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

D3.1 Preliminary Use case specification for transportation services

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Executive Summary

The 5G-VICTORI project focuses on demonstrating large scale trials for vertical use case (UC) verification concentrating on **Transportation**, **Energy**, **Media** and **Factories of the Future** as well as cross-vertical UCs over an integrated 5G platform. The purpose of 5G-VICTORI is to demonstrate that these different vertical services can share a common 5G infrastructure including common radio access, transport and core networks as well as compute resources.

The objective is to demonstrate that each vertical service gets the required characteristics, while at the same time guarantees isolation between services, i.e. not affecting other services, and not being affected by other services. Separation between services is performed taking advantage of Network Slicing and end-to-end (E2E) QoS assignment capabilities offered by 5G functionality.

As described in deliverable D2.1 [1], D2.2 [2] and D2.3 [3], the 5G-VICTORI transportation UCs focus on evaluating the capability to serve all communication requirements of train operators and passengers under the Future Railway Mobile Communication System (FRMCS) family of services, using 5G cellular radio.

This document focuses on Transportation services and mainly on rail transportation services. These services will be supported through the service types: enhanced Mobile BroadBand (eMBB), and ultra-Reliable Low Latency Communications (uRLLC). Four categories of applications are envisioned:

1. Transportation: Digital Mobility including the Mobility as a Service framework, the passenger followed pop-up network on-demand for infotainment services and emergency situations as well as a set of Innovative applications.
2. Provisioning of mission critical services for railway systems covering both on-board and trackside segments. These includes mission critical audio, data and video as well as signalling for interlocking and train devices.
3. Train management systems including onboard monitoring such as HD CCTV, etc., and remote maintenance.
4. Mobile broadband for passengers.

For each of the UCs, several transportation-related test cases are defined to set the specific configuration of the equipment/infrastructure where the measurement activities are carried out. The main target of these test cases is to test and validate Key Performance Indicators (KPIs) at the vertical services' level.

The identification of key vertical services/applications KPIs is of utmost importance towards the implementation of the transportation-related UCs in three of the 5G-VICTORI facilities: Patras in Greece, Bristol in the UK, and Berlin in Germany. Only then, these KPIs can be assessed against the network and network services KPIs for each of the deployments.

Acronyms

1.1 General acronyms

Acronym	Description
3D	Three dimensions, xyz
3GPP	Third Generation Partnership Project
4G	4^{th} Generation cellular system, LTE
4K	Picture resolution, 4k pixels per row, ~UHD (using 3840 pixels per row)
5G	Fifth Generation cellular system (3GPP related)
5G-VIOS	5G-VICTORI Operation System
AP	Access Point
APN	Access Point Name
App	Application
AR	Augmented Reality
BBU	Baseband Unit
BSCW	Document database used in the 5G-VICTORI project
C++	Extension of the C programming language, or “C with Classes”
CCTV	Closed Circuit TeleVision
CN	Core Network
CPU	Central Processing Unit
CSIF	Communication Service Interface
CSV	Comma-Separated Values (related to MS Excel files)
Cuda	parallel computing platform and programming model for GPUs computing
DCU	Data Capture Unit
DL	Downlink (= the direction from base station to UE)
E-Band	Radio links using 70 to 80 GHz
eMBB	enhanced MBB
EUT	Elements Under Test
FD	File Distribution (as per MCData FD Definition)
FRMCS	Future Rail Mobile Communication System
FTP	File Transfer Protocol
G.711	Narrowband audio codec, designed for toll-quality audio at 64 kbit/s
Gbps	Gigabits per second
gNB	gNodeB, a base station using the 5G New Radio technology
GNSS	Global Navigation Satellite System (incl. e.g. the GPS, GLONASS, Galileo)
GPS	Global Positioning System
GPU	Graphics Processing Unit
GSM	Global System for Mobile Communications
GSM-R	GSM Railway
GTP-U	GPRS Tunneling Protocol User plane
GW	GateWay
H.264	TV framing protocol

HD	High Definition
HO	Hand Over (UE connects to target cell and releases source cell)
HTTPS	HyperText Transfer Protocol Secure
HW	Hardware
ICMP	Internet Control Message Protocol
ICT	Information and Communication Technologies
IMPU	SIP Core Identity
IP	Internet Protocol
IPconn	IP connectivity (as per MCData Ipconn Definition)
iPerf	Measurement tool, can be downloaded here.
kbps	kilobits per second
KPI	Key Performance Indicator
L2	Layer 2, often related to Ethernet switching
LTE	Long Term Evolution, 4^{th} generation cellular system
MaaS	Mobility as a Service
MBB	Mobile BroadBand
Mbps	Megabits per second
MCData	Mission Critical service Data (includes SDS, FD (File Distribution), Ipconn)
MCPTT	Mission Critical service PTT
MCVideo	Mission Critical service Video
MCX	Mission Critical Services, X = {PTT, Data, Video}
MEC	Mobile Edge Computing (related to an Edge node next to a base station)
mMTC	massive Machine Type Communications
MVB	Merchant Venturers Building (University of Bristol building)
NIC	Network Interface Card, or Network Interface Controller
NR	New Radio (3GPP 5G term)
NSI	Network Slice Instance
OBG	On**board Gateway**
PC	Personal Computer
PDU	Packed Data Unit (IP, Ethernet, etc)
PLMN ID	Public Land Mobile Network ID
PoE	Power over Ethernet, passing electric power on twisted pair Ethernet cabling
PTT	Push-To-Talk
QoS	Quality of Service
QUIC	a general-purpose transport layer network protocol
RAID	Redundant Array of Inexpensive Disks
RAN	Radio Access Network
RaSTA	Rail Signaling Traffic
RSRQ	Reference Signal Received Quality
RSSI	Received Signal Strength Indicator
RTT	Round-Trip-Time (= the sum of the latency in both directions)
S-NSSAI	Single Network Slice Selection Assistance Information
SDS	Short Data Service

SIM	Subscriber Identification Module
SIP	Session Initiation Protocol
Sub-6 GHz	Wi-Fi 802.11ax
SW	Software
TAP	Test Access Point
TC	Test Case
TCP	Transmission Control Protocol
TOC	Table Of Content
UC	Use Case
UDP	User Datagram Protocol
UE	User Equipment (= the mobile phone)
UL	Uplink (= the direction from UE to base station)
UPF	User Plane Function
uRLLC	ultra-Reliable Low Latency Communications
Uu	Air-interface (3GPP term)
VIM	Virtualized Infrastructure Manager
VM	Virtual Machine (e.g. using Linux over VMware over MS Windows)
VNF	Virtualized Network Function
VoIP	Voice over IP
VP8, VP9	Open and royalty-free video compression formats
VR	Virtual Reality
VSI	Vertical Service Instance
WebRTC	Web Real-Time Communication, a free open-source software
Wi-Fi or WiFi	family of wireless network protocols, based on IEEE 802.11 standards

1.2 5G-VICTORI related acronyms and partners

Acronym	Description
5G VIOS	5G-VICTORI Infrastructure Operation System
5G-PPP	5G infrastructure Public Private Partnership
5G-UK	The Bristol ICT-19 Cluster
5G-VINNI	The Patras ICT-19 Cluster
5GENESIS	The Berlin ICT-19 Cluster
Alstom	Bombardier Transportation joined the Alstom Group 2021-01-29 (partner)
COSM	COSMOTE (partner)
D2.1	Deliverable D2.1 (within T2.1)
D2.2	Deliverable D2.2 (within T2.1)
D2.3	Deliverable D2.3 (within T2.1)
D3.1	Deliverable D3.1 (within T3.1)
D4.1	Deliverable D4.1 (within WP4)
DBH	Deutsche Bahn (partner)
DC	Data Center

DCAT	Digital Catapult (partner)
FhG	Fraunhofer FOKUS (partner)
HPN	University of Bristol's High-Performance Networks group
i2CAT	(partner)
IASA	Institute of Accelerating Systems and Applications (partner)
ICT-17	The 5G platform developed for the 5G-PICTURE EU project
ICT-19	The 5G platform developed for the 5G-VICTORI
ICOM	Intracom telecom (partner)
IHP	Innovations for High Performance Microelectronics (partner)
IR	Interim Review (done 2020-10-08)
KCC	Kontron (partner)
MATI	Mativision (partner)
MShed	Museum in Bristol
T3.1	Task 3.1 (within WP3)
TRAINOSE	Partner contractor
UNIVBRIS	University of Bristol, UoB (partner)
UoP	University of Patras (partner)
UHA	Urban Hawk, UHAWK (partner)
UTH	University of Thessaly (partner)
WP2	Work Package 2: Description – Use cases/ Specifications
WP3	Work Package 3: Vertical Services to be demonstrated
WP4	Work Package 4: Trials of Coexisting Vertical Services, Validation and KPI
WTC	We The Curious (at Millennium Square in Bristol)
ZN	Zeetta Networks (partner)

1 Introduction

A more efficient way of living calls for a shift towards a more interconnected world, which is the target of the ongoing digital transformation of public and private sectors, ensuring the provision of advanced, reliable and secure services to the end users in a direct and user-friendly way.

This transformation will require new service capabilities that network operators need to support including: i) connectivity for a growing number of very diverse devices, ii) ubiquitous access with varying degrees of mobility from low to high in heterogeneous environments and, iii) mission critical services currently handled by closed specific purpose networks, supporting highly variable performance attributes in a cost and energy-efficient manner.

All these changes have affected a large number of sectors related to ICT and verticals industries. Verticals such as **Transportation**, **Energy**, **Media** and **Factories of the Future** are receiving increased attention given their relevance and impact on society. Their ubiquitous effect in everyday lives dictates the need for their transformation, from legacy services into smart and flexible processes.

The benefits stemming from this digital transformation will only be reaped by intelligent and sustainable technologies able to support a wide range of applications with highly variable performance attributes offering i) connectivity for a massive number of very diverse devices, ii) enhanced mobile broadband services in heterogeneous environments and, iii) ultra-low latency and reliable communications for mission critical services.

5G-VICTORI leverages 5G networks to conduct large-scale trials for advanced use case (UC) verification in commercially relevant 5G environments for the abovementioned Verticals, as well as some specific UCs involving cross-vertical interaction [3]. The purpose of 5G-VICTORI is to demonstrate that these different Verticals can share a common 5G infrastructure including common radio access, transport and core networks as well as compute resources. A successful sharing of this infrastructure proves that each vertical service does not need to a dedicated purposely developed infrastructure to support its needs, instead a common 5G infrastructure can be used for all type of vertical services. A relevant framework that supports this approach is the successor of GSM-R for the rail industry the Future Rail Mobile Communication System (FRMCS) that can use any cellular system for the radio part, such as 5G.

Technology and architecture validation in 5G-VICTORI is carried out considering the most critical parameters of each vertical sector under real life conditions. For the architecture validation we not only consider the stringent requirements of the vertical applications but also the introduction of new business models. This validation will therefore take both a technology and a business perspective.

Work Package 3 (**WP3**) is responsible for the definition of a set Vertical services, which will leverage the 5G-VICTORI architecture (defined in **WP2**) and will be running on top of 5G infrastructures (real-world deployment) to demonstrate 5G-VICTORI functionalities (**WP4**). It provides a detailed definition and planning of the vertical services for rail services, media services and energy and infrastructure monitoring, including KPIs for the individual services to be tested.

The specific UCs of 5G-VICTORI bring along applications/services that will be deployed and demonstrated over the project facilities. In parallel to the identification of the network and network services Key Performance Indicators (KPIs) for each deployment, the identification of key vertical services/applications KPIs is needed. These are defined in **WP3** by various stakeholders, mainly service providers, vertical industries, application developers and end users. The detailed identification of these KPIs along with the testing and performance evaluation details is a subject of study in WP3 deliverables.

This document is the first release in Task 3.1, and it defines transportation related UCs that can be tested and evaluated in isolation or together with other services on one or more of the 5G facilities [2].

The main application categories are:

1. **Transportation**: Digital Mobility including the Mobility as a Service, passenger followed pop-up network on-demand for infotainment services, including new innovative applications. This has the potential to be a vital cornerstone of a venue like a Railway Station or a part of the city, potentially reducing commuting times, and creating an opportunity for passengers to customize their journeys.
2. **Mission critical services for railway systems** covering both on-board and trackside segments. These includes mission critical audio, data and video as well as signaling for interlocking and train devices.
3. **Train management systems** including onboard monitoring such as CCTV.
4. **Onboard passenger services**.

To assess the performance of these services, the 5G-VICTORI experimentation methodology revolves around the profiling of experiments, including specific configurations and conditions [4]. This methodology is aligned with the 5G-PPP Test, Measurement and KPIs Validation (TMV) Work Group (WG). Similarly to the work in this WG [5], we provide methodologies and **Test Cases** for the validation of the **End-to-End (E2E) services**. Methodologically, for the evaluation of the vertical services/applications KPIs, a mapping between Network and Vertical Services KPIs will be performed, and network and network services' KPIs will be refined accordingly. Application requirements are related to the requirements defined as part of **WP2** and some additional ones defined in WP3. Test case KPIs are listed in the test case tables that can be found in this document.

The different vertical services in this document focus on enhanced Mobile BroadBand (eMBB) and ultra-Reliable Low Latency Communications (uRLLC), services taking advantage of Network Slicing in 5G system to support the E2E QoS service requirements. The objective of these demos is to showcase that each vertical service can get its needed characteristics, regardless of background traffic, without affecting other services, and without being affected by other services i.e. showing isolation between vertical services.

Figure 1-1 below gives on overview of the Transportation Services in T3.1, where the majority of the services are rail related:

- **Enhanced Mobile BroadBand** (UC #1.1), 5G-VICTORI facility in Patras.
- **Digital Mobility** (UC #1.2), 5G-VICTORI facility in Bristol and Berlin.
- **Rail Critical Services** (UC #1.3), 5G-VICTORI facility in Berlin.

Figure 1-1 also indicates what partners that are involved in T3.1, contributing with:

- Cluster general content (5G, servers, backbone links, switches, etc.).
- Specific services (vertical service such as Augmented Reality (AR)/Virtual Reality (VR), PTT, Rail signaling).
- Demo responsible partners in WP4 are underlined.

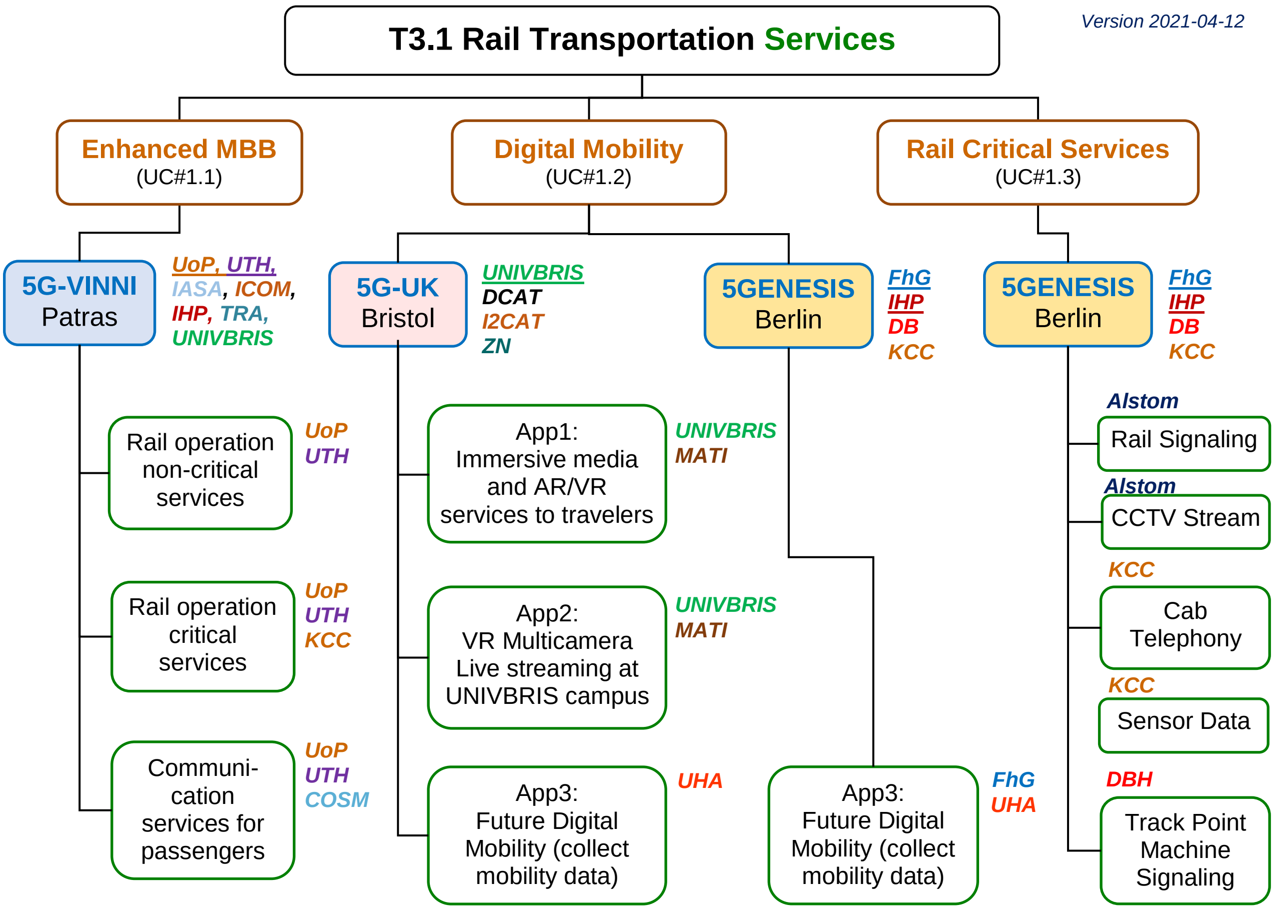

Figure 1-1: T3.1 Rail Transportation Services - Use-Cases, Clusters, Services, *Partners*, *Demo responsible*.

Figure 1-2 represents:

- **WP2** output provides input to WP3 UCs and test cases. Specifically, D2.1 contains UC, requirements and KPIs, while component descriptions and cluster configurations are reported in D2.2.
- **WP3** test case tables, whose content has been agreed as a **WP3**-**WP4** activity. The output of WP3 test cases provide input to **WP4** demonstration activities.

This document is the first deliverable of Task 3.1. At a later project stage, the test cases will be updated for the second delivery in Task 3.1, which is **D3.2** entitled “Final Use case specification for transportation services”. The output of this task will provide input to WP4 trial activities, where single and multiple vertical services are demonstrated within a cluster and with the goal to also show inter-cluster re-use of functionality. WP4 will produce demonstration test reports that will comprise the measured KPIs vs those targeted in WP2 and assessed as part of WP3 activities.

1.1 Objectives and Content

The objectives for the different vertical services in Task 3.1 are presented in the next subsections with a high level view of the relevant focus.

1.1.1 eMBB at Patras

The services offered in Patras plan to demonstrate a camera onboard the train, push-to-talk (PTT) service, and TV streaming as a passenger service.

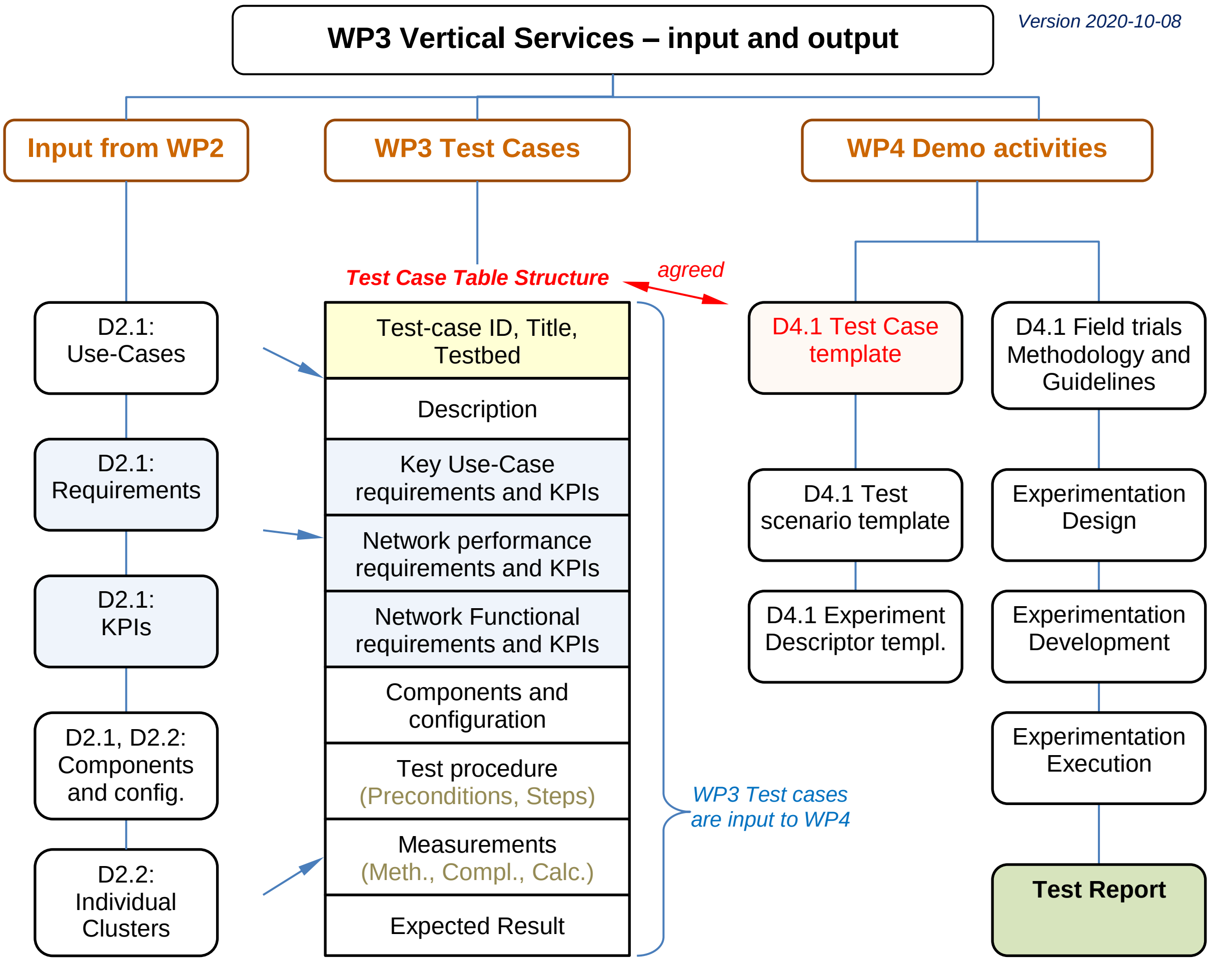

Figure 1-2: T3.1 Rail Transportation Services – Input from WP2, WP3 Test Cases, WP4 trials

What is common for the Patras 5G services is that the 5G air-interface is only present onboard the train. The setup in Patras is that the system interconnects with the track access points as the train moves along the track. The track access points use both mmWave and Wi-Fi radio access technology.

1.1.2 Digital Mobility in Bristol and Berlin

The services offered in Bristol and Berlin include Virtual Reality and Augmented Reality based services, where the mobile geolocation and rotation information is key in providing relevant and precisely located pictures to the user of the mobile AR/VR application. The users can walk around and get a 3D tour guide along a path from point A to a point B, or guidance on how to get from point A to point B. The latter relies on a guide which includes multimodal ways of transportation.

These digital mobility services focus and rely on Edge Computing, with synchronization to backend servers to make sure that the relevant edge server is all the time updated with the high speed and low latency data the user needs.

1.1.3 Rail Critical Services in Berlin

The rail critical services found for the Berlin demonstration activities include rail signaling emulation, CCTV streaming, PTT, and sensor data applications. 5G base stations are used at the Berlin Hbf where real handovers are done between a couple of 5G radio head located on poles in the Berlin Hbf on one of the tracks.

Edge computing is not the focus here, as a traditional radio access network (RAN) and core network (CN) are used. The Berlin rail critical services have equipment above the core network, in this document called the Berlin office.

1.2 Organization of the document

Following the introduction, section 2 provides an introduction on the testing methodology followed in the project, which stems from standards targeting this topic. As well, it provides the guidelines for test case development.

The description of the test cases defined for eMBB at the 5G-VICTORI facility in Patras is included in section 3.

Section 4 described the test cases defined for the Digital Mobility at the 5G-VICTORI facility in Bristol.

Section 5 discusses the test cases defined for the Digital Mobility UC at the 5G-VICTORI facility in Berlin.

Section 6 describes the test cases defined for the Rail Critical Services at the 5G-VICTORI facility in Berlin.

Finally, section 7 provides the conclusions of the document.

2 Testing methodology

2.1 Testing Methodology Description

The objective of this **D3.1** "test specification" is to describe the demonstration scenarios and the relevant test cases of the UCs that are planned to be demonstrated. These will be used as input to the **WP4** activities in the demonstrations execution. UCs are taken as input from the WP2 documents **D2.1** [1], **D2.2** [2], **D2.3** [2], and are further analysed and extended in WP3 as detailed test cases.

To successfully demonstrate the planned use cases in the different sites, it is necessary to validate the functionality of the developed services and stress test their performance under realistic conditions. The ultimate objective of the testing process is

1) to verify compliance with the values required for the service to operate reliably in the specified UC – and,
2) to estimate the confidence interval of the expected performance curve of the system thus assisting vertical users and operators to obtain reasonable assurance that the system operates within specific performance bounds [20].

As 5G services are deployed over distributed environments, the standardized testing methodology applied in distributed automated systems (see [18]) has been adopted. Aligned with this standard we consider each service to be composed of a set of elements which need to be tested. The collection of all Elements Under Test (EUT) form the Service Under Test (SUT). Figure 2-1 depicts the SUT and EUT entities and their interactions during the test setup process. Connectivity between the different components of the system is achieved through a set of communication protocols. A simplified version of the protocol communication stack is also depicted [19].

In this diagram, the layers that are part of the 3GPP network are referred to as lower communication layers (LCL). The communication stack also includes the application/service under test. The Open Systems Interconnection (OSI) layers related to providing data to the application are referred to as the higher communication layers (HCL). The interface between LCL and HCL is referred to as communication service interface (CSIF).

In order to verify that E2E services are provided over the infrastructures with the required KPIs, supplementary checks need to be also conducted in order to assess the performance of all entities involved including the communication protocols [18]. Therefore, for the assessment of the overall system performance, it is important to differentiate between the 3GPP network's performance (i.e., including only the LCL measured at the CSIF) and the overall system performance including the application layer. In Figure 2-1 the orange arrow depicts a measurement point for assessing the performance for an application from the vertical perspective point of view. The blue arrows indicate two options to measure the 3GPP network's performance, i.e., including and excluding the IP layer. In the same figure it can be also observed how messages are transmitted from a SUT (i.e. energy metering platform) (e.g., a programmable logic controller) to a target application device (e.g., MEC element). The source application function (AF) is executed in the source operating system (OS) and forwarding information to the application layer interface of the source communication device. In the higher communication layers (HCL), which are not part of the 3GPP system, information is processed. From the HCL the data is transferred to the lower communication layers (LCL), which are part of the 3GPP system. After transmission through the physical communication channel and the LCL of the target communication device, the data is passed to the HCL and lastly to the target application device [19].

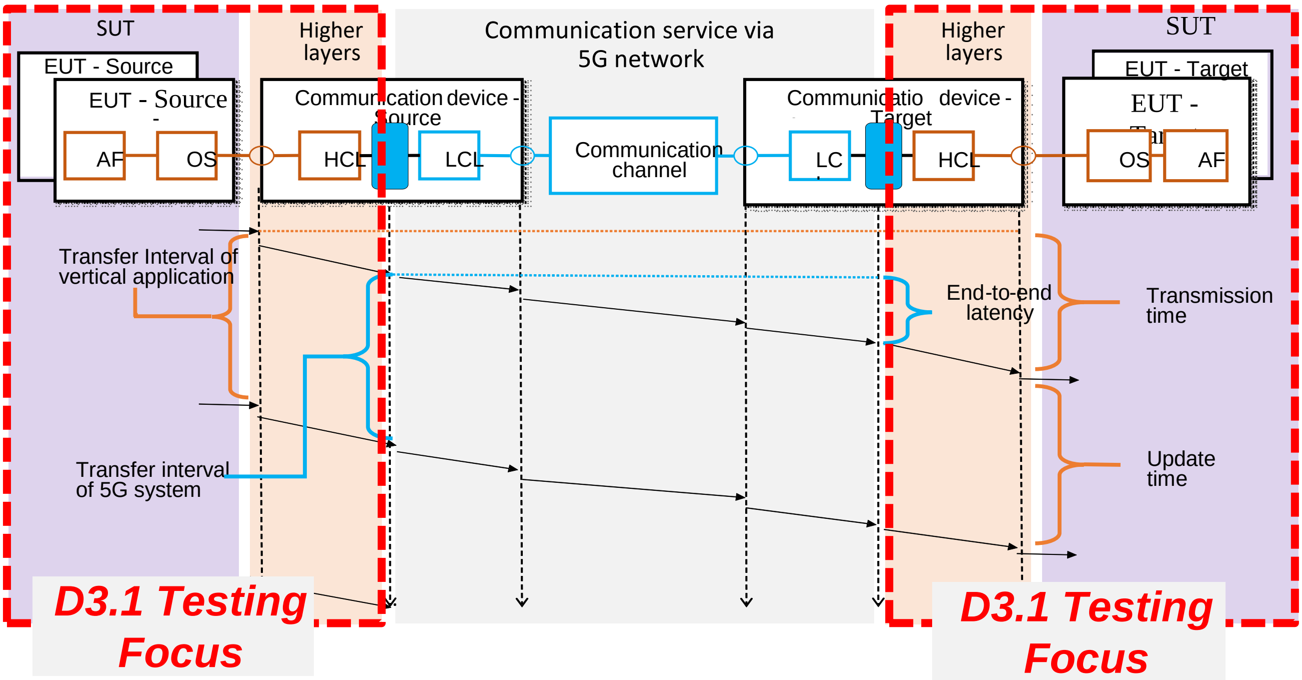

Figure 2-1: Services to be tested and parameters to be evaluated [19]

As deliverable D3.1 focuses on testing of services, the corresponding analysis is limited to the upper layers of the communication system including the applications and the HCL. As the testing results for the services need to be reproducible, the 5G system providing lower communication services will be considered as fixed. Although the various parameters of the 5G communication network influence the performance of the services, it will be not be examined in the present deliverable, as these aspects will be addressed by deliverable D4.1. However, all services will be tested under a precisely described and controlled 5G environment indicating parameters related to i) the environment where the network will be deployed (spatial extent of the real-world facilitates), ii) propagation environment in which the application operates during testing, iii) background network traffic including the number of wireless devices, number of virtual links established in the cloud environment hosting the 5G platform, iii) Positions of wireless devices and distances between them, iv) type of 5G user equipment and CPEs, v) Time during which tests were conducted on the system under test, vu network topology and network devices, vi) type of servers hosting the 5G platform.

Apart from baseline parameters which are considered fixed, an extended set of performance tests will be conducted measuring as shown in Figure 2-1 parameters related to *latency* (i.e. Transfer interval of vertical application: Time between the transmission of two successive pieces of data from the source application, Transmission time: Time measured from the point when a piece of data is handed from the application layer interface of the source application device, until the same piece of data is received at the application layer interface of the target application device, update time: Time between the reception of two consecutive pieces of data at the application layer interface to the target application device), *throughput*, *availability*, *reliability*, *jitter* etc.

Performance testing will be carried over multiple test groups as discussed in [20]. Each test group will investigate the performance parameter(s) of interest and consists of one or multiple test cases. For each test case, each baseline parameter (e. g. number of devices, 5G network topology, compute resources allocated to the RAN and Core functions,) has been assigned a specific value. To cover additional deployment options, the value of one or more baseline parameters may be altered within a test group, i. e. from one test case to the next, in order to assess the impact of the altered baseline parameter(s) on the performance parameter(s).

Although the baseline parameters do not vary within a test case, the performance parameters measured or achieved may exhibit a range of values. For example, the number of devices might be increased incrementally to establish the system's maximum performance in a high-density environment. Also, the impact of the number of devices on e.g., the achieved/ measured transmission time might be analyzed [20].

Once performance parameters and baseline parameters for the SUT have been defined, it is necessary to establish the testing system to measure and/or calculate corresponding performance values. The testing system needs to accurately measure the performance parameters and to accurately maintain the baseline parameters.

In the context of the 5G-VICTORI project performance testing will be carried out in three different environments

- Laboratory environment using software to emulate devices and system components.
- Physically emulated environment, for example an environment resembling the topology of the actual environment where the system will be deployed
- Real world environment testing where all components will be tested on-site at the actual facilities while system is in operation

In the following subsection, a description of the process/methodology that will be followed in the development of tests cases is provided following the ETSI EG 202 810 V1.1.1 standard [18].

2.2 Test case development

A pre-requisite for the specification of executable test cases is the availability of test descriptions. Such descriptions should capture all equipment used in the testing process, pre-conditions, equipment operation, as well procedures and messages exchanged during the testing process. Test descriptions provide valuable and easily understandable documentation. Additional test documentation in interoperability testing is especially important because of the large number of different interfaces involved in a test as well as its basis on multiple EUTs.

In order to facilitate the specification of test cases, test description tables contain the following information:

- *Test-case ID*,: A detailed description of the test IDs used to distinguish the various use cases and services to be tested. The ID number is unique 6-character string of letters and number providing a specific piece of information about the type of use case, the group where this use case belongs, the 5G cluster that this service belongs etc. The test-case ID structure in WP3 follows a set of specific principles. These principles, customized for T3.1 test cases, are described below:
  - The first prefix letter **R** stands for **Railway**".
  - The second prefix letter represents a use case group within each vertical service:
  - The third prefix letter is used to group types of services or network-related services
    - N: non critical
    - C: Critcal .
    - P: Passengers
    - T Telephony

    - D: Sensor Data
    - F: Future Mobility test
    - P: Point-machine
    - L: VR **L**ive test cases
  - The fourth prefix letter is a lower case one, which indicates the 5G cluster:
    - **v**: 5G-VINNI, Patras
    - **e**: 5G-EVE, Alba Iulia
    - **u**: 5G UK testbed , Bristo
    - **g**: 5GENESIS
  - The trailing number 01..99 in the test-case ID gives room for up to 99 test cases in each category.
  - This gives a list of test-case IDs for T3.3 and D3.5 looking like this:
    - **R**ail **E**nhanced MBB Patras network **D**eployment test-case (REDv)
    - **R**ail **E**nhanced MBB Patras rail operation **N**on-critical test cases (RENv)
    - **R**ail **E**nhanced MBB Patras - Rail operation **C**ritical Services (RECv)
    - **R**ail **E**nhanced MBB Patras - Business services for Passengers test-cases (REPv
    - **R**ail **D**igital mobility Bristol App1 **I**mmersive Media test cases (RDIu)
    - **R**ail **D**igital mobility Bristol App 2 VR **L**ive test cases (RDLu)
    - **R**ail Mobility - Bristol App 3 **F**uture Mobility test cases (RDFu)
    - **R**ail **D**igital mobility Bristol dedicated Network test cases (RDNu)
    - **R**ail **D**igital Mobility Berlin App 3 **F**uture Mobility test cases (RDFg)
    - **R**ail **C**ritical services Berlin Rail **S**ignaling test cases (RCSg)
    - **R**ail **C**ritical services Berlin **C**CTV Streaming test cases (RCCg)
    - **R**ail **C**ritical services Berlin Rail **T**elephony test cases (RCTg)
    - **R**ail **C**ritical services Berlin Sensor **D**ata test cases (RCDg)
    - **R**ail **C**ritical services Berlin **P**oint-machine object controller signaling test cases (RCPg)

- *Title, Testbed name*: Title of the use case and facility over which the testing process will be conducted.
- *Description of test* in concise manner explaining the purpose of the test. The description is also used to distinguish this test from any other test in the document
- *Key use-case requirements and KPIs*: The requirements and KPIs listed in the test case tables with a label come from **WP2** deliverable **D2.1**, which uses a unique numbering, being an example **S-FU-5301** (Smart Factory and Functional related and a number). These are categorized with:
  - User = vertical service related, Facility = network related.
  - Type: Functional (FU), Performance (PE), Capacity (CA), or Other (OTH).
- *Network performance and KPIs*
- *Network functional requirements and KPIs*

- *Listing and configuration of all components used in the testing process*. This includes a list of test specific pre-conditions including information about equipment configuration, the initial state of the SUT, etc.
- *Test procedure specification*. This section defines a sequence of elementary actions and checks being executed on different test entities.
- *Measurements*: This section provides information for the results to be obtained per test
- *Expected results* giving emphasis on tests that failed or the performance achieved didn't met performance the associated KPIs. For this case, description where the test case has failed, as well as the location where the error/unexpected performance has been observed will be highlighted.

