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

D3.4 Final Use case specification for Media Services

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Executive Summary

5G-VICTORI focuses on large-scale field trials for advanced Use Case (UC) verification in commercial environments deploying 5G infrastructures in support of a number of vertical industries. More specifically these vertical industries include **Transportation, Energy, Media** and **Factories of the Future**, as well as some specific UCs involving cross-vertical interaction. The planned validation activities will be conducted under real life conditions for the various vertical sectors involved.

Following the approach initially reported in deliverables **D3.1**, **D3.2** and **D3.3**, a common unified testing approach has been adopted across all **WP3** activities. This ensures that the test cases have the same structure, are easily identifiable and ordered sequentially, while the 5G performance for all test cases is evaluated taking a common methodology.

Focusing on the Media Services related UCs the facilities and specific services that will be demonstrated as part of the 5G-VICTORI field trials include:

- The Berlin 5G facility, where the Data Shower application will be tested, allowing large quantities of data to be transferred from the station's Content Delivery Network (CDN) cache to a train's server for use by passengers.
- The Patras 5G facility, where a data shower application similar to that of Berlin will provide a train with video-on-demand (VoD) and live content as it arrives at a train station. In addition, a 360° surveillance application will enable a train operator's security personnel to remotely monitor activity at multiple operator facilities. The aforementioned services are all derived from the CDN.
- The 5G-EVE cluster in Alba Iulia Municipality (**AIM**), where the services, based on the Digital Mobility UC, revolve around infotainment and public safety. The infotainment is provided through a portal in public buses, via on-board Wi-Fi and 5G backhauling. Three on-board cameras are used for public safety and Artificial Intelligence (AI) recognition of safety issues and prioritised communication with the Control and Command Centre (CCC) ensures that safety alters can be triggered.

In this context, this document defines media related services that will be tested and evaluated independently, or together with other services on the above mentioned 5G-VICTORI facilities. The target deployments are based on the 5G infrastructure specified in WP2, which is being currently implemented as part of the WP4 activities. For each service to be demonstrated, several test cases were defined and evaluated under laboratory conditions and in some cases initial field settings were also assessed. The test cases described in the document aim to assess the performance capabilities and the efficiency of the 5G-VICTORI infrastructure deployment options available at the different 5G-VICTORI facilities with emphasis on dense and static environments where bandwidth-hungry media content is delivered. In addition, this deliverable presents the proposed testing methodology including identification of a set of relevant Key Performance Indicators (KPIs) that will be monitored and assessed per test case and describes the proposed KPI measurement/calculation approach that will be taken to facilitate service level assessment, considering the specificities of the underlying 5G infrastructure. Finally, this document reports results collected from laboratory experiments and, where available, field tests. The reported testing methodology will be provided as input to WP4 for the evaluation of the UCs that will be demonstrated as part of the planned field trials focusing on the identified KPIs in support of the relevant evaluation activities.

Acronyms

General acronyms

Acronym	Description
3GPP	Third Generation Partnership Project
5G	Fifth Generation cellular system (3GPP related)
5G CN	5G Core Network
5G-SA	5G Stand Alone
AI	Artificial Intelligence
AMF	Access and Mobility Management Function
AP	Access Point
ARD	*Arbeitsgemeinschaft der öffentlich-rechtlichen Rundfunkanstalten der Bundesrepublik Deutschland* / Joint organization of Germany's regional public-service broadcasters
AW2S	Advanced Wireless Solutions and Services
BBU	Base Band Unit
CCC	Command and Control Center
CCTV	Closed Circuit Television
CDN	Content Delivery Network
DL/UL	Downlink/Uplink
DNS	Domain Name Service
E2E	End to End
FQDN	Fully Qualified Domain Name
GPS	Global Positioning System
GPU	Graphics processing unit
gNB	gNodeB
eMBB	Enhanced Mobile Broadband
MD5	Message-Digest Algorithm 5
MEC	Mobile Edge Computing
MBB	Mobile BroadBand
mmWave	Millimetre Wave
MSISDN	Mobile Station International Subscriber Directory Number
PDU	Protocol Data Unit
QoS	Quality of Service
RGB	Red Green Blue
RHU	Radio Hub Unit
RTT	Round Trip Time
SAND	Server and Network-assisted DASH
SIM	Subscriber Identity Module
SMF	Session Management Function

SMS	Short Message Service
SRA	Shared Resource Allocation
SSID	Service Set Identifier
TDD	Time Division Duplex
UC	Use Case
UDM	Unified Data Management
UDR	Unified Data Repository
UE	User Equipment
UPF	User Plane Function
URL	Uniform Resource Locator
uRLLC	Ultra-Reliable Low Latency Communications
VoD	Video-on-Demand
Wi-Fi	Wireless Fidelity

5G-VICTORI related acronyms

Acronym	Description
5GENESIS	The Berlin ICT-19 Cluster [4]
5G-EVE	The Alba Iulia ICT-17 Cluster [5]
5G-VINNI	The Patras ICT-19 Cluster [3]
AIM	Alba Iulia Municipality (5G-VICTORI Partner)
COSM	COSMOTE (5G-VICTORI Partner)
D2.1	Deliverable D2.1
D2.4	Deliverable D2.4
D3.3	Deliverable D3.3
D4.1	Deliverable D4.1
FhG	Fraunhofer FOKUS (5G-VICTORI Partner)
FR/RO	French/Romanian cluster
IASA	Institute of Accelerating Systems and Applications (5G-VICTORI Partner)
ICOM	Intracom Telecom (5G-VICTORI Partner)
IHP	Innovations for High Performance microelectronics (5G-VICTORI Partner)
ORO	Orange Romania (5G-VICTORI Partner)
PXI	PaxLife Innovations GmbH (5G-VICTORI Partner)
RBB	Radio Berlin Brandenburg (5G-VICTORI Partner)
T3.2	Task 3.2: Media Services
UoP	University of Patras (5G-VICTORI Partner)
WP2	Work Package 2: Description – Use cases/ Specifications
WP3	Work Package 3: Vertical Services to be demonstrated
WP4	Work Package 4: Trials of Coexisting Vertical Services, validation and KPI evaluation

1 Introduction

5G-VICTORI focuses on large-scale field trials for advanced Use Case (UC) verification in commercial environments deploying 5G infrastructures in support of a number of vertical industries. More specifically, these vertical industries include **Transportation, Energy, Media** and **Factories of the Future**, as well as some specific UCs involving cross-vertical interaction. The planned validation activities will be conducted under real life conditions for the various vertical sectors involved.

This document is the second and final release of Task 3.2, and it defines media related services that will be tested and evaluated independently or together with other services on one or more of the 5G VICTORI facilities using the 5G infrastructure as specified in **WP2** and implemented as part of the **WP4** activities.

More specifically, the Media Services related UCs that this deliverable concentrates on include:

- The Data Shower application that will be tested in the Berlin 5G facility, allowing large quantities of data to be transferred from the station's CDN cache to a train's server for use by passengers.
- The data shower application similar to that of Berlin that will be tested at the Patras 5G-facility. This will provide a train with video-on-demand (VoD) and live content when it arrives at a train station. In addition, a 360° surveillance application will enable a train operator's security personnel to remotely monitor activity at multiple operator facilities. The aforementioned services are all derived from the Content Distribution Network (CDN).
- Services based on the Digital Mobility UC that revolve around infotainment and public safety and will be tested at the 5G-EVE cluster in **AIM**. The infotainment is provided through a portal in public buses, via on-board Wi-Fi and 5G backhauling. Three on-board cameras are used for public safety and Artificial Intelligence (AI) recognition of safety issues and prioritised communication with the Control and Command Centre (CCC) ensures that safety alters can be triggered.

For each service to be demonstrated several test cases were defined and evaluated under laboratory condition and in some cases initial field settings were also assessed. The test cases described in the document aim to assess the performance capabilities and the efficiency of the 5G-VICTORI infrastructure deployment options available at different locations with emphasis on dense and static environments where bandwidth-hungry media content is delivered. The initial specifications were provided in **D3.3** following the identification and agreement of a unified methodology that was applied across all **WP3** tasks. This document includes the description of the test cases in their final form. In addition, it presents the proposed testing methodology including identification of a set of relevant Key Performance Indicators (KPIs) that will be monitored and assessed per test case and description of the proposed KPI measurement/calculation approach that will be taken to facilitate service level assessment, considering the specificities of the underlying 5G infrastructure. In addition, this document reports results collected from laboratory experiments and, where available, field tests. The reported testing methodology will be provided as input to WP4 for the evaluation of the UCs that will be demonstrated as part of the planned field trials focusing on the identified KPIs in support of the relevant evaluation activities.

1.1 Objectives

The objective of the deliverable is to define detailed final test case specifications and testing methodology for media services that will be demonstrated over the 5G-VICTORI facilities (see Figure 1-1 for an overview), identify suitable KPIs and KPI measurement/calculation approaches and provide evaluation results from laboratory experimental tests.

In **D3.3**, for each service to be demonstrated, several test cases were defined in a preliminary form. These test cases are applied to thoroughly assess the infrastructure's efficacy across different locations and verticals, especially in dense and static environments where bandwidth-hungry media content is delivered. This deliverable provides updates and enhancements to the initially defined test case descriptions to include the updated information associated with the 5G deployment options and platforms adopted per cluster as well as learnings from tests conducted in lab settings. In this context, special emphasis has been given to 5G performance related measurements that have been defined for each UC.

Figure 1-1 below provides an overview of the media services, which are described in detail in deliverable **D2.1** [1], and covered in this document:

- **UC #3** Content Delivery Network (CDN) Services: this UC will be tested in two different facilities: the 5G-VICTORI facility in Berlin and the 5G-VICTORI facility in Patras. A Data Shower application will be tested in Berlin, while both Data Shower and 360° Camera Applications will be tested in Patras.
- **UC #1.2** Digital Mobility: for this UC, three services will be conducted in Alba Iulia Municipality (**AIM**): Infotainment and Video Services, Prioritized Communication to Command and Control Center, and AI Recognition of Emergency Situations.

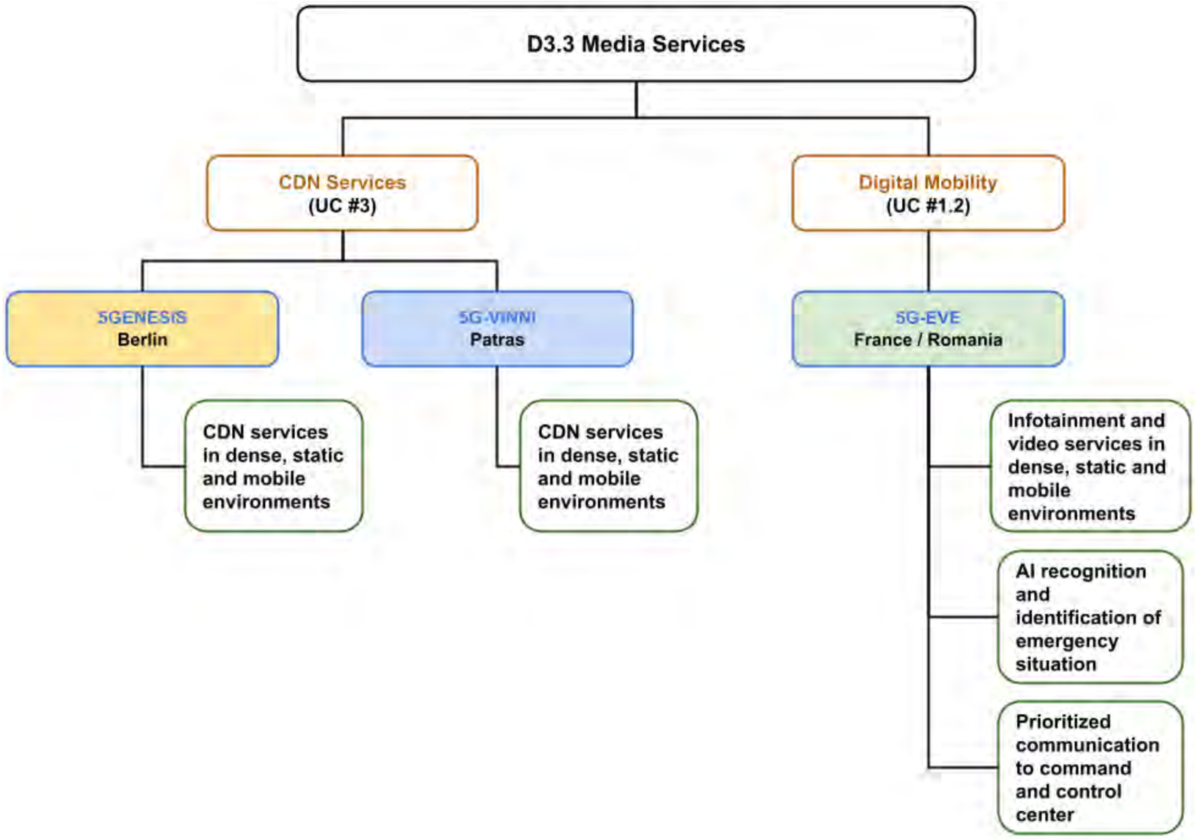


Figure 1-1 Media UCs, Clusters and Services

The specific objectives of the vertical services listed in this document are:

1. **CDN Services in Berlin**: The objective is to utilize millimetre wave (mmWave) connectivity to extend streaming service's CDN to trains, by equipping them with caches filled with content. This allows large amounts of media data to be transferred between caches on server placed in Berlin main train station to a train while stopped at a platform. The focus is on the rapid transfer of large amounts of media content within a very short time period over a short distance.
2. **CDN Services in Patras**. The objective here is to also use mmWave connectivity to transfer as much media content as possible between a cache in the station to one on a train. Similar, to the Berlin service, the focus is on the rapid transfer of large amounts of media content within a very short time period over a short distance. A further objective is to use mmWave and 5G air interface connectivity to provide high resolution, low latency video streaming capabilities for surveillance purposes.
3. **Digital Mobility in Alba Iulia**: The objective is to increase the safety and comfort of passengers. The infotainment is provided through a captive portal in public buses, via on-board Wi-Fi and 5G backhauling. For public safety three surveillance cameras are deployed on the buses, connected over Ethernet to the 5G router. The focus is on network slicing, services use three Network Slices (NS') for three different "clients" with different quality of service (QoS) needs: one enhanced Mobile Broadband (eMBB) slice for infotainment, one eMBB slice to convey the video for analytics and one ultra-Reliable Low Latency Communications (uRLLC) slice used to trigger the threats alarm.

1.2 Document Structure

The document is structured into six sections.

Following the introduction, section 2 provides a description of the overall testing methodology proposed in order to facilitate the adoption of a unified testing approach across all project demonstration evaluation activities and provides templates for test case reporting.

Section 3 describes the media services to be demonstrated at the 5G-VICTORI facility in Berlin. It includes a general description and individual tables containing detailed information for each final test case.

Section 4 describes media services to be demonstrated at the 5G-VICTORI facility in Patras.

Section 5 describes media services to be demonstrated at the 5G-VICTORI facility in Alba Iulia Municipality.

In each of these last three sections, a description of the vertical UC and the cluster 5G network topology and working environment is provided. This is followed by a general description of the test cases including the individual tables containing detailed information for each final test case. This is followed by a detailed description of lab results and, if available, field results including 5G performance measurements and finally suggested test combinations.

Finally, Section 6 concludes the deliverable.

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 standard [9] and includes the following steps.

1. **Definition of 5G network topology and environment of operation.** The specific services under test will be evaluated for the given network topology considering all equipment and virtualised 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.

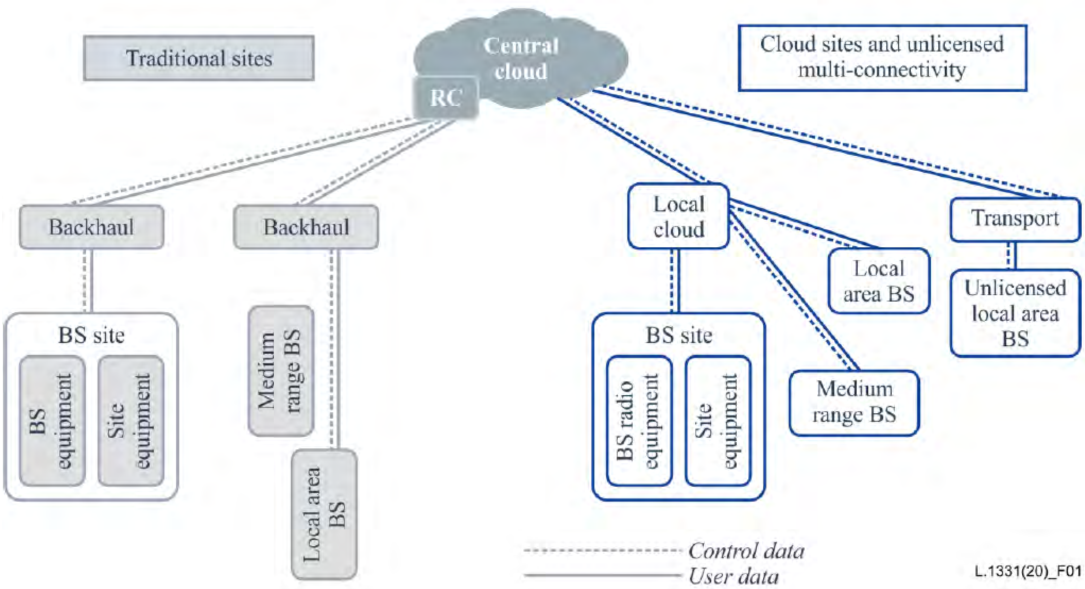


Figure 2-1 Deployment option topology/configuration [10]

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 NFs) 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) 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

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. This
	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.

Table 2-7 E2E (per slice metrics)

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 2-8 [8].

Table 2-8 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 CDN Services at the 5G-VICTORI facility in Berlin

3.1 Description of 5G infrastructure at 5G-VICTORI facility in Berlin (FOKUS)

The architecture illustrated in Figure 3-1 provides an overview of the three Berlin facility UCs. For this deliverable, only the components highlighted in **green** are relevant for the CDN Media services UC.

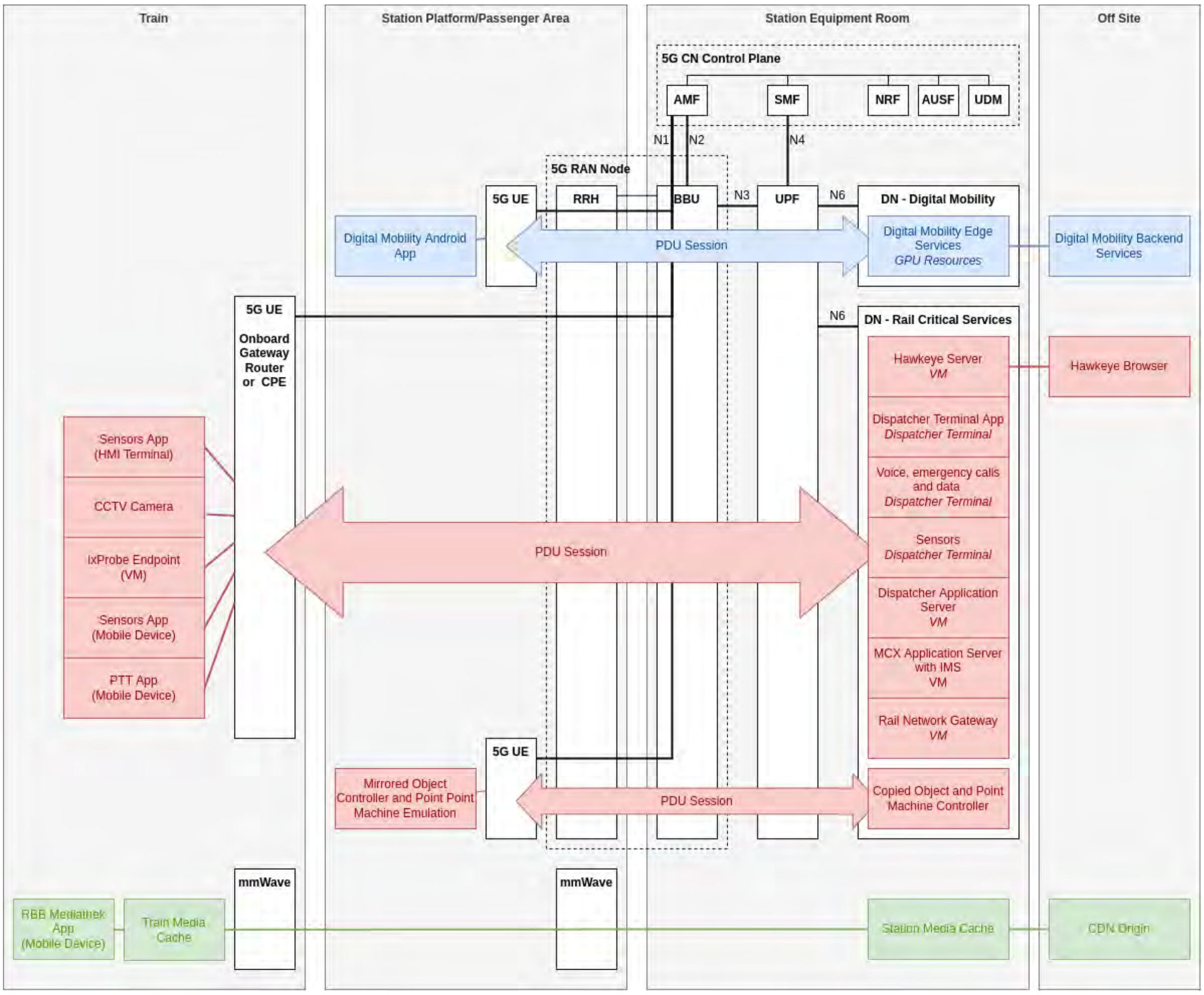


Figure 3-1 Berlin cluster UC services mapped to 5G and non-5G infrastructure at Berlin Central Train Station

These components are:

- **CDN Origin**: The CDN origin is the location where the source media content for RBB/ARD Mediathek is hosted. It is made available to any client via commercial CDN. In case of ARD/RBB, Akamai CDN is used.
- **Station Media Cache**: It is the component located in the station equipment room that prefetches popular media content from the CDN and caches them in the station cache at Berlin central station.
- **mmWave Equipment**: the sender component of the mmWave equipment is located at the station platform/passenger area and connected to the station media cache. The receiver component of the mmWave equipment is located onboard the train. It receives the transmitted data via mmWave, while the train is approaching the station and during train stops and stores the data at the train media cache.

