of the Rail Critical UC relies on introducing MCX/-pre-FRMCS capable clients such as railway onboard app or dispatcher app as well.

4.4.2.2 Facility specific requirements

The implementation of UC # 1.3 requires facility capabilities for service, slice and communication network delivery. The components developed and deployed by 5GENESIS, together with extensions brought by the 5G-VICTORI project, will facilitate the extension of the Berlin platforms to deployments at the Berlin Central Station (*Berlin Hbf*), and, most probably, to stations such as *Jungfernheide* and *Berlin-Rummelsburg*.

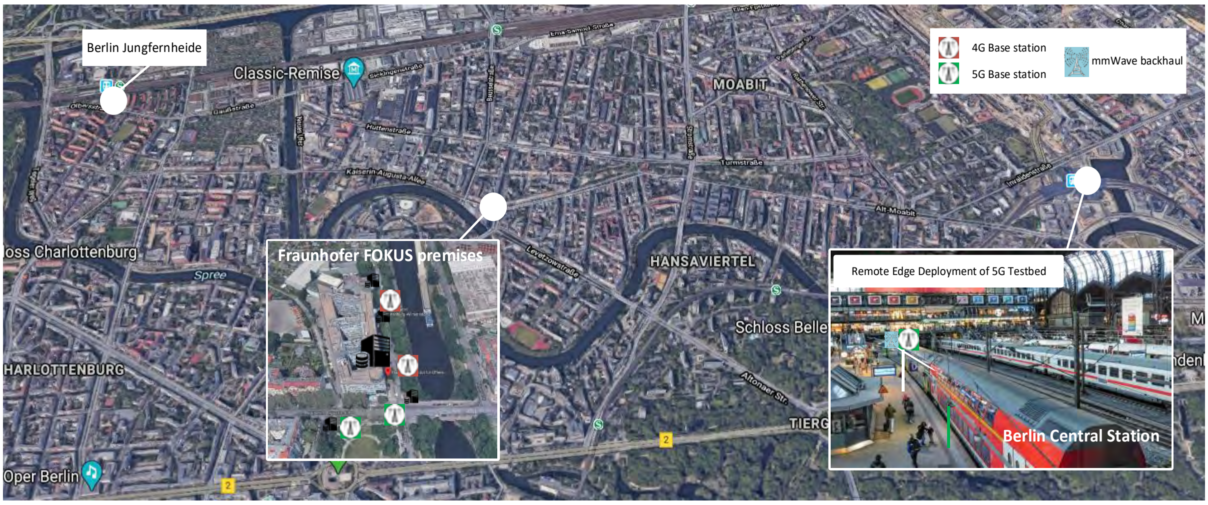


Figure 4-23 Local area of Berlin Cluster

The requirements are listed as a bottom up approach, starting from physical requirements to service communication design and delivery:

- Physical infrastructure deployment, including:
  - Radio network.
  - transmission network between components.
  - L2/L3 network elements.
  - Servers and MEC.
  - HW for functions that cannot be virtualised (OAI RAN).
  - On-board components (router, OBG, on-board systems, handhelds, CCTV, 5G UEs, antennas, power supplies, SIM cards, etc.).
  - Station components (router, dispatcher terminal, power supplies, etc.).
- Secured connectivity link between 5G Berlin Cluster and Berlin Central Station.
- Virtualized infrastructure for control plane and data plane layer, for VNFs and PNFs, including VIM and SDN controller.
- Management and orchestration capabilities for resources, service and slice orchestration.
  - Infrastructure monitoring tools.
  - Service configuration and execution.
  - Life Cycle Management and slicing life cycle management.
  - Scalability.
  - Monitoring.
- Network Slicing as dedicated network for specific UC communication.
  - QoS and service prioritisation.
- Service web portal:
  - Service design and creation tool.
  - VNFs onboarding, service composition and service deployment.
  - Service Operation and experimentation.
  - Monitoring tool.
  - Data collection tool.
  - 5G testing tool.
  - KPI analytics & performance tool.
- Interworking framework:
  - (multi)-site network service orchestrator.
  - (multi)-site catalogue and site inventory.
  - Run-time configurator.
  - Data collection.

- MCX/pre-FRMCS rail framework:
    - IMS-based SIP-core.
    - MCX/pre-FRMCS Rail Application Server.
    - Rail Dispatcher Application Server.
    - MCX/pre-FRMCS provisioning.
    - MCX client application for smartphones.
    - MCX client stack for integration with 3rd party rail applications.
    - Rail Dispatcher client.

4.4.3 UC # 3 – CDN services in dense, static and mobile environments

4.4.3.1 Integration capabilities

- ***FhG FOKUS's integration capabilities***

FhG FOKUS's Open5GCore is a SW platform, which implements 5GCN functions as standardised by the 3GPP. By deploying and configuring the Open5GCore 5GCN along with an NG-RAN and by provisioning 5G-capable UEs in the network, E2E connectivity can be enabled between a UE and a data network.

In the media UC taking place in Berlin, the 5G network enables high throughput transfer from a main media library or intermediate cache in the data network to the train-based cache via a train-based 5G UE.

- ***IHP's integration capabilities***

IHP is planning to integrate the necessary equipment for the backhaul connectivity from the platform to the train using its 60 GHz technology, assuming that the node inside the train will be attached to the window.

- ***RBB integration capabilities***

RBB will provide interfaces to its media library resources to allow for employing the used Multi-CDN infrastructure and the 5G testbed specific caching functionalities.

- ***IRT integration capabilities***

IRT advises its shareholders (the public broadcasters of Germany, Austria and Switzerland) on how to optimise the online distribution of their content for years. Accordingly, the Institute can draw on experience in relevant topics such as video coding profiles, bitrate adaptive streaming technologies and CDN infrastructures. IRT is currently working on a solution for its shareholders that will enable the dynamic control of content distribution via various CDN providers. This will allow a better response to price fluctuations and lead to more open competition in the CDN market. In addition, IRT is investigating the economic feasibility for its shareholders of building up their own CDN infrastructure in order to become more independent of CDN providers in the long term. IRT brings this experience to the project, in the development of the media delivery infrastructure based on the data shower principle. IRT will develop a media cache optimised for the intended use and a mechanism for cache prefilling. It will integrate the on-board cache infrastructure into the ARD's Multi-CDN infrastructure so that common ARD services (e.g. the ARD's video-on-demand service ARD-Mediathek) can use the infrastructure on the train without modification.

4.4.3.2 Facility-specific requirements

The 5G-VICTORI Media UC setup requires an E2E data rate for the station's private 5G network. This network should comprise a 5G base station and a 5G core network, able to support a ~2.8 Gbps downlink throughput for a single UE. Furthermore, the 5G UE used on the train for the connection to the private 5G network should also support a ~2.8 Gbps downlink throughput. The KPIs for the Media UC discussed in Section 3 will be validated within a large-scale, dense environment.

