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

D3.2 Final 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, the latter belonging to the vertical sectors **Transportation**, **Energy**, **Media** and **Factories of the Future**. Additionaly, the project demonstrates cross-vertical UCs over an integrated 5G platform. 5G-VICTORI targets the 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 UC validation will cover both technology and business perspectives and be conducted under real life conditions for each vertical sector.

This document focuses on transportation services and, mainly, on rail-related transportation services. These services range from applications for digital mobility in means of transport, the provision of mission critical services for railway systems, train management systems and the offering of eMBB services to passengers.

Prior to the evaluation of Key Performance Indicators (KPIs) of the aforementioned services in the operational environments (vertical-owned infrastructure), they need to be first deployed in controlled environments (e.g. laboratories) to better assess their performance considering the deployed 5G experimental platform. These facilities arise from a common flexible 5G network architecture [4], which has been inspired by standardised 5G architectural approaches, i.e. ETSI, 3GPP, IEEE and Open Radio Access Network (O-RAN), adding to these innovative features. It is important to bear in mind that the the four 5G-VICTORI facilities (Patras, Berlin, Bristol, FR/RO) offer different flavors of 5G implementations.

Based on the initial definition of the services and test cases (D3.1), and how these services are mapped over the available 5G infrastructures (D2.4), this document refines the specific configuration of the equipment/infrastructures that host the different measurement activities and provides a set of KPIs stemming from these measurements. These KPIs relate to both the evaluation of the services and the End-to-End (E2E) connectivity, and those stemming from the assessment of the underlying 5G system.

To carry out the measurement campaing and to produce the results (KPIs), test cases from D3.1 have been followed and, additionally, new test cases have been defined involving coexisting services, from which results have been obtained, and others that will be assessed from now on in parallel to the work in WP4.

Acronyms

General acronyms

Acronym	Description
3D	Three dimensions, xyz
3GPP	Third Generation Partnership Project
4G	4th 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
5QI	5G QoS Indicator
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
CPE	Customer Premises Equipment (a 5G mobile gateway)
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)
DSCP	DiffServ Code Point
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)
NS	Network Slice
NSI	Network Slice Instance
OBG	O**nboard 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)
SAT	Slice Activation Time
SCT	Slice Creation Time
SDS	Short Data Service
SIM	Subscriber Identification Module
SIP	Session Initiation Protocol
SN	Service Network (in 5GC called Data Nerwork)
SNMP	Simple Network Management Protocol
S-NSSAI	Single Network Slice Selection Assistance Information
STB	Set-Top-Box
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

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)
D2.4	Deliverable D2.2 (within T2.1)
D3.1	Deliverable D3.2 (within T3.1)
D3.4	Deliverable D3.4 (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	I2CAT Foundation (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 Transportation Austria AG (partner)
MATI	Mativision (partner)
MShed	Museum in Bristol
T3.1	Task 3.1 (within WP3)
T3.2	Task 3.2 (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

The ongoing digital transformation of public and private sectors related to the field of transportation demands 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.

The benefits stemming from this digital transformation will only be reaped by the definition of future-proof network architectures and the use of intelligent and sustainable technologies. These are expected 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.

The purpose of 5G-VICTORI is to demonstrate that different Verticals can share a common 5G infrastructure including common radio access, transport and core networks, as well as compute resources. In the transportation context, we attempt to prove that a common 5G infrastructure can be used to deploy all type of vertical services, which is aligned to the views of the Future Rail Mobile Communication System (FRMCS), which leverages a 5G cellular system for the radio part.

Technology and architecture validation in 5G-VICTORI is carried out considering the most critical parameters of each vertical sector under real life conditions. To that end, the assessment of the services for each sector needs to be first made under controllable conditions, with the target to optimize the deployment of these services and reach a mature state that can allow their deployment in operational environments, railway stations, railway tracks, etc.

As described in the 5G-VICTORI deliverables **D2.1** [1], **D2.2** [2], **D2.3** [3], and **D2.4** [4], the 5G-VICTORI transportation services and use cases (UCs) focus on the assessment of the capability to serve all communication requirements of train operators and passengers – under the umbrella of the Future Railway Mobile Communication System (FRMCS) family of services – using 5G cellular radio.

This document provides a detailed definition and planning of the transportation-related services. 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**.

This document is the second release of 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].

To assess the performance of these services, the 5G-VICTORI experimentation methodology revolves around the profiling of experiments, including specific configurations and conditions [5]. This methodology is aligned with the 5G-PPP Test, Measurement and KPIs Validation (TMV) Work Group (WG). Similarly to the work in this WG [7], 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 has been already performed in deliverable D2.4 [4]. In this document we refine the test cases included in deliverable **D3.1** and we provide lab-based results stemming from the execution of these test cases, together with the definition of additional test cases and their corresponding results.

The work in assessing and optimizing both the network and the delivery of the services will continue in parallel to the implementation of the UCs in the operational environments (WP4). Key findings of the former will definitely benefit the integration of the components (either HW or SW) in the facilities and the generation of results as part of WP4 trials.

1.1 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 (**UC #1.1**) at the 5G-VICTORI facility in Patras is included in section 3.

Section 4 described the test cases defined for the Digital Mobility (**UC #1.2**) at the 5G-VICTORI facility in Bristol.

Section 5 discusses the test cases defined for the Digital Mobility UC (**UC #1.2**) at the 5G-VICTORI facility in Berlin.

Section 6 describes the test cases defined for the Rail Critical Services (**UC #1.3**) at the 5G-VICTORI facility in Berlin.

Finally, section 7 provides the conclusions of the document.

2 Testing methodology

The main objective of this section is the assessment of transportation services that will be rolled out by the 5G-VICTORI platform. The assessment methodology is covering all building blocks of the 5G-VICTORI platform starting from the definition of the reference equipment configuration for the RAN and the core network, as well as the reference load levels and the scale-up to the required load levels over which an extensive set of metrics are calculated.

The assessment procedure contains the following tasks:

1) Identification of the topology and environment where the analysis will be conducted in order to assess the performance of the requested services.
2) Identification of the main equipment used to support the requested services including the gNB, backhauling systems, control plane solution, etc. For the building block of the system the assessment will:
    - List the basic parameters of each component.
    - List system level configuration and connectivity options.
    - Specify traffic load(s) for measurements.
3) Measure main performance indicators for each component under different load levels.
4) Calculate E2E performance metrics.
5) Collect and report the measurement and calculation results.

2.1 Testing Methodology Description

The testing methodology is in accordance with the relevant 3GPP standards.

1) **Definition of 5G network topology and environment of operation** The specific services will be evaluated for a given network topology considering all the equipment and virtualized network functions that are necessary for the provisioning of services (see Figure 2-1). This also includes the environment where the 5G-VICTORI platform is expected to operate

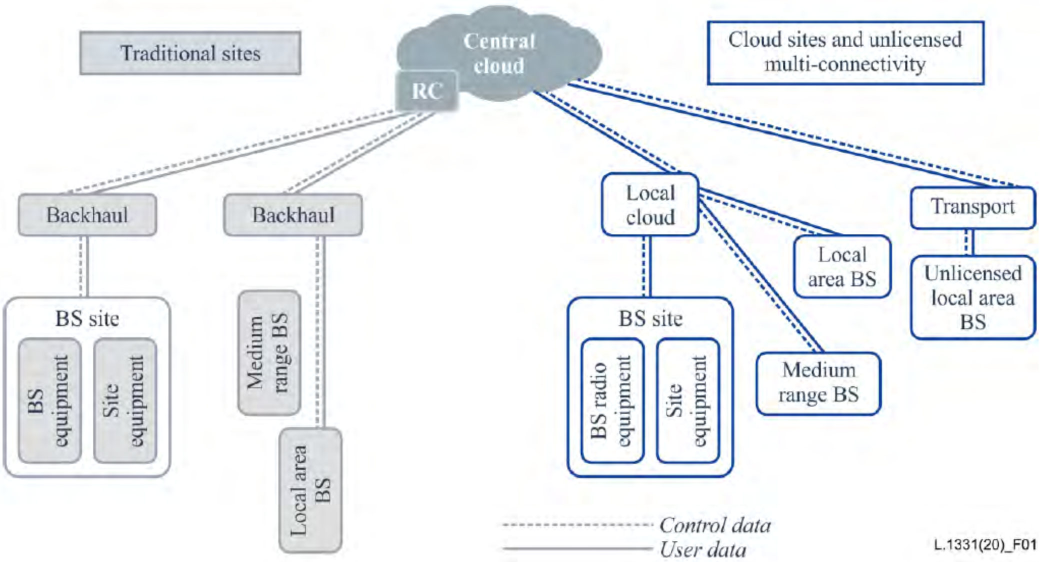


Figure 2-1 5G deployment option topology/configuration [5]

2) **Identification of the main building blocks per network.** For each topology deployed, the main building blocks will be listed providing a high level description of

software (virtualized 5G network functions) and hardware (networking equipment and servers) equipment and their specifications (see Table 2-1).

Table 2-1: Network Topology

Network Topology	
Type of sites in the network area	Number of gNBs: Size of gNBs:(wide, mid, small) Bandwidth of gNB gNB deployment Option: (split option) Type of gNB (commercial, prototype)
Fronthaul/Backhaul Information	Predominant type of backhauling [wireless, fibre, copper…] Number of backhauling links per type
Cloud Infrastructure	Servers (type, capacity, interfaces) Virtualization software

2.2 Performance measurements

The evaluation measurements are taken following the methodology indicated in Table 2-2.

Table 2-2 Measurement and traffic details

Measurement duration	Time duration of the measurement [T] *Repetition time* *Granularity of measurements*
Traffic offered in the site	Traffic Characteristics (rate) Number of connections: Traffic Pattern and interarrival time

2.2.1 Evaluation of individual building blocks including:

Table 2-3: Performance measurements for gNB under different deployment options

Performance measurements for gNB under different deployment options		
Metric		**Description**
Packet delay (units ms)	Average delay DL air-interface	This measurement provides the average (arithmetic mean) time it takes for packet transmission over the air interface in the downlink direction. This measurement is obtained as: sum of (point in time when the last part of an RLC SDU packet was sent to the UE which was consequently confirmed by reception of HARQ ACK from UE for UM mode or point in time when the last part of an RLC SDU packet was sent to the UE which was consequently confirmed by reception of RLC ACK for AM mode, minus time when corresponding RLC SDU part arriving at MAC layer) divided by total number of RLC SDUs transmitted to UE successfully.
	Average delay UL on over-the-air interface	This measurement provides the average (arithmetic mean) over-the-air packet delay on the uplink
	Distribution of DL delay between NG-RAN and UE	This measurement provides the distribution of DL packet delay between NG-RAN and UE, which is the delay incurred in NG-RAN (including the delay at gNB-CU-UP, on F1-U and on gNB-DU) and the delay over Uu interface.
	Distribution of UL delay between NG-RAN and UE	This measurement provides the distribution of the time it takes for packet transmission over the air-interface in the downlink direction

	DL/UL packet delay between NG-RAN and PSA UPF	This measurement provides the average DL GTP packet delay between PSA UPF and NG-RAN.
UE throughput	Average DL UE throughput in gNB	This measurement provides the average UE throughput in downlink
	Average UL UE throughput in gNB	This measurement provides the average UE throughput in uplink
PDU Session Management	Number of PDU Sessions requested to setup	This measurement provides the number of PDU Sessions by the gNB.
	Number of PDU Sessions successfully setup	This measurement provides the number of PDU Sessions successfully setup by the gNB from AMF
	Number of PDU Sessions failed to setup	This measurement provides the number of PDU Sessions successfully setup by the gNB from AMF
Mobility Management	Inter-gNB handovers	Number of requested handover resource allocations: This measurement provides the number of legacy handover preparations requested by the source gNB
QoS flow related measurements	QoS flow setup	Number of QoS flow attempted to setup. This measurement provides the number of QoS flows attempted to setup
		Number of QoS flow successfully established
		Number of QoS flow failed to setup

Table 2-4 Performance measurements for SMF

Performance measurements for SMF		
Metric		**Description**
Session Management	Number of PDU sessions (Mean)	This measurement provides the mean number of PDU sessions
	Number of PDU sessions (Maximum)	This measurement provides the max number of PDU sessions
	Number of PDU session creation requests	This measurement provides the number of PDU sessions requested to be created by the SMF.
	Number of successful PDU session creations	This measurement provides the number of PDU sessions successfully created by the SMF.
	Number of failed PDU session creations	This measurement provides the number of PDU sessions failed to be created by the SMF
	Mean time of PDU session establishment	This measurement provides the mean time of PDU session establishment during each granularity period
	Max time of PDU session establishment	This measurement provides the max time of PDU session establishment during each granularity period

QoS flow monitoring	Number of QoS flows requested to create	This measurement provides the number of QoS flows requested to create
	Number of QoS flows successfully created	This measurement provides the number of QoS flows successfully created
	Number of QoS flows failed to create	This measurement provides the number of QoS flows failed to create

Table 2-5 Performance measurements for UPF

Performance measurements for UPF		
Metric		**Description**
N3 interface related measurements	Number of incoming GTP data packets on the N3 interface, from (R)AN to UPF	This measurement provides the number of GTP data PDUs on the N3 interface which have been accepted and processed by the GTP-U protocol entity in UPF on the N3 interface
	Number of outgoing GTP data packets of on the N3 interface, from UPF to(R)AN	This measurement provides the number of GTP data PDUs on the N3 interface which have been generated by the GTP-U protocol entity on the N3 interface
	Incoming GTP Data Packet Loss in UPF over N3	This measurement provides the number of GTP data packets which are not successfully received at UPF. This measurement is obtained by a counter: Number of missing incoming GTP sequence numbers (TS 29.281) among all GTP packets delivered by a gNB to an UPF per N3 interface
	Round-trip GTP Data Packet Delay	Average round-trip N3 delay on PSA UPF: This measurement provides the average round-trip delay on a N3 interface on PSA UPF
One way packet delay between NG-RAN and PSA UPF	Packet delay between NG-RAN and PSA UPF	This measurement provides the average UL GTP packet delay between PSA UPF and NG-RAN
	Average round-trip packet delay between PSA UPF and NG-RAN	This measurement provides the average round-trip GTP packet delay between PSA UPF and NG-RAN.

Table 2-6 Common performance measurements for Network Functions (NFs)

Common performance measurements for Network Functions (NFs)		
Metric		**Description**
Virtual resource usage	Virtual CPU usage	This measurement provides the mean usage of the underlying virtualized CPUs for a virtualized 3GPP NF
	Virtual memory usage	This measurement provides the mean usage of the underlying virtualized memories for a virtualized 3GPP NF
	Virtual disk usage	This measurement provides the mean usage of the underlying virtualized disks for a virtualized 3GPP NF.

2.2.2 E2E Performance Metrics per 5G slice

E2E (per slice metrics)	
Metric	**Description**

Average e2e delay for a network slice	This KPI describes the average e2e UL packet delay between the PSA UPF and the UE for a network slice.
Throughput for Single Network Slice Instance	This KPI describes the downstream throughput of one single network slice instance by computing the packet size for each successfully transmitted DL IP packet through the network slice instance during each observing granularity period and is used to evaluate integrity performance of the end-to-end network slice instance. It is obtained by downstream throughput provided by N3 interface from all UPFs to NG-RAN which are related to the single network slice.
QoS flow Retainability	This KPI shows how often an end-user abnormally loses a QoS flow during the time the QoS flow is used.
Packet transmission reliability KPI in DL on Uu	This KPI describes the Reliability based on Packet Success Rate (PSR) Percentage between gNB and UE.
Average network jitter for the network slice	This KPI describes the differential time between the packet actual arrival time and its expected arrival time according to a standard clock.

2.3 Reporting template

A template for the reporting table that is being used to extract the evaluation results is indicated in Table 2-7 [6].

Table 2-7 Test Case template

Test Case Template		
<Test Case ID>	*<Test Case Title>*	
Description	*Description of the test case, and high level purpose*	
Key UC requirements and KPIs	*Definition of the UC requirements and targeted KPIs*	
Network performance requirements and KPIs	*Definition of Network performance requirements and KPIs. The definition of the main metric/KPI declares at least the reference points from which the measurement(s) will be performed, the underlay system, the reference protocol stack level, etc.*	
Network Functional requirements and KPIs	*Definition of Network functional requirements*	
Components and Configuration	*Components*	*A list of HW/SW components (for example, components that may be needed when testing alternative network deployments/ technologies) that are necessary for the test case*
	Configuration	*A list of features, capabilities, how components are interconnected, required by the SUT in order to execute the test*
Test procedure	*Pre-conditions*	*Any pre-condition that needs to be done before execution of the test case. A list of test specific pre-conditions that need to be met by the SUT including information about equipment configuration, traffic descriptor, i.e., precise description of the initial state of the SUT required to start executing the test steps*
	Test Case steps	*A number of steps (actions/ procedures) that need to be performed during the execution of the test. Depending on the test case nature / deployment / scope, this field can also specialise the test and measurement process (methodology) of the metric for the selected underlay system.*

Measurements	*Methodology*	*Acceptable values for the monitoring time, the iterations required, the monitoring frequency, etc.*
	Complementary measurements	*A secondary list of metrics/KPIs useful to interpret the values of the target metric/KPI. Getting these measurements is not mandatory for the test case.*
	Calculation process	*If needed, any information related to the required calculation process. This information may include details related to the underlay measurements/ monitoring system. The Units of the metric and, potentially, a request for first order statistics (Min, Max, etc.) can be also included*
Expected Result	*Brief description of the expected results and, where necessary, their representation. These can be: specific KPI target values, specific QoS profiles for the vertical services, etc., required in the form of single values, graphs, spider diagrams, etc.*	

3 Enhanced MBB at the 5G-VICTORI Patras facility

3.1 Description

As described in deliverables D2.1 [1] and D2.2 [2], 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.

UC #1.1 proposes a multi-technology infrastructure to provide connectivity to a train as it moves along a railway track. This UC makes use of an operational railway setup leveraging upon the 5G Patras network deployment.

The diagram in Figure 3-1 illustrates the 5G architecture adopted in support of **UC #1.1** relying on the disaggregated RAN architecture described in D2.4 [4] (deployment Option 3). Figure 3-1 includes all the elements (hardware/software) required to demonstrate the three services planned to be concurrently demonstrated at the Patras Facility. As can be seen, there is an on board network deployment that allows to various UC-specific NR UEs (UEs, cameras, laptops) to be connected via a multi-technology setup from the train rooftop to the backhaul network. An on board edge computing unit deploys network functions that allow both mobility management and disaggregation to take place (deployment Option 3), in alignment with the overall 5G-VICTORI architecture presented in D2.4. The overall network is interconnected to the UoP cloud and the public cloud. 5G-VIOS will be interconnected with OSM and/or OSS at the UoP cloud.

3.2 Rail Enhanced MBB Patras network deployment Test cases (REDv)

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

The onboard train network, integrated in a **TRA** train, will be based on a fibre ring network technology. This will interconnect all Access Points (APs) (Onboard 5G NR and/or Wi-Fi AP) and the rooftop antennas via an Software Defined Networking (SDN)-enabled switch, together with edge computing elements, as shown in Figure 3-1.

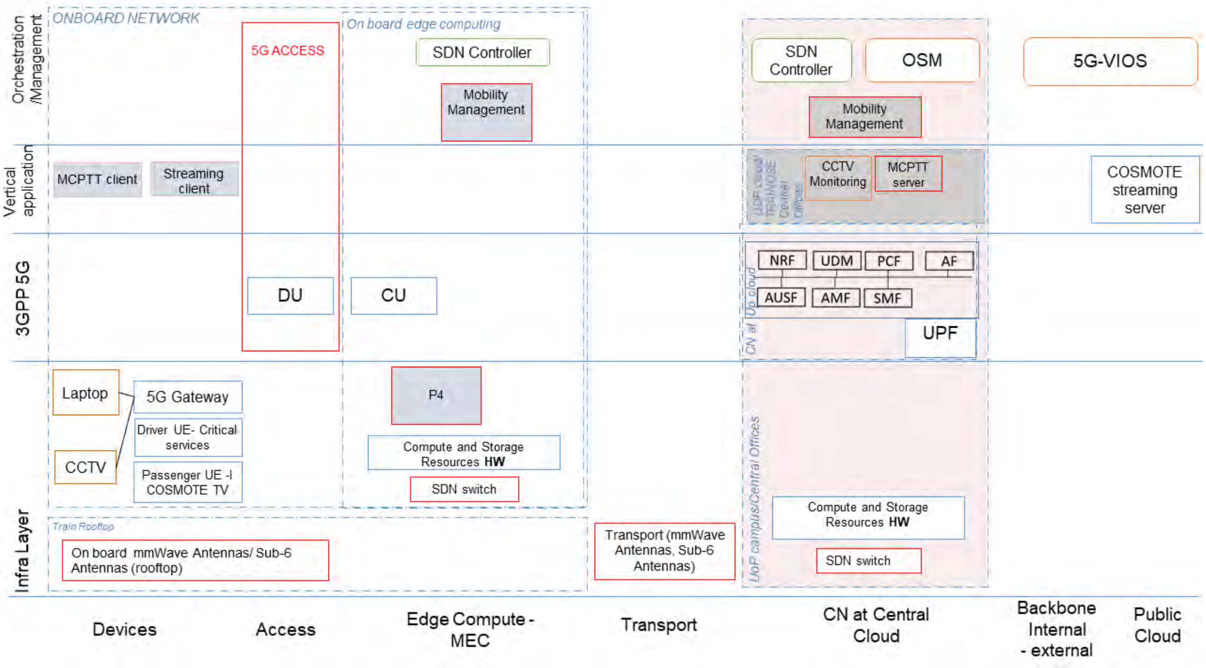


Figure 3-1 Enhanced MBB at the 5G-VICTORI Patras facility E2E architecture

This test case (Table 3-1) is required to ensure that the onboard network (in the lab) is fully operational and that it can be integrated within the 5G-VINNI facility. At first lab testing of the elements at the NITOS Lab (**UTH**) are tested and then integrated to the **UoP** facility.

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 emphasizing on testing 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 between UE and service end-points 20 ms. **F-CA-1104** Air Interface – Access Network Capacity
Network Functional requirements and KPIs	N/A
Components and configuration	**- Components:** 1. Onboard Ethernet Switch. 2. Onboard 5G NR with SDR. 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. **- 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)

3.2.2 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 and in 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.
- E2E connectivity testing over 5G-VINNI – 5G-VICTORI railway deployment and data transfer.
- These test cases are currently being tested at lab environments (**IHP** and **UTH**) and then will be integrated with **UoP** 5G-VINNI platform and field trials

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 E2E 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 APs at Stanchions (Sub-6). 5. Wayside APs 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.

3.2.3 REDv03: Handover between heterogeneous transport nodes (lab and field)

This test case is used for testing handover functionality between two subsequent heterogeneous transport nodes.

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

REDv03	Handover between heterogeneous transport 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 5G RAN. **- 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 5G RAN.

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, E2E latency is kept during the handover period <20 ms

3.2.4 Lab Testing and Results

In this section we present an initial evaluation of the mobility management scheme (**REDv03**), using a scaled down version of **UC #1.1**. We use four Raspberry Pis (Rpi) for forming our network as follows:

- two of them are used as the home and target Wi-Fi APs,
- one of them is used as the server in the core network, and
- one of them as the user that roams between the two APs.

Three of them are interconnected using a high-performance mini-PC, with the P4 bmv2 switch running on top. ONOS is the controller managing the switch and establishes the flows to/from the core network whenever a handover is happening. Simple Network Management Protocol (SNMP) traps are running on the Wi-Fi APs and send signals to the controller whenever a UE attaches on them. The overall topology is shown in Figure 3-2.

To test the network, we saturate the links with UDP/TCP traffic using the iperf traffic generator tool, the server side being located at the core network side and the client side on the UE. We focus mainly on preserving the established TCP connections throughout the process in order to test the feasibility of the scheme using the software switches.

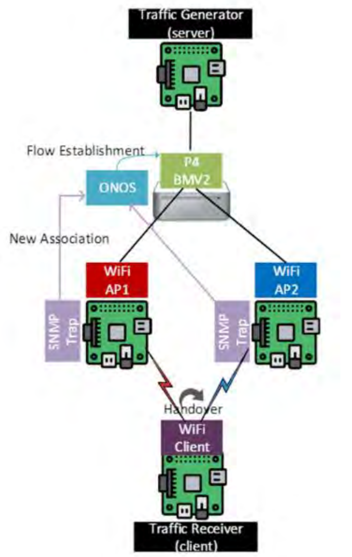


Figure 3-2 Handover evaluation lab topology

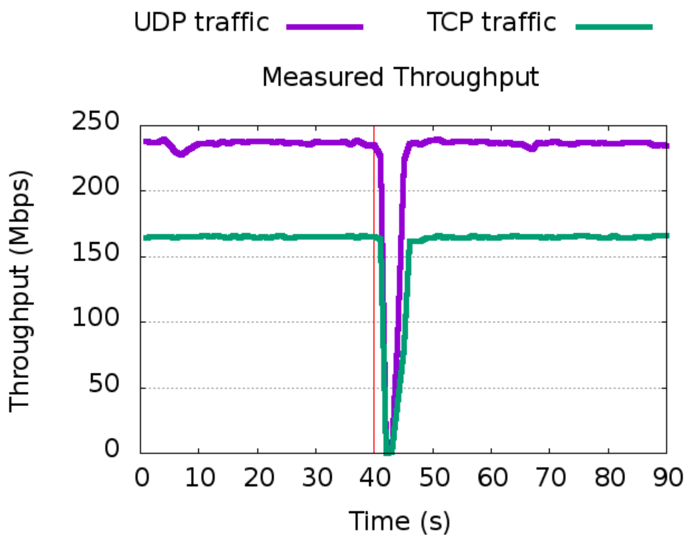


Figure 3-3 Handover results

Figure 3-3 shows the collected experimental results. The experiment duration is 90 seconds, and at the 40th second we instruct the UE to switch its AP association through external commands. As we see, for all the traffic cases we observe that there is a significant drop in the transferred throughput post the handover process. This is happening as the software switch struggles to establish the new flows. Although the messages from the SNMP trap interface are sent within one millisecond, and the controller assigns the flows instantly, the software switch is slow in establishing them as packet processing takes place entirely in application space. This is also reflected in the low TCP throughput that is less than 170 Mbps; since processing takes place in software, additional delays are placed for packet processing, causing TCP re-transmission timers (RTO) to expire and therefore the congestion window to decrease. This fact is also reflected in a simple RTT analysis with the tool, as shown in Table 3-1. Average RTT times for packets traversing the bmv2 switch are higher than expected. Nevertheless, since the focus of this work is to mainly test the feasibility of the session-continuity, the established sessions are not dropped during the entire experiment, allowing for a seamless handover.

Table 3-1 RTT analysis

Solution	Average	Minimum
Bmv2 p4 switch	2.479	2.344

Moreover, the fact that the mobility pattern – along the tracks – is known, allows to further lower the handover duration compared to common mobility patterns at cellular networks to just the time needed for the SNMP agents to transmit the information on the new association to the controller.

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

3.3.1 Description

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.

At the time of D3.2 submission there have been some updates and edits to the test case descriptions mainly focusing on delivering the service over 3GPP 5G networks on board. Regarding the delivery of testing only the preparatory phase of the lab test cases has been initiated. The delivery of the onboard network (in the lab) has been delayed and this affects the integration with the camera and the testing delivery. Hence, although there has been an update to the test case description, the results of the test case for lab testing will be presented at D4.2 as benchmark for the trial test results.

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	**NITOS lab (UTH) / 5G-VINNI Patras**
Description	The test case connects the CCTV camera with the Central Office APP over the 5G (onboard) network deployment . 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 Latency between camera and Control center 100 ms High Video Quality of CCTV session
Network performance requirements and KPIs	**U-PE-1103**: E2E 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. **Central** 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. 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

Measurements	**- Methodology** 1. The test procedure is repeated for various traffic conditions of the access nodes. 2. The test procedure is repeated in a number of positions along the TRAINOSE facilities tracks and under mobility conditions. 3. Measurements are collected for a number of 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. 2. Traffic conditions are also monitored and noted in each iteration (at 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 and 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 it takes to re-connect is calculated. 5. Mean-Opinion-Score criteria will be used for the evaluation of the high Video Quality of CCTV session KPI.
Expected Result	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.

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

At the time of D3.2 submission there have been some minor updates and edits to the test case descriptions of all RECv service test cases focusing on delivering the service over 3GPP 5G networks on board but also defining performance measurements in detail. These Critical services relay on the integration of the Kontron application on to the Patras 5G platform. The lab testing roadmap that we have developed in Task 3.1 assumes that integration will follow the successful integration of the application on the 5G Berlin platform and the resulting testing hence all testing will follow immediately after the finalization of the Belin cluster testing work. Hence, although there has been an update to the test case description (see Annex XXX), the results of the test case for lab testing will be presented at D4.2 as benchmark for the trial test results.

3.4.1 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 (PTT) 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 3-9.

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 E2E 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**: E2E 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 gNB. 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. Network 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 network. 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.
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.

3.4.2 RECv02: MCPTT Group Call services for railway operations staff

As mentioned above, 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 Mission Critical Push-To-Talk (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 3-2.

Table 3-2 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**: E2E 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 gNB. 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. Network 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 network 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, talker assignment time, 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 datarate statistics can be collected (e.g. average datarate). 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.

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.

3.4.3 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 3-3.

Table 3-3 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**: E2E 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))

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 gNB. 5. Mobility management function. 6. on-board terminal or user handset with MCData app. 7. 2nd on-board terminal or user handset in different location area (B). 8. on-board gateway (on-board Compute and Storage Resources HW). 9. MCX/FRMCS core. 10. next-gen dispatcher. 11. 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 additional UEs or traffic generating tool to perform iperf/ ftp sessions to emulate traffic conditions. 4. Provisioned MCX/FRCMS network and users (callers A, B, C). 5. Network configuration as in REDv01. 6. Transport nodes configuration as in REDv02.
Test procedure	**- Preconditions:** 1. All systems are up and running. 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. MCX/FRMCS has provisioned location areas 5. MCX/FRMCS clients can receive location from UE (UE location method is active e.g. via GPS) 6. At least one MCX client is operating in "high speed" environment (on-train). **Test Case Steps:** 1. End user connects to the on-board Wi-Fi node 2. Authorized user at Client A issues a "Railway emergency alert" via an MCX/FRMCS client- Data only Railway emergency alert. 3. 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) 4. When Data Railway emergency alert call is active, connection quality is monitored 5. Terminate Railway emergency alert by authorized MCX client. 6. 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 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)

This group of test cases focuses on the performance evaluation of indicative “Business” – usually being internet and infotainment services over public internet- services addressed to the train passengers over the on-board 5G network access. 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 will be demonstrated and evaluated. 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.

To emulate business services while at the same time being able to monitor the service performance we used a customized, Web-RTC-based Mobile TV streaming application - available over common web browsers at the client side. The application (**COSM** inhouse application) enables the retransmission of commercial COSMOTE TV live-streams from a commercial Set-Top-Box (STB) and retransmission to UEs with very low latency; while at the same time allows for real-time monitoring of data rates and channel change delays. At the application layer, the session is established over a WebRTC session layer, the encoding is based on H.264. The data traffic is of UDP type.

Regarding the network deployment, it is the same for the complete bundle of the services of this UC. As described, a heterogeneous transmission network deployment is foreseen, interconnecting 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 the onboard gNB. Seamless service provisioning for passengers during handovers at the transport segment is tested.

The high-level objectives of this vertical service are:

- Demonstrate TV streaming for passengers, using COSMOTE TV Streaming Service, addressed in section 3.5.1 with the test case described in Table 3-4.
- Demonstrate seamless service provisioning for passengers during handovers at the transport segment (as train moves) 3.5.2, with the test case described in Table 3-5.

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

At the time of D3.2 submission there have been some minor updates and edits to the test case descriptions of all REPv service test cases mainly refining their wording. These tests, originally focused on delivering data services to passengers over 3GPP 5G networks on board, and relied on a mobile TV streaming application provided by COSMOTE. REPv01 especially focused on validating the onboard 5G network deployment and evaluating the performance for 4K video, live-streaming content services.

Table 3-4 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 onboard 5G network deployment and evaluates the performance for 4K video, live-streaming content services.
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 (i.e. over 100MHz, 4x4MIMO, 256QAM; validated by yyMbps over zzMHz, 4x4MIMO, 256QAM). **U-PE-1103**: E2E 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 – estimated through scalability evaluation

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 gNB. 7. Mobility management. 8. Users with 5G UEs 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 network 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. Definition of position of UE under test. 5. 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.

Measurements	**- Methodology** 1. 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. 2. The test procedure is repeated for various traffic conditions of the nodes. Imposed traffic (from iperf server) may vary from no traffic (0 Kbps) to fully loaded conditions (depending on access node max. configuration). 3. Measurements are collected for several iterations. At least 10 iterations are needed for the evaluation of each KPI for each set of test conditions. 4. Erroneous measurements are discarded from the measurements set, since the environment is lab/test. **- Complementary measurements** 1. Signal quality (RSSI, RSRQ) and position (distance in m from access network node) related measurements are collected in each iteration at UE side. 2. Traffic conditions (at gNB level) are also monitored and noted in each iteration. **- 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. 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. 4. For each set of tests/ iterations -for the specific conditions- the mean/ max./ min data rate values (Mbps) are calculated. 5. Mean-Opinion-Score criteria will be used 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 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.

3.5.2 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 TV streaming services “business services” in FRMCS terminology) achieved through on-board 5G network deployment.

At the time of D3.2 submission there have been only some minor updates to the test since as originally planned it focused on delivering data services to passengers over 3GPP 5G networks on board at the TRAINOSE operational environment. This test case will be performed once the 5G-VICTORI deployment is finalized at TRAINOSE premises.

Table 3-5 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 onboard 5G network deployment in an operational environment and evaluates its performance for 4K video, live-streaming content, under various mobility conditions.
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 (i.e. over 100MHz, 4x4MIMO, 256QAM; validated by yyMbps over zzMHz, 4x4MIMO, 256QAM) **U-PE-1102**: Mobility **U-PE-1103**: E2E 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 – estimated through scalability evaluation
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 7. Mobility management function 8. Users with 5G UEs 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. 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 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.

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 criteria will be used 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.

3.5.3 Lab test results

3.5.3.1 RENv01: Lab deployment activities and preliminary results

To emulate business services –usually being internet and infotainment services – while, at the same time, being able to monitor the service performance, we used a customized, Web-RTC-based Mobile TV streaming application. The application (COSM inhouse application) enables the retransmission of commercial COSMOTE TV live-streams from a commercial Set-Top-Box (STB) and retransmission to UEs with very low latency; while at the same time allows for real-time monitoring of datarates and channel change delays. Initial testing of the application functions and performance was performed over COSM 5G Non-Standalone (NSA) testbed (see Figure 3-1) to serve as basis for cross-validation of the application performance results when tested over the NITOS 5G-VICTORI lab setup. The described setup and the lab environment for this scenario are illustrated in Figure 3-4.

Table 3-6 Business Services (Mobile TV) Lab Testing – Network Topology

Network Topology	
Type of sites in the network area	Network type: 5G NSA deployment (vendor: ATHONET) Number of gNBs: 1 gNB, configured at 2x2 MIMO, 256QAM (DL), 100 MHz bandwidth, n78 Type of gNB: commercial (vendor: NOKIA)
Fronthaul/Backhaul Information	Predominant type of backhauling: Fiber - Ethernet

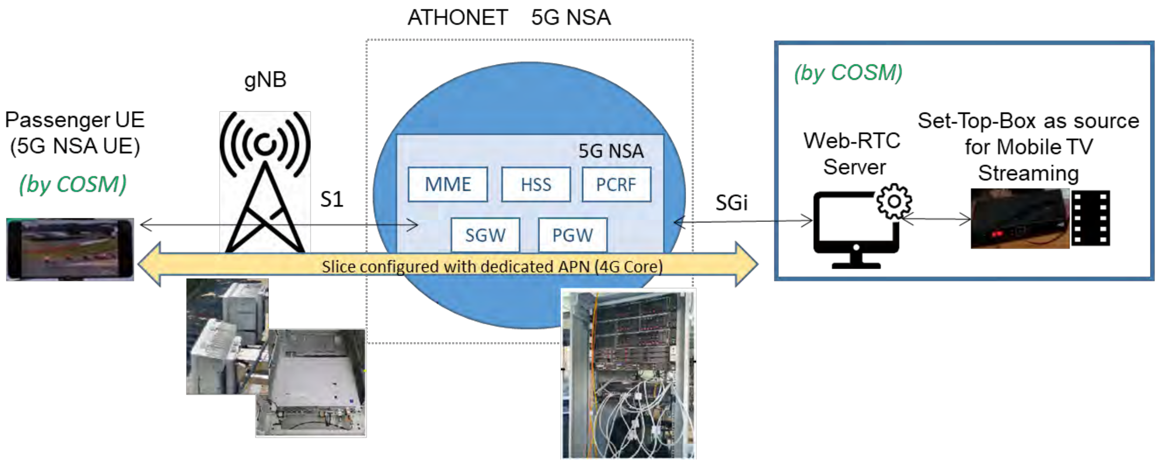
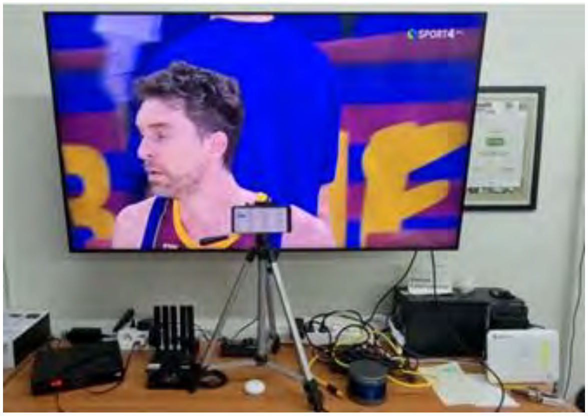


Figure 3-4: The lab setup for the Business Services (Mobile TV) initial validation (COSM)

At this stage, the lab tests were conducted with the aim to validate the application operation so there is no additional traffic offered in the site. In all tests, therefore, the measuring process characteristics were those included in Table 3-7:

Table 3-7 Business Services (Mobile TV) Lab Testing – Process characteristics

Measurement duration	**Time duration of the measurement [T]:** ***>10 minutes***, *>20 repetitions* ***Granularity of measurements:*** *Latency: in the order of ms* *Datarates: in the order of Kbps*
Traffic offered in the site	***Traffic Characteristics (rate)*** ***Number of connections:*** *Zero additional traffic*



Local setup (Set-Top-Box, connected TV, UE where Mobile TV stream is transmitted)

Zoomed In - illustrating the imperceivable (to human eye) latency between TV and UE streams

Figure 3-5 COSMOTE TV streaming service

The results obtained through lab testing correspond to E2E performance metrics for the configured 5G NSA slice and are summarized in Table 3-8.