- **Train Media Cache**: it is the component that caches the media content onboard the train. The content will be updated after each train stop.
- **RBB Mediathek App**: it is the web application that passengers use to watch media content from the ARD Mediathek. It includes core ARD player extended with SAND Client for playback metric monitoring and reporting and shared resource allocation.

3.2 CDN services test cases

3.2.1 MCBg01: Aggregation of relevant content for cache prefilling

Due to limited storage capacity on the train, *subsets* of content can only be made available to train passengers, rather than the *entire* content archives provided by VoD service providers. The aim of the test described in Table 3-1 is to specify, find and fetch a relevant subset of content from the VoD archives and successfully upload the content to the station's media cache.

Table 3-1 MCBg01: Aggregation of relevant content for cache prefilling

MCBg01	**Aggregation of relevant content for cache prefilling**	
Testbed	**5GENESIS Berlin [4]**	
Description	Storage capacity on the train is limited and will not be sufficient to store the entire content archive for any VoD service provider. It is therefore not feasible to simply copy the content archive to the media cache on the train. Instead, a relevant subset of content must be specified (in terms of total number of assets as well as different qualities of each) to upload to the cache. A subset may be identified by either of the following entities: human content editor, preselected subset, or machine learning algorithm. The content subsets are then sent to the 5G platform, which crawls content archives for matching content and collects the respective resource's location from the content providers' CDNs. Resource locations are then sent to the 5G platform's prefetching service, which requests the respective resources from the media cache in the station and downloads the resources from the VoD service providers' CDN. This test case determines whether or not the 5G platform can: fulfill the defined aggregation tasks, initiate the subsequent prefilling mechanism accordingly and verify the integrity of the asset collection. The test case will be verified by checking the built-in logging system to confirm that all actions performed as expected. The output list of media files and segments of all aggregated media contents must also be equivalent to the list of media files available in the CDN origin.	
Key Use Case requirements and KPIs	1. Catalogue of video content is available	
Network performance requirements and KPIs	N/A	
Network Functional requirements and KPIs	N/A	
Components and Configuration	Components	2. 5G Platform
	Configuration	Runtime-dependent human configuration or predefined collection

Test procedure	Pre-conditions	3. Connectivity shall be available across all infrastructure components of the "Architectural deployment" figure 4. Internet connectivity to the Aggregator shall be ensured. 5. Partner CDN URLs shall be accessible. 6. CDN cache size needs to be known.
	Test Case steps	Observe input data and service logs to validate whether or not the service is successfully implemented in the following steps: 7. Receive content subset configuration 8. Find content that matches given configuration in content archive and report potential deviations 9. Get CDN URLs for content items 10. For adaptive bitrate streaming formats, get segment URLs referenced in (nested) stream manifests 11. Compile a list of video and video segment URLs 12. Send list to prefetching service
Measurements	Methodology	N/A
	Complementary measurements	N/A
	Calculation process	N/A
Expected Result	Prefetching services receive an asset collection that can be parsed/processed.	

3.2.2 MCBg02: Pre-Fill Media Content in Station Cache from RBB Catalogue (via public CDN)

Following the test procedure described in test case MCBg01, a predetermined set of media content (from the **RBB** Catalogue) must be used to fill the cache in the train station, as described in Table 3-2. The aim of this test case is to assess if the content is successfully downloaded and queryable for any interested customers. In order for this test case to succeed, media assets must be accessible and properly indexed.

Table 3-2 MCBg02: Pre-Fill Media Content in Station

MCBg02	**Pre-Fill Media Content in Station**
Testbed	**5GENESIS Berlin [4]**
Description	The assets collection that has been determined and assembled in MCBg01 must be used to fill the station cache. For this, the 5G Platform must parse the asset collection, extract relevant assets, download (including verification) and store them in a consistent and predictable fashion. Once all assets have been downloaded, the successful download must be announced/queryable for any interested consumers. Furthermore, any mismatch/ lack of data shall be reported.

Key Use-case requirements and KPIs	Relevant Media Content is available via public CDN 2TB+ local cache size	
Network performance requirements and KPIs	200+Mbps downlink throughput to public Internet	
Network Functional requirements and KPIs	Stable Internet connectivity to public CDN	
Components and Configuration	Components	5G platform
	Configuration	Asset collection of MCBg01 via API call or by injection.
Test procedure	Pre-conditions	Successful acquisition of asset collections derived in MCBg01. Alternatively, this information can be constructed and injected into the test case (if the test cases are not performed sequentially).
	Test Case steps	Under continuous monitoring of the components' service logs, the following steps are necessary: 1. Ingestion of the asset collections from MCBg01 2. Downloading of the items referenced in the collections. a. This affects all selected streams as well as the selected bitrates of the individual streams. 3. Verification of the downloaded items 4. Consistency check and reporting of any missing/corrupt/unavailable data at its origin
Measurements	Methodology	1. Get the aggregated list of media content (list of URLs to HLS playlists *.m3u8) to download. 2. Create list of all related files to download (audio/video segments, subtitle files, manifests) 3. Download all list files to the Station cache 4. Check if all files are downloaded properly
	Complementary measurements	N/A
	Calculation process	1. Number. of chunks 2. Average chunk size 3. Time per chunk (min/max/avg) 4. Missing/dropped chunks per 1000/chunks
Expected Result	The assets provided by the Prefetcher have been stored on disk, are accessible and properly indexed.	

3.2.3 MCBg03: Data Shower High Speed Transport from Station Cache to Train Cache

In cases where media content is contained in the station's media cache but it is not completely uploaded to the train's cache, it is necessary to ensure that the remaining content can be uploaded via a 5G data link. In Table 3-3, this test case ensures that all remaining content is transferred to the train while the train is stationary at a station. For this test case to succeed, all content must be successfully transferred within a short period of time and over a high data rate.

Table 3-3 MCBg03: Data Shower High Speed Transport from Station Cache to Train Cache

MCBg03	**Data Shower High Speed Transport from Station Cache to Train Cache**	
Testbed	**5GENESIS Berlin [4]**	
Description	Media data in the station cache (that were not contained in the train's media cache already), also known as "media content delta", shall be uploaded to the train's media cache via the 5G data link whilst the train is stopped at the station. To transmit the media content delta during the train's standing time, an average data rate of at least 2.5 Gbps is required. The test case succeeds if the entire media content delta is transmitted to the train cache.	
Key Use-case requirements and KPIs	N/A	
Network performance requirements and KPIs	The mmWave data link between station and should be able to support a 2.5+Gbps downlink throughput for a single UE	
Network Functional requirements and KPIs	N/A	
Components and Configuration	Components	1. 5G data link (mmWave in this case) 2. Media cache in station (5G platform) 3. Media cache on train (5G train)
	Configuration	1. List of media items that need to be copied by file, diff or API call 2. Network deployment shall be performed as depicted in the Architectural Deployment Figure
Test procedure	Pre-conditions	1. No mmWave connectivity between train and station is established yet
	Test Case steps	1. mmWave connectivity between train and station is established 2. Data synchronization process starts upon connection 3. Data synchronization process stops if media content delta is transmitted or connection breaks
Measurements	Methodology	1. Assert that all data transmitted via the 5G Link from the Media Cache in the station are copied properly to the Media Cache in the train. MD5 hashes of the copied files can be used to ensure the integrity of the files. 2. Assert that the amount of transmitted data fits within the available bandwidth and duration of the train stop at the station

		3. Assert that an interruption in connectivity does not leave the data in an inconsistent state
	Complementary measurements	1. While performing steps 1 - 3, radio network quality measurements (RSSI/RSRQ) will be collected along with the UE/train position and timestamps. 2. While performing steps 1 - 3, real-time data rate measurements may be also collected. 3. Traffic conditions are also monitored and noted in each iteration.
	Calculation process	1. The time between an operation request and response is calculated – timestamps from the service and network layer messages are used for the calculations. (e.g. update request, update success, etc.). 2. For each set of tests/ iterations (for the specific conditions), the mean/ median/ max./ min of "Available edge cache update times" will be calculated. 3. Connectivity-related indicators, such as data rate, will be measured by the duration of the edge cache update session and the amount of data received. 4. For each set of tests/ iterations (for the specific conditions) the mean/ max./ min received data and data rate values will be calculated.
Expected Result	1. Assert that all data transmitted via the 5G Link from the Media Cache in the station are properly copied to the Media Cache in the train. MD5 hashes of the copied files can be used to ensure the integrity of the files. 2. Assert that the amount of transmitted data fits within the available bandwidth and duration of the train stop at the station	

3.2.4 MCBg04: Media Distribution in the Train (via Wi-Fi)

The aim of this test case is to determine whether or not the train passengers can access and stream content from the train cache via the train's 5G-VICTORI Wi-Fi connection. In Table 3-4, this test case allows passengers to continue using the content providers' standard Video on Demand VoD application/website (while in the train) to access content available on the train's cache. To ensure the success of this test case, the video player must be able to stream the content with sufficient quality.

Table 3-4 MCBg04: Media Distribution in the Train (via Wi-Fi)

MCBg04	**Media Distribution in the Train (via Wi-Fi)**
Testbed	**5GENESIS Berlin [4]**

<table>
<tr><td>Description</td><td colspan="2">Passengers use their smartphones/ tablets/ laptops on the train and connect their devices to the Wi-Fi hotspot. The railway company (e.g. "Deutsche Bahn", in case of Berlin Cluster setup at Berlin Central Station) usually offers a Wi-Fi hotspot to passengers, but in the 5G-VICTORI demonstration setup, a separate Wi-Fi (or dedicated Wi-Fi AP) will be provided in order to interface with other components required for the Media Services Use Case e.g. the Media CDN Cache in the train.
Once a passenger device is connected to the 5G-VICTORI Wi-Fi network onboard the train, the ARD Mediathek native Android/iOS App as well the Web App can be used (without any modifications) to watch the content from the ARD/RBB Catalogue. Only content available on the train’s cache will be offered for the User via the Mediathek application. To enable this, all requests made by the Mediathek application running on passenger devices to download media content from the public CDN (e.g. Akamai) will be intercepted by the Proxy Server, which is configured to serve content from the local CDN Cache in the train. This way, the passengers do not need to install a separate ARD Mediathek Application configured to use the 5G-VICTORI setup. A sub-test case with the same behavior is targeted for only relaying contents owned/provided by RBB.</td></tr>
<tr><td>Key Use-case requirements and KPIs</td><td colspan="2">U-FU-6301
U-FU-6302</td></tr>
<tr><td>Network performance requirements and KPIs</td><td colspan="2">Number of concurrent users
Average bitrate per user</td></tr>
<tr><td>Network Functional requirements and KPIs</td><td colspan="2">N/A</td></tr>
<tr><td rowspan="2">Components and Configuration</td><td>Components</td><td>1. ARD Mediathek App for Android, iOS and Web (either the default app or a developer version to allow for HTTP only if SSL certs cannot be procured)
2. Wi-Fi Hotspot/Gateway
3. Media Cache in the train
4. Media Server in the train to serve content from the Media Cache</td></tr>
<tr><td>Configuration</td><td>1. Media Server needs to be equipped with the SSL certificates for the domains served or the consuming apps (web or native) have to support plain HTTP transport.</td></tr>
<tr><td rowspan="2">Test procedure</td><td>Pre-conditions</td><td>N/A</td></tr>
<tr><td>Test Case steps</td><td>1. Passenger connects device to the 5G-VICTORI Wi-Fi Network in the train
2. Passenger installs the ARD Mediathek Android/iOS App if not done yet. This step is optional if the passenger decides to use the Web App instead.
3. Passenger opens the native ARD Mediathek iOS/ Android App or the Web App in a Browser
4. The ARD Mediathek App shows available content from the local Media Cache in the train. Content that is not available in the local Media cache shall not be</td></tr>
</table>

		displayed in the App in order to improve the User Experience. Therefore, users do not need to select a content item first to see if it is available or not. 4a - Passenger browses only the RBB Catalogue (as available on the train) and finds appropriate content to watch 5. The train's DNS resolver redirects all domains in question (i.e., media.ard.de to the train cache) 6. The App receives the URL of the HLS playlist manifest file (*.m3u8) and passes it to the underlying video player 7. The Video player parses the manifest file and requests video/ audio segments via HTTP 8. The HTTP requests to download video/ audio segments, which are intercepted by the Media Server as well and served from the local Media Cache 9. The Video Player receives the audio/ video segments and starts playback. User should be able to use playback functions (play/ pause/ seek/ stop) as usual
Measurements	Methodology	1. Only content available in the Media Cache is displayed in the ARD Mediathek App 2. The ARD Mediathek can play available media content properly in the appropriate bitrate, resolution and codec
	Complementary measurements	N/A
	Calculation process	5. Apache benchmark (ab) with 10/20/50/100 concurrent requests
Expected Result	1. Only content available in the Media Cache is displayed in the ARD Mediathek App 1a - Only RBB content is available 2. The ARD Mediathek can play available media content in the appropriate bitrate, resolution and codec	

3.2.5 MCBg05: Collecting of Playback Metrics (using MPEG-SAND)

The aim of this test case is to collect metrics on the performance of the service under evaluation in terms of the video stream's playback and presentation quality. Table 3-5 outlines the metrics that will be gathered and used to monitor and analyze the service. In order for the test case to succeed, all network and playback metrics must be collected and synced with the Master Server.

Table 3-5 MCBg05: Collecting of Playback Metrics (using MPEG-SAND)

MCBg05	**Collecting of Playback Metrics (using MPEG-SAND)**
Testbed	**5GENESIS Berlin [4]**

<table>
<tr><td>Description</td><td colspan="2">Once passengers are connected to the Wi-Fi network in the train, they are able to watch content that was already pre-fetched in the train’s CDN cache. To ensure that the content is played back properly on the client and presented in the expected quality, it is important to monitor and analyze streaming sessions and report any faulty/problematic sessions. This requires collecting playback metrics for each streaming session and storing them in a database for further analysis. The playback metrics that are being addressed in 5G-VICTORI follow the "Server and Network Assisted DASH" (SAND) specification, which is part of the MPEG-DASH standard. Example playback metrics are as follows: average throughput, buffer level, initial playout delay, HTTP request/response transactions, representation switch events, and playlist. These metrics will be used as inputs for test cases concerning “Shared Resource Allocation” and “Monitoring QoS for the End-to-End Workflow”.

The playback metrics are collected on the streaming client and reported to the SAND Server via HTTP. Some metrics can be collected by network elements (e.g. Proxy Streaming Server in the train in our case) present on the path between the origin server and the client and reported to the same SAND Server. This is practical if the client player cannot be extended to capture playback metrics, which is the case with the ARD Mediathek native application. On the other hand, the player metrics collected on the client (e.g., start time, buffer level, etc.) provide more insights into the streaming sessions and make it easier to detect and fix errors.</td></tr>
<tr><td>Key Use-case requirements and KPIs</td><td colspan="2">Access to ARD player on the respective platforms</td></tr>
<tr><td>Network performance requirements and KPIs</td><td colspan="2">N/A</td></tr>
<tr><td>Network Functional requirements and KPIs</td><td colspan="2">N/A</td></tr>
<tr><td rowspan="2">Components and Configuration</td><td>Components</td><td>1. SAND Client: will be integrated in the ARD Mediathek Web App to collect player metrics on the client
2. SAND Proxy: will be integrated in the Media Server (in the train) to collect network metrics of streaming sessions (no need to update the ARD Mediathek iOS and Android App)
3. SAND Master Server (Cloud): will be deployed in the cloud and collect all streaming metrics from all SAND Local Servers in all trains.
4. SAND Local Server (Train): is a standalone component deployed in the train in order to temporarily store player metrics reported by the SAND Client and SAND Proxy. Once reconnected to the Internet, the metrics are then sent to the SAND Master Server.</td></tr>
<tr><td>Configuration</td><td>1. SAND Client and SAND Proxy need to be configured with the SAND Local Server’s endpoint
2. SAND Local Server needs to be configured with the SAND Master Server’s endpoint running in the cloud</td></tr>
<tr><td>Test procedure</td><td>Pre-conditions</td><td>N/A</td></tr>
</table>

	Test Case steps	1. The SAND Client integrated in the ARD Mediathek Web App sends playback and network metrics of each session to the SAND Proxy via HTTP 2. The Local SAND Server integrated in the Media Server in the train intercepts HTTP requests of media segments and report network metrics to the SAND Proxy via HTTP 3. The SAND Local Server syncs the collected metrics with the SAND Master Server once the train is connected to the public internet
Measurements	Methodology	1. Collect playback metrics in the player and export them in a suitable format 2. Export collected playback metrics on the SAND Server in same format 3. Make sure that the reported metrics are identical by comparing all items and values in both exported lists.
	Complementary measurements	N/A
	Calculation process	N/A
Expected Result	1. Assert that the playback metrics (such as download speed, buffer level, startup time, requested bitrate, playback events, errors occurred) collected on the client corresponds to the actual session (e.g. if the video playback stalls, make sure that a corresponding playback event is intercepted and that a proper metric is reported). 2. Assert that the playback metrics collected on the client are reported to the SAND Local Server. 3. Assert that the network metrics collected on the SAND proxy correspond to the actual access history of video/ audio segments via the Media Server. 4. Assert that the network metrics collected on the SAND proxy are reported to the SAND Local Server. 5. Assert that all the metrics collected in all local SAND servers are synched properly with the master SAND Server running in the Cloud.	

3.2.6 MCBg06: Shared Resource Allocation (SRA) in the Train using collected playback metrics and via dedicated Gateway

In order for train passengers to enjoy smooth video playback, bandwidth resources should ideally be fairly allocated to all. In Table 3-6, this test case aims to ensure that there is a fair allocation of bandwidth resources to passengers on the train using the available Wi-Fi connection. In order for this test case to succeed, train passengers should be able to stream video content from the local cache without interruptions.

Table 3-6 MCBg06: Shared Resource Allocation (SRA) in the Train using collected playback metrics and via dedicated Gateway

MCBg06	**Shared Resource Allocation (SRA) in the Train using collected playback metrics and via dedicated Gateway**
Testbed	**5GENESIS Berlin [4]**

<table>
<tr><td>Description</td><td colspan="2">When several users on the train stream videos at the same time, they compete for bandwidth that a common Wi-Fi access point can provide. During playback, this can lead to unwanted behavior, such as playback discontinuities or fluctuations of video quality when streaming with adaptive bit rates. For example, like with streaming solutions such as “Dynamic Adaptive Streaming over HTTP” (DASH) or HLS. The streaming metrics collected in TC "MCBg05" are used in this case to enhance the streaming experience and network bandwidth utilization in multi-user scenarios. By means of the “Shared Resource Allocation” (SRA) feature within SAND, the App & Media Server manages the assignment of network bandwidth to clients (traffic shaping) such that the average QoS is maximized.</td></tr>
<tr><td>Key Use-case requirements and KPIs</td><td colspan="2">The bandwidth is distributed fairly between competing users in the same Wi-Fi network in the train</td></tr>
<tr><td>Network performance requirements and KPIs</td><td colspan="2">N/A</td></tr>
<tr><td>Network Functional requirements and KPIs</td><td colspan="2">N/A</td></tr>
<tr><td rowspan="2">Components and Configuration</td><td>Components</td><td>1. SRA Monitor: This component monitors the collected SAND playback metrics and makes sure that the available bandwidth is distributed fairly between the clients. It may also manipulate the DASH/HLS manifests and limit the available representations that fit within the available bandwidth.
2. SRA Client: This component will be integrated into the DASH/HLS player and control the representations that can be requested according to the available bandwidth. This will be used only for the ARD Mediathek Web App.</td></tr>
<tr><td>Configuration</td><td>1. The SRA Monitor shall be configured with the available bandwidth and strategy for distributing bandwidth fairly among the users
2. The SRA Monitor needs to be configured with the endpoint of the SAND Local Server in the train to monitor current sessions and assign a bandwidth to each session.
3. The SRA Monitor needs to be configured with the Media Server’s endpoint in the train to assign a bandwidth for each session.</td></tr>
<tr><td rowspan="2">Test procedure</td><td>Pre-conditions</td><td>Streaming session is started</td></tr>
<tr><td>Test Case steps</td><td>1. The SRA Monitor connects to the SAND Local Server and monitors current streaming sessions
2. The SRA Monitor calculates the bandwidth to be assigned for each session from the overall available bandwidth and the Manifest file of each session
3. The SRA Monitor assigns the bandwidth of the Wi-Fi connection (associated with the corresponding session) or tells the integrated SRA Client (in the player) to the requests’ segments according, to the available bandwidth</td></tr>
</table>

<table>
<tr><td rowspan="3">Measurements</td><td>Methodology</td><td>1. Select a reference video with at least 5 different video bitrate levels (show visual elements on top of the video indicating the bitrate level).
2. Assign a max bandwidth to each client that only allows to certain bitrate levels to be played (e.g., the first 3 levels).
3. Play content in ARD player across multiple platforms and make sure that only the permitted bitrate levels are selected.</td></tr>
<tr><td>Complementary measurements</td><td>Measure the optimal utilization of bandwidth provided by the Wi-Fi access point</td></tr>
<tr><td>Calculation process</td><td>1. The bandwidth assigned to each user is calculated from the overall available bandwidth in the Wi-Fi network in the train divided by the current number of connections.
2. The player selects the video/audio stream with a bitrate near the assigned bandwidth
3. The calculation process is dynamic and will be repeated each time the context is changed (e.g. a new playback session is initiated or completed).</td></tr>
<tr><td>Expected Result</td><td colspan="2">All clients connected to the Wi-Fi Network in the train should be able to play video content from the local cache without playback discontinuities or fluctuations. Bandwidth is also fairly distributed between the players.</td></tr>
</table>

3.3 Test Results from the Trials

The client side of the test process consists mainly of a clone of the main ARD-Mediathek website (see Figure 3-2). However, the website is able to load cached media items from the train server and display them on the homepage. The website also provides a fully responsive display for mobile apps.