3 Enhanced MBB at the 5G-VICTORI Patras facility

3.1 Description

In modern railway transportation there is a demand for a broad range of on-board applications for passengers, including guiding services, real time travel information, infotainment services, etc. – often referred to as “business services”.

The “rail critical services” comprise train control, and railway voice communication services (between drivers, controllers, operations center, dispatcher, etc.). Finally, train telemetry and maintenance services, non-critical real-time video (e.g. surveillance) services etc., are usually referred to as “performance services”.

As described in deliverable D2.1 [1] and D2.2 [2], the 5G-VICTORI transportation use cases focus on evaluating the capability to serve all communication requirements of train operators and passengers under the Future Railway Mobile Communication System (FRMCS) family of services, using 5G cellular radio.

UC #1.1 proposes a multi-technology infrastructure to provide connectivity to a train as it moves along a railway track. Specifically, UC1.1 in Patras, or the enhanced Mobile Broadband (eMBB) use case, makes use of an operational railway setup leveraging upon the 5G-VICTORI facility in Patras, aims to demonstrate eMBB capabilities achieved over the 5G-VICTORI heterogeneous technology network deployment providing network connectivity on-board the train wagons. This UC focuses on the following type of vertical services of the railway environment:

1. “Performance services”, non-critical services related to train operation, using as example **CCTV services** for supervision of the rail tracks quality (predictive maintenance related). Cameras are mounted on the front and rear of the train, capturing images that are forwarded in real time to the Operations Center (TRAINOSE facilities).
2. “Critical services”, related to voice emergency and safety services, using Mission Critical **Push-to-Talk** (e.g. between the controller(s) of the train/ operations centre and the driver/ on-train staff, etc.) as indicative application of this type.
3. “Business services”, that is, communication and broadband connectivity services usually provided to passengers when embarking, travelling and disembarking from the trains daily. Internet/data, Infotainment services, and **Video / TV streaming** services are used as an example.

These services are showcased over a unified 5G infrastructure, developed across multiple sites, at trackside and onboard the train for the specific trial. Several services co-exist in the developed facility over isolated network slices, which will be managed via the 5G-VINNI platform. Tests will be performed focusing on evaluating the Quality of Service (QoS) achieved for these services under static and train mobility scenarios.

The scheme that addresses the scope of this UC is shown in **Figure 3-1**, where the train moves along the stanchions that deploy various wireless technologies (D1 to D4). In order to connect with these technologies, the employed train incorporates two Sub-6 nodes and one mmWave node at the train roof. To demonstrate multi-technology track-to-train communication, the proposed setup comprises both mmWave (at D2 and D4 provided by IHP) and Sub-6 track-side APs to be deployed along the track between the two stations (see points D1 and D2). At the train side, to maximize connectivity and minimize the disconnection times between handovers from the train to the track APs, the proposed scheme requires antenna modules to be installed both at the front and at the rear of the train. As illustrated below the train moves along the stanchions and train to track connectivity is achieved either by the train node at the front or at the rear part of the train roof top. A 5G enabled on board fibre network is also designed and deployed in order to interconnect all access points (both 5G and non 5G technologies), use case specific elements. Edge processing units and roof top antennas.

The three service types comprise a large number of hardware and software devices that need to be interconnected and integrated with the overall infrastructure in order to enable the UC trials (WP4). For the verification of each group of services set of test cases is described, that will ensure that the deployment of the 5g enabled services can be evaluated. Each group of test cases that correspond to the three group of test cases are described in separate subsection of this chapter (RENv, RECv and REBv group of test cases correspondingly) .

As shown in Figure 3-1 in order to ensure that UC #1.1 will be evaluated an extension of the 5G VINNI facility in Patras (see point A) should be deployed and developed which concerns:

1. A 5G VICTORI established on board network.
2. A 5G VICTORI established multi-technology train to stanchion connectivity (four points D1-D4).
3. A 5G VICTORI deployed backhaul from and D4 to UoP.

The extension of the 5G-VINNI platform to interconnect to the **TRAINOSE** facility is being developed in parallel to the service development. Therefore, test cases focus on both infrastructure extensions and deployed services such as handover functionality. The test cases that concern the network deployment are described as a separate group of test cases, as these are common to all services (REDv) and will be described in a separate Section, as it is assumed that they are prerequisite to the overall service tests.

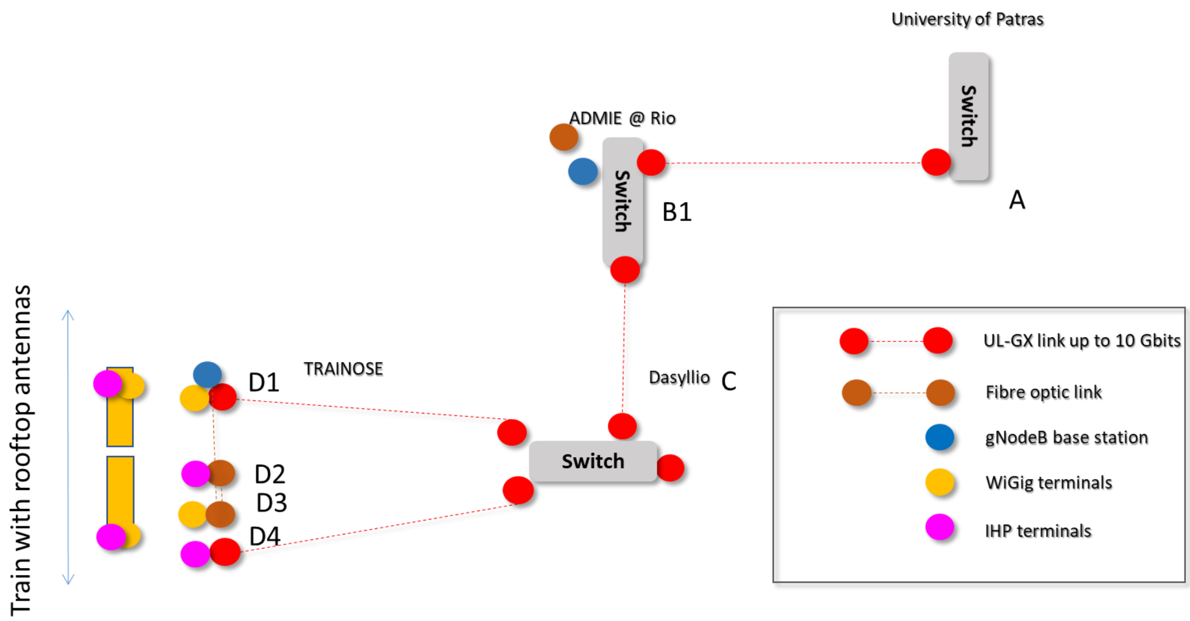

Figure 3-1: Deployment diagram of Patras facility for the Rail Enhanced MBB UCs

3.2 Rail Enhanced MBB Patras network deployment test-case (REDv)

3.2.1 Facility planning and deployment

The Patras facility to support this UC has been presented in D2.3 [2]. It spans from the Patras Central station (near to D4 in Figure 3-2) to the Depot, which is close to D1. The 5G-VICTORI network extension lies along the main **TRAINOSE** railtrack. The transport network interconnects the main 5G-VINNI facility (at UoP premises) through the backhaul network and ensures the execution of the services related to **UC #1.1** and **UC #4**. At the Depot (D1) the train is connected to the gNB of the Depot Station, which allows the execution of the CDN UC (**UC #3**). The train continues the journey in a part of the rail track where no 5G connectivity nor 5G-VICTORI network coverage exists. On the way back the train can again traverse the 5G-VICTORI extension along the rail track.

3.2.2 Description

Under this group of test cases, the Greek cluster focuses on the extension of the 5G-VICTORI facility in Patras City Center and along the TRAINOSE rail tracks to facilitate the test cases related to Task 3.1.

The elements that are extending the University of Patras (UoP) premises are according to the two dash-dotted frames shown in Figure 3-3, labeled as Patras Backhaul and Onboard with 5G RAN. The functionality of the elements is illustrated in the same figure. The train onboard network deployment as shown in the “on Board with 5G RAN” box of the figure. The train moves along the TRAINOSE tracks and connectivity is established via various technologies that exist on the side track stanchions (Trackside box in figure). This is achieved through roof top antennas. The interconnection for the on board service delivery takes place through the Patras backhaul (Patras Backhaul box). The 5G-VINNI cloud (shown in Office in UoP with 5G Core Network box) is enriched with all necessary software components for both service delivery and mobility management. These, together with the mobility management elements, are developed for the 5G-VICTORI eMBB trials. These are deployed and tested according to the test cases indicated as REDv, which is common for the service specific Patras 5G test cases.

The following sections describe the network part, starting with section 3.2.3 with its Table 3-1.

Figure 3-2 Infrastructure deployment at Patras facility for the Rail Enhanced MBB UCs

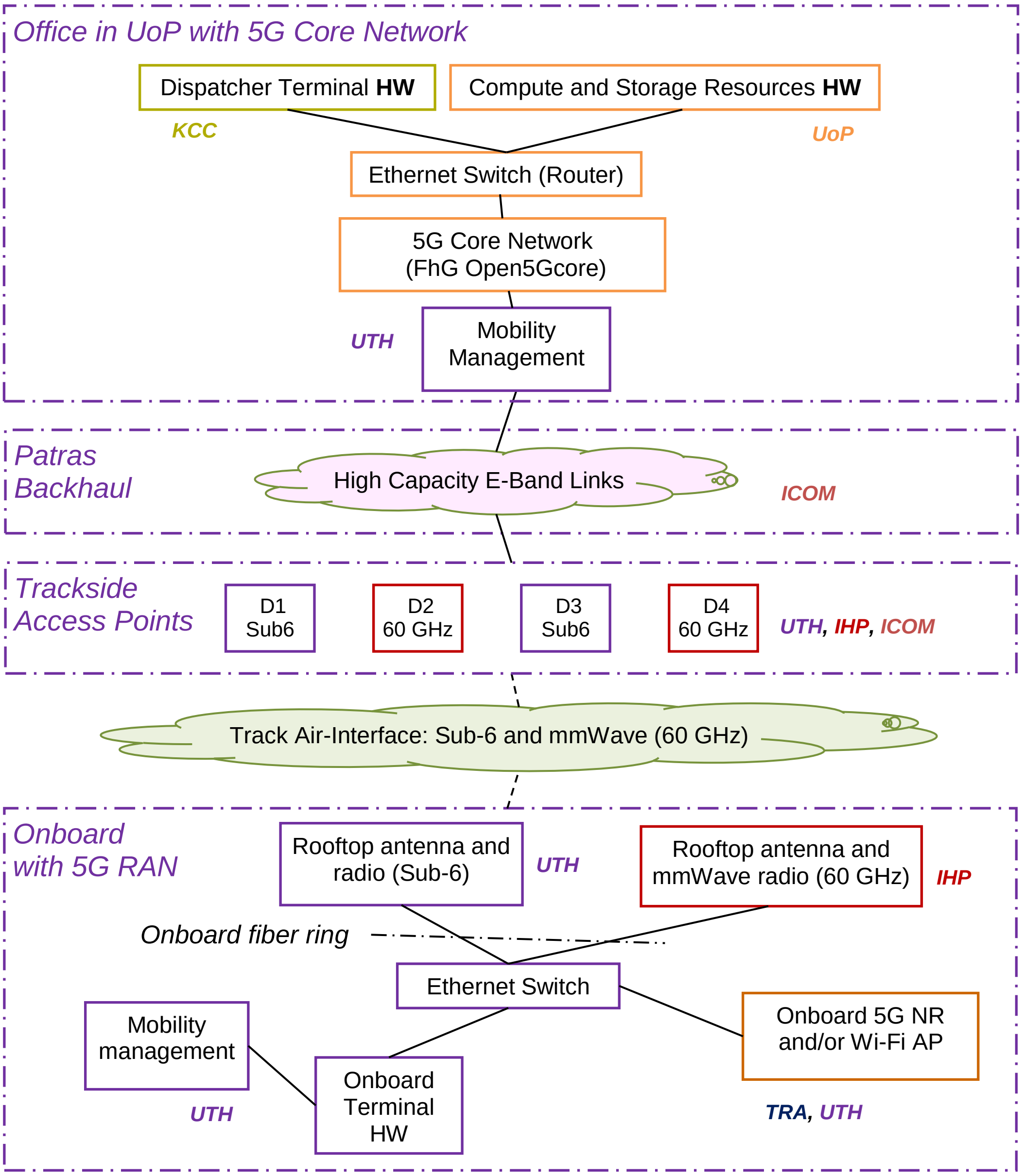

Figure 3-3: Enhanced MBB in Patras – Rail Operation Network extension deployment

3.2.3 REDv01: On board Network deployment testing, static case (lab test)

The on board network to be loaded and integrated on the TRAINOSE trains will be based on fibre ring network technology. This will interconnect all access points (Onboard 5G NR and/or Wi-Fi AP) and rooftop antennas via an SDN enabled switch, together with edge computing elements as shown in Figure 3-1.

This test case is required in order to ensure that the onboard network (in the lab) is fully operational and that this the onboard (standalone) network can be integrated to the 5G-VINNI facility. This concerns all elements that are required to be interconnected for the deployment of the mobility management. This means that the lower box of Figure 3-1 will be integrated to the upper box of Figure 3-1 to ensure that performance is adequate for the mobility management and Transport related services. The application specific hardware and software components are also integrated. This is the first step before deploying the onboard network on the train.

Table 3-1: REDv01 - On board Network deployment testing, static case (lab test)

REDv01	On board Network deployment testing, static case (lab test)
Testbed	**NITOS Lab (UTH) / 5G-VINNI Patras**
Description	This test-case demonstrates the connectivity within the onboard network (in the lab) and the connectivity between the onboard (standalone) network to the 5G-VINNI facility. Without the backhaul network.
Key Use-case requirements and KPIs	Latency, Uplink and Downlink capacity between the train and the **UoP** data center **U-PE-1103**- KPI: latency min. between UE and service end-points 20 ms.
Network performance requirements and KPIs	**U-PE-1103** Latency **F-CA-1104** Air Interface – Access Network Capacity Additional KPIs: • Guaranteed Bit Rate >99%
Network Functional requirements and KPIs	N/A
Components and configuration	**- Components:** 1. Onboard Ethernet Switch. 2. Onboard 5G NR with SDR and/or Wi-Fi AP. 3. Onboard fibre network. 4. On board server. 5. 5G Core Network VM in the 5G-VINNI cloud. 6. 5G UE for connecting to the network. **- Configuration:** 1. Onboard components are interconnected through the switch, and have access to the external network. 2. 5G Core network VM is reachable from the on-board 5G-NR gNB. 3. UE is in the coverage range of the gNB.
Test procedure	**- Preconditions:** 1. All components can be interconnected and operational. 2. Application specific hardware and software components are integrated. 3. Confirm that the corresponding onboard network components are registered to the **UoP** cloud. **- Test Case Steps:** 1. All equipment is connected and on-board terminal is also interconnected (with possibly wireless network as transport). 2. Create VNF on onboard server and core (**UoP** DC) and create network service between the two, traffic is generated. 3. The UE is connected, and traffic is generated - ICMP, TCP and UDP traffic generated from the UE reaches the **UoP** DC. 4. Confirm that all application specific software components are operational.

Measurements	**- Methodology** 1. gNB registers with the Core Network. 2. UE attaches to the gNB. 3. Bearers are allocated to the UE. 4. UE sends/receives ICMP requests/replies to/from the UoP cloud. 5. UDP/TCP traffic generated is sent in the UL and DL channel. 6. Wi-Fi access is tested (network attach and traffic generation). **- Complementary measurements** 1. N/A **- Calculation process** 1. Throughput calculation. 2. Round-Trip-Time (RTT) calculation.
Expected Result	Pass if the Latency is <20 ms and Throughput is >100 Mbps (5G gNB access)

3.2.4 REDv02: Connectivity of each stanchion to 5G-VINNI (lab and field)

To ensure that the multi technology interconnection can be enabled by 5G VICTORI, the various technologies that will be used for train to trackside connectivity will be integrated and tested in the lab ann idn the field.

This test case tests the connectivity between each trackside stanchion and 5G-VINNI Office, including:

- connectivity of each on board antenna to stanchion.
- connectivity of each on board antenna to 5G-VINNI.
- End-to-End connectivity testing over 5G-VINNI – 5G-VICTORI railway deployment and data transfer.

Table 3-2: REDv02 - Connectivity of each stanchion to 5G-VINNI (lab and field)

REDv02	Connectivity of each stanchion to 5G-VINNI (lab and field)
Testbed	**5G-VINNI Patras**
Description	This test case tests the connectivity between each stanchion and 5G-VINNI, including connectivity of each on board antenna to stanchion antenna, connectivity of each on board antenna to 5G-VINNI, and End-to-End connectivity testing over 5G-VICTORI railway deployment and data transfer. Furthermore, this test case includes the backhaul infrastructure.
Key Use-case requirements and KPIs	Latency, Uplink and Downlink capacity between train and UoP data center. **U-CA-1101**: Total capacity offered to a single train / wagon is about 1-2 Gbps. **U-PE-1103**: latency min. between UE and service end-points 20 ms. **F-CA-1104:** Antenna operation at high frequency bands delivering the required capacity.
Network performance requirements and KPIs	• <10 ms latency. • up to 1000 Mbps uplink and downlink throughput.
Network Functional requirements and KPIs	**F-FU-1112**: Slicing

Components and configuration	**- Components:** 1. On-board terminal (possibly unmounted). 2. Rooftop antenna and radio (Sub-6) (possibly unmounted). 3. Rooftop antenna and mmWave radio (60 GHz) (possibly unmounted). 4. Wayside Access Points at Stanchions (Sub-6). 5. Wayside Access Points at Stanchions (60 GHz). 6. High Capacity Backhaul network. 7. UoP Data Center. **- Configuration:** 1. The Onboard terminal connected via Ethernet switch to the roof top antennas. 2. Each Rooftop antenna can be connected to each stanchion. 3. Backhaul network is running.
Test procedure	**- Preconditions:** 1. Backhaul network is interconnected. 2. Confirm that all components are interconnected. 3. Confirm that the corresponding terminal is registered to the Virtualized Infrastructure Manager (VIM). **- Test Case Steps:** 1. All equipment, including the onboard terminal, is connected. The train is stopped. The onboard antenna is connected to the stanchion. The terminal is connected, and traffic is generated (ping to UoP DC). 2. The same step for each antenna/stanchion takes place sequentially and possibly unmounted. The terminal is connected through each antenna and traffic is generated (ping to UoP DC).
Measurements	**- Methodology** 1. Connect via stanchion. 2. Ping with UoP Data center. 3. Ping with Internet. 4. Generate traffic - Throughput to UoP data Center. 5. Generate traffic - Throughput to Internet. 6. Speedtest (Internet/UoP). **- Complementary measurements** 1. N/A. **- Calculation process** 1. Calculate throughput. 2. Calculate RTT.
Expected Result	Pass if the Latency is <10 ms and Throughput is >1 Gbps.

3.2.5 REDv03: Handover between transport and access nodes (lab and field)

This test case is used for testing:

- Handover functionality between two subsequent transport nodes.
- Handover functionality between two subsequent access nodes.

Table 3-3: REDv3 - Handover between transport and access nodes (lab and field)

REDv03	Handover between transport and access nodes (lab and field)
Testbed	**NITOS lab (UTH) / 5G-VINNI Patras**
Description	This test case is used for testing the seamless handover functionality between heterogeneous transport nodes. The solution is based on the mobility management framework (UTH) and P4-based network programming, and is tested at two different sites: • the NITOS side (in-lab and field trial with cars). • 5G-VINNI in Patras.
Key Use-case requirements and KPIs	Latency, Uplink and Downlink capacity between train and UoP data center. **U-CA-1101**- Total capacity offered to a single train / wagon is about 1 Gbps. **U-PE-1103**- KPI: latency min. between UE and service end-points 20 ms. **F-CA-1104** Antenna operation at high frequency bands delivering the required capacity.
Network performance requirements and KPIs	**U-PE-1102** Mobility. **F-CA-1104** Transport Network Capacity >1 Gbps.
Network Functional requirements and KPIs	**F-FU-1111** Multi-Tenancy. **F-FU-1112** Slicing. **S-FU-1114** Mobility – Handovers.
Components and configuration	**- Components:** 1. 2x Programmable NIC equipment (P4 compatible). 2. P4 network controller, running as a VM/microservice on the infrastructure. 3. mmWave track-side and on-board nodes. 4. Sub-6 GHz (802.11ax) track-side and on-board nodes. 5. On-board compute node. 6. On-board Networking switch. 7. On-board Wi-Fi network. 8. End-user applications (e.g. CCTV camera, MCPTT dispatcher). **- Configuration:** 1. On board Wi-Fi network connected to the switch. 2. The switch is connected to the programmable NIC equipment. 3. The on-board radio is connected to the programmable NIC. 4. The track-side radios is connected to the second programmable NIC. 5. On board compute node hosts the P4 controller for the on-board side, while the server side is controlled with a similar controller running as a VM in the cloud. 6. End-user applications and terminals are connected to the on-board Wi-Fi. 7. Server-side applications (CCTV server, MCPTT server) are instantiated as VMs in the cloud.

Test procedure	**- Preconditions:** 1. All components can be interconnected and operational. 2. Application specific hardware and software components are integrated. 3. On-board equipment is mounted on a car. 4. At least one track-to-train link is up and operational, and applications have established connections to the cloud. 5. P4 Controllers are up and can control the programmable NICs. **- Test Case Steps:** 1. Train car starts moving, gets into coverage of a subsequent track-side unit. 2. P4 controllers are notified of the change and establish the respective flows in the programmable NICs. 3. Handovers shall not impact applications running on-board.
Measurements	**- Methodology** 1. Connect to a stanchion and measure RTT. 2. Connect to subsequent stanchion and measure RTT continuously. 3. Measurement of UL/DL throughput during handovers. **- Complementary measurements** 4. Measurement of time between notification for a handover process and flow establishment in the P4 programmable NICs. **- Calculation process** 1. Calculate throughput during the handover process. 2. Calculate interruption time during the handover. 3. Calculate RTT during the handover process.
Expected Result	Handover interruption time < 5 ms, end-to-end latency is kept during the handover period <20 ms

3.3 Rail Enhanced MBB Patras rail operation non-critical test cases (RENv)

3.3.1 Description

Under this group of non-critical services (RENv), the Greek cluster focuses on maintenance infrastructure services. Specifically, one service that is showcased and delivered as a good representative example is CCTV capturing the rail track state live to monitor the tracks for predictive maintenance purposes.

CCTV cameras are mounted at the front and at rear part of the train and captured images are forwarded to Operations Center of TRAINOSE, which is co-located at the 5G-VINNI cloud. The cameras' application part is generating the CCTV monitoring frames that are sent and monitored at the Operations Center part. These parts are essentially the two components of the non-critical service for this UC. At application layer, the session is established over a H.264 session layer, and the traffic is of UDP type.

Considering the Patras network deployment, as shown in Figure 3-4, the cameras are integrated with the onboard network deployed on the TRANOSE trains. Images captured from the rail track are forwarded through the various technologies used for the stanchion to train connectivity as the train moves along the rail tracks, to the backhaul network and to the 5G-VINNI cloud.

IHP provides the mmWave (60 GHz) units from Mikrotik, wayside access points D2 and D4 and on train rooftop. **UTH** provides Sub-6 units for wayside access points D1 and D3.

The objective of the test cases is to demonstration the following:

- Demonstrate Track Monitoring using an onboard CCTV camera.
- Demonstrate seamless service provisioning from Train to the Office during backhaul handovers (when the train moves).

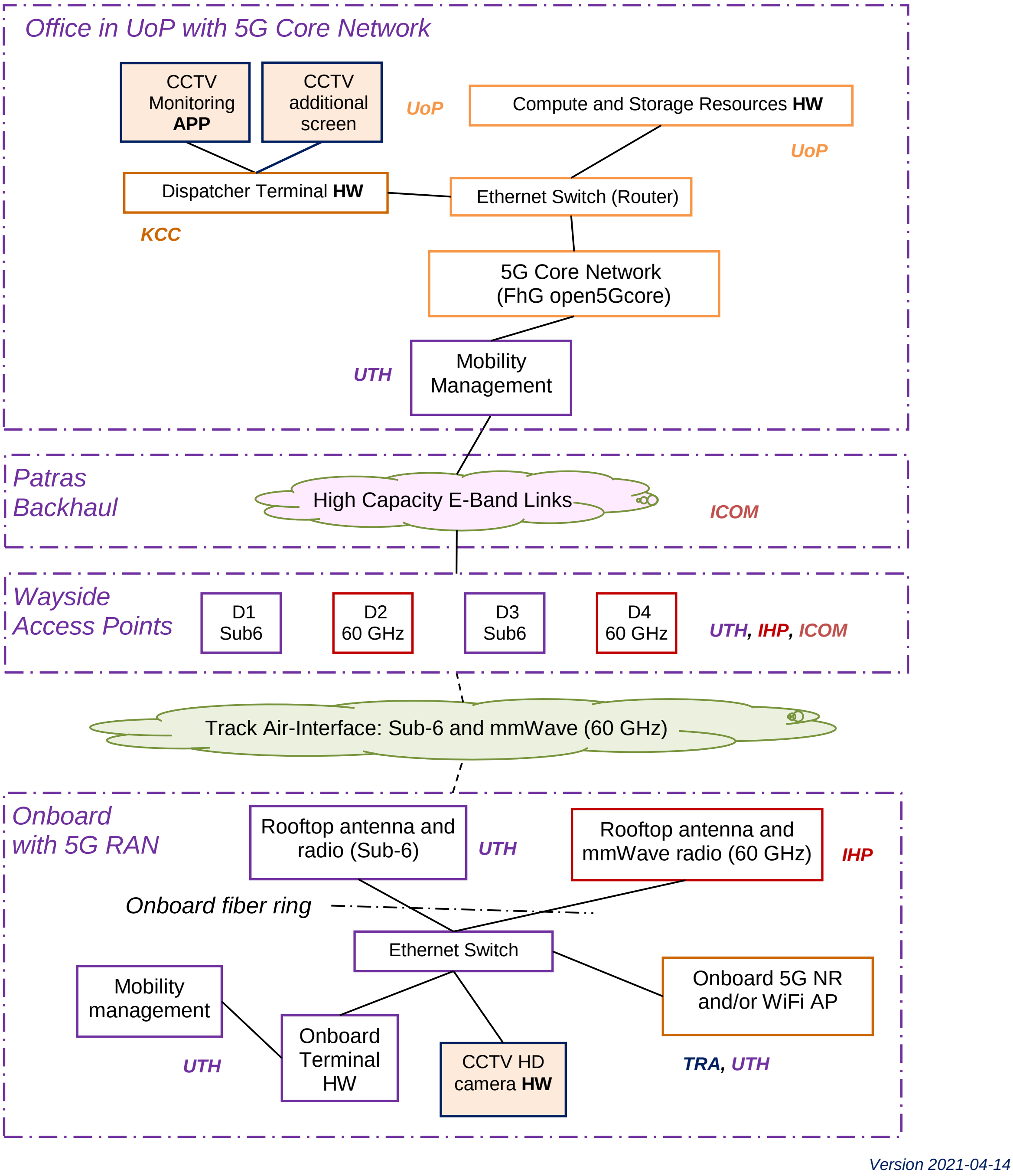

Figure 3-4: Enhanced MBB in Patras – Rail Operation Non-critical services – Onboard CCTV camera

3.3.2 RENv01: Track monitoring with on board camera over 5G

In general, Rail Operation non-critical services –e.g. track monitoring for various preventive maintenance and monitoring purposes- impose loose performance requirements. However, the performance of such services when deployed in the field shall be known as it is taken into account at post-processing stages of the data collection and for application fine-tuning (e.g.

resolution of the CCTV camera, definition of frame capturing rate). Therefore, this test case is necessary for providing insights about the application performance over the lab and field deployments for application parameters fine tuning.

Moreover, deploying such applications on board trains and testing in the field is a time / cost/ effort consuming process, so validation of the application shall be performed first at a lab environment. Therefore, this test case is necessary for initially validating the application operation over the 5G-VICTORI proposed deployment at lab environment prior to deploying it in the field.

This test case shows track monitoring using an onboard camera with video streaming over the 5G network to the Control center.

This test case ensures the integration of the camera, evaluates the capturing process of the track images to prepare the camera preview video for streaming on the onboard network.

In the second phase after the overall network is integrated, the camera preview is provided in a format suitable for streaming to the Control Center.

Table 3-4: RENv01 - Track monitoring with on board camera over 5G (lab test)

RENv01	Track monitoring with on board camera over 5G (lab test and field test)
Testbed	**5G-VINNI Patras**
Description	The test-case connects the CCTV camera with the Central Office HW and APP equipment over an Ethernet switch and cable. The first phase of the test aims at configuring the equipment to suit the CCTV test-cases. The second phase of the test case assumes the integrated onboard network is deployed in the lab and CCTV streaming is tested between the emulated Central station and the onboard train network using the 5G network in between. The test-case aims at checking that CCTV pictures start streaming when the train is powered up and when 5G connectivity comes up between camera and onboard network. Alerts are assumed to be monitored on board as well. The test case has two steps: 1. Integrate the camera on the onboard network (in the lab). 2. Video streaming to the Control center (in the field).
Key Use-case requirements and KPIs	150 Mbps for the cameras Connection of the camera Ethernet of Wi-Fi Latency between camera and Control center 100 ms High Video Quality of CCTV session
Network performance requirements and KPIs	**U-PE-1103**: End-to-end Latency: for this service type - Not critical **F-CA-1104**: Air Interface – Access/Transport Network Capacity **F-PE-1105**: Air Interface Characteristics
Network Functional requirements and KPIs	**F-FU-1111**: Multi-Tenancy **F-FU-1112**: Slicing

Components and configuration	**- Components:** 1. Office in the lab: CCTV Monitoring APP, CCTV additional screen HW, Mobility Management, Compute and Storage Resources HW, Dispatcher Terminal HW, Ethernet Switch (Router), 5G Core Network. 2. Emulated Rooftop antenna and radio (Sub-6) / Rooftop antenna and radio (60 GHz). 3. Emulated onboard network Ethernet Switch, Onboard 5G NR and/or WiFi AP. 4. CCTV HD camera HW, Onboard Terminal HW. **- Configuration:** 1. Connectivity between components performed as in Figure 3-4. 2. 5G access network node configuration as in REDv01. 3. Transport nodes configuration as in REDv02.
Test procedure	**- Preconditions:** 1. Onboard network in the lab. 2. Transports network deployed. **- Test Case Steps:** 1. Integrate camera on the onboard network 2. Capture camera preview 3. Encode camera preview 4. Ensure images are in suitable format for streaming On the integrated facility, continue with: 5. Establish a connection for video streaming to the server associated with the created session 6. Start streaming camera preview video via the established video connection 7. Receive camera preview stream on VM instance 8. Measure delay

<table>
<tr><td>Measurements</td><td>
- Methodology

The test procedure is repeated for various traffic conditions of the access nodes.
The test procedure is repeated in a number of positions along the TRAINOSE facilities tracks and under mobility conditions.
Measurements are collected for a number of iterations (~5 iterations need) for the evaluation of each KPI for each set of test conditions.
Erroneous measurements are discarded from the measurements.

- Complementary measurements

Position (GPS), and velocity related measurements are collected in each iteration/test.
Traffic conditions are also monitored and noted in each iteration (at Wi-Fi AP level).
Messages verifying seamless backhaul handovers are monitored continuously during the tests.

- Calculation process

Service layer messages and network layer messages are captured with their timestamp and the time difference between an operation request and a response is calculated. (e.g. service setup, etc.).
For each set of tests and iterations - for the specific conditions - the mean/ median/ max./ min latency values (in ms) are calculated.
Voice Quality is also monitored during the sessions. For each session data rate statistics can be collected (e.g. average data rate).
Messages verifying seamless backhaul handovers are monitored continuously during the tests. Any disconnection messages are captured along with their timestamp and the time it takes to re-connect is calculated.
Mean-Opinion-Score will be measured for CCTV video quality at TL1 for the evaluation of the high Video Quality of CCTV session KPI.

</td></tr>
<tr><td>Expected Result</td><td>In all positions, and under all conditions, an average data rate of 150 Mbps for cameras is achieved, and a high MOS is captured (at least >3 on average).
Seamless service provisioning shall be possible with no interruption time.</td></tr>
</table>

3.4 Rail Enhanced MBB Patras - Rail operation Critical Services (RECv)

3.4.1 Description

This group of test cases (RECv) focuses on the performance evaluation of indicative “Critical” services addressed to specific stakeholders engaged in railway operations usually in the provisioning of mission-critical, safety, emergency, or security services. This group of services requires maximum service availability and reliability levels – at given network availability.

As a good example of Mission-Critical services, Telephony and Data for the Train Operator, provided by KCC, are used as services and are demonstrated in the 5G-VINNI railway deployment. The Rail Critical Telephony services, including MCPTT (single session call and group call) and MCx Data, are provided between UoP Office and Onboard Train, where a set of on-train, mobile and fixed terminals will be running the relevant applications. Voice and data sessions will be established between these terminals. The sessions will be handled by session dispatching components that will be deployed at UoP Office (i.e. UoP cloud). The relevant application components are shadowed in orange in Figure 3-5.

The network deployment is the same for the complete bundle of the services of this UC (see REDv in section 3.2). As mentioned, a heterogeneous transmission network is deployed to interconnect the onboard access network components of the TRAINOSE train with the 5G-VINNI core network, the **UoP** central cloud facilities and the public internet.

For this bundle of services, the onboard train connectivity is provided over Wi-Fi Access Points connected via the heterogeneous wireless transport solution. Seamless service provisioning for passengers during backhaul handovers between different track side access points and technologies are tested.

The Mission-Critical applications deployment over this infrastructure is presented in Figure 3-5.

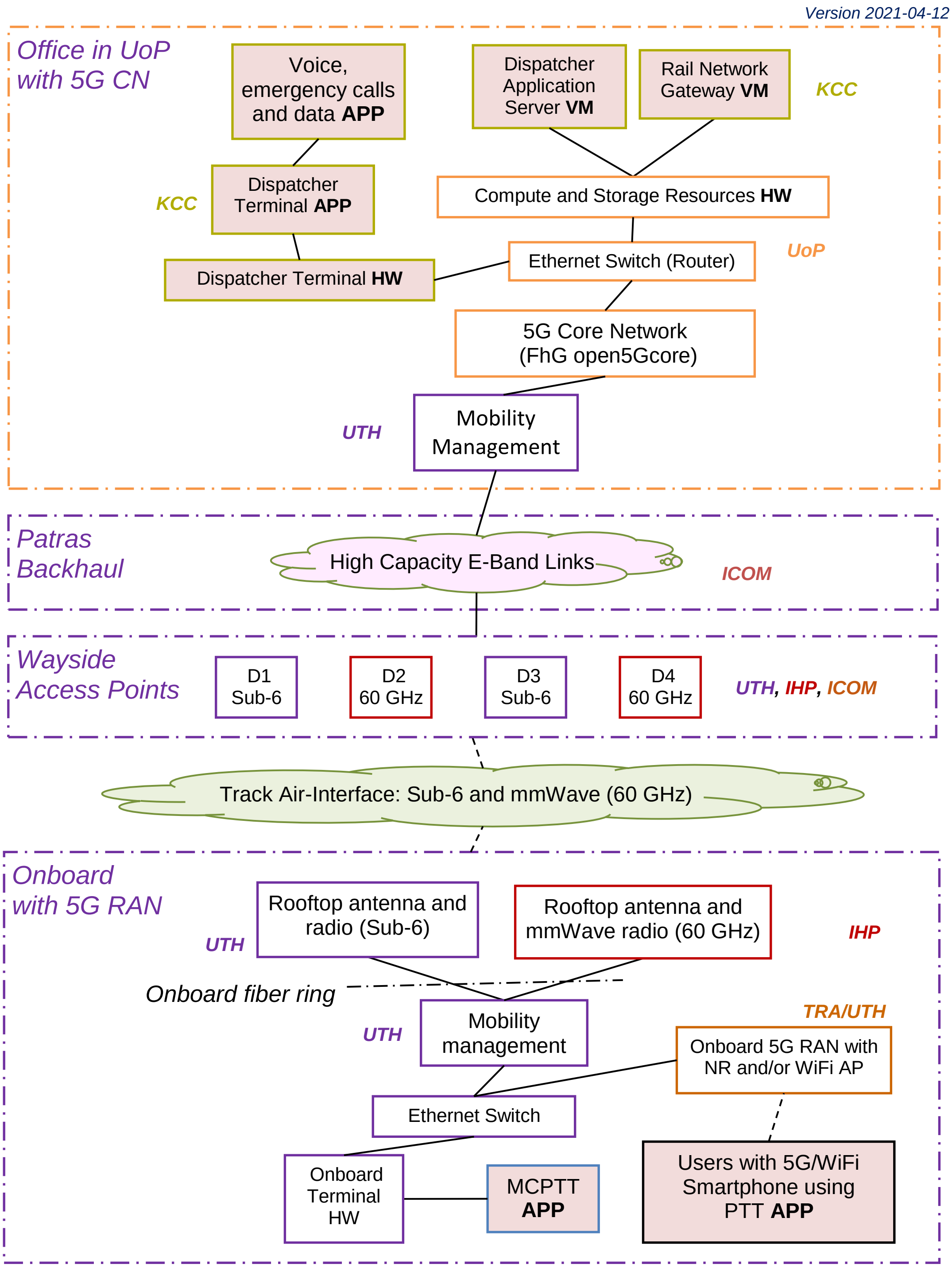

Figure 3-5: Enhanced MBB in Patras – Rail Operation Critical services – Mission Critical PTT

3.4.2 RECv01: Push-to-talk voice service for railway operation staff

In general, mission critical applications impose strict performance requirements (latency and reliability being two main KPIs), for the purpose of transferring intelligible mission critical information. Therefore, the application performance evaluation (in terms of establishing an intelligible PTT session) over the operational deployment prior to relying on it at operational stages is necessary. This test case provides the necessary validation and application performance evaluation.