Table 3-8 Business Services (Mobile TV) Lab Testing – E2E (per slice metrics) Performance Results

E2E (per slice metrics)		
Metric	**Description**	**Methodology**
Average e2e delay for a network slice	Average: 83 ms	100 packets of 1500Bytes (Max. Transfer Unit) sent through ping request. The seamingly high latency is attributed to the fact that this setup uses 5G NSA. Although the focus of the project is on 5GC deployments these measurements were kept to be used as reference for the following tests.
	Impercievable to end user	Channel switching time difference between STB and UE, . As noted in the red circle in Figure 3-5.
Throughput for Single Network Slice Instance	Average: 478 Mbps Min: 280 Mbps Max: 623 Mbps	DL iperf test sessions with 20 simultaneous connections were run between the two ends of the 5G NSA network (the UE where the mobile TV application runs and a server at the same topological place of the WebRTC server). Although the focus of the project is on 5GC deployments these measurements were kept to be used as reference for the following tests.
	Average: ~4-7Mbps depending on the channel	DL Traffic generated by the mobie TV channel streams between the UE and the WebRTC server for one channel.

Next, the NITOS lab setup has been connected with COSMOTE testbed, where the customized COSMOTE Mobile TV WebRTC server resides. Connectivity between the two testbeds (**COSM** and **UTH**) is ensured via a VPN tunnel (Open VPN), established at each UE. The lab deployment is illustrated in Figure 3-6, showing the handover between Wi-Fi APs. Although at the final deployment the handover will happen between heterogeneous technologies (Sub-6 and mmWave) the mechanism is still the same since it is based on the SNMP trap feature that is also supported on the mmWave nodes.

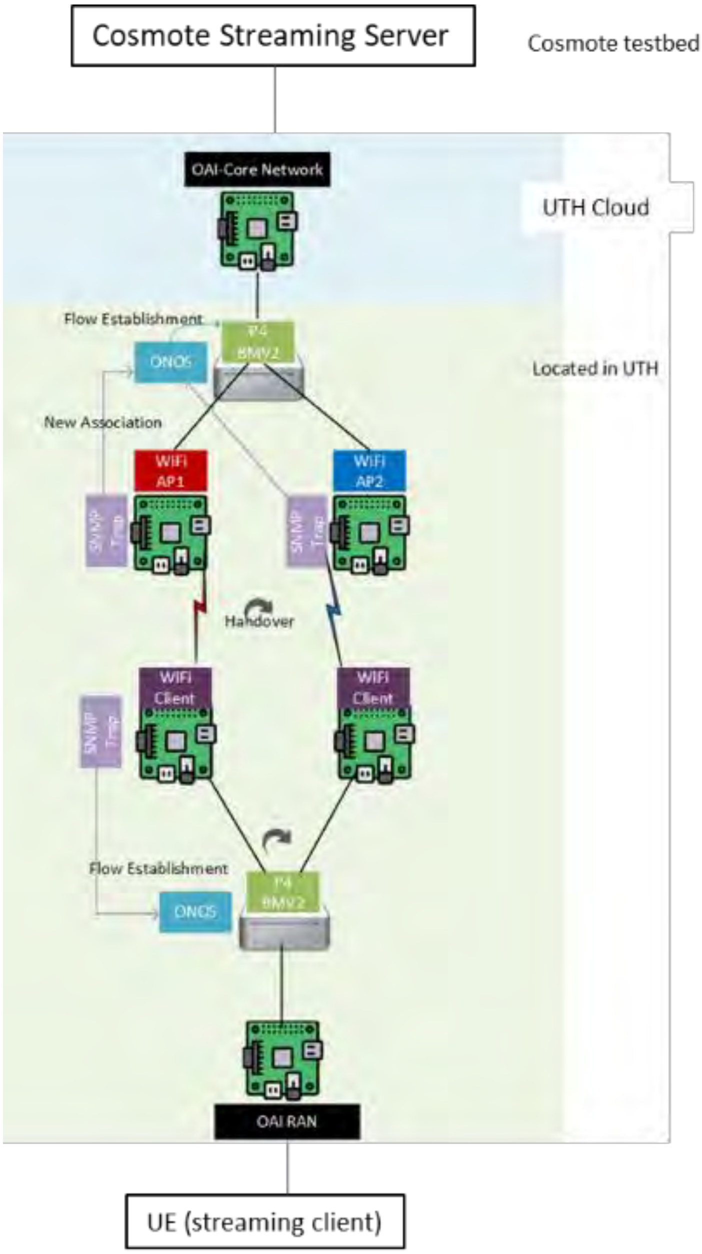


Figure 3-6 NITOS UTH Lab Setup for testing COSMOTE Mobile TV services

3.6 Test combinations

The test combinations suggested for the Patras 5G-VICTORI site emphasize on the performance of various FRMCS services (critical, performance, business) when delivered over the same 5G network deployment and, especially, over the same 5G access network node. The services considered in the Patras test combinations are the following:

- Rail Critical Communications: MCx Communications – corresponding to KCC's application.
- Performance services: CCTV services.
- Business services: mobile TV streaming services (the COSMOTE TV service implementation being the one described in the context of this UC).
- Other traffic:
    - o Background traffic via iperf or simple internet browsing (to load or saturate the air-interface).

The services mentioned above will be mapped to various combinations of QoS and Network Slices (NS') as available by the 5G network implementation per site (at NITOS/UTH and UoP).

- Using the same QoS and NS (no traffic differentiation)
- Using also different NS (the implementation adhering to the 5G network specifics).

3.6.1 Patras test combinations

The Patras test combinations considered are listed in Table 3-9, where:

- **Resources** denotes the way QoS is ensured in the test combination (by network slicing noted with "X" in the corresponding box, by simple QoS enabling noted with "X" in the corresponding box, or without any particular QoS ensurance mechanism –black boxes),
- **FRMCS services** denotes the use case services that are enabled in the combination where noted with "X", and
- **Other services,** denotes the presence or not of background traffic (e.g. through traffic generation), used to saturate the network at various levels.

Table 3-9 Patras test combinations

Resources and type of services	**Resources**		**FRMCS Services**			**Other Services**
Test Combinations	Network Slicing supported	QoS enabled	MCx Comm.	CCTV Streaming	mobile TV	Background Traffic
REComb01			X	X	X	
REComb02			X	X	X	X
REComb03		X	X	X		X
REComb04	X	X	X	X		X
REComb05		X	X	X	X	X
REComb06	X	X	X	X	X	X

The aim of these test combinations is to evaluate the performance of performance-demanding / performance-critical applications in the presence of high traffic loading conditions, and for various network configurations, namely for configurations where no QoS nor Network Slicing is used (similar to existing 4G networks) and for configurations where QoS and Network Slicing is available.

In particular, in the first place test combinations of all FRMCS service types will be performed, in the absence and presence of background traffic, without any QoS differentiation, nor any other type of NS configuration per services. The effect of background traffic on the various services will be assessed.

As a second step, QoS setting will be tailored to the various services/ service categories, and the level that these will affect the service performance will be assessed.

As a third step, NS configuration over 5G Standalone (SA) will be tailored to the specific services, and their performance will be assessed especially in heavy traffic conditions.

3.6.2 Network Slicing and QoS for the Rail Enhanced MBB Patras Services

Considering the Network Slicing and QoS definition in the test combinations of the Rail Enhanced MBB in Patras, two Network Slices are suggested:

- NS 1: Critical and Performance Services.
- NS 2: Business Services (including background traffic).

Each NS could be configured with its own set of 5G QoS Identifiers (5QIs). In the case of the Patras deployment, standardized (3GPP TS 23.501) 5QI values with characteristics will be selected.

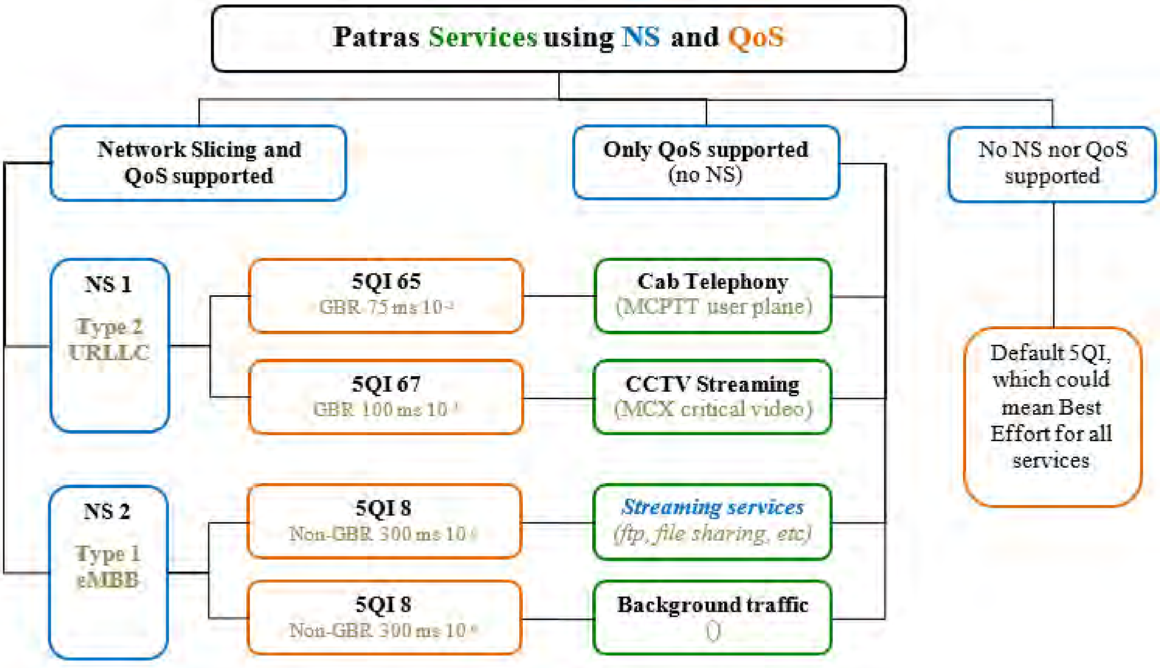


Figure 3-7 Patras Services with and without Network Slicing, plus QoS support

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

4.1 Description

As described in deliverable D2.1 [1], D2.2 [2], D2.3 [3] and D2.4 [4] 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, **ZN** (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 Rail Digital mobility Bristol dedicated Network test cases (RDNu)

4.2.1 Overview

As part of 5G-VICTORI, the 5GUK test network (**UNIVBRIS**) integrates **DCAT**'s 5GNR, **i2CAT**'s Slice manager and Wi-Fi solutions, and ZN's Zeetta Automate solution for providing various telecommunications services in a demonstration incorporating Digital Mobility at Bristol **App1**, **App2** and **App3** UCs as shown in Figure 4-1.

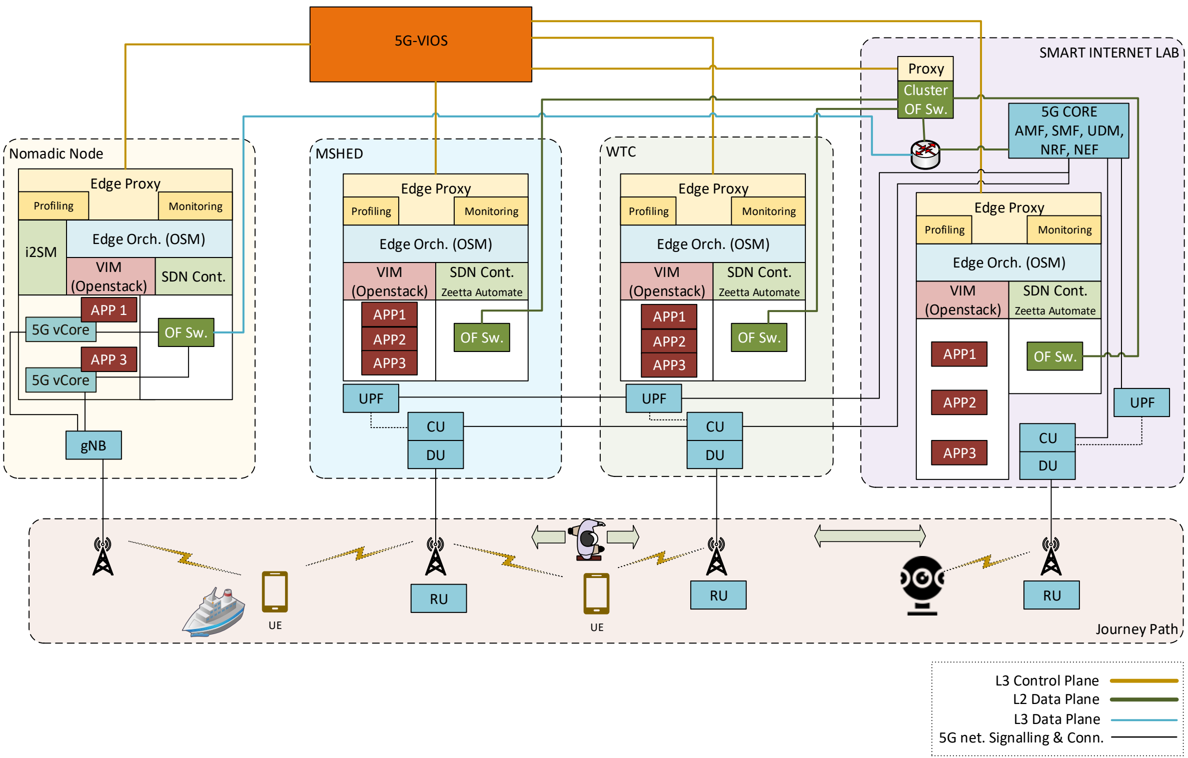


Figure 4-1 Digital Mobility Bristol- 5GUK Test network - E2E architecture

The demonstration, as already mentioned in deliverable D3.1, will involve 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. The journey starts from MShed, users will get on a boat from there, the boat will reach to the outside of SS Great Britain, while the users are still on the boat, then, will arrive to the other side of the Harbourside (Millenium Square). Where, the userd will get off the boat and will continue their journey to HPN (Smart Internet Lab) by walking. In addition, a 'Nomadic' node is also deployed on the boat, specifically for the requirements of 5G-VICTORI and the boat-ride demonstration. For this Nomadic node edge location, the i2CAT's Slice manager is used to create slices on-demand integrating 5GNR and Wi-Fi access nodes. For the rest of the edges, the ZN's Zeetta Automate solution is planned to be used.

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

The test-case shown in Table 4-1 tests the performance of dedicated 5G network resources such as latency, and throughput between the core and various edges.

Note: The High Performance Networks group (HPN) is part of the Smart Internet Lab, University of Bristol and WTC (We The Curious) is located in MSQ (Millenium Square).

Table 4-1: 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.

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

The test case shown in Table 4-2 tests the performance of dedicated 5G network resources such as latency, and throughput between the core and Nomadic node.

Table 4-2: 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 5G-VICTORI 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:** 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 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

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

The test case shown in Table 4-3 tests the performance of dedicated 5G network resources such as latency, and throughput between the 5G UEs and the core, as well as between the 5G UEs and various edges.

Table 4-3: 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

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

This test case (see Table 4-4) 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 4-4: 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)

4.2.6 RDNu05: 5G-VIOS experiment deployment (lab test)

This test case (see Table 4-5) demonstrates how efficiently 5G-VIOS can deploy an experiment. The main aim is to have an automated inter-domain service orchestration platform that is able to utilise existing services offered by different domains to build an end-to-end service. This is done with the help of the 5G-VIOS portal where the user is defining an Experiment. This is tranlated to an Experiment Descriptor that is used by the 5G-VIOS microservices to deploy the E2E service. An example of Experiment Descriptor is provided in Appendix section (section 8.1).

In this test case we are focusing on a single facility, which has multiple edges, each orchestrated by its own MANO system, inter-connected with an SDN enabled fabric, where we are deploying different services. These include **App1**, **App2** and **App3** as part of Bristol Cluster.

Using the 5G-VIOS portal and logs from the various micro-services we are able to track the progress of the deployment.

Table 4-5: RDNu05- 5G-VIOS experiment deployment test case (Lab test) on Bristol facility

RDNu05	5G-VIOS experiment deployment (Lab test) on Bristol facility
Testbed	**5G-UK Bristol**
Description	This test deploys an experiment to the virtualized testbed of Bristol. In this test, an experiment includes two network services deployed to the multiple intra-facilities edges.
Key use-case requirements and KPIs	N/A
Network performance requirement and KPIs	All the resources belonging to the experiment are deployed and configured within 90 mins.
Network function requirements and KPIs	Virtual network function descriptors (VNFD), network function descriptors (NSD), and experiment descriptors required for the experiment deployment are already onboarded and exposed to the VIOS platform.

Components and configurations	**Components:** - OpenStack - OSM - K8s cluster - 5G-VIOS platform. **Configurations:** - Edge proxy is deployed at the edge. - Edge is registered with 5G-VIOS - API Gateway, OSM, NetOS, profiler, and monitoring platform are configured with edge proxy. - OpenStack is registered with OSM.
Test Procedure	**Preconditions:** - Each edge is registered. - VIOS and edges are connected. - VNFDs and NSDs are onboarded to OSM and exported to the VIOS. **Test case steps:** - User creates the experiment. - Initiate the experiment deployment. - Deploy the experiment. - Monitor the experiment and terminate the experiment.
Measurements	**Methodology** - Monitor OSMs to check the Network services are created. - Monitor OpenStack to check VMs, VLANs, and private networks are created successfully. - Monitor 5G-VIOS for creation and completion time of experiment deployment. - Monitor 5G-VIOS portal for experiment status is deployed. **Calculation process** - Analyse 5G-VIOS log to measure the time required for the experiment deployment.
Expected Result	All the resources belonging to the experiment are deployed to the expected infrastructure. Pass/Fail results: Pass: If the experiment deployed correctly within the 90 mins threshold. Fail: If the experiment is not deployed correctly within 90 mins.

4.2.7 RDNu06: 5G-VIOS experiment deployment across multiple facilities (field test)

Following testcase RDNu05, this test case is focused on inter-facility service deployment.

Table 4-6 5G-VIOS experiment deployment across multiple facilities test case (field test).

RDNu06	5G-VIOS experiment deployment across multiple facilities (field test).
Testbed	**5G-UK Bristol**, **5G-VINNI Patras**
Description	This test deploys an experiment to the virtualised testbed of Bristol and Patras. During this filed trial, an experiment with two network services will be deployed to the multiple inter-facilities edges.
Key use-case requirements and KPIs	NA
Network performance requirement and KPIs	All the resources belonging to the experiment are deployed and configured within 90 mins.

Network function requirements and KPIs	Virtual network function descriptors (VNFD), network function descriptors (NSD), and experiment descriptors required for the experiment deployment are already onboarded and exposed from both the facilities/edge to the VIOS platform.
Components and configurations	**Components:** - OpenStack - OSM - K8s cluster - 5G-VIOS platform. **Configurations:** - Edge proxy is deployed at each edge. - Edge is registered with 5G-VIOS - API Gateway, OSM, NetOS, profiler, and monitoring platform are configured with edge proxy. - OpenStack is registered with OSM.
Test Procedure	**Preconditions**: - Both facilities/edges have connectivity. - Each edge is registered. - VIOS and edges are connected. - VNFDs and NSDs are onboarded to OSM and exported to the VIOS. **Test case steps:** - User creates the experiment. - Initiate the experiment deployment. - Deploy the experiment. - Monitor the experiment and terminate the experiment.
Measurements	**Methodology** - Monitor OSMs to check the Network services are created. - Monitor OpenStack to check VMs, VLANs and private networks are created successfully. - Monitor 5G-VIOS for creation and completion time of experiment deployment. - Monitor 5G-VIOS portal for experiment status is deployed. **Calculation process** - Analyse 5G-VIOS log to measure the time required for the experiment deployment.
Expected Result	All the resources belonging to the experiment are deployed to the expected infrastructure. **Pass/Fail results:** **Pass**: If the experiment deployed correctly within the 90 mins threshold. **Fail**: If the experiment is not deployed correctly within 90 mins.

4.2.8 Measurement and traffic details / Network topology

Measurement duration	**Time duration of the measurement** [T]:*The monitoring tool will capture data from the test network continuously into a data repository for realtime or post processing and presentation of the measurement for the use case under test.* **Repetition time***: The interval between each each measurement depends on the type of the measurement and varies between ms to minutes.* **Granularity of measurements***: every 1 sec at Prometheus*
Traffic offered in the site	**Traffic Characteristics (rate)**: *Only data traffic is possible at the Bristol Test Network. This is simulated using the iPerf3* *The data rate per service can be configured by the QoS parameters in the network. Usually, this parameter is limited for eMBB services by the RAN network in use. The cell capacity in a good radio environment is typically 600*

	Mbps downlink and 200 Mbps uplink, which can be shared as eMBB service among the number of UE's connected to the cell. **Number of connections**: *a number of UE's can simultaneously connect to the network and share the cell and network capacity.* *Also each UE can provide multiple service connection towards the core network with different QoS defined by the test case.* **Traffic Pattern and interarrival time**: *There are two type of traffic simulator in the test network. iPerf3 is the typical tool in use providing SCTP, UDP or TCP in Uplink or downlink.*

Network Topology	
Type of sites in the network area	Number of gNBs: **2** Size of gNBs:(wide, mid, small) **small/microcell** Bandwidth of gNB: **100 MHz** gNB deployment Option: (split option) **CPRI option for the RAN fronthaul only** Type of gNB (commercial, prototype): **Commercial**
Fronthaul/Backhaul Information	Predominant type of backhauling [wireless, fibre, copper…]: **Fibre optics** Number of backhauling links per type: **1 or 2 depending on gNBs**
Cloud Infrastructure	Servers (type, capacity, interfaces): **Dell High end servers, 40 cores/128GB Memory, multiple 10G NICs** Virtualization software: **OpenStack, Kubernetes, Opensource MANO (OSM)**

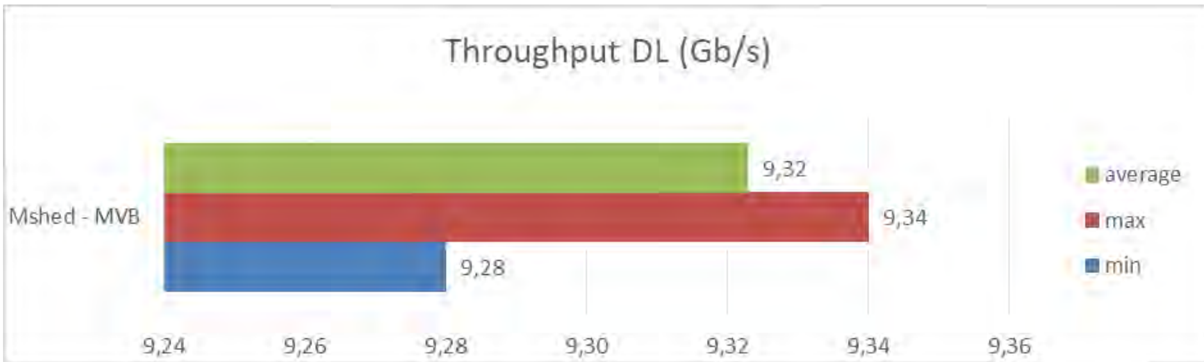
4.2.9 Lab test results

For testing the network KPIs detailed in related test cases, dummy VMs were instantiated at each edge (Mshed, WTC). Throughput and latency tests were conducted between the dummy VMs (instantiated at each edge) and the 5G Core (MVB). iPerf3 was ran for 20 s to measure the TCP DL/UL throughput. Ping was ran for 20 s to measure latency.

4.2.9.1 RDNu01: Throughput and Latency tests between edges

4.2.9.1.1 Throughput and Latency tests between MShed and 5G Core

The Throughput and Latency (RTT) between MShed and the 5G Core are shown in Figure 4-2.



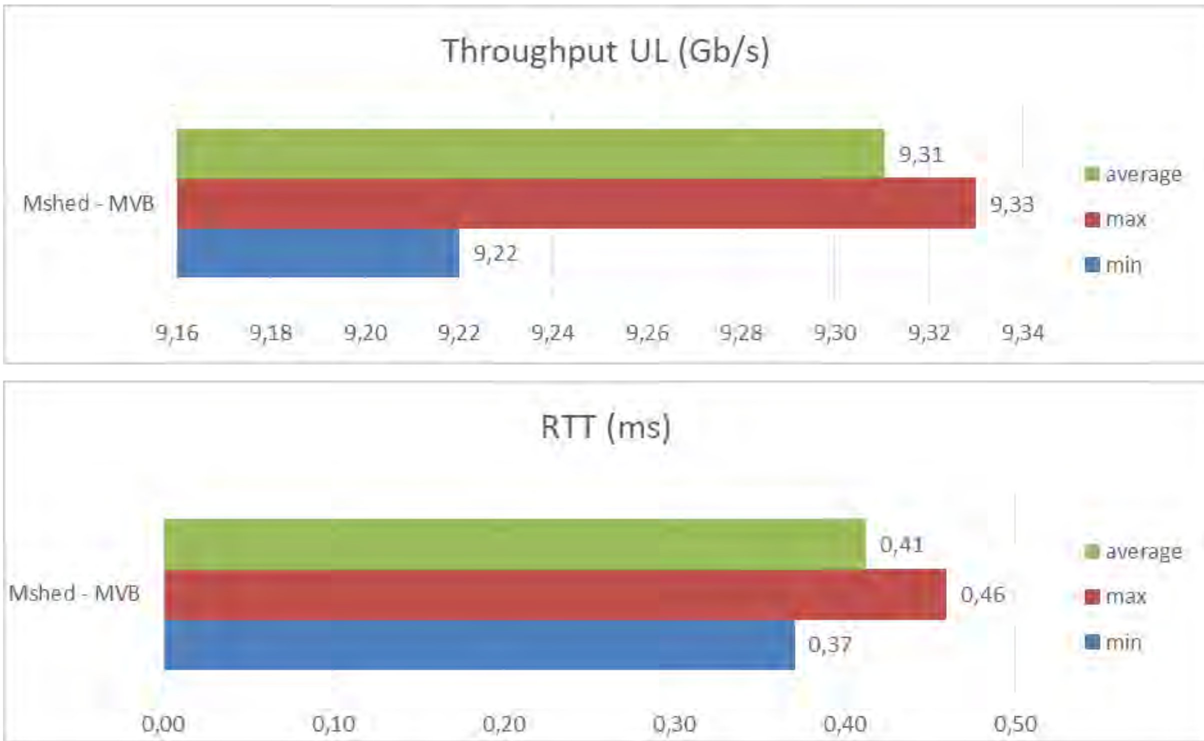
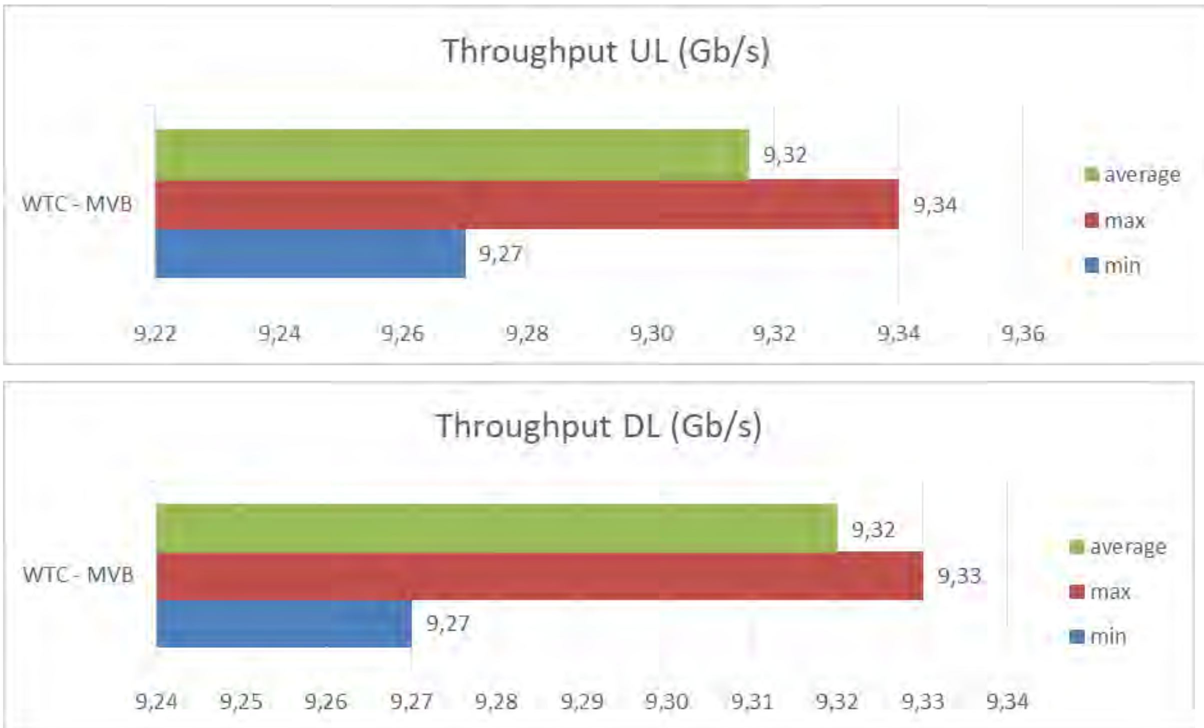


Figure 4-2 Throughput and Latency tests between MShed and the 5G Core

4.2.9.1.2 Throughput and Latency tests between WTC and 5G Core.

The Throughput and Latency (RTT) between WTC and the 5G Core are shown in Figure 4-3.



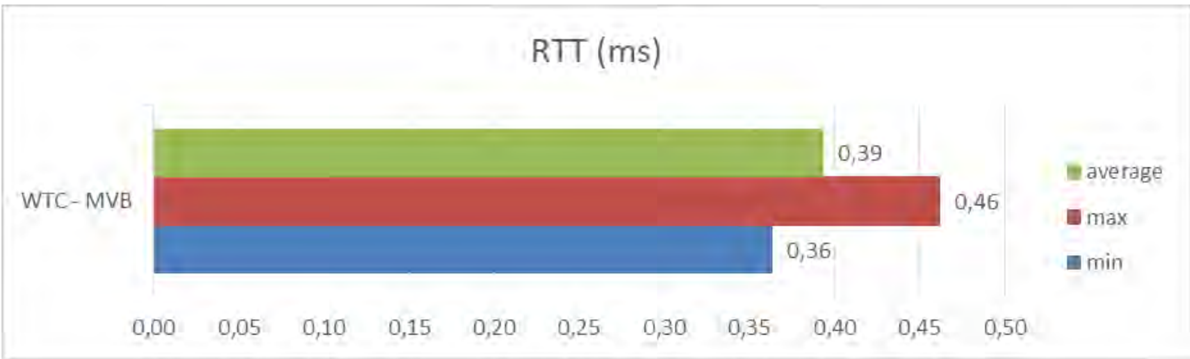


Figure 4-3 Throughput and Latency (RTT) between WTC and the 5G Core

4.2.9.1.3 Throughput and Latency tests between MShed and WTC.

Throughput and Latency tests between MShed and WTC are shown in Figure 4-4.

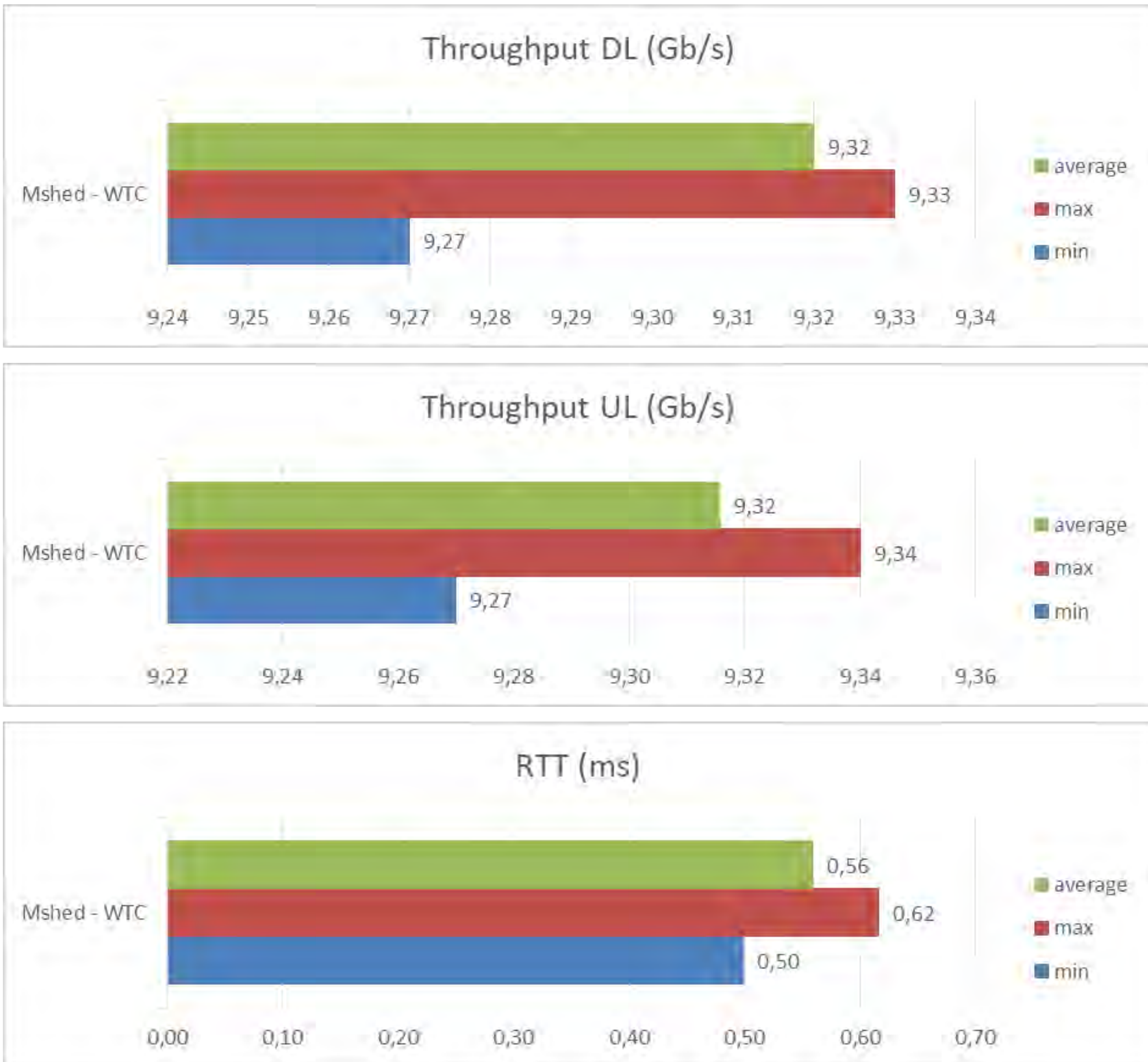


Figure 4-4 Throughput and Latency tests between MShed and WTC

4.2.9.2 RDNu04: Slice Deployment Time using i2CAT Slice Manager

The results presented in this section show the overall time required to deliver an active slice over the nomadic node infrastructure (lab testing in 5G UK premises) using i2CAT's Slice Manager (i2SM). For this test, we have considered a 5G SA scenario, where a slice deployment requires the instantiation of a full 5G Core (i.e. control and user plane network functions) in the edge resources (based on Open5Gs[1]) and the configuration of the Amarisoft gNB. In essence, the Slice Deployment Time (SDT) refers to the time required for the creation and activation of an E2E network slice, including the creation and configuration of all the virtual components, including RAN and compute resources that are entailed in the slice. This metric takes into account the execution of two main steps in the i2SM workflow: the slice creation and activation.

- Slice Creation Time (SCT): refers to the amount of time it takes the i2SM to return the results of a submitted slice creation request to an end-user. This operation includes the sequential creation of all the RAN and computing resources belonging to the slice and the grouping of those resources. This time is measured from the moment when the creation request of a slice is sent to the i2SM, until receiving the confirmation that the slice was created.
- Slice Activation Time (SAT): refers to the amount of time it takes the i2SM to return the results of a submitted slice activation request to an end-user. This operation includes the instantiation of the 5G mobile core and the configuration of the corresponding PLMNID in the RAN nodes included in the slice. This time is measured from the moment that the request is sent to the i2SM, until receiving the confirmation that the slice is ready to be used. Such confirmation is provided after receiving the acknowledgement from OpenStack about the mobile core instantiation and from the RAN Controller regarding the radio nodes configuration.

As shown in Figure 4-5, the SDT is the sum of SCT and SAT values, and is under 65 seconds (average of 30 independent experiments). Figure 4-5 depicts also the Slice Removal Time (SRT).

Figure 4-5: RDNu04: Slice Deployment Time KPIs. Average values and standard deviation of the 30 experiments

Finally, Table 4-7 shows performance results related to the deployed 5G SA slices (5 experiments per averaged value). The configuration of the Amarisoft 5G Radio was performed via the i2SM and comprehended the band 78 (frequency of 3.7 GHz), a bandwidth of 50 MHz, a subcarrier spacing of 30 kHz, MIMO 2x1 and the utilization of different TDD patterns using different slot period (5 ms and 2.5 ms) and distribution (7DS2U, 2DS7U,

[1] https://open5gs.org/

2DS2U and 3DSU). The experiments also considered two different 5G modems: Quectel RM500Q and Sierra Wireless EM9191.