To play the media items, the ARD-Player component (see Figure 3-3) was integrated into the user frontend, which is able to play HLS and mp4 video formats. The player provides basic functionality such as controlling volume, choosing different qualities, and displaying captions if available.

To observe and monitor the playback behavior, a SAND addon plugin was developed, which can be attached to the ARD-Player. This plugin is responsible for gathering playback metrics and sending them to a SAND server.

A dedicated stream analytics server (SAND) monitors the connection between server and client during the stream process (see Figure 3-4). This monitoring allows for real time metric reporting to observe the performance and behavior of the player by collecting client data such as average buffer, average bitrate, duration, stream errors, etc. Moreover, SAND also offers shared resource allocation to distribute bandwidth fairly among multiple clients in the same network by restricting the available stream quality of each client based on collected bandwidth data. The SAND plugin can receive instructions from the SAND server to optimize the quality based on the available bandwidth.

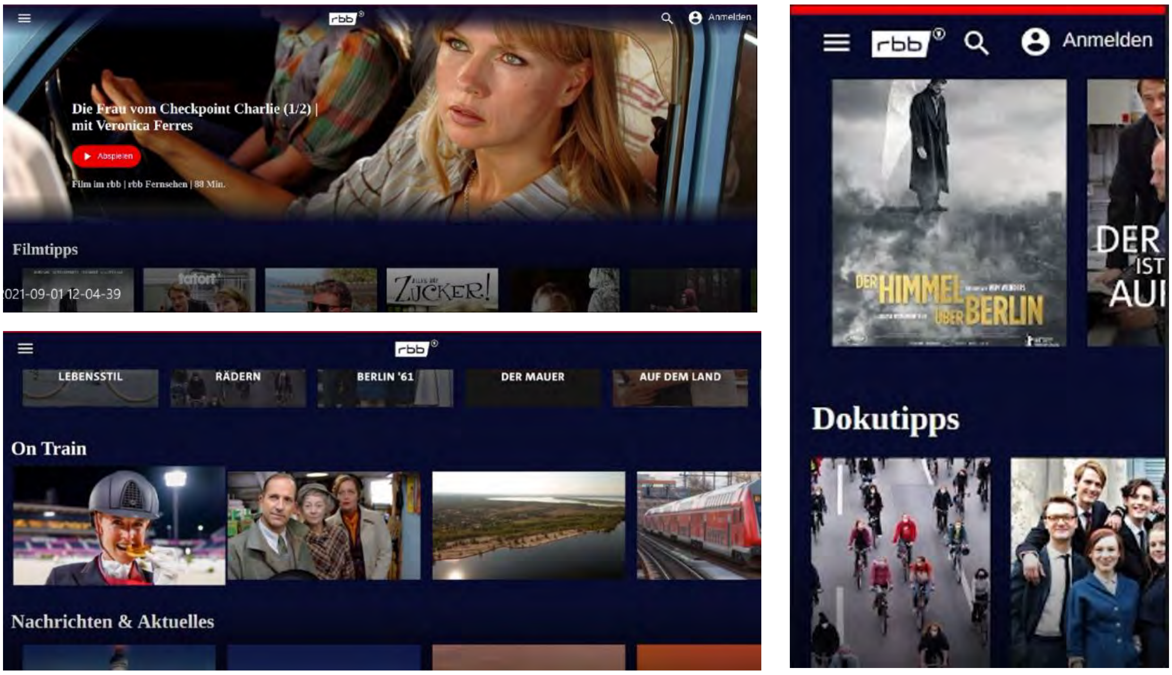


Figure 3-2 Homepage of the ARD-Mediathek website clone. The "On Train" row displays available content, which is cached on the train server

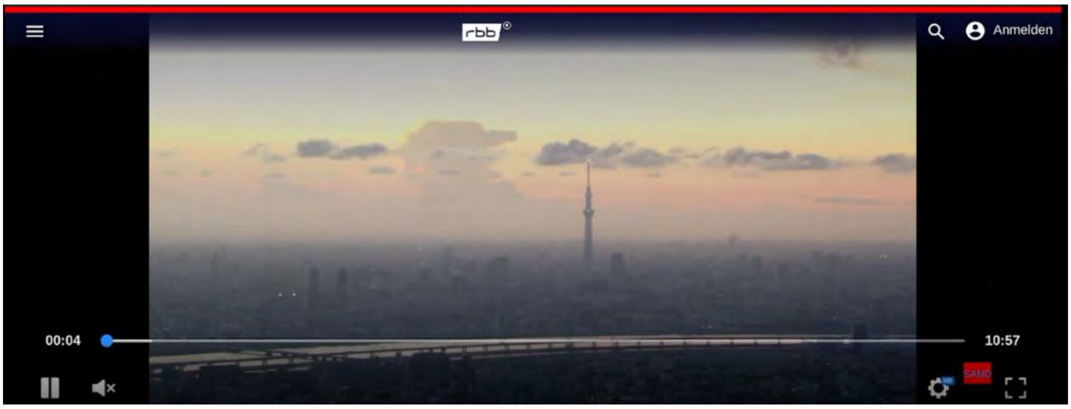


Figure 3-3 ARD-player playing a cached media stream

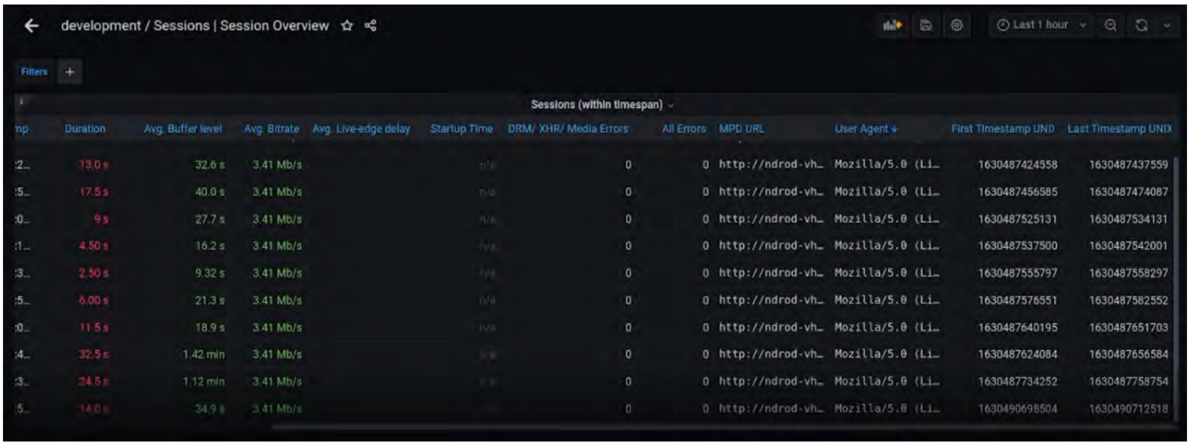


Figure 3-4 SAND interface for monitoring clients. Each client data is stored within a session

3.3.1 Lab trials

3.3.1.1 Context of the work and future plans

Due to the current unavailability of 5G user equipment and gNBs at the time the Description of Action (DoA aka the project proposal) was prepared, and given the use of mmWave technology in previous 5G-PPP projects, we have resorted to propose a mmWave link as a transient solution to implementing 5G wireless transport connectivity between the track and train in **UC #3**.

COTS mmWave devices can provide for high OTA throughput rates in the order of 2.5 Gb/s, required to transfer large amounts of data to the train server in a short time window. The mmWave link can thus be considered as a wireless transport solution for the data shower, which is also transparent to the upper communication layers, whereas the train can host either one or more of the access technologies (5G, Wi-Fi4, Wi-Fi6). A similar proposition is in place for the Patras Cluster, where the track-to-train transport link is planned as a heterogeneous network of both mmWave and Sub-6GHz wireless nodes distributed along the track.

The mmWave devices operate in the 60 GHz ISM band and have beamforming capabilities that are an important pre-requisite for **UC #3**, being able to establish the link to a moving train both during arrival and departure to a station. Furthermore, the mmWave link has the advantage of being inherently robust to the Doppler shift occurring in such a mobility scenario in comparison to other solutions operating in lower frequency bands. At a relatively low train speed of up to 20 km/h during the transit through a station (entry and exit) and a 60 GHz carrier frequency, the occurring Doppler shifts of up to approx. 1 kHz can be efficiently coped with by the 802.11ad standard carrier frequency estimation and compensation algorithms.

The proposed solution in the DoA opens up different possibilities in terms of the use of mmWave in combination with other radio access technologies (RATs). In the DoA and in past deliverables (e.g. D2.1, D2.2, and D2.3) we proposed a solution involving mmWave as the wireless transport technology interconnecting the platform and the train, to then utilize Wi-Fi as the RAT inside the train providing connectivity to the users.

There are other possibilities for providing connectivity to the train that are in this moment being assessed and they are taken into consideration for demonstration at the end of the project. These are:

1. the use of 5G as the RAT that interconnects the platform (gNB) and the train (using a 5G CPE or similar).

2. The use of mmWave as the wireless transport solution providing 5G connectivity from the platform to the train. In this case, mmWave would act as a transparent L2 connection.

For now, and to produce results associated to MCBg03, **UC #3** in the Berlin cluster makes use of mmWave as the technology enabler to provide high-data rate wireless connectivity from the platform to the train to allow CDN services to run on top of this infrastructure.

3.3.1.2 Definition of the trial and results

Testing of the mmWave connectivity was initially performed in a laboratory environment (static) and then executed in a real railway environment (train depot) first in a static and later dynamic fashion, prior to the tests to be carried out at Berlin Central Station.

The tests in each of these cases entailed the deployment of 3 mmWave nodes, two of them represent those to be installed at the trackside of the platform and one being mounted on the train. Figure 3-5 shows a representation of the system setup that interconnects such nodes.

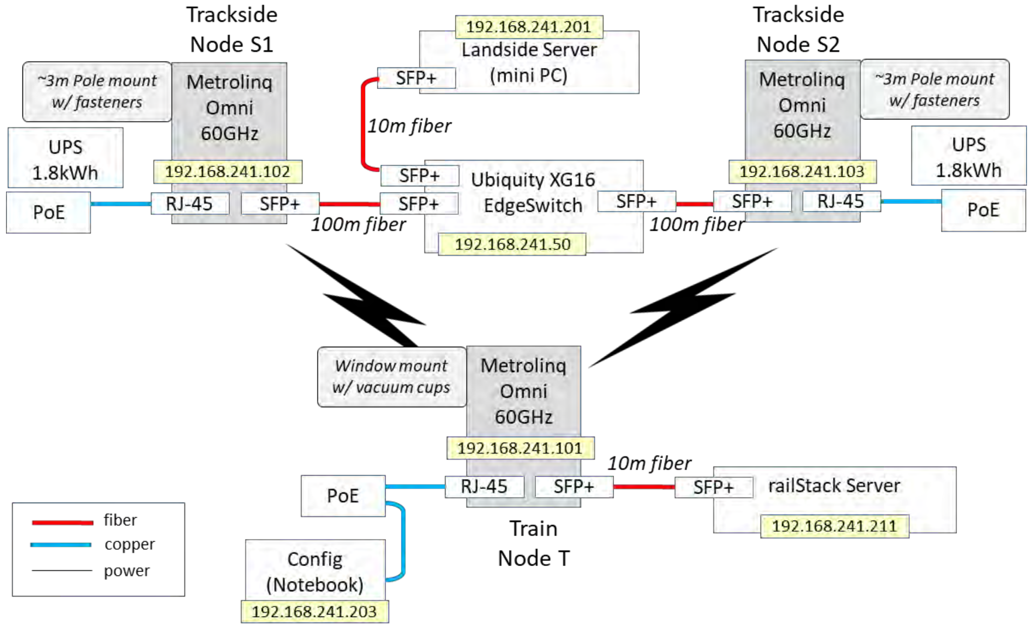


Figure 3-5 An overview of the system setup used for data shower tests over the 60 GHz PTMP link

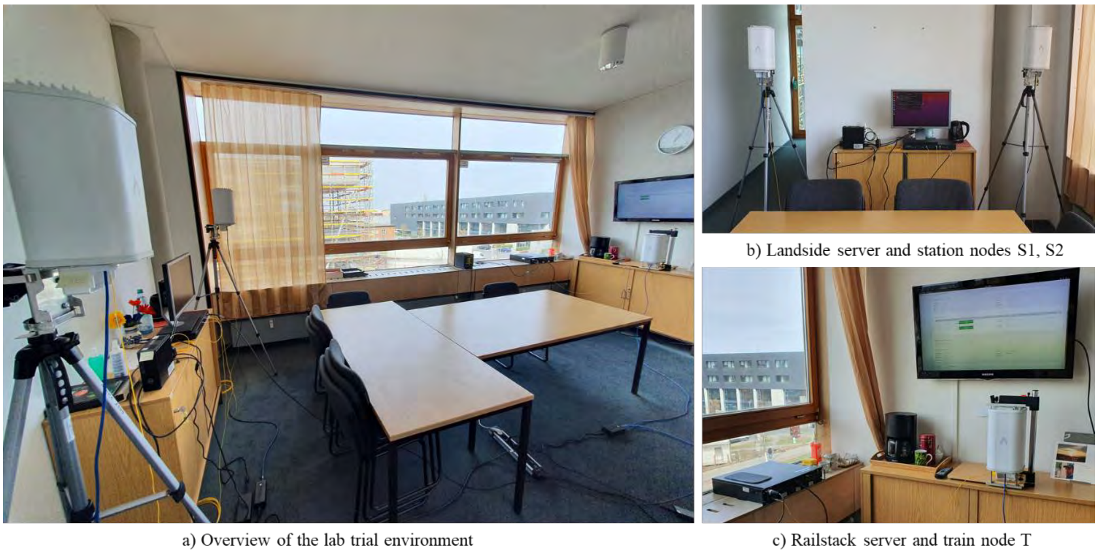


Figure 3-6 Lab environment trial of the data shower

In order to verify the settings of the mmWave nodes and their connectivity to the landside and trackside servers as a preparation for the field trials, preliminary tests were performed in a lab environment, as shown in Figure 3-6. The two trackside nodes S1 and S2 were symmetrically placed at a range of 4.8 m to the train node T, with the trackside nodes connected to the landside server via a switch and the train node connected to the railSTACK server.

The railSTACK server is an EN 50155 compliant 19” rack mountable server that is qualified for operations on board of trains. It operates on 110VDC and is thus easily powered directly from the train. On the software side it runs the edge component of PaxLife’s railSTACK. It allows for off-hands, autonomous operations and provides a runtime for (containerized) applications. It will host all back-end components for the playout on the train (such as webserver, SRA management, software) and is in charge of data synchronization between the landside and the trainside server.

A PTMP link was established between the three nodes, using the 58.32 GHz channel of the 60 GHz ISM frequency band, as shown in Figure 3-7. A summary of the radio link parameters is shown in Figure 3-7. Iperf3 and ping tests were performed with a 10 min duration in order to assess the net throughput and round-trip time of the mmWave transport link. An average throughput of 1.72 Gb/s and a round-trip-time of [min 0.277 / avg 1.103 / max 2.425 / mdev 0.149 ms] were measured, respectively. Furthermore, the point-to-multipoint connectivity of the nodes was verified. With the mmWave node settings used for the lab trial, the radio link margin (i.e. RSSI) was high enough to achieve the highest over-the-air throughput of 2.5 Gb/s that the MetroLinq Omni 60 GHz radios can support, which corresponds to net 1.72 Gb/s data throughput when accounting for the protocol overhead.

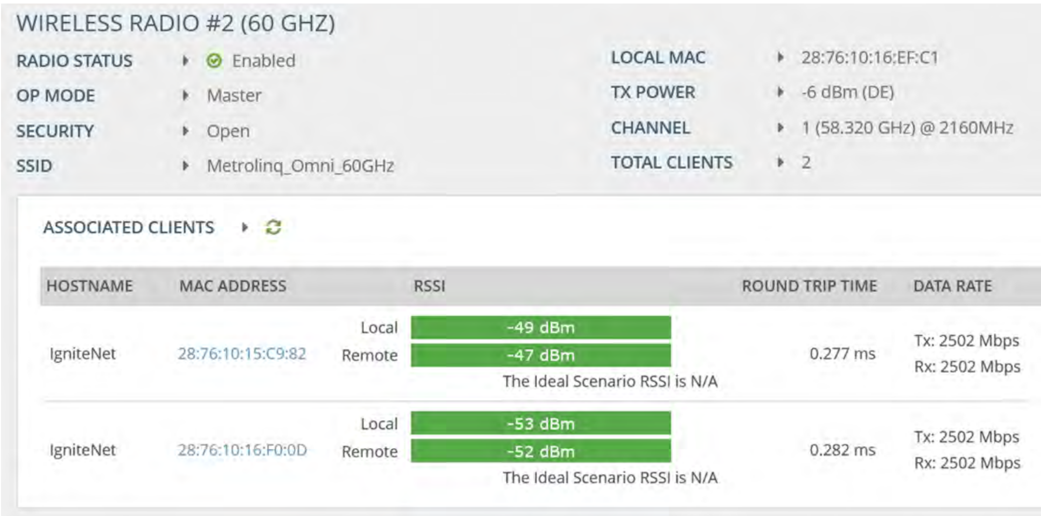


Figure 3-7 mmWave link radio parameters monitored at the train node T in a PTMP setup

Figure 3-8 Screenshot of the iperf3 measurements that were used to validated raw bandwidth. On the left-hand side is the landside server on the right-hand side the railSTACK server that acts as the train cache

3.3.2 Field Trial

The preliminary field trial of the data shower setup took place in a static scenario, where the equipment was mounted on an S-Bahn train stationed at the Deutsche Bahn (**DBH**) Depot in Schöneweide, Berlin, as depicted in Figure 3-9. The main goals of this trial were to verify that the setup is operational under realistic conditions, for example whether the train window would introduce blockage to the 60 GHz link or whether the angles of view between the nodes would be a limiting factor for the beamforming. The train node T was mounted behind the window of the S-Bahn train using removable vacuum suction mounts, with the antenna facing the platform. The two station nodes S1 and S2 were mounted on tripods at a height of 1.5 m, whereas the T node was at a 2.2 m height relative to the platform. The range for the link T-S1 was 2.8 m and the range of the link T-S2 was varied between 10-20 m by displacing the node S2 along the platform, in order to verify the connectivity under different angles of view.

a) Link T-S1 b) Link T-S2 c) View from S1 d) View from S2

Figure 3-9 Field environment trial of the data shower

Using the same setup settings as for the lab trial, it was shown that the PTMP 60 GHz link is operational in the field environment i.e. in deployment on a (stationary) train. By measuring the RSSI signal strength between the train node T and a station node S1, once through the window as shown in Figure 3-9, and once through a free space LoS path, it was determined that the window coating does not block the 60 GHz transmission and introduces a loss of approx. 5 dB to the link margin. Nevertheless, the link margin is still sufficient for achieving the 2.5 Gb/s OTA throughput and thus there is no impact to the performance of the link. Indeed, an average net throughput of 1.7 Gb/s was measured using the iper3 test in the T-S1 link for the field trial, verifying this conclusion. Regarding the angles of view and the position of node S2, it was established that the link T-S2 performance varies significantly, from an average net throughput of 1.5 Gb/s at the closest range of 10 m down to 200 Mb/s at the furthest range of 20 m. This performance degradation can be associated to both the narrow angle of view and the respective increased loss from the propagation through the window. Since the MetroLinq Omni 60GHz nodes can perform beamforming within a 120-degree sector, one important conclusion from the static field trial is that the geometry of the setup for the final implementation at *Berlin Hauptbahnhof* should satisfy these requirements, i.e. the station nodes S1 and S2 should be mounted at a separation of up to 30-40 m on the platform. To verify this approach, another field trial in the DB Schöneweide Depot is planned, with the train moving along a track outside the depot in a mobility scenario that resembles the conditions/geometry of the *Berlin Hauptbahnhof* platform.