5 5G-VICTORI architectural proposal

5.1 5G-PPP Overall Architecture

Figure 5-1 shows the 5G overall Architecture as it has been defined by the 5G-PPP Architecture Work Group (WG), published in the latest White Paper [17] Taking advantage of the proposed architectural structure, one of the fundamental features supported is infrastructure slicing requiring continuous adjustment of customer-centric Service Level Agreements (SLAs) with infrastructure-level network performance capabilities. Since service customers such as vertical industries request new types of services from the Service Providers, Service Creation and Service Operation will have to demonstrate a very high level of automation for the lifecycle management of network slice instances with the use of an E2E framework.

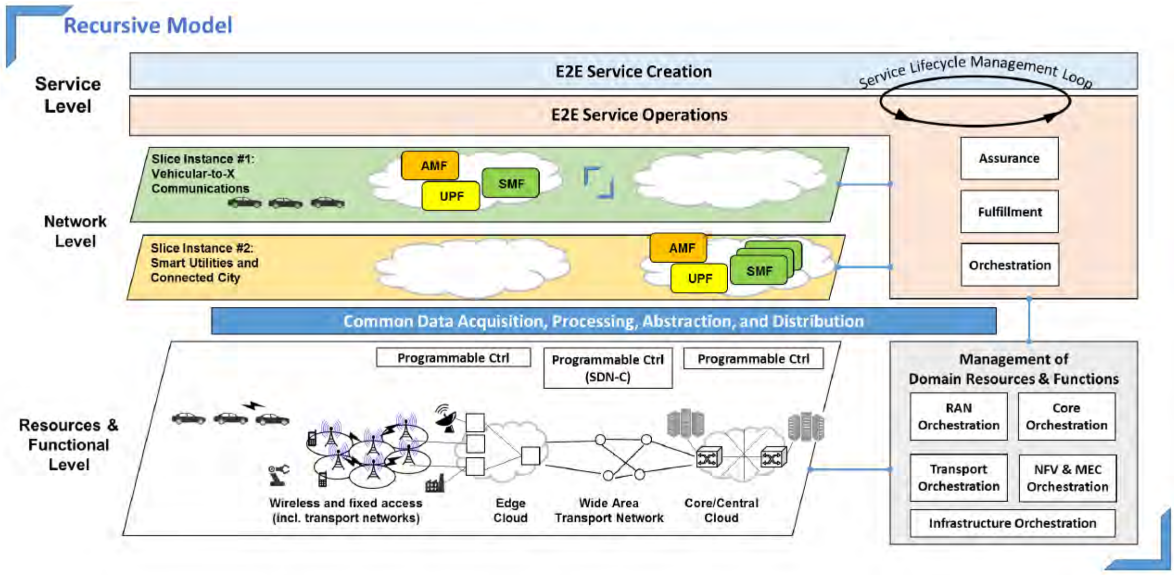


Figure 5-1 5G Overall Architecture [17]

5.1.1 E2E Service Operations – Lifecycle Management

Following the SW-platform infrastructure model [19], 5G targets to serve the "X as a service" concept, where X can be: infrastructure, SW and platform. Network slicing will be applied in order to meet the needs for customised, service-specific combinations of service components and network functions in all network segments. Service Developments Kits (SDKs) enable Lifecycle Management tools, offering reconfiguration or creation of new service versions. In order to meet the QoS expectations for the service development optimisation, many H2020 projects have contributed with a variety of proposed SDK approaches. More specifically, the proposed SDKs are:

- A NFV-enabled SDK proposed by 5G-TANGO [20]. The project proposes an integrated vendor-independent platform where the outcome of the development kit which is packaged NFV forwarding graph of the composed services, is tested and validated automatically for posterior development with a customisable orchestrator that is compatible with common VIMs as well as SDN controllers in the market.
- 5G-MEDIA SDK [21], which includes an all-in-one UI that enables developers access all SDK tools from a single interface, FaaS emulation implemented with Lean OpenWhisk, CLI tools for unikernels and VNF/NS Emulation toolkit including service monitoring and profiling tools.
- The 5G-CITY SDK Toolkit [22] offers a set of features to help Virtual operators to easily design and deploy their service, and includes a graphical environment for composing functions in E2E services, an adaption layer and a validation module.

- MATILDA [23] designs and implements a holistic E2E services operational framework that tackles the lifecycle of design, development and orchestration of 5G ready applications and network services over programmable infrastructure.

The tools of the SDK for E2E service LCM are [17]: Descriptor Creation tools, Descriptor Validators, Packaging tools, NFVI emulators, Profiling tools, Optimization tools, Deployment tools and Monitoring tools.

5.1.2 Vertical-specific architecture extensions

5G systems can be flexibly extended and customised to serve the needs of vertical industries. Those extensions include energy utilities, vehicular communications, enhanced content delivery, as well as media production and delivery. Many research projects have been involved and have delivered an important outcome for the vertical-specific extensions, among them 5G-Xcast has developed a novel framework for content delivery [24] and 5G-MEDIA [21] has contributed in Function-as-a-Service technologies such as OpenWhisk, that play a key role in media production and delivery extensions.

5.2 Radio and Edge Architecture

5.2.1 RAN Architecture

The overall RAN architecture emerges as the outcome of the 5G-PPP Phase 1 consensus and the 3GPP Release specifications on NG-RAN. The architecture includes the Service Data Adaption Protocol (SDAP) layer, as well as the F1 interface with CU and DU split. Moreover, it is capable to provide small cell coverage to many operators at the same time “as-a-Service”, adopting a two-tier architecture, one distributed tier to provide low-latency services and a second centralized tier that provides high processing power for compute-intensive network applications. High virtualisation techniques, VNF placement and live migration are also included to enhance the architecture versatility. The proposed solution aims to virtualize and partition small cell capacity, as well as to support enhanced edge cloud services, thus enriching the network infrastructure with an edge cloud.

The CU split can be extended into the CP part and the UP part and can be implemented at different locations. The lower layer split is an additional split option which can be applied to the DU. Figure 5-2 depicts all possible options for decomposition of the RAN environment.