Table 4-7: RDNu04: RAN performance KPIs

	UDP Downlink Throughput (Mbps)		UDP Uplink Throughput (Mbps)		Min RTT (ms)		Average RTT (ms)	
Modem	Quectel	Sierra	Quectel	Sierra	Quectel	Sierra	Quectel	Sierra
7DS2U	332.0	340.0	33.6	41.5	17.1	17.1	20.4	20.4
2DS7U	136.6	137.8	120.8	154.6	18.0	15.1	20.3	20.3
2DS2U	238.8	251.0	73.5	92.4	10.2	11.9	15.2	15.2
3DSU	371.0	371.4	35.2	44.1	9.5	11.8	15.2	15.2

4.2.9.3 RDNu02: Throughput and Latency tests between Nomadic node (Amarisoft gNB located in the Nomadic node at MVB, Smart Internet Lab) and Smart Internet Lab 5G Core

The Amarisoft gNB located at the Nomadic node was integrated to the 5GUK Testbed for lab testing (May 2022). Throughput and latency tests were conducted between the UE (connected to the Amarisoft 5G NR) and a dummy Virtual Machine (VM) on the Nomadic Node. The Amarisoft was operated only as RAN, while the Amarisoft 4G core was replaced by a 3rd party 5G core (open5gs) within the Nomadic edge. Two scenarios were tested within a lab environment, one where the Nomadic edge was physically wired to the rest of the network, and one with wireless connectivity over 5G using the 5GUK Bristol Testbed.

Please note that during the May's lab trial, we tested the wired and wireless backhaul between a UE connected to the Nomadic node and the 5G core at the Smart Internet lab. These results are provided in the next subsections. The latest measurements including the throughput and latency between the UE and the nomadic node (Amarisoft 5GBox as a gNB and 5G vCore hosted in Nomadic node (same setup as the Nomadic node edge in Figure 4-1) are as follows. iPerf3 with 50 parallel connections (-P100) was run for 60s to measure the TCP DL/UL throughput. Ping was run for 20s to measure latency.

- Average, Maximum, and Minimum Throughput DL between 5G UE and the 5G vCore hosted in Nomadic node: 251, 274, 213 Mbps.
- Average, Maximum, and Minimum Throughput UL between 5G UE and the 5G vCore hosted in Nomadic node: 45, 167, 19 Mbps.
- Average, Maximum, and Minimum Latency (RTT) between 5G UE and the 5G vCore hosted in Nomadic node: 28.56, 38.42, 19.29 ms.

4.2.9.3.1 Wired Backhaul: Throughput and Latency tests between UE connected to the nomadic node and the 5G Core.

Figure 4-6 shows the Throughput and Latency tests between UE (connected to the nomadic node) and 5G Core using wired backhaul.

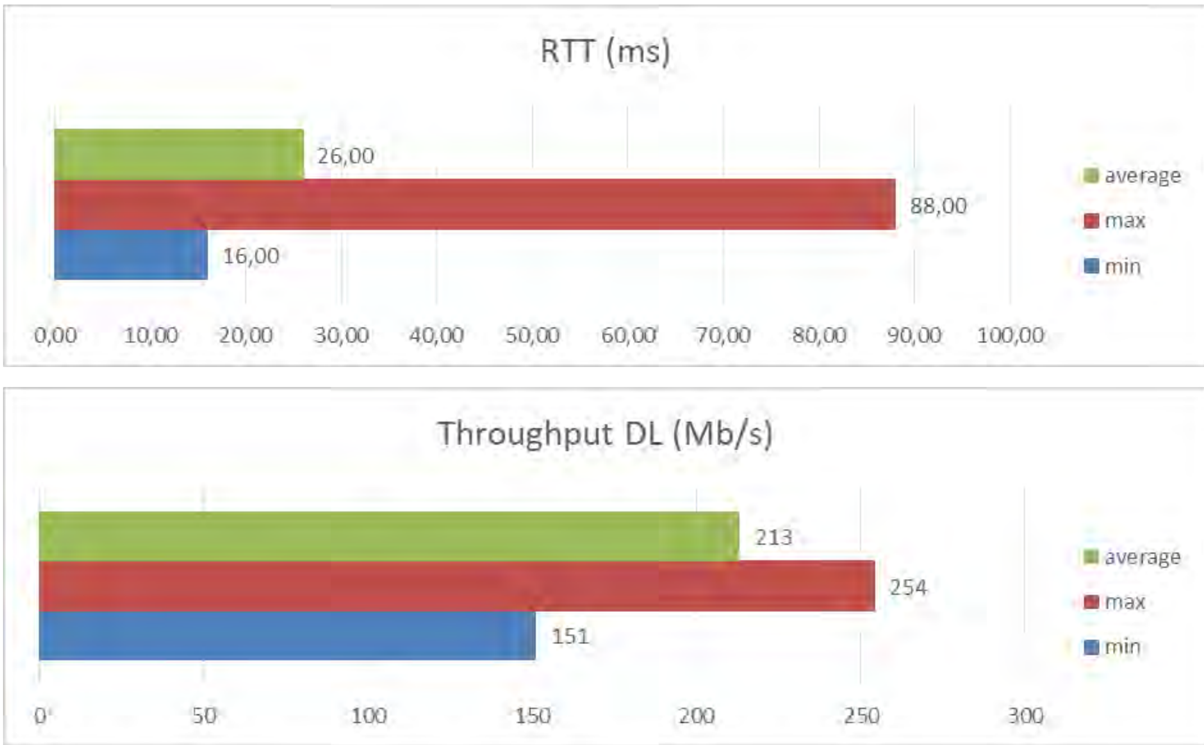


Figure 4-6 Wired Backhaul: Throughput and Latency tests between the UE (connected to the nomadic node) and the 5G Core

4.2.9.3.2 Wireless Backhaul (5G NR via WTC): Throughput and Latency tests between UE (Amarisoft - MVB) and 5G Core.

Figure 4-7 shows the Throughput and Latency tests between UE (connected to the nomadic node) and the 5G Core using wireless backhaul (5G NR via WTC).

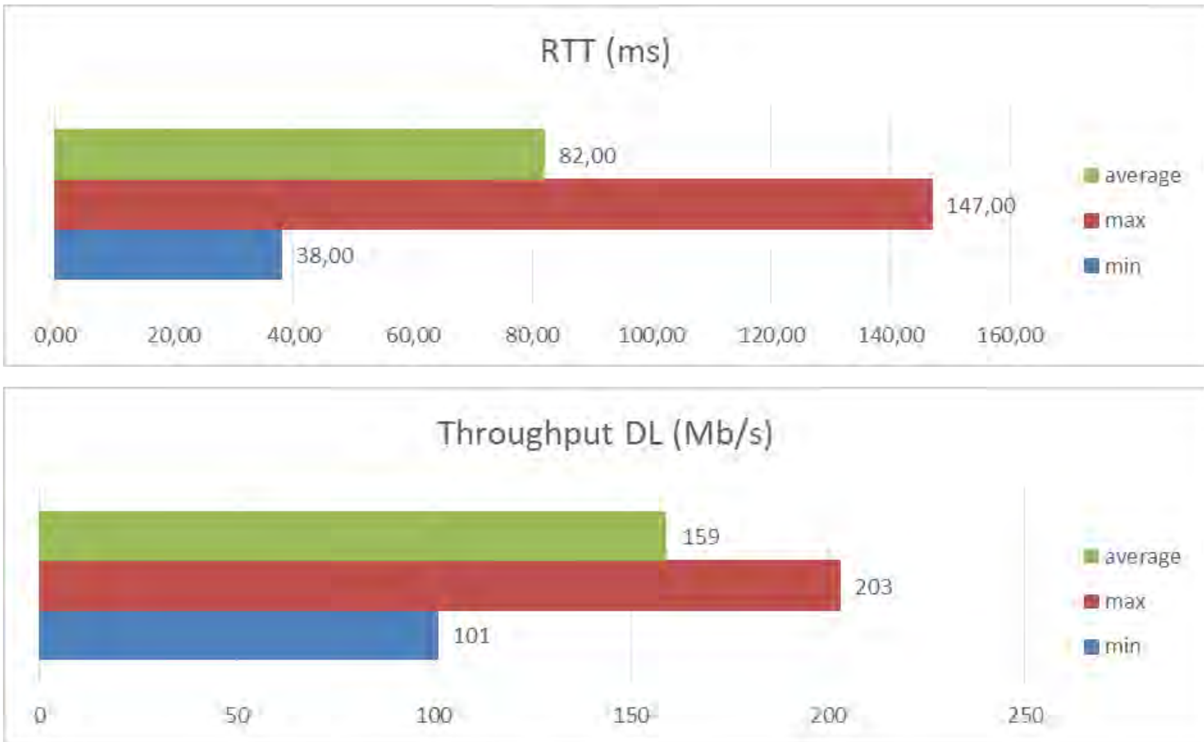


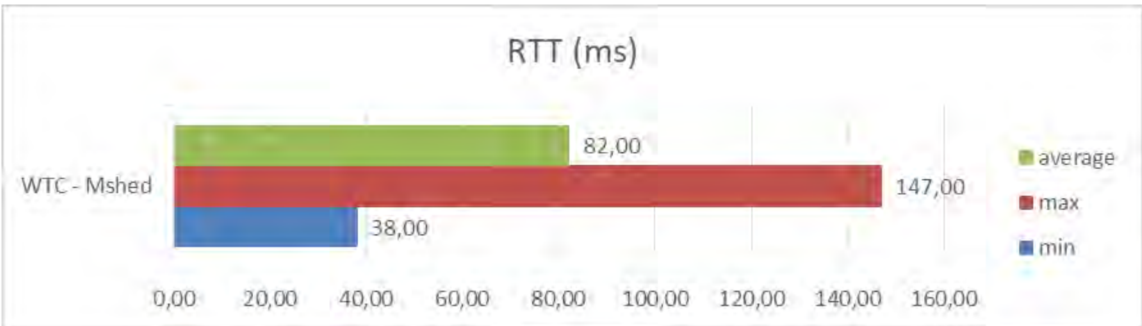
Figure 4-7 Wireless Backhaul (5G NR via WTC): Throughput and Latency tests between the UE (connected to the nomadic node) and the 5G Core.

4.2.9.4 RDNu03: Throughput and Latency tests between UE (connected to the nomadic node) and Core/Edges

Throughput and latency tests were conducted between UEs connected to the 5G NR at WTC and the 5G Core (HPN) or the Dummy VMs (Mshed, WTC). iPerf3 with 50 parallel connections (-P50) was run for 20s to measure the TCP DL/UL throughput. Ping was run for 20s to measure latency.

Figure 4-8 Throughput and Latency tests between UE (WTC) and 5G Core

4.2.10.5 Throughput and Latency tests between UE (connected to the 5GNR at WTC) and Mshed.



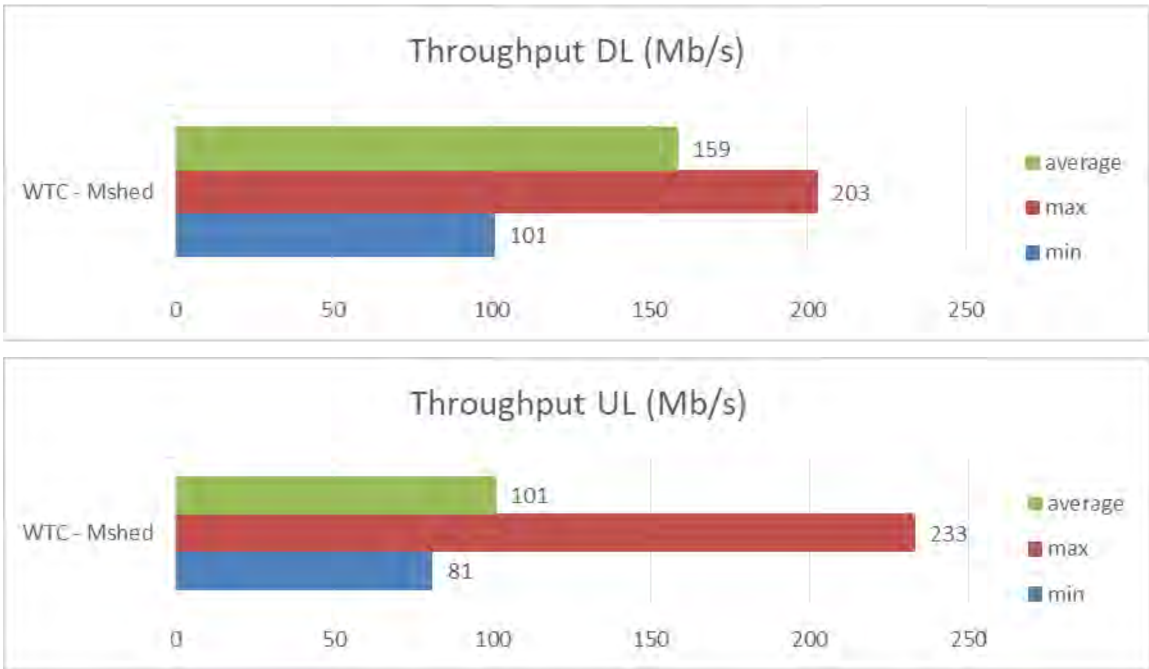


Figure 4-9 Throughput and Latency tests between UE (connected to the 5GNR at WTC) and MShed

4.2.9.5 5G-VIOS experiment deployment

During the last lab trial (May 2022), we successfully deployed the inter-edge experiment for Mativision **App1**. The **App1** experiment deployment includes deployment of two network services, namely the Mativision Cache Server and the Storage Server at two distinct edges (namely, MShed and WTC). We onboarded the experiment descriptor (section 8.1) from the portal and, then, the experiment gives request to the Service Manager and then the request goes to the profiler and the Broker for profile and VLAN selection. Further, with the help of the Inter-edge Connectivity Manager (ICM) and Edge Proxy (EPA), we have successfully deployed and configured inter-edge – e.g., Configuration of Dynamic Multipoint VPN (DMVPN) among edge routers – and intra-edge (e.g., deployment and configuration of VLAN to switches and VIM, OSPF configuration to edge router) E2E network.

During Lab trial, the total time taken by 5G-VIOS to deploy Mativision (**MATI**) **App1** was 53 seconds.

- Monitoring results: During May's lab trial, we tested the automatic integration of monitoring metrics from Zeetta Automate (exporting metrics from Zeetta Automate's ES to the Monitoring's ES), i2CAT SM (through MetricBeat), Applications 1 and 2 (Prometheus Node exporter's data of each NS through MetricBeat). ES's snapshots are shown in Figure 4-10 and Figure 4-11 (a to c).

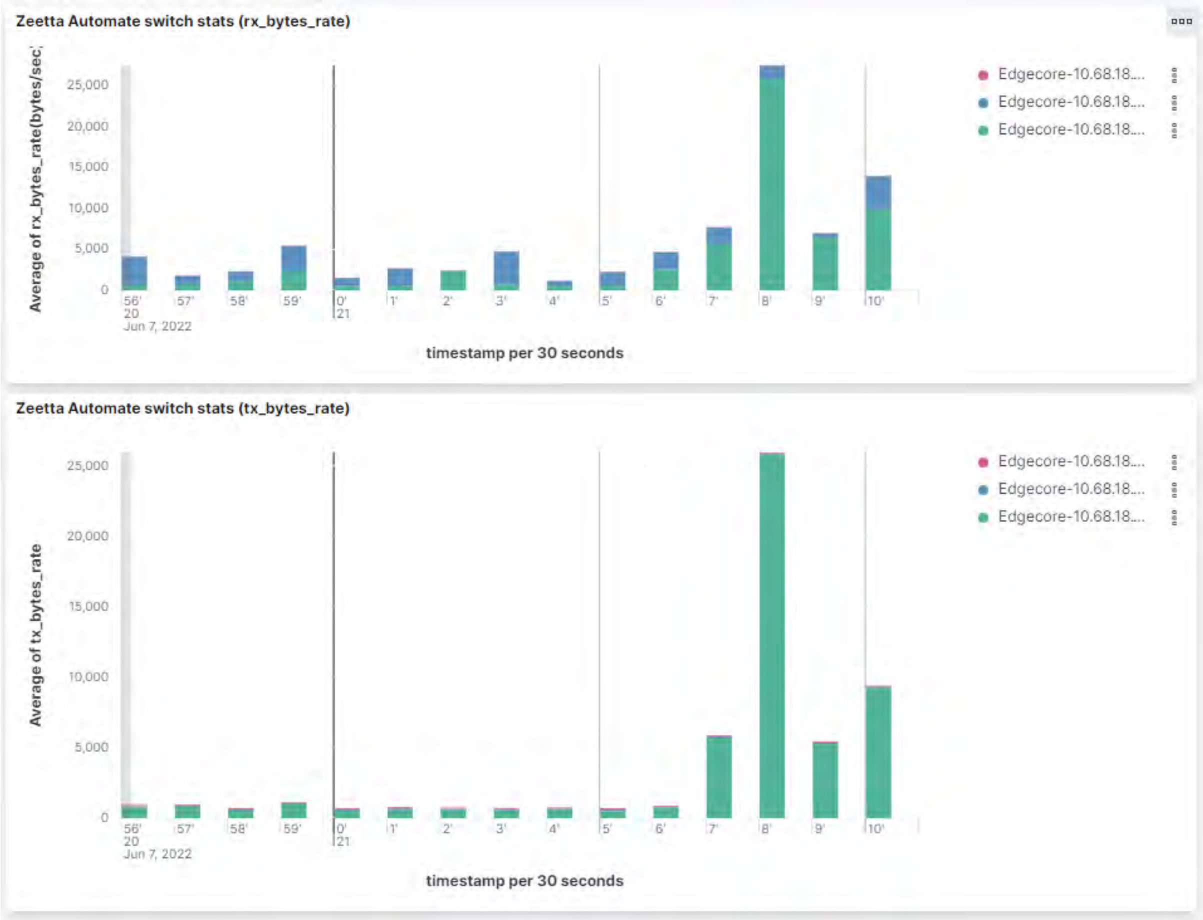
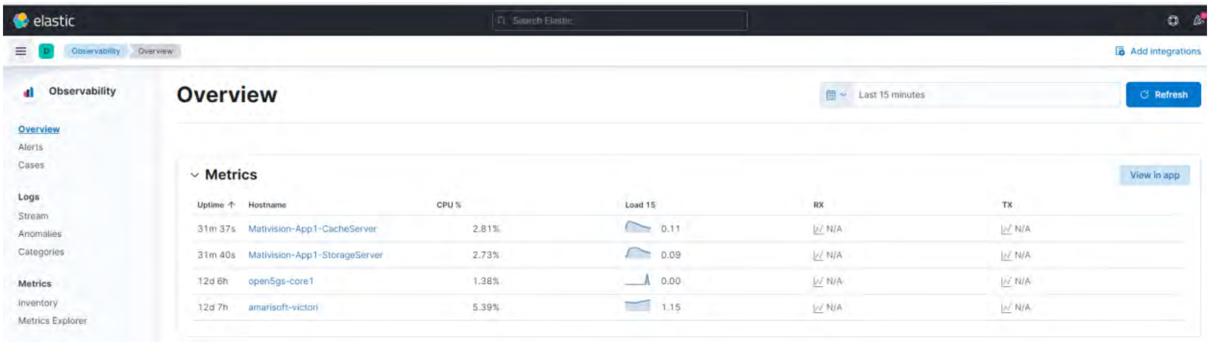


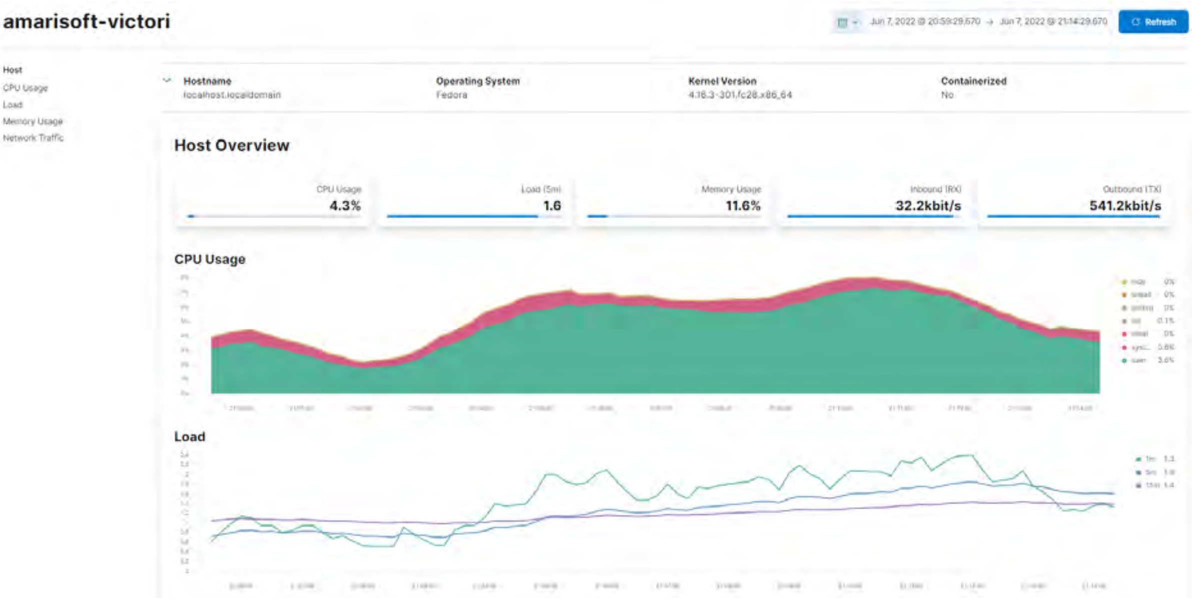
Figure 4-10 Dashboard overview of Zeetta Automate's switch stats metrics at the Edge Monitoring's ES

Figure 4-11 shows (a) Automatic integration of NSes, **i2CAT** SM and open5gs-core's monitoring metrics into the Edge Monitoring's ES (b) the Mativision (**MATI**) **App1**-Cache Server NS as an example (c) the Amarisoft (i2CAT SM) as an example.



(a)

(b)



(c)

Figure 4-11 Dashboard overview of open5gs-core at Edge Monitoring's ES

4.2.10 Demo tests planned for dedicated Network test cases

4.2.10.1 Description of the network setup

Small scale mobility tests have been conducted in a multi-edge scenario shown in Figure 4-1**.** Even though the actual project demonstration will include 4 edges, The May's lab trial test was limited to 3 edges; Nomadic Node, HPN and MShed. Different availability zones on the Openstack configuration of the 5GUK Testbed allowed inter-edge tests involving the Smart Internet Lab and MShed edges. Zeetta's Automate was integrated with 5G-VIOS and E2E service provision was tested between the aforementioned edges. Significant progress has been made on the Edge and VIOS Monitoring and Profiling. Edge computing capability and orchestration (I2CAT Slice Manager (i2SM)) were integrated to the Nomadic Node and were tested over wired (Ethernet) connectivity to the rest of the 5GUK Test Network. As mentioned in the last section, for testing the network KPIs detailed in the previous section, dummy VMs were instantiated at each edge (Mshed, WTC). Throughput and latency tests were conducted between the dummy VMs and the 5G Core (MVB). iPerf3 was ran for 20s to measure the TCP DL/UL throughput. Ping tests was executed for 20s to measure latency. The KPI results are provided in previous section.

Currently the final project demonstration in the city centre is planned towards the end October 2022. The actual date will be confirmed once the venue and event has been booked through the relevant team. The final demonstration will demonstrate two applications with three edge nodes connected to the core network at the University of Bristol as shown in Figure 4-1**.**

4.2.10.2 Description of the i2SM setup

The basic network architecture for the i2SM setup comprehends a i2SM instance deployed in the Smart Internet Lab (5GUK), the VIM (Openstack) deployed in the Nomadic edge compute node and an Amarisoft gNB located in the Nomadic node. Optionally, Wi-Fi 6 APs are also located in the Nomadic Node to enable multi-RAT slices. The i2SM is connected to the edge and the RAN resources through a dedicated VLAN for management purposes through the backhaul link between the Nomadic Node and the Smart Internet Lab. The i2SM dynamically configures the RAN nodes and deploys the required 5G vCores (full core or UPF) according to the required slices. Each slice comprehends one dedicated VLAN plus subnet for the Control Plane between the Amarisoft gNB and the 5G Core (i.e. N2 and N3 interfaces) and one dedicated VLAN plus subnet for the User Plane serving the connected UEs through the UPF, which is connected to applications deployed at the edge by 5G-VIOS.

4.2.10.3 Description of the inter-edge connectivity

The integration of I2SM within the 5G UK infrastructure has been demonstrated and evaluated, being it able to deploy dynamic or pop-up RAN slices at the Nomadic Node edge. As future plans for the field trial in October 2022, we will focus on increasing the automation level of the deployment of RAN slices at the Nomadic Node via i2SM, by:

- Allowing 5G-VIOS to dynamically deploy RAN slices through i2SM: As is done with OSM to orchestrate applications, the objective is to allow 5G-VIOS to dynamically orchestrate the RAN resources at the Nomadic Node. This will be done by interacting with i2SM's northbound.
- Integrating Application and UE networks: since Applications and Core networks are deployed through different VIMs, respectively managed by 5G-VIOS and i2SM, they belong to different subnets. In order to connect them, the i2SM will deploy an OpenStack router within the RAN slice instantiation procedure.
- Exposing 5G Core VM metrics to the Edge monitoring subsytem: the core network VMs expose compute-related metrics through a Prometheus' Node Exporter. The

configurations that are needed to expose them to the ELK framework through Metricbeat will be automated during VM instantiation via OpenStack's cloud-init.

For measuring RDNu04 KPIs, the network comprehended a i2SM instance deployed in a cloud compute node, an Openstack deployed in the Nomadic edge compute node and an Amarisoft gNB. The i2SM was connected to the edge and the Amarisoft through a dedicated VLAN for management purposes. To compute this KPI, a custom Python script was developed to automate the slice deployment, time measurement and slice removal by sending the required REST API calls to the i2SM. This script measures and stores the times involved in each operation in a database, simulating user requests (like the ones done via the Dashboard). Slice creation and activation basically involves the configuration of the Amarisoft gNB, the instantiation of the dedicated 5G Core at the edge node through Openstack, and the creation of the Control Plane (dedicated VLAN and subnet between the 5G Core and the Amarisoft) and User Plane (dedicated VLAN and subnet for UEs connectivity) networks through Openstack. Slice removal comprehends deleting the 5G Core, reconfiguring the Amarisoft and removing the aforementioned dedicated VLANs and subnets.

4.2.10.4 **Description of the Zeetta automate setup**

Zeetta Automate was installed on a VM. Edgecore switches were adopted, which allowed Automate to create services to set and change VLANs on their ports. Additional code was added to the VIOS edgeproxy to expose the REST endpoints to control the Zeetta Automate services. In addition, Statistics from each Edgecore switch adopted were obtained periodically by Zeetta Automate and were sent to the dedicated elasticsearch server at the corresponding Edge Monitoring component of 5G-VIOS.

4.2.10.5 **Description of the 5G-VIOS setup and integration with the 5GUK test network**

The integration of 5G-VIOS with the 5GUK test network had three steps:

- First, a Kubernetes cluster was created on the testbed where 5G-VIOS would be deployed. Using DepOps tools (github actions, helm charts), deployment of 5G-VIOS is automated. This creates the pod and instantiates all 5G-VIOS microservices.
- Then, three edges were defined (HPN, MShed and WTC) where OSM was installed and linked to the underlying virtual infrastructure. 5GUK defines them as different availability zones in its Openstack deployment. Another Kubernetes cluster is created on each edge and Edge Proxy is instantiated again using DevOps (Helm Charts).
- The final step is to onboard a particular edge with 5G-VIOS. For that, the 5G-VIOS Portal is used where an Edge Descriptor is uploaded (can also be manually added). This contains information about the edge, including its name, IP, Port, VLAN pool, the NSs that are installed, its location, etc. Example descriptor is in the Appendix Section. Once the onboarding is successful, the end user can then start deploying experiments.

4.2.10.6 **Description of the inter-edge connectivity through 5G-VIOS**

For each experiment, 5G-VIOS establishes an E2E inter-edge transport network by deploying inter-edge and intra-edge network configuration. Inter-edge Connectivity Manager (ICM) and Edge Proxy (EPA) microservices enable a Layer3 inter-edge connectivity by deploying HUB-SPOKE DMVPN configuration. As part of ICM and EPA, a router is installed (VyOS router https://vyos.io/) with each EPA and ICM for enabling inter-edge connectivity.

In parallel, and for intra-edge, different Layer2 or Layer3 SDN controllers could be utilised. Particularly for 5G UK Testbed, we have Zeetta Automate and i2cat Slice Manager that are responsible for creating and configuring parts of the network. For October's trial demo, the Edge Proxy will communicate through the APIs of Zeetta Automate (NetOS), i2cat slice manager to create new subnets, and configuring port switches with specific VLAN tags. In the last lab trial, the configuration of VLAN on the switches was done manually. Further, EPA utilises APIs of VIM (e.g., OpenStack) to deploy the corresponding VLAN at the virtualised infrastructure. Once inter-edge VLAN is configured, EPA attaches the VLAN and then, configure OSPF to edge VyOS router to enable communication among VLANs (private network) deployed at distinct edges.

For October's field trial, it is planned to demonstrate metrics from all the edges (e.g., resource utilisation by deployed NS, Network performance, etc.) at the VIOS monitoring component. VIOS monitoring microservice will fetch the metric from the edge monitoring component available at each edge via Edge Proxy and API gateway. Additionally, the deployment of experiment/network services will be done by utilising the 5G-VIOS profiling. The 5G-VIOS profiler will communicate with Edge Profiler to fetch all the profiles corresponding to network services belong to an edge. When the Service Manager receives a request to deploy a network service, it first sends a request to get a profile for NS from the 5G-VIOS profiler. Then, the Service manager sends the details to edge proxy to deploy a NS with a given profile. To enable this, the transferring of Performance profiles from the Edge Profiling's ES to the 5G-VIOS Profiling's database will be implemented.

On how the KPIs (RDNU05 to 6) have been measured, 5G-VIOS is logging every microservice with timestamped entries, so we are able to track each process, for example from the time a user is clicking the deploy button on the portal for a particular experiment until an acknowledgement that all services and networks are up and running is received back. Through log analysis, we are also able to track individual components and sub-processes.

4.2.10.7 **Monitoring setup (the Edge monitoring and VIOS monitoring components)**

Figure 4-12 (as already described in [10]) shows how metrics of Application NSs, Zeetta Automate, i2CAT SM, and 5GUK Monitoring and Measurement tool (UE Telemetry) are integrated at the ElasticSearch (ES) of Edge Monitoring.

To export the NSs' monitored metrics to the Edge Monitoring's ES, A Prometheus exporter (such as the Node Exporter) as well as an instance of Metricbeat are installed automatically on each NS (shown in Figure 4-13). It is important to note that the VIOS automatically installs the Node Exporter and Metricbeats on each NS at the deployment phase. In addition, Elasticsearch and Kibana are installed on the Edge Monitoring VM.

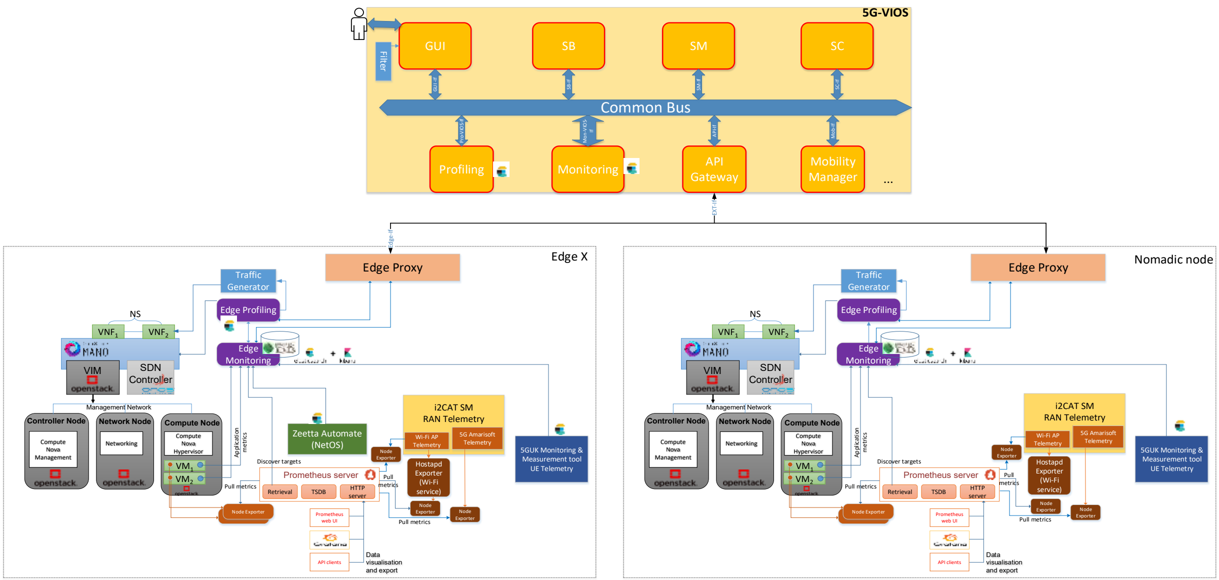


Figure 4-12 5G-VIOS Edge Monitoring and Edge Profiling components at different edges

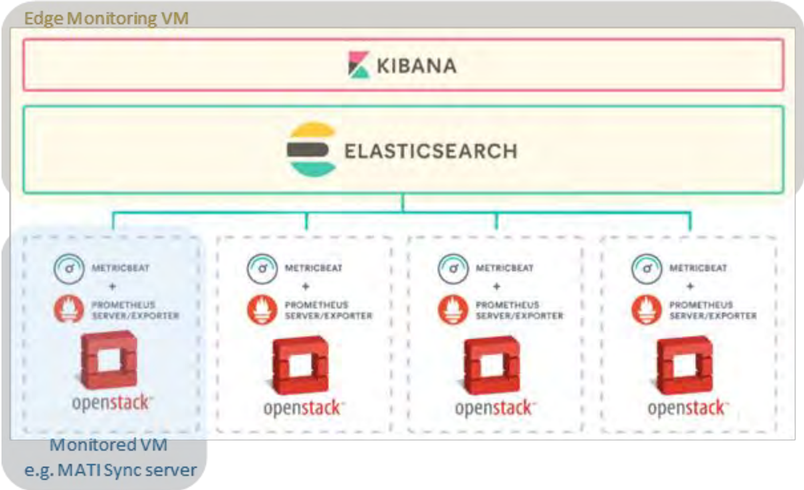


Figure 4-13 Prometheus data in ElasticSearch via Metricbeat

4.2.11 Discussion and Conclusion

In this section, we described the Rail Digital mobility Bristol dedicated Network test cases. In addition, we detailed the 5G performance measurements that are relevant in Bristol cluster followed by showing the KPI results for network test cases and 5G-VIOS experiment deployment, and Monitoring and profiling results. Then, we detailed our plan for the May's lab trial and future plan for the October's filed trial.

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

4.3.1 Overview

MATI's **App1** will provide immersive media and VR services to travellers arriving at MShed. A synchronous 360° tour guide at specific geolocations will be 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 [3]. In order to support mobility and seamless connectivity when moving from one edge to another, the synchronization edge and streaming server services will need to move as well, staying as close to the users as possible. The test cases provided in this section will 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. Figure 4-14 shows the 5GUK test network, E2E architecture including the Digital Mobility Bristol **App1** NSs and related KPIs. Please note different **App1** NSs shown at each edge.

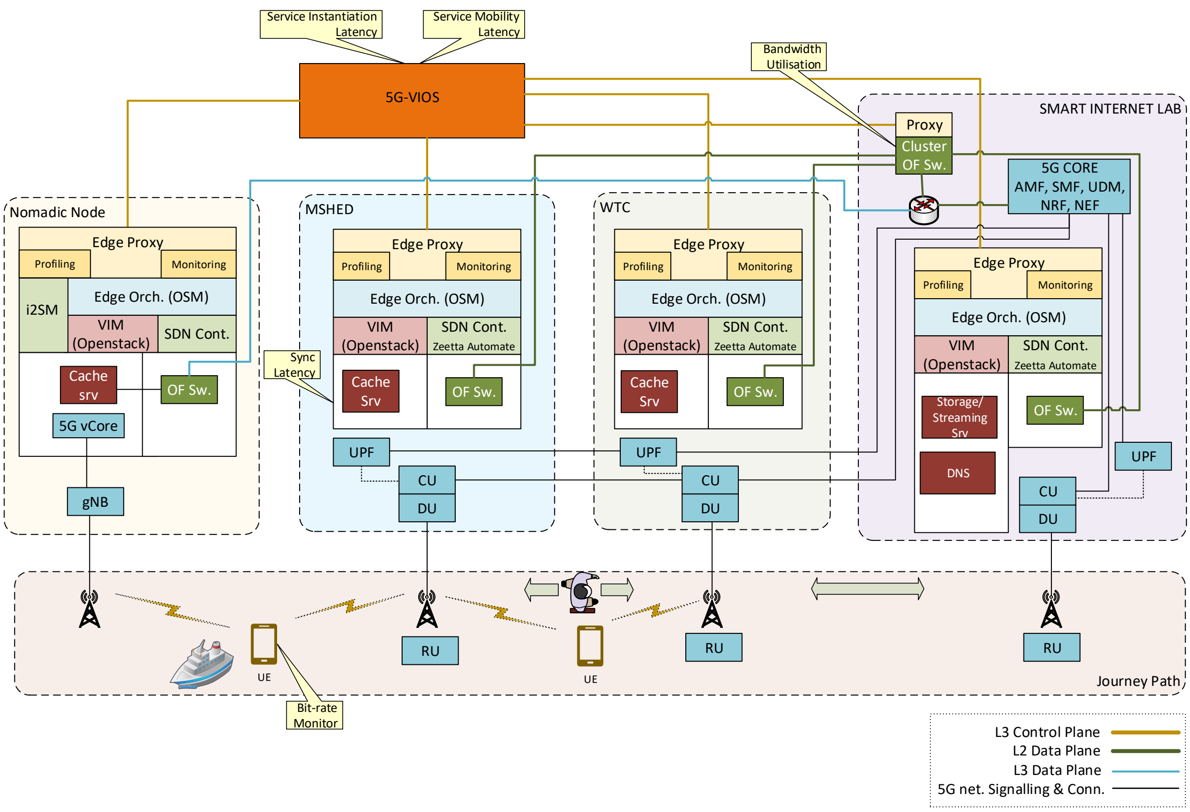


Figure 4-14 5GUK test network, E2E architecture including the Digital Mobility Bristol App1 NSs and related KPIs

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

Test case **RDIu01** will test the latency between a group leader (master) requesting a video and the whole group receiving and acknowledging the message. The test starts with a new message to the synchronization service and then waits for the response of all devices which measure the both the lowest and the highest latency in multiple spots in the test areas. The result will accurately depict both the best and worst-case scenario with multiple user groups running the same software close to each other.