3.4 Aggregation of relevant content for cache prefilling and pre-filling media content in local cache

The ingress of the data was completely rewritten. While the custom feed provided allowed for a straightforward processing, the overall data model of the ARD Mediathek (of which the RBB is a subset) is way richer and contains more meta data than could be provided by RBB on its own. A further advantage is that, the ARD Mediathek native app (on iOS, Android, Web) actually expects a data model as defined by the ARD Mediathek. Since ultimately the support for native apps is envisioned, we choose to go the extra mile and fully mirror the ARD data model.

A processor for the "global" data source, the ARD Mediathek, was written that allows for filtering by TV station, resolution and artifact type. For the tests we stuck to the content owned/provided by RBB but all other TV stations work as well. In terms of resolution and artifact types the operator can select to filter by 6 different qualities and for downloading fallback files (identical in content to the progressive playlists) as well.

A novelty that was required as the result of our lab and field tests is the "chunking" feature. During the measurements it turned out, that in order to optimally use high speed radio link, the files must not be too small (but play lists are composed of nothing but small files). If the files are too small, the link cannot achieve its maximum throughput before the connection is closed and a new one initiated. We tested various cases and it turned out that "chunking" the downloaded assets in packages of somewhere between 250-750MBs works best.

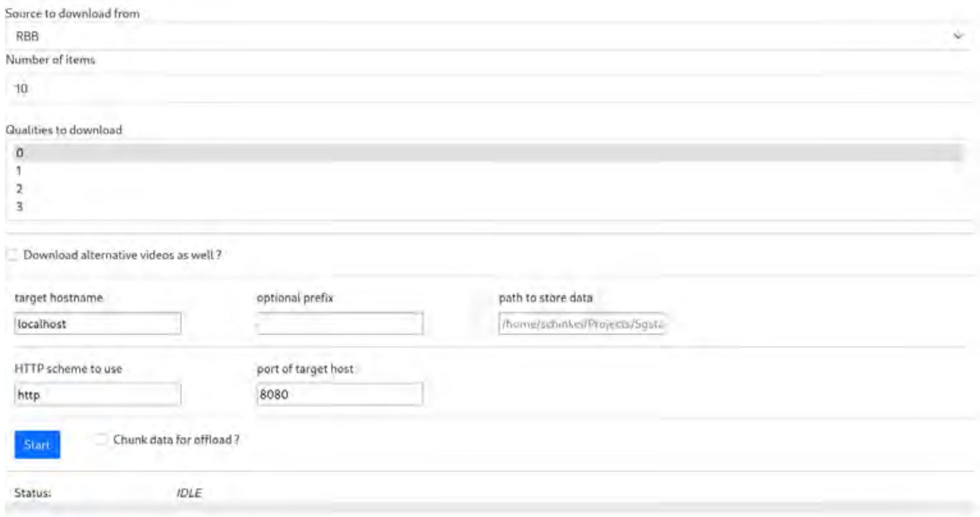


Figure 3-10 Extended interface to the aggregator

Aside from that the underlying logic of parsing and rewriting the contents of the manifests has not changed.

3.4.1 High speed data transfer

PXIs railSTACK supports a variety of transfer types. One of them is SCP, which was benchmarked to be the fasted (secure) method for transferring vast amounts of data. During our tests it became obvious that "just" transferring data is not enough as the data needs to chunked beforehand (see section 3.4). This requires an extension of the railSTACK storage types that also requires some logic (to recover after drops in connections, etc.). This is currently being implemented.

For the high speed data transfer we estimated the ideal “chunk” size. Prepared ~14GB of data to transfer and packaged it in various sizes. The results are summarized in Table 3-7 and we decided to package the data in chunks of 500MB in the future tests.

Table 3-7 Summary of time it task to transfer a sample set of data using scp on the 60 mm link

Chunksize in MB	Time to transfer 14GB (in sec)
Not chunked	>90
250	74
500	72
750	72
1000	72
1250	73

3.4.2 Media Distribution, Playback Metrics and Shared Resource Allocation

For the media distribution on board and the collection of metrics the integration developed by FHP will be hosted on the railSTACK server.

3.5 Test combinations at 5G-VICTORI facility in Berlin

No UC test combinations involving CDN services are planned for the 5G-VICTORI facility in Berlin. The 5G technology required for the CDN services does not in any way affect or interact with other proposed 5G services running simultaneously at the facility.

4 CDN Services at the 5G-VICTORI facility in Patras

4.1 Description of 5G-Infrastructure at 5G-VICTORI facility in Patras

The diagram in Figure 4-1 contains all the elements (hardware/software) required for demonstrating two different services at the Patras Facility for the Media UC, i.e. CDN-aided data shower and 360° camera-aided remote surveillance. The two services comprise different sets of requirements in order to achieve the expected KPIs.

The main aim of the UC is to achieve a data shower between the onboard network and the train station server through NR access. Passengers will benefit from this data shower service through a multi-level CDN integration with the station gNB. As shown in Figure 4-1, an on board network deployment allows passenger UEs to connect to the on board CDN server. When the train approaches the station there is a NR connection between the train station and the train, which allows the prefetching of large amounts of content in a short time. The specific UC also assumes that there is a 360° camera to monitor the train station, the field-of-view (FoV) of which is controlled through a low latency slice and provides two different footage qualities which are transmitted through two different slices (one high-quality and one low-latency) to the receiving end.

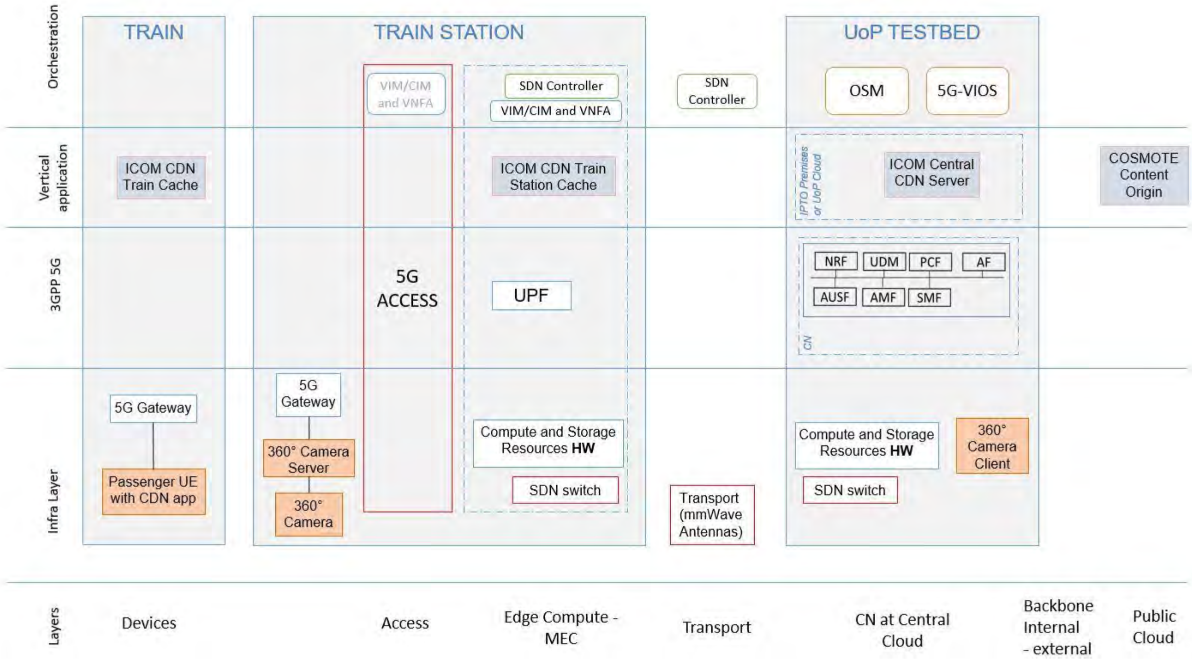


Figure 4-1 Deployment Diagram of 5G-VICTORI Media UC in Patras

The architecture illustrated in Figure 4-1 provides an overview of the two scenarios implemented for the Patras cluster Media use case. The components used for both scenarios, are the following:

- **Content Origin**: The segment that provides the source content for ICOM's CDN. It comprises three components: the Head-End –the component that interfaces with COSMOTE TV commercial/ operational infrastructure and obtains the live TV content, the OTT encoder which encodes/ decodes the streams according to the CDN streaming content configuration requirements, and the origin which provides the interface to the ICOM CDN. These modules are hosted at COSM premises to emulate a real deployment scenario. At the same time, VoD content is available, locally downloaded and streamed to ICOM's Central CDN.

- **Central CDN Server**: The component which receives the source content from the Content Origin to distribute it through ICOM's CDN system.
- **Train Station Cache**: The component located in the train station, which constantly synchronizes its content with the latest popular content available at the central CDN Server.
- **Train Cache**: The component located on-board the train, which acts as the receiver of the data shower mechanism and caches content on the train at every train stop.
- **Passenger UE with CDN application**: The mobile phone / laptop of the end user (passenger) with the CDN application that the passenger uses in order to watch media content of preference.
- **360° Camera**: The equipment used for capturing the situation at the train station area at all times.
- **360° Camera Server**: The component which is responsible for streams processing and forwarding to the appropriate locations at the 5G network.
- **360° Camera Client**: The receiver of the camera streams, which renders the video footage to the train station's security staff.

4.2 CDN services test cases

4.2.1 MCDv01: CDN Application Scenario Deployment

The first test case (see Table 4-1) of the MCDv test cases group concerns the initialization of CDN components that will facilitate the scenario deployment over the 5G-VINNI facility, as well as the evaluation of the initialization process. It is important to achieve a low deployment time of the components as VNFs, leading to quick deployment of the application in general, and this test case facilitates this verification.

Table 4-1 MCDv01: CDN Application Scenario Deployment

MCDv01	**CDN Application Scenario Deployment**	
Testbed	**5G-VINNI Patras**	
Description	The initial test case aims at validating and evaluating the deployment of CDN components over the 5G-VINNI facility through its orchestration layer and verifying initial connectivity between all components. Focus will be placed on the evaluation of aspects related to easiness and speed of deployment, creation of interfaces, steps required for fine tuning of deployment, etc.	
Key Use-case requirements and KPIs	**U-PE-6217:** Low deployment time of CDN's VNFs and for the complete graph of CDN application.	
Network performance requirements and KPIs	**Network KPIs:** The total duration shall be as minimum as 90 minutes.	
Network Functional requirements and KPIs	Capability to deploy an end-to-end service upon request.	
Components and Configuration	Components	1. gNB & MEC server available at train station 2. Content provider's niche End-Point (Transcoder) deployed 3. 4K VoD/live COSMOTE TV content to be streamed

		4. Central CDN server / Content receiver at Up 5. Edge server available in train 6. 5G modem available in train 7. Wi-Fi AP available in train 8. Passengers' mobile devices 9. ICOM CDN app available on the mobile devices
	Configuration	1. The content provider niche end-point resides where the transcoder feed is accessible. 2. The central CDN server needs to be located at UoP for elimination of delays for content transmission. 3. A tenant is created on MEC server hypervisor. 4. The on-board Edge server is configured with an on-board 5G modem (in order to allow the latter to communicate with the gNB at train station) and with a Wi-Fi AP for the passengers to connect to it. 5. The ICOM CDN app is installed in passengers' UEs, as it is the interface to select content of preference from the on-board server.
Test procedure	Pre-conditions	1. Connectivity shall be available across all infrastructure components, that is: 2. Connectivity shall be ensured between the MEC server (that will host the Main Cache) and central CDN server. 3. Connectivity shall be ensured between the MEC and on-board server that will host the Edge Cache. This connectivity will be done via the 5G-VINNI 5G mobile network, specifically via the gNB deployed at the train station and the 5G modem of the server onboard the train. 4. Connectivity shall be ensured between the Passengers' UEs and be able to connect to Wi-Fi AP at train. 5. The ICOM CDN app is installed in the passengers' UEs, as it is the interface to select preferred content 6. The ICOM CDN app is available as deployable software components
	Test Case steps	1. The user logs into the 5G-VINNI Orchestration platform 2. The SW components of the ICOM CDN app are on-boarded. The on-boarding time needed is measured. 3. The user triggers the deployment of the SW components on different infrastructure resources. a. The CDN Main Cache is deployed on the MEC server as VNF. b. The Edge Cache is deployed on the Edge server. The total time required for the deployment of the components is measured. 4. The passenger UEs are connected to the CDN application. Simple end-to-end connectivity at the Application Layer is verified. Otherwise, configuration activities are performed. The time needed for these activities is measured.

Measurements	Methodology	For step 2: to estimate the onboarding time, the time duration notification that may be available from the platform can be used. Alternatively, the time is measured by capturing the timestamps of each interaction/ process initiation of finalization. The on-boarding shall be performed at least once through the 5G-VINNI orchestrator. For step 3: to estimate the deployment time, the time duration notification that may be available from the platform can be used. Otherwise, the time is measured by capturing the timestamps of each interaction/ process initiation of finalization. The mean/max/min deployment time values are calculated.
	Complementary measurements	Amount of data for each CDN component shall be noted. Traffic conditions of 5G network shall be identified. Complementarily signal strength of 5G modem onboard
	Calculation process	For step 2: the total service on-boarding time is calculated using the time duration notification that may be available from the platform. Otherwise, the time is measured by the time difference between the initiated time of the service on-boarding and the time in which the finalization notification is received. For step 3: the total service deployment time is calculated using the time notification that may be available from the platform. Otherwise, the time is measured by the time difference between the initiated service deployment time and the time in which the finalization notification is received. The mean/max/min deployment time values are calculated using the measurements collected over all repetitions of the procedure.
Expected Result	Smooth and quick onboarding and deployment of CDN components. Total time of CDN components' on-boarding and deployment shall be <90 min. Connectivity between CDN components shall either be pre-configured or configured within the 90 min timeframe.	

4.2.2 MCDv02: CDN Connectivity Evaluation

After completing MCDv01, the required components to support the scenario are verified to be functional. This test case, as described in Table 4-2 will focus on the evaluation of the end-to-end connectivity across all CDN components, as it is crucial to verify that the required high data rate to support the data shower application is supported by the communication links between the various components.

Table 4-2 MCDv02: CDN Connectivity Evaluation

MCDv02	**Basic Connectivity Evaluation**
Testbed	**5G-VINNI Patras**
Description	The second test case aims at verifying and evaluating the end-to-end connectivity across all CDN components (including VNF). Focus will be placed on the evaluation of aspects related to data rate and latency achieved between the various CDN interfaces.
Key Use-case requirements	**U-PE-6210:** Very high data rates for proactive transfer of large volumes of high quality (e.g. 4K) VoD or TV streaming content from central CDN servers to local

and KPIs	MEC host **U-PE-6211:** Very high data rates for proactive transfer of prefetched high quality VoD or TV streaming content from MEC host to on-train Edge server	
Network performance requirements and KPIs	**Network KPIs:** Data rate between MEC Main Cache & Central CDN server: ~ 100 Mbps Data rate between MEC Main Cache & Edge Cache: 150-500 Mbps depending on live channels parameters / VoD content amount	
Network Functional requirements and KPIs	**U-FU-6310:** Very high data rates for proactive large volume and high-quality content transfer from central CDN server to local MEC host **U-FU-6311:** Very high data rates for proactive transfer of prefetched content from MEC host to on-train Edge server.	
Components and Configuration	Components	1. gNB & MEC server available at train station 2. Content provider's niche End-Point (Transcoder) deployed 3. 4K VoD/live content to be streamed 4. Central CDN server / Content receiver at UoP 5. Edge server available in train 6. 5G modem available in train 7. Wi-Fi AP available in train 8. Passengers' mobile devices 9. ICOM CDN app available on the mobile devices
	Configuration	1. The Central CDN server needs to be located at UoP to eliminate content transmission delays. 2. The onboard Edge server is configured with an onboard 5G modem (in order to allow the latter to communicate with the 5G base station at train station) and with a Wi-Fi AP for the passengers to connect to it. 3. The ICOM CDN app is installed in passengers' UEs as it is the interface to select content of preference. 4. Pinging between CDN components shall be enabled. 5. iperf or other data rate measuring tools shall be available and configured to be able to take measurements between the CDN components interfaces. 6. The radio interface measurement tool shall be available at the on-board 5G modem or/and other UEs.
Test procedure	Pre-conditions	1. Connectivity shall be available across all infrastructure components, that is: 2. Connectivity shall be ensured between the server that will host the Main Cache and the Central CDN server. 3. Connectivity shall be ensured between the MEC server and the on-board server that will host the Edge Cache. (via 5G-VINNI 5G mobile network, specifically via the gNB deployed at train station and the 5G modem of the on-board server) 4. Connectivity shall be ensured between the Passengers' UEs shall be able to connect to Wi-Fi AP at train. 5. The ICOM CDN app is installed in passengers' UEs as it is the interface to select content of preference 6. The ICOM CDN app is deployed over the 5G-VINNI facility.

	Test Case steps	1. The user accesses the CDN components. 2. Ping requests and data rate measurements are performed between all corresponding CDN components / all CDN interfaces. Connectivity is verified and RTT/latency measurements are noted. 3. iperf sessions requests are performed between all corresponding CDN components / interfaces. Connectivity is verified and data rate measurements are noted. 4. The passenger UEs are connected to the CDN application. End-to-end Connectivity at the Application Layer is verified.
Measurements	Methodology	For step 1: Ping tests are performed between interfaces of the CDN application. For step 2: Data rate (iperf) tests are performed between interfaces of the CDN application.
	Complementary measurements	Traffic conditions of 5G network shall be identified. Radio interface quality shall be identified.
	Calculation process	For step 1: For each set of ping tests between interfaces the mean/ median/ max./ min latency values (in ms) will be calculated. For step 2: For each set of tests/ iterations between interfaces the mean/ max./ min data rate values (Mbps) will be calculated.
Expected Result	Connectivity between CDN components shall either be pre-configured or configured within the 90min deployment time timeframe. End-to-End connectivity is verified.	

4.2.3 MCDv03: MEC Periodic Update

This test case, Table 4-3, stems from the need to verify that ICOM's Main Cache, located at the MEC server at the station, is constantly kept updated with new VoD or live content that has not yet been received. This will ensure that there will be fresh content available to push on the train when it arrives at the station.

Table 4-3 MCDv03: MEC Periodic Update

MCDv03	**MEC Periodic Update**
Testbed	**5G-VINNI Patras [3]**
Description	The purpose of this test case is to ensure that the server at the train station is periodically updated with content considered as popular. This update should be performed with a high frequency and in a push-based manner, so that the latest popular content is available at the station when the train arrives.
Key Use-case requirements and KPIs	**U-PE-6210:** Very high data rates for proactive transfer of large volumes of high quality (e.g. 4K) VoD or TV streaming content from central CDN servers to the local MEC host. (TL1b,c)
Network performance requirements and KPIs	**Network KPIs:** Data rate between MEC Main Cache & Central CDN server: ~ 100 Mbps High Connectivity to external hosts.
Network Functional requirements and KPIs	**U-FU-6310:** Very high data rates for proactive transfer of large volumes of high quality (e.g. 4K) VoD or TV streaming content from central CDN servers to local MEC host. **KPIs**: Network Slicing

Components and Configuration	Components	1. MEC server available for Main Cache 2. Content provider's niche End-Point (Transcoder) deployed 3. Central CDN server / Content receiver 4. 4K VoD/live content to be streamed
	Configuration	1. Connectivity between components performed as described in MCDv01 2. The Central CDN server needs to be located at UoP for elimination of delays for content transmission. 3. ICOM's Main Cache is deployed on 5G-VINNI MEC server 4. Message tracing tool shall be enabled at various CDN components. 5. Database and data monitoring tools shall be installed at MEC and Main Cache servers/components
Test procedure	Pre-conditions	1. End-to-end connectivity over CDN is verified through finalization of MCDv01 & MCDv02. 2. Applications for CDN and performance measurements capturing are running on all devices. 3. Identification of traffic conditions over the Central CDN - MEC Main Cache connection.
	Test Case steps	1. The central CDN server receives the content from the Content Provider. 2. The central CDN server will communicate periodically with the Main Cache at the MEC server and update it with the latest popular content that has not yet been received in previous updates (in a push manner). 3. The MEC Main Cache's database will be checked in order to verify that the content has been received (and refreshed). 4. The interval between the two periodic updates and their duration will be measured. 5. The amount of received data during a periodic update will be measured.
Measurements	Methodology	1. For evaluating various time indicators, both service and network layer messages will be captured with their timestamps (from message flows or database fields). 2. For evaluating connectivity indicators, data reception timestamps (from message flows or database fields) along with information on associated Data volumes will be captured.
	Complementary measurements	N/A.
	Calculation process	1. The time between an operation request and response is calculated - timestamps from service and network layer messages are used for the calculations (e.g. update request, update success etc.). For the "periodic update time", the time between the performance of two periodic updates

		will be calculated. 2. For each set of tests/ iterations (for the specific conditions) the mean/ median/ max./ min "periodic update times" will be calculated. 3. Connectivity - related indicators, such as data rate, will be measured by the time to update and the amount of data. 4. For each set of tests/ iterations (for the specific conditions) the mean/ max./ min received data and data rate values will be calculated.
Expected Result	Latest and non-received (since last update) content pushed on Main Cache at MEC	

4.2.4 MCDv04: Data shower from MEC to train cache

The data shower concept is the core focus of the virtualized CDN solution that is examined in the context of the Media UC, therefore it is crucial that its requirements are covered. For the data shower functionality, the test case MCDv04 is necessary in order to evaluate the available data rate and the content that will be transferred on the train through the data shower mechanism, which both have very high target values.