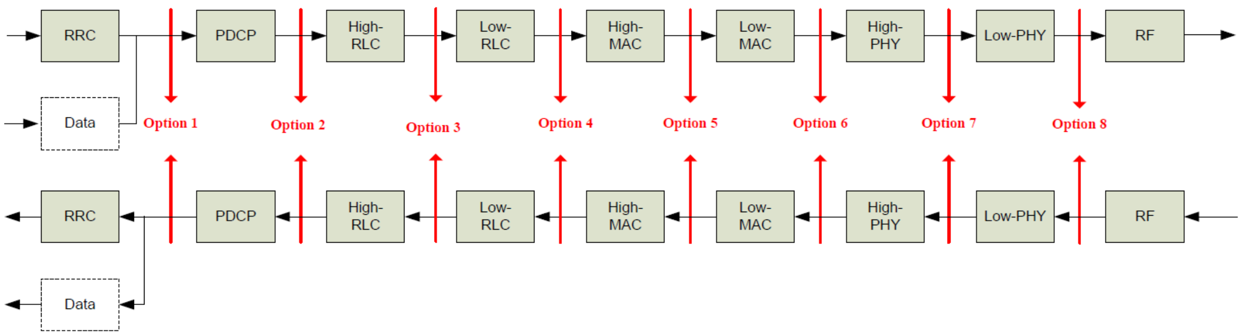


Figure 5-2 RAN functional splitting options [26]

5G-PPP has developed a series of innovative functional models that refine the RAN architecture and are outlined in detail in [17], such as the controller layer which enables RAN programmability.

Solutions supporting cooperation of different links are adopted to address challenging UCs including safety-critical vehicular communications while, in order to minimise latency between vehicles and road users in close proximity, local E2E paths are introduced.

As stated above, a number of 5G-PPP projects have contributed to the designation of the RAN architecture by proposing different architectures and approaches. 5G-MoNArch [27] proposes novel RAN slicing concepts, 5G-XCast [24] offers multicast and broadcast deployments in RAN and

BlueSpace [28] has proposed two Optical Beam Forming Network variants, namely a coherent and an incoherent.

The proposed RAN architecture enables the deployment of small cells that can be seen as a single small cell with no signaling cost with the 5G core. This is achieved through the adoption of a MEC model supporting of NFV allowing VNFs deployment in the cloud. Alternatively, small cells can be either directly connected to the 5G core through NG interfaces or can adopt dual connectivity modes, but at the expense of additional signaling requirements.

5.2.2 Edge Architecture

The Extended MEC (xMEC) hosting infrastructure includes edge computing functionalities involving virtualized MEC computing, networking and storage resources with the MEC Network Function Virtualization Infrastructure (NFVI) being its overlay. xMEC provides a set of VNFs as well as access to communication, computing and storage resources to service functions of multiple-domains in an integrated fashion and can accommodate all complex time critical functions, due to its physical proximity from the relevant network element.

5.3 Data plane and transport network infrastructure

5.3.1 5G access data plane

The 5G access data plane comprises a variety of heterogeneous resources that can be divided in three main tiers: the radio access, the edge nodes and the central DCs. All tiers aim at providing programmability features through abstraction of the underlying physical infrastructure that can be facilitated adopting the SDN model offering integration with the management and orchestration planes.

For the Radio access tier, 5G- PICTURE [29] offers a novel concept that adopts disaggregation of SW and HW components between wireless, optical and compute/storage domains. Resource disaggregation allows decoupling of the aforementioned components by creating a common “resource pool” from which individual network and compute resources can be selected independently and allocated on demand, in order to compose any infrastructure service. These solutions are based on HW programmability and network softwarisation.

The SDN architecture proposed by the 5GCity project [22] comprises three layers: WAN Resource Manager (The SDN Application), SDN Controllers (two types), and a data plane which involves Core NFVI, BH network, Edge NFVI, FH network, WLAN Access Points and LTE small cells.

5G-ESSENCE [30] proposed a Cloud Enabled Small Cell (CESC) environment that embodies a two-tier virtualised execution environment as a DC allowing SDN provisioning with a CESC Manager that triggers the SDN control plane operations. Finally, 5G-MoNArch [27] has contributed by envisioning the Controller layer for the RAN, which introduces RAN control functions as specific application implementations.

Non-RAN segments such as the Edge, the Core and the transport network, a programmable data plane is proposed as a means to provide network traffic slice QoS control in the data plane, thus enabling QoS-aware network slicing.

Regarding the **transport network** domain, a solution must be adopted that will meet the requirements of future RANs in terms of bandwidth, flexibility, and resource and energy efficiency.

5.3.2 Transport Network

In 5G Systems, there is a clear requirement for the provision of infrastructure connectivity from the Access Points to the Core Network, which is known as transport networks connectivity. Transport networks are a key element of 5G systems, thus providing the network fabric that interconnects network functions (NFs), CN and RAN, and the units of RAN. Since 5G enables new emerging services, new requirements on the transport networks must be met. For example, the RAN architectures adopt the Cloud-RAN concept that requires infrastructure connectivity within the RAN, for example between CUs and DUs, which is referred to as the FH. C-RAN can overcome the traditional RAN limitations, introducing the need to support new operational network services over the transport network. The transport connectivity can also support different RAN split options, allowing the decomposition of traditionally monolithic RAN processing functions stack to a set of different functional units.

5.3.2.1 Wireline technologies

A great challenge that needs to be addressed on the transport network is the connectivity between DUs and CUs using commonly digitised formats. These formats such as the Common Public Radio Interface (CPRI) and the enhanced CPRI (eCPRI), adopt more flexible interface options in the RAN, allowing the adaption of different functional splits between the DUs and CUs to UC requirements and transport network capabilities. Along with the digitised FH solution, attention is given to analogue FH solutions such as the Radio over Fibre (RoF) that offers reduced complexity, but also reduces architectural and connectivity flexibility.

Some of the most advanced transport technologies are currently being tested in different European 5G testbeds, and are shortly summarized below.

5G-XHaul [32] developed a Time Shared Optical Network (TSON) which offers elastic and fine granular bandwidth allocation, cooperating with advanced passive optical networks. The 5G-XHaul technologies are integrated in a city-wide testbed in Bristol, UK. TSON was adopted and further enhanced by 5G-PICTURE to offer increased flexibility and reliability HW programmable solution.

The Metro-Haul project [33] has focused on the design of cost-effective, energy-efficient, agile, scalable and programmable optical transport networks focusing on: all-optical metro nodes design, novel, spectrally efficient, and adaptive optical transmission networks and the concept of HW disaggregation

Finally, Space Division Multiplexing (SDM), aiming at increasing the aggregated transport network capacity has been adopted by the project BlueSpace [28] utilising optical beamforming interfaces designed for wireless transmission in the Ka-band.

5.3.2.2 Wireless Technologies

In the 5G heterogeneous environment, wireless access and transport networks adopt Sub-6 and mmWave technologies, as well as massive MIMO techniques in order to reach the required data rates, reliability and energy efficiency. A variety of research projects have been involved with 5G wireless technologies and have produced significant outcome.

5G-XHaul [34] proposed a wireless architecture that encompasses a variety of scenarios, by leveraging the wireless technologies that the project develops, such as mmWave FH with point-to-point links, Sub-6 and mmWave BH mesh.