Table 4-8: 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

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

Test case **RDIu02** will determine which is the most common bitrate when streaming to multiple devices at the same time. The video used during the test will be a 360 VR video consisting of multiple bitrates up to 50 Mbps. The test will rely on multiple devices requesting the same content at the same time. The software will record all bitrate changes happening and how long each bitrate is used. This will provide an accurate statistic of which is the most commonly achieved bitrate and most viewed in seconds.

Table 4-9: 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.

4.3.4 RDIu03: Mativision Mobility test (field test)

Test case RDIu03 will test 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 will record the time difference between the initial signal, the new service instance initialization and the first device logging in to the service.

Table 4-10: 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.

4.3.5 RDIu04: Mativision Edge Caching Performance (field test)

Test case RDIu04 will test the caching benefits of segments being cached on the edge and not being requested directly from the backhaul server.

Table 4-11: RDIu04 - Mativision Edge Caching Performance test (field test)

RDIu04	Mativision Edge Caching Performance test (field test)
Testbed	**5G-UK Bristol**
Description	Test to determine the caching performance of the edge service.
Key Use-case requirements and KPIs	Caching performce recorded by caching service running on the edge.

Network performance requirements and KPIs	The bandwidth saved by caching content segments on the edge..
Network Functional requirements and KPIs	Caching edge service being instanciated and being connected to the backhaul server.
Components and configuration	**- Components:** 1. Caching edge server VM 2. Backhaul video server VM 3. 5G-enabled Android Devices 4. MEC Server **- Configuration:** 1. 5G Connectivity
Test procedure	**- Preconditions:** 1. Caching service running on MEC. 2. Devices connected to caching service **- Test Case Steps:** 1. Devices start requesting content from the caching server 2. The caching server gets each segment once from the backhaul server. 3. The segments are cached on the edge service 4. Each segment is delivered to the requesting device 5. The caching server calculates the bandwidth coming in and going out of the VM.
Measurements	**- Methodology** 1. The incoming bandwidth is calculated. 2. The outgoing bandwidth is calculated. 3. The caching savings are calculated by comparing the incoming and outgoing bandwidth.. **- Complementary measurements** 1. N/A **- Calculation process** 1. Every 100 ms the traffic of the VM is calculated. 2. The incoming traffic is compared to the outgoing traffic. 3. The traffic is used to calculate the savings on bandwidth over the network by caching segments on the edge.
Expected Result	Bandwidth savings are recorded.

4.3.6 5G Performance measurements

Please refer to Sections 4.2.8 and 4.2.9 for the 5G Performance measurements and Reporting templates.

4.3.7 Lab test results

The following results are provided based on the Bristol cluster's lab testing in September 2021. Figure 4-15 (a and b) showes an snapshop from this lab trial.

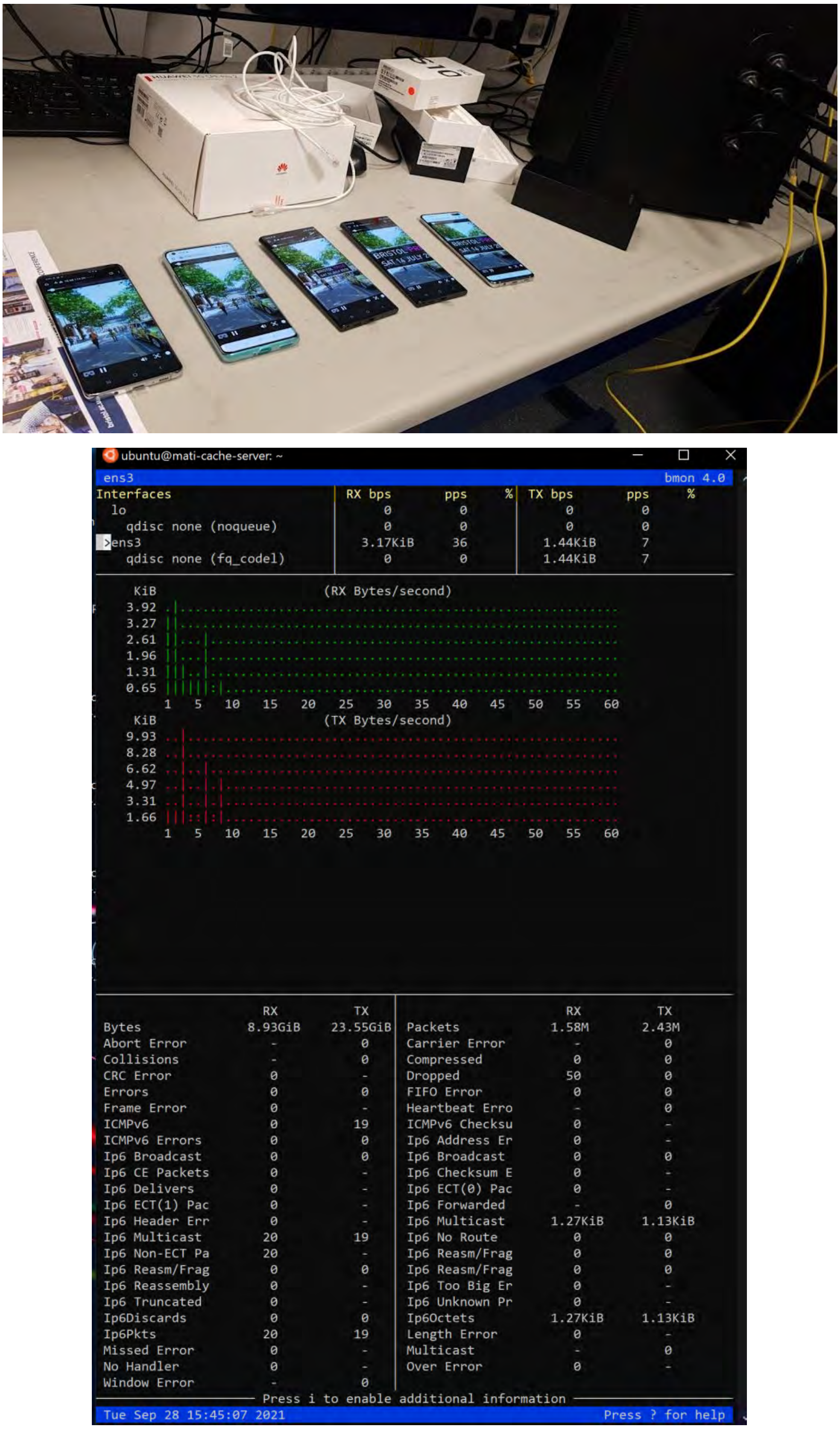


Figure 4-15 (a and b) Bristol lab trial in September 2021 to perform MATI test cases

4.3.7.1 Mativision Synchronization Latency (RDIu01)

Latency between master device message and first slave receiving the message: 15-26 ms

Latency between master device message and last slave receiving the message: 99-132 ms

4.3.7.2 Mativision 360 VR Video Streaming bitrate (RDIu02)

Mativision run tests with multiple UEs using different connections to the network as follows:

- Direct Wi-Fi: UEs connected to the network via Wi-Fi accesspoint
- CPE Wi-Fi: UEs connected to the CPE via Wi-Fi. CPE was connected to the network over 5G (The 5GNR solution provided by Amarisoft 5Gbox)
- Direct 5G: UEs connected directly to the 5G (The 5GNR solution provided by Amarisoft 5Gbox)

The results are as follows:

- Over Direct Wi-Fi using 3 UEs:
  - 3 UEs were able to consistently reach the best quality video included in the test (20 Mbps).
- Over the CPE Wi-Fi using 4 UEs:
  - 1 UE consumed the 20 Mbps stream
  - 2 UEs consumed the 10 Mbps stream
  - When a fourth UE was added it could only consume the 1.5 Mbps stream.
- Over Direct 5G using 2 UEs:
  - both 5G UEs (Samsung Note20) consumed the highest quality (20 Mbps).
- Over direct 5G using 2 UEs and over CPE Wi-Fi using 2 UEs:
  - 3 UEs consumed the 20 Mbps stream
  - 1 UE consumed the 10 Mbps stream
- Over Direct 5G using 2 UEs and over CPE Wi-Fi using 3 UEs:
  - 3 devices consumed the 20 Mbps stream
  - 1 device consumed the 10 Mbps stream
  - 1 device stopped receiving segments.

4.3.7.3 Mativision Mobility test (RDIu03)

No mobility tests were performed during the lab trial

4.3.7.4 Mativision Edge Caching Performance (RDIu04)

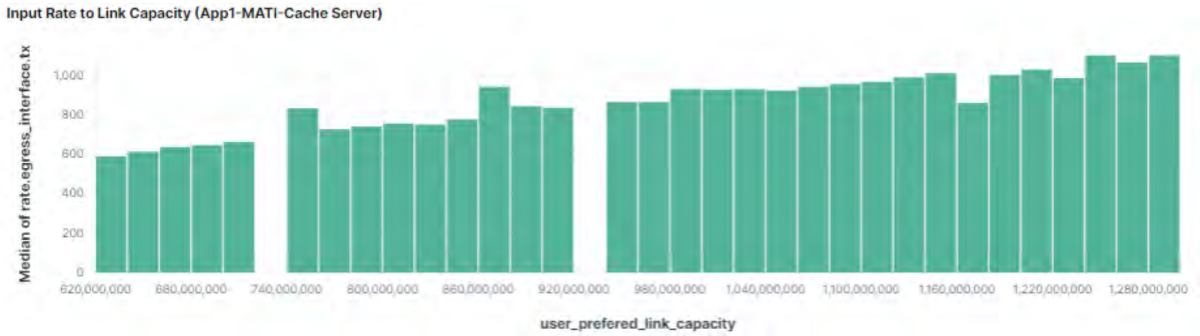
The caching server, caches the segments requested by the devices and only requests them once from the backhaul. Network performance gains depend on the device video quality. If 3 devices are on different streams the caching server caches all 3 qualities, if 3 devices are on the same quality stream the caching server caches the single requested stream and delivers it to all requesting devices.

The caching server reduced the traffic to the backhaul server 51% - 67% depending on the number of devices connected to the caching server. As more devices request the content the more efficient the caching becomes.

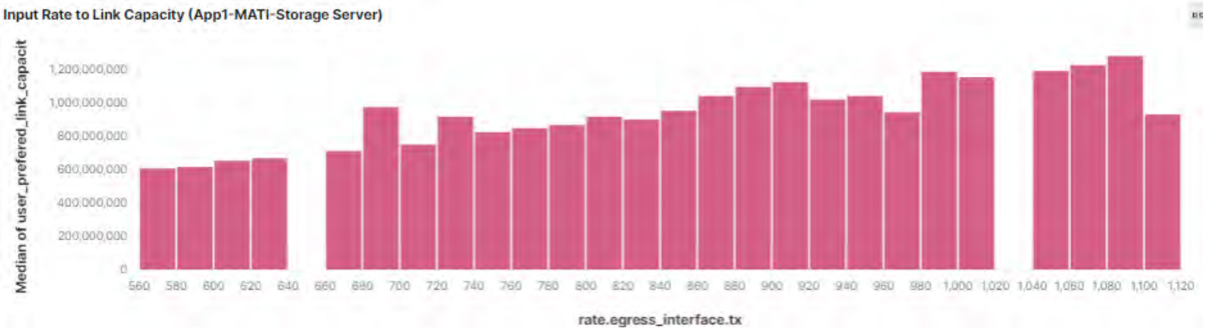
4.3.7.5 5G-VIOS Profiling results for MATI App1

As an example, to analyse the effect of various resources such as Network (Link capacity in Mbps) on the Optimum MOR (Maximum Output Rate in the rate of megabits per second) the "VNF Performance Dataset" of **MATI App1** Cache Server, Storage Server, and DNS Servers are explored from the Elastic stack repository and illustrated in Figure 4-16 a, b, and c, respectively. This can be interpreted as the higher the Link Capacity, the greater the load the NS can handle.

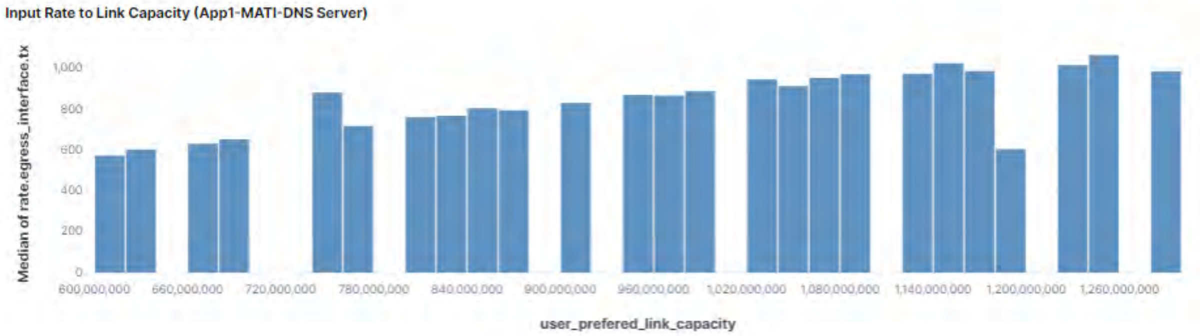
In addition, in Figure 4-17, a clear correlation between the CPU Utilisation and CPU cores can be seen increasing with the number of CPU cores.



(a)



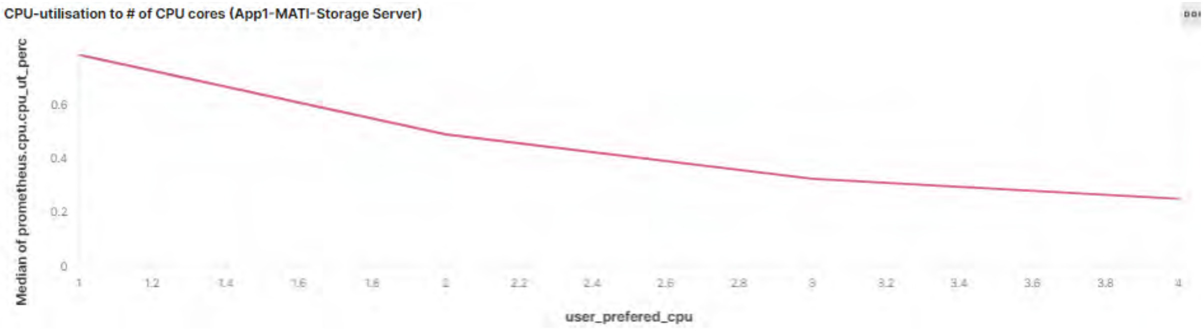
(b)



(c)

Figure 4-16 The Correlation between Link Capacity and the Optimum MOR per MATI App1 (a) Cache Server (b) Storage Server (c) DNS Server, respectively.

(a)



(b)

(c)

Figure 4-17 The Correlation between CPU cores and the CPU Utilisation KPI per MATI App1 (a) Cache Server (b) Storage Server (c) DNS Server, respectively.

4.3.8 Demo tests planned for Digital Mobility Bristol App1

- Description of the Network setup:

  The E2E architecture of 5GUK test network to demonstrate **App1** is shown in Figure 4-14. Description of the 5GUK test network setup, i2CAT SM and Zeetta Automate setup were described in Section 4.2.10, demo tests planned for dedicated Network test cases.

- Description of Application NSs instantiation and orchestration through VIOS

  During the May trial, we created three edges in the Smart Internet Lab called MShed, WTC, and HPN. At each edge, we created K8S-cluster and deployed the Edge proxy with CICD feature. For **App1**, an experiment descriptor has been onboarded from the portal to create and deploy the Network Services to distinct edges. The portal's role is to capture the information provided in each segment of the experiment descriptor and forward it to the relevant micro-service. If an experiment descriptor file is not available, the user can provide all the necessary experiment descriptor information in a form on the portal. The experiment descriptor includes information about edges, NSDs as well as the resource requirements (in the form of minimum and maximum values) for **App1**. An experiment descriptor for App1 has been compiled and provided in Appendix Section. **App1** contains two network services, namely Cache Server and Storage Server are deployed at two distinct edges (MShed and WTC) through the 5G-VIOS portal and other microservices. Once the Storage Server has been instantiated at the Smart Internet Lab edge, the Edge Proxy updates the DNS entry with the IP of that server. Currently this action is manual but it will be automated. These Network Services are shown in Figure 4-14. For deployment of App1, inter-edge (DMVPN) and intra-edge (VLAN) have been configured during lab trial by Inter-edge Connectivity Manager and Edge proxy microservice by utilising NetOS, VyOS and OpenStack APIs. The VLAN configuration of switch is currently done prior to deployment of experiment. But in future, it will be done by 5G-VIOS on the fly. During the field trial in October 2022, we will also test the migration of Cache Server from edge 1 (MShed) to edge 3 (HPN).

- Monitoring and profiling setup plan:

During the May lab trial, integration of Edge monitoring to 5G-VIOS microservices was done successfully. When a network service of **App1** is deployed, it automatically starts sending the metrics to Edge monitoring Elastic Seach. In October's field trial, all the monitoring metrics for App1 will be available at VIOS-Monitoring component.

During October's lab trial, the deployment of Network services of **App1** will be done with the profile available at the VIOS profiler. The edge profiler will intelligently calculate all the performance profiles corresponding to a Network service and send those profiles to the VIOS profiler. During NS instantiation, the Service Manager will fetch a profile and deploy the NS based on the given profile using Edge proxy.

The performance profiles with information on CPU, RAM, and bandwidth were gathered and stored in Elastic Search (ES) by the Edge Profiler. The Profiler can investigate three ML alternative techniques employed by the Predictor Manager to generate the predictor-based profiles: Multiple-Input-Multiple-Output General Regression Neural Networks (MIMO-GRNNs), Random Forest (RF), and Multi-Layer Perceptron (MLP). For the May's Lab trial, we used the MLP model as a sample. But we are capable of using the other mentioned models if needed. The role of the models generated by the Predictor Manager of the Profiler is to predict the absolute configuration of resources that is required for meeting with the given KPIs and Optimum load in the target environment. the performance profile dataset were normalised by utilising feature scaling. Each model has four input variables under the category of the KPIs and performance metrics and three output variables under the category of the resources. The input variables are CPU utilisation, Memory utilisation, Latency, and Optimum MIR, while the output variables are the number of vCPU cores, Memory, and Link Capacity (the corresponding inputs and outputs are shown in Figure 4-18).

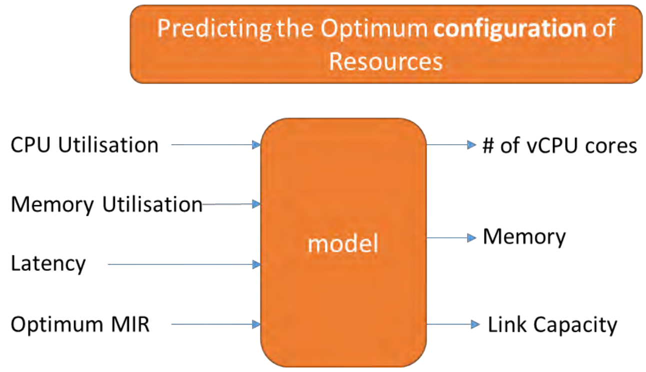


Figure 4-18 The ML model utilised by the Profiling's Predictor manager.

For the October's field trial, the VIOS Service Manager will use these predicted resources through appropriate APIs to deploy NSs with optimum resources.

- Demonstration of **App1**:
    - For the demonstration of **App1** the backhaul server and the edge service need to be instantiated via VIOS. The users will use the edge service to access cached content being streamed from the backhaul server. Once the application detects user mobility it will signal VIOS to start mobility of the edge service to the new edge location. For May's lab trial, Both backhaul and edge server VMs have been setup and tested in Smart Internet Lab (UNIVBRIS). In addition, they have been deployed

and tested through 5G-VIOS and KPIs are measured inside the application by the application code and stored in local files to the VM.

For the October's field trial, the 5G-VIOS API calls for mobility management and location edge caching will be implemented in the Application.

4.3.9 Discussion and Conclusion

In this chapter, we described the Digital mobility Bristol **App1** Immersive Media test cases. As the 5G performance measurements were the same as the network test cases, we only referred to sections 4.2.8 and 4.2.9. Then, we showed the KPI results for MATI **App1** test cases and 5G-VIOS Monitoring and profiling results. Finally, we detailed our plan for the May's lab trial and future plan for the October's filed trial.

4.4 Digital mobility Bristol App2 VR Live test cases (RDLu)

4.4.1 Overview

App2 will include a 360° VR Multicamera Live streaming and focuses mainly on large user connectivity and greater number of users. A remote training class will take 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 [3]. 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 a large number of users is streaming the content at the same time while taking into the average time spent on each bitrate. The E2E architecture including the NSs and related KPIs are shown in

Figure 4-19.

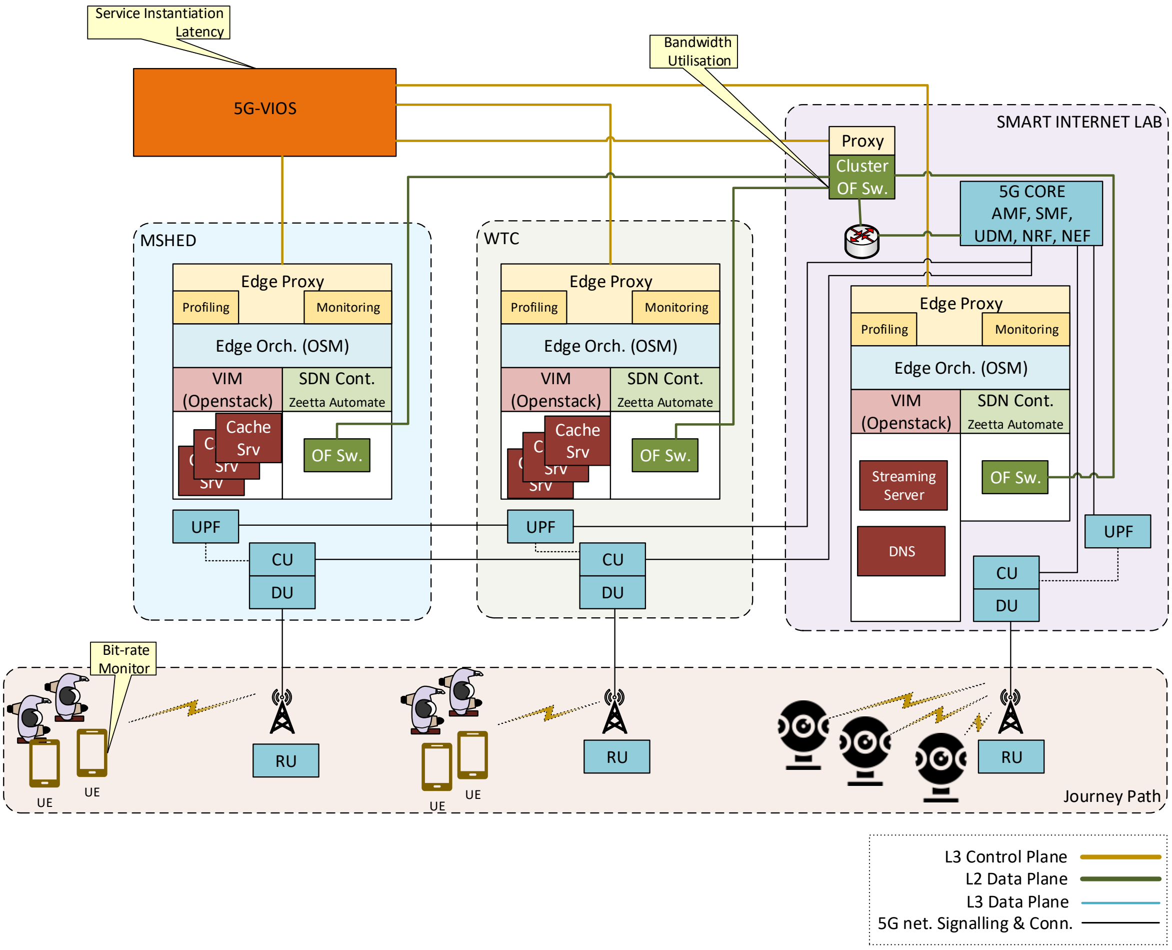


Figure 4-19 5GUK test network: E2E architecture including the Digital Mobility Bristol App2 NSs and related KPIs

Test case RDLu01 will determine which is the most common bitrate when streaming to multiple devices at the same time. The video used during the test will be a 360 VR video consisting of multiple bitrates up to 50 Mbps. The test will rely on multiple devices requesting the same content at the same time. The software will record all bitrate changes happening and how long each bitrate is used. This will provide an accurate statistic of which is the most commonly achieved bitrate and most viewed in seconds.

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

Table 4-12: 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.

<table>
<tr><td>Network Functional requirements and KPIs</td><td>The application needs to be able to request the instancing of the edge caching service VM via a 5GVIOS Api call.</td></tr>
<tr><td>Components and configuration</td><td>- 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</td></tr>
<tr><td>Test procedure</td><td>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.</td></tr>
<tr><td>Measurements</td><td>- 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.</td></tr>
</table>

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.

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

App2 notifies 5G VIOS to start up the instances on the edges. This test is to determine the latency between the request for an edge service and the edge service being up and running

Table 4-13: 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:** Caching edge server VM Backhaul Streaming VM 5G-enabled Android Devices MEC Server **- Configuration:** 5G Connectivity

Test procedure	**- Preconditions:** Streaming VM running on backhaul server. 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 instantiatethe 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** 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 theedge 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 latency.

4.4.4 RDLu03: Mativision Edge Caching Performance (field test)

Test case RDIu04 will test the caching benefits of segments being cached on the edge and not being requested directly from the backhaul server.

Table 4-14: RDIu03 - Mativision Edge Caching Performance test (field test)

RDIu03	**Mativision Edge Caching Performance test (field test)**
Testbed	**5G-UK Bristol**
Description	Test to determine the caching performance of the edge service.
Key Use-case requirements and KPIs	Caching performce recorded by caching service running on the edge.

Network performance requirements and KPIs	The bandwidth saved by caching content segments on the edge..
Network Functional requirements and KPIs	Caching edge service being instanciated and being connected to the backhaul server.
Components and configuration	**- Components:** Caching edge server VM Backhaul video server VM 5G-enabled Android Devices MEC Server **- Configuration:** 5G Connectivity
Test procedure	**- Preconditions:** 1. Caching service running on MEC. 2. Devices connected to caching service **- Test Case Steps:** 1. Devices start requesting content from the caching server 2. The caching server gets each segment once from the backhaul server 3. The segments are cached on the edge service 4. Each segment is delivered to the requesting device 5. The caching server calculates the bandwidth coming in and going out of the VM.
Measurements	**- Methodology** 1. The incoming bandwidth is calculated. 2. The outgoing bandwidth is calculated. 3. The caching savings are calculated by comparing the incoming and outgoing bandwidth.. **- Complementary measurements** N/A **- Calculation process** 1. Every 100ms the traffic of the VM is calculated. 2. The incoming traffic is compared to the outgoing traffic. 3. The traffic is used to calculate the savings on bandwidth over the network by caching segments on the edge.
Expected Result	Bandwidth savings are recorded.

4.4.5 Lab test results

4.4.5.1 Mativision Live 360 VR Video Streaming bitrate (RDLu01)

Mativision run tests with multiple UEs using different connections to the network as follows:

- Direct Wi-Fi: UEs connected to the network via WiFi accesspoint

- CPE Wi-Fi: UEs connected to the CPE via WiFi. CPE was connected to the network over 5G (The 5GNR solution provided by Amarisoft 5Gbox)
- Direct 5G: UEs connected directly to the 5G (The 5GNR solution provided by Amarisoft 5Gbox)

The results are as follows:

- Over Direct Wi-Fi using 3 UEs:
  - 3 UEs were able to consistently reach the best quality video included in the test (20 Mbps).
- Over the CPE Wi-Fi using 4 UEs:
  - 1 UE consumed the 20 Mbps stream
  - 2 UEs consumed the 10 Mbps stream
  - When a fourth UE was added it could only consume the 1.5 Mbps stream.
- Over Direct 5G using 2 UEs:
  - both 5G UEs (Samsung Note20) consumed the highest quality (20 Mbps).
- Over direct 5G using 2 UEs and over CPE Wi-Fi using 2 UEs:
  - 3 UEs consumed the 20 Mbps stream
  - 1 UE consumed the 10 Mbps stream
- Over Direct 5G using 2 UEs and over CPE Wi-Fi using 3 UEs:
  - 3 devices consumed the 20 Mbps stream
  - 1 device consumed the 10 Mbps stream
  - 1 device stopped receiving segments.

4.4.5.2 The latency between the request for an edge service and the edge service being up and running (RDLu02)

No VM instansiating tests were performed during the lab trial.

4.4.5.3 Mativision Edge Caching Performance (RDLu03)

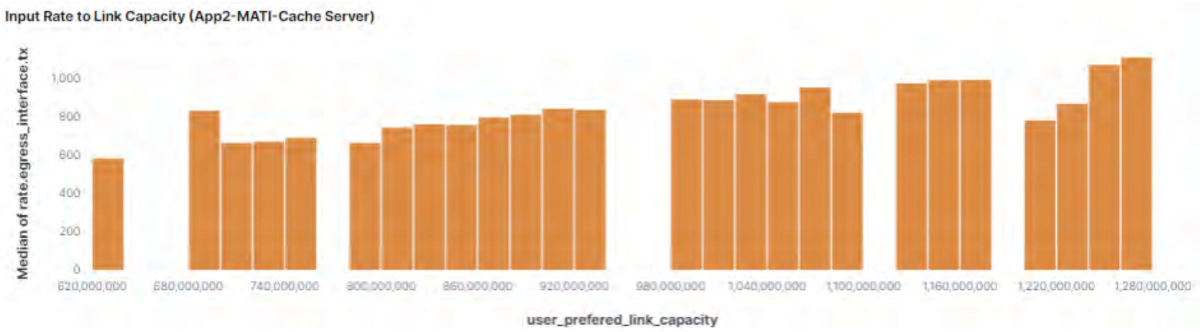
The caching server, caches the segments requested by the devices and only requests them once from the backhaul. Network performance gains depend on which quality video each device is. If 3 devices are on different streams the caching server caches all 3 qualities, if 3 devices are on the same quality stream the caching server caches the single requested stream and delivers it to all requesting devices.

The caching server reduced the traffic to the backhaul server 51% - 67% depending on the number of devices connected to the caching server. As more devices request the content the more efficient the caching becomes.

4.4.5.4 5G-VIOS Profiling results for MATI APP2

As an example, to analyse the effect of various resources such as Network (Link capacity in Mbps) on the Optimum MOR (Maximum Output Rate in the rate of megabits per second) the “VNF Performance Dataset” of MATI App2 Cache Server, and Streaming Server are explored from the Elastic stack repository and illustrated in Figure 4-20 a, b respectively. This can be interpreted as the higher the Link Capacity, the greater the load the NS can handle. In addition, following (b)

Figure 4-21, a clear correlation between the CPU Utilisation and CPU cores can be seen increasing with the number of CPU cores.



(a)

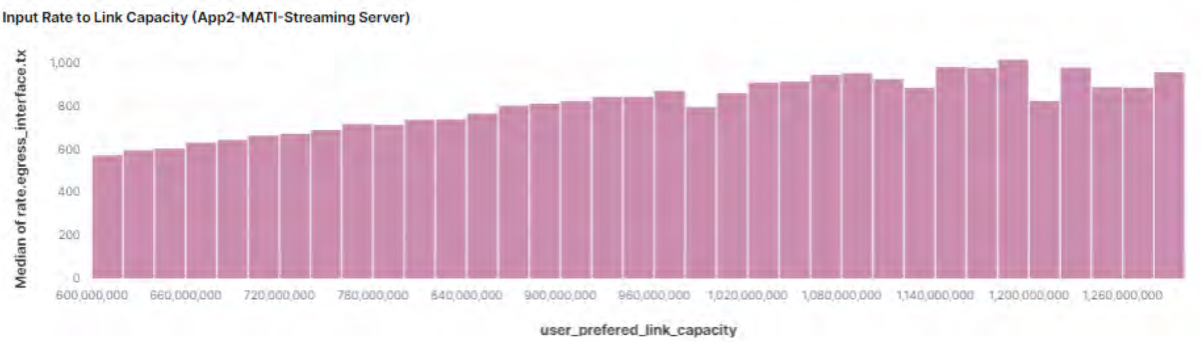
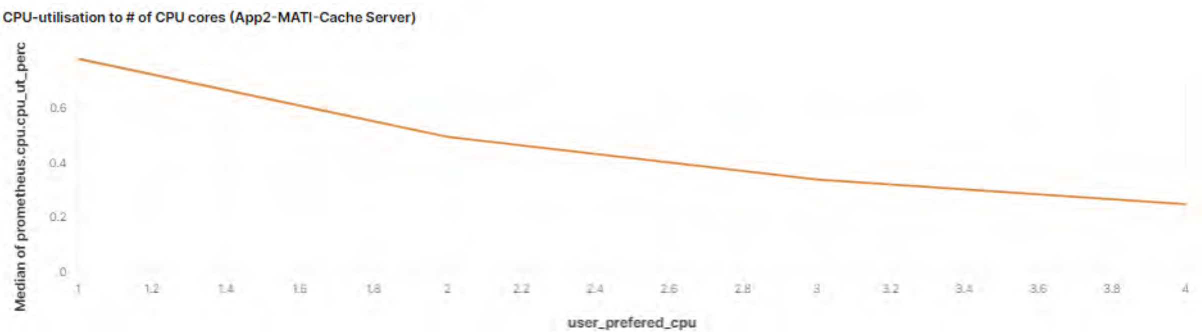
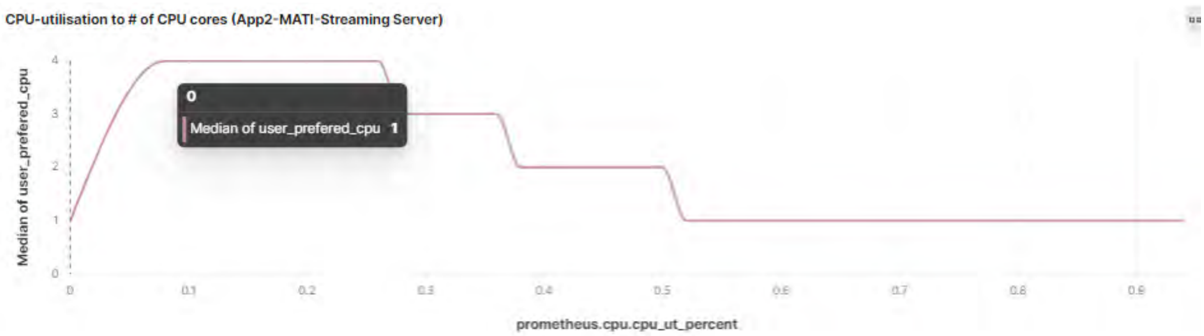


Figure 4-20 The Correlation between Link Capacity and the Optimum MOR per MATI App2 (a) Cache Server (b) Streaming Server, respectively.

(b)



(c)



(b)

Figure 4-21 The Correlation between CPU cores and the CPU Utilisation KPI per MATI App2 (a) Cache Server (b) Streaming Server, respectively.

To predict the optimum configuration of resources, we tested various combinations of resource configurations with the targeted performance metrics and KPIs for MATI **App2**-Streaming

Server NS. The ML model utilised by the Profiling's Predictor manager. The Blue boxes show how the predictor manager has predicted the optimum configuration of resources for MATI App2- Streaming Server NS. The blue boxes in Figure 4-22 show the result of the model, predicting the optimum configuration of resources for MATI **App2**, Streaming Server NS based on the user-defined target KPIs. Please note that these values are just an example, and the predictor model is able of predict the optimum resources based on any desired KPI by utilising ML techniques described in the demo test plans section.

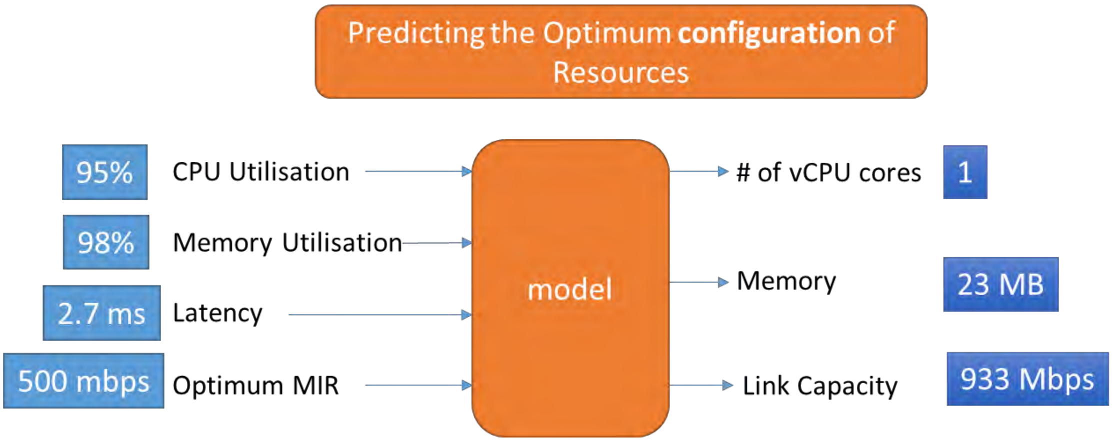


Figure 4-22 The ML model utilised by the Profiling's Predictor manager. The Blue boxes show the result of the predictor manager predicting the optimum configuration of resources for MATI App2- Streaming Server NS

4.4.6 **Demo tests planned for Digital Mobility Bristol App2**

- Description of the network setup:

The network setup is detailed in Section 4.2.10. A 360 camera was installed in Smart Internet Lab to stream data to the users at different edges.

- Description of Application 2 NSs instantiation and orchestration through 5G-VIOS

During the May trial, **App2** also uses the same infrastructure setup described in section 4.3.8. **App2** also includes two network services called Cache Server and Streaming Server. During the May lab trial, a Cache Server network service was successfully deployed at a district VLAN by the 5G-VIOS at MShed edge. During the field trial in October, 5G-VIOS will deploy the Network Service of App2 to an edge namely, MShed and Test migration of Cache Server from edge 1 (MShed) to edge 3 (HPN). ICM and edge proxy will setup and configure inter-edge and intra-edge network for **App2** by utilising VyOS, NetOS, OpenStack APIs.