Table 4-4 MCDv04: Data shower from MEC to train cache

MCDv04	**Data shower from MEC to train cache**	
Testbed	**5G-VINNI Patras [3]**	
Description	The purpose of this test case is to ensure that the server on the train is updated with popular content (not yet acquired) each time the train reaches a train station, i.e. whenever the train resides in 5G network coverage. This can be either VoD content that was not completely transferred during the previous stop due to its size, or live content that was shown during the train's trip from one stop to another and shall be stored on the train to be played as time-shifted (delayed by some minutes). This update should be performed in a pull-based manner, i.e. the train server requesting content from the station server, so that when leaving the station, the train server contains as much popular content as possible (from the previous stop's available download).	
Key Use-case requirements and KPIs	**U-PE-6211:** Very high data rates for proactive transfer of prefetched high quality VoD or TV streaming content from MEC host to on-train Edge server. (TL1c)	
Network performance requirements and KPIs	**Network KPIs** Data rate between MEC Main Cache & Edge Cache: 150-500Mbps, depending on live channel parameters and/or amount of VoD content. (TL1c) Amount of content transferred: 10 - 15GB VoD content / content from 3 live channels (TL1)	
Network Functional requirements and KPIs	**U-FU-6311:** Very high data rates for proactive transfers of prefetched 4K VoD content from MEC host to on-train Edge server. **F-FU-1112:** Network Slicing	
Components and Configuration	Components	1. gNB & MEC server available at train station 2. Content provider's niche End-Point (Transcoder) deployed 3. 4K VoD/live content to be streamed 4. Central CDN server / Content receiver at UoP 5. Edge server available in train 6. 5G modem available in train 7. WiFi AP available in train

		8. Passengers' mobile devices 9. ICOM CDN app available on the mobile devices
	Configuration	1. The ICOM CDN SW modules are deployed on MEC and Edge servers as in MCP02 and MCP03. - The on-board Edge server is configured with an on-board 5G modem (in order to allow the latter to communicate with the 5G base station at train station) and a WiFi AP for passengers' connection. 2. Ping/ iperf of other data rate measuring tools are available at on-board 5G modem. 3. A message capturing tool is set up (at network node or MEC server). 4. Radio interface measurement tool shall be available at the on-board 5G modem or/and other UEs.
Test procedure	Pre-conditions	1. CDN SW components are up and running. 2. Definition of initial position of the test. 3. Definition of traffic conditions of access network node.
	Test Case steps	1. The train starts entering the station. At this time, the MEC server at the station will have a certain amount of content (that is available) loaded from central CDN servers. 2. Once the train's 5G modem is connected to the 5G base station at the train station, latest content (content which the Edge server has not been updated with) starts being transferred from the MEC server of the train station to the Edge server of the train with a very high data rate, so as to transfer the highest possible volume of content on the train. 3. The data transfer is performed for the complete time period that the on-board 5G modem is connected to the gNB; i.e. as the train approaches the train station, during the time the train stops at the train station and as the train leaves the station. 4. The amount of data received is measured along with the time that connectivity is available between the on-board 5G modem and 5G access node at the train station.
Measurements	Methodology	1. Steps 1-4 will be performed at least once 2. At least 10 GB of data should be transferred to the train server during the train's stop in order to be acceptable and sufficient. 3. For the evaluation of the various time indicators, service layer messages and network layer messages will be captured with their timestamp (from message flows or database fields). 4. For the evaluation of the connectivity indicators, data reception timestamps (from message flows or database fields) along with information on associated data volumes will be captured.
	Complementary measurements	1. While performing steps 1-4, radio network quality measurements (RSSI/RSRQ) will be collected along with the UE/train position and timestamps. 2. While performing steps 1-4, real time data rate

		measurements may be also collected. 3. Traffic conditions are also monitored and noted in each iteration.
	Calculation process	1. The time between an operation request and response is calculated – timestamps from the service and network layer messages are used for the calculations. (e.g. update request, update success, etc.). For the "Edge cache update time" the time at which the application session is running will be calculated. 2. For each set of tests/ iterations (for the specific conditions), the mean/ median/ max./ min "Available edge cache update times" will be calculated. 3. Connectivity - related indicators, such as data rate, will be measured by the duration of the edge cache update session and the amount of data received. 4. For each set of tests/ iterations (for the specific conditions) the mean/ max./ min received data and data rate values will be calculated.
Expected Result	Latest and non-received (since last update) content pushed on Edge Cache in the train, with duration values longer than the travel time until the next train stop. At least 10 GB of data should be transferred to the train server during the train's stop in order to be acceptable and sufficient.	

4.2.5 MCDv05: Content distribution to passengers onboard

This test case, see Table 4-5, will examine: connection of the passengers to ICOM's CDN application, selection of their preferred VoD/live content, distribution of the content to the passengers and the streaming continuation during the trip. The desired result of the test case would be to have enough Wi-Fi capacity to support the maximum number of passengers that can travel on the train and enough content stored onboard so that no streaming interruptions occur.

Table 4-5 MCDv05: Content distribution to passengers onboard

MCDv05	**Content distribution to passengers onboard**	
Testbed	**5G-VINNI Patras [3]**	
Description	This test case focuses on verifying that the train passengers connect successfully to the ICOM CDN application and can select their content of preference to watch. We need to ensure that the on-board Edge server, which has stored the result of the data shower during its stop at the station, serves the passengers by streaming their selected content through an on-board Wi-Fi AP.	
Key Use-case requirements and KPIs	**U-PE-6212:** Uninterrupted streaming of high-quality videos or TV content to train passengers (TL1a)	
Network performance requirements and KPIs	**Network KPIs** Wi-Fi data rate per passenger: ~15Mbps (TL1a)	
Network Functional requirements and KPIs	**U-FU-6313:** The number of users able to be served must be at least equal to the total train capacity	
Components and Configuration	Components	1. gNB & MEC server available at train station 2. Content provider's niche End-Point (Transcoder) deployed 3. 4K VoD/live content to be streamed

<table>
<tr><td rowspan="2"></td><td></td><td>4. Central CDN server / Content receiver at UoP
5. Edge server available in train
6. 5G modem available in train
7. Wi-Fi AP available in train
8. Passengers' mobile devices
9. ICOM CDN app available on the mobile devices</td></tr>
<tr><td>Configuration</td><td>The ICOM CDN SW modules are deployed on MEC and Edge servers as in MCP02 and MCP03.
1. The on-board Edge server is configured both with an on-board 5G modem (in order to allow the latter to communicate with the 5G base station at train station) and with a Wi-Fi AP for the passengers to connect to it.
2. The ICOM CDN app is installed in passengers' UEs as it is the interface to select content of preference.
3. Ping/ iperf of other datarate measuring tools are available at passenger UEs.
4. An application layer message capturing tool is set up.
5. Radio interface measurement tool shall be available at other UEs - for comparison purposes.
6. A traffic monitoring tool may also be set up.</td></tr>
<tr><td rowspan="2">Test procedure</td><td>Pre-conditions</td><td>1. CDN SW components are up and running.
2. End-user Application is running on all devices.
3. End user connectivity through on-board Wi-Fi AP is verified.
4. Definition of initial position of the test.
5. Definition of traffic conditions of access network node.</td></tr>
<tr><td>Test Case steps</td><td>1. The passengers is onboard already or boards the train once it stopped at the station. They connect to an on-board Wi-Fi.
2. They open the CDN app and navigate through the interface in order to select the content they would like to watch.
3. The passenger(s) select(s) the preferred content, and the Edge server starts streaming the selected content to the passenger through the Wi-Fi.
4. The train departs, connectivity between 5G modem and gNB is lost at some point.
5. However, the UE continues to receive content from Edge Server for some time.
6. The time between the loss of connectivity and the loss of app content is measured.
7. The total time between the request for content and loss of app content is measured.
8. The continuity of content streaming is constantly monitored throughout the trip from one station to another, for each passenger/UE.</td></tr>
</table>

Measurements	Methodology	1. At least 1 iteration of the test case (i.e. one trip between two stations). 2. At least 2 passengers (watching different content -VoD or live content). 3. ~15 Mbps Wi-Fi capacity per passenger 4. For the evaluation of the various time indicators, service layer messages and network layer messages will be captured with their timestamp (from message flows or database fields). 5. For the evaluation of the connectivity indicators, data rates will be monitored.
	Complementary measurements	1. Radio network quality measurements (RSSI/RSRQ) will be collected along with the UE/train position and timestamps. 2. While performing steps 3-6, real time data rate measurements may be also collected. 3. Traffic conditions are also monitored and noted in each iteration.
	Calculation process	1. The time between an operation request and response is calculated – timestamps from the service and network layer messages are used for the calculations. For the "viewing time", the time at which the application session is running at passenger UE will be calculated. For each set of tests/ iterations (for the specific conditions) the mean/ median/ max./ min "Viewing times" will be calculated. 2. Connectivity - related indicators, such as data rate, will be measured by supplementary tools installed at UEs. For each set of tests/ iterations (for the specific conditions), the mean/ max./ min received data and data rate values will be calculated. 3. Additionally, other application layer KPIs such as session setup times, etc. will be calculated using timestamps of the service and network layer messages.
Expected Result	Uninterrupted VoD or time-shifted high-quality content streamed to the UEs of train passengers. At least 2 passengers (one watching VoD and the other watching live content). ~15 Mbps Wi-Fi datarates per passenger for smooth 4K streaming. Approximately 15 min viewing time between loss of connectivity and loss of app content is needed onboard.	

4.2.6 MCSv01: 360° camera Scenario Initialization

The first test case of the MCSv test cases group, see Table 4-6, concerns the initialization of the components that will facilitate the scenario deployment over the 5G-VINNI facility, as well as the verification and evaluation of the connectivity between these and the end-to-end connectivity across all components. It is important to achieve a low deployment time of the involved components, leading to quick deployment of the application in general, and this test case facilitates this verification.

Table 4-6 MCSv01: 360° camera Scenario Initialization

MCSv01	**360° camera Scenario Initialization**
Testbed	**5G-VINNI Patras**

<table>
<tr><td>Description</td><td colspan="2">The initial test case aims at setting up the scenario in terms of deployment, slicing and connectivity. It will verify and evaluate the end-to-end connectivity across all components. Focus will be put on the evaluation of aspects related to data rate and latency achieved between the various interfaces, to ensure that an eMBB and a uRLLC slice can be supported.</td></tr>
<tr><td>Key Use-case requirements and KPIs</td><td colspan="2">U-PE-6213 & U-PE-6214: Very high data rates for high resolution video transmission from 360° camera to the receiving control center
U-PE-6215 & U-PE-6216: Very low latency for lower resolution video streams transmission from 360° camera to the receiving control centre.</td></tr>
<tr><td>Network performance requirements and KPIs</td><td colspan="2">Network KPIs:
Low deployment time of scenario components. Deployment time should be as low as 90 min. (TL1) Data rate between Camera server and Camera receiver: 50-100 Mbps Latency between Camera server and Camera receiver: up to 20 ms</td></tr>
<tr><td>Network Functional requirements and KPIs</td><td colspan="2">U-FU-6314 & U-FU-6315: Very high data rates between 360° camera server and camera client/receiver.
U-FU-6316 & U-FU-6317: Very low latency for lower resolution video streams transmission from 360° camera to the receiving control centre.</td></tr>
<tr><td rowspan="2">Components and Configuration</td><td>Components</td><td>1. gNB available at train station
2. 5G modem available at train station
3. 4K 360° camera at train station
4. Camera server (PC/Laptop) at train station
5. Camera Client (Windows PC) at UoP
6. gNB at UoP
7. 5G modem available at UoP</td></tr>
<tr><td>Configuration</td><td>1. The 360° camera will be configured to communicate with the camera server to send the streams for optimization
2. The camera server will be configured to communicate with the 5G modem at train station
3. The camera client will be configured to communicate with the 5G modem at UoP
4. Ping between components shall be enabled
5. iperf or other data rate measuring tool shall be available and configured to be able to take measurements between the component interfaces.</td></tr>
<tr><td rowspan="2">Test procedure</td><td>Pre-conditions</td><td>Connectivity shall be available across all infrastructure components, that is:
1. Connectivity shall be ensured between the 360° camera/camera server and the 5G Core at UoP (via 5G-VINNI 5G mobile network, specifically via the gNB and the 5G modem deployed at the train station).
2. Connectivity shall be ensured between the camera client and the 5G Core at UoP (via 5G-VINNI 5G mobile network),</td></tr>
<tr><td>Test Case steps</td><td>Once all the components are deployed:
1. Ping requests and data rate measurements are performed between all components/interfaces. Connectivity is verified and the RTT/latency measurements are noted.</td></tr>
</table>

		2. iperf sessions requests are performed between all components/interfaces. Connectivity is verified and the data rate measurements are noted.
Measurements	Methodology	**For step 1**: Ping tests are performed between the interfaces of the application. **For step 2**: Data rate (iperf) tests are performed between the interfaces of the application.
	Complementary measurements	Not relevant for this test case
	Calculation process	**For step 1**: For each set of ping tests between interfaces, the mean/ median/ max./ min latency values (in ms) will be calculated. **For step 2**: For each set of tests/ iterations between interfaces, the mean/ max./ min data rate values (Mbps) will be calculated.
Expected Result	Initial operation and connectivity verification. Smooth & quick onboarding and deployment of scenario components. Total time of components' on-boarding and deployment shall be <90min. Connectivity between CDN components shall either be pre-configured or configured within the 90min timeframe. End-to-End connectivity is verified.	

4.2.7 MCSv02: 360° camera HQ streaming

After completing MCSv01, the required components to support the scenario are verified to be functional. As described in Table 4-7, the scope of MCSv02 is to ensure that the camera footage is being streamed in high quality to a camera operator when the field-of-view (FoV) is stable.

Table 4-7 MCSv02: 360° camera HQ streaming

MCSv02	**360° camera HQ streaming**	
Testbed	**5G-VINNI Patras [3]**	
Description	This test case will examine the camera HQ footage streaming to a camera operator when the FoV is stable. The aim is to ensure that the operator receives the footage in HQ when he is not rotating the FoV.	
Key Use-case requirements and KPIs	**U-PE-6213 & U-PE-6214:** Very high data rates for high resolution video transmission from 360° camera to the receiving control center	
Network performance requirements and KPIs	**Network KPIs** Data rate between Camera server and Camera receiver: ~ 50-100 Mbps (TL1a,b)	
Network Functional requirements and KPIs	**Requirements** **U-FU-6314 & U-FU-6315:** Very high data rates for high resolution video transmission from 360° camera to the receiving control center **U-FU-6316 & U-FU-6317:** Very low latency for lower resolution video streams transmission from 360° camera to the receiving control center **KPIs** Network slicing	
Components and Configuration	Components	1. 5G Base station available at train station 2. 5G modem available at train station 3. 4K 360° camera at train station

		4. Camera server (PC/Laptop) at train station 5. Camera Client (Windows PC) at UoP 6. 5G-NR connectivity at UoP 7. 5G modem available at UoP
	Configuration	1. The 360° camera will be configured to communicate with the camera server to send the streams for optimization 2. The camera server will be configured to communicate with the 5G modem at train station 3. The camera client will be configured to communicate with the 5G modem at UoP 4. iperf or other data rate measuring tool shall be available and configured to be able to take measurements between the component interfaces.
Test procedure	Pre-conditions	Connectivity shall be available across all infrastructure components, that is: 1. Connectivity shall be ensured between the 360° camera/camera server and the 5G Core at UoP (via 5G-VINNI 5G mobile network, specifically via the gNB and the 5G modem deployed at the train station) 2. Connectivity shall be ensured between the camera client and the 5G Core at UoP (via 5G-VINNI 5G mobile network)
	Test Case steps	1. The 360° camera continuously sends the 360° streams to the camera server in both high and lower qualities. These streams are sent to the other end via the 5G network through two concurrent network slices; one eMBB for the high quality stream and one uRLLC for the lower quality stream. 2. The camera operator selects a FoV to receive. 3. The preferences are communicated to the server and the operator starts getting served with the footage in high quality by the eMBB slice.
Measurements	Methodology	For step 3: 1. Monitor the eMBB stream on the camera operator's screen for at least 20 sec. 2. Data rate (iperf) tests are performed between the interfaces of the application.
	Complementary measurements	
	Calculation process	For step 3: For each set of tests/ iterations between interfaces, the mean/ max./ min data rate values (Mbps) will be calculated.
Expected Result	Angle of view displayed in high quality on the camera operator's screen.	

4.2.8 MCSv03: 360° camera FoV rotation

The test case described in Table 4-8 is necessary to verify the smoothness in the camera footage watched by the operator and the motion sickness avoidance when he changes the angle of view.

Table 4-8 MCSv03: 360° camera FoV rotation

MCSv03	**360° camera FoV rotation**	
Testbed	**5G-VINNI Patras [3]**	
Description	This test case will examine the camera FoV rotation from the camera operator. The aim is to ensure that while the operator rotates the FoV, he receives the footage of the new angles without motion sickness, until the angle is stable again (he stops rotating).	
Key Use-case requirements and KPIs	**U-PE-6215 & U-PE-6216:** Very low latency for lower resolution video streams transmission from 360° camera to the receiving control center (TL1a/b) **U-FU-6318:** Video continuity when switching to a new FoV during head motion, for smooth and seamless transition from high to lower resolution video and vice versa. (TL1a/b)	
Network performance requirements and KPIs	**Network KPIs** Latency between Camera server and Camera receiver: up to 20 ms	
Network Functional requirements and KPIs	**Requirements** **KPIs** Network slicing	
Components and Configuration	Components	1. 5G Base station available at train station 2. 5G modem available at train station 3. 4K 360° camera at train station 4. Camera server (PC/Laptop) at train station 5. Camera Client (Windows PC) at UoP 6. 5G-NR connectivity at UoP 7. 5G modem available at UoP
	Configuration	1. The 360° camera will be configured to communicate with the camera server to send streams for optimization. 2. The camera server will be configured to communicate with the 5G modem at train station. 3. The camera client will be configured to communicate with the 5G modem at UoP. 4. iperf or other data rate measuring tool shall be available and configured to be able to take measurements between the component interfaces.
Test procedure	Pre-conditions	Connectivity shall be available across all infrastructure components, that is: 1. Connectivity shall be ensured between the 360° camera/camera server and the 5G CoreatUoP (via 5G-VINNI 5G mobile network, specifically via the gNB and the 5G modem deployed at the train station) 2. Connectivity shall be ensured between the camera client and the 5G CoreatUoP (via 5G-VINNI 5G mobile network). 3. The camera operator is already watching a specific FoV on his screen in high quality, after having completed MCSv02.

	Test Case steps	1. The 360° camera continuously sends the 360° streams to the camera server in both high and lower qualities. These streams are sent to the other end via the 5G network through two concurrent network slices; one eMBB for the high quality stream and one uRLLC for the lower quality stream. 2. The camera operator uses the mouse to rotate the FoV he is watching, and shall continue rotating for a while. During the rotation, he starts getting served by the uRLLC slice with the footage in lower quality but with very low latency, in order to have no gaps between the consecutive images. 3. The camera operator stops the rotation at a specific FoV. He then starts again, getting served by the eMBB slice with the footage in high quality.
Measurements	Methodology	1. Steps 2-3 will be performed for at least 2 times. 2. Step 3 (FoV stability) will have at least 20 sec duration before repeating the test case steps. 3. Data rate (iperf) tests are performed between the interfaces of the application.
	Complementary measurements	
	Calculation process	For steps 2 and 3: For each set of tests/ iterations between interfaces, the mean/ max./ min data rate values (Mbps) will be calculated.
Expected Result	FoV is displayed with low latency in lower quality in camera operator's screen during rotation, and in high quality once it is stabilized.	

4.3 Lab Results

This section provides an overview of the preliminary results obtained through lab tests that were conducted at the UoP premises, aiming at measuring the defined KPIs and identifying potential issues to be improved for the field trials in the future. The setups that were used during the lab trials for both scenarios were simplified in relation to the target field setups, and are explained in detail below.