The 5G-PPP Phase 2 5G-PICTURE project [41] proposes a hybrid beamforming for MIMO in mmWave, which offloads some of the MIMO processing to the analogue domain, and presents a trade-off in terms of power consumption and HW complexity. In this hybrid beamforming architecture, an analogue beamforming stage is used to form the sharp beams, which compensates for the large path loss at mmWave bands.

5GENESIS [11] deploys small cells in mmWave at V-Band for dense urban topologies. Moreover, satellite communications of the BH links are employed, while Sat5G [43] leverages 5G features and technologies in satcom.

5.4 Domain Management and Orchestration

5.4.1 Multi-domain Management

In general, the multi-domain management problem involves interaction between E2E Service operations and all of the involved management domains. Two general multi-domain scenarios where services are provided across multiple service providers as discussed in [44]: the classical roaming approach and the business vertical scenario.

5.4.2 Application-aware Orchestration

The multi-domain orchestration framework is designed taking a holistic approach in the 5G ecosystem. The proposed novel approach relies on the separation of network services that support the developed applications and the specification and management of infrastructure slices that will be application aware. 5G-PPP projects such as MATILDA [23] have significantly contributed in this direction, by proposing various orchestration approaches.

5.4.3 Management & Orchestration Architecture

MANO systems aim to offer, an integrated and holistic approach able to support NS and VNF management. The concept of network softwarisation targets reduced cost, flexibility, versatility, as well as new business model opportunities for the telecom operators. The MANO architecture originally designed by ETSI has received contributions over from a variety of 5G-PPP projects.

5G-TANGO [20] [25] has extended the open source SONATA service platform with the aim to manage the lifecycle of VNFs, NSs and Network Slices. In this context, the ETSI NFV Orchestrator and VNF Manager functions are implemented by the MANO framework that also supports on-boarding and management of the VNFs and NSs lifecycle.

5G-ESSENCE [31] aims at enhancing the value of 5G services at the network edge through virtual machines and containers exploiting virtualization technologies as well as a holistic resource management and orchestration approach for the cloud-radio environment for resource and cost efficiency benefits.

5GCity [35] has utilized and extended the ETSI OSM. The orchestrator proposed by 5G-CITY complies with ETSI NFV MANO and adapts to specific distributed edge infrastructures and 5G technologies, including network slicing. The proposed approach aiming at enabling network operators to offer orchestrated services to different vertical industries from different platforms. 5G-CITY adopts a hierarchical orchestration approach.

5.4.3.1 **Implementation patterns for MANO frameworks**

MANO system can be implemented taking a variety of approaches including monolithic orchestration offering ease of implementation but suffering maintainability, dependability and performance limitations. Alternative implementations alternative approaches.

An approach to increase flexibility and reduce complexity, proposed by 5G-MoNArch [27], is based on the notion of microservices that can support a fine-grained functional split. Moreover, a lot of attention was put by several projects such as SONATA [36] to message-bus based orchestrator structures.

Research projects have also targeted their research to algorithmic aspects that orchestrators have to deal with. A MAPE-K loop approach was adopted by 5G-MEDIA [37] and NRG5 [38].

5.4.3.2 **DevOps meets Orchestration**

The term DevOps refers to the integration of development and operation of complex software systems, and it is an effective candidate for NVF and orchestration. 5G-TANGO [39] and NGPaaS [40] have proposed different approaches that strongly depend on the relevant support tools. Tool support is needed at multiple stages at the development time, pre-deployment time, deployment time and runtime, which of course are interlinked. The DevOps approach also affects the internal structure of an orchestrator. In this context, 5G-TANGO proposes an architecture that considers these needs.

This section provides 5G-VICTORI E2E reference architecture for vertical's services validation from infrastructure capabilities perspective, the UCs requirements analysis being translated in the 5G proposed architecture solution of the facilities. The 5G architecture, including references to control and management plane, network infrastructure and specific implementation for service orchestration and slices instantiation will be further used as input for further system and sub-systems integration into 5G architecture.

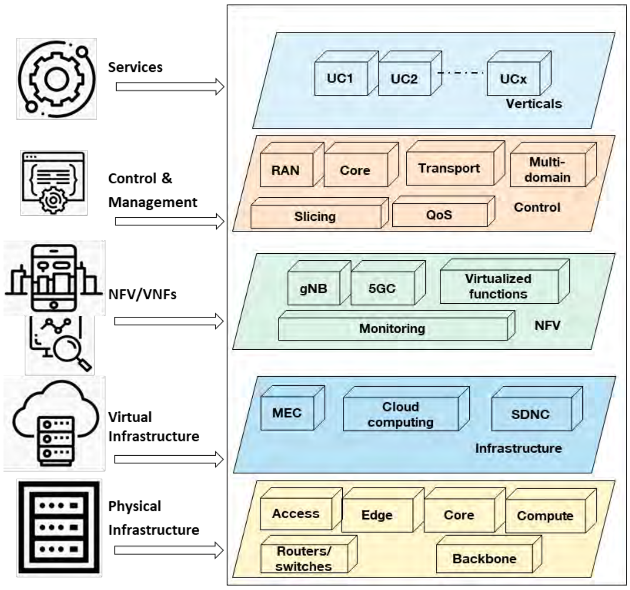


Figure 5-3 Simplified 5G Architecture

As described in Figure 5-3 5G-Overall Architecture, the 5G system architecture is composed by several layers, that can be flexible extended and customized for vertical's needs:

- **Resources Level**, physical and virtual infrastructure.
- **Network Level**, NFV/VNFs for 5G service implementation.
- **Service Level**, network service orchestration and slicing instantiation.

5.5 5G VICTORI Architecture Definition

The 5G-VICTORI architecture is designed in accordance to the overall 5G vision, the relevant service requirements, KPIs and proposed architecture described in detail above. As already described 5G-VICTORI will provide a vertical-optimised common platform aiming to address the requirements and business needs of vertical industries. To achieve this, the 5G-VICTORI solution will be implemented over the 5G platforms described in detailed above. The preliminary 5G-VICTORI architecture which is well aligned with the overall 5G vision and the 5G-PPP architectural proposal is also described. The UC and KPIs analysis described in the previous section is translated into technical requirements used to drive the definition of the 5G reference architecture of the project.

To enable the offering of a single E2E platform across its multiple facility sites, 5G-VICTORI will provide interconnection and interworking creating a common infrastructure of integrated network and compute/storage resources. This is a key aspect of the 5G vision as these resources will be able to be managed and accessed on demand by any service or application, enhancing resource utilisation efficiency and providing measurable benefits for the vertical industries in terms of cost, scalability, sustainability and management simplification.