In particular, the purpose of this test-case is to validate the establishment and the performance over 5G-VICTORI deployment of on-train voice communication (bi-directional critical Push-to-Talk voice MCPTT). The PTT session is established between an Onboard End-point (denoted as caller A e.g. driver's UE) and a responsible controller at the Control Center (caller B). PTT can be initiated by driver or controller.

The test case details are described in Table 3-5.

Table 3-5: RECv01 - Push-to-talk voice service for railway operation staff

RECv01:	Push-to-talk voice service for railway operation staff
Testbed	**5G-VINNI Patras**
Description	The test validates the end-to-end deployment of MCPTT application in 5G-VINNI facilities (over the 5G-VINNI heterogeneous wireless transport deployment using Wi-Fi access), and evaluates the performance of MCPTT / MCX Voice service between a caller A onboard (e.g. driver) and a caller B (e.g. responsible controller) at Control Center, initiated by any of the parties.
Key Use-case requirements and KPIs	1. Voice Quality of MCPTT session shall be highly intelligible (technically it will require 60 ms RTT, 100 kbps rate, 10^{-6} packet loss). 2. Setup time of a communication session shall be <1 sec. 3. Session Loss Rate (shall be $<10^{-2}$ /h in operational conditions). 4. Service Reliability >99.99%.
Network performance requirements and KPIs	**U-PE-1102**: Mobility **U-PE-1103**: End-to-end Latency: for this service type – 20 ms **F-PE-1105**: Air Interface Characteristics Additional Performance KPIs: • Packet Loss: <1% • Guaranteed Data Rate: ~100 kbps • Availability: 99.99% • Reliability: 99.99%
Network Functional requirements and KPIs	**F-FU-1111**: Multi-Tenancy **F-FU-1112**: Slicing **S-FU-1114**: Mobility - Handovers (HO), i.e. HO between subsequent trackside nodes (access or transport network nodes)

Components and configuration	**- Components:** 1. Ethernet Switch (Router). 2. Rooftop antenna and radio (Sub-6)/ Rooftop antenna and radio (60 GHz). 3. On-board Switch. 4. On-board Wi-Fi AP. 5. Mobility management function. 6. on-board terminal or user handset with MCX app. 7. on-board gateway (on-board Compute and Storage Resources HW). 8. MCX/FRMCS core. 9. next-gen dispatcher. 10. Emulated Central Office components. **- Configuration:** 1. Connectivity between components performed as in Table 3-4. 2. Setup a message capturing tool at end-points. 3. Setup a datarate monitoring/ measuring tool at end-points. 4. Setup a second/third etc. UE or traffic generating tool to perform iperf/ ftp sessions to emulate traffic conditions. 5. MCX/FRCMS network and users (Caller A, B; driver, controller) are provisioned. 6. Wi-Fi network node configuration as in REDv01. 7. Transport nodes configuration as in REDv02.
Test procedure	**- Preconditions:** 1. Application running on all devices. 2. End user connectivity through on-board Wi-Fi AP is verified. 3. All MCX/FRMCS clients are registered and authorized to use MCX/FRMCS services. 4. Definition of position of UE under test and while moving (GPS positioning shall be available). 5. Definition of traffic conditions of access network node. **- Test Case Steps:** 1. End user connects to the on-board Wi-Fi node. 2. GPS positioning of UE and/or train node is available, and location is captured all the time. 3. Caller A (e.g. Driver) starts on-demand private call to Caller B (e.g. controller). 4. The call is received on dispatcher and accepted by the controller. 5. The voice call is active, and Connectivity is verified all the time. 6. Voice quality is monitored throughout the session. 7. Voice call is terminated by Caller A or B. 8. Steps 1-7 are followed both when the train is static and on the move.

Measurements	**- Methodology** 1. The test procedure is repeated for various traffic conditions of the access nodes. 2. The test procedure is repeated in several positions along the TRAINOSE facilities tracks and under mobility conditions. 3. Measurements are collected for several iterations (~5 iterations need) for the evaluation of each KPI for each set of test conditions. 4. Erroneous measurements are discarded from the measurements. **- Complementary measurements** 1. Position (GPS), and velocity related measurements are collected in each iteration/test (at UE level). 2. Traffic conditions are also monitored and noted in each iteration (at on-board WiFi AP). 3. Messages verifying seamless backhaul handovers are monitored continuously during the tests. **- Calculation process** 1. Service layer messages and network layer messages are captured with their timestamp and the time difference between an operation request and a response is calculated. (e.g. service setup, etc.) 2. For each set of tests/ iterations -for the specific conditions- the mean/ median/ max./ min latency values (in ms) are calculated. 3. Voice Quality is also monitored during the sessions. For each session data rate statistics can be collected (e.g. average data rate). 4. Messages verifying seamless backhaul handovers are monitored continuously during the tests. Any disconnection messages are captured along with their timestamp and the time to re-connect is calculated. 5. Mean-Opinion-Score will be measured for audio quality at TL1 for the evaluation of the high Voice Quality of MCPTT session KPI.
Expected Result	1. Voice call established successfully within target setup time. 2. Voice connection stable and of good quality 3. Session loss rate captured but evaluated given the restrictions of the test environment.

3.4.3 RECv02: MCPTT Group Call services for railway operations staff

As aforementioned, mission critical applications impose strict performance requirements (latency and reliability being two main KPIs), for the purpose of transferring intelligible mission critical information. Therefore, it is necessary to proceed with the performance evaluation of this service in terms of establishing a MCPTT Group Call session that (1) includes successfully all parties that need to participate in the call, and (2) that transfers intelligible mission critical information to all necessary parties, over the operational deployment prior to relying on it at operational stages. In this context, the purpose of this test-case is to validate the establishment and the performance over 5G-VICTORI deployment of the onboard voice Group call (MCPTT).

MCPTT is tested both between two onboard end-points (denoted as caller A and C e.g. driver's UE) and a responsible controller at the Control Center (caller B).

The test case details are found in Table 3-6.

Table 3-6: RECv02 - MCPTT Group Call services for railway operations staff

RECv02	MCPTT Group Call services for railway operations staff
Testbed	**5G-VINNI Patras**
Description	The test evaluates the performance of MCPTT / MCX Group Call (Voice) service between two on-board callers (e.g. driver and staff) and a third caller as responsible controller at the Control Center, initiated by any of the three parties.
Key Use-case requirements and KPIs	1. Voice Quality of MCPTT group call session shall be highly intelligible (technically it will require 60 ms RTT, 100 kbps rate, 10^{-6} packet loss). 2. Setup time of a communication session shall be <1 sec. 3. Caller Assignment time shall be 300 ms.. 4. Session Loss Rate (shall be $<10^{-2}$ /h in operational conditions). 5. Service Reliability >99.99%.
Network performance requirements and KPIs	**U-PE-1102**: Mobility **U-PE-1103**: End-to-end Latency: for this service type - 20ms **F-PE-1105**: Air Interface Characteristics Additional Performance KPIs: • Packet Loss: <1%. • Guaranteed Data Rate: ~100 kbps. • Availability: 99.99%. • Reliability: 99.99%.
Network Functional requirements and KPIs	**F-FU-1111**: Multi-Tenancy. **F-FU-1112**: Slicing. **S-FU-1114**: Mobility - Handovers (HO), i.e. HO between subsequent trackside nodes (access or transport network ones).
Components and configuration	**- Components:** 1. Ethernet Switch (Router). 2. Rooftop antenna and radio (Sub-6)/ Rooftop antenna and radio (60 GHz). 3. On-board Switch. 4. On-board Wi-Fi AP. 5. Mobility management function. 6. Two on-board terminal or user handset with MCX app. 7. On-board gateway (on-board Compute and Storage Resources HW). 8. MCX/FRMCS core. 9. Next-gen dispatcher. 10. Emulated Central Office components. **- Configuration:** 1. Connectivity between components performed as in Figure 3-5. 2. Setup a message capturing tool at end-points. 3. Setup a data rate monitoring/ measuring tool at end-points. 4. Setup additional UEs or traffic generating tool to perform iperf / ftp sessions to emulate traffic conditions. 5. Provisioned MCX/FRCMS network and users (callers A, B, C). 6. Wi-Fi network node configuration as in REDv01. 7. Transport nodes configuration as in REDv02.

Test procedure	**- Preconditions:** 1. Application running on all devices. 2. End user connectivity through on-board Wi-Fi AP is verified. 3. All MCX/FRMCS clients are registered and authorized to use MCX/FRMCS services 4. Definition of position of UE under test and while moving (GPS positioning shall be available). 5. Definition of traffic conditions of access network node. **- Test Case Steps:** 1. End users connect to the on-board Wi-Fi node. 2. GPS positioning of UE and/or train node is available, and location is captured all the time. 3. Caller A (e.g. Driver) starts a group call to Caller B (e.g. controller) and also adds Caller C. 4. The call is received on dispatcher and accepted by the controller. 5. The time it takes for a caller to be added to a running group call is calculated. 6. The voice call is active, and connectivity is verified all the time. 7. Voice quality is monitored throughout the session. 8. Voice call is terminated by Caller A, B or C. 9. Steps 1-8 are followed both when the train is static and on the move.
Measurements	**- Methodology** 1. The test procedure is repeated for various traffic conditions of the access nodes. 2. The test procedure is repeated in several positions along the TRAINOSE facilities tracks and under mobility conditions. 3. Measurements are collected for several iterations (~5 iterations need) for the evaluation of each KPI for each set of test conditions. 4. Erroneous measurements are discarded from the measurements. **- Complementary measurements** 1. Position (GPS), and velocity related measurements are collected in each iteration/test. (at UE level). 2. Traffic conditions are also monitored and noted in each iteration. (at on-board Wi-Fi level). 3. Messages verifying seamless backhaul handovers are monitored continuously during the tests. **- Calculation process** 4. Service layer messages and network layer messages are captured with their timestamp and the time difference between an operation request and a response is calculated. (e.g. service setup, talker assignment time, etc.) 5. For each set of tests/ iterations -for the specific conditions- the mean/ median/ max./ min latency values (in ms) are calculated. 6. Voice Quality is also monitored during the sessions. For each session datarate statistics can be collected (e.g. average datarate). 7. Messages verifying seamless backhaul handovers are monitored continuously during the tests. Any disconnection messages are captured along with their timestamp and the time to re-connect is calculated. 8. Mean-Opinion-Score will be measured for audio quality at TL1 for the evaluation of the high Voice Quality of MCPTT group call session KPI.

Expected Result	1. Voice Group call established, and talkers assigned successfully within target setup times. 2. Voice connection stable and of good quality. 3. Session loss rate captured but evaluated given the restrictions of the test environment.

3.4.4 RECv03: MCX Data services for railway operation staff

As aforementioned, mission critical applications impose strict performance requirements (latency and reliability being two main KPIs), for the purpose of transferring intelligible mission critical information. Therefore, it is necessary to proceed with the performance evaluation of this service in terms of establishing a MCX Data session that transfers mission critical data with high integrity and reliability and with low delay to the necessary parties, over the operational deployment prior to relying on it at operational stages. This test case serves the purpose of evaluating the performance – over the 5G-VICTORI deployment – of MCX Data application between an onboard end-point (denoted as caller A e.g. driver's UE) and a responsible controller at the Control Center (caller B).

We can assume that such data constitute railway emergency alerts (e.g. which is presented on an onboard screen), triggered by authorized users.

The test case is described in Table 3-7.

Table 3-7: RECv03 - MCX Data services for railway operation staff

RECv03	**MCX Data services for railway operation staff**
Testbed	**5G-VINNI Patras**
Description	The test evaluates the performance of MCPTT / MCX Group Call (Voice) service between two on-board callers (e.g. driver and staff) and a third caller as responsible controller at the Control Center, initiated by any of the three parties.
Key Use-case requirements and KPIs	1. Railway emergency alert, voice and/or data (bi-directional critical voice/data) triggered by authorized users aware of a hazard, triggered within an automatically configured group is send to those users likely to be affected by the emergency. 2. Immediate setup of data session.
Network performance requirements and KPIs	**U-PE-1102**: Mobility **U-PE-1103**: End-to-end Latency: for this service type – 200 ms. **F-PE-1105**: Air Interface Characteristics. Additional Performance KPIs: • Guaranteed Data Rate: ~100 kbps. • Availability: 99.99%. • Reliability: 99.99%.
Network Functional requirements and KPIs	**F-FU-1111**: Multi-Tenancy. **F-FU-1112**: Slicing. **S-FU-1114**: Mobility – Handovers (HO) (i.e. HO between subsequent trackside nodes (access or transport network ones))

<table>
<tr><td>Components and configuration</td><td>
- Components:

Ethernet Switch (Router).
Rooftop antenna and radio (Sub-6)/ Rooftop antenna and radio (60 GHz).
On-board Switch.
On-board Wi-Fi AP.
Mobility management function.
on-board terminal or user handset with MCData app.
2nd on-board terminal or user handset in different location area (B).
on-board gateway (on-board Compute and Storage Resources HW).
MCX/FRMCS core.
next-gen dispatcher.
Emulated Central Office components.

- Configuration:

Connectivity between components performed as in Figure 3-5.
Setup a message capturing tool at end-points.
Setup additional UEs or traffic generating tool to perform iperf/ ftp sessions to emulate traffic conditions.
Provisioned MCX/FRCMS network and users (callers A, B, C).
Wi-Fi network node configuration as in REDv01.
Transport nodes configuration as in REDv02.

</td></tr>
<tr><td>Test procedure</td><td>
- Preconditions:

All systems are up and running.
End user connectivity through on-board Wi-Fi AP is verified.
All MCX/FRMCS clients are registered and authorized to use MCX/FRMCS services
MCX/FRMCS has provisioned location areas
MCX/FRMCS clients can receive location from UE (UE location method is active e.g. via GPS)
At least one MCX client is operating in "high speed" environment (on-train).

Test Case Steps:

End user connects to the on-board Wi-Fi node
Authorized user at Client A issues a "Railway emergency alert" via an MCX/FRMCS client- Data only Railway emergency alert.
Railway emergency alert is automatically received on MCX/FRMCS clients (including Client B) in defined location area (could be including dispatcher client at control center)
When Data Railway emergency alert call is active, connection quality is monitored
Terminate Railway emergency alert by authorized MCX client.
Steps 1-7 are followed both when the train is static and on the move.

</td></tr>
</table>

Measurements	**- Methodology** 1. The test procedure is repeated for various traffic conditions of the access nodes. 2. The test procedure is repeated in several positions along the TRAINOSE facilities tracks and under mobility conditions. 3. Measurements are collected for several iterations (~5 iterations need) for the evaluation of each KPI for each set of test conditions. 4. Erroneous measurements are discarded from the measurements. **- Complementary measurements** 1. Position (GPS), and velocity related measurements are collected in each iteration/test. (at UE level). 2. Traffic conditions are also monitored and noted in each iteration. (at on-board Wi-Fi AP level). 3. Messages verifying seamless backhaul handovers are monitored continuously during the tests. **- Calculation process** 1. Service layer messages and network layer messages are captured with their timestamp and the time difference between an operation request and a response is calculated. (e.g. service setup, etc.). 2. For each set of tests/ iterations -for the specific conditions- the mean/ median/ max./ min latency values (in ms) are calculated. 3. Messages verifying seamless backhaul handovers are monitored continuously during the tests. Any disconnection messages are captured along with their timestamp and the time to re-connect is calculated.
Expected Result	1. MCData session established successfully. 2. Session setup time is within "immediate setup" KPI range. 3. Quality of Session is acceptable in terms of data exchange times. 4. Stable data connection is achieved (for Data calls).

3.5 Rail Enhanced MBB Patras - Business services for Passengers test-cases (REPv)

3.5.1 Description

This group of test cases focuses on the performance evaluation of indicative “Business” services addressed to the train passengers. These services are characterized by low criticality but are susceptible to high error rates e.g. possibly associated with sub-optimal mobility/handover functionality incurred at medium-high mobility speeds; so such issues are addressed in the associated test cases. Wireless internet/data, infotainment services, and live TV streaming services (COSMOTE TV) as indicative such services are demonstrated and evaluated. Especially the application delivering the live TV streaming services comprises an end-user application to be installed at passengers with UEs (smartphones) and a Streaming Server part (re-transmitting COSMOTE TV live content for the purposes of the testing) that is accessible over internet (e.g. located at COSM premises). These parts are essentially the two components of the service for this use case, shadowed in blue in Figure 3-6. At application layer, the session is established over a WebRTC session layer, the encoding is based on H264. The data traffic is of UDP type.

Assuming such versatile mobile broadband services typical data rates required would be of 5-10 Mbps per passenger. Considering a total of 100 passengers in a station/train area, the maximum capacity needed would be of 0.5-1 Gbps over a single cell coverage area for this type of services.

Regarding network deployment, it is the same for the complete bundle of the services of this UC. As described, a heterogeneous transmission network is deployed to interconnect the on-board network components of TRAINOSE train with the 5G-VINNI core network and the public network (internet and public COSMOTE TV retransmission server).

On-board the train, passenger connectivity is provided over Wi-Fi and/or over the onboard 5G node. Seamless service provisioning for passengers during handovers between different backhaul nodes/technologies is tested.

The high-level objectives of this vertical service are:

- Demonstrate TV streaming for passengers, using COSMOTE TV Streaming Service.
- Demonstrate seamless service provisioning for passengers during Backhaul Handovers (when train moves).

3.5.2 **REPv01: 5G data services for passengers – lab TV streaming (lab test)**

In general, business services such as internet/ infotainment services although not accompanied with strict performance guarantees, require high datarates and impose high traffic to the network over which they are transferred. Network capacity and coverage availability are key factors affecting the performance of these services in the railway environment. To this end, especially in the cases where these services are charged by service providers, it may be necessary for service providers to have an understanding of the performance of these applications at various locations –eventhough the services are delivered over public internet. As an example, regarding the COSMOTE TV services (pay-mobile TV services) having insights of the performance and availability of the service along the railway tracks can be significant in promoting this service and acquiring subscriptions. This is associated with performing the necessary application validation and performance evaluation.

The test case provided in this section validates at static, lab environment the provisioning of "business services" through Wi-Fi and the 5G access nodes that are later deployed on board the TRAINOSE train and integrated with 5G-VICTORI deployment at Patras site.

A customized COSMOTE TV service is used as indicative live-streaming content. Mainly data rates and latency measurements for various service operations are evaluated.

The test case is presented with details in the below Table 3-8.

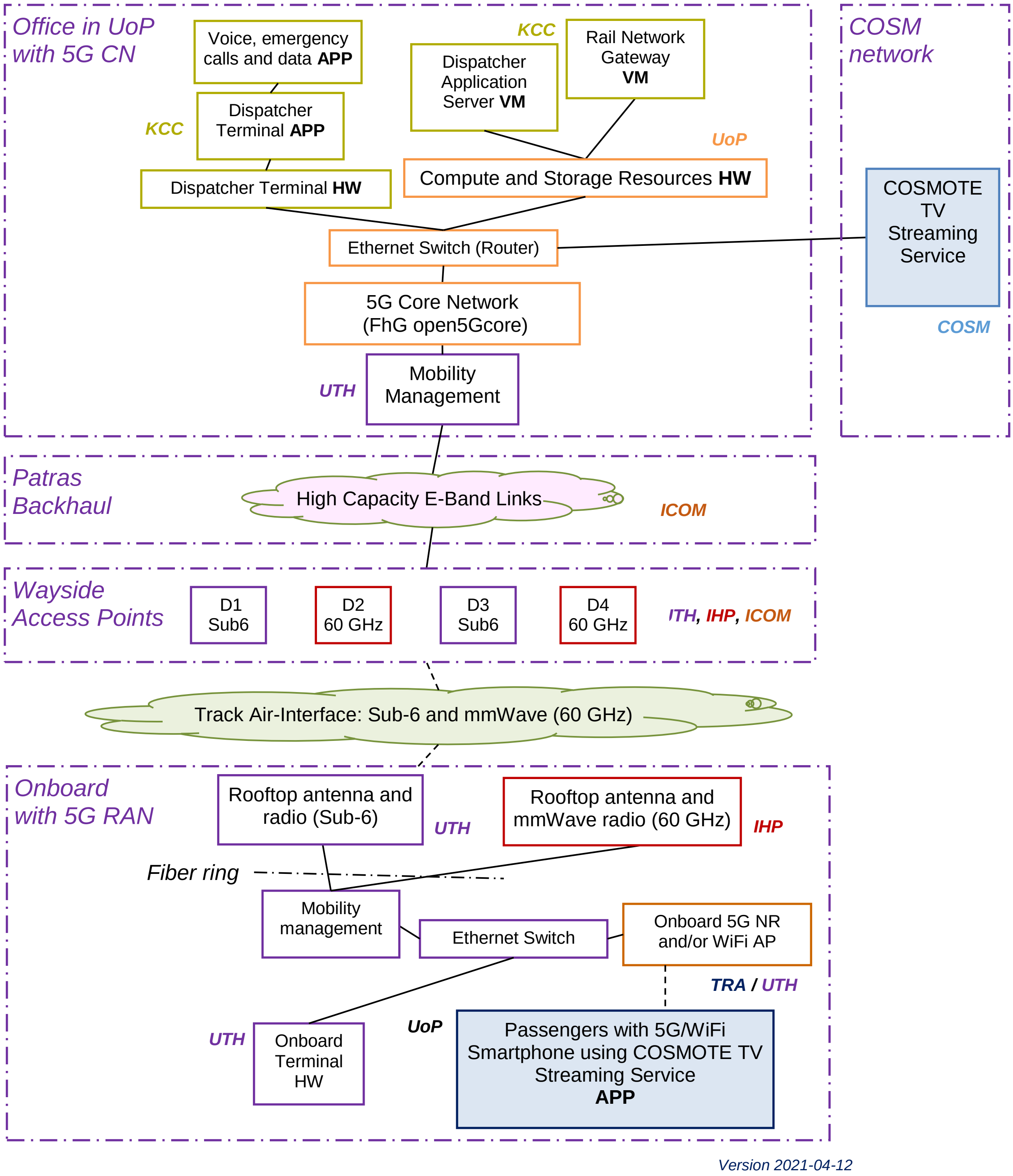

Figure 3-6: Enhanced MBB in Patras – Rail communication service for passengers – TV Streaming Service

Table 3-8: REPv01 - 5G data services for passengers – lab TV streaming (lab test)

REPv01	**5G data services for passengers – lab TV streaming (lab test)**
Testbed	**5G-VINNI Patras**
Description	The test validates the static (lab) environment which the dual connectivity achieves through Wi-Fi and the 5G access nodes on board train components, and evaluates the performance for 4K video, live-streaming content over both connectivity options.
Key Use-case requirements and KPIs	1. High-resolution Real-time Video Quality of video/ TV streaming channels/content. 2. Low Channel/ Stream Switching time experienced by end-user: Total channel switching delay <1 sec. 3. Adequate Total Wagon Traffic Density: ~0.5-1 Gbps per train.
Network performance requirements and KPIs	**CA-1101**: High Traffic Density: ~1Gbps per Train. **U-PE-1103**: End-to-end Latency: for this service type - Not critical: < 150 ms **F-CA-1104**: Air Interface – Access/Transport Network Capacity **F-PE-1105**: Air Interface Characteristics Additional Performance KPIs: • Jitter: <40 ms • Packet Loss: <1% • Guaranteed Data Rate: 5-10 Mbps • Connection Density: ~100-300 users per train for this service under operational circumstances
Network Functional requirements and KPIs	**F-FU-1111**: Multi-Tenancy **F-FU-1112**: Slicing
Components and configuration	**- Components:** 1. COSMOTE TV Streaming Service Server and Client. 2. Ethernet Switch (Router). 3. 5G Core Network. 4. Rooftop antenna and radio (Sub-6)/ Rooftop antenna and radio (60 GHz). 5. Onboard Switch. 6. Onboard 5G NR and Wi-Fi AP. 7. Mobility management. 8. Users with 5G/Wi-Fi Smartphone using customised COSMOTE TV App. **- Configuration:** 1. Connectivity between components performed as in Table 3-6. 2. Setup a message capturing tool to 5G Access network nodes and Core Network. (E.g. Wireshark). 3. Setup a message capturing tool to Streaming server and/ or UE 4. Setup a datarate monitoring/ measuring tool to the UE. 5. Setup a second/third etc. UE or traffic generating tool to perform iperf/ ftp sessions to emulate various traffic conditions. 6. 5G access network node configuration as in REDv01. 7. Transport nodes configuration as in REDv02.

Test procedure	**- Preconditions:** 1. Customised COSMOTE TV server running and accessible over public internet. 2. Application running on all devices. 3. End user connectivity through on-board 5G node is verified. 4. End user connectivity through on-board WiFi AP is verified. 5. Definition of position of UE under test. 6. Definition of traffic conditions of access network node. **- Test Case Steps:** 1. End user connects to the on-board 5G node 2. User initiates video streaming through the application interface. 3. Server streams this content to the user. 4. The time difference between the initiation message and the beginning of streaming is measured. 5. Datarate is measured throughout the session. 6. User switches channels through the application interface. 7. Server streams the new channel content 8. The time difference between the initiation message and the beginning of streaming is measured. 9. Datarate is measured throughout the session. 10. End user connects to the on-board Wi-Fi Access point 11. Steps 2-9 are followed once more using WiFi Access point connectivity.

<table>
<tr><td>Measurements</td><td>
- Methodology

The test procedure is repeated in several positions within the short range of the access nodes, corresponding to the train wagon dimensions. Other/ further measurements shall not be taken into consideration.
The test procedure is repeated for various traffic conditions of the nodes. Imposed traffic (from TL4 iperf server) may vary from no traffic (0 Kbps) to fully loaded conditions (>650 Mbps depending on access node max. configuration).
Measurements are collected for several iterations. At least 10 iterations are needed for the evaluation of each KPI for each set of test conditions.
Erroneous measurements are discarded from the measurements set, since the environment is lab/test.

- Complementary measurements

Signal quality (RSSI, RSRQ) and position (distance in m from access network node) related measurements are collected in each iteration at UE side.
Traffic conditions (at gNB level) are also monitored and noted in each iteration.

- Calculation process

Service layer messages and network layer messages are captured with their timestamp. The time difference between an operation request and a response is calculated. (e.g. service setup, channel switching etc.)
For each set of tests/ iterations -for the specific conditions- the mean/ median/ max./ min latency values (in ms) are calculated.
Datarate measurements are also collected throughout the streaming sessions. For each session data rate statistics are collected (e.g. average data rate) and instantaneous data rate measurements are monitored in real time.
For each set of tests/ iterations -for the specific conditions- the mean/ max./ min data rate values (Mbps) are calculated.
Mean-Opinion-Score will be measured for video quality at TL1 for the evaluation of the “High-resolution Real-time Video Quality of video/ TV streaming channels/content” KPI.

</td></tr>
<tr><td>Expected Result</td><td>
In all positions, and under all conditions, an average datarate of 5-10 Mbps per user achieved.

In all positions, and under all conditions, an average setup time and channel switching latency of 1-2 sec achieved.

Total capacity per access network node achieved according to air interface configuration.

Comparative measurements from TL2 and TL4 will be evaluated.
</td></tr>
</table>

3.5.3 REPv02: 5G data services for passengers – onboard TV streaming (field test)

As aforementioned, as far as the passenger services are concerned, it may be necessary for service providers to have an understanding of the performance and availability of the (e.g. infotainment/ live TV/ etc.) applications at various locations towards promoting the service and acquiring subscriptions. This is associated with performing the necessary application validation and performance evaluation at the operational environment. This test case serves this purpose, and aims at evaluating at TRAINOSE operational environment in Patras the performance of “business services” achieved through on-board Wi-Fi and 5G access node as part of the 5G-VICTORI deployment.

Access to internet and public streaming servers - using the aforementioned customised COSMOTE TV services as indicative live-streaming content – is evaluated. Focus is put on evaluating end-to-end performance while the train is on the move.

The TV streaming field test case is outlined in Table 3-9 below.

Table 3-9: REPv02 - 5G data services for passengers – onboard TV streaming (field test)

RENv02	**5G data services for passengers – onboard TV streaming (field test)**
Testbed	**5G-VINNI Patras**
Description	The test validates the operational environment for dual connectivity achieved through Wi-Fi and the 5G access nodes on board train components, and evaluates the performance for 4K video, live-streaming content, under various mobility conditions over both connectivity options.
Key Use-case requirements and KPIs	1. Seamless service provisioning under high mobility over different wireless transport technologies 2. High-resolution Real-time Video Quality of video/ TV streaming channels/content 3. Low Channel/ Stream Switching time experienced by end-user: Total channel switching delay < 1-2 sec. 4. Adequate Total Wagon Traffic Density: ~0.5-1 Gbps per train
Network performance requirements and KPIs	**CA-1101**: High Traffic Density: ~1 Gbps per Train **U-PE-1102**: Mobility **U-PE-1103**: End-to-end Latency: for this service type - Not critical: <150 ms **F-CA-1104**: Air Interface – Access/Transport Network Capacity **F-PE-1105**: Air Interface Characteristics Additional Performance KPIs: • Jitter: <40 ms • Packet Loss: <1% • Guaranteed Data Rate: 5-10 Mbps • Connection Density: ~100-300 users per train for this service under operational circumstances
Network Functional requirements and KPIs	**F-FU-1111**: Multi-Tenancy **F-FU-1112**: Slicing **S-FU-1114**: Mobility – Handovers (HO) (i.e. HO between subsequent trackside nodes (access or transport network ones))

Components and configuration	**- Components:** 1. COSMOTE TV Streaming Service Server and Client 2. Ethernet Switch (Router) 3. 5G Core Network 4. Rooftop antenna and radio (Sub-6)/ Rooftop antenna and radio (60 GHz) 5. On-board Switch 6. On-board 5G NR and WiFi AP 7. Mobility management function 8. Users with 5G/WiFi Smartphone using customized COSMOTE TV App **- Configuration:** 1. Connectivity between components performed as in Table 3-6. 2. Setup a message capturing tool to 5G Access network nodes and Core Network. (E.g. Wireshark) 3. Setup a message capturing tool to Streaming server and/ or UE 4. Setup a data rate monitoring/ measuring tool to the UE. 5. Setups a second/third etc. UE or traffic generating tool to perform iperf/ ftp sessions to emulate traffic conditions. 6. 5G access network node configuration as in REDv01. 7. Transport nodes configuration as in REDv02.
Test procedure	**- Preconditions:** 1. Customised COSMOTE TV server running and accessible over public internet 2. Application running on all devices. 3. End user connectivity through on-board 5G node is verified. 4. End user connectivity through on-board Wi-Fi AP is verified. 5. Definition of position of UE under test and while moving (GPS positioning shall be available). 6. Definition of traffic conditions of access network node. **- Test Case Steps:** 1. End user connects to the on-board 5G node 2. GPS positioning of UE and/or train node is available, and location is captured all the time 3. User initiates video streaming through the application interface. 4. Server streams this content to the user. 5. The time difference between the initiation message and the beginning of streaming is measured. 6. Connectivity is verified all the time 7. Data rate is measured throughout the session 8. User switches channels through the application interface. 9. Server streams the new channel content 10. The time difference between the initiation message and the beginning of streaming is measured. 11. Data rate is measured throughout the session. 12. End user connects to the on-board Wi-Fi Access point. 13. Steps 3-11 are followed once more. 14. Steps 1-13 are followed both when the train is static and on the move.

Measurements	**- Methodology** 1. The test procedure is repeated at a number of positions in the train wagon. 2. The test procedure is repeated for various traffic conditions of the nodes. Imposed traffic (from an iperf server) may vary from no traffic (0 kbps) to fully loaded conditions (>650 Mbps depending on access node max. configuration). 3. The test procedure is repeated in a number of positions along the TRAINOSE facilities tracks and under mobility conditions. 4. Measurements are collected for a number of iterations (~5 iterations need) for the evaluation of each KPI for each set of test conditions. 5. Erroneous measurements are discarded from the measurements. **- Complementary measurements** 1. Signal quality (RSSI, RSRQ), position (GPS), and velocity related measurements are collected in each iteration/test at UE side. 2. Traffic conditions (at gNB level) are also monitored and noted in each iteration. 3. Messages verifying seamless backhaul handovers are monitored continuously during the tests. **- Calculation process** 1. Service layer messages and network layer messages are captured with their timestamp. The time difference between an operation request and a response is calculated. (e.g. service setup, channel switching etc.) 2. For each set of tests/ iterations -for the specific conditions- the mean/ median/ max./ min latency values (in ms) are calculated. 3. Data rate measurements are also collected throughout the streaming sessions. For each session data rate statistics are collected (e.g. average data rate) and instantaneous data rate measurements are monitored in real time. 4. For each set of tests/ iterations -for the specific conditions- the mean/ max./ min data rate values (Mbps) are calculated. 5. Messages verifying seamless backhaul handovers are monitored continuously during the tests. Any disconnection messages are captured along with their timestamp and the time to re-connect is calculated. 6. Mean-Opinion-Score will be measured for video quality at application layer – as means for the evaluation of the “High-resolution Real-time Video Quality of video/ TV streaming channels/content” KPI.
Expected Result	In all positions, and under all conditions, an average data rate of 5-10 Mbps per user achieved. In all positions, and under all conditions, an average setup time and channel switching latency of 1-2 sec achieved. Total capacity per access network node of ~0.5-1 Gbps achieved. Seamless service provisioning shall be possible with no interruption time.

4 Digital Mobility at the 5G-VICTORI facility in Bristol

4.1 Description

As described in deliverable D2.1 [1], D2.2 [2] and D2.3 [3], the main objective of the Digital Mobility UC is to develop a common framework for innovative mobility applications and services. In this UC, it is demonstrated how the E2E 5GUK facility can be configured on the fly to provide:

- Application 1 (App1): Immersive media and AR/VR services to travelers in Bristol.
- Application 2 (App2): VR Multicamera Live Streaming at University of Bristol Campus.
- Application 3 (App3): Future Mobility Passenger Transport Journey Planning Guidance.

The 5GUK test network (located at UNIVBRIS premises) is used to carry out the tests (related to App1, App2, and App3) under various network and resource configurations to measure the metrics and evaluate the KPIs specified in the following test cases.

To demonstrate App1 and App3, the 5GUK test network integrates DCAT's 5GNR, Zeetta Automate solution, and i2CAT's Wi-Fi and Slice Manager solutions. In addition, the 5GUK facility utilizes 5G-VIOS to onboard the Digital Mobility UC applications and run the corresponding experiments and test cases.

4.2 Digital mobility Bristol App1 Immersive Media test cases (RDIu)

4.2.1 Description

MATI's App1 provides immersive media and VR services to travelers arriving at MShed (Figure 4-1). A synchronous 360° tour guide at specific geolocations is given to a group of users with 5G connectivity. It provides a seamless service virtual tour guide while passengers pass the route planned through the city of Bristol, see [3].