More specifically, for the **data shower scenario**, the experiments took place at the computer networks lab of UoP, with all components being deployed locally. At this time, no mmWave backhauling is in place to use, therefore the whole 5G connectivity was supported within the UoP lab. There, the train cache was emulated with an ICOM laptop, which had an Ethernet connection to UoP's 5G-CPE, to interact with UoP's local gNB. The train station cache as well as the Central CDN server were deployed as VNFs in UoP's OpenStack environment. Finally, the VoD content provided by **COSM** was locally downloaded and streamed to the central CDN server and a train passenger UE was emulated at the same laptop that served as the train cache, resulting in both the passenger UE and the train cache to be directly connected to the 5G-CPE. The network conditions were constantly monitored by a monitoring software provided by UoP and the results were displayed on a separate screen. The described setup and the lab environment for this scenario are illustrated in Table 4-9 and the figures.

Table 4-9 CDN Lab Testing – Network Topology

Network Components and Configuration	
Type of sites in the network area	Number of gNBs:

	1 Small scale gNB gNB deployment Option: No distributed RAN deployment – all gNB functions deployed on a single HW component Type of gNB commercial – for testing purposes
Fronthaul/Backhaul Information	Predominant type of backhauling: Fiber - Ethernet
Cloud Infrastructure	The cloud platform offers a total computing power of 450 CPUs and 1,5 TB of RAM and 50 TB of storage. All servers are interconnected on TOR 10GbE/40GbE NVIDIA Cumulus switches with dual 10GbE NICs DPDK enabled Virtualization software: OpenStack, ETSI MANO OSM

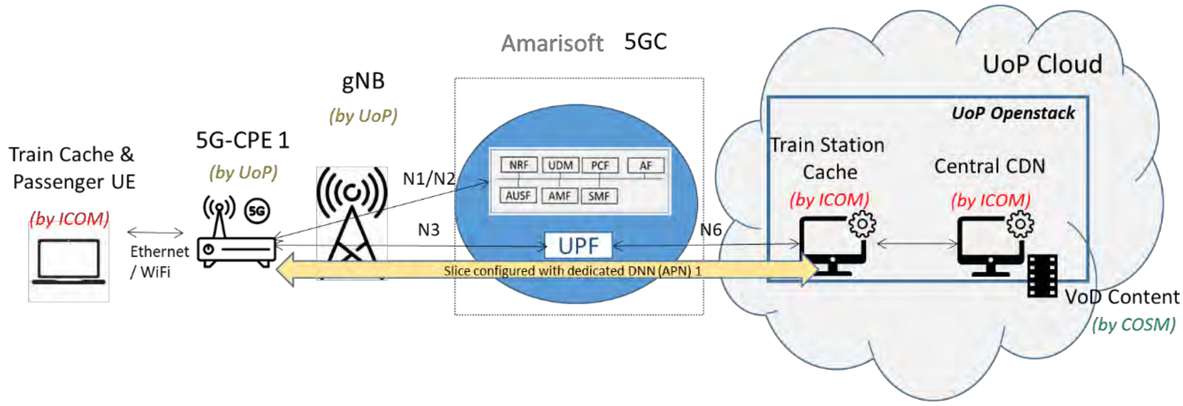


Figure 4-2 The lab setup of the data shower scenario for the Patras cluster Media UC

At this stage the lab tests were conducted with the aim to validate the network and network operation so no additional traffic was offered at the site. Therefore, during all the tests the measuring process characteristics were the following:

Table 4-10 CDN Lab Testing – Process characteristics

Measurement duration	**Time duration of the measurement [T]:** *For MCD01: Not applicable* *For MCDv02-MCDv05: 10 minutes* ***Repetition time:*** *5-10 repetitions x 1-2 mins* ***Granularity of measurements:*** *Deployment times: in the order of minutes* *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* ***Traffic Pattern and interarrival time:*** *Not applicable*

Figure 4-3 UoP's local gNB

Figure 4-4 UoP's 5G-CPE

Figure 4-5 ICOM's train cache laptop & passenger UE streaming COSM VoD content

Figure 4-6 UoP's network monitoring screen

The results obtained from the experiments for the five test cases corresponding to the data shower scenario are presented below.

For test case **MCDv01: CDN Application Scenario Deployment**, the CDN components were deployed over the 5G-VINNI facility through the orchestration layer of OSM at UoP's testbed. The average time required for the VNFs deployment was measured, targeting only the train station cache VNF, as in the field trials setup the central CDN server will be considered to be already deployed before the start of the scenario and the train cache will be again a physical laptop. An average duration of *5:12 minutes* was measured as the required time for the VNFs deployment, illustrated in Figure 4-7. After deployment of the CDN components, initial connectivity between all of them was verified.

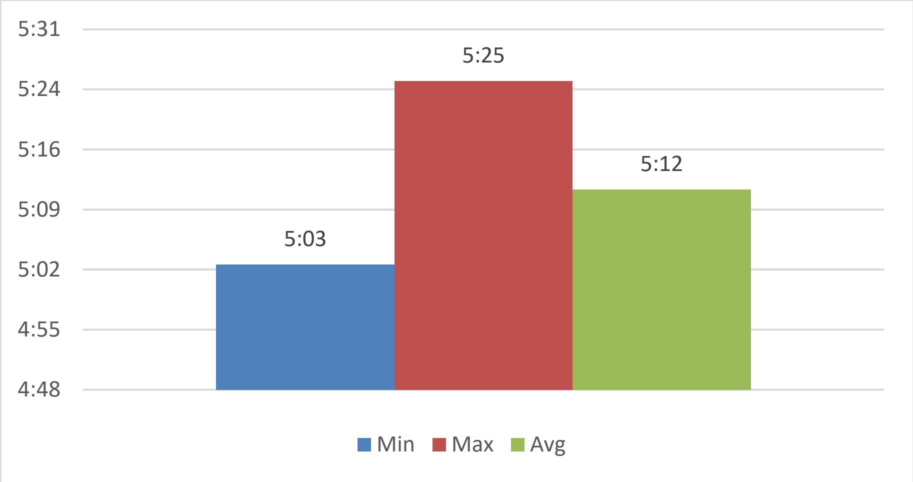


Figure 4-7 Lab Testing results: CDN Application Deployment Time (minutes)

After having deployed the CDN components, the connectivity across all CDN components was evaluated for test case **MCDv02: CDN Connectivity Evaluation.** In particular, tests focused on evaluating the performance of the communication links between the various CDN components. In the link between the train cache and the train station cache (implemented over the UoP lab 5G test network) an average latency of *50.464 ms* was achieved; occurring from 100 packets sent through ping request. As for the data rate evaluation on the same link, which is necessary for the data shower mechanism, an iperf test session with 20 simultaneous connections was performed, resulting in an average of *346.4 Mbps*. The results are illustrated in Figure 4-8.

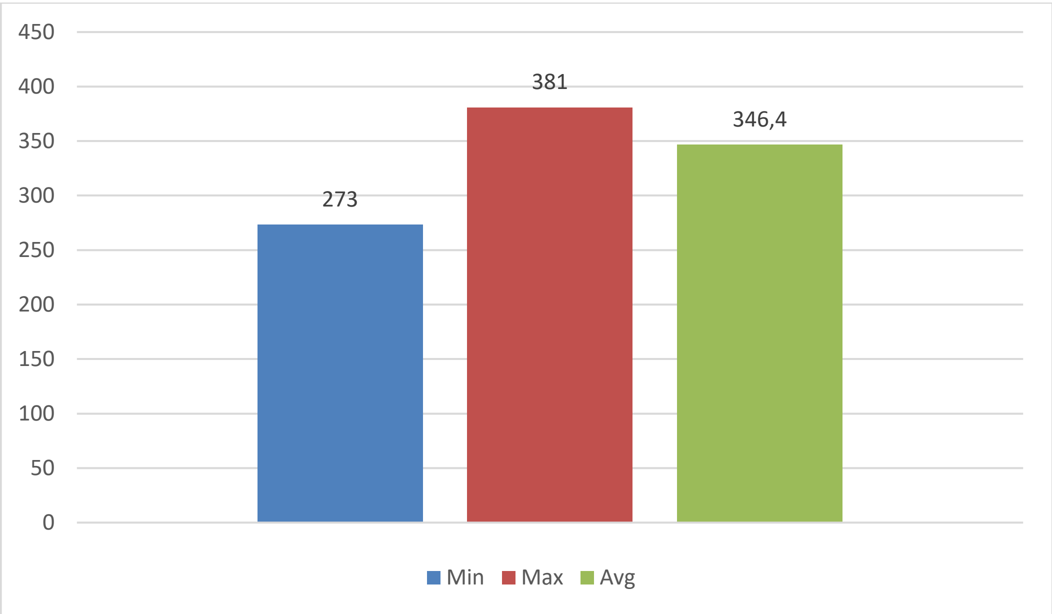


Figure 4-8 Lab Testing results: Data Rate between Train Cache and Train Station Cache (Mbps)

Since the Central CDN server and the train station cache were deployed as VNFs at the same facility i.e. UoP's OpenStack environment, an iperf session showed that very high data rates were supported on the link between them.

The next step of the experiments was to synchronize the train station cache with the latest content being streamed at the central CDN server, in order to evaluate test case **MCDv03: MEC (Train Station Cache) Periodic Update**. For the lab trials, only VoD content was used, as the completion of the integration of COSM TV content with ICOM's CDN is planned for the upcoming project period. An 11GB file of VoD content provided by COSM was fed into ICOM's CDN system and the train station cache pulled new chunks of content as a continuous stream in a repetitive manner, meaning that the content started over once the train station cache reached the end of the chunks. It was measured that the train station cache continuously downloads content from the Central CDN server with a data rate of *4.5 – 5 Mbps*. Since the Central CDN server and the train station cache where deployed as VNFs at the same facility i.e. UoP's OpenStack environment, an iperf session on the link between them showed that the data rate is high enough to cover the synchronization rate of the train station cache.

After the train station cache was updated with the latest content from the central CDN, the data shower mechanism from the train station cache to the train cache was examined. For the test case **MCDv04: Data Shower from MEC to train cache**, the average data rate with which the content was downloaded in the train cache was measured to be *30.817 Mbps*, as shown in the figure below. These measurements are considered as a benchmark for the next testing rounds and are translated into the relevant KPIs in order to be used for future reference.

The respective average data volume that was downloaded in a 4-minute window at the train cache was *924.4 MB*, illustrated in Figure 4-10.

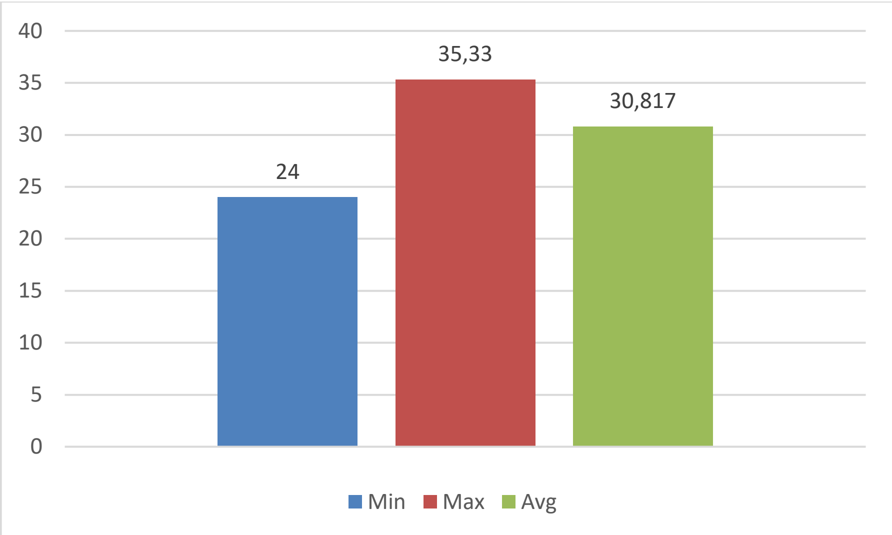


Figure 4-9 Lab Testing results: Data Rate of Data Shower mechanism

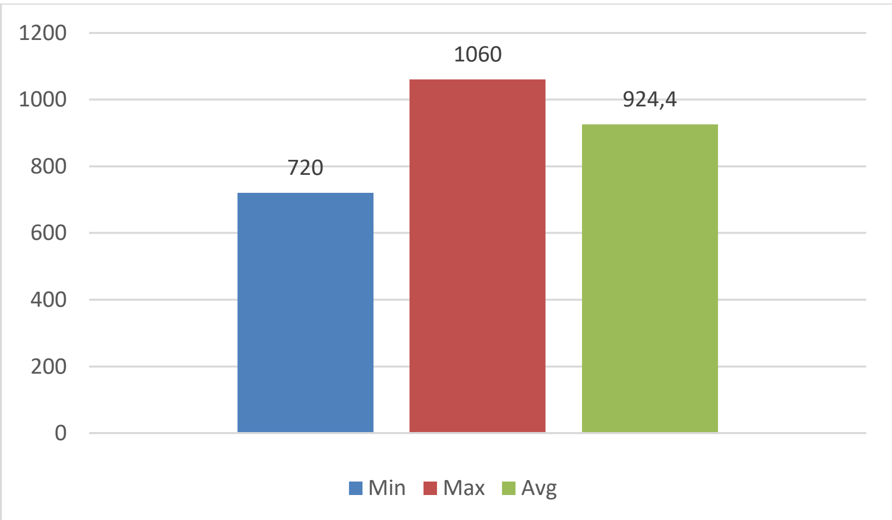


Figure 4-10: Lab Testing results: Downloaded data volume of Data Shower Mechanism in a 4-minute time frame

The available data rate of the 5G NR link (between the train station cache and the train cache) was measured to be 346.4 Mbps on average, as reported for the test case MCDv02 above. The data shower mechanism was also tested in another local setup at ICOM premises, where the train station cache and the main cache were both deployed as VMs in the same network (non-5G). In this experiment, an average rate of 1.5 Gbps was achieved. Evidently there is still room for improving the integration of the CDN application over the 5G network, since the achievable data rate is only a percentage of the expected (maximum) one. Currently the bottleneck for the deployments and the integration are identified and mitigation measures will be taken in the next round of testing.

The data shower scenario experimentation ended with the measurements for the test case **MCDv05: Content Distribution to passengers onboard**. In the context of the lab trials, the train passenger was emulated on the same laptop where the train cache was hosted. Since it would not be meaningful to measure the link between these two components on the same machine, another laptop emulated a second passenger by connecting at the same 5G-CPE where the train cache (laptop) was connected. Iperf sessions were run between the two laptops and the average bandwidth that was available for the passenger to watch the content of preference from the train cache was *47.56 Mbps,* which is considered enough to stream high quality video (e.g. 4K). It was verified that the end user (passenger) was able to view uninterrupted COSM content.

The results obtained through lab testing correspond to E2E performance metrics for the configured CDN 5G slice and are summarized in Table 4-11.

Table 4-11 CDN Lab Testing – E2E (per slice metrics) Performance Results

E2E (per slice metrics)		
Metric	**Description**	**Methodology**
Average e2e delay for a network slice	Average: 50.464 ms	100 packets sent through ping request
Throughput for Single Network Slice Instance	Average: 346.4 Mbps Min: 263 Mbps Max: 346 Mbps	DL iperf test sessions with 20 simultaneous connections were run between the ends where train station cache and the train cache were deployed
	Average: 30.817 Mbps Min: 24 Mbps Max: 35,33 Mbps	DL Traffic stemming from Data shower mechanism from the train station cache to the train cache.
	Average: 924.4 MB Min: 720 MB Max: 1060 MB	Calculation of data volume that was downloaded in a 4-minute window from the train station cache to the train cache.
QoS flow Retainability	Not evaluated at lab testing	
Packet transmission reliability KPI in DL on Uu	Not evaluated at lab testing	

Moving to the **remote surveillance scenario**, the experiments again took place at the computer networks lab of UoP, with all the components being deployed locally. The 360° camera provided by ICOM was IPC-EBW81230. The camera was set to monitor the lab's interior and was connected through Ethernet to ICOM's camera server, responsible for the streams processing and transmission. The camera server was connected through Ethernet to UoP's 5G-CPE, in order to interact with UoP's local gNB. Finally, for this round of trials, the camera client brought by ICOM was connected through Ethernet to a VLAN directly forwarding the traffic to the gNB. For the first round of lab tests, only one slice was available to be set up, so both the high quality stream and the low quality stream as well as the control plane of the surveillance application were served by the same high-bandwidth slice. For the second round of lab tests, a low-latency slice will be dedicated to the low quality stream and the control plane. The network conditions were again constantly being monitored by the monitoring software provided by UoP as described in the data shower scenario, and the results were displayed in a large screen. The described setup and the lab environment for this scenario are illustrated in Table 4-12 and the subsequent figures.

Table 4-12 MCS Lab Testing – Network Topology

Network Topology	
Type of sites in the network area	Number of gNBs: 1 Small scale gNB gNB deployment Option: No distributed RAN deployment – all gNB functions deployed on a single HW component Type of gNB commercial – for testing purposes
Fronthaul/Backhaul Information	Predominant type of backhauling: Fiber - Ethernet
Cloud Infrastructure	The cloud platform offers a total computing power of 450 CPUs and 1,5 TB of RAM and 50 TB of storage. All servers are interconnected on TOR 10GbE/40GbE NVIDIA Cumulus switches with dual 10GbE NICs DPDK enabled Virtualization software: OpenStack, ETSI MANO OSM

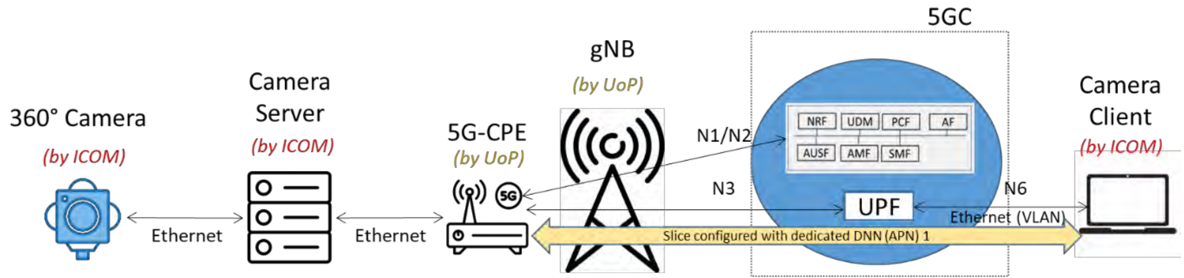


Figure 4-11 The lab setup of the remote surveillance scenario for the Patras cluster Media UC

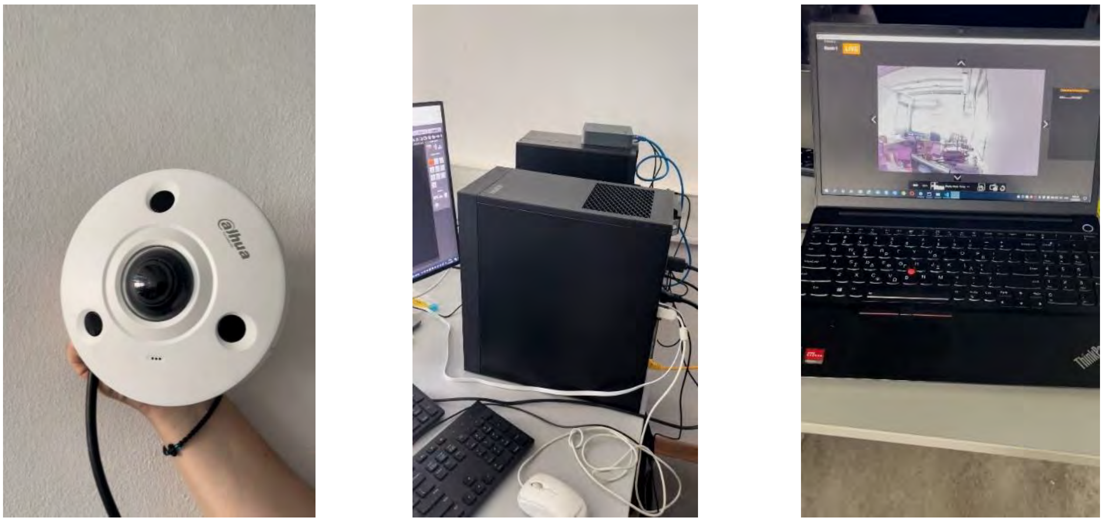


Figure 4-12 From left to right: The IPC-EBW81230 360° camera, the camera server, and the camera client receiving the surveillance footage

At this stage the lab tests, were conducted with the aim to validate the network and network operation so no additional traffic offered in the site. In all tests therefore the measuring process characteristics were the following:

Table 4-13 MCS Lab Testing – Process characteristics

Measurement duration	**Time duration of the measurement [T]:** 10 minutes ***Repetition time:*** *10 repetitions x 1 min* ***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* ***Traffic Pattern and interarrival time:*** *Not applicable*

For test case **MCSv01: 360° Camera Scenario Initialization**, the relevant components (360° camera, camera server, camera client) were deployed over the 5G-VINNI facility and the initial connectivity between all of them was verified. Then, the connectivity across all of them was evaluated, especially in terms of aspects related to data rate and latency of the communication links between the various interfaces. For the link between the camera server and the camera client, iperf test sessions with 20 simultaneous connections were performed with a downlink configuration at this stage, resulting in an average uplink data rate of *5.103 Mbps* (see Figure 4-13*).* The target is to examine an uplink configuration to achieve even higher uplink rates, in order to be able to support traffic generated even from multiple surveillance cameras.