An additional key challenge of the proposed solution is to optimally support both 5G ICT and vertical service composition over a common infrastructure. This will be achieved through the creation of repositories comprising programmable HW and SW components as well as vertical industry specific NFs. Part of the project activities will focus on the creation of programmable network functions that are necessary for the operation of vertical industries (i.e. synchronisation, positioning, signaling, voice, etc.) and will be part of these repositories. This offering of vertical functions and applications under the framework of a common repository is a very important feature, as through this the need of specific purpose HW and network devices associated with each vertical can be eliminated. The construction elements of these repositories will be jointly deployed to support dynamic on demand allocation of a variety of resources (flexible mix-and-match) for service provisioning. It should be noted that to efficiently exploit the technology, resources and services offered across facilities in 5G-VICTORI, HW and SW components as well as functions available in the common repository, will be able to be deployed. These components and functions may be associated with different facilities and geographical locations and will be combined together to effectively support the required vertical services and applications at any other location of the infrastructure.

Another key enabler for the proposed approach is its multi-tenancy capabilities. 5G-VICTORI will offer a common platform over which a variety of vertical industries will be able to provide independently and in isolation their service offerings deploying resources and functions available through the common 5G-VICTORI repository. This capability will be facilitated through the creation of infrastructure slices that can be provided as independent entities for vertical use. To take advantage of the technology, resources and services offered across facilities in the common 5G-VICTORI repository, slices will be composed across platforms taking a cross-platform infrastructure slicing approach.

Flexible service provisioning over cross-platform slices will rely on the combination and orchestration of a set of NFs through Service Chaining (SC) over the integrated programmable infrastructure. Cross-domain infrastructure slicing, SC and orchestration will be facilitated merging together the SDN reference architecture and the ETSI NFV standard and leveraging on existing developments including the 5G-XHaul control plane, and the orchestrator from the Phase-2 5G-PPP project 5G-PICTURE. A key aspect that will be also considered is the support of interoperability with legacy SW and HW technologies and architectures, which dominate the current vertical industries ecosystem.

To facilitate inter-domain orchestration and interconnection, a thin inter-domain orchestration brokering solution will be developed. This will build on top of the orchestration solutions of each facility, to provide E2E services across the different sites. The cross-domain orchestrator will implement suitable drivers to communicate with the Northbound Interfaces (NBIs) of the site orchestrators, while also provisioning and orchestrating the necessary Layer 3 (L3) or Layer 2 (L2) dynamic connectivity across the data plane of the sites.

To make the application of verticals deployable over the 5G-VICTORI platform, suitable application packaging will be provided through the development of VNFs and Network Services (NS) descriptors. These descriptors will facilitate applications to be deployed in a single domain/site but will also be extended to enable cross-domain/platform network services.

Specifically, 5G-VICTORI will rely on a lightweight multi-site active inventory that will be responsible to maintain virtual resources along with their interrelated logical entities exposed by the underlying facilities. The lightweight multi-site inventory system will be dynamically updated to reflect changes in hardware/software resources of the underlying facilities. It will also provide to vertical service providers a self-configured SDN control plane approach capable of reacting rapidly to traffic demand changes, network failures and requests for the creation of new services from the service orchestration layer.

The 5G-VICTORI lightweight multi-site inventory will be able to keep the current state of the virtual and logical network layers, and their interrelationships with the underlying 5G platforms. This is critical for the provisioning of services for vertical industries as in many cases the created service chains rely on network slicing and inventory data that typically cross several network domains. Given that verticals require services with very high reliability, the 5G-VICTORI multi-site inventory will also provide tools for performing root-cause analysis of service impacting network faults and configuration issues that manifest themselves at higher network layers or in other network domains. To achieve this, the multi-site inventory will interact with testing system that will allow full root-cause analysis and rapid fault resolution across the whole system.

In addition to this, it will provide access to service catalogues available at the various sites acting as single marketplace. This repository will allow users to search, select, purchase and deploy, under specific SLAs, slice templates offered by 3rd party providers. 3rd party providers and users will be able to develop their own components or services through the VNF developer kit. SLAs will be offered with respect with respect to the relevant service policy imposed be the various site facilities.

Figure 5-4 provides a pictorial representation of the 5G-VICTORI architecture including the proposed layered approach and the different platforms that are being integrated.