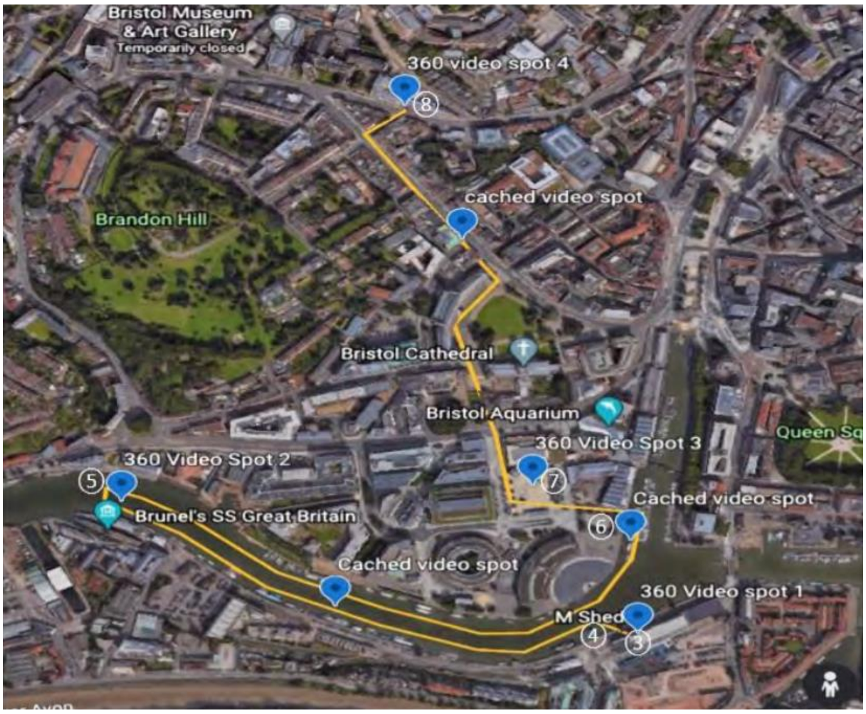

Figure 4-1 Application 1's route of travel

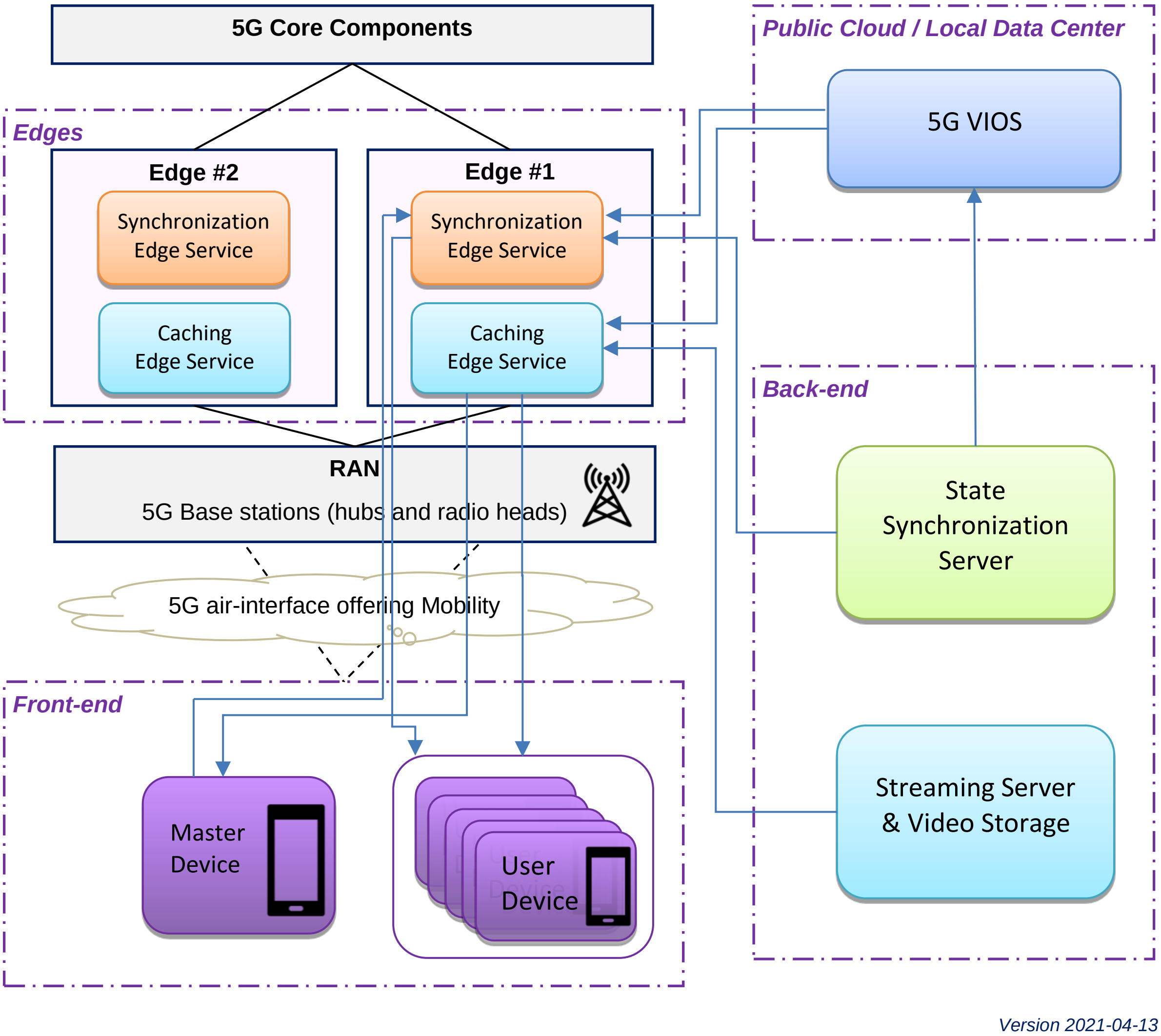

Figure 4-2: Digital Mobility in Bristol – App1: Mativision immersive media and AR/VR services to travelers

To support the mobility and seamless connectivity when moving from one edge to another, the synchronization edge and streaming server services need to move as well, staying as close to the users as possible.

The test cases provided in this section determine the latency between messaging and acknowledgment of messages, the most common bitrates achieved by multiple devices running the same high bitrate content and the latency between a mobility request and all the devices connecting to the newly instantiated service.

4.2.2 RDIu01: Mativision Synchronization Latency (lab & field test)

Test case RDIu01 tests the latency between a group leader requesting a video and the whole group receiving and acknowledging the message.

The test starts with a new message sent to the synchronization service and ends with the response from all devices. The shortest and the longest latency is measured in multiple spots in the test areas. The result accurately depicts both the best and worst-case scenario with multiple user groups running the same software close to each other.

A step-by-step instruction on how to perform the test-case is given in Table 4-1.

Table 4-1: RDIu01 - Mativision Synchronization Latency (lab & field test)

RDIu01	**Mativision Synchronization Latency (lab & field test)**
Testbed	**5G-UK Bristol**
Description	Test to determine the latency in communications with synchronization server relaying of master device messaging and slave device acknowledgment.
Key Use-case requirements and KPIs	Latency between master device messaging and slave acknowledgment, reported by synchronization server to analytics package.
Network performance requirements and KPIs	<200 ms latency between Master device sending a message to the sync edge server and the message being received on the slave device.
Network Functional requirements and KPIs	The application needs to be able to signal 5GVIOS via an API call to instance the edge service and on which edge it needs to be instantiated. The application needs a reliable connection and low latency for signaling slave devices.
Components and configuration	**- Components:** 1. Synchronization edge server VM 2. 5G-enabled Android Devices 3. MEC Server **- Configuration:** 1. 5G Connectivity 2. configuration and setup of 5G-enabled devices
Test procedure	**- Preconditions:** 1. Synchronization service running on MEC by 5GVIOS. 2. Application running on all devices. 3. All devices are connected to the synchronization service. **- Test Case Steps:** 1. User initiates video playback by tapping on a video. 2. Master device sends playback message with time stamp to the synchronization server. 3. The synchronization server relays the message to all slave devices. Each slave device reports the time stamp of acknowledgment of message. 4. The synchronization server calculates the time difference between master message time stamp and slave acknowledgment timestamps. 5. Each delay is reported to the backhaul analytics package.

Measurements	**- Methodology** 1. When a message is received on the slave devices the timestamp of the message is sent back to the server. 2. The master message timestamp and each slave time stamp are used to calculate the latency between the messages. 3. The latency is stored in the analytics package as a data point. 4. The data is used to calculate the mean and median average latency. **- Complementary measurements** 1. N/A **- Calculation process** 1. Each message acknowledgment is sent to the server with a time stamp. 2. The dt (time difference) is calculated by subtracting one timestamp form the other. 3. The result is the latency between the message being sent and being received by the end device. 4. Each latency is exported to a CSV file. 5. The CSV data file is used to calculate the mean and median average latency.
Expected Result	Analytics package is checked for reported latencies. Latencies should be < 200 ms

4.2.3 RDIu02: Mativision 360 VR Video Streaming (lab & field test)

Test case RDIu02 determines which is the most common bitrate when streaming to multiple devices at the same time. The video used during the test is a 360 VR video consisting of multiple bitrates up to 50 Mbps.

The test relies on multiple devices requesting the same content at the same time.

The software records all bitrate changes happening and how long each bitrate is used. This provides an accurate statistic of which is the most achieved bitrate and most viewed in seconds.

Table 4-2: RDIu02 - Mativision 360 VR Video Streaming (lab & field test)

RDIu02	**Mativision 360 VR Video Streaming (lab & field test)**
Testbed	**5G-UK Bristol**
Description	Test to determine the most common streaming bitrate when streaming high-bandwidth 360 VR video.
Key Use-case requirements and KPIs	Bitrate average of all devices recorded by each player instance and reported to analytics package.
Network performance requirements and KPIs	The application needs >10 Mbps of downlink bandwidth to be able to reliably stream good quality 360 video content.
Network Functional requirements and KPIs	The application needs to be able to signal via 5G-VIOS to the edge caching server instance that caches the video segments. The application needs high bandwidth and a reliable connection to stream the 360° video content.

Components and configuration	**- Components:** 1. Backhaul server VM 2. Edge Caching server VM 3. 5G-enabled Android devices 4. Linux Dummy ingest VM 5. MEC server 6. Backhaul Server **- Configuration:** 1. 5G Connectivity 2. configuration and setup of 5G-enabled devices
Test procedure	**- Preconditions:** 1. Edge caching server running by 5GVIOS 2. Edge caching server is connected to backhaul server 3. Application running on all devices 4. Dummy VM devices up and running **- Test Case Steps:** 1. All applications are signaled via the synchronization service to start streaming video. 2. All applications connect to the caching server and request the same content. 3. The caching server starts pulling the video segments from the backhaul VM and caches them locally before pushing them to each device separately. 4. Each device analyzes the traffic and switches to a better bitrate if bandwidth allows. 5. Each bitrate change, and how much time is spent on each, is recorded, and relayed to the analytics package.
Measurements	**- Methodology** 1. When streaming video, each stream corresponds to a specific bitrate. 2. The master file container each stream available and which bitrate it corresponds to. 3. During playback, the player calculates the available bandwidth of the connection. 4. At the end of each playback segment (usually 6 seconds) by knowing the connection speed the player decides which stream is should switch to or if it should stay on the same stream. 5. At each stream switch the player reports to the analytics package the new stream bitrate and how long it stayed on each bitrate. **- Complementary measurements** 1. N/A **- Calculation process** 1. Each bitrate switch is stored with its accompanying bitrate and how long (in seconds) the player stayed on that bitrate. 2. All bitrate data is exported to a CSV file 3. The data is used to find which bitrate was the most common by calculating the seconds spent on each bitrate by all devices.
Expected Result	Analytics package is checked for recorded bitrates and analyzed to determine the most prominent bitrate based on the time between each bitrate change.

4.2.4 RDIu03: Mativision Mobility test (field test)

The test case tests the latency between a group of users initiating a mobility request by leaving a predetermined geofence and connecting to the new service instantiated in the new location.

The test records the time difference between the initial signal, the new service instance initialization and the first device logging in to the service.

The mobility test case is outlined in Table 4-3.

Table 4-3: RDIu03 - Mativision Mobility test (field test)

RDIu03	**Mativision Mobility test (field test)**
Testbed	**5G-UK Bristol**
Description	Test to determine the latency between mobility start and all devices re-establishing communication with synchronization service.
Key Use-case requirements and KPIs	Latency recorded by synchronization server between mobility messaging and all devices re-establishing connection with the service.
Network performance requirements and KPIs	The time it takes between issuing a request for mobility, the initialization of the service on the target edge and devices re-establishing their connection with target edge should be <60 s.
Network Functional requirements and KPIs	5G-VIOS VM Instancing of synchronization server, 5G-VIOS API for mobility messaging
Components and configuration	**- Components:** 1. Synchronization edge server VM 2. Backhaul State synchronization VM 3. 5G-enabled Android Devices 4. MEC Server **- Configuration:** 1. 5G Connectivity
Test procedure	**- Preconditions:** 1. Synchronization service running on MEC. 2. Devices connected to synchronization service **- Test Case Steps:** 1. Master device sends a mobility message of geofence movement to the synchronization server. 2. The synchronization server sends a message to the backhaul state server that the devices have moved to a new geofence location. 3. The state server notifies 5GVIOS via API call to start mobility with the new geofence location. 4. The state server records the timestamp of the 5GVIOS API message. 5. 5GVIOS migrates the service to the new MEC. 6. The synchronization service starts up. 7. The synchronization service sends a message with the time stamp of its initialization to the backhaul state server. 8. All devices start to reconnect to the synchronization service. 9. The state server calculates the latency between mobility start and synchronization service initialization and reports it to the analytics package.

Measurements	**- Methodology** 1. The state server notifies 5GVIOS start mobility of the edge service. 2. The time stamp of the call is stored. 3. The edge service is up and running on the new location. 4. The time stamp of the start-up sequence is relayed to the state server. 5. The time delay is stored on the analytics package. **- Complementary measurements** 1. N/A **- Calculation process** 1. Each API call timestamp is recorded. 2. The start-up sequence timestamp is also recorded. 3. The dt (time difference) between the call for mobility and the start-up of the edge service is calculated. 4. The time difference is stored on the analytics package. 5. All data is exported to a CSV file. 6. The mean average is calculated for the delay in mobility. 7. The latency of each mobility event per location is calculated.
Expected Result	Analytics package is checked for the recorded mobility latency.

4.3 Digital mobility Bristol App 2 VR Live test cases (RDLu)

4.3.1 Description

App 2 includes a 360° VR Multicamera Live streaming and focuses mainly on large user connectivity and greater number of users. A remote training class takes place at the University of Bristol (MVB) and users can attend via 360° VR in real-time from anywhere in Bristol with access to the 5G UK network [2].

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

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

The test cases for App2 mainly measure and evaluate the KPIs related to the number of concurrent users and bitrate achieved by users. The main KPI is the most prominent bitrate that can be achieved when many users stream the content at the same time while taking into account the average time spent on each bitrate.

The high level objectives of this vertical service are:

- Demonstrate 360° VR Multicamera Live streaming to Users.
- Demonstrate user connectivity for many Users.

Figure 4-3 The journey related to App 2

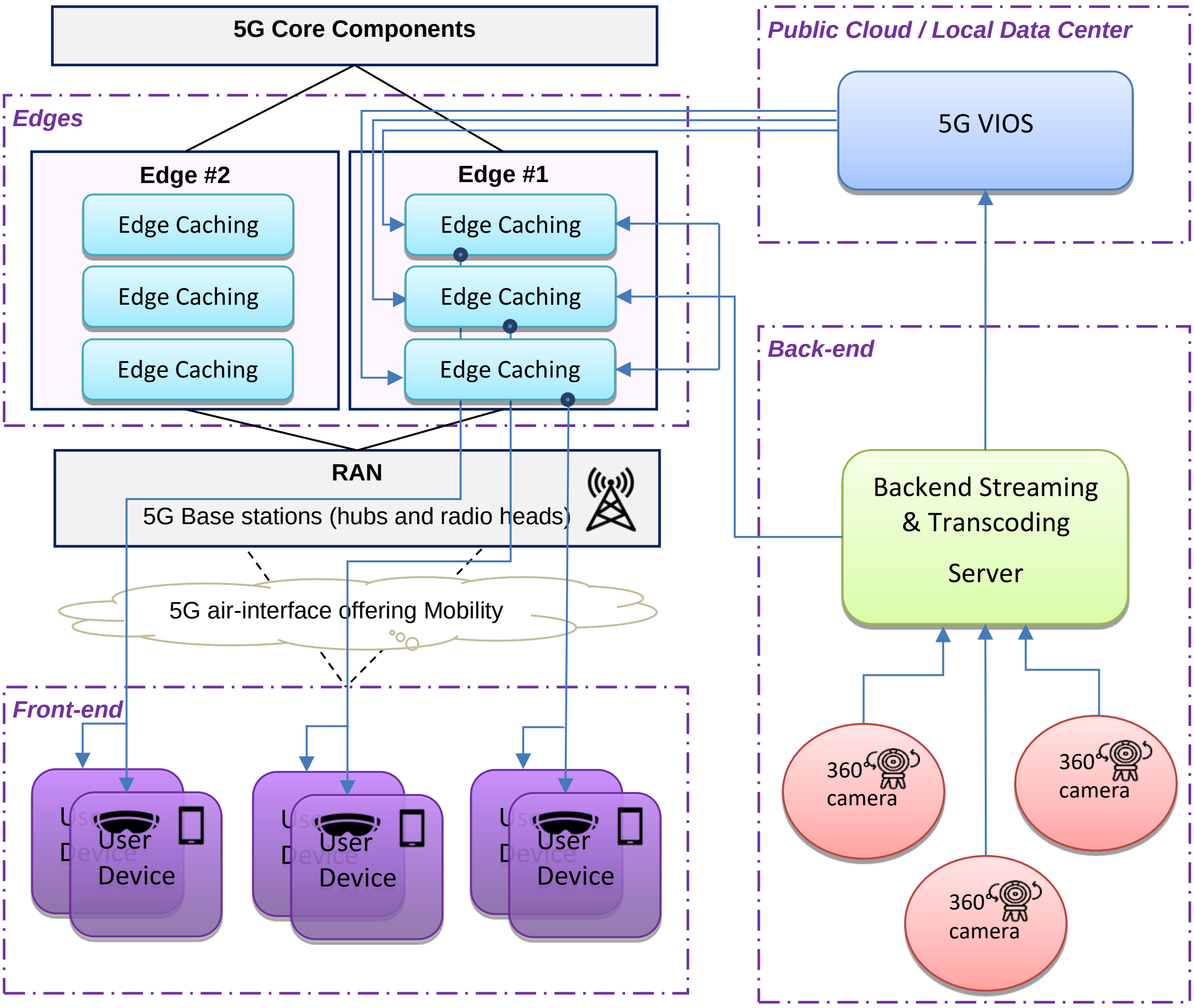

Figure 4-4: Digital Mobility in Bristol – App2: MATIVISION VR Multicamera Live streaming at UNIVBRIS campus

4.3.2 RDLu01: Mativision Live 360 VR Video Streaming (lab & field test)

Test case RDLu01 determines which is the most common bitrate when streaming to multiple devices at the same time. The video used during the test is a 360 VR video consisting of multiple bitrates up to 50 Mbps.

The test relies on multiple devices requesting the same content at the same time. The software records all bitrate changes happening and how long each bitrate is used. This provides an accurate statistic of which is the most achieved bitrate and most viewed in seconds.

The video streaming bitrate histogram type of test case is outlined in Table 4-4.

Table 4-4: RDLu01 - Mativision Live 360 VR Video Streaming (lab & field test)

RDLu01	**Mativision Live 360 VR Video Streaming (lab & field test)**
Testbed	**5G-UK Bristol**
Description	Test to determine the most common streaming bitrate when live streaming high-bandwidth 360 VR video.
Key Use-case requirements and KPIs	Bitrate average of all devices recorded by each player instance and reported to analytics package.
Network performance requirements and KPIs	The application needs >10 Mbps of downlink bandwidth to be able to reliably stream good quality 360 video content.
Network Functional requirements and KPIs	The application needs to be able to request the instancing of the edge caching service VM via a 5GVIOS Api call.
Components and configuration	**- Components:** 1. Backhaul server VM 2. Edge Caching server VM 3. 5G-enabled Android devices 4. Linux Dummy ingest VM 5. MEC server 6. Backhaul Server 7. Streaming encoder **- Configuration:** 1. 5G Connectivity 2. configuration and setup of 5G-enabled devices

Test procedure	**Preconditions:** 1. Edge caching server running by 5GVIOS 2. Edge caching server is connected to backhaul server 3. Application running on all devices 4. Dummy VM devices up and running **- Test Case Steps:** 1. All instances are signaled via the synchronization service to start streaming video. 2. All instances connect to the caching server and request the same content. 3. The caching server starts pulling the video segments from the backhaul VM and caches them locally before pushing them to each device separately. 4. Each device analyzes the traffic and switches to a better bitrate if bandwidth allows. 5. Each bitrate changes and how much time is spent on each is recorded and relayed to the analytics package.
Measurements	**- Methodology** 1. When streaming video, each stream corresponds to a specific bitrate. 2. The master file container each stream available and which bitrate it corresponds to. 3. During playback, the player calculates the available bandwidth of the connection. 4. At the end of each playback segment (usually 6 seconds) by knowing the connection speed the player decides which stream is should switch to or if it should stay on the same stream. 5. At each stream switch the player reports to the analytics package the new stream bitrate and how long it stayed on each bitrate. **- Complementary measurements** 1. N/A. **- Calculation process** 1. Each bitrate switch is stored with its accompanying bitrate and how long (in seconds) the player stayed on that bitrate. 2. All bitrate data is exported to a CSV file. The data is used to find which bitrate was the most common by calculating the seconds spent on each bitrate by all devices.
Expected Result	Each bitrate change happening due to changing network conditions is recorded to the analytics package. Each change is also accompanied by a timestamp providing the analytics package the exact time spent on each bitrate. The bitrates used to encode the 360 videos are predetermined and range from a 1 Mbps stream up to a 50 Mbps stream. The most prominent bitrate is the one most used for the most amount of time.

4.3.3 RDLu02: Mativision Edge Instancing test (lab & field test)

Test case RDLu02 reveals how long it takes between requesting an edge service from the backhaul server and the service being up and running.

The test determines how long time in advance the system needs to request the new service and how long time in advance a live stream needs to start before the whole infrastructure is up and running. The edge instancing test case is described in Table 4-5.

Table 4-5: RDLu02 - Mativision Edge Instancing test (lab & field test)

RDLu02	**Mativision Edge Instancing test (lab & field test)**
Testbed	**5G-UK Bristol**
Description	Test to determine the latency between the request for an edge service and the edge service being up and running.
Key Use-case requirements and KPIs	Latency recorded by server between service request and edge service establishing connection with the server.
Network performance requirements and KPIs	The application needs to able to request a new edge service to cache content. The time between API request and the VM being fully initialized should be <60 s
Network Functional requirements and KPIs	5G-VIOS VM Instancing of synchronization server, 5G-VIOS API for mobility messaging.
Components and configuration	**- Components:** 1. Caching edge server VM 2. Backhaul Streaming VM 3. 5G-enabled Android Devices 4. MEC Server **- Configuration:** 1. 5G Connectivity
Test procedure	**- Preconditions:** 1. Streaming VM running on backhaul server. 2. 360 Camera connects to backhaul streaming server. **- Test Case Steps:** 1. 360 video camera stream connects to the streaming server. 2. The streaming server notifies 5GVIOS via API call to instantiate the edge caching services. 3. The server records the timestamp of the 5GVIOS API message. 4. 5GVIOS instantiate the services on the MECs. 5. The caching service starts up. 6. The service sends a message with the time stamp of its initialization to the backhaul server. 7. The server calculates the latency between the request and service initialization and reports it to the analytics package.

Measurements	**- Methodology** 1. The server notifies 5GVIOS to instantiate the edge services. 2. The time stamp of the call is stored. 3. The edge service is up and running on the edge location. 4. The time stamp of the start-up sequence is relayed to the backhaul server. 5. The time delay is stored on the analytics package. **- Complementary measurements** 1. N/A **- Calculation process** 1. Each API call timestamp is recorded. 2. The start-up sequence timestamp is also recorded. 3. The dt (time difference) between the call for initialization and the start-up of the edge service is calculated. 4. The time difference is stored on the analytics package. 5. All data is exported to a CSV file. 6. The mean average is calculated for the delay in initialization. 7. The latency of each initialization event per location is calculated.
Expected Result	Analytics package is checked for the recorded mobility latency.

4.4 Digital Mobility - Bristol App 3 Future Mobility test cases (RDFu)

4.4.1 Description

App 3 will collect and analyse information from passengers and travelers including their location, their mobility and movement. They may use the old Bristol Harbourside train (i.e., point ① to point ② in Figure 4-5) to reach to a staring location, e.g., MShed (i.e., point ③ in Figure 4-1). Taking advantage of the 5G connectivity and the UHA Future Mobility App installed on their phones, an AR journey will take place through the river on a boat and by foot.

In UHA's Future Mobility App3, travelers pass by from MShed. Taking advantage of the 5G connectivity and the UHA Future Mobility App on their phones, an AR journey takes place through the river on a boat and by foot. Some network services such as the Synchronization service, spatial data renderer/visualizer, journey planner, and video streaming service are deployed and run at edge and backend servers.

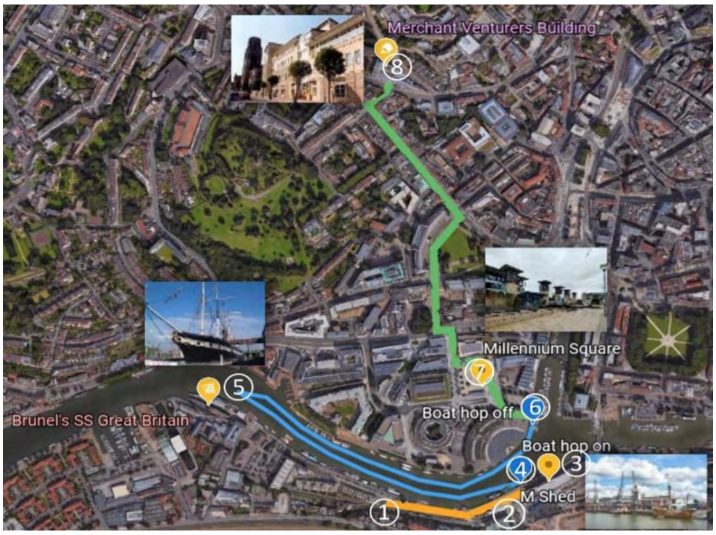

Figure 4-5 5G-VICTORI Bristol facility and sites involved in the trials. The orange and green paths denote the routes covered on foot while the blue path is covered by boat.

People's information including their location, their mobility and movement are collected and analyzed. Furthermore, the application provides passengers with specific location guidance and multi-modal transport journey planning beyond the starting location using AI techniques. See also ref [2].

The high-level objectives of this vertical service are:

- Demonstrate passenger's guidance with multi-modal transport journey planning.
- Collect and analyse information from passengers and travelers (location, mobility, movement).

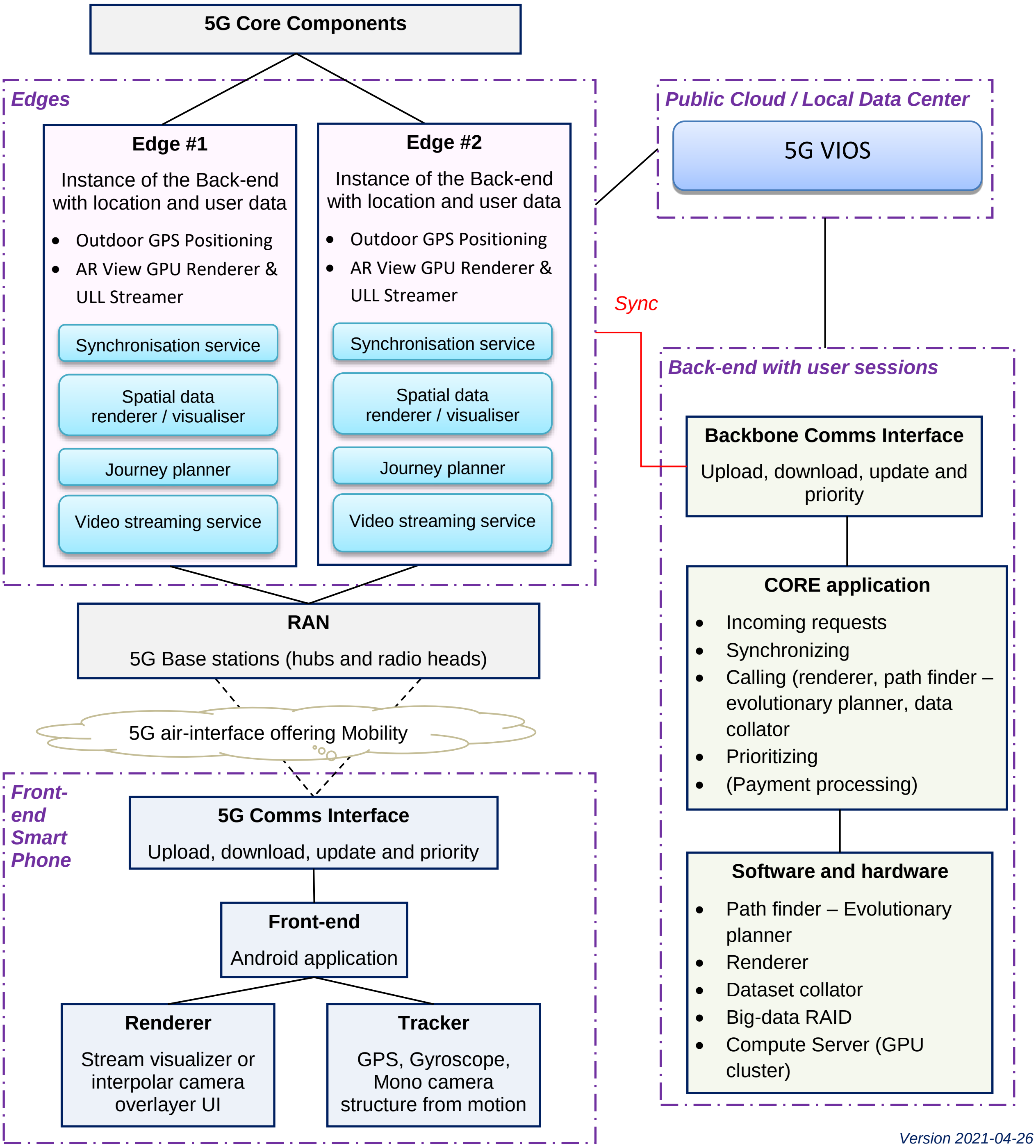

Figure 4-6: Digital Mobility in Bristol - App 3: Urban Hawk's Future Mobility Application

4.4.2 RDFu01: Future Mobility edge location spatial scanning and mapping (lab & field)

This test aims at mapping the spatial scanning data, done at location, with the corresponding 3D model. The goal is to reach a user (smartphone) position accuracy of half a meter when the user stands still and one meter when the user navigates (walks around) using the 3D model.

The bitrate, latency and precision related test case is found in Table 4-6. Note: a corresponding test case is also used for the Berlin location.

Table 4-6: RDFu01 - Future Mobility edge location spatial scanning and mapping (lab & field)

RDFu01	**Future Mobility edge location spatial scanning and mapping (lab & field)**
Testbed	**5G-UK Bristol**
Description	Test the UHA Future Mobility's spatial scanning/mapping capability. This is an application specific case. The backbone of UHA's insight that leads to *Situational Awareness* in physical infrastructure and transport.
Key Use-case requirements and KPIs	Primary: maximum 0.5 m error in the scanning accuracy. Secondary: maximum 1 m error when in simultaneous navigation on the mobile device and the digital twin.
Network performance requirements and KPIs	Minimum 10 Mbits/s connection for the Edge data stream to reach the end user's mobile device. Maximum 20 ms latency.
Network Functional requirements and KPIs	The application needs reliable connectivity.
Components and configuration	**- Components:** 1. Camera equipment for capturing the edge location for instance outside the MShed as a pointcloud. For the lab testing, due to COVID restrictions an alternative venue may be selected such as the UHA's office environment. 2. Nomadic GPU compute capability that can pre-process the captured data live - used only for the edge scanning. 3. Edge GPU compute capability. 4. One test passenger; Due to Covid restrictions and for the lab testing, one or two UEs can be considered for the functionality testing and early KPI measurements. Field trials include more UE devices and more extensive testing. 5. Spatial scanning in the middle of the field testing, completely being real-time with point-cloud scans injected into the voxel grid 30-50 times per second. 6. GPUs: UHA provides the GPUs in a separate compute server next to other equipment. High-end GPUs are needed, e.g. RTX 3090 (the low-end version RTX-2080 would be the absolute minimum for the test-case). **- Configuration:** 1. Stereo camera with UHA's depth reconstruction software and/or Lidar. 2. The GPUs are provided and configured by UHA. 3. UHA real-time 3D tile processing engine written in C++ and OpenCL/Cuda to receive and integrate the pointcloud into the digital twin.

<table>
<tr><td>Test procedure</td><td>- Preconditions:
UHA personnel scans the edge location. The captured data is fed into the digital twin and marked up and geo-tagged.
The Edge node contains UHA's digital twin.
A test passenger tests himself for COVID then enters the station and tests the app. An early version of the Frontend application is running on the passenger's mobile device.
- Test Case Steps:
The Edge node makes connection with the passenger's mobile device (Frontend).
The Frontend sends location and orientation data and a still camera snapshot to the Edge node. The Edge node renders a still of the 3D digital twin and overlays that on top of the received camera still.
The two images are compared, and the difference is measured.</td></tr>
<tr><td>Measurements</td><td>- Methodology
See before.
- Complementary measurements
The number of falls is manually counted. That shall be the ground truth data.
- Calculation process
The detection accuracy of the UHA's depth extraction method can be re-applied here to measure the difference, which is calculated through the comparison of the automatic detections and the ground truth data.
Note: the same problem when comparing the left and right eye views and computing the shift that leads to the depth estimate versus comparing the camera still and the rendered counterpart.</td></tr>
<tr><td>Expected Result</td><td>The accuracy of the spatial scan is expected to fall within the thresholds described above. The aim is to prove that low error 3D navigation can be run simultaneously in the virtual twin as the passenger moves with the mobile device.</td></tr>
</table>

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

This test case is used to test the communication between:

- Backend to Frontend
- Frontend to Edge nodes

The minimum expected bitrate to the user smartphone is 10 Mbps with latency of 20 ms. The application needs in a very high extend a reliable connectivity.

With the 5G-VICTORI scope, the solution is expanding into multi scenery, mobile and streamed scenarios with real-time front-end access. For that multiple copies of the back-end system are running simultaneously (Edge + Back-end) that exchange data plus communicate with the front-end user nodes. Note: a corresponding test case is used for the Berlin facility.

Table 4-7: RDFu02 - Future Mobility communication between Backend, Frontend and Edge nodes (lab & field)

RDFu02	**Future Mobility communication between Backend, Frontend and Edge nodes (lab & field)**
Testbed	**5G-UK Bristol**
Description	UHA has been using its technology either in single scenes or where the data had already been captured beforehand, without front-end access, just back-end for insight, analytics and simulation purposes. With the 5G-VICTORI project goal, the solution is expanding into multi scenery, mobile and streamed scenarios with real-time front-end access. For that multiple copies of the back-end system are running simultaneously (Edge + Back-end) that exchange data plus communicate with the front-end user nodes. A new communication layer has been implemented and integrated with the rest of the system that handles the real-time flow of data in between all nodes. The data includes location (GPS or other source) and orientation data that is crucial for efficient edge-user rendering and AR experience through passenger guidance.
Key Use-case requirements and KPIs	Primary: test data from Edge to Front-end and vice versa. Secondary: test communication between Back-end – Front-end and Back-end - Edge nodes.
Network performance requirements and KPIs	The minimum bitrate for the 5G connection between an Edge node and an End-user mobile device shall be 10 Mbits/s. The maximum latency over the 5G connection between an Edge node and an End-user mobile device shall be 20 ms. Note: Low latency is key to keep user phone (front-end) with edge rendering in sync when in AR passenger guidance mode.
Network Functional requirements and KPIs	The application needs reliable connectivity and handover between the outdoor Edge nodes.
Components and configuration	**- Components:** 1. The communication module of UHA's digital twin capable to make connection, establish a user session and send data (a render for example). 2. UHA's Frontend application is capable of receiving data from the Edge and send position with orientation data back to the Edge as well as the Backend. As GPS positioning is required, testing takes place on-site at the edge location covering Mshed and Millennium Square. Note: Outdoor test is required, as the UE needs to receive GPS signal. This means that “lab test” includes on-site testing with one or two UEs for functionality testing and early KPI measurements. Field trials includes additional UE devices and a more extensive testing. 3. One test user; Due to Covid restrictions and for the lab testing, one or two UEs can be considered for the functionality testing and early KPI measurements. Field trials include more UE devices and more extensive testing. **- Configuration:** 1. Two Edge servers (CPU). 2. Backend server (CPU). 3. UHA communication module written in C++.