- 5G-VIOS Profiling setup:

The performance profiles of MATI **App2** NSs with information on CPU, RAM, and bandwidth have been gathered and stored in ES by the Edge Profiler. As mentioned in the previous section, the Profiler can investigate three ML alternative techniques employed by the Predictor Manager to generate the predictor-based profiles; for the May's Lab trial, we used the MLP model as a sample. But we are also capable of using the other mentioned ML models if needed. The role of the models generated by the Predictor Manager of the Profiler is to predict the absolute configuration of resources that is required for meeting with the given KPIs and Optimum load in the target environment (details are provided in section 4.3.8).

- Demonstration of **App2**

For the demonstration of **App2** the edge service is instantiated via 5G-VIOS. The backhaul server is singular and needs to be running at a specific IP with a license installed. The users will use the edge service to access cached content being streamed from the streaming server.

During the May's lab trial, both backhaul and edge server VMs have been setup and tested in Smart Internet Lab (UnivBris) and being deployed and experimented by the 5G-VIOS. For remote testing ports 1935 needed to be opened. KPIs are measured inside the application by the application code and stored in the VM. Browser based reporting interface can be used to access the data. For October's field trail, the 5G-VIOS corresponding API calls will be developed at the application.

4.4.7 Discussion and Conclusion

At this chapter, we described the Digital mobility Bristol **App2** VR live test cases. As the 5G performance measurements were the same as the network test cases, we only referred to section 4.2.8 and 4.2.9. Then, we showed the KPI results for MATI **App2** test cases and 5G-VIOS Monitoring and profiling results. Finally, we detailed our plan for the May's lab trial and future plan for the October's filed trial.

4.5 Digital Mobility - Bristol App3 Future Mobility test cases (RDFu)

4.5.1 Overview

Building towards live spatial scanning of indoor transport Hubs to achive situational awareness that outperforms any other mapping and routing service available for multi-modal long distance travellers. The spatial data is collated with transport operators' live data streams (arrival times, cancellations, etc.). The arising solution is offered as a service to passengers via 5G connected smartphones.The E2E architecture including the NSs and related KPIs are shown in **Figure 4-23**.

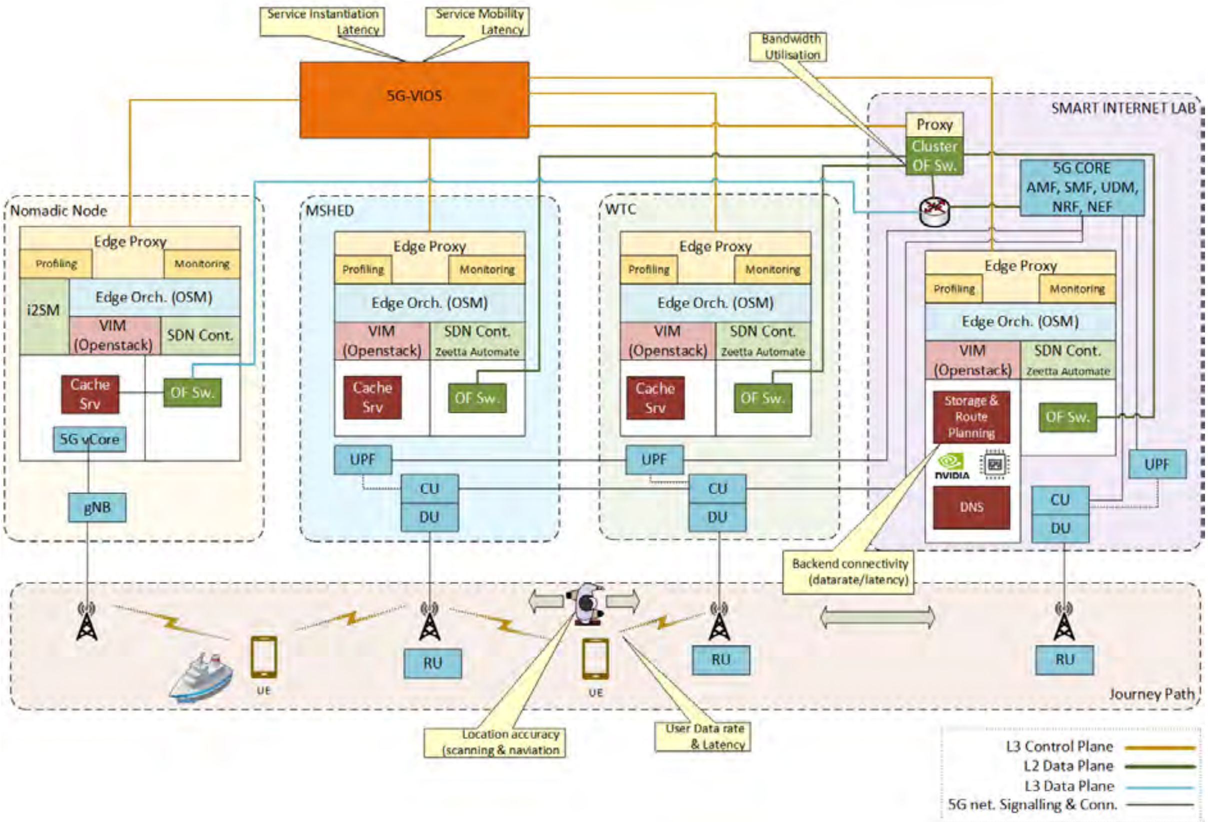


Figure 4-23 5GUK test network: E2E architecture including the Digital Mobility Bristol App3 NSs and related KPIs

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

Table 4-15 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.

Test procedure	**- Preconditions:** 1. UHA personnel scans the edge location. The captured data is fed into the digital twin and marked up and geo-tagged. 2. The Edge node contains UHA's digital twin. 3. 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:** 1. The Edge node makes connection with the passenger's mobile device (Frontend). 2. 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. 3. The two images are compared, and the difference is measured.
Measurements	**- Methodology** 1. See before. **- Complementary measurements** 1. The number of falls is manually counted. That shall be the ground truth data. **- Calculation process** 1. 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. 2. 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.
Expected Result	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.

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

Table 4-16 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.

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

Table 4-17 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.

4.5.5 Lab test results

4.5.5.1 RDFu01

The goal of these measurements was to compare spatial scan accuracy against ground truth. Our Lidar has about 100 m range. 16 laser streams with about 600,000 points per second scan performance when tilted in 45 degrees and manually walked across a building or area. The error in our office is less than 3 cm (see Figure 4-24), which is within threshold.

Our stereo camera depth estimation via neural net has an error rate of 1% that quadratically increases up to the 30-40 meters range (beyond that we ignore results as they don't deliver useful data). The worst case scenario is 10%. That gives a varying error rate between 1cm and 40cm. This type of data is useful in narrow areas where Lidar performs rather poorly. Due to the quadratic degrade this type of data needs to be supervised. If full automation is necessary then we must cut away the less performing patterns based on our confidence map values. Then it can be kept within threshold. Our office room we used is less than 3 meters at the side, therefore the error did not increase rapidly. We expect to use this technique in narrow corridors where the cross section is less than that. See Figure 4-25.

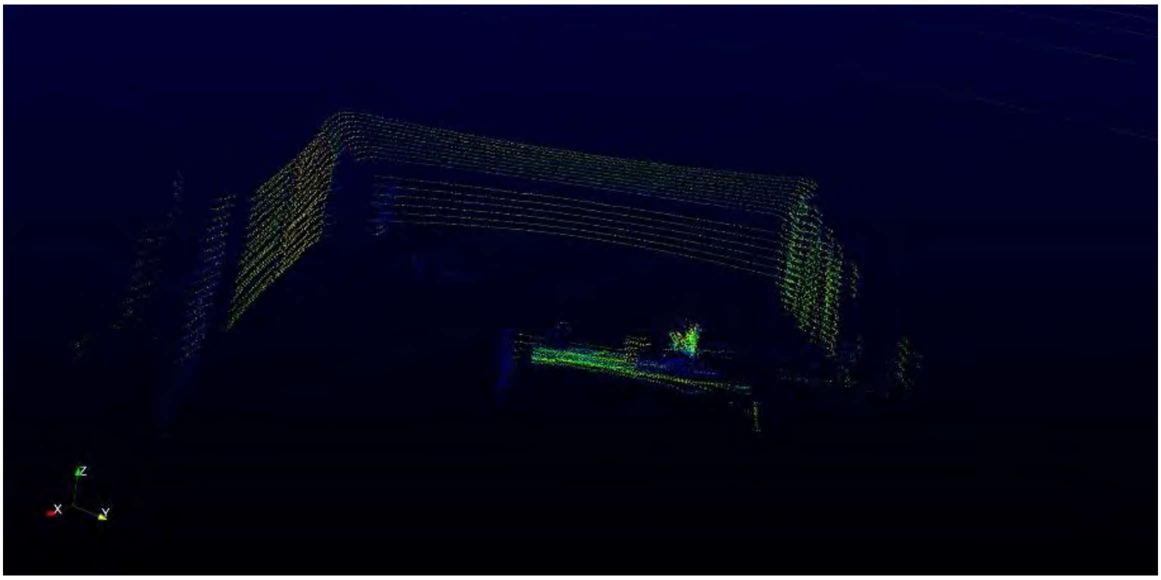


Figure 4-24 Lidar scan result in the abovementioned office area.

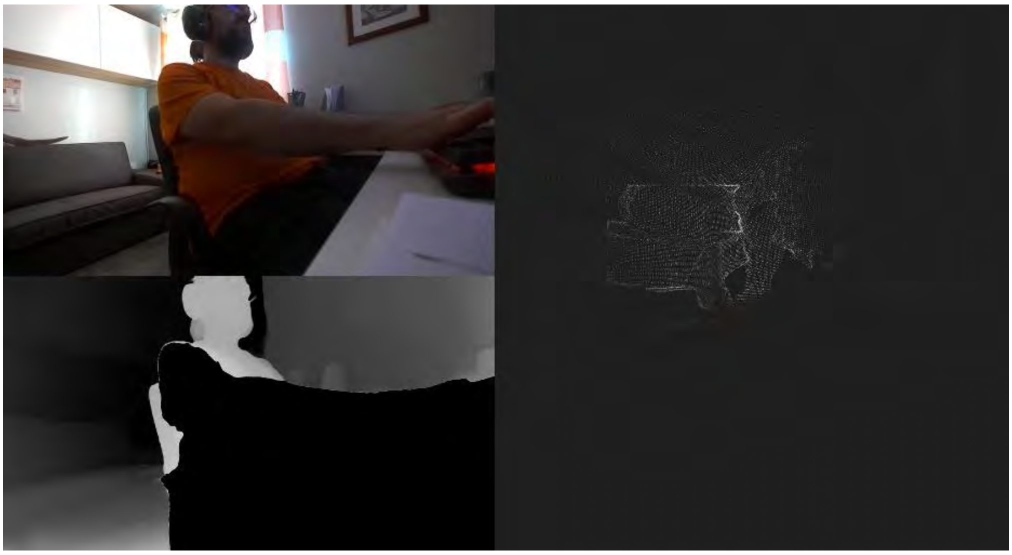


Figure 4-25 Neural net point cloud scan result via stereo camera

Figure 4-26 Cylindrical shape is the Lidar, the pair of oculars is the stereo camera

The two sensors (Figure 4-26) strengthen each other, by neural net + camera performing in narrow areas and Lidar in larger distances = Sensor fusion.

Position is tracked via GPS and structure from motion (both on Lidar and camera pointclouds). When indoors then only structure from motion is viable due to the lack of GPS signal. Structure from motion accuracy (camera position and orientation reconstruction from frame to frame) outperforms the depth accuracy. Within threshold.

4.5.5.2 RDFu02

Result A: Polaron in action in the what's on the other side of the wall first responder challenge in the US a week ago:

The sensor that penetrates walls and concrete, and was used in the lab then field test.

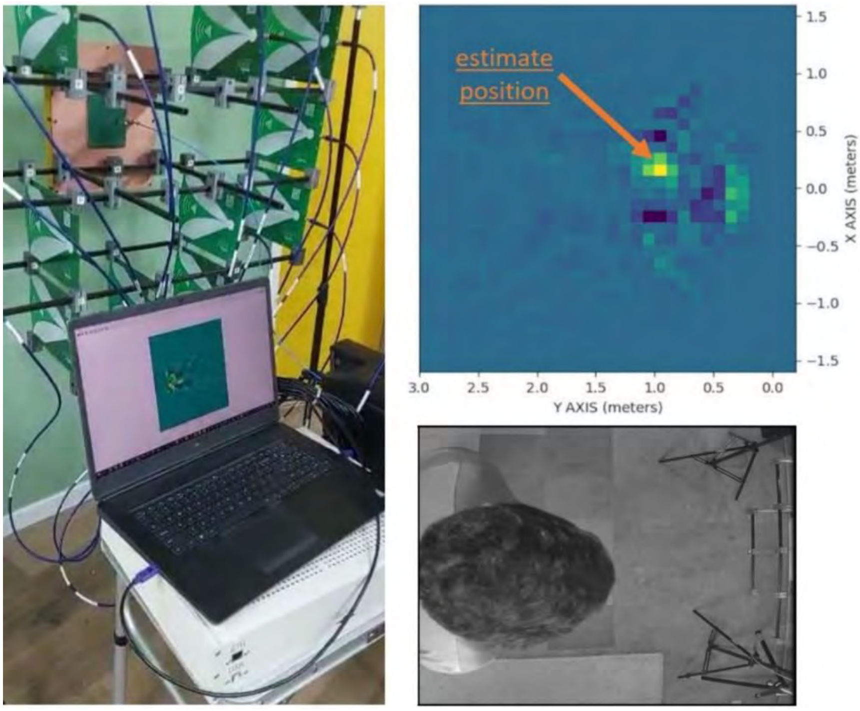


Figure 4-27 Volumetric sensor caption data

Figure 4-27 shows another sensor in action, where the captured volumetric data is liove integrated and analysed in a single grid (the integrated sensor data becomes part of the joint dataset in a single uniform grid; thereby bypassing the nearest neighbor challenge) scene in Polaron.

The data live integrated into a synthetic set already in Polaron, then processed and evaluated by the Polaron engine's AI.

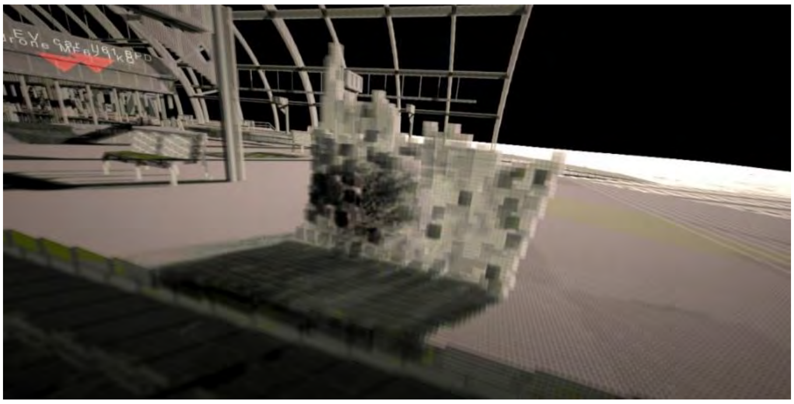


Figure 4-28 Following integration the volumetric view is rendered from the sensor side of the wall.

Figure 4-29 shows the volumetric view similar to Figure 4-28. However, this image is rendered from the other side of the wall. To see through walls is not a requirement in 5G-VICTORI, however it highlights the strengths of the overall solution in an excellent way.

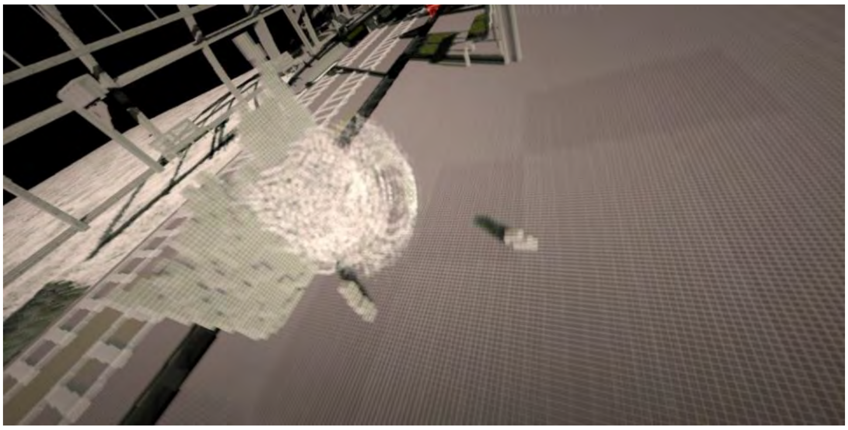


Figure 4-29 Volumetric view of the other side of the wall

Figure 4-30 Like Figure 4-28 without volumetric translucency. Only the surface of the data cube is rendered.

Video: https://www.youtube.com/watch?v=3zZmxK1Hgw8

The data has been imported from the sensor at 10 to 15 Hz pace, that is more than sufficient for the transport scenario. The 3D visuals were rendered at 100 to 200 Hz. The rest of the latency will be down to the 5G network. To be tested further.

Result B: Polaron successfully acquired the whole of OpenStreetMap's dataset for England in adaptive up to 10 cm spatial resolution. The data already sits in a grid therefore the nearest neigbour and other graph related problems are gone. Ready for fast spatial searches and route planning.

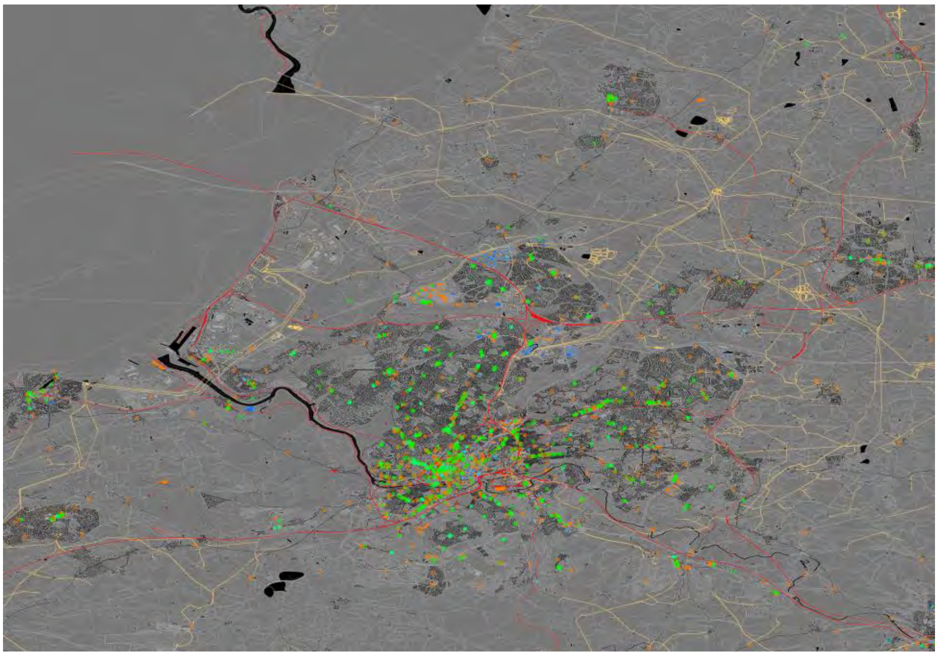


Figure 4-31 Sample image of data Points in England

UHA does have the same intel about the whole of England like Google Maps or OSM, as shown in Figure 4-31. With the difference that our GIS data is collated into a spatial grid, instead of vectors and graphs like in traditional GIS datasets and tools, that is similar to the 3D grid in Result A only this one is in 2D due to the vast area of the territories (could not be stored as a full 3D volume). Again, we managed to bypass the nearest neighbor challenge and open the door for very complex route planning (any Angle A* withg complex cost functions). The 2D and 3D datasets work tegther as one, the station areas and travel hub interiors will be in 3D 10 cm spatial resolution, the surrounding city and country wide infrastructure in 2D. Both will be rendered in 3D for the end user at front-end as a joint 3D experience.

Bristol Airport

Initial situational awareness around the Bristol Airport Terminal building and surroundings before spatial scanning (purely from OSM's GIS data):

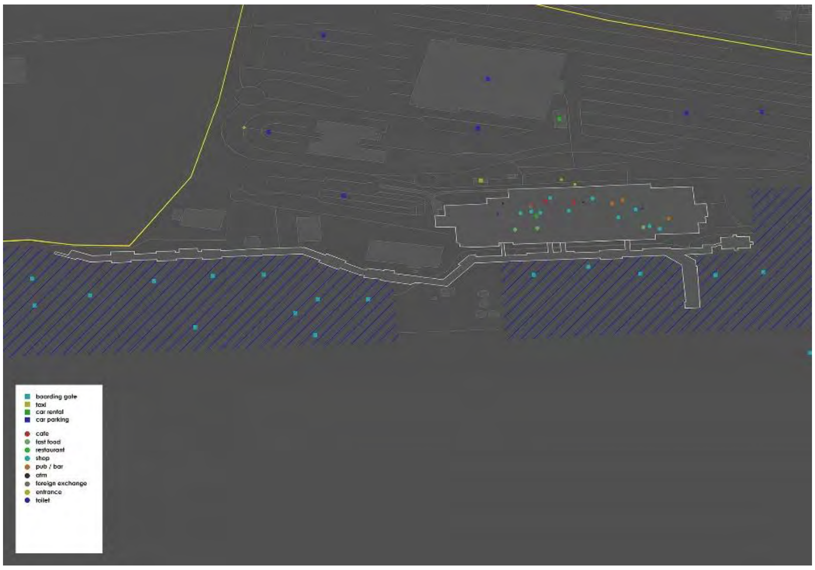


Figure 4-32 Bristol airport terminal current GIS location intelligence results.

Figure 4-32 includes the position and existence of terminal toilets, ATMs, diners and cafes, boarding gates and shops. Parking (free and paid and opening hours), footways. Further data can be scarped by following the websites (most are embedded in the OSM GIS data; otherwise can be looked up via the brand name) of each indoor facility. This will be replaced by a full 3D scan of the terminal in 2023 beyod the scope of 5G-VICTORI.

- Migration time

For Polaron to integrate the whole of England OSM dataset into our adaptive up to 10 cm spatial resolution 2D grid takes about 7 minutes. That means the data can be updated on a daily basis to keep it in sync with the core OSM dataset updates.

4.5.5.3 RDFu03

As originally forecasted when first defining the KPIs and lab versus field testing, this item will be operational for the field test only.

4.5.6 Demo tests planned for Bristol cluster-App3

- Description of the Application setup:

Please note that the Future Mobility application has been setup and tested at UHA's office. It is planned to integrate it with the 5GUK test network for the October's field trial and add the corresponding APIs for interacting with 5G-VIOS. In addition, after UHA adds the related VMs to the test-bed, we plan to generate their performance profiles and predict the optimum configuration of resources utilising ML techniques.

For testing the Future Mobility edge location spatial scanning and mapping, we measured wall and object corners and edge centers from the sensor position using a laser distance measure tool (common in construction) to get the quasi accurate ground truth. Then we compared the relevant parts of the point cloud scans against our ground truth.

Being an application developer, transitioning the application architecture from TRL 5 to TRL 7 was the goal so far and we can proudly say it has been achieved! Polaron is fully operational and being integrated with its front-end in 5G-VICTORI developed by Fraunhofer.

As mentioned above, integration with 5GUK test network in Bristol is yet ongoing. We will attempt to connect front to back-end, send captured spatial data to back-end, integrate in Polaron, then send the integrated result to front-end and show. Network testing can be simulated via commercial 5G in UHA's lab in the meanwhile.

4.5.7 Discussion and Conclusion

At this chapter, we described the Digital mobility Bristol App3 Future Mobility test cases. As the 5G performance measurements were the same as the network test cases, we only referred to section 4.2.8 and 4.2.8. Then, we showed the KPI results for **UHA App3** test cases, being measured at the UHA office. Finally, we detailed our plan for the May's lab trial and future plan for the October's filed trial.

4.6 Test-Combinations

For combined test cases, we can provide two options and run the test cases,which are mentioned in sections 4.3 to 4.5 for both options. Then, compare the expected results at the end.

- Option 1: a mixture of all 3 Bristol applications running at the same time, and on the same edge/s.
- Option 2: a mixture of all 3 Bristol applications running at the same time, but not necessarly on the same edges.

An x in the table below means that the function or service is active in the test combination.

4.6.1 Test-Combinations for Digital mobility Bristol App1 Immersive Media test cases (RDIuComb)

Table 4-18 shows the test combinations for Digital Mobility Bristol App1 (RDIuComb). A 'Main' in the table means that for that specific combined test case, the corresponding application (**App1**) will be running as the *main* application and the other applications (e.g., **App2** and **App3**) (referred to as 'Combined') will be running at the same time at the corresponding edges.

Table 4-18 Test Combinations for Digital Mobility Bristol App1 Immersive Media test cases (RDIuComb)

Test Combinations	Applications running at the same time at the corresponding edges		
	Digital Mobility Bristol App1	Digital Mobility Bristol App2	Digital Mobility Bristol App3
RDIuComb01	Main	Combined	Combined
RDIuComb02	Main	Combined	Combined
RDIuComb03	Main	Combined	Combined
RDIuComb04	Main	Combined	Combined

4.6.1.1 RDIuComb01: Mativision Synchronization Latency combined test case (lab & field test)

This test case is the same as **RDIu01**, but in a case that more than one application is running at corresponding edges. Note that the expected latency might be greater than a single running UC. Please refer to the **RDIu01** (Section 4.3.2) for the description and test case details. The combined applications are shown in Table 4-18.

4.6.1.2 RDIuComb02: Mativision 360 VR Video Streaming combined test case (lab & field test)

This test case is the same as **RDIu02**, but in a case that more than one application is running at corresponding edges. Note that the expected bitrates might be less than a single running UC. Please refer to the RDIu02 (Section 4.3.3) for the description and test case details. The combined applications are shown in Table 4-18.

4.6.1.3 RDIuComb03: Mativision Mobility combined test (field test)

This test case is the same as **RDIu03**, but in a case that more than one application is running at corresponding edges. Note that the expected mobility latency might be greater than a single running UC. According to the structure of this test case, when the service is migrated from one edge to the other edge, it is suggested to run the combined applications on both edges (the source and destination edges). Please refer to the RDIu03 (Section 4.3.4) for the description and test case details. The combined applications are shown in Table 4-18.

4.6.1.4 RDIuComb04: Mativision Edge Caching Performance combined test case (field test)

This test case is the same as **RDIu04**, but in a case that more than one application is running at corresponding edges. Note that the expected Edge Caching Performance (Bandwidth savings) might be less than a single running UC. Please refer to the **RDIu04** (Section 4.3.5) for the description and test case details. The combined applications are shown in Table 4-18.

4.6.2 Test-Combinations for Digital mobility Bristol App 2 VR Live test cases (RDLuComb)

Table 4-19 shows the test combinations for Digital Mobility Bristol **App2** (RDLuComb). A 'Main' in the table means that for that specific combined test case, the corresponding application (**App2**) will be running as the *main* application and the other applications (e.g., **App1** and **App3**) (referred to as 'Combined') will be running at the same time at the corresponding edges.

Table 4-19 Test Combinations for Digital Mobility Bristol App2 VR Live test cases (RDLuComb)

Test Combinations	Applications running at the same time at the corresponding edges		
	Digital Mobility Bristol App1	Digital Mobility Bristol App2	Digital Mobility Bristol App3
RDLuComb01	Combined	Main	Combined
RDLuComb02	Combined	Main	Combined
RDLuComb02	Combined	Main	Combined

4.6.2.1 RDLuComb01: Mativision Live 360 VR Video Streaming combined test case (lab & field test)

This test case is the same as RDLu01, but in a case that more than one application are running at corresponding edges. Note that the expected bitrate might be less than a single running UC. Please refer to RDLu01 (Section 4.4.2) for the description and test case details. The combined applications are shown in Table 4-19.

4.6.2.2 RDLuComb02: Mativision Edge Instancing combined test case (lab & field test)

This test case is the same as RDLu02, but in a case that more than one application are running at corresponding edges. Note that the expected latency might be greater than a single running UC. Please refer to RDLu02 (Section 4.4.3) for the description and test case details. The combined applications are shown in Table 4-19.

4.6.2.3 RDLuComb03: Mativision Edge Caching Performance combined test case (field test)

This test case is the same as RDLu03, but in a case that more than one application are running at corresponding edges. Note that the expected Edge Caching Performance (Bandwidth savings) might be less than a single running UC. Please refer to RDLu03 (Section 4.4.4) for the description and test case details. The combined applications are shown in Table 4-19.

4.6.3 Test- Combinations for Digital mobility Bristol App 3 Future Mobility test cases (RDFuComb)

Table 4-20 shows the test combinations for Digital Mobility Bristol App3 (RDFuComb). A 'Main' in the table means that for that specific combined test case, the corresponding application (**App3**) will be running as the main application and the other applications (e.g., **App1** and **App2**) (referred to as 'Combined') will be running at the same time at the corresponding edges.

Table 4-20 Test Combinations for Digital Mobility Bristol App3 Future Mobility test cases (RDFuComb)

Test Combinations	Applications running at the same time at the corresponding edges		
	Digital Mobility Bristol App1	Digital Mobility Bristol App2	Digital Mobility Bristol App3
RDFuComb02	Combined	Combined	Main
RDFuComb03	Combined	Combined	Main

4.6.3.1 RDFuComb02: Future Mobility communication between Backend, Frontend and Edge nodes combined test case (lab & field)

This test case is the same as RDFu02, but in a case that more than one application are running at corresponding edges. Note that the expected bitrate might be less than a single running UC and latency might be greater than a single running UC. Please refer to RDFu02 (Section 4.5.3) for the description and test case details. The combined applications are shown in Table 4-20.

4.6.3.2 RDFuComb03: Future Mobility high bitrate data distribution between Back-end and Edge nodes combined test case (field test)

This test case is the same as RDFu03, but in a case that more than one application are running at corresponding edges. Note that the expected latency might be greater than a single running UC and the expected bitrate might be less than a single running UC. Please refer to RDFu03 (Section 4.5.4) for the description and test case details. The combined applications are shown in Table 4-20.

4.6.4 Test-combinations for Rail Digital mobility Bristol dedicated Network test cases (RDNuComb)

Table 4-21 shows the test combinations for Rail Digital mobility Bristol dedicated Network test cases (RDNuComb). A 'Combined in the table means that for that specific combined test case, all the corresponding applications will be running at the same time at the corresponding edges.

Table 4-21 Test Combinations for Rail Digital mobility Bristol dedicated Network test cases (RDNuComb)

Test Combinations	Applications running at the same time at the corresponding edges		
	Digital Mobility Bristol App1	Digital Mobility Bristol App2	Digital Mobility Bristol App3
RDNuComb01	Combined	Combined	Combined
RDNuComb02	Combined	Combined	Combined
RDNuComb03	Combined	Combined	Combined
RDNuComb04	Combined	Combined	Combined

4.6.4.1 RDNuComb01: 5GUK Infrastructure combined test case Between Core and MSHED or MSQ Edges (lab & field test)

This test case is the same as RDNu01, but in a case that more than one application are running at corresponding edges. Note that the expected throughput might be less than a single running UC, and the expected latency might be greater than a single running UC. Please refer to RDNu01 (Section 4.2.2) for the description and test case details. The combined applications are shown in Table 4-21.

4.6.4.2 RDNuComb02: 5GUK Infrastructure combined test case Between Core and the Nomadic Node (field test)

This test case is the same as RDNu02, but in a case that more than one application are running at corresponding edges. Note that the expected throughput might be less than a single running UC, and the expected latency might be greater than a single running UC. Please refer to RDNu02 (Section 4.2.3) for the description and test case details. The combined applications are shown in Table 4-21.

4.6.4.3 RDNuComb03: 5GUK Infrastructure combined test case between UEs-Core, and UEs-Edges (lab & field)

This test case is the same as RDNu03, but in a case that more than one application are running at corresponding edges. Note that the expected throughput might be less than a single running UC, and the expected latency might be greater than a single running UC. Please refer to RDNu03 (Section 4.2.4) for the description and test case details. The combined applications are shown in Table 4-21.

4.6.4.4 RDNuComb04: 5GUK Infrastructure combined test case for Multi-Slice Deployment (lab & field test)

This test case (see Table 4-22) demonstrates the performance of slice management, and in particular, it is aimed to validate the effective establishment of two network slices, one per deployed service, and to measure the required slice deployment time. This test case considers two scenarios, extending the test case RDNu04 that was defined in D3.1 and in Section 4.2.5:

- MOCN-based network slicing scenario, where each slice comprehends a dedicated 5G Core.
- SNSSAI-based network slicing scenario, where the slices share a common CP and a dedicated UP.

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 4-22 RDNuComb04 - 5GUK Infrastructure combined test case for Multi-Slice Deployment (lab & field test)

RDNucombined04	**5GUK Infrastructure test case for Multi-Slice Deployment (lab & field test)**
Testbed	**5G-UK Bristol**
Description	Test the performance of on-demand multi-slice management, considering 5GNR SA RAN, in terms of network slice establishment and slice deployment time. Compare MOCN-based and SNSSAI-based network slicing approaches.
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 (5GNR SA) 3. End-user equipment (e.g. 5G-compliant mobile phone) **- Configuration:** 1. SIM card configured with testing PLMNID and APN
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 both slices 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 first slice request is received until the instant when the radio service of the second slice is active and the involved VNFs are up and running (i.e. slice status of both slices = active) 2. Repeat previous step over a minimum of 30 iterations (MOCN-based and SNSSAI-based)
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

Figure 5-1 shows the high level architecture of the Digital Mobility application of the Berlin Cluster. It integrates 5G capabilities with the MPEG Network Based Media Processing (NBMP) standard leveraging processing capabilities and resources in the 5G network. It utilizes utilizing compute, storage and graphical processing capabilities on the 5G Edge (within Data Network), taking advandage of the extremely low latency of 5G connectivity between the UE, which runs the client application (Digital Mobility Client App), and the DN, which runs the server part (Digital Mobility Edge Server). Other App resources such as 3D assets, media and application files are provided via central cloud (Digital Mobility Cloud Server) and downloaded to the Edge Server for further processing/rendering when they are needed. The whole Digital Mobility application is designed as a NBMP Workflow that consists of a set of interconnected NBMP Tasks distributed between UE, Edge Cloud and Central Cloud. Each NBMP Task is implemented as a Docker container that can be easily deployed and integrated within media processing workflows. This is a big advantage of NBMP by addressing fragmentation and offer a unified way to perform media processing on top of any cloud platform and on any IP network.

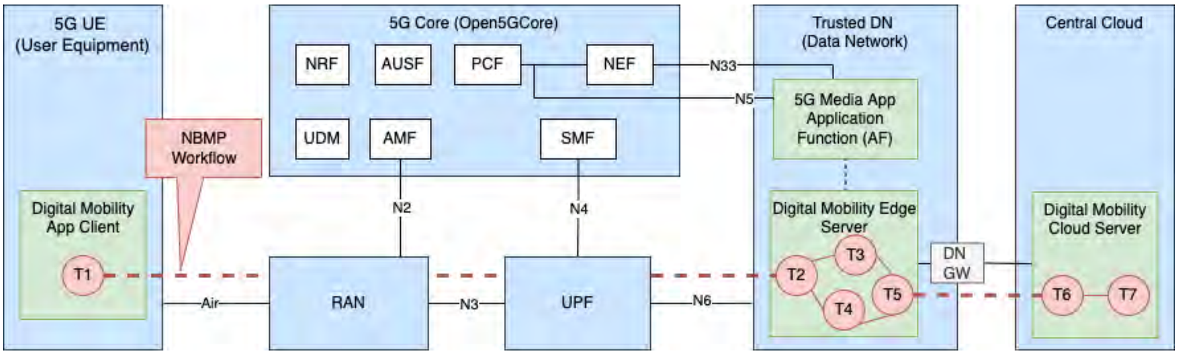


Figure 5-1 High level architecture of the Digital Mobility application of the Berlin Cluster

The components included in Figure 5-1 are:

5G UE (User Equipment): The UEs in the 5G deployment will be commercially available smartphones that are capable of connecting with 5G SA networks over 5G New Radio (NR).

Radio Access Network (RAN): The RAN consists of one or more commercially available gNodeBs utilising the 5G SA architecture. The radio will use 5G NR at a band in the 3.7-3.8 GHz range allowed in Germany for campus networks.

5G Core Network: The Berlin cluster 5G-VICTORI 5G architecture stems on the work carried out in 5GENESIS, which is heavily tied to the Open5GCore software toolkit. The Open5GCore software includes an implementation of 3GPP-standardised 5GCN supporting 5G SA networks. The NFs are implemented to adhere to 3GPP specification in their function and in protocol stacks used by the network interfaces, however they are not complete implementations of all functionality and APIs. The base 5GCN deployment comprises of the following NFs:

- Network Repository Function (NRF)
- Access and Mobility Management Function (AMF)
- Session Management Function (SMF)
- Authentication Server Function (AUSF)
- Unified Data Management (UDM)
- User Plane Function (UPF)

- Policy Control Function (PCF)
- Network Exposure Function (NEF)

Data Network (DN): The DN will be a network where the exposed N6 interface of the UPF serves as a network gateway to the IPv4 address range assigned to UEs who have PDU Sessions to the DN. A software router with an interface in the DN can be used to dynamically masquerade uplink UE traffic to external networks.

5.2 Digital Mobility Berlin App3 Future Mobility test cases (RDFg)

5.2.1 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.

5.2.2 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

5.2.3 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

5.2.4 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

5.2.5 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

5.2.6 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	E2E 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

5.2.7 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.

5.2.8 RDFg08: Future Mobility – in/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.

5.2.9 5G Performance masurements

b) Evaluation of individual building blocks.