Since in the current setup a low-latency slice was not available and all the traffic was concatenated into one high-bandwidth link, the network latency was measured in the existing link for reference, as it is a required metric for the streaming of the low quality stream and the control plane. An average of *34 ms* was measured, occurring from 100 packets sent through ping request (see Figure 4-14).

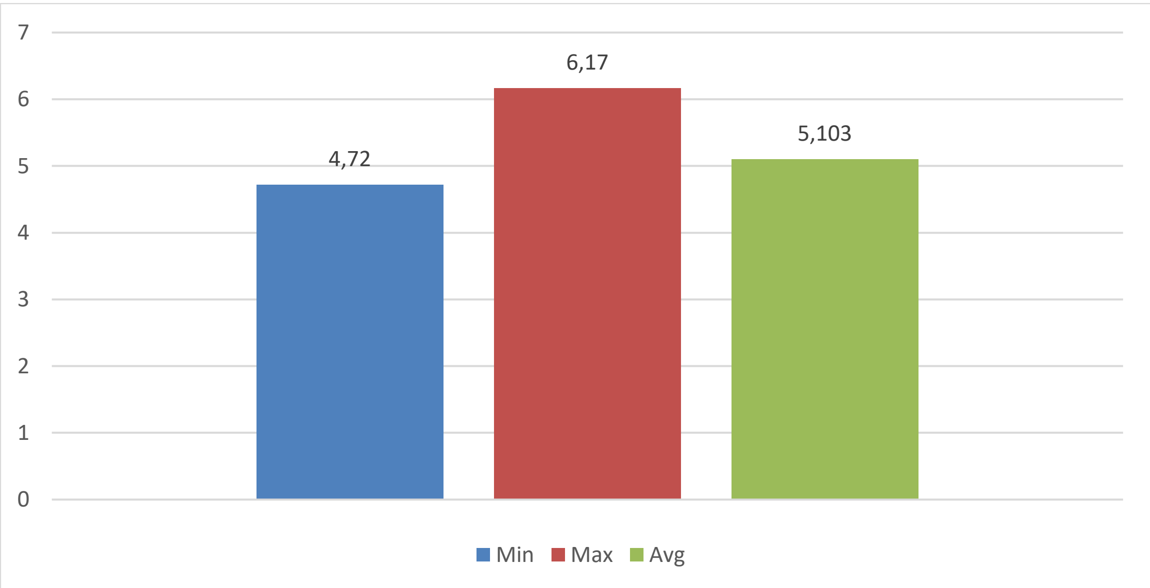


Figure 4-13: Lab Testing results: Data Rate between Camera Server and Camera Client (Mbps)

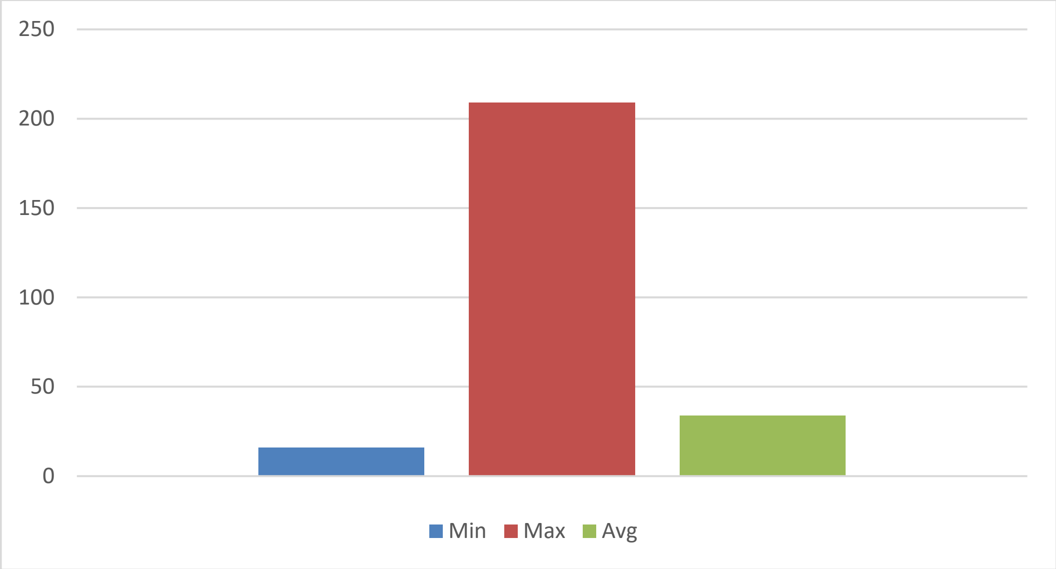


Figure 4-14: Lab Testing results: Latency between Camera Server and Camera Client (ms)

After the evaluation of the network capabilities between the surveillance scenario components, the camera was set to transmit the field-of-view to the camera client. For the test case **MCSv02: 360° camera HQ streaming**, it was observed that the high-quality stream requires an average bandwidth of *3.7 Mbps* to be transmitted.

Finally, since two concurrent slices – one high-bandwidth and one low-latency - were not available at this time, the test case **MCSv03: 360° camera FoV rotation** could not be evaluated separately at this point, but is targeted for later experiments.

The results obtained through lab testing correspond to E2E performance metrics for the configured MCS 5G slice and are summarized in Table 4-14:

Table 4-14 MCS Lab Testing – E2E (per slice metrics) Performance Results

E2E (per slice metrics)		
Metric	**Description**	**Methodology**
Average e2e delay for a network slice	Average: 34 ms	100 packets sent through ping request
Throughput for Single Network Slice Instance	Average: 5,103 Mbps Min: 4,72 Mbps Max: 6,17 Mbps	UL iperf test sessions with 20 simultaneous connections were run between the ends where the camera server and the camera client were deployed.
	Average: 3.7 Mbps Min: 24 Mbps Max: 35,33 Mbps	Traffic stemming between camera server and client.
QoS flow Retainability	Not evaluated at lab testing	
Packet transmission reliability KPI in DL on Uu	Not evaluated at lab testing	

4.4 Test combinations at 5G-VICTORI facility in Patras

At this time, no UC test combinations involving the Media services were conducted for the 5G-VICTORI facility in Patras. For the next round of trials, it is planned to run test combinations of the data shower service at the same time with the remote surveillance service, in order to evaluate the scenario of combining multiple slices dedicated to different services 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:

- Enhance Mobile Broadband services for data shower based Content Delivery: DCN services – corresponding to ICOM application and COSMOTE TV content
- Mission Critical Services: for the Video Surveillance service
- Other traffic: Background traffic via iperf or simple internet browsing (to load or saturate the air-interface).

The aforementioned services will be mapped to various combinations of QoS and Network Slices as available by the 5G network implementation at Patras (UoP) facility.

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

The Patras test combinations considered are listed in Table 4-15.

Table 4-15 Patras Test-combinations over CDN deployment

Resources and type of services	Resources		Services		Other Services
Test Combinations	Network Slicing supported	QoS enabled	CDN	MCS	Background Traffic
REComb01			X	X	
REComb02			X	X	X
REComb03		X	X	X	X
REComb04	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 conditions, and in various network configurations. These configurations include cases without QoS or Network Slicing requirements (similar to existing 4G networks) and configurations where QoS and Network Slicing are available.

Initially, test combinations of the two service types will be performed, in the absence and in presence of background traffic, without any QoS differentiation, or any other type of NS configuration per service. The effect of background traffic on the various services will be assessed.

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

At a third step, NS configuration over the 5G SA platform will be tailored to the specific services, and their performance will be assessed especially under heavy traffic conditions.

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

Considering the Network Slicing and QoS definition in the test combinations, two Network Slices are suggested:

- NS 1: CDN Services (including background traffic).
- NS 2: MCS Services.

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

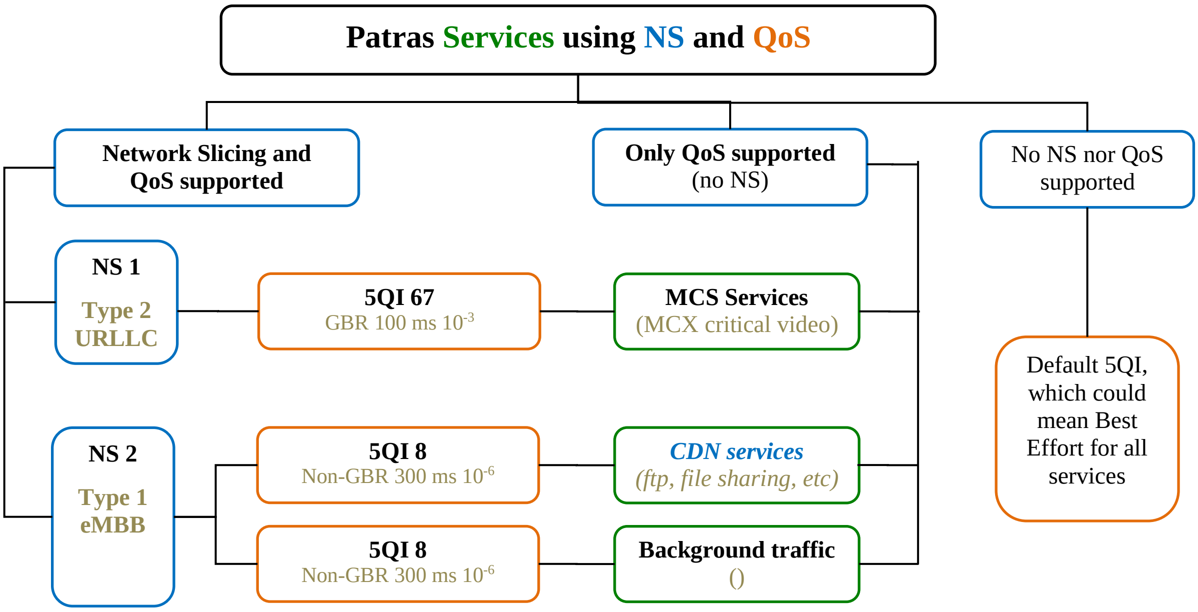


Figure 4-15 Patras Services with and without Network Slicing, plus QoS support

5 Digital Mobility at the 5G-VICTORI facility in Alba Iulia

5.1 Description of 5G-Infrastructure at 5G-VICTORI facility in Alba Iulia

The architecture of Figure 5-1 provides an overview of the Media UC FR/RO cluster in AIM, as components in blue are relevant for the Emergency Video Services, analytics implementation for emergency detection, triggering PDU traffic prioritization within the E2E 5G service chain.

Media services UC components are:

- **5G UE and Video camera**: the cameras are located in the bus and through the 5G SA device and/or locally installed L2 switch, connected to the analytics server, acting as an Edge Computing Component for video service, the communication component is provided over the Low Latency PDN slice.
- **5G SA Network**: it is the component installed in Orange 5G site, as RRH/BBU, 5GCN core network components, network interfaces and local processing servers.
- **Digital Mobility C&C**: it is the component under AIM/UC responsible, connected through N6 interface to the Emergency service video services.
- **5G UE Wi-Fi**: the router is located on the bus and is providing Internet access through Wi-Fi, passengers are connected to the AIM service portal and internet, the communication component is provided over the broadband PDN slice.
- **Analytics application**: it is the component that is performing real time video services analytics for the emergency UC.

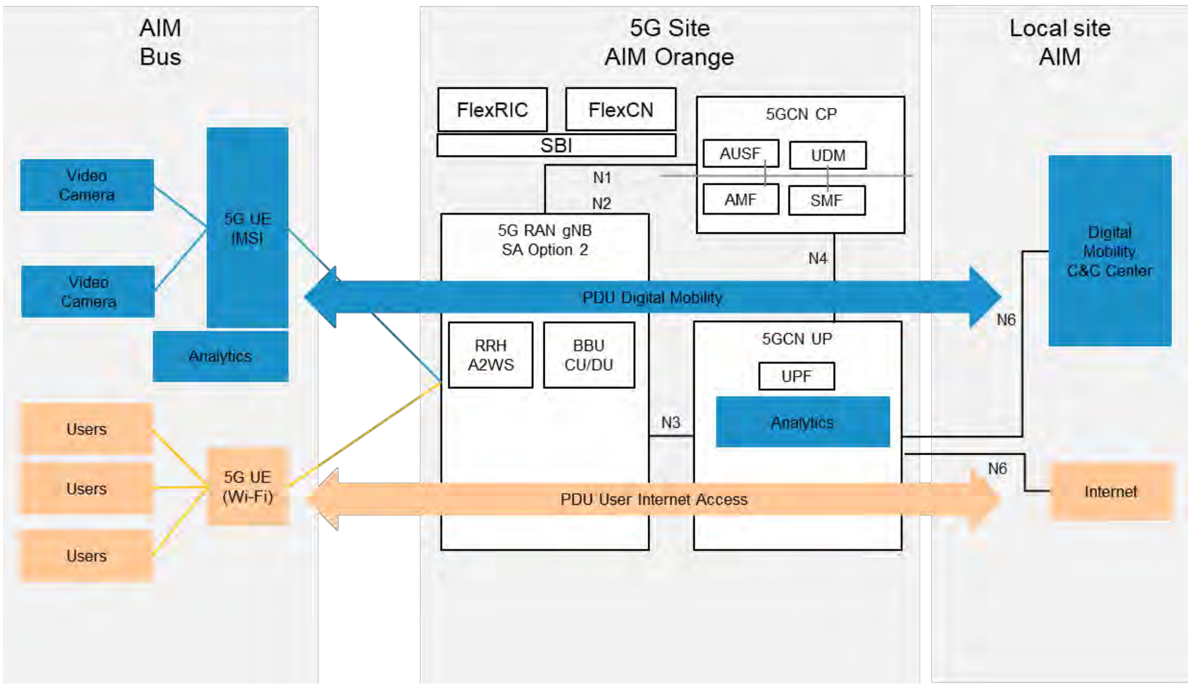


Figure 5-1 FR/RO cluster UC services mapped to 5G infrastructure at AIM

5.2 Infotainment/ Video Services in Dense, Static and Mobile Environment Test Cases

5.2.1 MDIe01: User authentication using captive portal

The aim of this test case, which is described in Table 5-1, is to check the user authentication process using the captive portal. The UE attaches to SSID Wi-Fi from the bus, is redirected to the portal that is offering administration information such as surveys, local news and tourism ads. For free internet access an authentication procedure based on Mobile Station International Subscriber Directory Number (MSISDN) is performed, the traveler inputs the number on the captive portal, receives a code by SMS, which can be used in the portal for gaining free internet access.

Table 5-1 MDIe01: User authentication using captive portal

MDIe01	**User authentication using captive portal**	
Testbed	**5G-EVE Alba Iulia [5]**	
Description	The purpose of this test-case is to check the user authentication steps (user connected over Wi-Fi for Internet access over the MBB slice)	
Key Use-case requirements and KPIs	Not relevant	
Network performance requirements and KPIs	Not relevant	
Network Functional requirements and KPIs	eMBB slice is enabled in the network. No specific KPIs needed.	
Components and Configuration	Components	1. One laptop/tablet 2. Wi-Fi AP 3. Wi-Fi portal 4. eMBB slice configured over 5G network
	Configuration	1. One laptop/tablet is connected to the Wi-Fi AP; 2. After the successful authentication, the user can browse the Internet. 3. The backhaul of the Wi-Fi AP is assured over the eMBB slice.
Test procedure	Pre-conditions	Connectivity shall be ensured across the Network deployment depicted in Figure 5-1. The Bus shall be in the 5G network coverage. The user phone number shall be registered to the 5G network.
	Test Case Steps	1. The laptop/tablet connects to the Wi-Fi SSID from the bus 2. The user is redirected towards the authentica-tion page (captive portal) 3. On the portal various information is shown (news from the city, sightseeing, etc.) 4. The user can request free Wi-Fi: (a) introduces his/her phone number, (b) receive an SMS with the code. 5. Using the phone number and code, the user can authenticate on the portal and gain free Wi-Fi access.
Measurements	Methodology	N/A
	Complementary measurements	N/A
	Calculation process	N/A

Expected Result	The user is redirected towards the captive portal; the user can request free Wi-Fi access; the user successfully authenticates on the portal and can browse the Internet.

5.2.2 MDIe02: Captive portal data availability

The scope of the test case described in Table 5-2 is to check the successful integration of the portal with different content sources. The portal should contain information from multiple data sources, all of equal importance from the municipality's point of view. Another objective of the test case is to measure the time necessary to display the requested information, the backhaul of the Wi-Fi AP is an eMBB slice.

Table 5-2 MDIe02: Captive portal data availability

MDIe02	**Captive portal data availability**	
Testbed	**5G-EVE Alba Iulia [5]**	
Description	The captive portal integrates various data sources to provide relevant information to the users. In this test we check that portal loads all the necessary data (from selected data sources) and measure the loading times.	
Key Use-case requirements and KPIs	Browsing time (latency) – time to display the requested information < 3s; Service availability > 99%	
Network performance requirements and KPIs	Not relevant, the KPIs are measured at application level for this use-case.	
Network Functional requirements and KPIs	eMBB slice is enabled in the network. No specific KPIs needed.	
Components and Configuration	Components	1. One laptop/tablet 2. Wi-Fi AP 3. Wi-Fi portal 4. eMBB slice configured over 5G network 5. One synthetic monitoring tool.
	Configuration	1. Connectivity shall be ensured across the Network deployment depicted in Figure 5-1. 2. The Bus shall be in the 5G network coverage. 3. One laptop/tablet is connected to the Wi-Fi AP. 4. The backhaul of the Wi-Fi AP is assured over the eMBB slice. 5. One synthetic monitoring tool (software) is installed on the laptop/tablet. In the synthetic monitoring tool, a predefined test is configured to measure how fast the information loads on the captive portal. Once executed, the test runs with a periodicity of 5 min. The duration of the test is maximum 1 minute.
Test procedure	Pre-conditions	N/A
	Test Case Steps	1. The laptop/tablet is connected to the Wi-Fi AP. 2. The synthetic monitoring test is executed over 24 hours. 3. The results of the loading times are registered by the synthetic monitoring tool.
Measurements	Methodology	The synthetic monitoring test is started and executed over a duration of 24 hours. The synthetic monitoring tool registers the results of the loading times for each of the data sources integrated with the captive portal. When the loading times exceeds a threshold (5s) for one data source, the test is marked as unsuccessful for that specific data source.

		The synthetic monitoring tool presents the following results: 1. min/average/max loading times for each of the data sources 2. Total number of unsuccessful tests for each data source 3. Total number of successful test for each data source
	Complementary measurements	N/A
	Calculation process	Browsing time is calculated as an average of the "average loading times" (for all data sources) for all the successful tests Service availability is calculated as: Total number of successful tests (for all data sources) divided by the total number of tests (for all data sources).
Expected Result	The KPIs are achieved.	

5.3 Prioritized Communication to Command and Control Center Test Cases

5.3.1 MDCe01: Establishment of basic E2E connectivity over a specific slice

The scope of this test case is to verify the establishment of E2E connectivity over an interactive eMBB slice for a tablet which is already authenticated on the portal towards the Control and Command Centre server, using ping and traceroute. As described in Table 5-3, to also verify the Fully Qualified Domain Name (FQDN) function, necessary to browse over the internet, the server of the CCC will be checked with ICMP protocol having as attribute the IP or the URL of the server.

Table 5-3 MDCe01: Establishment of basic E2E connectivity over a specific slice

MDCe01	**Establishment of basic E2E connectivity over a specific slice (user-> Wi-Fi AP -> 5G backhaul -> Internet/specific destination)**	
Testbed	**5G-EVE Alba Iulia [5]**	
Description	Test device connected over Wi-Fi, authenticated to the network. One slice configured in the network. Ping is working from test device towards one test IP (Command & Control or other)	
Key Use-case requirements and KPIs	Not relevant (as basic connectivity is tested)	
Network performance requirements and KPIs	Not relevant	
Network Functional requirements and KPIs	Testing e2e connectivity over the eMBB preconfigured slice, no specific KPIs defined	
Components and Configuration	Components	1. One laptop 2. Wi-Fi AP 3. eMBB slice configured over 5G network.
	Configuration	1. One laptop/tablet is connected to the Wi-Fi AP.
Test procedure	Pre-conditions	1. Connectivity shall be ensured across the Network deployment depicted in Figure 5-1. 2. The Bus shall be in the 5G network coverage. 3. The laptop is already authenticated to the Wi-Fi AP 4. The Wi-Fi AP connected on uplink to the 5G network on the eMBB slice
	Test Case Steps	1. On the eMBB slice the laptops should have access to the Command & Control. 2. In order to test this from the laptop a ping & traceroute are executed:

		a) towards the IP of the Command & Control server b) towards the URL of the Command & Control servers
Measurements	Methodology	ICMP messages sent towards IP and URL of the C&C servers. Check if the procedure is successful. If it is failed the traceroute procedure is used to identify the break point
	Complementary measurements	N/A
	Calculation process	N/A
Expected Result	The ping towards the IP of the Command & Control server works. The ping towards the URL of the Command & Control server works (meaning that also the URL is resolved by the DNS service).	