Test procedure	**- Preconditions:** 1. The outdoor Edge nodes and the Backend contain UHA's communication module. 2. UHA's Frontend is pre-installed on the user's mobile device. **- Test Case Steps:** 1. The Frontend connects to the Backend, logs in and sends the location data. Based on the user's location the Backend appoints Edge #1 as the closest match and instructs that Edge and the user to connect. 2. The Edge establishes a session and signals the Backend that it took over. Edge #1 sends data to the Frontend. The Frontend receives the data and stores it for later verification. 3. The user moves and the Frontend starts to send data to the Edge. The Edge receives and stores the data for later verification. The user's position is also sent to the Backend every time it changes. 4. User approaches Edge #2. The Backend instructs the handover. Edge #2 takes the session over from Edge #1. Edge #1 transmits all user relevant data to the Backend for syncing then drops the user and closes the session. User's historical data is copied over to Edge #2 from the Backend asynchronously. 5. Edge #2 sends test data to the Frontend that is stored there for later verification. Edge #2 starts receiving data from the Frontend that is again stored for later verification. 6. The test ends.
Measurements	**- Methodology** 1. See above. Location data via GPS coordinates. **- Complementary measurements** 1. Bandwidth fluctuation. **- Calculation process** 1. The received and stored data sets are manually verified. 2. Optional: or using a simple script.
Expected Result	The aim is to demonstrate and validate UHA's new mobility comm module.

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

The test case demonstrates the needed bitrate of at least 20 Mbps between the Backend and the Edge nodes. There is a need to transfer 1 Gbyte of data in a reasonable time (less than 50 x 8 = 400 seconds).

Note: a corresponding test-case is used for the Berlin facility.

Table 4-8: RDFu03 - Future Mobility high bitrate data distribution between Back-end and Edge nodes (field test)

RDFu03	**Future Mobility high bitrate data distribution between Back-end and Edge nodes (field test)**
Testbed	**5G-UK Bristol**
Description	Test-case for the UHA Future Mobility's data distribution. The test-case demonstrates the needed bitrate of at least 20 Mbps between the Backend and the Edge nodes. There is a need to transfer 1 Gbyte of data in a reasonable time (less than 50 x 8 = 400 seconds). Note: this is a field test only, because UHA might not be able to establish the very high bitrate connection between UHA office and Bristol University. The high bitrate distribution test also paves the way for a future commercial realization.

Key Use-case requirements and KPIs	Primary: large spatial data (above 1 Gigabyte) is copied from the Backend to the Edge.
Network performance requirements and KPIs	Minimum 20 Mbits/s connection for the Edge and the Backend.
Network Functional requirements and KPIs	The application needs reliable connectivity and handover between the outdoor Edge nodes.
Components and configuration	**- Components:** 1. Edge GPU compute capability. 2. Backend GPU compute capability. **- Configuration:** 1. RTX-2080 or RTX 3090 GPU. GPU is provided by UHA. 2. UHA real-time 3D tile processing engine written in C++ and OpenCL/Cuda that operate the digital twin. 3. Back-end server (CPU). 4. UHA communication module written in C++.
Test procedure	**- Preconditions:** 1. The Bristol outdoor Edge nodes and the Backend contain UHA's communication module. Due to Covid restrictions, UE testing is currently limited to 2 devices. If GPS positioning is required, then the outdoor edge nodes shall be tested at Mshed or Millennium Square. 2. Reliable connectivity and handover between edge nodes rely on copying large spatial data to the edge. If copying data to edge involves UE GPS information then outdoor test is required in the sense that UE needs to be able to receive GPS signal, i.e. field test needed. **- Test Case Steps:** 1. The Backend instructs the Edge node to prepare for a spatial dataset update. The backend starts to stream the data. The Edge receives the data. The Edge upgrades the local dataset according to the spatial coordinates received from the Backend in each 3D tile.
Measurements	**- Methodology** 1. See above. **- Complementary measurements** 1. Bandwidth fluctuation. 2. Connection stability and reliability. 3. Investigate the room for optimizing so that only the most necessary data pieces are transmitted (to minimize redundancy). **- Calculation process** 1. The received and stored data sets are verified via a simple render exercise. - If flawless visuals appear then success. - If corrupted visuals or a crash happens then fail.
Expected Result	The aim is to demonstrate and validate UHA's new spatial data distribution feature.

4.5 Rail Digital mobility Bristol dedicated Network test cases (RDNu)

4.5.1 Description

As part of 5G-VICTORI, the 5GUK test network (**UNIVBRIS**) integrates **DCAT**'s 5GNR and **i2CAT**'s Slice manager and Wi-Fi solutions for providing various telecommunications services in a demonstration incorporating Digital Mobility at Bristol App1, App2 and App3 use cases.

The demonstration is currently planned to consist four key locations:

1. SS Great Britain Steam Ship Museum (outside area).
2. MShed Museum (outside and inside areas).
3. Millenium Square - MSquare/We The Curious - WTC (outside area).
4. University of Bristol's High-Performance Networks group (HPN) hosting Smart Internet Lab (inside area).

Users follow a route that allow their devices to utilize various RATs while moving around either on foot, or on a boat. The network can provide 5G, LTE and/or Wi-Fi connectivity at key locations. In addition, a 'Nomadic' node is also deployed on a boat, specifically for the requirements of 5G-VICTORI and the boat-ride demonstration. For this edge location, the i2CAT's Slice manager is used to create slices on-demand integrating 5GNR and Wi-Fi access nodes.

The following test cases test the performance of dedicated 5G network and compute resources to the 5G-VICTORI project.

4.5.2 RDNu01: 5GUK Infrastructure test case Between Core and MSHED or MSQ Edges (lab & field test)

This test case tests the performance of dedicated 5G network and compute resources to the 5GVICTORI project such as latency, and throughput between the core and various edges.

Note: the University of Bristol's High Performance Networks group (HPN) hosts the Smart Internet Lab.

Table 4-9: RDNu01 - 5GUK Infrastructure test case Between Core (HPN) and MSHED or MSQ Edges (lab & field test).

RDNu01	**5GUK Infrastructure test case Between Core (HPN) and MSHED or MSQ Edges (lab & field)**
Testbed	**5G-UK Bristol**
Description	Test the performance of dedicated 5G network and compute resources to the 5G-VICTORI project such as latency, and throughput between the core and edges.
Key Use-case requirements and KPIs	Latency, Uplink and Downlink capacity between dummy compute nodes in core and edges as well as between the edges.
Network performance requirements and KPIs	<1 ms latency >1 Gbps uplink and downlink throughput
Network Functional requirements and KPIs	It is required to instantiate dummy VMs on corresponding compute resources before starting the test.

Components and configuration	**- Components:** 1. Dummy VMs on both core and edge compute resources 2. Core and MEC servers **- Configuration:** 1. Network slice deployment
Test procedure	**- Preconditions:** 1. Confirm that the corresponding edges are configured and all Edge components such as the Edge Orchestrator, VIMs and WIMs are up and running. 2. Confirm that the corresponding edges are registered to the 5G-VIOS. **- Test Case Steps:** 1. run a network service comprising 2 VNFs. One in the core, and one in MSHED or MSQ edge servers with the same required resources as the use case application requirements. 2. Create a network Slice between these 2 nodes. 3. Start Monitoring and KPI measurement using the 5GUK monitoring and measurement tool 4. Extract the result and make the report to validate the KPIs
Measurements	**- Methodology** 1. Generate the traffic 2. Monitor the corresponding metrics 3. Measure the KPIs 4. Create and record the network performance profiles 5. Generate the Pass/Fail test results 6. Expose the results to the authenticated users. **- Complementary measurements** 1. N/A **- Calculation process** 1. Compute the throughput by dividing the amount of received data by the time taken to transmit data from sender to receiver and convert to (Gbps). 2. Measure Round Trip Time (RTT) using corresponding monitoring tools such as Ping.
Expected Result	This would contain the exact records of measured KPIs and network performance profiles. Pass/fail results; Pass if the Latency is <1 ms and Throughput is >1Gbps Note: Create two test records one for MSHED and another for MSQ edge servers.

4.5.3 RDNu02: 5GUK Infrastructure test case Between Core and the Nomadic Node (field test)

This test case tests the performance of dedicated 5G network and compute resources to the 5G-VICTORI project such as latency, and throughput between the core and Nomadic node.

Table 4-10: RDNu02 - 5GUK Infrastructure test case Between Core (HPN) and the Nomadic Node (field test)

RDNu02	**5GUK Infrastructure test case Between Core (HPN) and the Nomadic Node (field test)**
Testbed	**5G-UK Bristol**
Description	Test the performance of dedicated 5G network and compute resources to the 5GVICTORI project such as latency, and throughput between the core and Nomadic node.
Key Use-case requirements and KPIs	Latency, Uplink and Downlink capacity between dummy compute nodes in core and edges as well as between the edges.
Network performance requirements and KPIs	<100 ms latency >100 Mbps uplink and downlink throughput
Network Functional requirements and KPIs	It is required to instantiate dummy VMs on corresponding compute resources before starting the test.
Components and configuration	**- Components:** 1. Dummy VMs on both core and edge compute resources 2. Core and MEC servers 3. Nomadic Node **- Configuration:** 2. Network slice deployment
Test procedure	**- Preconditions:** 1. Confirm that the corresponding edges are configured and all Edge components such as the Edge Orchestrator, VIMs and WIMs are up and running. 2. Confirm that the corresponding edges are registered to the 5G-VIOS. **- Test Case Steps:** 1. Run a network service comprising 2 VNFs. One in the core, and one in Nomadic Node edge servers with the same required resources as the use case application requirements. 2. Create a network Slice between these 2 nodes 3. Start Monitoring and KPI measurement using the 5GUK monitoring and measurement tool 4. Extract the result and make the report to validate the KPIs

Measurements	**- Methodology** 1. Generate the traffic 2. Monitor the corresponding metrics 3. Measure the KPIs 4. Create and record the network performance profiles 5. Generate the Pass/Fail test results 6. Expose the results to the authenticated users. **- Complementary measurements** 1. N/A **- Calculation process** 1. Compute the throughput by dividing the amount of received data by the time taken to transmit data from sender to receiver and convert to (Mbps) 2. Measure Round Trip Time (RTT) using corresponding monitoring tools such as Ping
Expected Result	This would contain the exact records of measured KPIs and network performance profiles Pass/fail results: • Pass if the Latency is <100 ms and Throughput is >100 Mbps • Fail if the Latency is >=100 ms or Throughput is <=100 Mbps

4.5.4 RDNu03: 5GUK Infrastructure test case between UEs--Core, and UEs--Edges (lab & field)

This test case (Table 4-11) tests the performance of dedicated 5G network and compute resources to the 5G-VICTORI project such as latency, and throughput between the 5G UEs and core as well as between the 5G UEs and various edges.

Table 4-11: RDNu03 - 5GUK Infrastructure test case between UEs and Core (HPN), and between UEs and Edges (lab & field test)

RDNu03	**5GUK Infrastructure test case between UEs and Core (HPN), and between UEs and Edges (lab & field test)**
Testbed	**5G-UK Bristol**
Description	Test the performance of dedicated 5G network and compute resources to the 5G-VICTORI project such as latency, and throughput between the 5G UEs and core as well as between the 5G UEs and edges
Key Use-case requirements and KPIs	Latency, Uplink and Downlink capacity between UEs and dummy compute nodes in core and edges.
Network performance requirements and KPIs	<100 ms latency (UE to Edge) <500 ms latency (UE to Core) >100 Mbps uplink and downlink throughput
Network Functional requirements and KPIs	Instantiate dummy VMs on corresponding compute resources

Components and configuration	**- Components:** 1. Dummy VMs on both core and edge compute resources 2. Core and MEC servers 3. 5G-enabled Android Handsets **- Configuration:** 1. Network slice deployment 2. Configuration and setup of 5G-enabled devices
Test procedure	**- Preconditions:** 1. Confirm that the corresponding edges are configured and all Edge components such as the Edge Orchestrator, VIMs and WIMs are up and running. 2. Confirm that the corresponding edges are registered to the 5G-VIOS. 3. Confirm that handsets are registered with the 5GUK 5GNR/DCAT 5GNR. **- Test Case Steps:** 1. Run a network service comprising 4 VNFs. One in the core, and one in each of the three Edges (MSHED, MSQ, and Nomadic Node) with the same required resources as the use case application requirements 2. Create a network Slice between these 3 nodes and RAN. 3. Start the Monitoring and KPI measurement using the 5GUK monitoring and measurement tool to do the above mentioned KPI measurements on the UEs 4. Extract the result and make the report to validate the KPIs
Measurements	**- Methodology** 1. Generate the traffic 2. Monitor the corresponding metrics 3. Measure the KPIs 4. Create and record the network performance profiles 5. Generate the Pass/Fail test results 6. Expose the results to the authenticated users. **- Complementary measurements** 1. N/A **- Calculation process** 1. Compute the throughput by dividing the amount of received data by the time taken to transmit data from sender to receiver and convert to (Gbps) 2. Measure Round Trip Time (RTT) using corresponding monitoring tools such as Ping

Expected Result	This would contain the exact records of measured KPIs and network performance profiles Pass/fail results: • Pass if the Latency between the UE and corresponding edges (MShed, MSQ, and Nomadic node) is <100 ms **and** Throughput is >100 Mbps • Fail if the Latency between the UE and corresponding edges (MShed, MSQ, and Nomadic node) is >=100 ms **or** Throughput is <=100 Mbps Pass/fail results: • Pass if the Latency between the UE and the Core is <500 ms **and** Throughput is >100 Mbps • Fail if Latency between the UE and the Core is >=500 ms **or** Throughput is <=100 Mbps Note: Create four KPI records: • UE-MShed • UE-MSQ • UE-Nomadic node • UE-Core

4.5.5 RDNu04: 5GUK Infrastructure test case for Multi-RAT Slice Deployment (lab & field test)

This test case (see Table 4-12) demonstrates the performance of slice management, and in particular, it is aimed to validate the effective establishment of a network slice and measure the required slice deployment time, considering multiple Radio Access Technologies (RATs) such as 5GNR and Wi-Fi.

Following the indications provided in this test case, lab and field tests are conducted. During field trials, access nodes are located at the Nomadic Node.

Table 4-12: RDNu04 - 5GUK Infrastructure test case for Multi-RAT Slice Deployment (lab & field test)

RDNu04	**5GUK Infrastructure test case for Multi-RAT Slice Deployment (lab & field test)**
Testbed	**5G-UK Bristol**
Description	Test the performance of on-demand multi-RAT slice management, considering 5GNR and Wi-Fi access nodes, in terms of network slice establishment and slice deployment time.
Key Use-case requirements and KPIs	Network slicing support is required.
Network performance requirements and KPIs	Network slice capabilities/management is required.
Network Functional requirements and KPIs	Slicing establishment is required. Slice deployment time <90 min.

Components and configuration	**- Components:** 1. Core and Edge servers 2. Radio access nodes (Wi-Fi and 5GNR) 3. End-user equipment (e.g. 5G-compliant mobile phone) **- Configuration:** 1. SIM card configured with testing PLMNID, APN and S-NSSAI
Test procedure	**- Preconditions:** 1. Nomadic Node edge registered to the 5G-VIOS. 2. Edge server and radio access nodes registered and reachable from the Slice Manager and RAN Controller components. 3. VNF images available at the corresponding edge compute (DHCP, 5GC NFs). **- Test Case Steps:** 1. Indicate required edge and radio access nodes 2. Create and activate the slice 3. Monitor slice status and end user's connectivity 4. Generate the Pass/Fail test result for the required slice establishment 5. Generate measurement result for the slice deployment time KPI 6. Create and record the network performance profiles 7. Expose the results to the authenticated users.
Measurements	**- Methodology** 1. Trigger slice deployment 2. Monitor slice status and end user's connectivity 3. Once status = active, record elapsed time 4. Validate end-user access and connectivity (i.e. slice establishment) 5. Create and record the network performance profiles 6. Expose the results to the authenticated users. **- Complementary measurements** 1. N/A **- Calculation process** 1. Compute time elapsed from the moment the slice request is received until the instant when the radio service is active and the involved VNFs are up and running (i.e. slice status = active) 2. Repeat previous step over a minimum of 30 iterations
Expected Result	This would contain the exact records of measured KPIs and network performance profiles (e.g. Slice establishment: Passed; and Slice deployment time < 90 min)

5 Digital Mobility at the 5G-VICTORI facility in Berlin

5.1 Description

The Future Mobility Use Case provided in the Bristol Cluster runs at the Berlin Central Station facility (*Berlin Hauptbahnhof*). This UC aims to optimize media streaming services in mobile environments enabled by 5G technologies, including Edge Computing. **UC #1.2** consist of an app that renders a 3D twin 2 overlayed on the passenger's smartphone's live camera feed, which will allow the user to navigate in and around the Berlin Central station [3] (section 3.2).

Travelers can use the Future Mobility App after installing it on their Smartphones as a travel guide to reach out to their destinations. More specifically, by taking advantage of the 5G connectivity in the Berlin Central Station and the Future Mobility App, passengers are guided to their gates using the AR capability of the App that shows guidance overlays to the user on top of the camera live preview.

Support for low-capability devices that are not able to analyse and display the overlays in real-time is considered as well. This is one of the key features of the Future Mobility App that is demonstrated in the pilot at Berlin Central Station, which makes use of the Mobile Edge Computing (MEC) capability of 5G.

5.2 Digital Mobility Berlin App 3 Future Mobility test cases (RDFg)

5.2.1 Description

The specific 5G infrastructure Berlin Central Station comprises a main data centre that can be deployed at the stations' equipment room (hosting a 5G core) with an edge deployment that is interconnected with the 5G Radio Access Network (RAN) installed at the platform that will be in charge to provide 5G connectivity to the users walking throughout the station (see Figure 5-1).

The diagram depicted in Figure 5-2 below shows the main software and hardware components for the different UCs in Berlin.

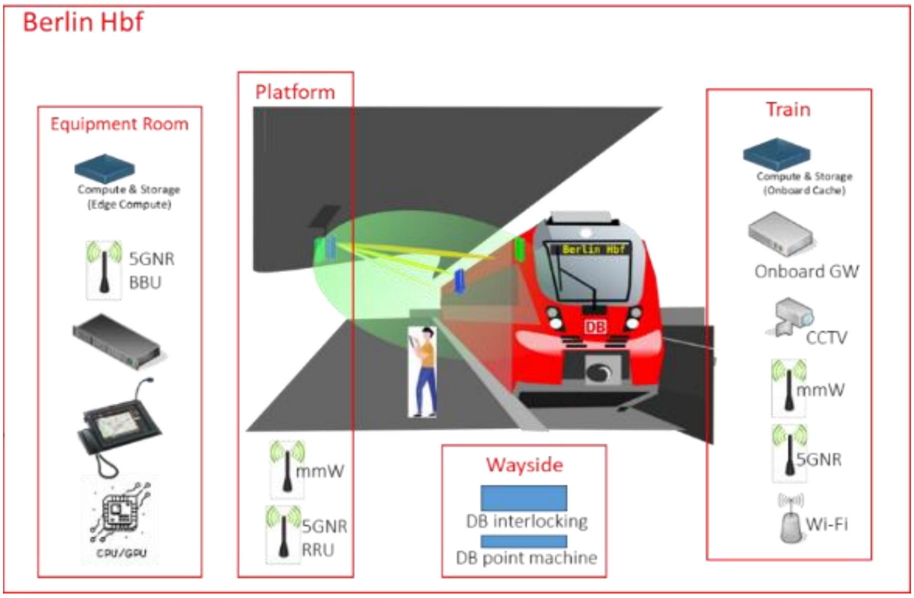

Figure 5-1 Berlin Central station facility in support of the Berlin UCs, UC #1.2 benefits from the 5G connectivity to passengers walking throughout the station

These are essentially the same components as for the Bristol Future Mobility App with one addition related to the Edge Rendering and Streaming capability as showed in the diagram (Edges box). Each Edge node can serve multiple clients (Future Mobility App installed on passenger smartphones) and renders the AR view from passenger point of view on the Edge instead of rendering it locally on the smartphone.

The low latency capability of 5G plays a central role to make this feature useful from user experience point of view. The selection of a suitable video codec (H.264, VP8, VP9…) and real-time streaming protocol (WebRTC or QUIC) is also essential to improve the user experience.

The Motion-to-Photon latency which is the delay until a user movement (detected via motion sensors) is reflected in the AR view should be reduced to a minimum. A Motion-to-Photon latency below 20 ms is well known to provide a good user experience.

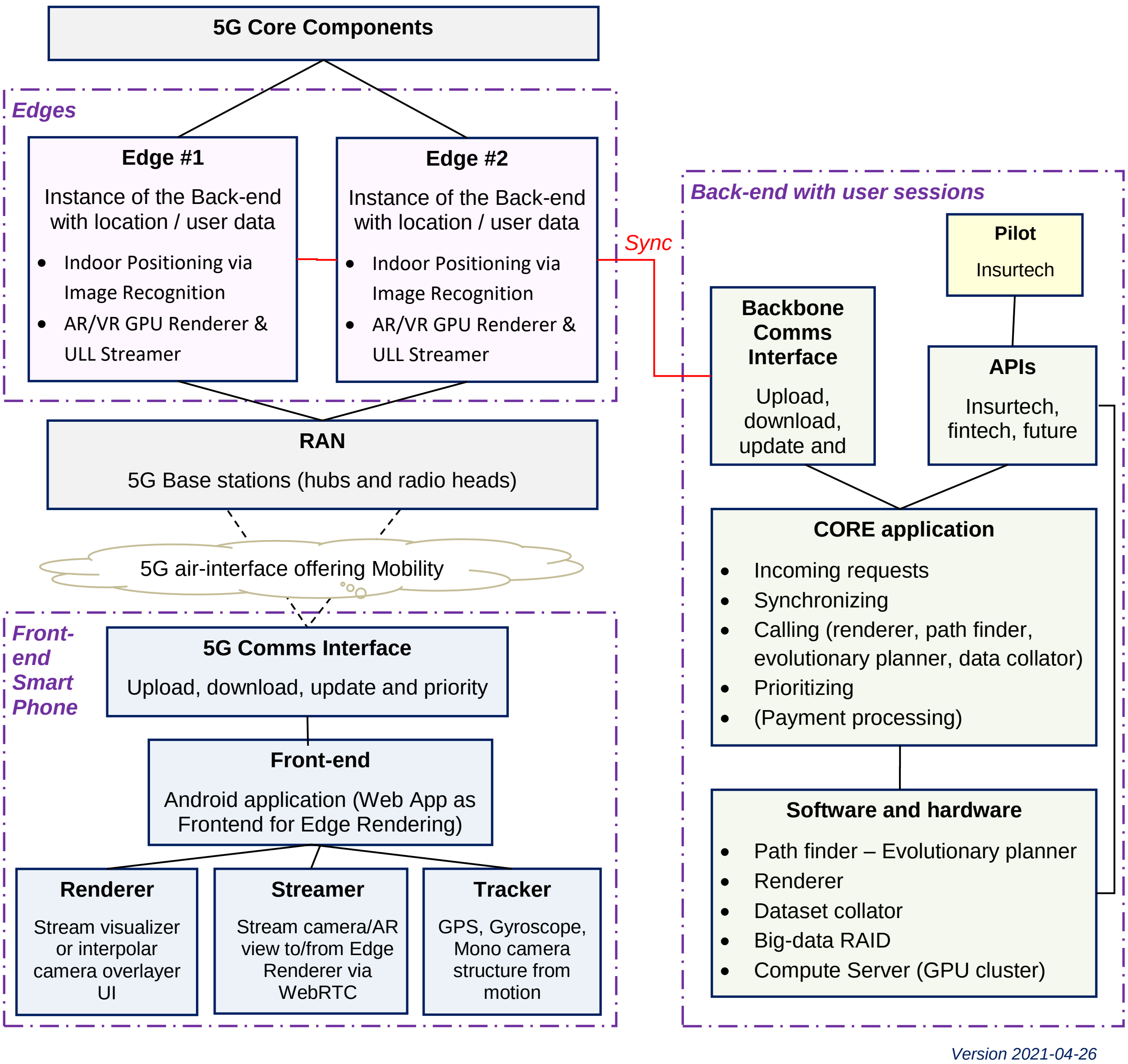

Figure 5-2: Digital Mobility at 5GENESIS in Berlin App 3 - Future Mobility Application

5.2.2 RDFg01: Edge Rendering - capture camera preview and sensor data (field)

This test case considers the capturing process in the future mobility application to prepare the camera preview video and sensor data for streaming: User location and User orientation. The test case is presented in Table 5-1.

Table 5-1: RDFg01 - Edge Rendering - capture camera preview and sensor data (field)

RDFg01	**Edge Rendering - capture camera preview and sensor data (field)**
Testbed	**5GENESIS Berlin**
Description	In this test case, the camera preview in the Future Mobility App together with the user location and orientation sensor data is captured and prepared for up-streaming in a suitable format. The camera preview video needs a video codec suitable with the streaming protocol. Uploading the front-end's camera stream (naturally with users' permission in a potential future commercial rollout) opens a whole new world of exciting opportunities, such as crowd-sourced mapping/digitisation of indoor environments and their surroundings. That leads to more frequent updates of 3D and other features, an ever-upgrading quasi live 3D digital twin of the transport landscape.
Key Use-case requirements and KPIs	Latency to capture the camera stream and device orientation sensors should be <1 ms
Network performance requirements and KPIs	N/A
Network Functional requirements and KPIs	N/A
Components and configuration	**- Components:** 1. Camera preview capturer 2. Sensor data (Location, Orientation) capturer **- Configuration:** 1. Video codec, resolution, framerate and bitrate of camera preview 2. Frequency of sensor data capturing
Test procedure	**- Preconditions:** 1. User already confirmed that the application can access camera and location/orientation sensors **- Test Case Steps:** 1. Capture raw camera preview 2. Encode camera preview according configuration 3. Capture raw sensor data 4. Convert sensor data in suitable format for streaming

Measurements	**- Methodology** 1. Prepare a special video stream that includes time codes that allow to measure the latency between the actual video and the captured camera preview 2. Record the actual video and camera preview within the mobile app using a high framerate camera **- Complementary measurements** 1. N/A **- Calculation process** 1. analyze the recorded video and calculate the difference between the time codes in the camera preview and the actual video .
Expected Result	The encoded camera preview stream and sensor data are in-line with the provided configuration.

5.2.3 RDFg02: Edge Rendering - upstream camera preview and sensor data

The capture video and sensor data from previous test are sent to the Edge using appropriate real-time streaming protocol like WebRTC. The test case is presented in Table 5-2.

Table 5-2: RDFg02 - Edge Rendering – upstream camera preview and sensor data

RDFg02	**Edge Rendering - upstream camera preview and sensor data**
Testbed	**5GENESIS Berlin**
Description	In this test case, the encoded camera preview and the prepared sensor data are streamed to the Edge via the 5G connection. WebRTC is used as Real-Time streaming protocol. The video stream is sent via RTCPeerConnection while the sensor data an RTCDataChannel
Key Use-case requirements and KPIs	Camera stream and sensor data are ready for streaming
Network performance requirements and KPIs	Latency <5 ms Bandwidth >15 Mbps
Network Functional requirements and KPIs	Reliable connection between the UE and the Edge
Components and configuration	**- Components:** 1. Frontend camera preview streamer 2. Frontend sensor data (Location, Orientation) streamer 3. Edge Streaming Server **- Configuration:** 1. N/A

Test procedure	**- Preconditions:** 1. camera preview and sensor data from Test Case RDFg01 are ready for streaming 2. A free Edge Renderer instance is already reserved, and the endpoint is provided **- Test Case Steps:** 1. Create a streaming session on the Edge Renderer instance. 2. Establish a connection for video streaming to the Edge Renderer Endpoint (WebRTC or QUIC) associated with the created session. 3. Establish a connection for sensor data streaming to the Edge Renderer Endpoint (WebRTC or QUIC) associated with the created session. 4. Start streaming camera preview video via the established video connection. 5. Start streaming sensor data via the established data connection. 6. Receive camera preview stream on Edge Renderer instance. 7. Receive sensor data stream on Edge Renderer instance.
Measurements	**- Methodology** 1. Stream a prepared stream that includes time codes. 2. Measure the time when each video frame is received on the edge using the time codes embedded in the video stream. **- Complementary measurements** 1. Measure reliability of camera preview streaming 2. Measure reliability of sensor data streaming 3. Measure latency of camera preview streaming 4. Measure latency of sensor data streaming **- Calculation process** 1. Calculate the time between send and receiving of each video frame 2. Calculate the average latency
Expected Result	The encoded camera preview stream and sensor data are received on the Edge Renderer instance without modification

5.2.4 RDFg03: Pre-process camera preview and sensor data on the edge

The received camera stream and sensor data from preview test case are decoded and prepared in a suitable format for further processing on the Edge. The test case is presented in Table 5-3.

Table 5-3: RDFg03 – Edge Rendering – pre-process camera preview and sensor data on the edge

RDFg03	**Edge Rendering – pre-process camera preview and sensor data on the edge**
Testbed	**5GENESIS Berlin**
Description	In this test case, the received camera preview and sensor data streams via WebRTC are pre-processed and prepared for the AR View Renderer. The output is the list of decoded video frames and sensor data items in a format that can be processed by the Rendering component.
Key Use-case requirements and KPIs	The video stream and sensor data can be pre-processed in real-time with a delay <1 ms

Network performance requirements and KPIs	N/A
Network Functional requirements and KPIs	N/A
Components and configuration	**- Components:** 1. The Edge Streaming Server 2. Real-time Video decoder 3. Sensor data pre-processor **- Configuration:** 1. N/A
Test procedure	**- Preconditions:** 1. N/A **- Test Case Steps:** 1. The Edge Streaming Server listens to video and data connections and pass them to the Video Decoder and Data processor 2. The Real-time Video Decoder reads the video data from the live camera stream and decodes the video frames 3. The Data processor reads the user location and orientation data from the data stream and provide them in a suitable format used by the Renderer
Measurements	**- Methodology** 1. The video frame data are dec0ded. 2. The sensor data are preprocessed. 3. The decoded video frames are compared to the reference video frames to check if they are received in the expected quality. 4. The decoded time is measured to check if the frames are available in real-time and no frames are dropped. 5. The sensor data are compared to the reference sensor data prepared for this test. **- Complementary measurements** 1. N/A **- Calculation process** 1. Calculate the hash of each sensor data item to check if the pre-processed data are valid. 2. Each video frame includes a unique identifier embedded in a QR code in the video frames. 3. The information inside the QR codes are decoded and analyzed. A discontinuity in frame numbers results in dropped frames. 4. Real-time detection can be easily calculated from the number of decoded frames within a second and compare it to the framerate of the video.
Expected Result	The stream of the camera preview is decoded, and the video frames are provided. The location data are available in the correct format that can be processed by the Edge Renderer

5.2.5 RDFg04: Edge Rendering – render AR/VR view on the edge

The pre-processed video and sensor data streams are sent to the GPU Rendering module running on the Edge and the AR or VR views are calculated based on the current position of the user. The output are the generated AR/VR view images.

Table 5-4: RDFg04 – Edge Rendering – render AR view on the edge

RDFg04	**Edge Rendering – Edge Rendering – render AR view on the edge**
Testbed	**5GENESIS Berlin**
Description	In this test case, the decoded camera stream frames and pre-processed location data are passed to the AR/VR view renderer which adds overlays on top of the camera stream using the location data using information from the captured 3D map of the Berlin Central Station. VR, when the user runs ahead on the planned route virtually (by clicking a button on screen) and studies later parts of the journey through visuals that can be aligned with the basic AR location and orientation or work as a standalone walk through (like when airlines show a video presentation and map of the arrival terminal a few minutes before landing; to help passengers plan ahead).
Key Use-case requirements and KPIs	The AR/VR views can be generated in real-time and with a latency <1 ms
Network performance requirements and KPIs	N/A
Network Functional requirements and KPIs	N/A
Components and configuration	**- Components:** 1. The AR View Renderer **- Configuration:** 2. N/A
Test procedure	**- Preconditions:** 1. N/A **- Test Case Steps:** 1. Read frames extracted from the camera stream in previous test case 2. Read location data provided in previous test case 3. For each camera frame and location data renders the output AR frame which adds overlays on top of the input camera frame 4. Provides the output frames to the next component to generate the AR View stream

Measurements	**- Methodology** 1. The input decoded video frames include QR codes with information about the current frame. 2. The AR/VR renderer is configured in a way that the QR codes embedded in the input video frames are still visible in the calculated AR/VR view images **- Complementary measurements** 1. N/A **- Calculation process** 1. after parsing the QR Codes for each input and output image, the delay for rendering the AR/VR view can be calculated. 2. in the same way, dropped frames by the AR/VR renderer can be detected.
Expected Result	The AR view frames with location-based overlays are rendered

5.2.6 RDFg05: Edge Rendering – generate AR view video stream

The generated AR/VR view frames are encoded as a video and prepared for streaming via WebRTC.

Table 5-5: RDFg05 – Edge Rendering – generate AR view video stream

RDFg05	Edge Rendering – generate AR view video stream
Testbed	**5GENESIS Berlin**
Description	In this test case, the rendered AR/VR View frames generated in previous test case are encoded as a video and prepared for streaming in the next test case.
Key Use-case requirements and KPIs	The AR/VR video stream is available in a suitable codec
Network performance requirements and KPIs	Latency <5 ms Bandwidth >15 Mbps
Network Functional requirements and KPIs	Reliable connection between the UE and the Edge
Components and configuration	**- Components:** 1. The AR View Encoder **- Configuration:** 1. Video encoder configurations in terms of video codec, framerate, resolution, etc.
Test procedure	**- Preconditions:** 1. N/A **- Test Case Steps:** 1. Read rendered AR view frames from previous test case 2. Encode the AR view frames as a video stream 3. Send the AR view video stream to the client via the established connection

Measurements	**- Methodology** 1. The AR/VR video includes QR codes 2. The received AR/VR video stream on the UE is captured and the QR codes are analyzed **- Complementary measurements** 1. N/A **- Calculation process** 1. The information embedded in the QR codes together with the time of sending and receiving the AR/VR frames are used to calculate the latency
Expected Result	The AR view stream is received by the client with proper overlays corresponding to user location

5.2.7 RDFg06: Edge Rendering – display AR/VR view stream in the mobility App

The received AR/VR view video stream is displayed to the user in the mobile application.

Table 5-6: RDFg06 – Edge Rendering – display AR view stream in the mobility App

RDFg06	**Edge Rendering – Edge Rendering – display AR view stream in the mobility App**
Testbed	**5GENESIS Berlin**
Description	In this test case, the received AR/VR View live stream is played back in the mobility App.
Key Use-case requirements and KPIs	The displayed AR/VR view corresponds to the user position with a video quality
Network performance requirements and KPIs	End-to-End latency <20 ms
Network Functional requirements and KPIs	N/A
Components and configuration	**- Components:** 1. The AR View Player **- Configuration:** 1. N/A
Test procedure	**- Preconditions:** 1. N/A **- Test Case Steps:** 1. Receive AR/VR view video stream. 2. Playback the AR/VR view video stream in the mobile App.

Measurements	**- Methodology** 1. The application displays the camera preview and the renderer AR view in the same page. 2. The app display is recorded with a high framerate camera. **- Complementary measurements** 1. N/A **- Calculation process** 1. The time between the appearance of the same video frame in the Camera preview and the displayed AR/VR View is calculated.
Expected Result	The AR view stream is displayed and rendered properly in the App

5.2.8 RDFg07: Future Mobility high bitrate data distribution between Backend and Edge

This test case is about verifying the data distribution capability for the Future Mobility App between the Edge Nodes in the Berlin Central Station and the **UHA** Cloud.

Table 5-7: RDFg07 – Future Mobility high bitrate data distribution between Backend and Edge

RDFg07	**Future Mobility high bitrate data distribution between Backend and Edge (field test)**
Testbed	**5GENESIS Berlin**
Description	Test the UHA Future Mobility's data distribution feature.
Key Use-case requirements and KPIs	Primary: large spatial data (the digital twin; above 1 Gigabyte) is copied from the Back-end to the Edge.
Network performance requirements and KPIs	Minimum 20 Mbps connection for the Edge and the Backend.
Network Functional requirements and KPIs	The application needs reliable connectivity and handover between the outdoor Edge nodes.
Components and configuration	**- Components:** 1. Edge GPU compute capability. 2. Backend GPU compute capability. **- Configuration:** 1. RTX-2080 or RTX 3090 GPU. To be provided by UHA. 2. UHA real-time 3D tile processing engine written in C++ and OpenCL/Cuda that operate the digital twin. 3. Backend server (CPU). 4. UHA communication module written in C++.