Performance measurements for SMF			
Metric		**Description**	**Measurements**
Session Management	Number of PDU sessions (Mean)	This measurement provides the mean number of PDU sessions	For the duration of the initial MCX trial: 3 (1 used by MCX services, 2 unrelated)
	Number of PDU sessions (Maximum)	This measurement provides the max number of PDU sessions	For the duration of the initial MCX trial: 3 (1 used by MCX services, 2 unrelated)
	Number of PDU session creation requests	This measurement provides the number of PDU sessions requested to be created by the SMF.	For the duration of the initial MCX trial: 0 (all PDU sessions were requested prior)

	Number of successful PDU session creations	This measurement provides the number of PDU sessions successfully created by the SMF.	For the duration of the initial MCX trial: 0 (no PDU sessions were requested during the trial)
	Number of failed PDU session creations	This measurement provides the number of PDU sessions failed to be created by the SMF	For the duration of the initial MCX trial: 0 (no PDU sessions were requested during the trial)
QoS flow monitoring[2]	Number of QoS flows requested to create	Number of QoS flow attempted to setup. This measurement provides the number of QoS flows attempted to setup	For the duration of the intial MCX trial: 0
	Number of QoS flows successfully created	Number of QoS flow successfully established	For the duration of the intial MCX trial: 0
	Number of QoS flows failed to create	Number of QoS flow failed to setup	For the duration of the intial MCX trial: 0

A packet trace was started on the internal AMF-SMF connection (N11) in the VICTORI core network and restarted the entire network to trigger the three CPEs to re-register and re-establish their PDU sessions. Using the methodology from TS 28.522, for the three PDU session establishments, these were the timings:

Performance measurements for SMF:	
Mean time of PDU session establishment	31.638 ms
Max time of PDU session establishment	39.527 ms

5.2.10 Reporting template

Network Topology	
Type of sites in the network area	Number of gNBs: 1 (Lab has more available, but an individual experiment does not involve inter-gNB mobility) Size of gNBs:(wide, mid, small): varies Bandwidth of gNB: varies gNB deployment Option: (split option): current commercial RAN equipment in use does not employ open interfaces for functional splits in the gNB Type of gNB (commercial, prototype): Commercial
Fronthaul/Backhaul Information	Predominant type of backhauling [wireless, fibre, copper…]: Fibre optics Number of backhauling links per type: 1
Cloud Infrastructure	Servers (type, capacity, interfaces): Cisco high-end servers Virtualization software: VMWare

[2] (If mean and max values were included, these would both be 3, as each UE requests 1 PDU session each with 1 default QoS flow each)

5.3 Lab test results

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

A decision is taken to use Web technologies for this application. There are Web APIs for all necessary features required for this application especially the WebRTC Stack which is implemented in all browsers. This is the main advantage of using web technologies which enables the App to run across different device platforms. The following APIs are especially used for capturing the camera and sensor data:

- **Media Capture and Streams API**[3]: It is a JavaScript API allowing a Web application to access the Camera. It is used in the client application to access the smartphone camera. The camera stream is provided in a format that can be directly cusumed in the next test to be sent to the Edge Server available in the DN via the 5G connection.
- **DeviceOrientation Event API**[4]: It is a JavaScript API allowing Web applications to monitor the device orientation. The orientation event are captured in JSON format and prepared for streaming via WebRTC (Figure 5-2).

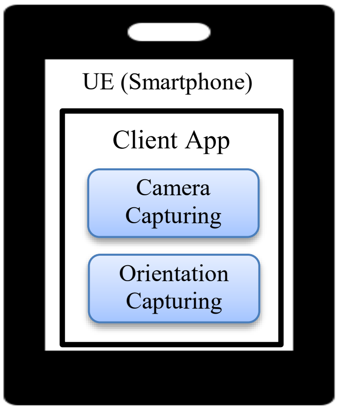


Figure 5-2 Architecture Client App

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

The video streams and orientation data from the previous test are streamed to the Edge Server via WebRTC Video and Data Channels over 5G connectivity. The videos are encoded using h264 video codec which is widely supported on all browser platforms with HW encoding and decoding capabilities. The Edge Server runs an NBMP Task as docker container which receives the WebRTC streams for further processing. This is explained in further details in the next test (Figure 5-8).

[3] https://www.w3.org/TR/mediacapture-streams/

[4] https://www.w3.org/TR/orientation-event/

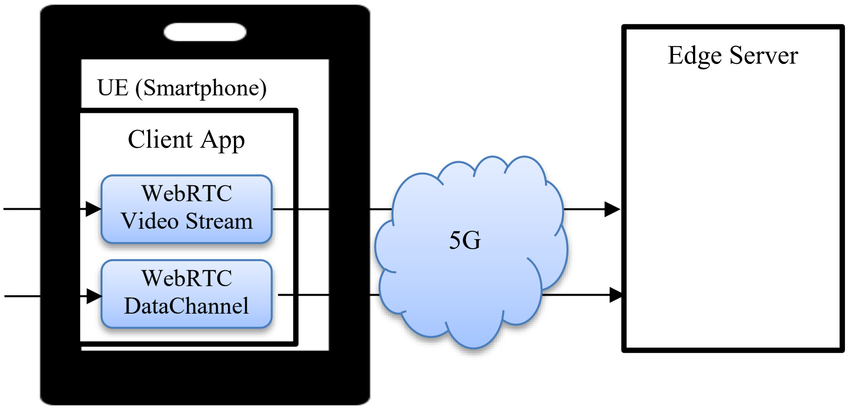


Figure 5-3: Edge rendering Architecture

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

After the video streams and orientation data are received on the edge server via the WebRTC Agent, the video stream data are decoded and sensor data are parsed and prepared for further processing in the edge rendering component. For establishing WebRTC connectivity between client and edge peers, a signaling server and STUN server are required. The signaling server is required to exchange the SDP (Session Description Protocol) data between the peers in order to establish a peer-to-peer connectivity between the client app and the edge app (Figure 5-4).

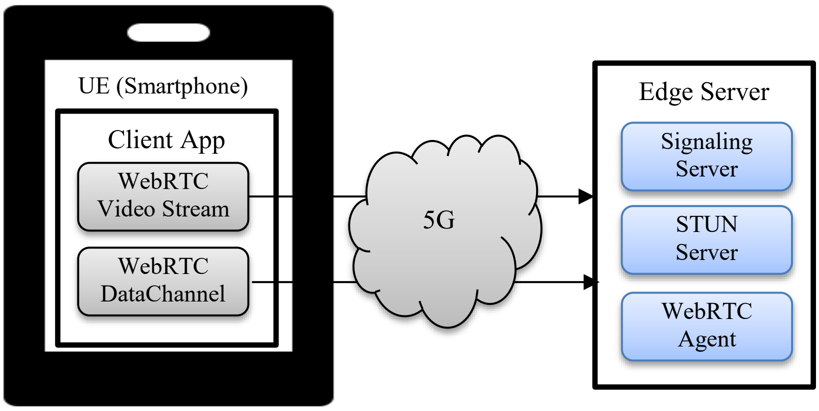


Figure 5-4: Edge app component overview

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

The edge rendering component is the core component in the workflow. It runs in headless mode on a GPU cluster which renders the AR/VR scene using the decoded camera and sensor data from previous step. The Game Engine Unity is used for this purpose, but any other engine can be used as well. The unity engine is extended to run as an NBMP task within a docker container with direct access to the underlying graphical computing resources to achieve the best performace. Within the unity scene, a virtual camera captures the field of view of the inspector (Figure 5-5).

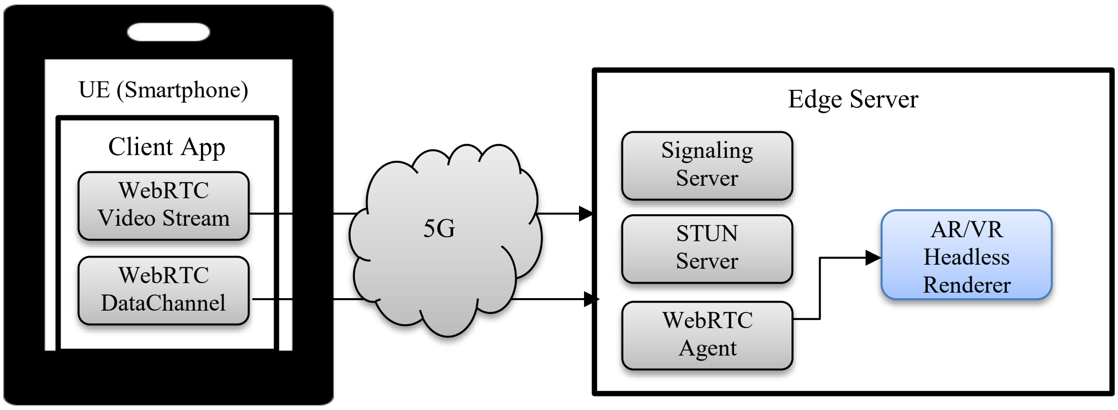


Figure 5-5: Edge rendering Client - Server communication

5.3.5 RDFg05: Edge Rendering – generate AR view video stream

The output of the virtual camera placed within the Unity scene from previous step is captured and streamed back to the client app again via WebRTC video channel (Figure 5-6).

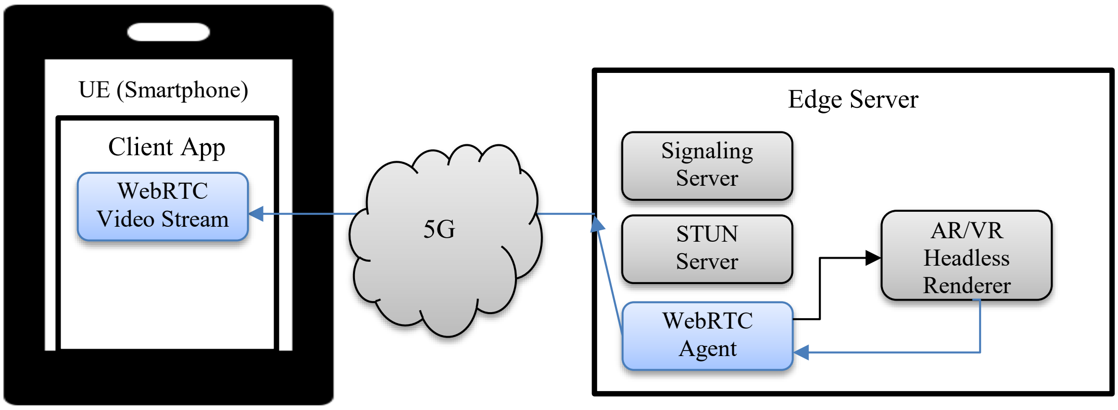


Figure 5-6: Edge rendering Server - Client communication

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

The client application receives the WebRTC video streams and renders it within an HTML5 video element inside the client application. The WebRTC video channel and the video player are configured for a minimal latency during encoding, decoding and buffering (Figure 5-7).

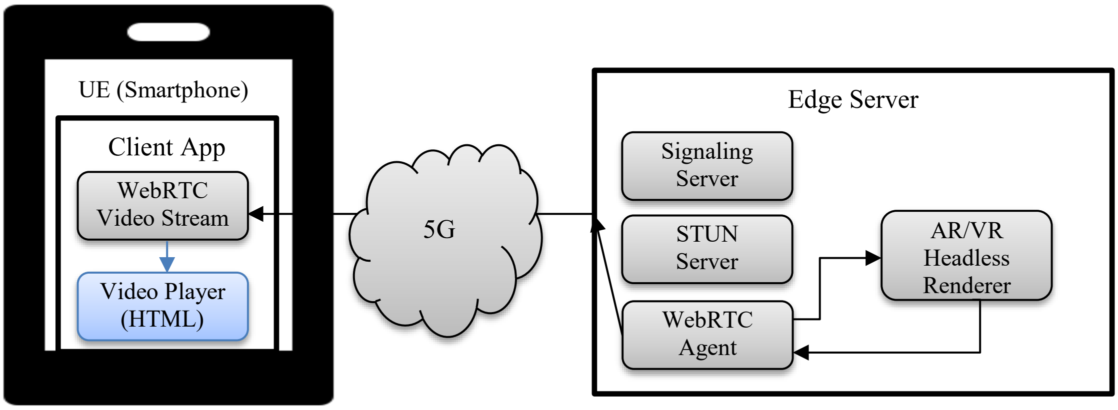


Figure 5-7: Edge render output to client

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

Same test case as in Future Mobility **App3** in the Bristol cluster.

5.3.8 RDFg08: Future Mobility – in/outdoor passenger guidance and journey planning via digital twin

Same test case as in Future Mobility **App3** in the Bristol cluster.

5.4 Test-Combinations

A combination of test cases **RDFg01** - **RDFg06** allows us to evaluate the whole experience reflecting the E2E workflow starting from user interaction with the application (through touch, key, orientation) until the scene is rendered and displayed for the user.

The lab setup consists of several components that represent the individual test cases and their functions.

5.4.1 RDFg01

For the UE, the Oppo X3 Pro 5G smartphone was used, since it has 5G connectivity and camera. This smartphone will be used to stream the AR/VR view stream.

5.4.2 RDFg02

The 5G connectivity will be provided using the Amarisoft Callbox mini in combination with the Open5GCore. The Amarisoft Callbox mini can support up to 500 UE active connections with a downlink speed upto 200 Mbps as well as uplink speed upto 75 Mbps. Figures Figure 5-8 and Figure 5-9 show the test installation.

Figure 5-8 Open5GCore station and its components in lab

Figure 5-9 Amarisoft Callbox Mini RNA

5.4.3 RDFg03

The Edge server is a supermicro instance with the following specifications. Its GPU rendering is powerful enough to render the unity scene.

- GPU: 5*V100 [5]
- RAM: 1 TB
- Disk: 12 TB
- CPU: 2* Xeon Gold 5120 [6]
- OS: Linux Ubuntu 18.04.3 LTS

5.4.4 RDFg06

After all components have been integrated together within the test lab, the Oppo smartphone is able to stream the AR/VR view stream over a 5G connection (see Figure 5-10).

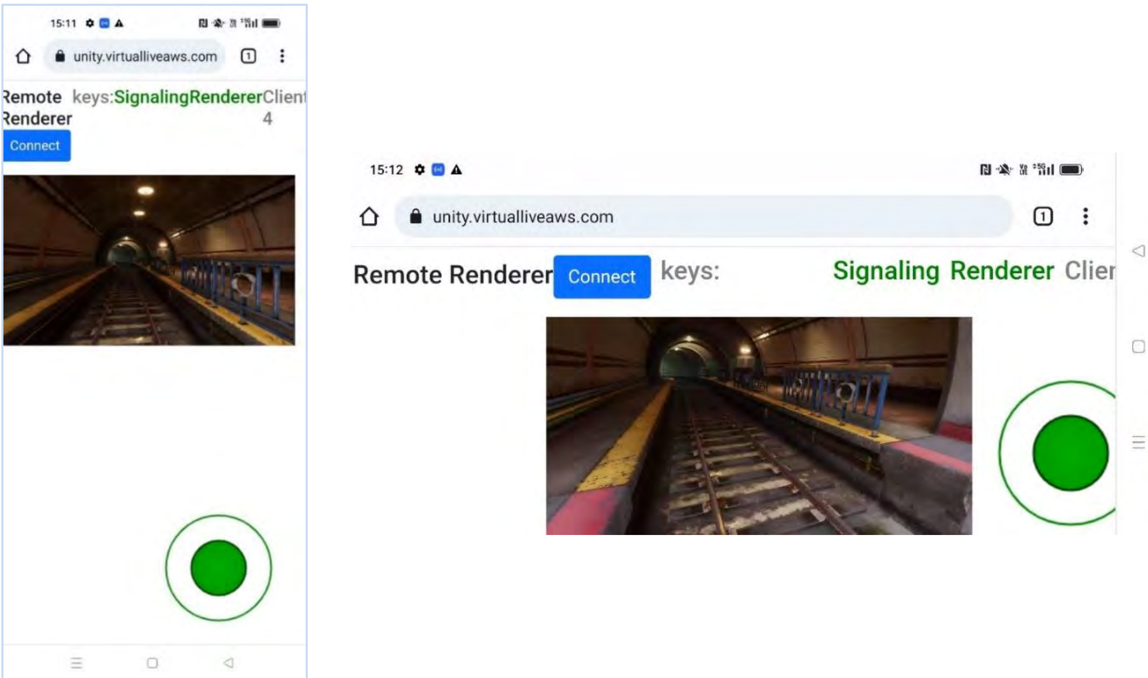


Figure 5-10 AR/VR stream streamed on Oppo X3 UE

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[5] More details: https://www.nvidia.com/en-us/data-center/v100/

[6] More details: https://ark.intel.com/content/www/us/en/ark/products/120474/intel-xeon-gold-5120-processor-19-25m-cache-2-20-ghz.html

During the lab test, some measurements were conducted to test the latency of the VR/AR stream. These measurements include ping, jitter, downlink and uplink speed. The measurements were collected using both external (SpeedTest - public) and internal (LibreSpeed - within the Open5GCore to avoid buffers and connection latency) tools. The average ping was 21 ms, average jitter 4 ms, download speed 145 Mbps, and upload speed 40 Mbps (see figures Figure 5-11 and Figure 5-12).

Figure 5-11 Measurements collected using external tool

Figure 5-12 Measurements collected using internal tool

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

6.1 Description

Many kind of vertical services traditionally need their own radio communication solution. Railway communications with Rail Signaling, Rail Cab Voice, Rail Sensor Data, and Rail Surveillance CCTV, Predictive Maintenance, etc., could envision to use cellular systems in the same way as all other vertical services in the society. Different requirements on availability and criticality for specific critical services (e.g. Emergency calls for Rail Cab Voice) might imply specific requirements for the underlying 5G transport network, but the principle network structure should be similar for all services.

The Rail Critical Services at 5GENESIS in Berlin, belonging to **UC #1.3** in deliverable D2.3, comprises five representative type of services in 5G-VICTORI, where four are onboard related and one is wayside related[7]. The onboard related are the ones subject of study in this deliverable, and these are: Rail Signaling, CCTV streaming, Cab Telephony, and Sensor Data. These onboard rail critical services are represented in **UC #1.3**, together with Other Services from other tasks at the Berlin Central Station (the 3D guide and potentially the CDN service). The latter two services are very bursty, or are not using 5G at all, therefore a Background Traffic is used to represent all Other serviced when testing Rail Signaling with different QoS.

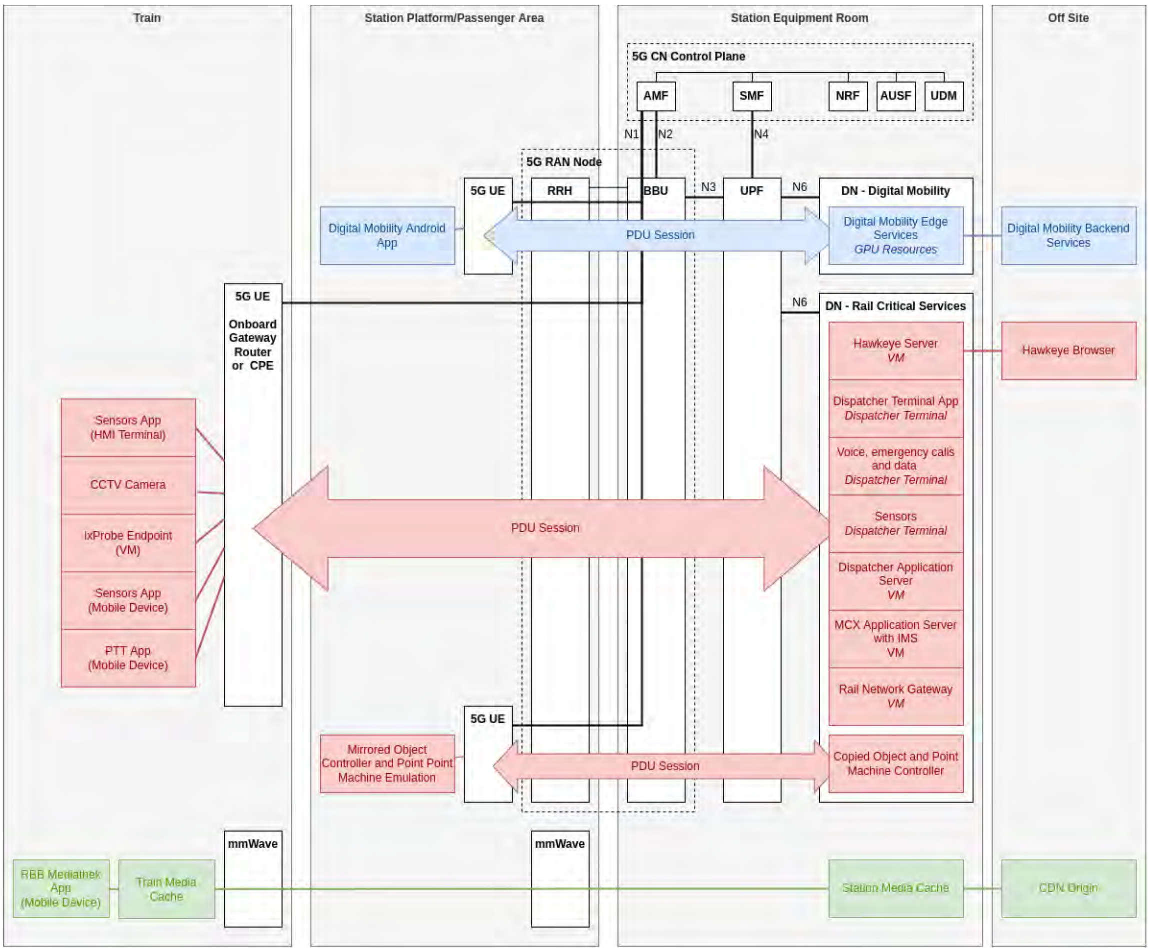


Figure 6-1 Berlin cluster UC services mapped to planned 5G infrastructure at a station

[7] Details about this UC are included in the Appendix (section 8.2)

Lab test results are provided in this final WP3 document related to Task 3.1.

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

6.2.1 Description

The purpose with the Rail Signaling service in the project is to demonstrate that Rail Signaling is conveyed over 5G with the expected characteristics, regardless of other services.

Figure 6-2 gives an overview of the Rail Signaling and CCTV Streaming services at the Berlin Central Station in the 5G-VICTORI project. The demo shall also show the usage of different 5G QoS and Network Slices for Rail Signaling compared with Other Services.

Rail Signaling in the 5G-VICTORI project for Berlin uses the IXIA software Hawkeye server, which runs over Linux on a Compute and Storage server in the Fraunhofer FOKUS data center. Rail signaling is emulated between Performance Endpoints, or “probes”, with a bitrate that represent rail signaling in real life.

A web-browser is used for logging in to the Hawkeye Server, which uses a public IP address (the web-browser can therefore be located anywhere with Internet access). Hawkeye is used for configuring traffic between endpoints, starting test cases, getting results and reports, etc.

The hardware box IxProbe can be used on the train for generating and terminating traffic. In this way no other computer is needed to host an Endpoint on the train, it is enough with the IxProbe. The IxProbe has two Ethernet ports A and B for traffic (A is northbound), and one Management port MGMT for configuring and monitoring in general of the IxProble. Thus, the IxProbe needs three Ethernet connections. The IxProbe can be moved around if needed, as it automatically connects to the Hawkeye server.

The 5G network needs to have the connection in between the probe pairs always established. In this way, the Hawkeye test cases are not involved in any 5G network connection setup procedures.

The Hawkeye test cases can configure a DiffServ Code Point (DSCP), which is the only way QoS can be indicated. However the Open5GCore implementation doesn’t support mapping DSCP to 5G QoS and NS. Therefore when running several traffic flows at the same using Test Combinations, the Open5GCore needs to be configured with different QoS setting for each probe.

6.2.2 Probes at FhG Berlin for the lab test results

The Hawkeye server in Berlin has been tested with traffic generation between these probes (Performance Endpoints):

<u>Data Network probe</u>: genesis-fokus_data-net

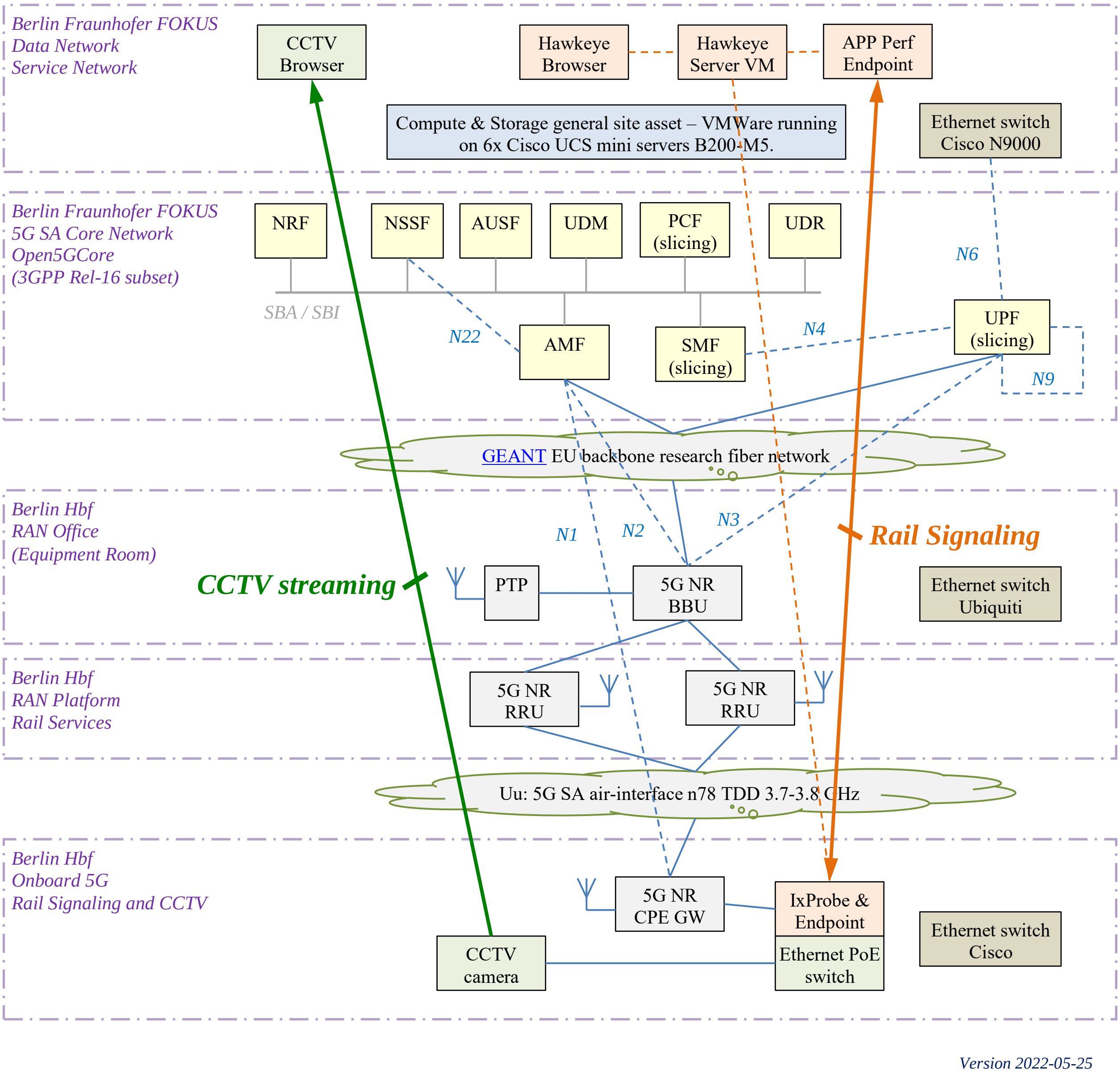
- Base station IP address: 192.168.243.32
- Management IP address: 192.168.242.32

<u>Onboard CPE probe</u>: 5genesis-cpe-ug2-vorne-huawei-hawkeye

- Onboard CPE IP address: 192.168.8.120
- Management IP address: 192.168.242.106

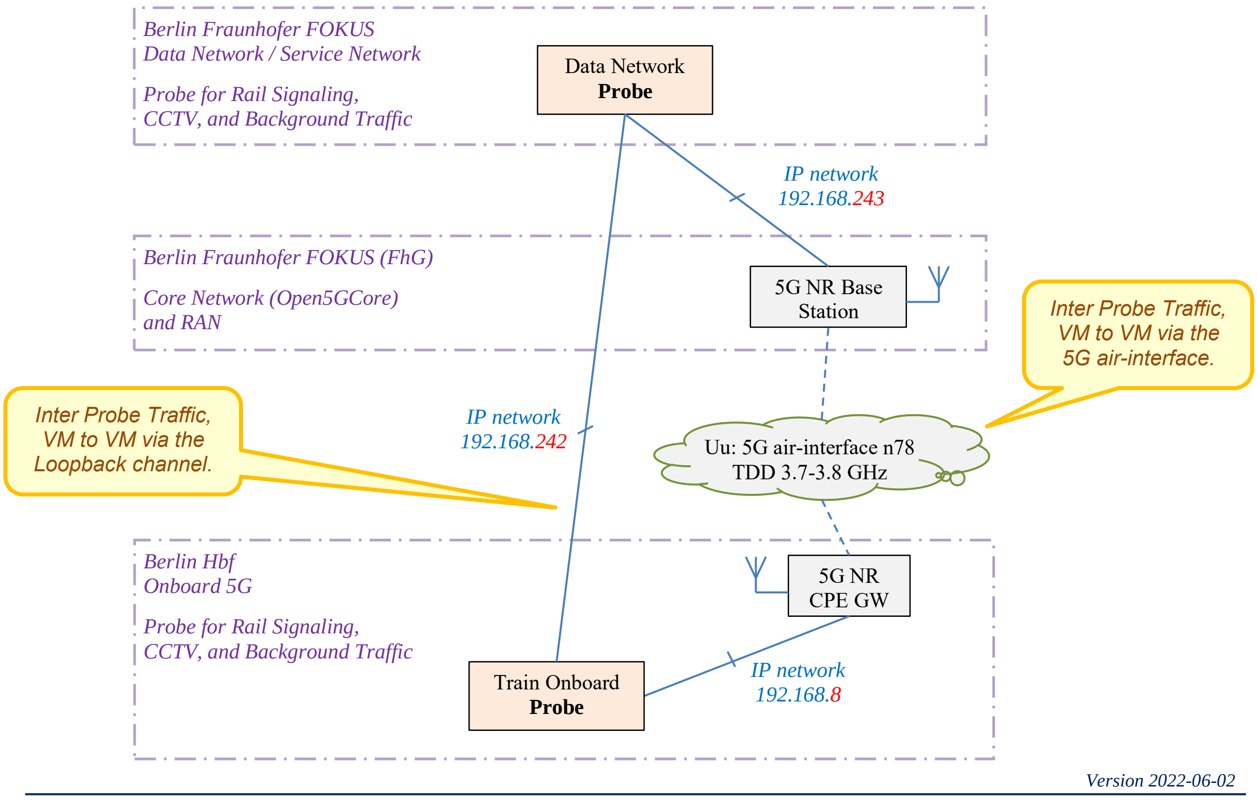
The only available probes at 5GENESIS for 5G-VICTORI at FhG Berlin in May 2022 were one Data Network Probe and two CPE Onboard probes. The onboard probes show very similar results, only one onboard probe is here used for lab results, the “ug2” one.

The IP network mask for all these networks is 255.255.255.0. In Figure 6-3, only the class C network addresses are mentioned.



5G	5th Generation 3GPP defined cellular network	NS / NSSF	Network Slice / Network Slice Selection Function
AMF	Access and Mobility Function	PCF	Policy Control Function
AUSF	Authentication Server Function	PFCP	Packet Forwarding Control Protocol (TS 29.244)
BBU	Baseband Unit	PoE	Power over Ethernet
CCTV	Closed Circuit Television	PTP	Precision Time Protocol (IEEE 1588v2)
CN	Core Network	RAN	Radio Access Network
CPE	Customer Premises Equipment	RRU	Remote Radio Unit
GW	Gateway	SA	Stand Alone (=5G supporting signaling)
N1	Non-Access Stratum signaling (UE - CN)	SBA / SBI	Service Based Architecture / Interfaces
N2	Access Stratum signaling (RAN - CN)	SMF	Session Management Function
N3	RAN - UPF data plane	TDD	Time Division Duplex
N4	UPF - SMF signaling (PFCP protocol)	UDM	Unified Data Management
N6	UPF (IP anchor) – Data Network	UDR	Unified Data Repository
N9	UPF – UPF (interconnects UPF instances)	UE	User Equipment
NR	New Radio (compare with Old Radio – Ha ha!)	UPF	User Plane Function
NRF	Network Repository Function	VM	Virtual Machine (for example running on VMware)

Figure 6-2: Rail Signaling and CCTV via 5G Core Network in Berlin – block diagram



5G	5th Generation 3GPP defined cellular network	NR	New Radio
CCTV	Closed Circuit Television	RAN	Radio Access Network
CN	Core Network	RRU	Remote Radio Unit
CPE	Customer Premises Equipment (a UE GW)	TDD	Time Division Duplex
GW	Gateway	UE	User Equipment
IP	Internet Protocol	VM	Virtual Machine (for example running on VMware)

Figure 6-3: FhG Berlin Hawkeye Probes for Rail Signaling, CCTV, and Background Traffic lab results

The CPE onboard probe is also connected via a management interface, which can be used for testing VM to VM connectivity over the Loopback channel to the Data Network probe (IP network 192.168.242.x).

Note: the wanted four pair of probes for Rail Signaling demonstration with different QoS and Network Slicing (NS) settings, together with Background Traffic, are outlined in section 6.2.7, Figure 6-4. These four probe pairs will be useful for both for lab and field tests demonstrating QoS and NS.

6.2.3 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.

6.2.4 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.

6.2.5 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 6.2.4 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 per train over a 5G network), KPI: • Rail signaling traffic can use 200 kbps per train, regardless of background traffic. • Twelve trains use 12 x 0.2 = 2.4 Mbps.
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. • Twelve trains use 12 x 0.2 = 2.4 Mbps.
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.

6.2.6 Lab test results for Rail Signaling RCSg02 and RCSg03 - at FhG in Berlin

The traffic emulation software Hawkeye has been used at **FhG** in Berlin for 5G-VICTORI in May 2022. Different pre-defined type of tests in Hawkeye are used to get test result characteristics. All tests are here for Rail Signaling done of the 5G air-interface in the FhG lab.

See also the Background Traffic lab test results. It has been checked that the 5G air-interface really is the bottleneck compared with inter-VM traffic sent over the Loopback channel. This is important, as the probes sending and terminating traffic run over VMs and it is the 5G air-interface which is the important interface in this 5G-VICTORI project. See section 6.4.3.

6.2.6.1 Network KPI via 5G air-interface, all rail signaling test cases:

This test gives a uni-directional delay, jitter and loss for the network over the 5G air-interface, from the probe in the “Data Network” and the probe “Onboard the train” for DL, and another test was used to get UL result.

Probes:

- From: genesis-fokus_data-net
  IP address: 192.168.243.32 (base station IP address)
- To: 5genesis-cpe-ug2-vorne-huawei-hawkeye
  IP address: 192.168.8.118 (CPE air-interface IP address)

Result for all Rail Signalig test cases:

- Delay: 4.4 ms (DL) / 4.1 ms (UL)
- Jitter: 0.0 ms (DL) / 0.5 ms (UL)
- Loss: 0.0% (DL) / 0.0% (UL)
- Max Delay Variation: 7.0 ms (DL) / 13 ms (UL)

Conclusion: Characteristics are well according to expectation.

6.2.6.2 TCP Throughput via 5G air-interface, RCSg02 and RCSg03

This test gives actual throughput compared with wanted throughtput defined in the test cases RCSg02 and RCSg03, which is rail signaling for one or twelve trains (note: twelve trains is normally the maximum number of trains per cellular base station at a normal big train station). This test gives both Downlink and Uplink results.

Probes:

- From: genesis-fokus_data-net
  IP address: 192.168.243.32 (base station IP address)
- To: 5genesis-cpe-ug2-vorne-huawei-hawkeye
  IP address: 192.168.8.118 (CPE air-interface IP address)

Test result for **RCSg02**, one train, 200 kbps, DL and UL:

- Throughput DL: 200 kbps
- Throughput UL: 197 kbps

Test result for **RCSg03**, twelve trains, 2400 kbps, DL and UL:

- Throughput DL: 2400 kbps
- Throughput UL: 2399 kbps

Conclusion: Characteristics are well according to expectation.

6.2.7 Field Tests planned for Rail Signaling - at FhG and Berlin central station

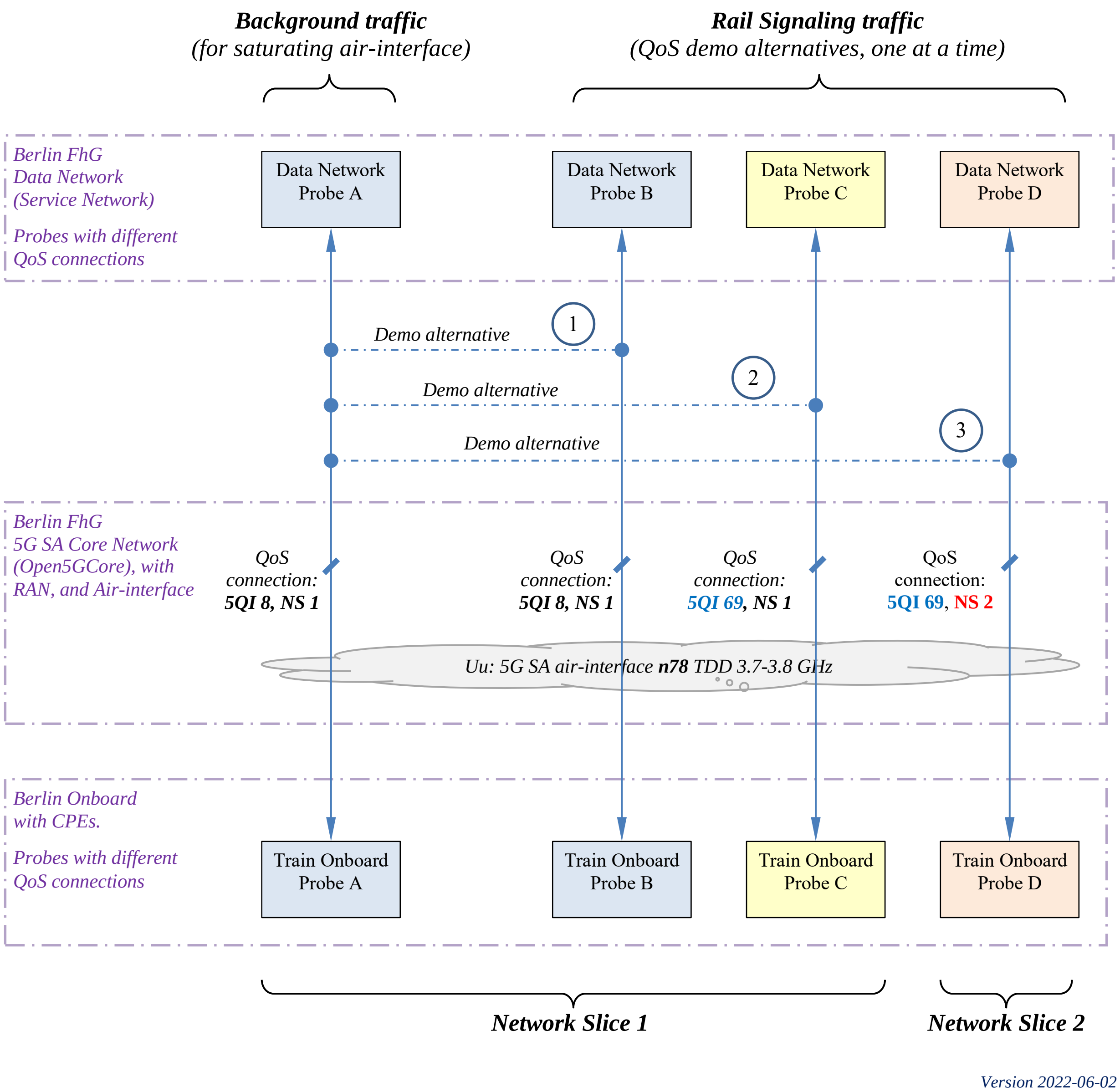
These are the Rail Signaling tests that are planned for FhG Berlin. Using Background traffic, which saturates the air-interface, should give a result which differs from the QoS settings of the Rail Signaling traffic.