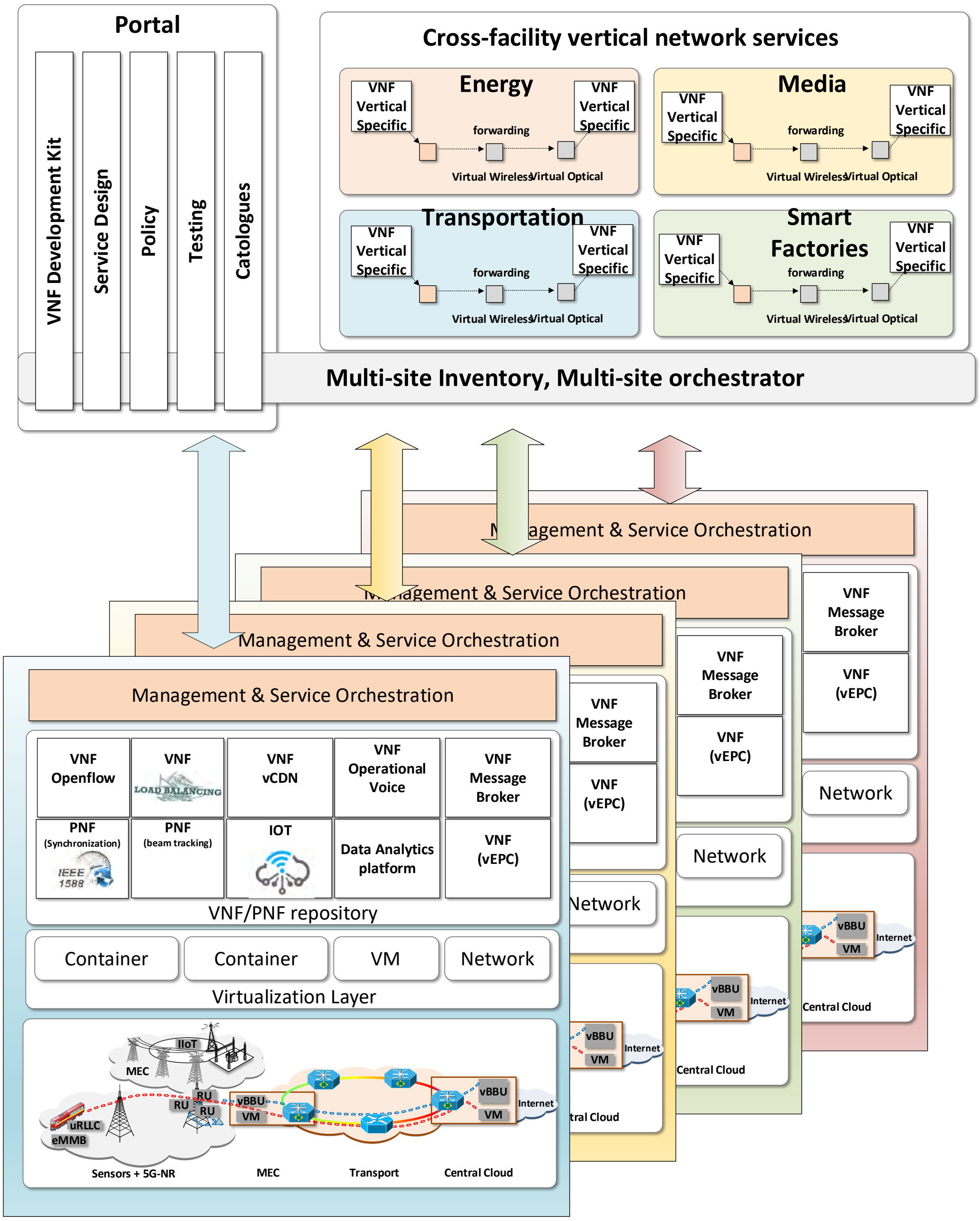


Figure 5-4 5G-VICTORI reference architecture

5.6 Summary of 5G-VICTORI facilities architecture elements

As already discussed, the 5G-VICTORI reference architecture aims at an integrated platform that brings together the specific architectures of the individual cluster facilities based on the ICT-17 projects 5G-VINNI, 5GENESIS and 5G-EVE and the 5G UK facility. These are summarised below:

5G-VINNI/Patras facility's architecture summary for UCs implementation:

- Physical network and compute elements for:
  - o 5G NSA/SA capabilities.
  - o L1/L2/L3 network components.
- Cloud computing capabilities and MANO services, CDN platform.
- OpenStack and OSM for NFVs/VNFs deployments, Kubernetes.
- Monitoring and data visualization tools.

- Analytics tool VNFs and decision making VNFs.
- KPIs monitoring and analysis.
- Access network technologies, backhaul and MEC capabilities for 5G NSA and SA.
- 5G Core and support for 5G IoT services (VNFs), slicing availability.
- SDN/NFV infrastructure.
- Service design and instantiation.
- Slice and network orchestration and LCM, multiple slice instantiation.
- Service mobility.
- Inter-site connectivity.
- Security capabilities.

5G-EVE/Paris architecture summary for UCs implementation:

- Physical network and compute elements for:
    - 5G SA network.
    - 5G NSA network for preliminary activities.
    - L1/L2/L3 network components and MPLS VPNs.
- Cloud computing, virtualization and MANO capabilities.
- Service design portal.
    - Service design and creation tool.
    - VNFs onboarding and catalogues.
    - Service Operation and experimentation.
    - 5G testing tool.
    - KPI analytics & performance tool.
- OpenStack and OSM for NFVs/VNFs deployments, Kubernetes.
- Management and orchestration
    - Infrastructure monitoring tools.
    - MEC functions for emergency service.
    - Service configuration and execution.
    - Life Cycle Management and slicing life cycle management.
    - Scalability.
    - Closed loop functions.
    - Monitoring.
    - Inventory.
- Monitoring and data visualisation.
- Data Analytics VNFs and KPIs monitoring, QoS.
- 5G RAN technologies, transport.
- MEC infrastructure.
- 5G Core services.
- 5G for IoT services (VNFs).
- SDN/NFV infrastructure.
- Service design and instantiation.
- Slicing availability.
- Slice and network orchestration, multiple slice instantiation.
- Service mobility and data security.
- Security capabilities.
- Tools: ONAP, OSMv6, OpenStack, Kubernetes, Prometheus, Grafana.

5G UK architecture summary for UCs implementation:

- Physical network and compute elements for:
  - 5G SA network.
  - 5G NSA network for preliminary activities.
  - L1/L2/L3 network components.
- 3GPP LTE/5G network and radio access (including LTE-M).
- Cloud computing infrastructure, virtualization.
- SDN functions for L2 switches.
- NFVs/VNFs deployments capabilities.
- Management and orchestration.
- 5G Core services.
- SDN/NFV infrastructure.
- Service design and instantiation, service composer and manager, NSB.
- Slicing availability.
- Slice and network orchestration, multiple slice instantiation.
- Inter-domain capabilities.
- Security capabilities.
- Tools: OpenStack, OSM.

5GENESIS architecture summary for UCs implementation:

- Physical network and compute elements for:
  - 5G network, 5GC.
  - L1/L2/L3 network components.
- Cloud computing infrastructure, virtualisation (NFVI).
- SDN/NFV.
- Management and Orchestration, NFV MANO, VIM, Catalogues, Inventory.
- NFVs/VNFs deployments capabilities.
- Service design and instantiation, experimental portal, catalogues and repository.
- Life Cycle Manager.
- Monitoring data and Analytics.
- Slicing availability.
- Slice and network orchestration, multiple slice provisioning, slice registry.
- Security capabilities.
- Tools: OpenStack, OSM, NMS.

6 Conclusions

5G-VICTORI focuses on conducting large scale trials for advanced vertical UC verification focusing on Transportation, Energy, Media and Factories of the Future and cross-vertical UCs over an integrated 5G platform. The Project will exploit extensively existing ICT-17 5G Testbed Infrastructures interconnecting main sites of the 5G-VINNI (Patras, Greece), 5GENESIS (Berlin, Germany), 5G-EVE (France/Romania) and the 5G UK testbed (Bristol, UK) in a Pan-European network infrastructure. 5G-VICTORI will modify these existing infrastructures to extend their coverage towards the integration of commercially relevant, operational environments. This is key for the demonstration of the large variety of 5G-VICTORI vertical and cross-vertical UCs.

This deliverable focuses on defining and describing the proposed UCs and their specific requirements, as they are dictated by the associated vertical industries, including also a methodology of UC analysis. The specific UCs under consideration include: "*Enhanced Mobile broadband under high-speed mobility*", Vertical: Transportation – Rail, "*Digital Mobility*", Cross-Vertical – Transportation and Media, "*Critical services for railway systems*", Vertical: Rail, "*Smart Energy Metering*", Cross-Vertical: Energy and Rail, "*Digitization of Power Plants*", Vertical: Smart Factory, and "*CDN services in dense, static and mobile environments*", Vertical: Media.

Following the UC description, we provide a definition of relevant KPIs relating both to the delivered services as well as the required underlying network performance. These KPIs are discussed and analysed considering also the overall 5G-PPP vision and they are quantified for the specific UCs of interest in relevant tables. The KPIs are also visualised in common spider diagrams charts on a per UC basis. This analysis clearly indicates that the specificities of different UCs dictate a different set of stringent requirements that need to be met, thus defining different KPIs for different UCs. These KPIs include metrics such as delay and synchronisation, increased levels of bandwidth, bit error rate, mobility, availability, reliability, etc., that can only be supported by 5G technology solutions.