Test procedure	**- Preconditions:** 1. The Edge nodes at Berlin Central Station and the Backend contain UHA's communication module. **- Test Case Steps:** 1. The Backend instructs the Edge node to prepare for a spatial dataset update. 2. The backend starts to stream the data. 3. The Edge receives the data. 4. The Edge upgrades the local dataset according to the spatial coordinates received from the Backend in each 3D tile.
Measurements	**- Methodology** 1. See above **- Complementary measurements** 1. Bandwidth fluctuation. Connection stability and reliability. 2. Investigate the room for optimizing so that only the most necessary data pieces are transmitted (minimize redundancy). **- Calculation process** 1. The received and stored data sets are verified via a simple render exercise. If flawless visuals appear then success. If corrupted visuals or a crash happens then fail.
Expected Result	The aim is to demonstrate and validate UHA's new spatial data distribution feature that unlocks multi scenery multi-user access and interaction with the digital twin. Note: This is an improvement over the previous back-end only simulation and analytics based usage.

5.2.9 RDFg08: Future Mobility – in- and outdoor passenger guidance and journey planning via digital twin

This test case is about verifying that live data from external sources can be integrated into the virtual 3D replica or digital twin quasi instantly.

Table 5-8: RDFg08 – Future Mobility - in and outdoor passenger guidance and journey planning in multi modal transport via digital twin

RDFg08	**Future Mobility - in and outdoor passenger guidance and journey planning in multi modal transport via digital twin (lab & field)**
Testbed	**5GENESIS Berlin**
Description	Transport data feed collation
Key Use-case requirements and KPIs	Primary: 1 to 5 times a minute live train time and location data download from pre-selected data streams of the transport operator. Secondary: integration into the digital twin real-time for immediate use.
Network performance requirements and KPIs	Minimum 10 Mbits/s connection for the Edge data stream to reach the end user's mobile device. Maximum 20 ms latency. Minimum 10 Mbits/s connection at the Backend.
Network Functional requirements and KPIs	The application needs reliable connectivity.

Components and configuration	**- Components:** 1. UHA's Backend (a replica of the Edge SW but containing all locations' data). 2. Edge GPU compute capability. **- Configuration:** 1. "RTX-2080 GPU. 2. UHA real-time 3D tile processing engine written in C++ and OpenCL/Cuda to receive and integrate the point-cloud into the digital twin."
Test procedure	**- Preconditions:** 1. Both the Backend and the Edge node contains UHA's digital twin. 2. The transport operator's data feed is live and accessible. 3. The scanned virtual replica of the station exists in the twin. **- Test Case Steps:** 1. The Backend connects to the transport operator's data feed and downloads the whole (or the change wherever possible). 2. Transport data is integrated into the digital twin. 3. The virtual replica of the station is visualized at the Backend with the transport live data present.
Measurements	**- Methodology** 1. Transport data is spatially matched through geo-tags. **- Complementary measurements** 1. N/A **- Calculation process** 1. UHA's Backend has the capability to visualize very large datasets additional to the real-time 3D render of the physical environment's (station) virtual replica. The collated transport data shall appear in the visual render real time. Test samples are manually selected from the downloaded data feed and from the collated version of it inside the digital twin to compare and verify.
Expected Result	The aim is to demonstrate that live data from external sources can be integrated into the virtual 3D replica or digital twin quasi instantly.

6 Rail Critical Services at the 5G-VICTORI facility in Berlin

6.1 Description

The air interface for radio communication in general is the scarce resource in our society, it is a natural resource. Many kind of vertical services traditionally need their own radio communication solution. Trains use typically GSM-R, Voice use 3G or 4G, Power meter readings use GSM or low bitrate long range solutions, Taxi cars use their own radio – the list can be made long. This is at least how it looks like today.

What if 5G can be used by all these vertical services. Imagine if a cellular system could offer solutions that makes it possible to use only one type of cellular systems in the society to satisfy all these vertical services – in principle using the same frequency spectrum and resources for all these users.

Railway communications with Rail Signaling, Rail Cab Voice, Rail Sensor Data, and Rail Surveillance CCTV, Predictive Maintenance, etc., could use the same cellular system together with all other vertical services in the society. The Rail Critical Services at 5GENESIS in Berlin, belonging to **UC #1.3** in deliverable D2.3 [3], comprises five representative type of services in 5G-VICTORI, where four are onboard related and one is wayside related:

Onboard services:

- Rail signaling.
- CCTV monitoring.
- Telephony (Cab Voice and Emergency Calls).
- Sensor data.

Wayside services:

- Wayside Point-machine Object controller signaling.

Figure 5-1 represented the different parts of the infrastructure within the Berlin Central station that will be involved in **UC #1.3**. The Berlin Equipment Room (aka. Berlin Office), can host all management components of the Berlin facility – so it can be done at the Fraunhofer FOKUS site for testing between the two sites. The Equipment Room hosts the edge compute/data centre, together with the 5G NR Baseband Unit (BBU), and switching components. At the Platform, the 5G NR equipment will be installed for provisioning 5G connectivity to the train. The wayside equipment will involve the use of a point machine and the train hosts the onboard computing and storage plus the access network equipment of various technologies.

6.2 Rail Critical services Berlin Rail Signaling test cases (RCSg)

6.2.1 Description

The Rail Signaling traffic is performed between Berlin Office (or Equipment room) and Onboard the Train by using a traffic generator which can be configured to send traffic in both directions. The traffic generator is from Keysight, model Hawkeye, and consists of one Console and a number of Performance End-points. Traffic is generated and monitored via the End-points, result presented on the console.

The minimum license is valid for one Console user and ten End-points (which means that other services can be emulated as well).

- The Console application runs on the Windows based Dispatcher Terminal in the Berlin Office.

- The rail signaling end-point application run on an Onboard Terminal.

The purpose with the Rail Signaling service on high level is the following:

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

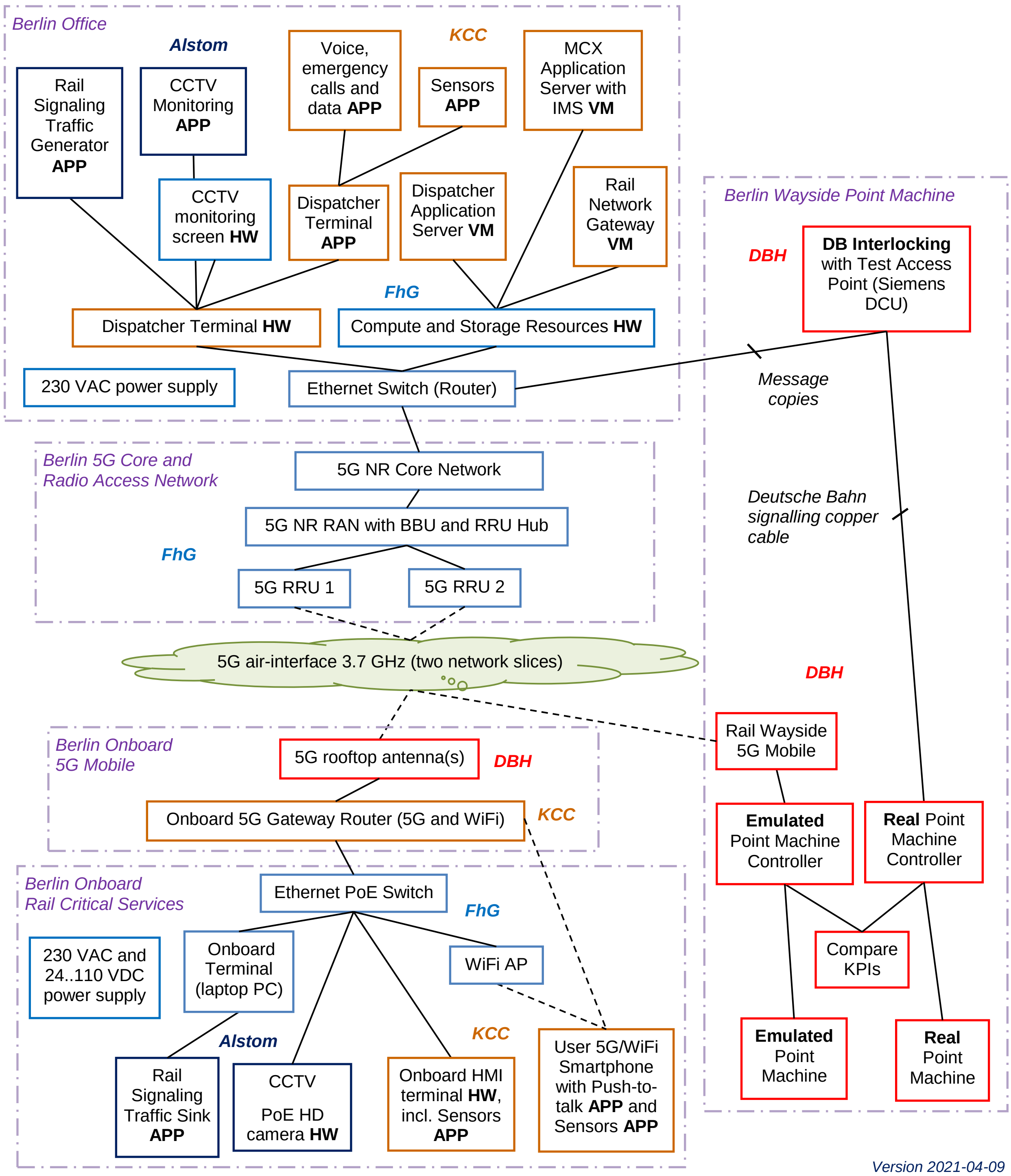

Figure 6-1: Rail Critical Services – HW and SW Overview (with indicated contributing Partners)

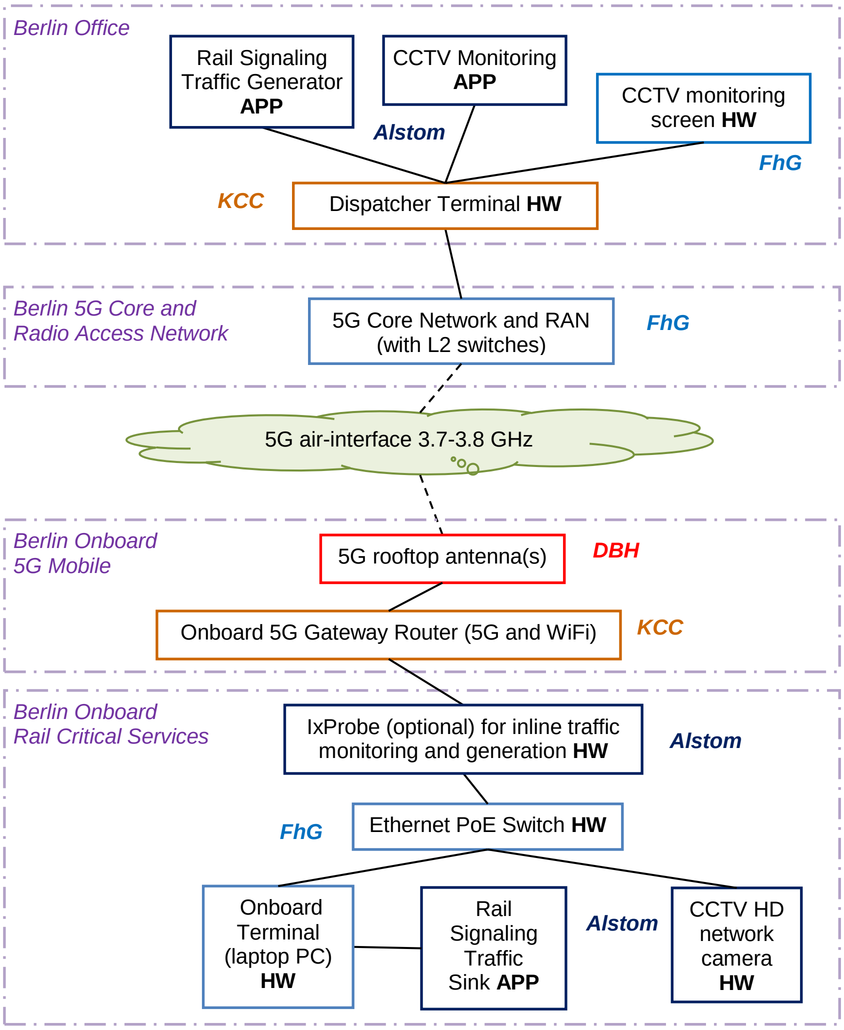

Figure 6-2: Rail Critical Services – Rail Signaling and CCTV Streaming

6.2.2 RCSg01: Rail Signaling pre-test without 5G Network (lab test)

Rail signaling is tested between the Berlin Office and Onboard the train. Traffic is generated in both directions between Performance End-points. These End-points are installed on an office computer and on an onboard computer. The Console is the Hawkeye application where traffic is managed, it is there you setup traffic and monitor KPIs.

This test case is an early version without the need of a 5G network. It is to test the traffic generator and monitoring equipment, suitable for lab activities. The purpose with this test is to get familiar with the test equipment and to setup the equipment for the Rail Signalling test cases.

The lab related test case without 5G is outlined in Table 6-1.

Table 6-1: RCSg01 - Rail Signaling pre-test without 5G Network (lab test)

RCSg01	**Rail Signaling pre-test without 5G Network (lab test)**
Testbed	**5GENESIS Berlin**
Description	The purpose with this test-case is to first establish rail signaling traffic directly between the Berlin Office End-point and the Onboard End-point, without a 5G network. The reason is to exclude 5G cellular network complexity as a first step. Note: with this direct connection not using 5G, Network Slicing and 5G QoS Indicator have no meaning.
Key UC requirements and KPIs	**U-FU-3101** (signaling traffic possible between Performance end-points), **U-FU-3102** (Console installed on Dispatcher Terminal, Windows OS), **U-FU-3103** (End-points can be installed in an onboard Windows PC), **U-FU-3104** (End-point installed on Office Dispatcher Terminal), **U-FU-3105** (emulating rail signaling, fake packets with similar characteristics), **U-FU-3106** (IP network connectivity between Performance End-points), **U-FU-3107** (Maintaining signaling between End-points after non-5G connectivity), **U-FU-3108** (Rail signaling starts again after when a 5G connectivity comes back). KPIs: • Round-trip-time less than 100 ms. • Packet loss ratio lower than 0.5%. Note: The result is expected regardless of background traffic in the network.
Network performance requirements and KPIs	N/A
Network Functional requirements and KPIs	N/A
Components and configuration	**- Components:** 1. Berlin Office Dispatcher Terminal, the computer on which the Console and the Office Performance End-point are installed. 2. Traffic generator Console Application (software running over Linux). 3. Office Ethernet switch. 4. (Onboard PoE Ethernet switch, optional). 5. Onboard Terminal (PC laptop). 6. VM software with Linux running over PC Windows. 7. Performance End-point Apps. **- Configuration:** 1. The Berlin Office Dispatcher Terminal is connected directly via one or more Ethernet switches (Office and Onboard) to the Onboard Terminal (PC laptop). 2. Optional: Several End-points can be installed and used to emulate several trains, and other services like emulating data.

Test procedure	**- Preconditions:** 1. The traffic generator Console Application is installed on the Dispatcher Terminal. 2. Performance End-points are installed on Office computer and on an Onboard Terminal. 3. The Berlin Office Dispatcher Terminal is connected via the Ethernet switch to the Onboard Terminal (PC laptop) **- Test Case Steps:** 1. From the Console, find the End-points and establish a connection. 2. From the Console, setup bi-directional traffic between Office and Onboard End-points. Use a randomized packet payload content, packet size 300 bytes, and a bitrate in each direction of 160 kbps.
Measurements	**- Methodology** 1. Rail signaling traffic is setup between a Performance End-points, one in Office and one Onboard the train. KPIs are monitored using the Hawkeye console, which communicates with the end-points. 2. Optional: to get familiar with the optional IxProbe HW, it can be used as well to monitor traffic in this lab environment. **- Complementary measurements** 1. If an optional tool like iPerf is used, it can be used for comparison. 2. If the optional IxProbe HW is used, it can be used to monitor traffic. The Console communicates with IxProbe, where you can monitor traffic. **- Calculation process** 1. The bitrate given in the test-case is the rail signalling payload bitrate. Overhead from UDP/IP etc transportation network protocols are added.
Expected Result	The rail signalling traffic meets the expected KPIs, regardless of other traffic.

6.2.3 RCSg02: Rail Signaling over 5G corresponding to one train (lab & field)

Rail signaling is tested between the Berlin Office and Onboard the train. Traffic is generated in both directions between Performance End-points. The end-points are installed on an office computer and on an onboard computer.

In this test case, Rail signaling is done over the 5G network as well. The purpose with this test-case is to show rail signaling characteristics over 5G, regardless of background traffic (other simultaneous test cases running at the same time).

The test case is found in Table 6-2.

Table 6-2: RCSg02 - Rail Signaling over 5G corresponding to one train (lab & field)

RCSg02	**Rail Signaling over 5G corresponding to one train (lab & field)**
Testbed	**5GENESIS Berlin**
Description	The purpose with this test-case is to emulate rail signaling over 5G corresponding to one train. Establish rail signaling traffic between the Berlin Office traffic generator Console and the Onboard End-point over 5G.

Key Use-case requirements and KPIs	The same Use-case requirements and KPIs can be used as in RCSg01. Note: The use-case KPI result is expected regardless of background traffic in the network (the reason is 5G Network Slicing with a suitable 5G QoS Indicator).
Network performance requirements and KPIs	**U-FU-3203** (rail signaling traffic using 200 kbps over a 5G network), KPI: • Rail signaling traffic can use 200 kbps, regardless of background traffic.
Network Functional requirements and KPIs	**U-FU-3301** (all onboard Rail Critical Services use the same 5G RF spectrum), **U-FU-3302** (the 5G network at the station deployed in a decent way), **U-FU-3303** (rail signaling traffic shall come up and run after a train power up), **U-FU-3304** (rail signaling traffic between onboard and office with 5G connectivity), **U-FU-3305** (rail signaling KPIs kept, or uploaded, before train power down). KPIs: • Rail signaling traffic can use 200 kbps, regardless of background traffic.
Components and configuration	**- Components:** 1. Berlin Office Dispatcher Terminal, the computer on which the Console and the Office Performance End-point are installed. 2. Traffic generator Console Application (software running over Linux) 3. Office Ethernet switch 4. (Onboard PoE Ethernet switch, optional) 5. Onboard Terminal (PC laptop) 6. VM software with Linux running over PC Windows 7. Performance End-point Apps. 8. 5G Network between Office and Onboard. **- Configuration:** 1. Agreed 5G Network Slice for Rail Critical Services and a suitable 5G QoS Indicator. 2. The Berlin Office Dispatcher Terminal is connected via the Office Ethernet switch, with the 5G infrastructure, via the Onboard Ethernet switch and the Onboard Terminal (PC laptop). 3. Optional: Several End-points can be installed and used to emulate several trains (or add corresponding signaling packet intensity), and other services like emulating data.

Test procedure	**- Preconditions:** 1. The traffic generator Console Application is installed on the Dispatcher Terminal. 2. Performance End-points are installed on Office computer and on an Onboard Terminal. 3. It is assumed that when 5G connectivity becomes available between Berlin Office and Berlin Onboard, the Office and Onboard applications gests connectivity in between over 5G without any connection establishment procedures needed by the applications. 4. Use an agreed 5G Network Slice for Rail Critical Services and a suitable 5G QoS Indicator. 5. The Berlin Office Dispatcher Terminal is connected via the Office Ethernet switch, with the 5G infrastructure, via the Onboard (PoE) Ethernet switch and the Onboard Terminal (PC laptop). **- Test Case Steps:** 1. From the Console, find the End-points and establish a connection. 2. From the Console, setup bi-directional traffic between Office and Onboard End-points. Use a randomized packet payload content, packet size 300 bytes, and a bitrate in each direction of 160 kbps.
Measurements	**- Methodology** 1. Rail signaling traffic is setup between a Performance End-points, one in Office and one Onboard the train. KPIs are monitored using the Hawkeye console, which communicates with the end-points. 2. Optional: to get familiar with the optional IxProbe HW, it can be used as well to monitor traffic in this lab environment. **- Complementary measurements** 1. If an optional tool like iPerf is used, it can be used for comparison. 2. If the optional IxProbe HW is used, it can be used to monitor traffic. The Console commicates with IxProbe, where you can monitor traffic. **- Calculation process** 1. The bitrate given in the test-case is the rail signalling payload bitrate. Overhead from UDP/IP etc transportation network protocols are added.
Expected Result	The rail signalling traffic meets the expected KPIs, regardless of other traffic.

6.2.4 RCSg03: Rail Signaling over 5G corresponding to twelve trains (field test)

Rail signaling is tested between the Berlin Office and Onboard the train. Traffic is generated in both directions between Performance end-points. The end-points are installed on an office computer (dispatcher terminal) and on an onboard computer (laptop). This test case bridges the 5G network.

The purpose with this test is the same as in section 6.2.3 with RCSg02, but here instead emulating 12 trains, which basically means that the rail signaling packet intensity gets 12 times higher. The reason why emulating 12 trains is that this is often the maximum in a common two-line station with four tracks, where each track occupies three trains. This could be a train congested situation where one train just left the station, one strain stands at the station, and one train is waiting. Or a similar situation.

Measure characteristics for the rail signaling traffic over 5G, regardless of background traffic (other simultaneous test-cases running at the same time).

See the test case details in Table 6-3.

Table 6-3: RCSg03 - Rail Signaling over 5G corresponding to twelve trains (field test)

RCSg03	**Rail Signaling over 5G corresponding to twelve trains (field test)**
Testbed	**5GENESIS Berlin**
Description	The purpose with this test is to emulate 12 trains, which basically means a packet frequency 12 times higher. Else the test-case is the same as for RCSg02.
Key Use-case requirements and KPIs	The same Use-case requirements and KPIs can be used as in RCSg02. Note: The use-case KPI result is expected regardless of background traffic in the network (the reason is 5G Network Slicing with a suitable 5G QoS Indicator).
Network performance requirements and KPIs	**U-FU-3203** (rail signaling traffic using 200 kbps over a 5G network), KPI: • Rail signaling traffic can use 200 kbps, regardless of background traffic.
Network Functional requirements and KPIs	**U-FU-3301** (all onboard Rail Critical Services use the same 5G RF spectrum), **U-FU-3302** (the 5G network at the station deployed in a decent way), **U-FU-3303** (rail signaling traffic shall come up and run after a train power up), **U-FU-3304** (rail signaling traffic between onboard and office with 5G connectivity), **U-FU-3305** (rail signaling KPIs kept, or uploaded, before train power down). KPIs: • Rail signaling traffic can use 200 kbps, regardless of background traffic.
Components and configuration	**- Components:** 1. Berlin Office Dispatcher Terminal, the computer on which the Console and the Office Performance End-point are installed. 2. Traffic generator Console Application (software running over Linux). 3. Office Ethernet switch. 4. (Onboard PoE Ethernet switch, optional). 5. Onboard Terminal (PC laptop). 6. VM software with Linux running over PC Windows. 7. Performance End-point Apps. 8. 5G Network between Office and Onboard. **- Configuration:** 1. Agreed 5G Network Slice for Rail Critical Services and a suitable 5G QoS Indicator. 2. The Berlin Office computer (Dispatcher Terminal) is connected via the Office Ethernet switch, with the 5G infrastructure, via the Onboard Ethernet switch and the Onboard Terminal (PC laptop). 3. Optional: Several Performance End-points can be installed and used to emulate several trains, and other services like emulating data (optional).

Test procedure	**- Preconditions:** 1. The traffic generator Console Application is installed on the Dispatcher Terminal. 2. Performance End-points are installed on Office computer and on an Onboard Terminal. 3. It is assumed that when 5G connectivity becomes available between Berlin Office and Berlin Onboard, the Office and Onboard applications gests connectivity in between over 5G without any connection establishment procedures needed by the applications. 4. Use an agreed 5G Network Slice for Rail Critical Services and a suitable 5G QoS Indicator. 5. The Berlin Office Dispatcher Terminal is connected via the Office Ethernet switch, with the 5G infrastructure, via the Onboard (PoE) Ethernet switch and the Onboard Terminal (PC laptop). **- Test Case Steps:** 1. From the Console, find the End-points and establish a connection. 2. From the Console, setup bi-directional traffic between Office and Onboard End-points. Use a randomized packet payload content, packet size 300 bytes, and a bitrate in each direction of 12 x 160 kbps = 1.92 Mbps.
Measurements	**- Methodology** 1. Rail signaling traffic is setup between a Performance End-points, one in Office and one Onboard the train. KPIs are monitored using the Hawkeye console, which communicates with the end-points. 2. Optional: to get familiar with the optional IxProbe HW, it can be used as well to monitor traffic in this lab environment. **- Complementary measurements** 1. If an optional tool like iPerf is used, it can be used for comparison. 2. If the optional IxProbe HW is used, it can be used to monitor traffic. The Console commicates with IxProbe, where you can monitor traffic. **- Calculation process** 1. The bitrate given in the test-case is the rail signalling payload bitrate. Overhead from UDP/IP etc transportation network protocols are added.
Expected Result	The rail signalling traffic meets the expected KPIs, regardless of other traffic.

6.3 Rail Critical services Berlin CCTV Streaming test cases (RCCg)

6.3.1 Description

The overview block diagram of the Onboard CCTV camera and the Office CCTV monitoring with APP are outlined in Figure 6-2 on page 93.

The purpose with the test-cases for CCTV streaming is:

- Demonstrate that onboard CCTV moving pictures are streamed to office with good expected quality, undisturbed, with good-enough short latency (which also depends on video coder buffer depth in the camera).
- Demonstrate that the characteristics are fulfilled regardless of background traffic (i.e. traffic from other Vertical service users in the 5G system).

- The video stream can be configured to generate 5 Mbps.
- The use of an inline IxProbe makes it possible to monitor further KPIs and also generate more traffic, like emulating in total 12 cameras (60 Mbps).

The purpose with the CCTV Streaming service on high level is the following:

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

6.3.2 RCCg01: CCTV streaming pre-test without 5G Network (lab test)

This is an early lab test for CCTV streaming, here tested between the Berlin Train and the Berlin Office, using a simple Ethernet cable and switch in between.

The 5G network is here not used. The reason is to get a first simplified setup.

This test-case is aimed for the lab, to get familiar with the CCTV equipment and to configure the equipment to suit the CCTV test-cases.

When the IxProbe hardware is used, it is connected in-line next to the PoE switch, on the Office side (assuming IxProbe doesn't convey PoE). IxProbe monitors traffic, inserts traffic, and communicates with the Console. The IxProbe has a Fail-to-wire functionality with internal relays if its power fails.

The Hawkeye Console is used for controlling IxProbe traffic and monitor KPIs.

Table 6-4: RCCg01 – CCTV streaming pre-test without 5G Network (lab test)

RCCg01	**CCTV streaming pre-test without 5G Network (lab test)**
Testbed	**5GENESIS Berlin**
Description	The test-case connects the physical CCTV camera with the Office monitoring HW and APP equipment over an Ethernet cable. 5G is here not used. The purpose with the test-case is to configure the equipment to suit the CCTV test-cases in the Berlin project. The test-case aims at getting familiar with the equipment without bothering about a 5G network in between. This test-case is suitable for lab environment, or on a desk.
Key UC requirements and KPIs	**U-FU-3143** (CCTV monitoring software installed on office dispatcher terminal) **U-FU-3144** (CCTV monitoring software running on office dispatcher terminal KPIs: • CCTV applications installed Note: The result is expected regardless of background traffic in the network.
Network performance requirements and KPIs	**F-PE-3241** (CCTV camera shall have access to 5 Mbps over the network) KPIs: • CCTV bitrate over network around 5 Mbps. • CCTV streaming latency 150 ms. • CCTV maximum packet loss ratio 0.5%. Note: The result is expected regardless of background traffic in the network.

Network Functional requirements and KPIs	**F-FU-3303** (at train power up, CCTV streaming shall start automatically) **F-FU-3304** (when 5G becomes available, CCTV shall come up over 5G) **F-FU-3305** (when train powers down, CCTV logs shall be available) **F-FU-3341** (check that CCTV camera Power of Ethernet (PoE) works fine) KPIs: • CCTV streaming starts when train powers up. • CCTV logs becomes available at train power down. • CCTV power over Ethernet works fine. Note: The result is expected regardless of background traffic in the network.
Components and configuration	**- Components:** 1. Onboard CCTV camera (Axis P3935-LR Network Camera) 2. Optional IxProbe (HW), this is powered via 230 VAC, max 10 W. 3. Onboard PoE Ethernet switch (PoE powers the camera) 4. Onboard Performance End-point (software app), or if an End-point functional can be supported by the Hawkeye Console. 5. Office PC computer (Dispatcher Terminal from Kontron) 6. Office PC screen to show CCTV monitoring pictures. 7. Office Hawkeye Console application, controlling the IxProbe. **- Configuration:** 1. The CCTV camera is connected to the onboard PoE Ethernet switch. 2. The (optional) IxProbe (HW) is connected inline between the onboard PoE switch and the office (assuming no 5G network in this test-case). 3. CCTV monitoring software installed and running on the office computer. Note: only one camera is used, which means that monitoring tool could simply be a web browser logged in to the camera, showing the live view. 4. Configure the camera to stream with a bitrate of around 5 Mbps. This is done by configuring the camera (under the Stream tab) to use 1 P-frame (default for surveillance is else around 40 or so). 5. Optionally certificates can be given to the CCTV camera, which makes it possible to use HTTPS in the web browser.

Test procedure	**- Preconditions:** 1. CCTV camera up and running. 2. Dispatcher Terminal with CCTV monitoring software up and running. a. The CCTV monitoring software can simply be a web page pointing at IP address of the camera. The user needs to log in to the CCTV camera (User: root, Password: CCTVfor5G-V). There you can configure the camera and present live view pictures from the camera. b. Optional solution (not preferred in this case): use the Axis Companion application, which is good when using several cameras. In this test-case we use only one camera, so using Companion is probably overkill. 3. PC screen with the CCTV monitoring software / web browser visible. 4. The CCTV camera assumes by default to get an IP address via a DHCP server in the network. **- Test Case Steps:** 1. Power on equipment (if needed). 2. Address the IP address of the camera in a web browser. 3. Login to the camera. 4. Start streaming moving pictures. Configure settings to e.g. reach 5 Mbps. 5. View result. The camera pictures can be configured with an overlay text which presents camera data like bitrate, frame rate, frame size, etc. 6. Optionally setup additional traffic between an office Performance End-point and IxProbe, with the purpose being able to view additional KPIs such as latency, and to view bitrates on different abstraction levels.

Measurements	**- Methodology** 1. The Onboard CCTV camera sends pictures to the Office monitoring application (a simple web page, or the Axis Companion software). The Axis camera video stream bitrate is measured as the raw video payload stream, not including any network transportation overhead protocols like UDP/TCP/HTTP. a. On-screen (configured video overlay text) measurements: This is the data sent by the Axis camera product. The Onscreen overlay text bitrate is the encoding driver bitrate averaged over the last 5 seconds, updated every second. b. Client stream information (e.g. the web-browser): This is the data received by the browser, where the web browser bitrate the last 1 second is presented. 2. The optional IxProbe hardware is connected onboard inline next to the PoE switch, towards the office (assuming IxProbe can't convey PoE). The IxProbe can both monitor and generate traffic. The advantage with the IxProble is that some additional traffic (on top of the traffic sent by the CCTV camera) can be setup which enables efficient measurements of latency etc that the IxProbe supports. The IxProbe communicates nicely with the Hawkeye Console. **- Complementary measurements** 1. If an optional tool like iPerf is used, it can be used for comparison. 2. If the IxProbe is used, the bitrate on different abstraction levels can be measured, e.g. codec bitrate or including UDP/IP, etc. Setup a connection between IxProbe and the Console (or a Performance End-point in the Office) of 1 Mbps or so. In this way latency etc can be studied. **- Calculation process** 1. The bitrates described under Methodology are the CCTV codec bitrate. Overhead from UDP/IP etc transportation network protocols are added.
Expected Result	Nice looking CCTV pictures are expected on the monitoring screen.

6.3.3 RCCg02: CCTV streaming over 5G corresponding to one train (field)

CCTV streaming is here tested between the Berlin Train and the Berlin Office, using an onboard CCTV camera and an office web browser.

This use-case has an active 5G network in between the train and the office.

This test-case is suitable for both lab and field. This test case focuses on getting the CCTV equipment up and running over the 5G network.

The test-case aims at checking that CCTV pictures start streaming when the train is powered up and when 5G connectivity comes up between the camera and the monitoring equipment.

When the IxProbe hardware is used, it is connected in-line next to the PoE switch, on the Office side (assuming IxProbe does not convey PoE). IxProbe monitors traffic, inserts traffic, and communicates with the Console. The IxProbe has a Fail-to-wire functionality with internal relays, should its power fail.

The Hawkeye Console is used for controlling IxProbe traffic and monitor KPIs.

Table 6-5: RCCg02 - CCTV streaming over 5G using one camera on one train (field)

RCCg02	**CCTV streaming over 5G using one camera on one train (field)**
Testbed	**5GENESIS Berlin**
Description	The test-case connects the physical CCTV camera with the Office monitoring HW and APP equipment over the Berlin 5G cellular network. The purpose with the test case is to show CCTV moving pictures conveyed from the train, via the 5G cellular network, and monitored on the office CCTV monitoring application. The test-case is also to check that CCTV streaming starts automatically when power comes up and when the 5G connectivity in between comes up. This test-case is suitable for both in the lab and field tests.
Key UC requirements and KPIs	**U-FU-3141** (CCTV camera is put in the train driver's cab, pointing forward) **U-FU-3143** (CCTV monitoring software installed on office dispatcher terminal) **U-FU-3144** (CCTV monitoring software running on office dispatcher terminal KPIs: • CCTV mounted in Train driver's cab, inside window, looking forward. • CCTV applications installed. Note: The result is expected regardless of background traffic in the network.
Network performance requirements and KPIs	F-PE-3241 (CCTV camera shall have access to 5 Mbps over the network) KPIs: • CCTV bitrate over network around 5 Mbps. • CCTV streaming latency 150 ms. • CCTV maximum packet loss ratio 0.5%. Note: The result is expected regardless of background traffic in the network.
Network Functional requirements and KPIs	**F-FU-3303** (at train power up, CCTV streaming shall start automatically) **F-FU-3304** (when 5G becomes available, CCTV shall come up over 5G) **F-FU-3305** (when train powers down, CCTV logs shall be available) **F-FU-3341** (check that CCTV camera Power of Ethernet (PoE) works fine) KPIs: • CCTV streaming starts when train powers up. • CCTV logs becomes available at train power down. • CCTV power over Ethernet works fine. Note: The result is expected regardless of background traffic in the network.

<table>
<tr>
<td>Components and configuration</td>
<td>
- Components:

Onboard CCTV camera (Axis P3935-LR Network Camera)
Optional IxProbe (HW), this is powered via 230 VAC, max 10 W.
Onboard PoE Ethernet switch (PoE powers the camera)
Onboard Performance End-point (software app), or if an End-point functional can be supported by the Hawkeye Console.
5G cellular network in between Onboard and Office.
Office PC computer (Dispatcher Terminal from Kontron), with a web browser logged in to the camera.
Office PC screen for showing CCTV monitoring pictures.
Office Hawkeye Console application, controlling the IxProbe.

- Configuration:

The Onboard CCTV camera is connected via the PoE Ethernet switch to the onboard 5G cellular equipment.
The (optional) IxProbe (HW) is connected inline between the onboard PoE switch and the onboard 5G mobile, using RJ45 Ethernet cables.
CCTV monitoring software installed and running on the office computer (as we only have one camera, the monitoring tool could simply be a web browser logged in to the camera, where a live view is presented).
Configure the camera to stream with a bitrate of around 5 Mbps. This is done by configuring the camera to use only 1 P-frame (default for surveillance is else around 40 or so).
Optionally certificates can be given to the CCTV camera, which makes it possible to use HTTPS in the web browser.

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</table>

<table>
<tr>
<td>Test procedure</td>
<td>
- Preconditions:

CCTV camera is powered and up and running.
5G connectivity is up and running
Dispatcher Terminal with CCTV monitoring software up and running.
<ol type="a">
The CCTV monitoring software can simply be a web page pointing at IP address of the camera.
Another solution is to use the Axis Companion application, which is good when using several cameras. In this test-case we use only one camera, so using Companion is probably overkill here.

PC screen with the CCTV monitoring software / web browser visible.
Login to the camera: The user needs to log in to the CCTV camera: (User: root, Password: CCTVfor5G-V). There you can configure the camera and present live view pictures from the camera.
The CCTV camera assumes by default to get an IP address via a DHCP server in the network.

- Test Case Steps:

Power on equipment (if needed).
Establish 5G connectivity between Train 5G mobile and Office apps.
Login to the camera
Start streaming moving pictures. Configure settings to e.g. reach 5 Mbps.
View result. The camera pictures can be configured with an overlay text which presents camera data like bitrate, frame rate, frame size, etc.
Optionally setup additional traffic between an office Performance End-point and IxProbe, with the purpose being able to view additional KPIs such as latency, and to view bitrates on different abstraction levels. Start streaming pictures
Remove 5G connectivity
Power down equipment
Check logs.