6.2.7.1 These tests are done with Rail Signaling as the prime service, running together with Background Traffic that shall saturates the 5G air-interface. High level demonstration purpose with Rail Signaling at FhG in Berlin:

- Demonstrate that Rail Signaling with QoS can share the same 5G air-interface with other traffic.
- Demonstrate that the best for Rail Operators in a Rail Corridor is to use their own Network Slice.

6.2.7.2 Wanted logical traffic probes for Rail Signaling over QoS and NS demo

To be able to demonstrate Rail Signaling together with a saturating Background Traffic in the Berlin 5G cluster 5GENESIS in 5G-VICTORI, these different probes with the different QoS connections are needed. See Figure 6-4.



5G	5th Generation 3GPP defined cellular network	NR	New Radio
5QI	5G Qos Indicator	NS	Network Slice
BS	Baste Station	RRU	Remote Radio Unit
CN	Core Network	TDD	Time Division Duplex
CPE	Customer Premises Equipment (UE onboard GW)	UE	User Equipment
GW	Gateway	UPF	User Plane Function

Figure 6-4: FhG Berlin Hawkeye Rail Signaling – QoS demo alternatives with saturated 5G air-interface

6.2.7.3 Test setup to make sure the 5G air-interface is the bottleneck at FhG in Berlin

1. The 5G system shall be empty and use the same or Best Effort kind of QoS. Run bi-directional saturating traffic between two probes in the Service Network (SN), between two VMs via the Loopback channel. 5G is not involved in this case, only used as reference.
   Reason: to make sure the demo alternatives test result becomes reliable, and to test the capacity of the Hawkeye Probes, making sure these are not the bottleneck

compared with 5G-air-interface.
Note: saturating traffic sends UDP packets with a higher bitrate than the link can handle, with big frame losses.

2. Run bi-directional saturating traffic between a probe in SN and a probe Onboard (OB), emulating Onboard traffic.
Note: IF the SN-OB saturating traffic doesn't differ much from the SN-SN traffic, THEN lower the 5G air-interface capacity.
Reason: to check that the 5G air-interface is the real bottleneck in the 5G system. The main purpose with these tests (item 1 and 2) is to make sure that the 5G air-interface is the real bottleneck.
Note: This can be done by configuring a lower CPE Tx power and Basestation Tx power, and also pointing these antennas to non-Line-of-sight (LOS) condition, etc.

6.2.7.4 Demo alternatives with different QoS settings over 5G air-interface at FhG in Berlin

1. Run bi-directional Background Traffic SN-OB traffic together with bi-directional Rail Signaling SN-OB, both using Best Effort QoS.
Reason: demonstrate that Rail Signaling will suffer a lot together with saturating traffic in the system, both using Best Effort QoS.

2. Run Rail Signaling using QoS EF and 5QI 69 together with saturating Background Traffic using QoS BE and 5QI 8.
Reason: This shall result in that Rail Signaling comes out much better with low frame losses, due to the use of different QoS.
Note: depending on implementation and circumstances, Rail Signaling might suffer somewhat anyway with frame losses.

3. If possible: Run Rail Signaling using QoS 5QI 69 and NS1 together with saturating Background Traffic using QoS 5QI 69 and NS 2.
Reason: This should result in equal or better performance for Rail Signaling compared with using only QoS differentiation.

6.3 Rail Critical services in Berlin - CCTV streaming test cases (RCCg)

6.3.1 Description

The overview block diagram for CCTV Streaming, with the Onboard CCTV camera and the Office CCTV monitoring, is outlined in Figure 6-2 (the same figure is used for both Rail Signaling and CCTV Streaming).

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.
- 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 e.g. 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 CCTV network camera onboard a train in Berlin is of type Axis P3935. The camera is powered from a Power over Ethernet switch (or an insert box), using PoE IEEE 802.3af/802.3at Type 1 Class 3. The camera is connected via an RJ45 connector. The camera gets an IP address from a DHCP server or is configured with an IP address. The camera sends video using compression protocols H.264, H.265, or JPEG over Ethernet.

A web-browser at Fraunhofer FOKUS or at Berlin Hbf is used for monitoring pictures from the network camera. As only one camera is used, a web-browser is feasible. The web-browser surfs in to the IP address of the network camera and logs in to it (see D3.1 test cases).

The 5G Core Network needs to be configured such that a UPF IP address shows up for the network camera, making possible for the web-browser to reach the network camera. The 5G Core Network needs to be configured such that the connection is always on, as the CCTV camera is not a mobile.

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 using one train (lab and 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 UC 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 train (lab and field)

RCCg02	**CCTV streaming over 5G using one train (lab and 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.

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. 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. 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 is powered and up and running. 2. 5G connectivity is up and running 3. 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. 4. PC screen with the CCTV monitoring software / web browser visible. 5. 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. 6. 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. 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. Start streaming pictures 7. Remove 5G connectivity 8. Power down equipment 9. Check logs.

<table>
<tr><td>Measurements</td><td>
- 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 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 E2E 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.
</td></tr>
<tr><td>Expected Result</td><td>Nice looking CCTV pictures are expected on the monitoring screen.</td></tr>
</table>

6.3.4 RCCg03: CCTV streaming over 5G using twelve train cameras (lab and 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 using twelve train cameras (lab and field)

RCCg03	**CCTV streaming over 5G using twelve train cameras (lab and 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 per train camera • 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. The probe is here used for emulation of 11 CCTV cameras.
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).
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).
Optionally certificates can be given to the CCTV camera, which makes it possible to use HTTPS in the web browser.

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

Test procedure	**- 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.

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

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.
<ol type="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.
<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.

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.
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

If an optional tool like iPerf is used, it can be used for comparison.
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

The bitrates described under Methodology are the CCTV codec bitrate. Overhead from UDP/IP etc transportation network protocols are added.
When the Hawkeye Console is used, KPIs can be monitored on different levels, reports can be extracted, traffic can be scheduled over time, etc.

</td></tr>
<tr><td>Expected Result</td><td>Nice looking CCTV pictures are expected on the monitoring screen and via KPIs for this extended test case emulating twelve CCTV 5 Mbps streams.</td></tr>
</table>

6.3.5 Lab test results for CCTV Streaming RCCg02 and RCCg03 - at FhG Berlin

These lab tests were conducted in May 2022 at FhG in Berlin, using the Hawkeye server software with probes.

Two probes are used for these lab tests:

- one Data Network probe
- one CPE onboard probes
  note: there were two CPE onboard probes available at FhG Berin in May 2022, and these show very similar results so only one of the probes are used here, the "ug2" probe.

The lab results are based on one or twelve emulated video streams.

Note: The field test at Berlin central station for CCTV streaming with twelve train cameras are planned to use one real CCTV network camera onboard a train, and eleven emulated ones onboard the train from a probe.

6.3.5.1 Video Stream using Hawkeye via the 5G air-interface, uplink only

Probes:

- **To**: genesis-fokus_data-net
  IP address: 192.168.243.32 (base station IP address)
- **From**: 5genesis-cpe-ug2-vorne-huawei-hawkeye
  IP address: 192.168.8.118 (CPE air-interface IP address)

Result for **RCCg02**, CCTV uplink, one train, 5 Mbps:

- Throughput: 5 Mbps
- Delay: 9 ms
- Jitter: 3 ms
- Jitter max: 4 ms
- Loss: 0.0%

Result for **RCCg03**, CCTV uplink, twelve trains, 60 Mbps:
(note: this test is run several times and these are average figures)

- Throughput: ~45 Mbps (much less than 60 Mbps)
- Delay: ~100 ms (a bit long, but OK)
- Jitter: ~0.2 ms
- Jitter max: 1 ms
- Loss: 25% (bigger than required)

Note: it seems that 60 Mbps uplink for twelve train cameras is a bit problematic for the lab setup via the ug2 CPE 5G air-interface.

6.3.6 Lab test results for CCTV Streaming over Ethernet, RCCg01

6.3.6.1 Video Stream using real CCTV network camera RCCg01 – at Alstom Stockholm

Tests were done at Alstom Stockholm in Feb 2022 using the real CCTV camera, using a Windows 10 web browser. No 5G network was available.

The intranet was based on Gigabit and Fast Ethernet interconnection. The results show very short delays and good characteristics.

6.3.6.2 Video Stream using emulated CCTV stream RCCg01 – at FhG Berlin

Probes:

- **To**: genesis-fokus_data-net
  IP address: 192.168.242.32 (management interface)
- **From**: 5genesis-cpe-ug2-vorne-huawei-hawkeye
  IP address: 192.168.242.106 (management interface)

Result for **RCCg01**, CCTV uplink, one train, 5 Mbps:

- Throughput: 5 Mbps
- Delay: 0.2 ms
- Jitter: 0.0 ms

- Jitter max: 0.0 ms
- Loss: 0.0%

Conclusion:

- video traffic between two VMs over the Loopback interface show very short delays and low jitter figures with full bitrate.

6.4 Other Services Berlin – Background Traffic test cases (RCBg)

6.4.1 Description

This generic "service" is used instead of Other Services in Berlin, to saturate the 5G air-interface while demonstrating services like Rail Signaling at the same time. So this "service" is more for WP4 to consider when running several servies at the same time.

The reason is that the 3D Guide service is very bursty between very low and very high bitrates, all depending on if these users are active or not, moving or now.

6.4.2 RCBg01: Background traffic for saturating the 5G air-interface (lab and field)

The purpose with the Background Traffic is to represent all other traffic while demonstrating for example Rail Signaling traffic at the Belrin Central Station.

The Background traffic sends UDP traffic which saturates the 5G air-interface. In this way it easier to see the difference between the different QoS and Network Slices that are applied for Rail Signaling and Other Traffic in the Berlin Central Station.

At least two Hawkeye probes are needed in the Service Network and two probes in the Onboard Network. Preferably four probe pairs. Each probe pair shall be configured to have same or different QoS and Network Slice settings.

Table 6-7: RCBg01 – Background traffic for saturating the 5G air-interface (lab and field)

RCCg01	**Background traffic for saturating the 5G air-interface (lab and field)**
Testbed	**5GENESIS Berlin**
Description	The purpose with the Background Traffic is to represent all other traffic while demonstrating for example Rail Signaling traffic at the Belrin Central Station. The Background traffic sends UDP traffic which saturates the 5G air interface. In this way it easier to see the difference between the different QoS and Network Slices that are applied for Rail Signaling and Other Traffic in the Berlin Central Station. At least two Hawkeye probes are needed in the Service Network and two probes in the Onboard Network. Preferably four probe pairs. Each probe pair shall be configured to have same or different QoS and Network Slice settings.
Key UC requirements and KPIs	KPIs: • The maximum Background Traffic bitrate over the 5G air-interface shall be much lower than the corresponding maximum bitrate between two VMs bridging the Loopback interface (not bridgning the 5G air-interface). Note: This is to make sure that the 5G air-interface is the real bottleneck.

Network performance requirements and KPIs	KPIs: • The maximum Background Traffic bitrate over the Loopback interface (not bridgning the 5G air-interface) shall be much higher than the corresponding maximum bitrate between two VMs bridging the 5G air-interface. Note: This is to make sure that the 5G air-interface is the real bottleneck.
Network Functional requirements and KPIs	KPIs: • The network needs to support Hawkeye probes for both Rail Signaling and Background traffic, both using same or different QoS and Network Slices.
Components and configuration	**- Components:** 1. Several Haweye Probe pairs needed in at FhG Berlin facility (in Service Network and in Onboard Network). 2. Each probe pair configured with same or different QoS and Network Slices. **- Configuration:** 1. Four probes are needed for Background Traffic and Rail Signaling Traffic using same QoS (same NS), different QoS (same NS) and different NSs.
Test procedure	**- Preconditions:** 1. The four probe pairs shall be connected to the Open5GCore with same or different QoS settings. 2. The four probe pairs shall be connected to the Open5GCore using the same or different Network Slices. **- Test Case Steps:** 1. With four probe pairs up and running in 5GENESIS for 5G-VICTORI, the two probe pairs needed for the demo is selected in Hawkeye. 2. In this way different QoS and NS settings can be used for Background Traffic and Rail Signaling.
Measurements	**- Methodology** 1. The Hawkeye tests between the probe pairs give results which is studied. **- Complementary measurements** 1. If an optional tool like iPerf is used, it can be used for comparison. 2. If the IxProbe is used, some measurements can be extracted from it. **- Calculation process** 1. The bitrates, latency, etc is mainly fetched from the Haweye tool.
Expected Result	The Background Traffic shall saturate the 5G air-interface and represent Other Traffic in Berlin. The purpose is also to make sure that the 5G air-interface is the real bottleneck, showing a much lower maximum bitrate than for the VM-to-VM tests over the Loopback interface.

6.4.3 Lab test results for Background Traffic RCBg01 – at FhG Berlin in May 2022

The purpose with the Background Traffic is to emulate “other traffic” over the 5G air-interface. When for example testing Rail Signaling over 5G air-interface with different QoS and NS settings, a Background Traffic which saturates the 5G air-interface is needed to be able to see any characteristics difference.

The other traffic which we foresee in Berlin has either very low bitrates (cab voice, sensor data, CCTV), is very bursty (the 3D guide), or is not using 5G at all (CDN).

The Background Traffic can be used to make sure that the 5G air-interface really is the bottleneck, which is required to see any difference between QoS and NS settings.

6.4.3.1 Speed tests – check both via Loopback channel and 5G air-interface

The Hawkeye traffic type **Speed tests** performed both between VMs via the loopback interface, VM via the 5G air-interface to VM.

The purpose with comparing the Loopback channel with the 5G air-interface is that the 5G air-interface shall be the clear bottleneck, at least 10 times difference. From the test we can see a clear difference.

Speed test - VM via Loopback interface to VM (via the loopback management interface x.x.242.x on the same physical machine)

Probes:

- From: 5genesis-cpe-ug2-vorne-huawei-hawkeye
  IP address: 192.168.242.106 (management interface)
- To: genesis-cpe-smart-huawei-hawkeye
  IP address: 192.168.242.108 (management interface)

Throughput:

- From->To (DL): 12.9 Gbps
- To->From (UL): 12.5 Gbps
- Note: it is expected that these DL and UL bitrates are very similar, as equipment should be equal on both sides)

Conclusion:

- Inter-VM throughput over the Loopback interface is much higher than over 5G air-interface, which is very good, as the 5G air-interface shall be the real bottleneck in these 5G tests.

Speed test - VM over 5G air-interface to VM (using the air-interface IP address address 192.168.8.x for the CPE)

Probes:

- From: genesis-fokus_data-net
  IP address: 192.168.243.18 (base station IP address)
- To: genesis-cpe-smart-huawei-hawkeye
  IP address: 192.168.8.120 (CPE air-interface IP address)

Throughput:

- From->To (DL): 346 Mbps
- To->From (UL): 19 Mbps
- Note: normally DL is faster than UL due to orthogonality over the air-interface, but it also depends on TDD DL/UL switch-point, power settings in basestation and CPE, etc.

Conclusion: The maximum bitrate over the 5G air-interface is much lower than the Inter-VM throughput over the Loopback interface – which is good, as the 5G air-interface shall be the real bottleneck.

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

6.5.1 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, while the 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.

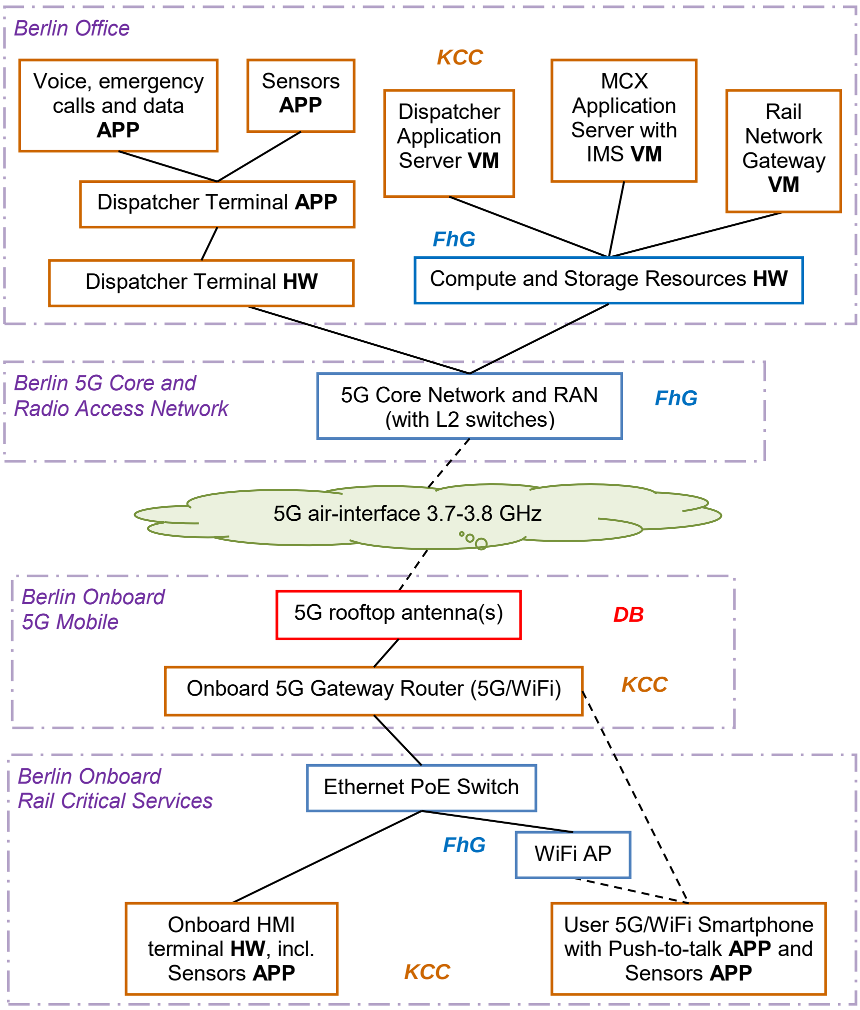


Figure 6-5: Rail Critical Services – Voice, Emergency calls, and Sensors data

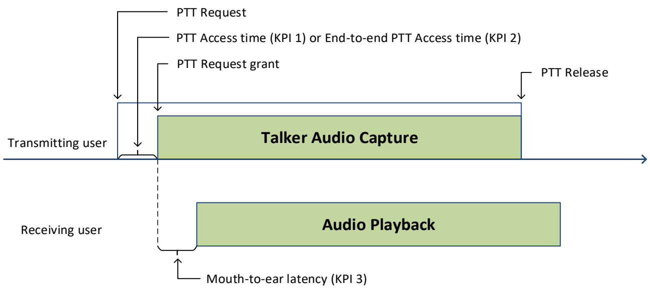
6.5.2 RCTg01: On-train voice communication (lab & field)

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 6-8.

Table 6-8: 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

Measurements	- **Methodology** 1. Latency: user data transport delay measured E2E 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. E2E 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), E2E 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. E2E 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.
Expected Result	1. Voice call established successfully. 2. Voice connection stable. 3. Good voice quality.

6.5.3 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 6-9.

Table 6-9: 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.

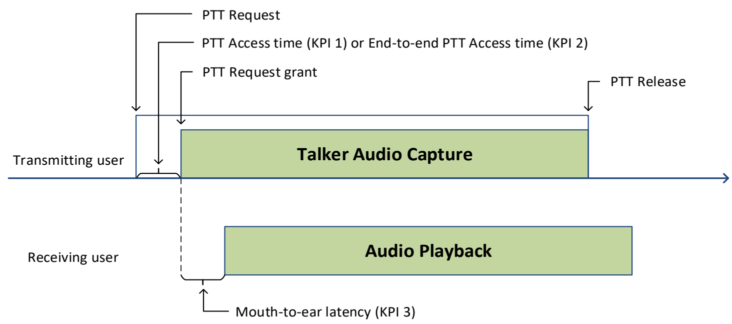
<table>
<tr>
<td>Measurements</td>
<td>

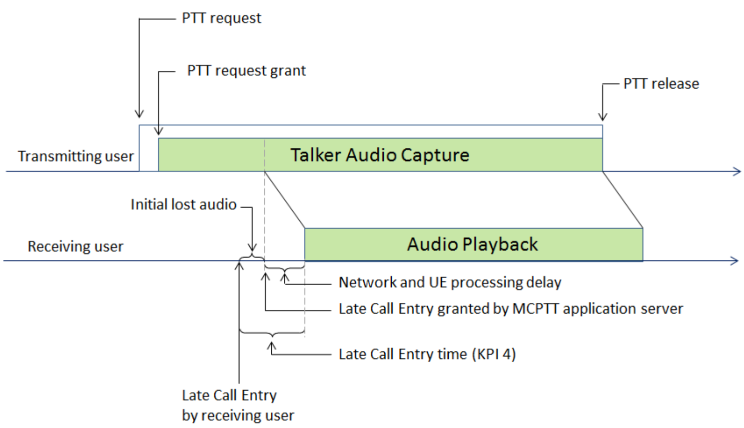
- **Methodology**

1. Latency: user data transport delay measured E2E 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. E2E 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), E2E 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.





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</table>

	- **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. E2E 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)

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

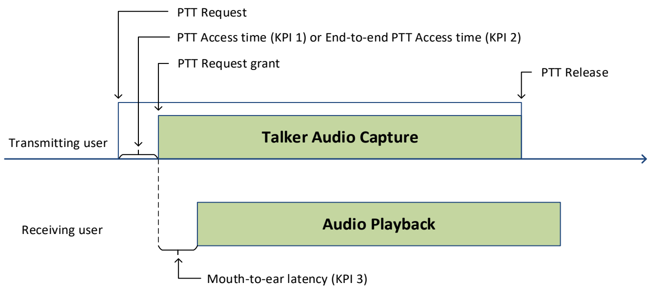
The purpose of this test case is to examine capabilities of application (MCX/FRMCS application), service (MCX/FRMCS service) and transport stratum (5G network) to guarantee isolation and communication quality level of each critical, performance and business rail applications.

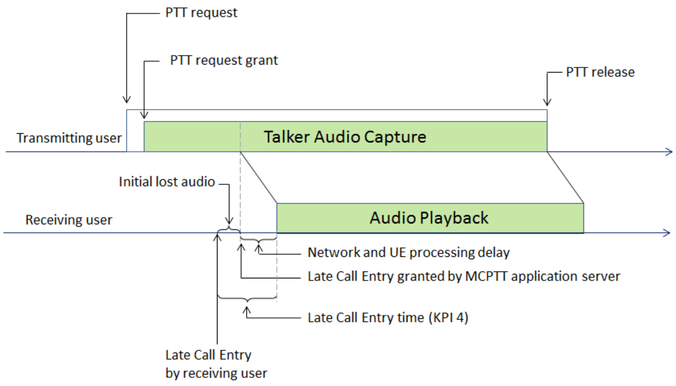
See the details outlined in Table 6-10.

Table 6-10: 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

Measurements	- **Methodology** 1. Latency: user data transport delay measured E2E 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. E2E 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), E2E 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. E2E 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.

6.5.5 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 6-11.

Table 6-11: 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**

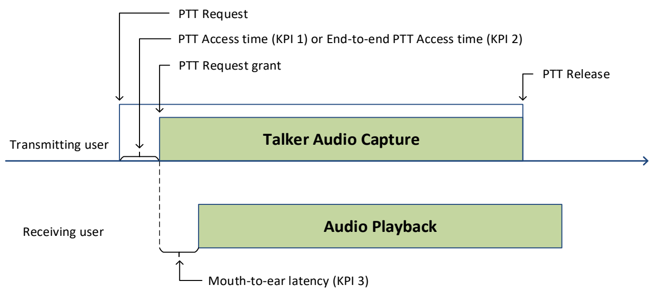
1. Latency: user data transport delay measured E2E between MCX/FRMCS clients
2. Bandwidth: throughput speed measured on MCX/FRMCS client
3. Reliability: packet loss measured at transport level on MCX/FRMCS client
4. Setup time: duration of the communication session establishment on MCX/FRMCS client
5. 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**

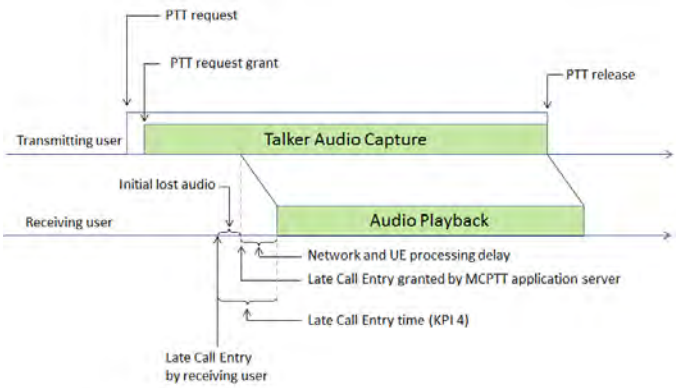
1. MCPTT Access time (cKPI1): time between when an user of MCX/FRMCS client requests to speak (normally by pressing MCPTT control) and when this user gets a signal to start speaking. This time does not include confirmations from receiving users, affiliation but does include call setup request and potentially bearer establishment. It's applicable on both call setup request and subsequent MCPTT request that are part of the same call.

2. E2E 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), E2E 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. E2E 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

6.5.6 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 6-12: 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 E2E 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.

6.5.7 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 6-13.

Table 6-13: 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 E2E 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

6.5.8 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 6-14.

Table 6-14: 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 E2E 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).

6.5.9 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 6-15.

Table 6-15: 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 E2E 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.

6.5.10 Lab test results for Rail Telephony

As first phase in the setup of 5G-VICTORI Berlin’s Rail Critical lab selected Rail Telephony, test cases had been executed in two environments:

- in a so called Over-The-Top setup using local virtualized client, and
- in 5G SA setup using virtualized client connected to 5G CPE routing traffic via 5G SA intrastructure of Huawei via default data network to the mission-critical SIP core and MCX application server.

The diagram of Berlin’s testbed of the first phase is shown in Figure 6-6.

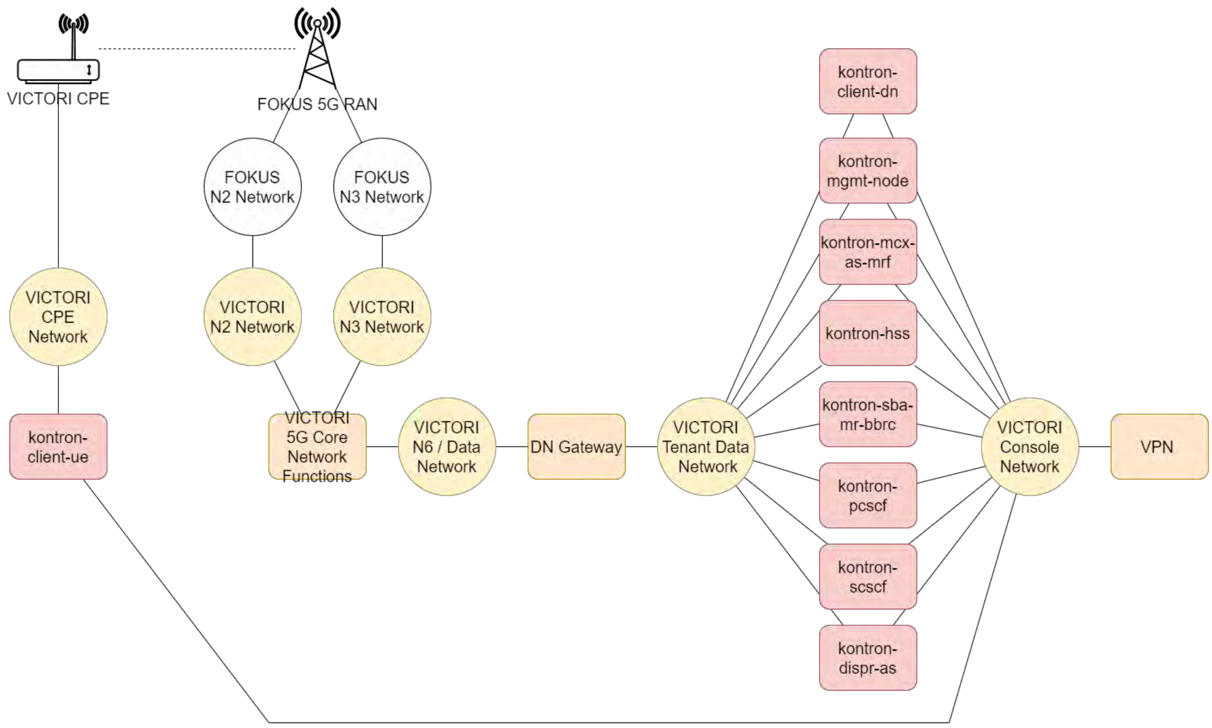


Figure 6-6 Berlin testbed for rail critical services

The test lab in **FhG** is designed to enable product prototyping in a realistic 5G E2E environment. Multiple products from multiple users can run on the testbed at the same time without affecting each other's setup. In order to achieve this, the testbed has parallel network component for each tenant. Therefore there are VICTORI N2 and N3 networks. The N2 networks are the 5G control plane interfaces between RAN and 5GC, whereas the N3 network is the user plane's interface between the RAN and the user plane function (UPF). The RAN component in the testbed depicted in the diagram and labelled as "FOKUS 5G RAN" is manufactured by Huawei, its model name is indoor pRRU. And the CPE labeled as "VICTORI CPE" in the diagram is also by Huawei, with model number "5G CPE pro2".

Each pink box represents a service in the tenant's network. Accessing the hosts of these services for management can be achieved over the internet while connecting to FOKUS VPN, which gives access to the VICTORI console network. On the other hand, with the corresponding routing configuration, these services can exchange traffic with the 5GC using the VICTORI Tenant Data Network. Using the component "DN Gateway", the data from the user services are routed into the 5G core network functions, notice that the "DN Gateway" component is connected with the "VICTORI 5G Core Network Functions" using the N6. N6 is a 5G interface, that provides connectivity between the UPF and any external (or internal) services, such as the internet. On the other hand some similarities exist in the case of exchanging traffic from and to "kontron-client-ue" box. On this box there is rail client application running and installed by the tenant (**KCC**). The box connects with the "VICTORI CPE" using a LAN cable (Ethernet connection). Data from kontron-client-ue can be sent over the air interface into the 5GC through the CPE. Therefore, the corresponding routing configurations are set on the "kontron-client-ue" box, so that it routes public traffic though it. So this box does not have a direct connection to the 5G core, but similarly to the other service, it has a connection wit the "VICTORI console network", where we can use this connection for accessing the host for its management or configuration.

Finally, it is important to mention some data about the network:

- the PLMN ID:

- Mobile Country Code (MCC): 999
- Mobile Network Code (MNC): 56

- Data Network Name: Default. It is not separated. Only one instance is used.

The primary objective of this setup from May 2022 was to obtain first benchmarks on the performance KPIs. To measure defined KPIs there is an application internal, built-in measurement SW module, which had been implemented to support mission-critical performance indicators (cKPIs):

- MCPTT access time;
- E2E MCPTT access time;
- Late call entry;

Due to limitations of the first phase of the lab setup focusing on onboarding and commissioning of rail critical components in May 2022, measurement of the remaining KPIs were not yet feasible, but is envisioned for next lab phase during June/July 2022.

The next lab phase, planned for June/July 2022, includes deployment and commissioning of rail onboard and office equipment incl. 5G SA smartphones, rail dispatcher terminal, onboard gateway with two 5G SA radio modules for n77 allowing to run test cases focusing on continuity of rail services during transition, co-existence of rail critical services with contending applications and combined test cases.

6.5.10.1 **Mission-Critical KPIs**

The requirements for mission-critical KPIs including measurement definition is standardized in 3GPP TS 22.179 [18]. The following figures (Figure 6-7, Figure 6-8) and subsequent chapters describe the targeted and achieved KPIs.

The prerequisities for executing the cKPIs were:

- on-demand MCPTT session was used.
- no MCPTT XML body encryption was used.
- no MRF transcoding was performed, all rail clients were using G.711 audio codec.
- predefined MCPTT group and emergency group call was used in RCTg02.

The cKPIs were evaluated according to 3GPP TS 22.179 requirements. The rail critical service shall be capable of providing the performance specified by the standard for all affiliated rail group members.

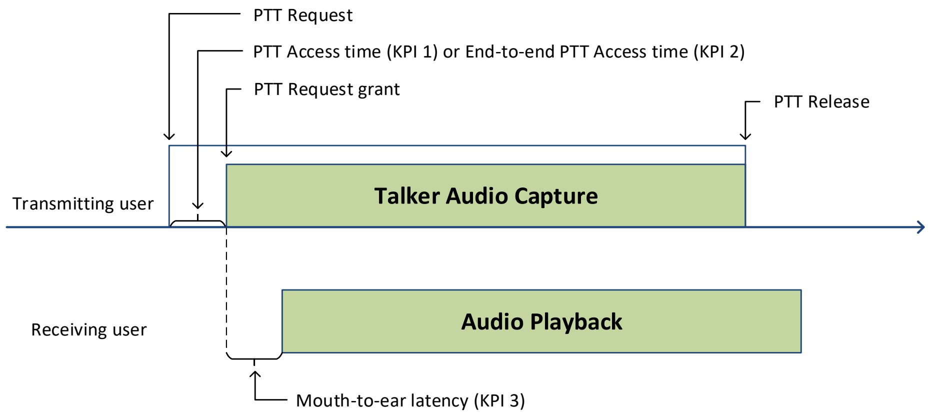


Figure 6-7: 3GPP TS 22.179 illustrating PTT access times

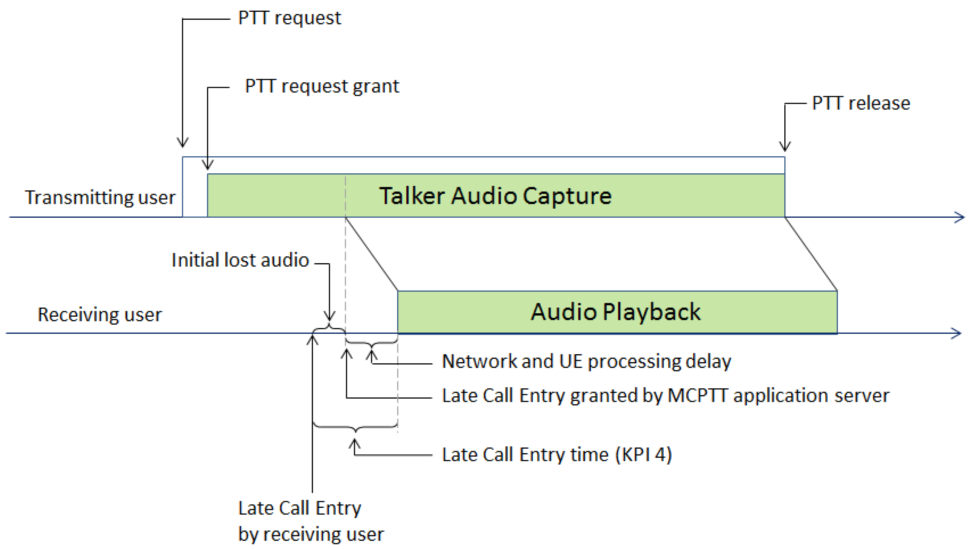


Figure 6-8 3GPP TS 22.179 illustrating late call entry time

6.5.10.1.1 MCPTT Access Time cKPI1

For rail application and users, one of the most important performance criteria is the MCPTT Access time (cKPI 1).

The MCPTT Access time is defined as the time between when an rail user request to speak (normally by pressing the push-to-talk button on device) and when the user gets a signal to start speaking. This time does not include confirmations from receiving users.

The cKPI1 was measured during execution of RCTg01 and RCTg02 (see Figure 6-9 and Figure 6-10).