In addition to the UC definition and KPI quantification, this deliverable provides a description of the various 5G-VICTORI facilities that are forming the project 5G platform and are planned to host the various UCs. For each of the facilities the relevant architectural approaches and technology solutions, that are already in place or will be deployed for the 5G-VICTORI demonstration activities, are also discussed.

To capture the additional requirements of the 5G-VICTORI facilities, in terms of new technology deployment, this deliverable also reports on the required enhancements and extensions of the existing facilities exploited by the project, towards integration of the variety of vertical and cross-vertical UCs that have been planned to support.

An overview of the architectural proposals of the various 5G-PPP activities as they have been reported to date is provided. In this deliverable, the UC and KPIs' analysis is translated into technical requirements used to define the 5G reference architecture of the project. The preliminary 5G-VICTORI architecture, which is well aligned with the overall 5G vision and the 5G-PPP architectural proposal, is also described. This architecture aims at 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. These functions can be accessed and shared on demand and deployed to compose very diverse set of services in support of the variety of services and ecosystems that the project is focusing on.

This deliverable will provide input to the upcoming project activities within WP2 including preparation of D2.2 "Preliminary individual site facility planning", D2.3 "Final individual site facility planning", and 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".

7 References

[1] 5G-TRANSFORMER, "Deliverable D1.1 "Report on vertical requirements and use cases", http://5g-transformer.eu/, 2018.

[2] Specification # 22.261 - 3GPP, http://www.3gpp.org/DynaReport/22261.htm

[3] 5G-PPP Program, European Commission, Living document on “5G-PPP use cases and performance evaluation models”.

[4] 5G Americas, “5G Services and Use Cases”, White paper, November 2017. URL: http://www.5gamericas.org/files/6214/3569/1603/4G_Americas_Mobile_Broadband_Evolution_Toward_5G-Rel-12_Rel-13_June_2015.pdf, (visited on 5/12/2017).

[5] 5G-PPP, 5G and Verticals, URL: https://5g-ppp.eu/verticals/

[6] 3GPP TR 22.863, “Feasibility study on new services and markets technology enablers for enhanced mobile broadband”.

[7] 3GPP TR 22.861, “Feasibility Study on New Services and Markets Technology Enablers for Massive Internet of Things”.

[8] 3GPP TR 22.862, “Feasibility Study on New Services and Markets Technology Enablers for Critical Communications”.

[9] 5G-EVE Deliverable D2.6: Participating vertical industries planning. Retrieved from http://5g-eve.eu".

[10] 5G-VINNI Deliverable D3.1: Specification of services delivered by each of the 5G-VINNI facilities".

[11] 5GENESIS D2.2 Overall Facility Design and Specification. December 2018".

[12] NGMN 5G Initiative White Paper, https://www.ngmn.org/wp-content/uploads/NGMN_5G_White_Paper_V1_0.pdf

[13] Future Railway Mobile Communication System, User Requirements Specification v4.0, https://uic.org/rail-system/frmcs/, January 2019.

[14] Katsaros, Konstantinos, Dimitrios Gkounis, Dritan Kaleshi, Ben Thomas, John Harris, Hamid Falaki, and Dimitra Simeonidou. "Enhancing Tourist Experiences through 5G-The 5G Smart Tourism Case Study." In 2019 IEEE 2nd 5G World Forum (5GWF), pp. 471-476. IEEE.

[15] 5G Smart Tourism Project, https://uk5g.org/5g-updates/research/5g-smart-tourism-project-overview/

[16] 5GENESIS Project, deliverable D4.14 “The Berlin Platform (Release B)”.

[17] "5G-PPP Architecture Working Group: View on 5G Architecture, Version 3.0," 2019.

[18] CEF, ETCS over GPRS/Edge capacity study in station environment (ERTMS objective 1 & 2), CEF 2014-EU-TM-0279-S, O-3300 v1.0.0

[19] Evgenia Kapassa, Marios Touloupou, Dimosthenis Kyriazis, "SLAs in 5G: A complete framework facilitating VNF- and NS- tailored SLAs," 2018.

[20] 5GTANGO deliverable "D5.2 Service Platform final release", https://www.5gtango.eu/".

[21] 5G-MEDIA Project, "D5.1 5G-MEDIA Programming Tools, http://www.5gmedia.eu/," 2018.

[22] 5GCity Project, "From service design to network slices: https://www.5gcity.eu/".

[23] MATILDA Project , "https://www.matilda-5g.eu/".

[24] 5G-XCast Project, "http://5g-xcast.eu/".

[25] 5GTANGO Project, "5G Development and validation platform for global industry-specific network services and Apps," 2019.

[26] 3GPP TR 38.801 “Technical Specification Group Radio Access Network; Study on new radio access technology: Radio access architecture and interfaces”.

[27] 5G-MoNArch Project, deliverable D2.3 “Final overall architecture,” 2018, retrieved from https://5g-monarch.eu/.

[28] BlueSPACE Project, "https://www.bluespace-5gppp.eu/".

[29] 5G-PICTURE, deliverable D2.2 “System architecture and preliminary evaluations,” 2018, retrieved from https://www.5g-picture-project.eu/.

[30] 5G ESSENCE, deliverable D2.2 “Overall System Architecture and Specifications,”2018, retrieved from http://5g-essence-h2020.eu/.

[31] 5G-ESSENCE deliverable D2.1: System Use Cases and Requirements. November 2017".

[32] A. Tzanakaki et al., “5G infrastructure supporting end-user and operational services: The 5G-XHaul architectural perspective”, IEEE ICC 2016".

[33] METRO-HAUL Project, "https://metro-haul.eu/".

[34] 5G-XHaul deliverable D2.2: “System Architecture Definition".

[35] 5GCity deliverable D4.1: “Orchestrator design, service programming and machine learning models. June 2017.

[36] SONATA deliverable D2.2: “Architecture Design”. December 2015".

[37] 5G-MEDIA deliverable D3.3: “Specification of the 5G-MEDIA QoS Control and Management Tools. August 2018".

[38] NRG5 deliverable D1.2: “NRG-5 Reference Architecture & Functional Decomposition”. May 2018.

[39] 5GTANGO, deliverable D3.3: “Final release of the VNFs/NS Store”. May 2019.

[40] NGPaaS Project. Deliverable D2.2: Final overall Next Generation PaaS Vision. January 2019".

[41] 5G-PICTURE, deliverable D3.1: Initial report on Data Plane Programmability and infrastructure components. April 2018.

[42] D. Camps-Mur et al., "5G-XHaul: A Novel Wireless-Optical SDN Transport Network to Support Joint 5G Backhaul and Fronthaul Services," in IEEE Communications Magazine, vol. 57, no. 7, pp. 99-105, July 2019.

[43] Sat5G Project, "https://www.sat5g-project.eu/".