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</table>

Measurements	**- Methodology** 1. The Onboard CCTV camera sends pictures to the Office monitoring application (a simple web page, or the Axis Companion software). The Axis camera video stream bitrate is measured as the raw video payload stream, not including network transportation overhead protocols like UDP/TCP/HTTP. a. On-screen (configured video overlay text) measurements: This is the data sent by the Axis camera product. The Onscreen overlay text bitrate is the encoding driver bitrate averaged over the last 5 seconds, updated every second. b. Client stream information (e.g. the web-browser): This is the data received by the browser, where the web browser bitrate the last 1 second is presented. 2. The optional IxProbe hardware is connected onboard in-line next to the PoE switch, towards the office (assuming IxProbe can't convey PoE). See figure. IxProbe both monitors and generates traffic. The advantage with the IxProble is that some additional traffic (on top of the traffic sent by the CCTV camera) can be setup which enables efficient measurements of end-to-end latency etc, which the IxProbe supports to measure. The IxProbe communicates nicely with the Hawkeye Console. The office needs to use a Performance End-point, either a separate app or if supported by the Hawkeye console. 3. When the equipment is put on a train which passes Berlin Hbf many times per day and many days during a week, many weeks during a month, etc. Then the Hawkeye console can be used to monitor KPIs over time, do reporting, storing of data, etc. **- Complementary measurements** 1. If an optional tool like iPerf is used, it can be used for comparison. 2. If the IxProbe is used, the bitrate on different abstraction levels can be measured, e.g. codec bitrate or including UDP/IP, etc. **- Calculation process** 1. The bitrates described under Methodology are the CCTV codec bitrate. Overhead from UDP/IP etc transportation network protocols are added.
Expected Result	Nice looking CCTV pictures are expected on the monitoring screen.

6.3.4 RCCg03: CCTV streaming over 5G corresponding to twelve cameras (field)

CCTV streaming is here tested between the Berlin Train and the Berlin Office, using in total 12 cameras (max 60 Mbps).

- One real CCTV camera (max 5 Mbps).
- Eleven emulated CCTV cameras (max 55 Mbps).

This UC has an active 5G network in between the train and the office. The test case aims at showing that the 5G network can convey data corresponding to twelve CCTV cameras (real and emulated ones).

The IxProbe hardware is used for emulation and for checking additional KPIs that are not possible to extract from the real CCTV cameras itself.

IxProbe monitors traffic, inserts traffic, and communicates with the Console. The IxProbe has a Fail-to-wire functionality with internal relays, should its power fail.

The Hawkeye Console is used for controlling IxProbe traffic and monitor KPIs.

Table 6-6: RCCg03 - CCTV streaming over 5G corresponding to twelve cameras (field)

RCCg03	**CCTV streaming over 5G corresponding to twelve cameras (field)**
Testbed	**5GENESIS Berlin**
Description	The test-case connects the physical CCTV camera with the Office monitoring HW and APP equipment over the Berlin 5G cellular network. Additional 11 emulated camera streams are added by using IxProbe and the Hawkeye Concole. The purpose with the test-case is to show CCTV moving pictures conveyed from twelve cameras (on one or more trains), via the 5G cellular network, and monitored on the office CCTV monitoring application. This test-case is suitable for both lab and field tests.
Key UC requirements and KPIs	**U-FU-3141** (CCTV camera is put in the train driver's cab, pointing forward) **U-FU-3143** (CCTV monitoring software installed on office dispatcher terminal) **U-FU-3144** (CCTV monitoring software running on office dispatcher terminal KPIs: • CCTV mounted in Train driver's cab, inside window, looking forward. • CCTV applications installed. Note: The result is expected regardless of background traffic in the network.
Network performance requirements and KPIs	**F-PE-3241** (CCTV camera shall have access to 5 Mbps over the network) KPIs: • CCTV bitrate over network around 5 Mbps. • CCTV streaming latency 150 ms. • CCTV maximum packet loss ratio 0.5%. Note: The result is expected regardless of background traffic in the network.
Network Functional requirements and KPIs	**F-FU-3303** (at train power up, CCTV streaming shall start automatically) **F-FU-3304** (when 5G becomes available, CCTV shall come up over 5G) **F-FU-3305** (when train powers down, CCTV logs shall be available) **F-FU-3341** (check that CCTV camera Power of Ethernet (PoE) works fine) KPIs: • CCTV streaming starts when train powers up. • CCTV logs becomes available at train power down. • CCTV power over Ethernet works fine. Note: The result is expected regardless of background traffic in the network.

Components and configuration	**- Components:** 1. Onboard CCTV camera (Axis P3935-LR Network Camera) 2. Optional IxProbe (HW), this is powered via 230 VAC, max 10 W. The probe is here used for emulation of 11 CCTV cameras. 3. Onboard PoE Ethernet switch (PoE powers the camera) 4. Onboard Performance End-point (software app), or if an End-point functional can be supported by the Hawkeye Console. 5. 5G cellular network in between Onboard and Office. 6. Office PC computer (Dispatcher Terminal from Kontron), with a web browser logged in to the camera. 7. Office PC screen for showing CCTV monitoring pictures. 8. Office Hawkeye Console application, controlling the IxProbe. **- Configuration:** 1. The Onboard CCTV camera is connected via the PoE Ethernet switch to the onboard 5G cellular equipment. 2. The (optional) IxProbe (HW) is connected inline between the onboard PoE switch and the onboard 5G mobile, using RJ45 Ethernet cables. 3. CCTV monitoring software installed and running on the office computer (as we only have one camera, the monitoring tool could simply be a web browser logged in to the camera, where a live view is presented). 4. Configure the camera to stream with a bitrate of around 5 Mbps. This is done by configuring the camera to use only 1 P-frame (default for surveillance is else around 40 or so). 5. Configure 11 CCTV streams of 5 Mbps each (or one stream with 11 times the bitrate). This traffic goes between the IxProbe and a Performance End-point in the office (either an Ixia app download on the office computer or a functionality supported by the Hawkeye Console). 6. Optionally certificates can be given to the CCTV camera, which makes it possible to use HTTPS in the web browser.

<table>
<tr>
<td>Test procedure</td>
<td>
- Preconditions:
1. Onboard CCTV camera is powered and up and running.
2. Onboard IxProbe and Office Performance End-points.
3. 5G connectivity is up and running.
4. Dispatcher Terminal with CCTV monitoring software up and running.
    a. The CCTV monitoring software can simply be a web page pointing at IP address of the camera.
    b. Another solution is to use the Axis Companion application, which is good when using several cameras. In this test-case we use only one camera, so using Companion is probably overkill here.
5. PC screen with the CCTV monitoring software / web browser visible.
6. Login to the camera: The user needs to log in to the CCTV camera: (User: root, Password: CCTVfor5G-V). There you can configure the camera and present live view pictures from the camera.
7. The CCTV camera assumes by default to get an IP address via a DHCP server in the network.
- Test Case Steps:
1. Power on equipment (if needed).
2. Establish 5G connectivity between Train 5G mobile and Office apps.
3. Login to the camera.
4. Start streaming moving pictures. Configure settings to e.g. reach 5 Mbps.
5. Setup eleven emulated 5 Mbps CCTV streams between onboard IxProbe and an office Performance End-point (either 11 streams, or 11 times the bitrate on one stream).
6. View result. The camera pictures can be configured with an overlay text which presents camera data like bitrate, frame rate, frame size, etc.
7. Optionally setup additional traffic between an office Performance End-point and IxProbe, with the purpose being able to view additional KPIs such as latency, and to view bitrates on different abstraction levels. Start streaming pictures.
8. Remove 5G connectivity.
9. Power down equipment.
10. Check logs.
</td>
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</table>

Measurements	**- Methodology** 1. The Onboard CCTV camera sends pictures to the Office monitoring application (a simple web page, or the Axis Companion software). The Axis camera video stream bitrate is measured as the raw video payload stream, not including network transportation overhead protocols like UDP/TCP/HTTP. a. <u>On-screen (configured video overlay text) measurements:</u> This is the data sent by the Axis camera product. The Onscreen overlay text bitrate is the encoding driver bitrate averaged over the last 5 seconds, updated every second. b. <u>Client stream information (e.g. the web-browser):</u> This is the data received by the browser, where the web browser bitrate the last 1 second is presented. 2. The IxProbe hardware is connected onboard in-line next to the PoE switch, towards the office (assuming IxProbe can't convey PoE). See figure. IxProbe both monitors and generates traffic. The IxProble is here used to emulated 11 CCTV steams (on top of the traffic sent by the CCTV camera). The IxProbe communicates nicely with the Hawkeye Console. The office needs to use a Performance End-point, either a separate app or if supported by the Hawkeye console. 3. When the equipment is put on a train which passes Berlin Hbf many times per day and many days during a week, many weeks during a month, etc. Then the Hawkeye console can be used to monitor KPIs over time, do reporting, storing of data, etc. **- Complementary measurements** 1. If an optional tool like iPerf is used, it can be used for comparison. 2. If the IxProbe is used, the bitrate on different abstraction levels can be measured, e.g. codec bitrate or including UDP/IP, etc. **- Calculation process** 1. The bitrates described under Methodology are the CCTV codec bitrate. Overhead from UDP/IP etc transportation network protocols are added. 2. When the Hawkeye Console is used, KPIs can be monitored on different levels, reports can be extracted, traffic can be scheduled over time, etc.
Expected Result	Nice looking CCTV pictures are expected on the monitoring screen and via KPIs for this extended test-case emulating twelve CCTV 5 Mbps streams.

6.4 Rail Critical services Berlin Rail Telephony test cases (RCTg)

6.4.1 Description

The Rail Critical Telephony is performed between Berlin Office and Onboard Train using a set of on-train, mobile and fixed terminals running rail applications (voice, emergency call, data app and sensor app) communicating with each other by rail critical voice and critical/performance/business data sessions. The on-board, mobile and fixed devices with application are from Kontron Transportation while performance endpoint IxProbe used to monitor specific KPIs is from Keysight. Measured result are presented on the Keysight console.

For part of the testcases a specific Mission Critical Data service is used, which is called "MCData IPconn".

MCData IPconn provides generic IP level connectivity between two MCX Clients which can be used to transmit arbitrary IP data between two MCX Clients. This is a very powerful data service which allows any data service capable of using IP service used via the 3GPP Mission Critical Service Framework.

As MCData IPconn uses all the MCx native functions (e.g. for call setup, addressing, etc.) this IP service is fully embedded in the MCX Framework and thus a reliable IP service in the service domain for the rail critical environment.

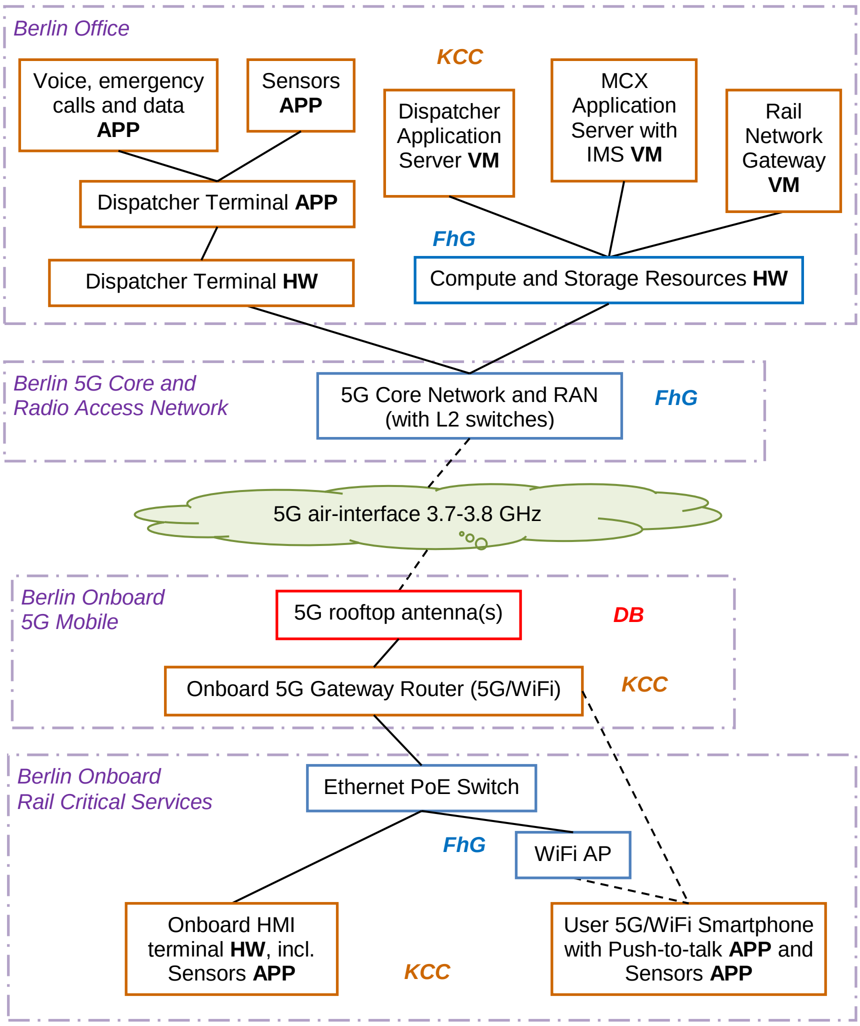


Figure 6-3: Rail Critical Services – Voice, Emergency calls, and Sensors data

6.4.2 RCTg01: On-train voice communication (lab & field)

Purpose with this test case is to examine on-train voice communication (bi-directional critical voice with PTT) between driver and responsible controller, initiated by driver or controller in 5G environment.

See the details for the on-train voice communication test case in Table 6-7.

Table 6-7: RCTg01 - On-train voice communication (lab & field)

RCTg01	**On-train voice communication (lab & field)**
Testbed	**5GENESIS Berlin**
Description	Purpose of the test case is to examine on-train voice communication (bi-directional critical voice with PTT) between driver and responsible controller, initiated by driver or controller in 5G environment.
Key Use-case requirements and KPIs	**U-FU-3161** (on-train voice comm.)
Network performance requirements and KPIs	**F-PE-3201** (isolation performance) **F-PE-3202** (mobility - train speed)
Network Functional requirements and KPIs	**F-FU-3301** (frequency band). **F-FU-3302** (network setup) **F-FU-3303** (on-board demo indicator) **F-FU-3304** (on-board 5G conn. Indicator) **F-FU-3305** (power down indicator)
Components and configuration	**- Components:** 1. on-board terminal or user handset with MCX app 2. on-board gateway 3. 5G transport network 4. MCX/FRMCS core 5. next-gen dispatcher. **- Configuration:** 1. provisioned MCX/FRMCS network and users (driver, controller) 2. 5G SIM cards
Test procedure	**- Preconditions:** 1. all systems up & running 2. all MCX/FRMCS clients are registered and authorized to use MCX/FRMCS services **- Test Case Steps:** 1. driver starts on-demand private call to a controller 2. call is received on dispatcher and accepted by the controller 3. voice call is active, check voice connection (*quality) 4. terminate voice call by driver or controller

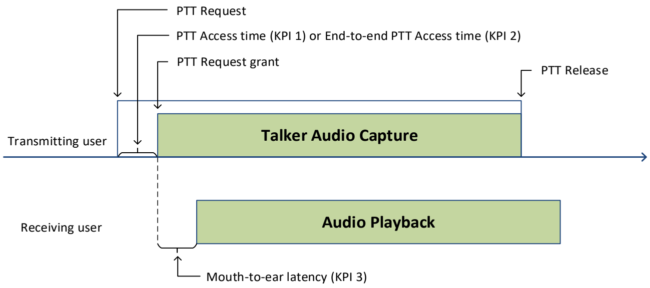
<table>
<tr>
<td>Measurements</td>
<td>

- **Methodology**

1. Latency: user data transport delay measured end-to-end between MCX/FRMCS clients.
2. Bandwidth: throughput speed measured on MCX/FRMCS client.
3. Reliability: packet loss measured at transport level on MCX/FRMCS client.
4. Setup time: duration of the communication session establishment on MCX/FRMCS client.
5. Speed: moving speed of on-train MCX/FRMCS client based on GNSS.

- **Complementary measurements**

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



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

- **Calculation process**

1. Latency: half of Round-Trip-Time measured and calculated by IxProbe.
2. Bandwidth: measured and calculated by IxProbe.
3. Reliability: packet loss measured and calculated by IxProbe.
4. Setup time: measured and calculated as MCPTT Access time.
5. Speed: GNSS speed calculation.
6. MCPTT Access time (cKPI1): measured time on MCX/FRMCS client using synchronized clock, see as well 3GPP TS 22.179 §16.5.3.
7. End-to-end MCPTT Access time (cKPI2): measured time on MCX/FRMCS client using synchronized clock, see as well 3GPP TS 22.179 §16.5.3.

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	8. Mouth-to-ear latency (cKPI3): measured time on MCX/FRMCS client using synchronized clock, see as well 3GPP TS 22.179 §16.5.3. 9. Late call entry (cKPI4): measured time on MCX/FRMCS client using synchronized clock, see as well 3GPP TS 22.179 §16.5.3. 10. Mean-Opinion-Score: measured for VoIP using G711 and calculated by IxProbe.
Expected Result	1. Voice call established successfully. 2. Voice connection stable. 3. Good voice quality.

6.4.3 RCTg02: Railway emergency (lab & field)

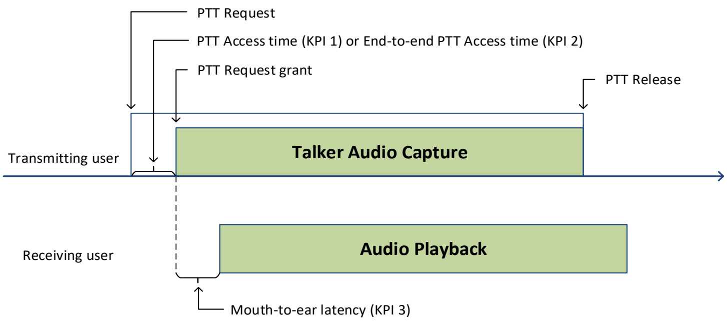
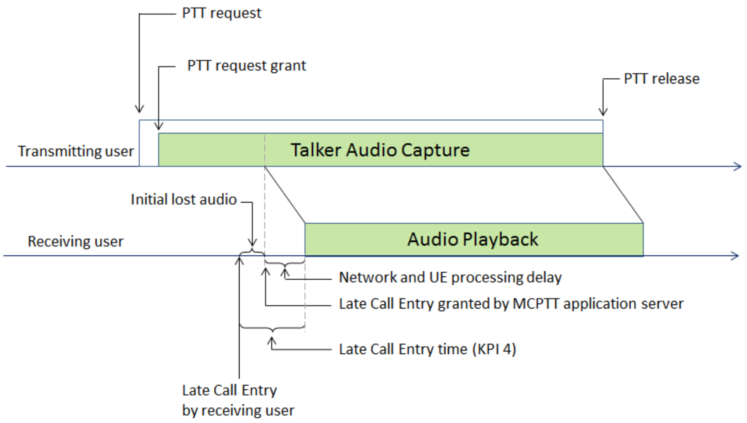
The purpose of this test-case is to examine and test the correct sending and reception of the Railway emergency alert, either voice and/or data alert which is triggered by authorized users.

The emergency voice test caser is found in Table 6-8.

Table 6-8: RCTg02 – Railway emergency (lab & field)

RCTg02	**Railway emergency (lab & field)**
Testbed	**5GENESIS Berlin**
Description	The purpose of this test-case is to examine and test the correct sending and reception of the Railway emergency alert, either voice and/or data alert which is triggered by authorized users.
Key Use-case requirements and KPIs	**U-FU-3162** (Railway emergency alert, voice and/or data)
Network performance requirements and KPIs	**F-PE-3201** (isolation performance) **F-PE-3202** (mobility - train speed)
Network Functional requirements and KPIs	**F-FU-3301** (frequency band). **F-FU-3302** (network setup). **F-FU-3303** (on-board demo indicator). **F-FU-3304** (on-board 5G conn. Indicator).
Components and configuration	**- Components:** 1. on-board terminal or user handset (Client A). 2. 2nd on-board terminal or user handset in different location area (Client B). 3. on-board gateway. 4. 5G transport network. 5. MCX/FRMCS core. 6. next-gen dispatcher. **- Configuration:** 1. provisioned MCX/FRMCS network and users (driver, controller). 2. 5G SIM cards. 3. configured location areas in MCX System.

Test procedure	**- Preconditions:** 1. all systems up & running. 2. all MCX/FRMCS clients are registered and authorized to use MCX/FRMCS services. 3. MCX/FRMCS has provisioned location areas. 4. MCX/FRMCS clients can receive location from 5G UE (5G UE location method is active e.g. via GPS). 5. at least one MCX client is operating in "high speed" environment (on-train). **- Test Case Steps:** 1. authorized user at Client A issues a "Railway emergency alert" via an MCX/FRMCS client: Variant 1: Voice only Railway emergency alert Variant 2: Data only Railway emergency alert Variant 3: Voice and Data Railway emergency alert 2. Railway emergency alert is automatically received on MCX/FRMCS clients (including Client B) in defined location area (could be including dispatcher client). 3. In Voice, Data or Voice/Data Railway emergency alert call is active, check voice connection (*quality). 4. terminate Railway emergency alert by authorized MCX client.

Measurements	**- Methodology** 1. Latency: user data transport delay measured end-to-end between MCX/FRMCS clients. 2. Bandwidth: throughput speed measured on MCX/FRMCS client. 3. Reliability: packet loss measured at transport level on MCX/FRMCS client. 4. Setup time: duration of the communication session establishment on MCX/FRMCS client. 5. Speed: moving speed of on-train MCX/FRMCS client based on GNSS. **- Complementary measurements** 1. MCPTT Access time (cKPI1): time between when a user of MCX/FRMCS client requests to speak (normally by pressing MCPTT control) and when this user gets a signal to start speaking. This time does not include confirmations from receiving users and affiliation but does include call setup request and potentially bearer establishment. It's applicable on both call setup request and subsequent MCPTT request that are part of the same call. 2. End-to-end MCPTT Access time (cKPI2): time between when an user of MCX/FRMCS client requests to speak (normally by pressing the MCPTT control) and when this user gets a signal to start speaking, including MCPTT call establishment (if applicable) and possibly acknowledgement from first receiving user before voice can be transmitted. For MCPTT Private Calls (with Floor control), end-to-end MCPTT Access time (also KPI 2) is measured from the initiating client's Private call request to reception of either a Private Call response for automatic commencement or the MCPTT ringing indication for manual commencement. 3. Mouth-to-ear latency (cKPI3): time between an utterance by the transmitting user, and the playback of the utterance at the receiving user's speaker.  

	- **Calculation process** 1. Latency: half of Round-Trip-Time measured and calculated by IxProbe 2. Bandwidth: measured and calculated by IxProbe 3. Reliability: packet loss measured and calculated by IxProbe 4. Setup time: measured and calculated as MCPTT Access time 5. Speed: GNSS speed calculation 6. MCPTT Access time (cKPI1): measured time on MCX/FRMCS client using synchronized clock, see as well 3GPP TS 22.179 §16.5.3 7. End-to-end MCPTT Access time (cKPI2): measured time on MCX/FRMCS client using synchronized clock, see as well 3GPP TS 22.179 §16.5.3 8. Mouth-to-ear latency (cKPI3): measured time on MCX/FRMCS client using synchronized clock, see as well 3GPP TS 22.179 §16.5.3 9. Mean-Opinion-Score: measured for VoIP using G711 and calculated by IxProbe
Expected Result	1. Voice call established successfully 2. Voice connection stable 3. Call setup time is within "immediate setup" KPI range 4. Good voice quality 5. Stable data connection (for Data calls)

6.4.4 RCTg03: Co-existence and isolation of contending rail application categories (lab & field)

The purpose of this test-case is to examine capabilities of application (MCX/FRMCS application), service (MCX/FRMCS service) and transport stratum (5G network) to guarantee isolation and communication quality level of each critical, performance and business rail applications.

See the details outlined in Table 6-9.

Table 6-9: RCTg03 - Co-existence and isolation of contending rail application categories (lab & field)

RCTg03	**Co-existence and isolation of contending rail application categories (lab & field)**
Testbed	**5GENESIS Berlin**
Description	The purpose of this test-case is to examine capabilities of application (MCX/FRMCS application), service (MCX/FRMCS service) and transport stratum (5G network) to guarantee isolation and communication quality level of each critical, performance and business rail applications.
Key Use-case requirements and KPIs	**U-FU-3164** (contending applications)
Network performance requirements and KPIs	**F-PE-3201** (isolation performance) **F-PE-3202** (mobility - train speed)

Network Functional requirements and KPIs	**F-FU-3301** (frequency band). **F-FU-3302** (network setup) **F-FU-3303** (on-board demo indicator) **F-FU-3304** (on-board 5G conn. Indicator) **F-FU-3305** (power down indicator)
Components and configuration	**- Components:** 1. on-board terminal or user handset with MCX app (critical cat. in rail VSI, critical NSI). 2. on-board gateway. 3. 5G transport network. 4. MCX/FRMCS core. 5. next-gen dispatcher. 6. sensor app (performance cat. from rail VSI, performance NSI). 7. media app (business cat. from media VSI). **- Configuration:** 1. provisioned MCX/FRMCS network and users (driver, controller). 2. 5G SIM cards.
Test procedure	**- Preconditions:** 1. all systems up & running, as well apps (MCX app, sensor app, media app) from all categories (critical, performance, business). 2. all MCX/FRMCS clients are registered and authorized to use MCX/FRMCS services. 3. 5G transport network can provide internet access. **- Test Case Steps:** 1. media app stream/download starts to consume whole transport capacity of the 5G network 2. sensor app starts to provide performance data to the backoffice 3. OBG is directing sensor traffic through rail performance 5G NSI 4. 5G network recognizes bottleneck in rail NSI and re-assigns resource from media VSI to rail performance NSI 5. driver starts emergency group call 6. bandwidth/QoS bottleneck is recognized by the 5G transport network and resources are reassigned to fulfill QoS of critical cat. in rail critical NSI 7. emergency call is alerted and automatically received in auto-commencement mode by all impacted users in area 8. emergency call is active, check voice connection (*quality) 9. terminate emergency call by driver 10. freed resources of the rail critical NSI are made available to other contending VSI/NSI

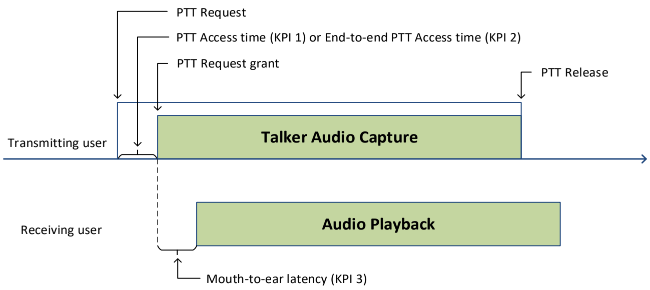
<table>
<tr>
<td>Measurements</td>
<td>

- Methodology

1. Latency: user data transport delay measured end-to-end between MCX/FRMCS clients
2. Bandwidth: throughput speed measured on MCX/FRMCS client
3. Reliability: packet loss measured at transport level on MCX/FRMCS client
4. Setup time: duration of the communication session establishment on MCX/FRMCS client
5. Speed: moving speed of on-train MCX/FRMCS client based on GNSS

- Complementary measurements

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



4. Late call entry (cKPI4): time to enter an ongoing MCPTT Group call measured from the time that a user decides to monitor such an MCPTT Group Call, to the time when the MCPTT UE's speaker starts to play the audio. The performance requirements for Late call entry time only applies to when there is ongoing voice transmitted at the time the MCPTT User joins the call.

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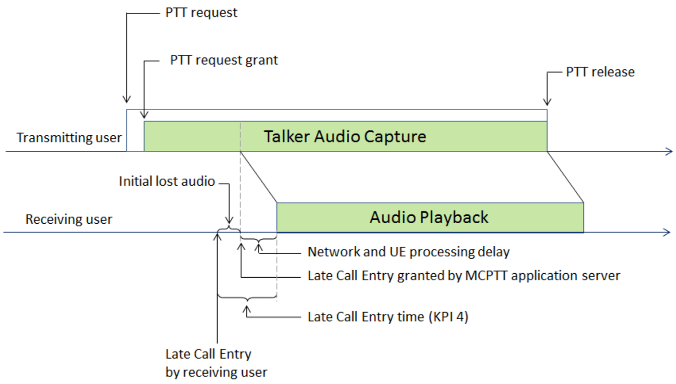
	 5. Mean-Opinion Score voice quality: QoE for voice calls - **Calculation process** 1. Latency: half of Round-Trip-Time measured and calculated by IxProbe 2. Bandwidth: measured and calculated by IxProbe 3. Reliability: packet loss measured and calculated by IxProbe 4. Setup time: measured and calculated as MCPTT Access time 5. Speed: GNSS speed calculation 6. MCPTT Access time (cKPI1): measured time on MCX/FRMCS client using synchronized clock, see as well 3GPP TS 22.179 §16.5.3 7. End-to-end MCPTT Access time (cKPI2): measured time on MCX/FRMCS client using synchronized clock, see as well 3GPP TS 22.179 §16.5.3 8. Mouth-to-ear latency (cKPI3): measured time on MCX/FRMCS client using synchronized clock, see as well 3GPP TS 22.179 §16.5.3 9. Late call entry (cKPI4): measured time on MCX/FRMCS client using synchronized clock, see as well 3GPP TS 22.179 §16.5.3 Mean-Opinion-Score: measured for VoIP using G711 and calculated by IxProbe
Expected Result	1. Emergency call is immediately established successfully. 2. Voice connection stable. 3. Good voice quality. 4. 5G network manages the resource and app. cat. isolation successfully.

6.4.5 RCTg04: Continuity of railway critical services and seamless transition between networks (lab & field)

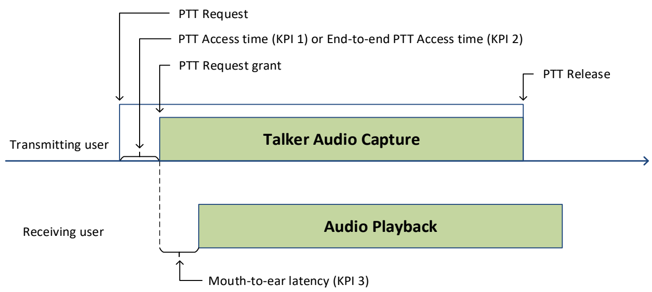
The purpose of this test-case is to examine and check the correct transition between two 5G networks without interruption of rail critical services and application usage.

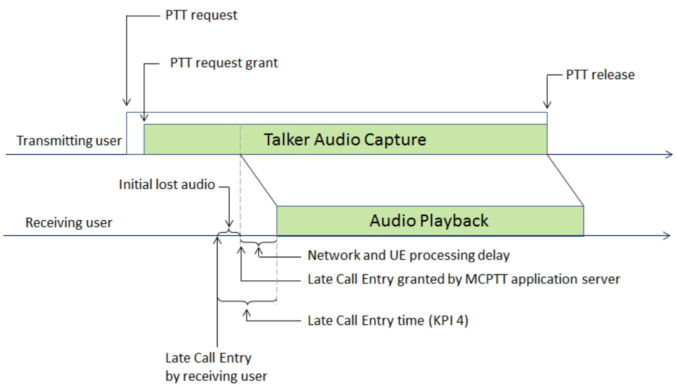
The test case for evaluation of voice quality during 5G connectivity, including handovers, is included in Table 6-10.

Table 6-10: RCTg04 - Continuity of railway critical services and seamless transition between networks (lab & field)

RCTg04	**Continuity of railway critical services and seamless transition between networks (lab & field)**
Testbed	**5GENESIS Berlin**
Description	The purpose of this test-case is to examine and check correct transition between two 5G networks without interruption of rail critical services and application usage.
Key Use-case requirements and KPIs	**U-FU-316**5 (5G network transition)
Network performance requirements and KPIs	**F-PE-3201** (isolation performance) **F-PE-3202** (mobility - train speed)
Network Functional requirements and KPIs	**F-FU-3301** (frequency band). **F-FU-3302** (network setup) **F-FU-3303** (on-board demo indicator) **F-FU-3304** (on-board 5G conn. Indicator)
Components and configuration	**- Components:** 1. on-board terminal A (or user handset). 2. on-board terminal B (or user handset). 3. on-board gateway. 4. 5G transport network A. 5. 5G transport network B. 6. MCX/FRMCS core. 7. next-gen dispatcher. **- Configuration:** 1. provisioned MCX/FRCMS network and users (driver, controller). 2. 5G SIM cards, activated and provisioned for 5G transport network A and 5G transport network B. 3. 5G transport network A and 5G transport network B have a significant overlapping region in radio coverage.

Test procedure	**- Preconditions:** 1. all systems up & running 2. MCX/FRMCS client A is registered and authorized to use MCX/FRMCS services via 5G network A 2a - MCX/FRMCS client B is registered and authorized to use MCX/FRMCS services via 5G network B *3 - at least one MCX client is operating in "high speed" environment (on-train) (field only) – the highest possible speed for demo purposes. **- Test Case Steps:** 1. MCX/FRMCS onboard client attached to 5G network A starts an Private Point-to-Point call to dispatcher client (via terminal A). *1a - Variant 1: MCX/FRMC onboard client attached to 5G network A starts a Group call including Dispatcher MCX/FRMCS client. 2. In Voice, Data or Voice/Data Railway emergency alert call is active, check voice connection (*quality). 3. on-board client located on moving train crosses the 5G network overlapping region between 5G transport network A and 5G transport network B. 4. on-board terminal B gets connection to 5G transport network B while moving. 5. on-board terminal A loses connection to 5G transport network A. 6. terminate Railway emergency alert by authorized MCX client while on-board terminal B has connection to 5G transport network B.

Measurements	**- Methodology** 1. Latency: user data transport delay measured end-to-end between MCX/FRMCS clients 2. Bandwidth: throughput speed measured on MCX/FRMCS client 3. Reliability: packet loss measured at transport level on MCX/FRMCS client 4. Setup time: duration of the communication session establishment on MCX/FRMCS client 5. Speed: moving speed of on-train MCX/FRMCS client based on GNSS 6. Continuity: checking continuity of rail critical service during transition between FRMCS networks observed by user and measured interruption of audio transmission in voice call **- Complementary measurements** 1. MCPTT Access time (cKPI1): time between when an user of MCX/FRMCS client requests to speak (normally by pressing MCPTT control) and when this user gets a signal to start speaking. This time does not include confirmations from receiving users, affiliation but does include call setup request and potentially bearer establishment. It's applicable on both call setup request and subsequent MCPTT request that are part of the same call. 2. End-to-end MCPTT Access time (cKPI2): time between when an user of MCX/FRMCS client requests to speak (normally by pressing the MCPTT control) and when this user gets a signal to start speaking, including MCPTT call establishment (if applicable) and possibly acknowledgement from first receiving user before voice can be transmitted. For MCPTT Private Calls (with Floor control), end-to-end MCPTT Access time (also KPI 2) is measured from the initiating client's Private call request to reception of either a Private Call response for automatic commencement or the MCPTT ringing indication for manual commencement. 3. Mouth-to-ear latency (cKPI3): time between an utterance by the transmitting user, and the playback of the utterance at the receiving user's speaker.  4. Late call entry (cKPI4): time to enter an ongoing MCPTT Group call measured from the time that a user decides to monitor such an MCPTT Group Call, to the time when the MCPTT UE's speaker starts to play the audio. The performance requirements for Late call entry time only applies to when there is ongoing voice transmitted at the time the MCPTT User joins the call.

	 5. Mean-Opinion Score voice quality: QoE for voice calls - **Calculation process** 1. Latency: half of Round-Trip-Time measured and calculated by IxProbe 2. Bandwidth: measured and calculated by IxProbe 3. Reliability: packet loss measured and calculated by IxProbe 4. Setup time: measured and calculated as MCPTT Access time 5. Speed: GNSS speed calculation 6. MCPTT Access time (cKPI1): measured time on MCX/FRMCS client using synchronized clock, see as well 3GPP TS 22.179 §16.5.3 7. End-to-end MCPTT Access time (cKPI2): measured time on MCX/FRMCS client using synchronized clock, see as well 3GPP TS 22.179 §16.5.3 8. Mouth-to-ear latency (cKPI3): measured time on MCX/FRMCS client using synchronized clock, see as well 3GPP TS 22.179 §16.5.3 9. Late call entry (cKPI4): measured time on MCX/FRMCS client using synchronized clock, see as well 3GPP TS 22.179 §16.5.3 10. Mean-Opinion-Score: measured for VoIP using G711 and calculated by IxProbe 11. Continuity: measure time while continuously transmitted audio is interrupted on receiving MCX client.
Expected Result	1. Voice call established successfully 2. Voice connection stable 3. Voice call connection stable during 5G network transition period *4 - Voice call connection has good voice quality during 5G network transition period

6.4.6 RCTg05: Critical data applications for railways (lab)

The purpose of this test case is to test mission critical reliable data transfer between communication endpoints (MCX/FRMCS application) using IP data transfer.