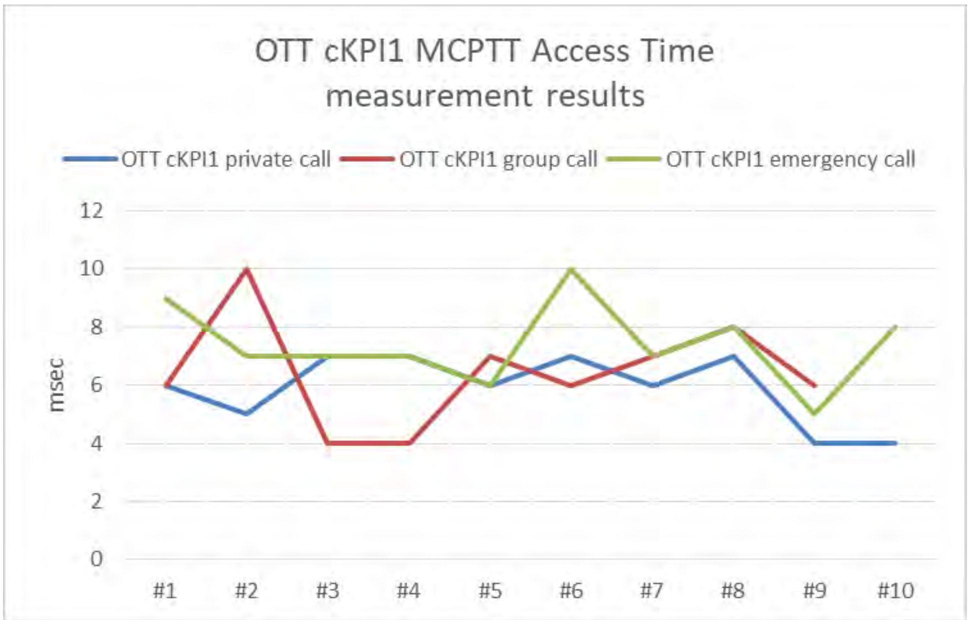


Figure 6-9 OTT measurement results of cKPI1 MCPTT Access Time

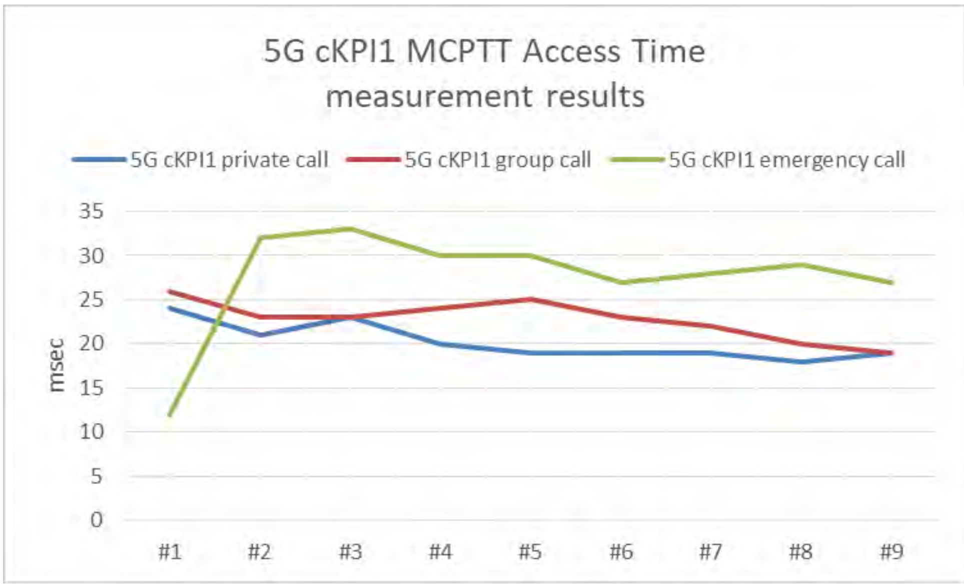


Figure 6-10 Measurement results of 5G cKPI1 MCPTT Access Time

According to TS 22.179:

- [R-6.15.3.2-012] For group calls where no acknowledgement is requested from affiliated MCPTT group members, the MCPTT Service shall provide an MCPTT Access time (KPI 1) less than 300 ms for 95% of all MCPTT Request.
- [R-6.15.3.2-012a] For group and private calls where the call is already established, the MCPTT Service shall provide an MCPTT Access time (KPI 1) less than 300 ms for 95% of all MCPTT PTT Requests.
- [R-6.15.3.2-013] For MCPTT Emergency Group Calls and Imminent Peril Calls the MCPTT Service shall provide an MCPTT Access time (KPI 1) less than 300 ms for 99% of all MCPTT Requests.

The cKPI1 measurements are fulfilling the TS 22.179 requirements.

6.5.10.1.2 E2E MCPTT Access Time cKPI2

The E2E MCPTT Access time (cKPI 2) is defined as the time between when the rail user requests to speak (normally by pressing the push-to-talk button on device) and when this user gets a signal to start speaking. This includes MCPTT call establishment (if applicable) and possibly acknowledgement from first receiving user before voice can be transmitted. Group calls can be set up with or without acknowledgements from receiving users.

The cKPI2 was measured during execution of RCTg01 and RCTg02 (see Figure 6-11 and Figure 6-12).

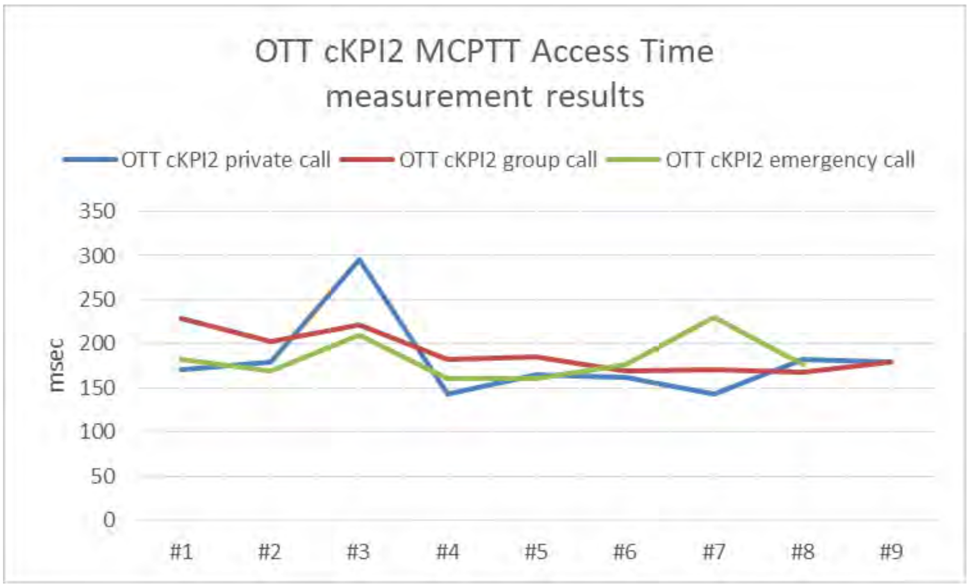


Figure 6-11 measurement results of OTT cKPI2 E2E MCPTT access time

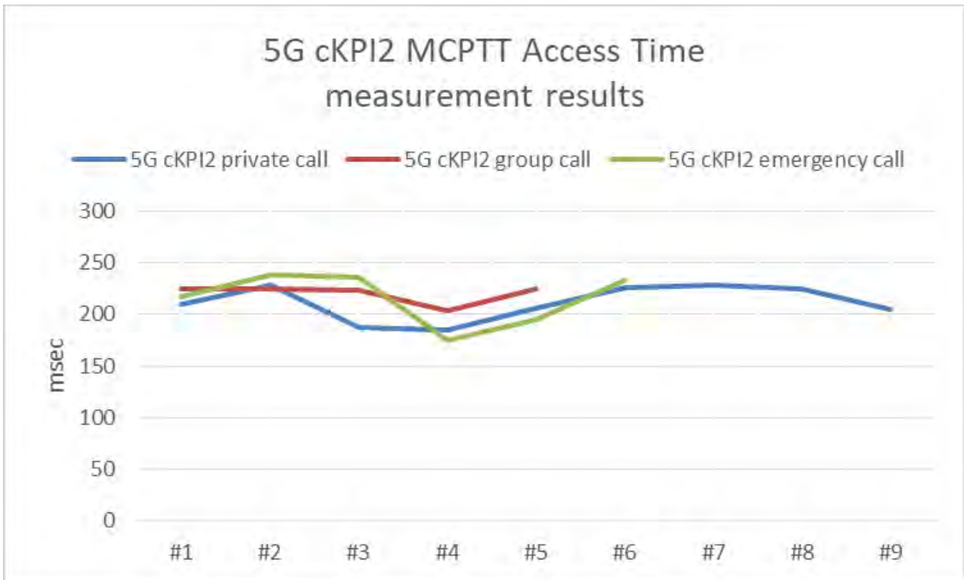


Figure 6-12 measurement results of 5G cKPI2 E2E MCPTT access time

According tto TS 22.179:

- [R-6.15.3.2-014] For group calls where automatic acknowledgement is requested from the UEs of the affiliated MCPTT group members, the MCPTT Service shall provide an E2E MCPTT Access time (KPI 2) less than 1000 ms for users under coverage of the same network.
- [R-6.15.3.2-019] The MCPTT Service shall provide private call E2E MCPTT Access time (KPI 2) equal to or less than 1000 ms for users under coverage of the same network when the MCPTT private call is setup in the Manual Commencement mode.
- [R-6.15.3.2-020] The MCPTT Service shall provide private call E2E MCPTT Access time (KPI 2) equal to or less than 1000 ms for users under coverage of the same network when the MCPTT private call is setup in the Automatic Commencement mode.

The cKPI2 measurement results are fulfilling the TS 22.179 requirements.

6.5.10.1.3 Late call entry cKPI4

A rail user is able to join or leave already ongoing MCPTT Group calls. Late call entry is the activity when an Affiliated MCPTT Group Member joins an MCPTT Group call in which other Affiliated MCPTT Group Members are already active. The Late call entry time (cKPI 4) is the time to enter an ongoing MCPTT Group call measured from the time that a rail user decides to monitor such an MCPTT Group Call, to the time when the MCPTT UE's speaker starts to play the audio. The performance requirements for Late call entry time only applies when there is ongoing voice transmitted at the time the MCPTT User joins the call.

The cKPI4 was measured during execution of RCTg01 and RCTg02 (see Figure 6-13 and Figure 6-14).

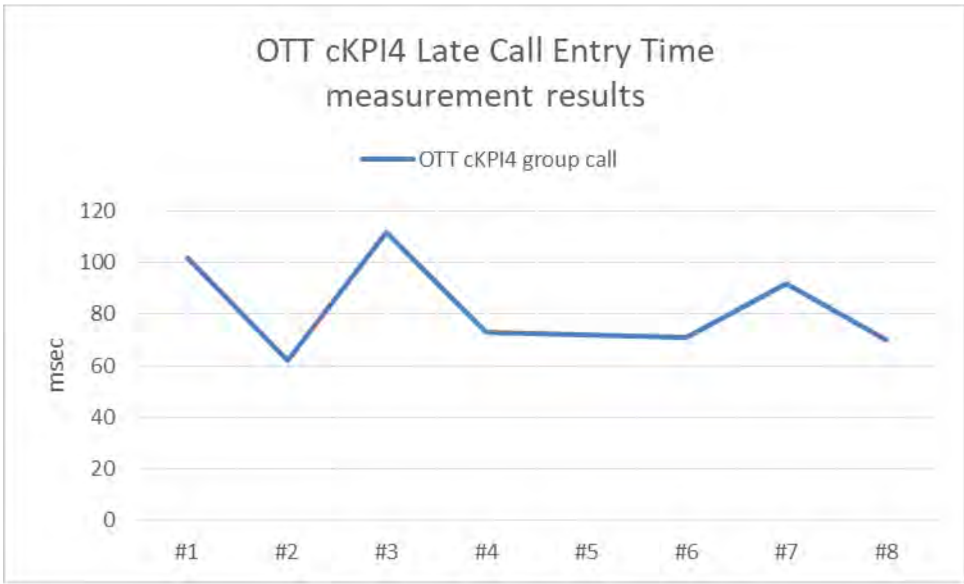


Figure 6-13 measurement results of OTT cKPI4 Late Call Entry time

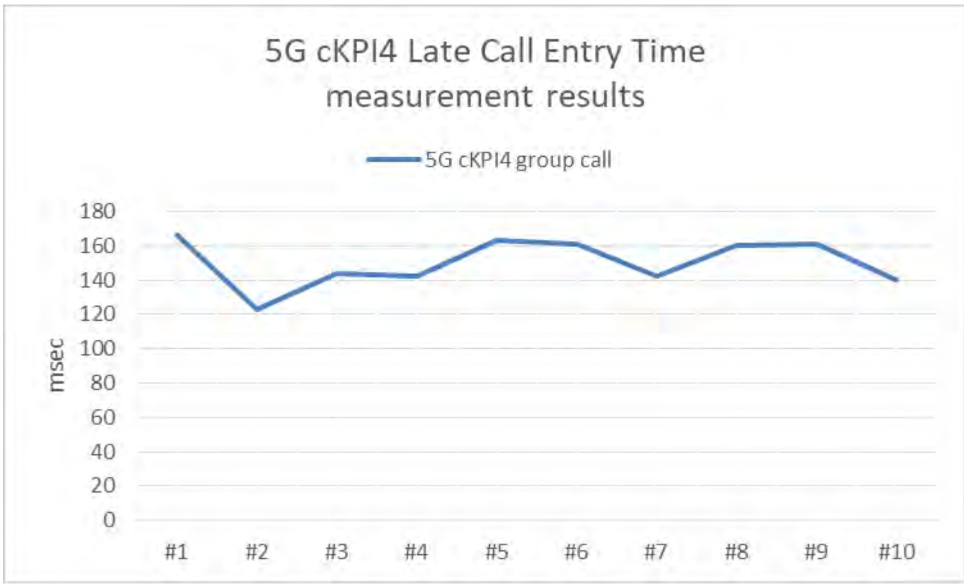


Figure 6-14 measurement results of 5G cKPI4 Late Call Entry Time

According to TS 22.179:

- [R-6.15.4.2-003] The maximum Late call entry time (KPI 4a) for calls without application layer encryption within one MCPTT system shall be less than 150 ms for 95% of all Late call entry requests.

The cKPI4 measurement results are fulfilling the TS 22.179 requirements but are very close to the allowed limit.

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

6.6.1 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.

6.6.2 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 6-16: 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

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 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.
Measurements	**- 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.
Expected Result	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 E2E latency for messaging is not defined. However, we propose to use the Target of E2E Latency for "Critical Data communication," which should be ≤ 500 ms.

6.6.3 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 6-17.

Table 6-17: 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.

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 calculate the file throughput with IxProbe measurement. **- 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. 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 E2E 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.

6.6.4 Lab test results for Rail Sensor Data – from FhG Berlin and Kontron Transportation Vienna

As first phase in the setup of 5G-VICTORI Berlin's Rail Critical lab selected Rail Critical Sensor Data test cases had been executed in following environment:

- 5G SA setup using virtualized client connected to 5G CPE routing traffic via 5G SA intrastructure of Huawei via default data network to the mission-critical SIP core and MCX application server

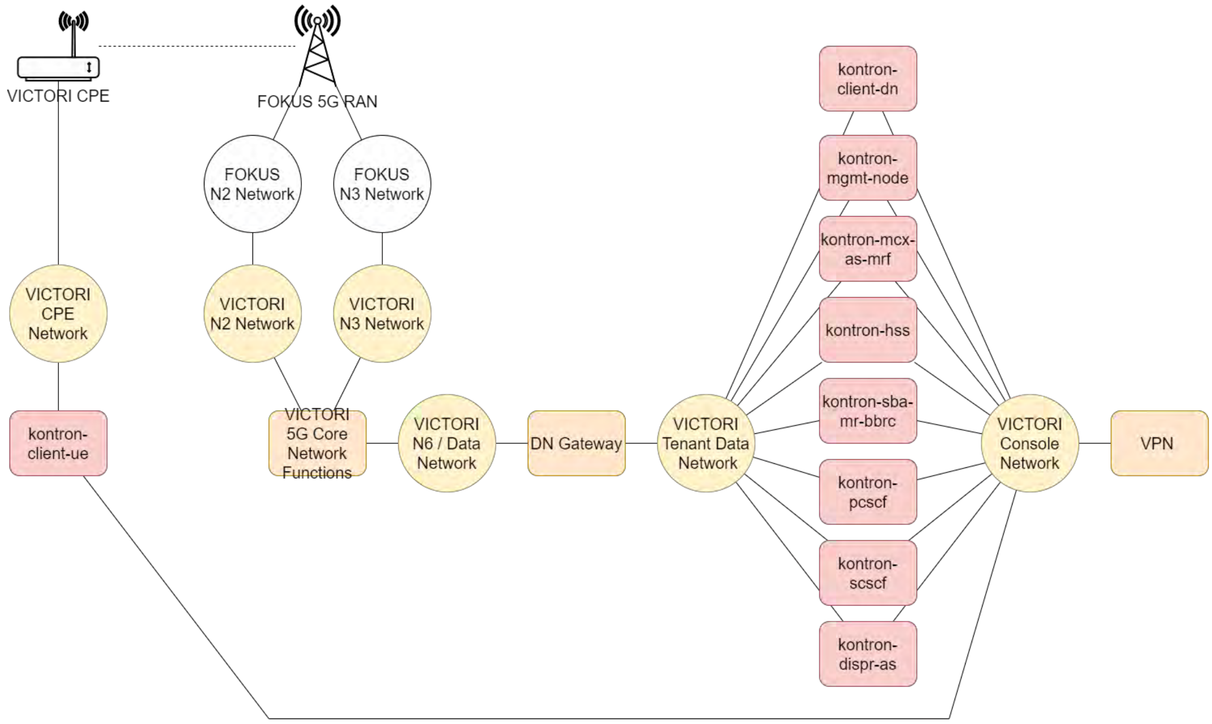


Figure 6-15 Berlin testbed for rail critical services

The diagram of Berlin's testbed of the first phase is shown on Figure 6-15.

The test lab in FOKUS is designed to enable product prototyping in a realistic 5G E2E environment. Multiple products from multiple users can run on the testbed at the same time without affecting each other's setup. In order to achieve this, the testbed has parallel network component for each tenant. Therefore there are VICTORI N2 and N3 networks. The N2 networks are the 5G control plane interfaces between RAN and 5GC, whereas the N3 network is the user plane's interface between the RAN and the user plane function (UPF). The RAN component in the testbed depicted in the diagram and labelled as "FOKUS 5G RAN" is manufactured by Huawei, its model name is indoor pRRU. And the CPE labeled as "VICTORI CPE" in the diagram is also by Huawei, with model number "5G CPE pro2".

Each pink box represents a service in the tenant's network. Accessing the hosts of these services for management can be achieved over the internet while connecting to FOKUS VPN, which gives access to the VICTORI console network. On the other hand, with the corresponding routing configuration, these services can exchange traffic with the 5GC using the VICTORI Tenant Data Network. Using the component "DN Gateway", the data from the user services are routed into the 5G core network functions, notice that the "DN Gateway" component is connected with the "VICTORI 5G Core Network Functions" using the N6. N6 is a 5G interface, that provides connectivity between the UPF and any external (or internal) services, such as the internet. On the other hand some similarities exist in the case of exchanging traffic from and to "kontron-client-ue" box. On this box there is rail client application running and installed by the tenant (Kontron Transportation). The box connects with the "VICTORI CPE" using a LAN cable (Ethernet connection). Data from kontron-client-ue can be sent over the air interface into the 5GC through the CPE. Therefore, the corresponding routing configurations are set on the "kontron-client-ue" box, so that it routes public traffic though it. So this box doesn't have a direct connection to the 5G core, but similarly to the other service, it has a connection wit the "VICTORI console network", where we can use this connection for accessing the host for its management or configuration.

Finally, it is important to mention some data about the network:

- the PLMN ID:
  - o Mobile Country Code (MCC): 999
  - o Mobile Network Code (MNC): 56
- Data Network Name: Default. It is not separated. Only one instance is used.

The primary objective of this setup from May 2022 was to obtain first benchmarks on the MCData KPIs.

To measure defined KPIs an application internal, there is a built-in measurement SW modul which measures following performance indicators:

- E2E MCData SDS latency;
- E2E MCData FD throughput.

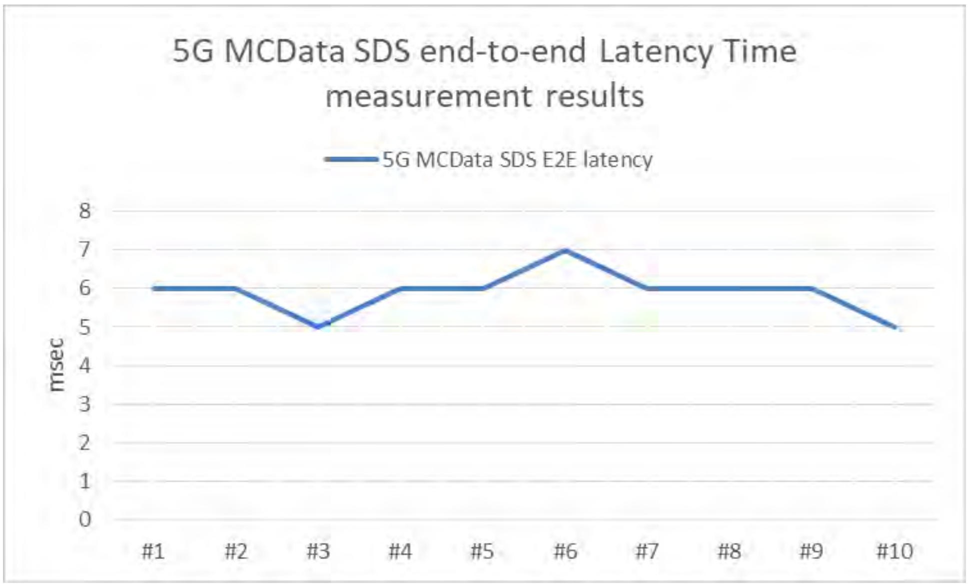


Figure 6-16 measurement results of 5G MCData SDS E2E Latency Time

The KPI MCData SDS E2E Latency was measured during execution of RCDg01.

Due to limitations of the first phase of lab setup available at May 2022, measurement of the MCData FD throughput was not yet feasible at that time, but is envisioned for next lab phase.

The next lab phase planned for June/July 2022 includes deployment and commissioning of rail onboard and office equipment incl. 5G SA smartphones, rail dispatcher terminal, onboard gateway with two 5G SA radio modules for n77 allowing to run test cases focusing on performance data transmissions and test combinations.

6.7 Test Combinations

The Test-combinations suggested for Berlin are here written with Rail Signaling as the prime service (an example of a Rail Critical service), and where Background traffic is used to saturate the 5G air-interface.

The test-combinaitons further down in the table can be used for other services as well to select from.

All services using the same 5G air-interface n78 are of interest.

6.7.1 Berlin services using 5G air-interface n78

Rail Critical Services: Rail Signaling, Cab Telephony, CCTV streaming, Sensor data

Other traffic: Multimodal 3D travel guide, CDN chache updates (note: if using 5G air-interface n78).

- Background traffic (to load or saturate the air-interface).

6.7.2 Test-Combinations for Rail Signaling using different QoS and NS settings

With Rail Signaling and Background Traffic, the test-combinations demo effect is to play with running these over different combinations of QoS and Network Slices.

- Using the same QoS and NS (no differentiation).
- Using different QoS settings (Rail Signaling gets higher priority).
- Using also different NS.

6.7.3 Test-Combinations together with Other Services

The suggested test-combinations for the Rail Critical Services in Berlin must use the same air-interface n78, also mandated for "Other Traffic", including the new type Background traffic (which WP4 needs to specify).

The Background traffic is important to bring in, to make the test cases and test-combinations more useful. These test combinations emulate an environment that is similar to a FRMCS deployment.

6.7.4 Test-Combination and their Numbering

The test-combinations are here named RCgCombNN, RCg extracted from D3.1, Comb added, and NN is the test case combination number.

Test cases are here suggested on Service level, not going down to specified D3.1 test cases for each of the services. WP4 needs to select a good test case per service.

The test-combinations could be called RCgComb01, RCgComb02, etc.

6.7.5 Test-Combinations suggested for WP4

An x in the table below means that the function or service is active in the test combination. The first three table rows are the most important ones for Rail Signaling.

Table 6-18: Rail Signaling focused Berlin test-combinations with using Network Slicing and QoS

Resources and type of services	**Resources**		**Rail Critical Services**				**Other Services**		
Test Combinations (below)	Network Slicing supported	QoS enabled	**Rail Signaling**	Cab Telephony	CCTV Streaming	Sensor Data	3D Travel Guide	CDN Cache updates (n78)	**Background Traffic**
RCgComb01			x						x
RCgComb02		x	x						x
RCgComb03	x	x	x						x
RCgComb04		*x*	*x*	*x*	*x*	*x*			
RCgComb05	*x*	*x*	*x*	*x*	*x*	*x*			
RCgComb06		*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*
RCgComb07	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*

Table row details:

- The first rows of the table (RCgComb01..03) is Rail Signaling focused and is run together with Background Traffic in the Other Services part.
  - The purpose with the Background traffic is that it shall saturate the 5G n78 air-interface (sending more traffic than the air-interface can handle, resulting in frame drops).
  - With these two services running at the same time, combinations of Network Slicing and/or QoS, or non of them, shall be used.
- The last rows of the table (RCgComb04..07) includes all Rail Critical Services outlined in D3.1, plus the Other Services. This part also includes a CDN service running over the 5G n78 air-interface. These combinations could be used where a subset of all these services is selected.

6.7.5.1 Rail Critical Services

The test-combination table outlined in this contribution is written with focus on Rail Critical Services in Berlin 5GENESIS (RCg), with Rail Signaling as the prime service, which is interesting from an Alstom point of view.

The rail critical services in Berlin has a pretty low bitrate compared to what the 5G air-interface can offer. This has the affect that regardless of QoS and NS settings, there will be no difference in performance.

What is interesting to study is when the air-interface is the bottleneck, as this is the real bottleneck in a cellular system, also in 5G.

Note: Playing with “fake bottlenecks” in RAN backhaul, Core Network and Service Network gives nothing, as then the air-interface could be any type.

The Berlin test-combinations must therefore include services that can load the network to an extent that the air-interface almost reaches its capacity. The important service is the Background Traffic in the Other Services part.

6.7.5.2 Other services

- **3D Travel Guide**: very bursty. When data is needed, when the user is moving, the App3 guide would like to get a very high bitrate in downlink, the higher the better, and when the user is not moving, the bitrate is almost zero.
- **CDN Cache Updates**: the service in a 5G-VICTORI point of view is useless if it uses non-5G mmWave equipment, it contributes with nothing. Therefore the CDN service shall use the same n78 air-interface as the other services in Berlin.
- **Background Traffic**: very useful, it can load the 5G air-interface with a high bitrate, emulating a high background load which rail signaling and the other rail critical services compete with. Background traffic is prerequisite for good demo test experience.

6.7.6 The idea behind the outlined rail critical test-combinations

Here is the thinking behind the steps in the table:

1. First rail signaling is used in an empty network, used as baseline with KPIs for further test-combinations. This is a test without a combination.
2. Then add Background Traffic that loads the network, both using “Best Effort” (same QoS settings).
3. Then activate QoS where Rail signaling gets a higher prio QoS compared with Background Traffic.

4. The acrivate Network Slicing and put Rail signaling in a second Network Slice and see how rail signaling behaves. The air-interface shall be saturated by the Background Traffic, or close being saturated. The air-interface shall be the real bottleneck.
5. Then, if WP4 finds interesting, add Rail Critical Services and Other Services, play with QoS and NS. The air-interface shall be close to saturated.
6. The last part is with all services run at the same time, both rail critical servies and other traffic, with QoS and NS. If found needed.

6.7.7 Network Slicing and QoS for the Berlin Services

This section outlines an approach for Network Slicing and QoS for the Berlin Rail Signaling deployment. When Network Slicing (NS) is supported, two Network Slices are suggested:

- NS 1: Other Services
- NS 2: Rail Critical Services

When FRMCS comes into place, it is very likely that Rail Operators running trains in the same Rail Corridor will be allocated a 5G Network Slice for their Rail Critical Service.

Each NS could be configured with its own set of 5G Qos Identifiers (5QIs), but as the Berlin services are fully different in the two NSs, the 5QIs can be kept different, regardless of supporting NS or not.

Standardized 5QI values with characteristics are found in table 5.7.4-1 in 3GPP TS 23.501.

DSCPs shall be mapped to 5QIs and NSs, and are then mapped to Data Radio Bearers over the air-interface, both for Downlink and for Uplink.

The Berlin test combinations are suggested to include test cases developed in these tasks and delivery documents:

- T3.1 and D3.2
- T3.2 and D3.4
- Background traffic

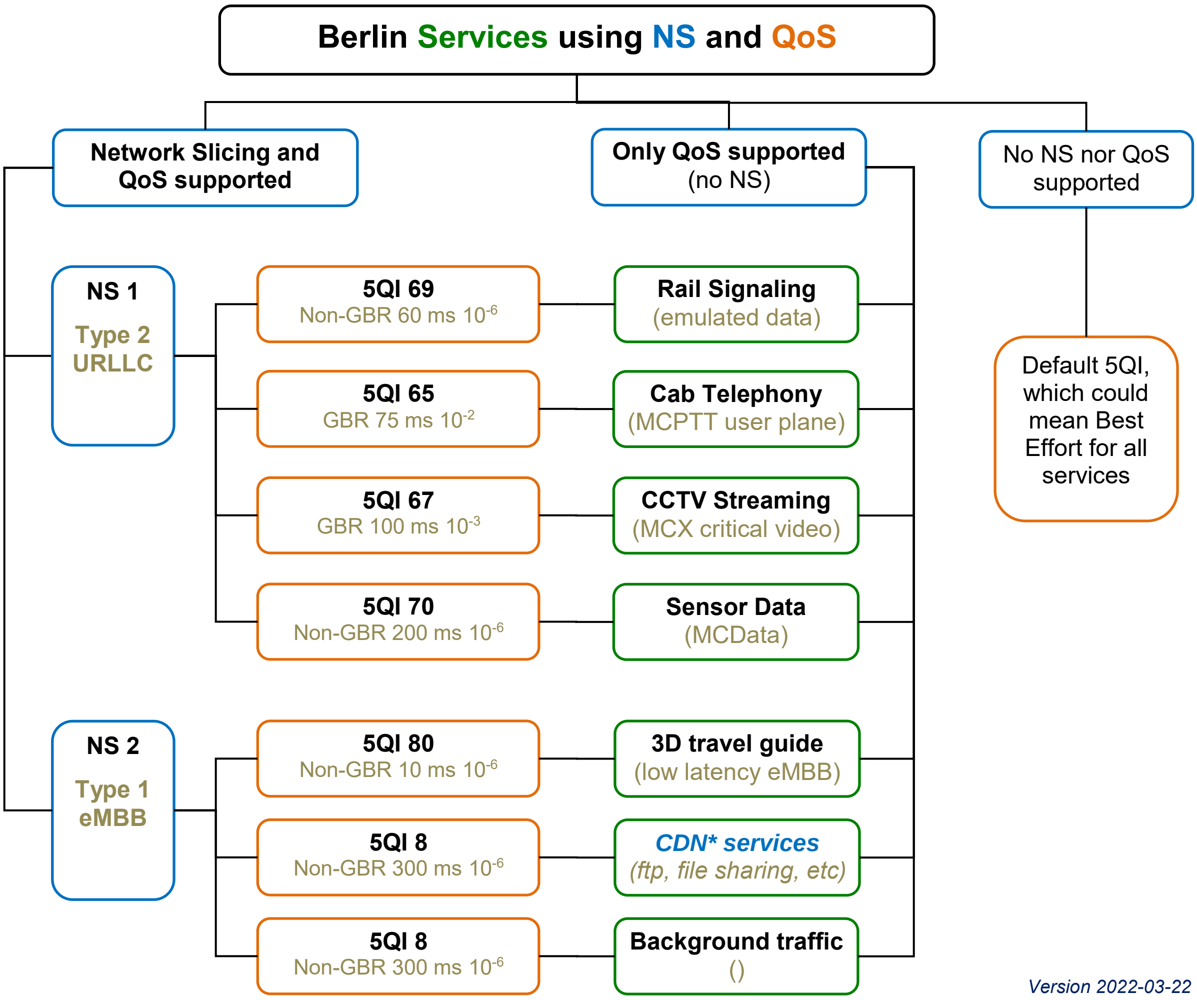


Figure 6-17: Berlin Services with and without Network Slicing, plus QoS support.

Note:* Demonstrating CDN services using the same n78 air-interface as the other services would contribute to a better 5G experience project result.

6.8 Inter-cluster demo testing

Not applicable according to the project specification, which says for Task 3.1:

> *"This task will define rail related use cases that can be tested and evaluated alone or together with other services on one of the 5G infrastructures".*

7 Conclusions

In support of the overall 5G vision, and with the aim to offer transportation services and to support new business models and opportunities in the rail-related ecosystem, 5G-VICTORI has built up a set of novel UCs that are facilitated by the deployment of vertical services on top of several 5G facilities. The 5G-VICTORI platform has been designed to offer increased functionality and flexibility to accommodate these services.

This document is the second and final release of Task 3.2, and defines transportation related UCs that can be tested and evaluated in isolation or together with other services at one or more 5G facilities. In this case, D3.2 provides a refined version of these UCs and test cases, and provides measurement campaigns involving the services deployed onto the underlying 5G infrastructures carried out in laboratories. Additionally, this deliverable considers the concurrent execution of different test cases (with dissimilar KPI targets) in the facilities, which is enabled by the implementation of logically separated networks, e.g. network slicing, or, alternatively, assigning quality indicators to a specific service.

The assessment of the performance of these services and that of the 5G infrastructure is subject of analysis and allows the evaluation of the results and, when possible, the optimization of the performance towards the deployment of these services onto vertical facilities (operational environments) in WP4.

Future work to be carried out in the framework of WP4 refers to:

- Assessment of the seamless handover of the multi-technology network involving heterogeneous transport nodes.
- Immersive media and caching performance performance evaluation
- Integration front to back-end, send captured spatial data to back-end, integrate in Polaron, then send the integrated result to front-end for the future mobility UC.
- Assessment of the continuity of rail (operational, critical, business, performance) services during transition (train on the move) in the different facilities.
- Co-existence of different types of services, e.g. rail critical services with contending applications (e.g. digital mobility) and the execution of combined test cases in lab-scale and operational environments. The former allows optimization of the use case that can be later on incorporated to the field trials.
- Integration of the UCs together with 5G-VIOS.

5G-VICTORI is able to offer the necessary tools to provide services across the different facilities. In this regard, the integration of the UCs together with 5G-VIOS is planned until the end of the project. 5G-VIOS will be able to support both intra-facility and inter-facility trials.

Two inter-facility scenarios are considered based on the Vertical application deployment options. These are separately addressed in this document and they include: a) a cross-facility UC between Patras and Bristol that focuses on the provisioning of a 360° VR Multicamera live stream that will be concurrently delivered to students located at UoP and at UNIVBRIS, and b) a cross-facility UC between Berlin and Bristol that focuses on the provisioning of an AR service available in the Berlin cluster that will be delivered to end-users in Bristol.

All these outputs 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 Appendix

8.1 Sample Experiment Descriptor for App1

Experiment Descriptor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 "Type": "Standard",
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   "max_cores": "8"
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   "max": "10000"
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   "max": "1400000000"
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  "threshold_mbps": {
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 "profiling_duration": {
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Edge Descriptor


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      "virtual-link-connectivity": [
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          "constituent-cpd-id": "client-ext"
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      "vnfd-id": "client-vnfd"
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   "userDefinedData": {},
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   "modified": 1637241051.583758,
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   "projects_write": ["41568c1b-865e-46ba-bbfb-d5293c112c22"],
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   "operationalState": "ENABLED",
   "usageState": "NOT_IN_USE",
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    "pkg-dir": "demo_nsd",

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        "zipfile": "demo_nsd.tar.gz"
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    },
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    "nsdOperationalState": "ENABLED",
    "nsdUsageState": "NOT_IN_USE",
    "_links": {
      "self": {
        "href": "/nsd/v1/ns_descriptors/afd07015-9445-4728-8ca3-edbf4b67f5aa"
      },
      "nsd_content": {
        "href": "/nsd/v1/ns_descriptors/afd07015-9445-4728-8ca3-edbf4b67f5aa/nsd_content"
      }
    }
  }
 ]
}
```


8.2 Delay and Modification of the use case “Wayside Point Machine”

The UC in discussion is intended to illustrate how 5G could be adopted as a backup solution for wayside signaling in case of a failure (or due to vandalism) of the currently (wired) used solution by DB. The detailed test-case Specification is available in WP3 D3.1 “Preliminary Use case specification for transportation services”, Section 6.2 “Rail Critical services Berlin Rail Signaling test Cases” (P. 91) at the Projects homepage and in the Participant Portal: https://www.5g-victori-project.eu/wp-content/uploads/2021/09/2021-07-31-5G-VICTORI_D3.1-Prel-Test-Cases-for-Trp-Services_v1.0.pdf

The test cases described in deliverable D3.1 cannot be implemented due to the following reasons: The required measures to implement the specified test cases and UC described in deliverable D2.1 have shown that pulling out rail critical information from the point machine violates company security practices and regulations. The wayside point machine is a closed system in which messages may not simply be extruded and copied in production areas such as Berlin HBF. In general, any alteration to such systems requires recertification by *Eisenbahnbundesamt* (EBA), the, federal railway authority, which involves a lengthy process. Due to the pandemic situation, it was not possible to trigger these processes.

9 References

9.1 5G-VICTORI Project Documents

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[8] 5G-VICTORI Project Proposal (describes partners, objectives, WPs and Tasks, etc).

[9] 5G-VICTORI deliverable D2.5, "5G-VICTORI Infrastructure Operating System – Initial Design Specification", December 2020, https://www.5g-victori-project.eu/wp-content/uploads/2020/10/2020-07-31-5G-VICTORI_D2.5_v1.0.pdf

[10] 5G-VICTORI deliverable D2.6 (T2.4) 5G-VICTORI Infrastructure Operating System – Final Design Specification (DCAT)

[11] 5G-VICTORI deliverable D3.1 (T3.1) Preliminary Use case specification for transportation services (Alstom, 31 May 2021)

[12] D3.2 Minutes of Meetings

[13] 5G-VICTORI deliverable D3.2 (T3.1) Final Use case specification for transportation services (DB)

[14] 5G-VICTORI deliverable D3.3 (T3.2) Preliminary Use case specification for Media Services (RBB, 31 May 2021)

[15] 5G-VICTORI deliverable D3.4 (T3.2) Final Use case specification for Media Services (RBB)

[16] 5G-VICTORI deliverable D3.7 (T3.4) Use Case Assessment (IZT)

[17] 5G-VICTORI deliverable D2.4 (T3.1) 5G-VICTORI end-to-end reference architecture, https://www.5g-victori-project.eu/wp-content/uploads/2022/05/2022-04-11-D2.4-5G-VICTORI-end-to-end-reference-architecture.pdf

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9.2 Standards

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9.3 5G-VICTORI inherited platforms

[24] 5GENESIS

[25] 5G-EVE

[26] 5GPPP

[27] 5G-UK

[28] 5G-VINNI

10 List of Figures

11 List of Tables