[44] "Next Generation Mobile Networks Alliance (NGMN), “Description of Network Slicing Concept by NGMN Alliance, NGMN 5G P1 Requirements & Architecture Work Stream End-to-End Architecture,”," 2016.

[45] 5GCroCo Project, "http://5gcroco.eu/".

[46] 5G-CARMEN Project, "http://5gcarmen.eu".

[47] 5G-MOBIX Project, "www.5g-mobix.com".

[48] 5G-PICTURE Project, "https://www.5g-picture-project.eu/".

[49] 5G-XHaul Project "https://www.5g-xhaul-project.eu/".

[50] 5GENESIS Project "https://5genesis.eu/".

[51] Recommendation ITU-R M.2083-0 (09/2015) "IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond”.

[52] 3GPP TS 22.261 V16.1.0 3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Service requirements for the 5G system.

[53] 3GPP TR 22.864 Feasibility Study on New Services and Markets Technology Enablers - Network Operation

[54] Maguire, Martin and Bevan, Nigel, User Requirements Analysis: A Review of Supporting Methods. Proceedings of IFIP 17th World Computer Congress, January 2002

[55] Olphert & Damodaran (2002) Getting what you want, or wanting what you get? - beyond user centred design, *Proceedings of the Third International Conference on Design and Emotion*, Loughborough, UK, 1-3 July 2002

[56] Mobile Operators Top Three Opportunities to Future proof Your Business whitepaper by Juniper Research

[57] "Promote early deployment in major urban areas and along major transport paths" by European Commission - Digital Single Market policy / 5G for Europe Action Plan

[58] http://www.geant.org

[59] 5G-PPP Platforms Cartography, URL: https://5g-ppp.eu/5g-ppp-platforms-cartography/

[60] https://www.etsi.org/technologies/multi-access-edge-computing].

[61] Axis company, URL: https://www.axis.com/en-ro

[62] AXIS P3915-R Mk II Network Camera, URL: https://www.axis.com/en-us/products/axis-p3915r-mkii

[63] S-Bahn Berlin, URL:https://sbahn.berlin/fileadmin/user_upload/Liniennetz/S_U-Bahn-Netz_gueltig_ab_2019_08_04.pdf

[64] N. Makris, C. Zarafetas, P. Basaras, T. Korakis, N. Nikaein and L. Tassiulas, "Cloud- based convergence of heterogeneous RANs in 5G disaggregated architectures", proc. of IEEE ICC 2018.

[65] 5G-VICTORI deliverable D5.1 "Standardisation, Dissemination, Communication and liaison Activities Plan", December 2019, https://www.5g-victori-project.eu/wp-content/uploads/2020/01/2019-12-14-5G-VICTORI_D5.1_v1.0.pdf

8 Acronyms

Acronym	Description
5G-PPP	5G Public Private Partnership
5GS	5G Systems
ACS	Axis Camera Station
AGR	Agriculture and farming
AIM	Alba Iulia Municipality (5G-VICTORI Partner)
AMF	Access and Mobility Management Function
AP	Access Point
API	Application Programming Interface
ARQ	Automatic Repetition Request
BBUS	Baseband units
BH	Backhaul
CBTR	Coding-Building-Testing-Releasing
CCC	Command & Control Centre
CDN	Content Delivery Network
CESC	Cloud Enabled Small Cell
CN	Core Network
COTS	Commercial Off-The-Shelf
CP	Control Plane
CPE	Customer Premises Equipment
CPRI	Common Public Radio Interface
CPU	Central Processing Unit
CU	Centralized Unit
DASH	Dynamic Adaptive Streaming over HTTP
DC	Data Centre
DU	Distributed Unit
DWDM	Dense Wavelength Division Multiplexing
E2E	End-to-End
eCPRI	Enhanced CPRI
eMBB	Enhanced Mobile Broadband
ETCS	European Train Control System
FH	Fronthaul
FhG	Fraunhofer FOKUS (5G-VICTORI Partner)
FPRF	Field Programmable RF
FRMCS	Future Railway Mobile Communication System
HD CCTV	High Definition Closed Circuit Television
HV	High Voltage

IDCM	Inter-Domain Connectivity Manager
IoT	Internet of Things
ISO	International Organization for Standardization
LoRaWAN	Long Range Wide Area Network
LPWA	Low Power Wide Area
LV	Low Voltage
LTE-M	Long Term Evolution Machine Type Communication
MaaS	Mobility as a Service
MANO	Management and Network Orchestration
MATI	Mativision (5G-VICTORI Partner)
MCPTT	Mission-Critical Push-To-Talk
MCX	Mission Critical Communication Standard
MEC	Multi-access Edge Computing
MIMO	Multiple Input Multiple Output
mIoT	Massive Internet of Things
mMTC	Machine Type Communications
MPEG	Moving Pictures Expert Group
NB-IoT	Narrow Band IoT
NF	Network Function
NFV	Network Function Virtualization
NFVI	Network Function Virtualization Infrastructure
NFVO	NFV Orchestrator
NG-RAN	New Generation Radio Access Network
NGMN	Next Generation Mobile Network
NGPaaS	New Generation Platform as a Service
NMS	Network Management System
NSA	Non-Stand-Alone
NSB	Network Service Broker
OAI	OpenAirInterface
OBG	on-board Gateway
OCC	operations and control center
ONAP	Open Networking Automation Platform
ORO	Orange Romania (5G-VICTORI Partner)
OSM	Open Source MANO
PoE	Power over Ethernet
PTT	Push-To-Talk
PWS	Public Warning Systems
RAMS	Reliability, Availability, Maintainability, and Safety
RBE	Regenerative Braking Energy

RoF	Radio over Fibre
QCI	QoS Class Identifier
QoS	Quality of Service
SAND	Server and Network Assisted DASH
SBC	single board computer
SC	Service Chaining
SDAP	Service Data Adaption Protocol
SDKs	Service Developments Kits
SDN	Software Defined Networking
SDO	standards development organization
SLAs	Service Level Agreements
SME	Small and Medium-sized Enterprise
SMF	Session Management Function
TCO	Total Cost of Ownership
TPSS	TRA suburban trains traction
TRA	TRAINOSE (5G-VICTORI Partner)
TSO	Transmission System Operator
TSON	Time Shared Optical Network
UAV	Unmanned Aerial Vehicle
UC	Use case
UHA	Urban Hawk (5G-VICTORI Partner)
UP	User Plane
UPF	User Plane function
URLLC	Ultra-Reliable and Low Latency Communications
URS	User Requirements Specifications
VIMs	Virtual Infrastructure Managers
VNF-FGs	Virtual Network Functions Forwarding Graphs
VNFM	Virtual Network Function Manager
VoD	Video on Demand
VSI	Vertical Service Instance
xMEC	Extended MEC