Table 6-11: RCTg05 - Critical data applications for railways (lab)

RCTg05	**Critical data applications for railways (lab)**
Testbed	**5GENESIS Berlin**
Description	The purpose of the test case is to test mission critical reliable data transfer between communication endpoints (MCX/FRMCS application) using IP data transfer.
Key Use-case requirements and KPIs	**U-FU-3166** (Critical Data application).
Network performance requirements and KPIs	**F-PE-3203** (bitrate around 200 kbps). **F-PE-3202** (mobility - train speed).
Network Functional requirements and KPIs	**F-FU-3301** (frequency band). **F-FU-3302** (network setup). **F-FU-3303** (on-board demo indicator). **F-FU-3304** (on-board 5G conn. indicator).
Components and configuration	**- Components:** 1. on-board terminal or user handset (Client A) 2. data server at fixed network attached with FRMCS client 3. on-board gateway 4. 5G transport network MCX/FRMCS core **- Configuration:** 1. provisioned MCX/FRMCS network and users (driver, controller) 2. 5G SIM cards
Test procedure	**- Preconditions:** 1. all systems up & running. 2. all MCX/FRMCS clients are registered and authorised to use MCX/FRMCS services. 3. MCX/FRMCS client onboard (Client A) have IP connection to data source/sink (e.g. on-board GW or Laptop). 4. fixed network MCX/FRMCS client (Client B) has IP connection to data source/sink (e.g. ftp server, ...) 5. at least one MCX client is operating in "high speed" environment (on-train). **- Test Case Steps:** 1. Authorized user at Client A issues a "MCData IPconn call" via an MCX/FRMCS client 1. MCData IPconn request is received on MCX/FRMCS client (Client B)

	2. In MCData IPconn Data connection is established, 3. Transmit test data via MCData IPconn connection (e.g. iPerf or FTP down/uploads) 4. Terminate MCData IPconn connection by authorized MCX client
Measurements	- **Methodology** 1. Latency: user data transport delay measured end-to-end between MCX/FRMCS clients. 2. Bandwidth: throughput speed measured on MCX/FRMCS client. 3. Reliability: packet loss measured at transport level on MCX/FRMCS client. 4. Immediate setup: duration of the immediate communication session establishment on MCX/FRMCS client. 5. Speed: moving speed of on-train MCX/FRMCS client based on GNSS. - **Complementary measurements** N/A - **Calculation process** 1. Latency: half of Round-Trip-Time measured and calculated by IxProbe. 2. Bandwidth: measured and calculated by IxProbe. 3. Reliability: packet loss measured and calculated by IxProbe. 4. Setup time: measured and calculated as MCPTT Access time. 5. Speed: GNSS speed calculation.
Expected Result	1. MCData IPconn call established successfully. 2. MCData IPconn connection stable. 3. MCData IPconn connection has sufficient bitrate. 4. MCData IPconn connection meets latency/delay requirements.

6.4.7 RCTg06: Performance data applications for railways with MCData IPconn (lab & field)

The purpose with this test case is to test data transfer between communication endpoints of MCX/FRMCS performance category application such as driver’s time table using MCData IPconn data transfer.

The test case details are captured in Table 6-12.

Table 6-12: RCTg06 - Performance data applications for railways with MCData IPconn (lab & field)

RCTg06	**Performance data applications for railways with MCData IPconn (lab & field)**
Testbed	**5GENESIS Berlin**
Description	The purpose with this test case is to test data transfer between communication endpoints (MCX/FRMCS application of performance category such as driver's time table) using MCData IPconn data transfer.

Key Use-case requirements and KPIs	**U-FU-3168** (performance data application)
Network performance requirements and KPIs	**F-PE-3202** (mobility - train speed)
Network Functional requirements and KPIs	**F-FU-3301** (frequency band). **F-FU-3302** (network setup) **F-FU-3303** (on-board demo indicator) **F-FU-3304** (on-board 5G conn. indicator)
Components and configuration	**- Components:** 1. on-board terminal or user handset with performance function (Client A). 2. data server at fixed network attached with FRMCS client. 3. on-board gateway. 4. 5G transport network. 5. MCX/FRMCS core. **- Configuration:** 1. provisioned MCX/FRMCS network and users (driver, controller). 2. 5G SIM cards.
Test procedure	**- Preconditions:** 1. all systems up & running. 2. all MCX/FRMCS clients are registered and authorised to use MCX/FRMCS services. 3. MCX/FRMCS client onboard with performance function (Client A) has IP connection to data source/sink (e.g. on-board GW or Laptop). 4. fixed network MCX/FRMCS client (Client B) has IP connection to data source/sink (e.g. FTP server, ...). 5. at least one MCX client is operating in "high speed" environment (on-train). 6. priority and session's QoS for MCX Users should be applicable for performance application category. **- Test Case Steps:** 1. authorized user at Client A issues a "MCData IPconn request" via an MCX/FRMCS client on behalf of performance function on Client A. 2. MCData IPconn request is received on MCX/FRMCS client (Client B) which is performance sink/source. 3. In MCData IPconn Data call is established. 4. Transmit test data via MCData IPconn connection (e.g. iPerf or FTP down/uploads). 5. terminate MCData IPconn connection by authorized MCX client.

Measurements	**- Methodology** 1. Latency: user data transport delay measured end-to-end between MCX/FRMCS clients. 2. Bandwidth: throughput speed measured on MCX/FRMCS client. 3. Reliability: packet loss measured at transport level on MCX/FRMCS client. 4. Immediate setup: duration of the immediate communication session establishment on MCX/FRMCS client. 5. Speed: moving speed of on-train MCX/FRMCS client based on GNSS. **- Complementary measurements** N/A **- Calculation process** 1. Latency: half of Round-Trip-Time measured and calculated by IxProbe. 2. Bandwidth: measured and calculated by IxProbe. 3. Reliability: packet loss measured and calculated by IxProbe. 4. Setup time: measured and calculated as MCPTT Access time. 5. Speed: GNSS speed calculation.
Expected Result	1. MCData IPconn call established successfully 2. MCData IPconn connection stable 3. MCData IPconn connection has sufficient bitrate corresponding to performance application category 4. MCData IPconn connection meets latency/delay requirements corresponding to performance application category

6.4.8 RCTg07: Business data app for railways with 5G Data incl passenger Media transfer (lab & field)

The purpose of the this test case is to test data transfer between communication endpoints (data clients or apps) using standard 5G IP data transfer for both Media transfer and business data (e.g. passenger information service) using standard IP transfer via the onboard gateway.

For the business applications stability test case details, see Table 6-13.

Table 6-13: RCTg07 - Business data applications for railways with standard 5G Data including parallel passenger Media transfer (lab & field)

RCTg07	**Business data applications for railways with standard 5G Data including parallel passenger Media transfer (lab & field)**
Testbed	**5GENESIS Berlin**
Description	The purpose of the this test case is to test data transfer between communication endpoints (data clients or apps) using standard 5G IP data transfer for both Media transfer and business data (e.g. passenger information service) using standard IP transfer via the onboard gateway.
Key Use-case requirements and KPIs	**U-FU-3169** (business data application)

Network performance requirements and KPIs	**F-PE-3202** (mobility - train speed)
Network Functional requirements and KPIs	**F-FU-3301** (frequency band). **F-FU-3302** (network setup) **F-FU-3303** (on-board demo indicator) **F-FU-3304** (on-board 5G conn. Indicator)
Components and configuration	**- Components:** 1. on-board terminal or user handset 2. on-board gateway 3. 5G transport network **- Configuration:** 1. 5G SIM cards
Test procedure	**- Preconditions:** 1. all systems up & running, as well apps (media app) and IP connectivity to onboard gateway. 2. business application category's QoS settings for both applications applied 3. 5G transport network can provide internet access. 4. media app (business cat. from media VSI). **- Test Case Steps:** 1. media app stream/download start to consume whole transport capacity of the 5G network 2. business data IP transmission starts providing IP connectivity data to the backoffice (e.g. for passenger information) via the OBG 3. OBG is directing passenger information to business IP data stream 4. parallel IP streams running with no specific QoS 5. end transmission of both media app and business IP stream
Measurements	- **Methodology** 1. Latency: user data transport delay measured end-to-end between MCX/FRMCS clients 2. Bandwidth: throughput speed measured on MCX/FRMCS client 3. Reliability: packet loss measured at transport level on MCX/FRMCS client 4. Immediate setup: duration of the immediate communication session establishment on MCX/FRMCS client 5. Speed: moving speed of on-train MCX/FRMCS client based on GNSS - **Complementary measurements** N/A - **Calculation process** 1. Latency: half of Round-Trip-Time measured and calculated by IxProbe 2. Bandwidth: measured and calculated by IxProbe 3. Reliability: packet loss measured and calculated by IxProbe 4. Setup time: measured and calculated as MCPTT Access time 5. Speed: GNSS speed calculation

Expected Result	1. media App streams continuously. 2. business data connection stable. 3. verify IP throughput and latency of business data connection. 4. OBG successfully recognizes application category and routes its traffic corresponding to the right IP connection (for business data connection).

6.4.9 RCTg08: Performance data railway apps with MCData FD incl passenger Media transfer (lab & field)

The purpose of with this test case is to test performance data transfer between communication endpoints (data clients) using MCData FD with parallel standard 5G IP data transfer for Media transfer.

The Mission Critical Data related test case is found in Table 6-14.

Table 6-14: RCTg01 - Performance data applications for railways with MCData FD including parallel passenger Media transfer (lab & filed)

RCTg01	**Performance data applications for railways with MCData FD including parallel passenger Media transfer (lab & field)**
Testbed	**5GENESIS Berlin**
Description	The purpose with this test case is to test performance data transfer between communication endpoints (data clients) using MCData FD with parallel standard 5G IP data transfer for Media transfer
Key Use-case requirements and KPIs	**U-FU-3168** (Performance Data Application)
Network performance requirements and KPIs	**F-PE-3201** (isolation performance) **F-PE-3202** (mobility - train speed) **F-PE-3203** (bitrate around 200 kbps)
Network Functional requirements and KPIs	**F-FU-3301** (frequency band). **F-FU-3302** (network setup) **F-FU-3303** (on-board demo indicator) **F-FU-3304** (on-board 5G conn. indicator)
Components and configuration	**- Components:** 1. on-board terminal or user handset with MCXapp (critical cat. in rail VSI, critical NSI) 2. on-board gateway (OBG) 3. 5G transport network 4. MCX/FRMCS core 5. next-gen dispatcher 6. Performance Data File (performance cat. from rail VSI, performance NSI) 7. media app (business cat. from media VSI) **- Configuration:** 1. provisioned MCX/FRMCS network and users (driver, controller) 2. 5G SIM cards

Test procedure	**- Preconditions:** 1. all systems up & running, as well apps (MCX app, media app) from categories (performance, business). 2. all MCX/FRMCS clients are registered and authorised to use MCX/FRMCS services. 3. 5G transport network can provide internet access. **- Test Case Steps:** 1. Media app stream/download start to consume whole transport capacity of the 5G network. 2. MCData Dispatcher file app starts providing performance large data to the backoffice. 3. MCData client receives large file via MCData FD service. 4. MCData serve should receive priority compared to Media app.
Measurements	**- Methodology** 1. The Timestamp of the outgoing File Transfer (Start of Transfer) at Client A should be captured either directly in the MCX Client (logging) or on the MCX Client Interface via tracing. 2. The Time stamp of the reception of the File Transfer (End of complete File Transfer) at Client B should be captured either directly in the MCX Client (logging) or at the MCX Client to network interface via tracing. **- Complementary measurements** 1. Calculate the average data throughput for the File Transfer or using IxProbe based measurements. **- Calculation process** 1. Calculate the difference between reception File timestamp at Client B and transmitting File timestamp at Client A. 2. Calculate the average data throughput from the file size and the time difference from Step 1.
Expected Result	1. Media App successfully started media stream. 2. MCData File transfer downloaded with high Priority. 3. *Check degraded bitrate at Media App during MCData File Transfer. **KPI:** According to 3GPP TS 22.289, V17.0.0, Table 5.2.2-1 “Performance requirements for rail scenarios – main line” the End-to-End latency for messaging is not defined. As Alternative the throughput for File Transfer for MCData FD Service can be used. According to 3GPP TS 22.289, V17.0.0, Table 5.2.2-1 the User experienced data rate should be min 100 kbps.

6.5 Rail Critical services Berlin Sensor Data test cases (RCDg)

6.5.1 Description

The Rail Critical Sensor Data test cases are performed between Berlin Office and Onboard Train using a set of on-train, mobile and fixed terminals running sensor data application, which are communicating with each other by rail critical/performance/business data sessions.

The on-board mobile and fixed devices with application are from Kontron Transportation while performance endpoint IxProbe used to monitor specific KPIs is from Keysight. Measured result are presented on the Keysight console.

6.5.2 RCDg01: Sensor Data transmission via MCData SDS - one-to-one (lab & field)

The purpose with the test case is to test mission critical reliable data transfer between communication endpoints (MCX/FRMCS application) using mission critical SDS data transfer. - one to one connection.

Table 6-15: RCDg01 - Sensor Data transmission via MCData SDS - One-to-One (lab & field)

RCDg01	Sensor Data transmission via MCData SDS - one-to-one (lab & field)
Testbed	**5GENESIS Berlin**
Description	The purpose of this test case is test mission critical reliable data transfer of sensor data between communication endpoints (MCX/FRMCS application) using mission critical SDS data transfer - one to one connection.
Key Use-case requirements and KPIs	**U-FU-3167** (monitoring and controlling critical infrastructure)
Network performance requirements and KPIs	**F-PE-3202** (mobility - train speed) **F-PE-3203** (bitrate around 200 kbps)
Network Functional requirements and KPIs	**F-FU-3301** (frequency band). **F-FU-3302** (network setup) **F-FU-3303** (on-board demo indicator) **F-FU-3304** (on-board 5G conn. indicator)
Components and configuration	**- Components:** 1. on-board terminal or user handset (Client A). 2. dispatcher terminal fixed network attached with FRMCS client. 3. on-board gateway. 4. 5G transport network. 5. MCX/FRMCS core. **- Configuration:** 1. provisioned MCX/FRMCS network and users (driver, controller). 2. 5G SIM cards. 3. Static/dynamic mapping of the SIP identity (i.e. IMPU) vs. mcdata_id

<table>
<tr><td>Test procedure</td><td>- Preconditions:
1. all systems up & running.
2. all MCX/FRMCS clients are registered and authorized to use MCX/FRMCS services.
3. MCX/FRMCS client onboard (Client A) ready to send Sensor data via SDS.
4. fixed network MCX/FRMCS client (Client B, dispatcher client) ready to receive sensor data via SDS.
5. at least one MCX client is operating in "high speed" environment (on-train).
- Test Case Steps:
1. authorized user at Client A sends a multipart SIP.
2. message encapsulating a standalone one-to-one SDS User 2.
3. SDS one-to-one standalone message received by Client B.</td></tr>
<tr><td>Measurements</td><td>- Methodology
1. The Timestamp of the outgoing SDS at Client A should be captured either directly in the MCX Client (logging) or on the MCX Client Interface via tracing.
2. The Time stamp of the reception of the SDS at Client B should be captured either directly in the MCX Client (logging) or at the MCX Client to network interface via tracing.
- Complementary measurements
1. Using IxProbe based measurements for calculating the SDS delay.
- Calculation process
1. Calculate the difference between reception SDS timestamp at Client B and transmitting SDS timestamp at Client A.</td></tr>
<tr><td>Expected Result</td><td>1. SDS Message successfully send from Client A
2. SIP message arrives at originating participating
a. SIP message forwarded from the originating to the controlling.
b. Controlling sends back 202.
c. SIP message forwarded from the controlling to the terminating.
3. SDS one-to-one standalone message properly received and decoded by Client B
KPI: According to 3GPP TS 22.289, V17.0.0, Table 5.2.2-1 “Performance requirements for rail scenarios – main line” the End-to-End latency for messaging is not defined. However, we propose to use the Target of End-to-End Latency for “Critical Data communication,” which should be ≤ 500 ms.</td></tr>
</table>

6.5.3 RCDg02: Performance Data transmission via MCData FD one-to-one via HTTP (lab & field)

The purpose with this test case is to test mission critical reliable data transfer between communication endpoints (MCX/FRMCS application) using mission critical File Distribution (FD) data transfer - One to One connection – via HTTP file distribution.

For the File Distribution test case details, see Table 6-16.

Table 6-16: RCDg02 - Performance Data transmission via MCData SDS - One-to-One (lab & field)

RCDg02	**Performance Data transmission via MCData SDS - one-to-one (lab & field)**
Testbed	**5GENESIS Berlin**
Description	The purpose with this test case is to test mission critical reliable data transfer between communication endpoints (MCX/FRMCS application) using mission critical FD data transfer - One to One connection - via HTTP file distribution.
Key Use-case requirements and KPIs	**U-FU-3168** (performance data application)
Network performance requirements and KPIs	**F-PE-3202** (mobility - train speed) **F-PE-3203** (bitrate around 200kbps)
Network Functional requirements and KPIs	**F-FU-3301** (frequency band). **F-FU-3302** (network setup) **F-FU-3303** (on-board demo indicator) **F-FU-3304** (on-board 5G conn. indicator)
Components and configuration	**- Components:** 1. on-board terminal or user handset (Client A) 2. dispatcher terminal fixed network attached with FRMCS client 3. on-board gateway 4. 5G transport network 5. MCX/FRMCS core **- Configuration:** 1. Provisioned MCX/FRCMS network and users (driver, controller) 2. 5G SIM cards 3. Static/dynamic mapping of the SIP identity (i.e. IMPU) vs. mcdata_id
Test procedure	**- Preconditions:** 1. All systems up & running. 2. All MCX/FRMCS clients are registered and authorised to use MCX/FRMCS services. 3. MCX/FRMCS client onboard (Client A) ready to send Performance data via SDS. 4. Fixed network MCX/FRMCS client (Client B, dispatcher client) ready to receive sensor data via MCData FD. 5. At least one MCX client is operating in "high speed" environment (on-train). **- Test Case Steps:** 1. Authorized user at Client A sends a file to Client B. 2. Waiting for download link at Client B to finish. 3. Client B starts to download the file.

<table>
<tr>
<td>Measurements</td>
<td>
- Methodology

The Timestamp of the outgoing File Transfer (Start of Transfer) at Client A should be captured either directly in the MCX Client (logging) or on the MCX Client Interface via tracing.
The Time stamp of the reception of the File Transfer (End of complete File Transfer) at Client B should be captured either directly in the MCX Client (logging) or at the MCX Client to network interface via tracing.

- Complementary measurements

Calculate the average data throughput for the File Transfer or calculate the file throughput with IxProbe measurement.

- Calculation process

Calculate the difference between reception File timestamp at Client B and transmitting File timestamp at Client A.
Calculate the average data throughput from the file size and the time difference from Step 1.

</td>
</tr>
</table>

Expected Result	1. check MCData client tries to discover the absolute URI for the file START of optional part 2. needs specific access to servers and analyzers -- 3. check MESSAGE received at the orig. MCData participating server 4. check The participating server adapts the mcdata-info accordingly and creates a 5. MESSAGE to the controlling server 6. check MESSAGE received at the MCData controlling server 7. check The MSF function within the MCData controlling server creates the URL for 8. the file and responds with another MESSAGE 9. check MESSAGE received at the orig. MCData participating server 10. check MESSAGE received at the first MCData client 11. check MCData client establishes a secure connection with HTTP proxy and uploads the file using HTTP POST 12. check HTTP proxy forwards the file to the MSF 13. check MCData client sends an invitation for downloading the file to the other user 14. with a SIP MESSAGE 15. check MESSAGE received at the orig. MCData participating server 16. check The participating server adapts the mcdata-info accordingly and creates a 17. MESSAGE to the controlling 18. check MESSAGE received at the MCData controlling server 19. check The controlling server checks permissions and forwards the MESSAGE to 20. the participating server of the callee END of optional part 21. check Upon arrival of the MESSAGE adapted by the terminating function. 22. the terminating Client User 2 is notified. 23. after action "User 2 wants to download the file". 24. check MCData client establishes a secure connection with the HTTP proxy and downloads the file using HTTP GET. **KPI:** According to 3GPP TS 22.289, V17.0.0, Table 5.2.2-1 “Performance requirements for rail scenarios – main line” the End-to-End latency for messaging is not defined. As Alternative the throughput for FileTransfer for MCData FD Service can be used. According to 3GPP TS 22.289, V17.0.0, Table 5.2.2-1 the User experienced data rate should be min 100 kbps.

6.6 Rail Critical services Berlin Point-machine object controller signaling test cases (RCPg)

6.6.1 Description

For the Point-machine object controller signaling test case, the Rail Signaling traffic is extracted from a productive interlocking system via the usage of a network Test Access Point (TAP) – Siemens Data Capture Unit (DCU).

The real signaling traffic from the Deutsche Bahn (DB) Interlocking is in this test-case transmitted via two parallel paths:

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

The KPIs of the real and emulated point machine controllers are compared. Along with triggering the emulated point machine data is logged for usage in comparing the KPIs for transportation service.

The high level purpose with the vertical services is to:

- Demonstrate that a DB copper signaling cable can be traded with signaling over 5G.
- Show that the Emulated and Real Point Machine behavior experience similar result.

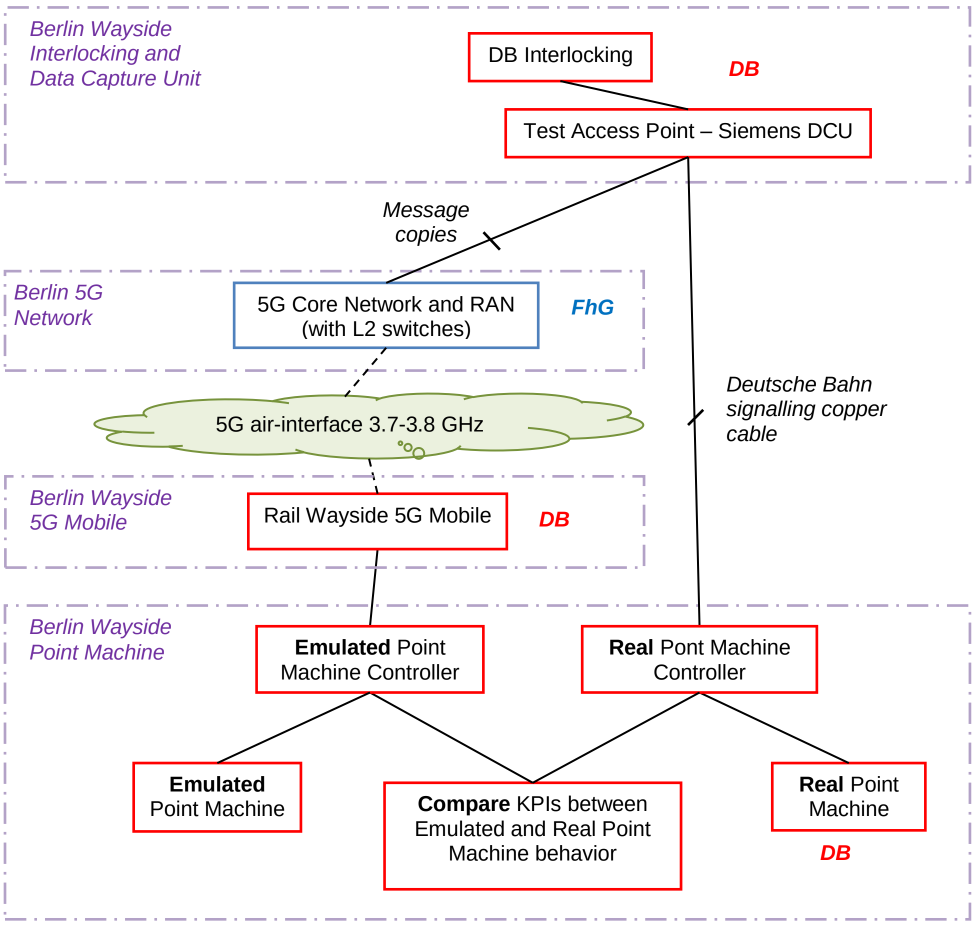


Figure 6-4: Rail Critical Services – Point Machine signaling over 5G

6.6.2 RCPg01: Rail Point-machine test case without 5G network

The general setup is tested without making usage of the 5G network to ensure, that the extraction of the Signaling data as well as the emulation of the point-machine work correctly.

Table 6-17: RCPg01 - Rail Point-machine test case without 5G Network (lab test)

RCPg01	**Rail Point-machine test case without 5G Network (lab test)**
Testbed	**5GENESIS Berlin**
Description	The purpose with this test-case is to first establish rail signaling traffic directly between the real interlocking to the emulated point-machine via the network TAP, without a 5G network. The reason is to exclude complexity as a first step. Note: with this direct connection not using 5G, Network Slicing and 5G QoS Indicator have no meaning.
Key UC requirements and KPIs	KPIs: • Round-trip-time less than 50 ms. • Stable RaSTA connection. Note: The result is expected regardless of background traffic in the network.
Network performance requirements and KPIs	N/A
Network Functional requirements and KPIs	N/A
Components and configuration	**- Components:** 1. Siemens DCU (network TAP). 2. Controller for filtering. 3. Office Ethernet switch. 4. Emulated point-machine controller. 5. Emulated point-machine. **- Configuration:** 1. The DCU is attached in the communication link of the interlocking and configured to capture only relevant signaling traffic 2. A micro controller is attached to the DCU to receive the captured packets, take the information of these and send them to the emulated point-machine controller 3. Before sending the traffic, the time Is logged 4. A switch is used to connect controller and emulated point-machine controller directly 5. The point-machine controller takes the received signal, logs the time, and then triggers the emulated point-machine accordingly

Test procedure	**- Preconditions:** 1. The network tap is installed in the interlocking network. 2. Measurement endpoints are installed on micro controller as well as emulated point-machine controller. 3. The endpoints are connected via a wired network. 4. Endpoints must be time synchronized. **- Test Case Steps:** 1. Establish connection link between both endpoints. 2. Send randomized data packets between the endpoints.
Measurements	**- Methodology** 1. Rail signaling traffic (RaSTA) is setup between the endpoints. KPIs are monitored at the endpoints. **- Complementary measurements** 1. Measurement of transmission times and failure rates. **- Calculation process** 1. Signaling payload as well as RaSTA overhead and UDP overhead are added.
Expected Result	The rail signaling traffic meets the expected KPIs.

6.6.3 RCPg02: Rail Point-machine test case with 5G Network

The general setup is tested with usage of the 5G network, to ensure that the extraction of the Signaling data as well as the emulation of the point-machine and transport path to it work correctly.

Table 6-18: RCPg02 - Rail Point-machine test case with 5G Network (field test)

RCPg02	**Rail Point-machine test case with 5G Network (field test)**
Testbed	**5GENESIS Berlin**
Description	The purpose with this test-case is to first establish rail signaling traffic directly between the real interlocking to the emulated point-machine via the network TAP, with a 5G network.
Key UC requirements and KPIs	KPIs: • Round-trip-time less than 50 ms • Stable RaSTA connection • Rail signaling traffic can use 100 kbps at any time Note: The result is expected regardless of background traffic in the network.
Network performance requirements and KPIs	N/A
Network Functional requirements and KPIs	N/A

Components and configuration	**- Components:** 1. Siemens DCU (network TAP) 2. Controller for filtering 3. 5G communication equipment 4. Emulated point-machine controller 5. Emulated point-machine **- Configuration:** 1. The DCU is attached in the communication link of the interlocking and configured to capture only relevant signaling traffic 2. A micro controller is attached to the DCU to receive the captured packets, take the information of these and send them to the emulated point-machine controller 3. Before sending the traffic the time is logged 4. Connection via 5G equipment is performed 5. The point-machine controller takes the received signal, logs the time, and then triggers the emulated point-machine accordingly
Test procedure	**- Preconditions:** 1. The network tap is installed in the interlocking network. 2. Measurement endpoints are installed on micro controller as well as emulated point-machine controller. 3. The endpoints are connected via an agreed 5G Network Slice for Rail Critical Services. 4. A suitable QoS indicator is set. 5. Endpoints must be time synchronized. **- Test Case Steps:** 1. Establish connection link between both endpoints. 2. Send randomized signaling data packets between the endpoints.
Measurements	**- Methodology** 1. Rail signaling traffic (RaSTA) is setup between the endpoints. KPIs are monitored at the endpoints. **- Complementary measurements** 1. Measurement of transmission times and failure rates. **- Calculation process** 1. Signaling payload as well as RaSTA overhead and UDP overhead are added.
Expected Result	The rail signaling traffic meets the expected KPIs.

6.6.4 RCPg03: Rail Point-machine timing test case with 5G Network

The general setup is tested with usage of the 5G network in order to ensure, that the extraction of the Signaling data as well as the emulation of the point-machine and transport path to it work correctly.

Table 6-19: RCPg03 - Rail Point-machine timing test case with 5G Network (field test)

RCPg03	**Rail Point-machine timing test case with 5G Network (field test)**
Testbed	**5GENESIS Berlin**
Description	The purpose with this test-case is to ensure, that specific timing KPIs of the communication can be met while different situations are being simulated.
Key UC requirements and KPIs	KPIs: • Round-trip-time less than 20 ms. • Stable RaSTA connection. • Rail signaling traffic can use 100 kbps at any time. Note: The result is expected regardless of background traffic in the network.
Network performance requirements and KPIs	N/A
Network Functional requirements and KPIs	N/A
Components and configuration	**- Components:** 1. Siemens DCU (network TAP) 2. Controller for filtering 3. 5G communication equipment 4. Emulated point-machine controller 5. Emulated point-machine **- Configuration:** 1. The DCU is attached in the communication link of the interlocking and configured to capture only relevant signaling traffic 2. A micro controller is attached to the DCU to receive the captured packets, take the information of these, and send them to the emulated point-machine controller 3. Before sending the traffic, the time is logged 4. Connection of the equipment via 5G is performed 5. The point-machine controller takes the received signal, logs the time, and then triggers the emulated point-machine accordingly
Test procedure	**- Preconditions:** 1. The network tap is installed in the interlocking network. 2. Measurement endpoints are installed on micro controller as well as emulated point-machine controller. 3. The endpoints are connected via an agreed 5G Network Slice for Rail Critical Services. 4. A suitable QoS indicator is set. 5. Endpoints must be time synchronized. 6. In parallel several other experiments are running (e.g. data shower) **- Test Case Steps:** 1. Establish connection link between both endpoints. 2. Send randomized signaling data packets between the endpoints

Measurements	**- Methodology** 1. Rail signaling traffic (RaSTA) is setup between the endpoints. KPIs are monitored at the endpoints. **- Complementary measurements** 1. Measurement of transmission times and failure rates. **- Calculation process** 1. Signaling payload as well as RaSTA overhead and UDP overhead are added.
Expected Result	The rail signaling traffic meets the expected KPIs.

6.6.5 RCPg04: Rail Point-machine test case with 5G Network and co-existing traffic

The communication of the point machine with the interlocking via 5G is tested while other co-existing traffic is running to and from the point machine.

Table 6-20: RCPg04 - Rail Point-machine test case with 5G Network and co-existing traffic (field test)

RCPg04	**Rail Point-machine test case with 5G Network and co-existing traffic (field test)**
Testbed	**5GENESIS Berlin**
Description	The purpose with this test-case is to ensure, that specific timing KPIs of the communication can be met as well as different types of traffic can happen at the same time without influencing the signaling traffic.
Key UC requirements and KPIs	KPIs: • Round-trip-time less than 20 ms. • Stable RaSTA connection. • Rail signaling traffic can use 100 kbps at any time for each connection. • Security relevant traffic can be transmitted at any time (with lesser priority than signaling). Note: The result is expected regardless of background traffic in the network.
Network performance requirements and KPIs	N/A
Network Functional requirements and KPIs	N/A

Components and configuration	**- Components:** 1. Siemens DCU (network TAP) 2. Controller for filtering 3. 5G communication equipment 4. Emulated point-machine controller 5. Emulated point-machine 6. Log Host for security relevant log files **- Configuration:** 1. The DCU is attached in the communication link of the interlocking and configured to capture only relevant signaling traffic 2. A micro controller is attached to the DCU in order to receive the captured packets, take the information of these and send them to the emulated point-machine controller 3. Before sending the traffic the time Is logged 4. Connection via 5G equipment is performed 5. The point-machine controller takes the received signal, logs the time and then triggers the emulated point-machine accordingly 6. The Log host is configured at the location of the interlocking
Test procedure	**- Preconditions:** 1. The network tap is installed in the interlocking network. 2. Measurement endpoints are installed on micro controller as well as emulated point-machine controller. 3. The endpoints are connected via an agreed 5G Network Slice for Rail Critical Services. 4. A suitable QoS indicator is set. 5. Endpoints must be time synchronized. 6. In parallel several other experiments are running (e.g. data shower) 7. Logging is activated at the emulated point-machine **- Test Case Steps:** 1. Establish connection link between both endpoints. 2. Send randomized signaling data packets between the endpoints
Measurements	**- Methodology** 1. Rail signaling traffic (RaSTA) is setup between the endpoints. KPIs are monitored at the endpoints. 2. Retries in sending log files is measured. **- Complementary measurements** 1. Measurement of transmission times and failure rates. **- Calculation process** 1. Signaling payload as well as RaSTA overhead and UDP overhead are added.
Expected Result	The rail signaling traffic meets the expected KPIs. Also, high priority data is transmitted.

7 Conclusions

This document is the first release of Task 3.1, and defines transportation related UCs that can be tested and evaluated in isolation or together with other services on one or more of the 5G facilities [2]. More specifically it focuses on rail transportation services supported through: enhanced Mobile BroadBand (eMBB), and ultra-Reliable Low Latency Communications (uRLLC) services. In this context four categories of applications are envisioned:

1. Transportation: Digital Mobility including the Mobility as a Service framework, the passenger followed pop-up network on-demand for infotainment services and emergency situations as well as a set of Innovative applications.
2. Provisioning of mission critical services for railway systems covering both on-board and trackside segments. These includes mission critical audio, data and video as well as signalling for interlocking and train devices.
3. Train management systems including onboard monitoring such as HD CCTV, etc., and remote maintenance.
4. Mobile broadband for onboard passengers.

To assess the performance of these services, the 5G-VICTORI experimentation methodology revolves around the profiling of experiments, including specific configurations and conditions [4]. This methodology is aligned with the 5G-PPP Test, Measurement and KPIs Validation (TMV) Work Group (WG). Similarly to the work in this WG [5], we provide methodologies and **Test Cases** for the validation of the **End-to-End (E2E) services**. Methodologically, for the evaluation of the vertical services/applications KPIs, a mapping between Network and Vertical Services KPIs will be performed, and network and network services' KPIs will be refined accordingly. Application requirements are related to the requirements defined as part of **WP2** and some additional ones defined in WP3. Test case KPIs are listed in the test case tables that can be found in this document.

The different vertical services in this document focus on enhanced Mobile BroadBand (eMBB) and ultra-Reliable Low Latency Communications (uRLLC), services taking advantage of Network Slicing in 5G system to support the E2E QoS service requirements. The objective of these demos is to showcase that the required characteristics of services are satisfied, regardless of background traffic or other services that the common 5G-VICTORI infrastructure may support.

The specific Transportation Services to be demonstrated at the Patras, Berlin and Bristol facilites include:

- **Enhanced Mobile BroadBand** (UC #1.1), 5G-VICTORI facility in Patras.
- **Digital Mobility** (UC #1.2), 5G-VICTORI facility in Bristol and Berlin.
- **Rail Critical Services** (UC #1.3), 5G-VICTORI facility in Berlin.

This document is the first deliverable of Task 3.1. At a later project stage, the test cases will be updated for the second delivery in Task 3.1, which is D3.2 entitled "Final Use case specification for transportation services". The output of this task will provide input to WP4 trial activities, where single and multiple vertical services are demonstrated within a cluster and with the goal to also show inter-cluster re-use of functionality. WP4 will produce demonstration test reports that will comprise the measured KPIs vs those targeted in WP2 and assessed as part of WP3 activities.

8 References

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[11] D3.1 Minutes of Meetings

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8.2 Standards

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8.3 5G-VICTORI inherited platforms

[21] 5GENESIS

[22] 5G-EVE

[23] 5GPPP

[24] 5G-UK

[25] 5G-VINNI

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