5.3.2 MDCe02: Establishment of advanced E2E connectivity over two different slices with different QoS metrics configured

This test case (Table 5-4) checks the deployment of two different network slices having two different quality of service metrics: one eMBB slice for interactive service/camera's video and one slice with uRLLC capability. For each slice one tablet or laptop is used, measuring the performance of the network (bandwidth, jitter, latency) through iperf application.

Table 5-4 MDCe02: Establishment of advanced E2E connectivity over two different slices with different QoS metrics configured

MDCe02	**Establishment of advanced E2E connectivity over two different slices with different QoS metrics configured**	
Testbed	**5G-EVE Alba Iulia [5]**	
Description	Two slices configured in the network. Connect test devices over 5G radio and test connectivity over each slice towards test IP. This UC also checks the different slices creation	
Key Use Case requirements and KPIs	N/A	
Network performance requirements and KPIs	• Network slice capabilities/management (Yes/No); • E2E latency for interactive service (in ms) < 30ms; • E2E latency for public safety service (in ms) < 5ms; • High bandwidth required for data intensive public safety applications and HD video streaming > 20Mbps; • Jitter for URLLC < 1ms	
Network Functional requirements and KPIs	• Network slice capabilities/management (Yes/No)	
Components and Configuration	Components	1. Two laptops/tablets, 2. Wi-Fi AP 3. Two slices configured over 5G network: URLCC, eMBB.
	Configuration	1. Two laptops/tablets are connected to the two different slices: eMBB & URLCC; the connection is performed directly over 5G using SIM.

		2. The two slices are configured in the 5G network with the needed QoS. 3. On each of the two laptops/tablets iperf is activated for measuring network performance (bandwidth, latency and jitter)
Test procedure	Pre-conditions	1. Connectivity shall be ensured across the Network deployment depicted in Figure 5-1. 2. The Bus shall be in the 5G network coverage. 3. No congestion in the network (5G or Wi-Fi) 4. A test server with IP addresses on each of the slices
	Test Case Steps	1. Configure the two slices 2. Attach devices on each of the two slices 3. Check that successful network connectivity is in place for all the slices (ping/traceroute towards the specific IP addresses of the test server) 4. Run iperf tests (as per methodology), write down results
Measurements	Methodology	1. Check if all two slices are up 2. The iperf is performed utilizing a test server with connectivity within all the two slices. 3. Two tests are performed on all the slices simultaneously (one test/slice). On the eMBB slice, the traffic flow is configured with a bandwidth of 25 Mbps. For the URLCC slice, the traffic flow is configured with a bandwidth of 100 kbps. 4. The tests are repeated three times, resulting in a total number of 6 tests. 5. The KPIs have to be achieved for each of the tests.
	Complementary measurements	N/A
	Calculation process	N/A
Expected Result	The two slices are successfully configured. Connectivity is up and running over the two slices. The KPIs are achieved.	

5.3.3 MDCe03: Load test for observing the QoS prioritization among slices with congestion on radio part

Once the threat alarm is triggered, the CCC operator needs to access camera images from the bus to decide what further emergency measures need to be taken. In this respect, the QoS of the slices with guaranteed bandwidth and low latency must be fulfilled. To test this scenario (see Table 5-5), the radio cell is congested pushing traffic through all two slices, checking if the critical services are prioritized against the interactive ones.

Table 5-5 MDCe03: Load test for observing the QoS prioritization among slices with congestion on radio part

MDCe03	**Load test for observing the QoS prioritization among slices with congestion on radio part**
Testbed	**5G-EVE Alba Iulia [5]**
Description	Iperf_1 connected over eMBB slice. Congest radio cell by pushing traffic. Iperf_2 connected over URLLC slice, push 100kb stream of traffic. Check QoS parameters for each of the slice.
Key Use-case requirements and KPIs	Prioritization of slices shall be performed based on slices characteristics.

Network performance requirements and KPIs	• E2E latency for interactive service (in ms) < 30 ms; • E2E latency for public safety service (in ms) < 5 ms; • High bandwidth required for data intensive public safety applications and HD video streaming > 20 Mbps; • Jitter for URLLC < 1 ms	
Network Functional requirements and KPIs	N/A	
Components and Configuration	Components	1. Two laptops/tablets, 2. WiTwoFi AP 3. Two slices configured over 5G network: URLCC, eMBB.
	Configuration	1. Two laptops/tablets are connected to the two different slices: for eMBB & URLCC the connection is performed directly over 5G using SIM. 2. The two slices are configured in the 5G network with the needed QoS. 3. On each of the two laptops/tablets iperf is activated for measuring network performance (bandwidth, latency and jitter)
Test procedure	Pre-conditions	1. Connectivity shall be ensured across the Network deployment depicted in Figure 5-1. 2. The Bus shall be in the 5G network coverage. 3. Congestion in the 5G radio part by pushing traffic with iperf_1 4. A test server with IP addresses on each of the slices 5. Necessary devices are already registered to the 5G network.
	Test Case Steps	1. Configure the two slices 2. Attach devices on each of the two slices 3. Check that successful network connectivity is in place for all the slices (ping/traceroute towards the specific IP addresses of the test server) 4. Run iperf tests (as per methodology), write down results
Measurements	Methodology	1. Check if the two slices are up 2. The iperf is performed utilizing a test server with connectivity within all two slices. 3. On eMBB slice, the traffic flow is configured with a bandwidth higher than the total available bandwidth of the 5G cell. 4. Two tests are performed on the 2 slices (eMBB and URLCC) simultaneously (one test/slice). For eMBB the traffic flow is configured with a bandwidth of 20Mbps. For the URLCC slice, the traffic flow is configured with a bandwidth of 100kbps. 5. The tests are repeated three times, resulting in a total number of 6 tests. 6. The KPIs have to be achieved for each of the tests
	Complementary measurements	N/A
	Calculation process	Extract from iperf the average, min and max values for throughput and latency, for both slices
Expected Result	The two slices are successfully configured. Connectivity is up and running over the two slices. The KPIs are achieved, meaning that even if the 5G cell is congested with lower priority traffic, the throughput, delay and jitter from the eMBB & URLCC slices are achieved while dropping lower priority traffic.	

5.3.4 MDCe04: Stability test - injecting traffic over one slice for 7 consecutive days

Being a UC in the public safety and security area, the availability and the stability of the services are very important. The following test-case, described in Table 5-6, measures the performance of the E2E connectivity over one slice for a period of seven days. The interactive slice was chosen to be tested in order to check also the connectivity via Wi-Fi AP. The expected result is to have network availability over 99.9% and latency lower than 30 ms.

Table 5-6 MDCe04: Stability test - injecting traffic over one slice for 7 consecutive days

MDCe04	**Stability test - injecting traffic over one slice for 7 consecutive days**	
Testbed	**5G-EVE Alba Iulia [5]**	
Description	Check the stability of the e2e connection by injecting constant traffic over a 7-day period.	
Key Use-case requirements and KPIs	N/A	
Network performance requirements and KPIs	Network availability > 99.9%, E2E latency for interactive service (in ms) < 30ms;	
Network Functional requirements and KPIs	N/A	
Components and Configuration	Components	1. One laptop/tablet, 2. Wi-Fi AP, 3. One slice configured (e.g. eMBB)
	Configuration	1. One laptop/tablet is connected to the Wi-Fi network using the eMBB slice as backhaul. 2. Iperf is activated for measuring network performance (bandwidth, latency and jitter) and Network availability.
Test procedure	Pre-conditions	1. A test server with IP addresses on eMBB slice
	Test Case Steps	2. Configure the eMBB slice 3. Connect the laptop/tablet to the Wi-Fi AP 4. Check that successful network connectivity is in place for the eMBB slice (ping/traceroute towards the specific IP addresses of the test server) 5. Run iperf tests (as per methodology), write down results
Measurements	Methodology	1. The iperf is performed utilizing a test server with connectivity in the eMBB slice. 2. On the eMBB slice, the traffic flow is configured with a bandwidth of 20 Mbps. 3. The test is run for 7 days.
	Complementary measurements	N/A
	Calculation process	Extract from iperf the average, min and max values for throughput and latency, for both slices
Expected Result	The KPIs are achieved	

5.4 Artificial Intelligence Recognition and Identification of Emergency Situation Test Cases

5.4.1 MDAe01: Passenger fall detection in an emergency break

One of the events that can occur when travelling on a bus is an emergency brake. In this scope, an accelerometer is used to highlight such an event. To see if there is a consequence of the sudden brake among passengers, possible injured passengers laying on the floor or in any other unusual position, the footage from two video cameras installed inside the bus is analyzed. The third video camera, at the front of the bus, is used to identify the scenario that led to the emergency brake. Table 5-7 describes this test case.

Table 5-7 MDAe01: Passenger fall detection in an emergency break

<table>
<tr><th>MDAe01</th><th colspan="2">Passenger fall detection in an emergency brake</th></tr>
<tr><td>Testbed</td><td colspan="2">5G-EVE Alba Iulia [5]</td></tr>
<tr><td>Description</td><td colspan="2">We automatically identify if one or more passengers fall while the bus is decelerating or accelerating beyond a threshold. Then, an alert is triggered accordingly.</td></tr>
<tr><td>Key Use-case requirements and KPIs</td><td colspan="2">Primary: minimum 75% passenger pose detection accuracy from the video stream. Based on that alerts will be triggered.
Secondary: categorizing the remaining 25% of the poses to avoid and/or radically reduce false alerts.</td></tr>
<tr><td>Network performance requirements and KPIs</td><td colspan="2">Min 10 Mbits/s connection for the camera video streaming with maximum 20 ms latency.</td></tr>
<tr><td>Network Functional requirements and KPIs</td><td colspan="2">The application needs reliable connectivity and handover between Edge nodes.</td></tr>
<tr><td rowspan="2">Components and Configuration</td><td>Components</td><td>1. Working RGB camera.
2. GPU compute capability in the Edge node.
3. People pose detection code for the parallel Artificial Intelligence (AI) network execution.
4. Accelerometer.
5. Volunteer test passengers.</td></tr>
<tr><td>Configuration</td><td>1. RTX-2080 GPU.
2. Pose detector written in C++ and OpenCL/Cuda.</td></tr>
<tr><td rowspan="2">Test procedure</td><td>Pre-conditions</td><td>1. Test signals both from the camera and the accelerometer shall be sent to the Edge node to verify connectivity.
2. The Edge node shall send a test alert to the Backend.</td></tr>
<tr><td>Test Case Steps</td><td>1. Camera stream and accelerometer data are received by AI app's Edge code.
2. Pose detection starts.
3. In case of a simulated emergency breaking incident passengers falling, laying on the floor or in any other unusual pose are detected and further evaluated.
4. An alert that contains the detection results is sent to ORO's backend server.</td></tr>
<tr><td rowspan="3">Measurements</td><td>Methodology</td><td>Monitoring frequency is minimum 5 times per second.</td></tr>
<tr><td>Complementary measurements</td><td>The number of falls to be manually counted. That shall be the ground truth data.</td></tr>
<tr><td>Calculation process</td><td>The detection accuracy will be calculated through the comparison of the automatic detections and the ground truth data.</td></tr>
</table>

Expected Result	Performance and detection accuracy are expected to fall within the thresholds described above. The aim is to prove that low error fully automated fall detection in an emergency breaking event can be realized in real-time.

5.4.2 MDAe02: Detection of violence in the bus

Each passenger is detected and marked once he/she boards on the bus and until he/she gets off the bus. The mobility of the skeleton is analyzed, unusually fast movement of the legs or the arms shall be detected using the pre-defined thresholds. As described in Table 5-8 the aim of this test case is to detect violence in the bus.

Table 5-8 MDAe02: Detection of violence in the bus

MDAe02	**Detection of violence in the bus**	
Testbed	**5G-EVE Alba Iulia [5]**	
Description	We are automatically detecting if one or more passengers make sudden body movements (acceleration above threshold value) while the bus is driving normally or is still. Then an alert is triggered accordingly.	
Key Use-case requirements and KPIs	Primary: minimum 75% passenger body motion tracking accuracy from the video stream and follow on pattern recognition that looks for violent body movements. Based on the outcome alerts will be triggered. Secondary: categorizing the remaining 25% of the movements to avoid and/or radically reduce false alerts.	
Network performance requirements and KPIs	Min 10 Mbits/s connection for the camera video streaming with maximum 20 ms latency.	
Network Functional requirements and KPIs	The application needs reliable connectivity and handover between Edge nodes.	
Components and Configuration	Components	1. Working RGB camera. 2. GPU compute capability in the Edge node. 3. People pose detection and movement tracking code for the parallel AI network execution. 4. Volunteer test passengers.
	Configuration	1. RTX-2080 GPU. 2. Pose detector and movement tracker written in C++ and OpenCL/Cuda.
Test procedure	Pre-conditions	1. Test signals both from the camera and the accelerometer shall be sent to the Edge node to verify connectivity. Also, the Edge node shall send a test alert to the Backend.
	Test Case Steps	2. Camera stream received by AI app Edge code. 3. Pose detection and motion tracking starts. 4. Unusually fast movement of the legs or the arms shall be detected. Initially through a dedicated and hard coded algorithm that looks for values within pre-set thresholds. *Potential follow-on/spin out research projects (beyond the scope of 5G-Victori):* • detection of unusual body movements and gesture via deep learning to classify various forms of human activity (ex. fight, smoking, drinking & eating, dance, exercise); • knife, firearm and other sorts of weapons detection. • In case an unusual movement is detected an alert is sent to ORO's backend server.

Measurements	Methodology	Monitoring frequency is 10-15 times per second.
	Complementary measurements	The number of anti-social incidents to be manually counted. That shall be the ground truth data.
	Calculation process	The detection accuracy will be calculated by comparing the automatic detections against the ground truth data.
Expected Result	Performance and detection accuracy is expected to fall within the thresholds described above. The aim is to prove that low error fully automated fall detection in an emergency break event can be realized real-time.	

5.4.3 MDAe03: Health issue with one passenger

This test case (see Table 5-9) is trying to identify possible health issues of passengers. If the traveler's head drops under a specific height and the velocity is above the threshold, then is considered as a fall. For this specific person the following are recorded: the 'type' of the incident and the 'timestamp'. A loop through the list of incidents is performed and only unique occurrences are recorded (while a person is on the floor no new record is added).

If the passenger manages to recover (stands up) then depending on the elapsed time since the detection, the incident gets reclassified to 'recovered' or 'recovered but late'. If the person cannot recover at all then the incident gets reclassified to 'serious'.

Table 5-9 MDAe03: Health issue with one passenger

MDAe03	**Health issue with one passenger**	
Testbed	**5G-EVE Alba Iulia [5]**	
Description	We detect if a passenger falls and does not recover within reasonable time. Then an alert is triggered accordingly.	
Key Use-case requirements and KPIs	Primary: minimum 75% passenger pose detection accuracy from the video stream. Based on that alerts will be triggered. Secondary: categorizing the remaining 25% of the poses to avoid and/or radically reduce false alerts.	
Network performance requirements and KPIs	Min 10 Mbits/s connection for the camera video streaming with maximum 20 ms latency.	
Network Functional requirements and KPIs	The application needs reliable connectivity and handover between Edge nodes.	
Components and Configuration	Components	1. Working RGB camera. 2. GPU compute capability in the Edge node. 3. People pose detection code for the parallel AI network execution. 4. Accelerometer. 5. Volunteer test passengers.
	Configuration	1. RTX-2080 GPU. 2. Pose detector written in C++ and OpenCL/Cuda.
Test procedure	Pre-conditions	1. Test signals both from the camera and the accelerometer shall be sent to the Edge node to verify connectivity. 2. The Edge node shall send a test alert to the Backend.
	Test Case Steps	3. Camera stream and accelerometer data are received by AI app's Edge code. 4. Pose detection starts. 5. Passengers either falling or in unusual pose not moving for more than a number of seconds shall be detected.

		6. Such pose candidates are compared against the accelerometer's data. If the bus didn't go into a sudden break a moment earlier we assume it's no accident but a potential medical emergency and the pose candidates are forwarded to the alerting mechanism. 7. An alert is sent to ORO's backend server.
Measurements	Methodology	Monitoring frequency is minimum 5 times per second.
	Complementary measurements	The number of falls and unusual poses to be manually counted. That shall be the ground truth data
	Calculation process	Detection accuracy will be calculated through the comparison of the automation outcome and the ground truth data.
Expected Result	Performance and detection accuracy are expected to fall within the thresholds described above. The aim is to prove that low error fully automated detection of body poses that might require medical attention can be realized in real-time	

5.4.4 MDAe04: Lost item – detection and alerting

Although AI is quite effective in detecting human bodies and tracking these throughout frames, it is not a 100% reliable method. In bad light conditions (night time) body shadows and reflections can trigger false skeletons to appear in the scene or cause loss of temporal continuity in movement. To avoid this type of errors, each newly detected skeleton is classified as 'ghost' and retain each until one boards the bus from the entrance area to the rest of the bus. Then a ghost becomes a 'passenger'. It is imperative to have visual clarity at the entrances. Through such strict control the algorithm knows the exact number of people on board. If it loses track of a skeleton, it can re-associate it through nearest neighbor search and distance to movement trajectories. This is required to maintain good tracking to associate objects (bags, trollies, coats) to passengers. The test case, described in Table 5-10, will implement the above to detect lost items and issue an alert.

Table 5-10 MDAe04: Lost item – detection and alerting

MDAe04	**Lost item – detection and alerting**	
Testbed	**5G-EVE Alba Iulia [5]**	
Description	We track passengers as they enter and leave the bus. We also track carried baggage that we link to the passenger's body pose when entering. If the baggage stays on board while the passenger (to whom it has been linked) leaves we trigger an alert.	
Key Use-case requirements and KPIs	Primary: minimum 75% passenger pose and 75% object detection accuracy from the video stream. Based on that alerts will be triggered. Secondary: categorizing the remaining 25% of the poses and objects to avoid and/or radically reduce false alerts.	
Network performance requirements and KPIs	Min 10 Mbits/s connection for the camera video streaming with maximum 20 ms latency.	
Network Functional requirements and KPIs	The application needs reliable connectivity and handover between Edge nodes.	
Components and Configuration	Components	1. Working RGB camera. 2. GPU compute capability in the Edge node. 3. People pose detection code for the parallel AI network execution. 4. Accelerometer. 5. Volunteer test passengers with items.

	Configuration	1. RTX-2080 GPU. 2. Pose detector written in C++ and OpenCL/Cuda.
Test procedure	Pre-conditions	1. Test signals both from the camera and the accelerometer shall be sent to the Edge node to verify connectivity. 2. The Edge node shall send a test alert to the Backend
	Test Case Steps	1. Camera stream and accelerometer data are received by AI apps's Edge code. 2. Pose and object detection starts. 3. Poses are registered as new passenger at the entrance door. If carried objects are detected that are connected to the human body skeleton, then those get registered and linked to the pose's ID. 4. When a tracked pose leaves the bus through the doors but one or more of the linked objects remain on board and alert is triggered and sent to ORO's back-end server.
Measurements	Methodology	Monitoring frequency is minimum 5 times per second.
	Complementary measurements	The number of lost items to be manually counted. That shall be the ground truth data.
	Calculation process	Detection accuracy will be calculated through the comparison of the automation outcome and the ground truth data.
Expected Result	Performance and detection accuracy is expected to fall within the thresholds described above. The aim is to prove that low error fully automated detection of body poses and associated carry items or luggage can be realized in real-time. An extreme case, such as the passenger throws the object from the bus, or in through a window, is not handled.	

5.5 5G Performance Measurements

	Network Topology
Type of sites in the network area	Number of gNBs:One gNB [20MHz N78] Size of gNBs:(wide, mid, small): Small gNB deployment Option: (split option): CU/DU Split Type of gNB (commercial, prototype): Prototype
Fronthaul/Backhaul Information	Predominant type of backhauling [wireless, fibre, copper…] Fiber; Number of backhauling links per type: One backhauled, collocated
Cloud Infrastructure	Servers (type, capacity, interfaces): HPE Gen10; 1TB RAM; 128vCPU; 10 Gbps interfaces Virtualization software: K8s

Measurement duration	**Time duration of the measurement [T]: 1h** ***Repetition time: 10 times*** ***Granularity of measurements:***
Traffic offered in the site	Traffic Characteristics (rate): eMBB; Prioritized Low Latency traffic Number of connections: < 10 Traffic Pattern and interarrival time: 60s

Performance measurements for gNB under different deployment options			
Metric		**Description**	**Measurements**
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.	DL One-way delay: ~ 10s, not optimized
	Average delay UL on over-the-air interface	This measurement provides the average (arithmetic mean) over-the-air packet delay on the uplink	UL One-way delay: ~ 10s, not optimized
	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.	The gNB/UPF are deployed in the same K8s cluster, on the single server. DL GTP ~ <<0.1 ms
UE throughput	Average DL UE throughput in gNB	This measurement provides the average UE throughput in downlink	30 Mbps, measured at the UE level
	Average UL UE throughput in gNB	This measurement provides the average UE throughput in uplink	10Mbps, measured at the UE level
PDU Session Management	Number of PDU Sessions requested to setup	This measurement provides the number of PDU Sessions by the gNB. This	Minimum 1 PDU Maximum 5 PDU
	Number of PDU Sessions successfully setup	This measurement provides the number of PDU Sessions successfully setup by the gNB from AMF	Manual session measurements 100% setup
	Number of PDU Sessions failed to setup		0%
Mobility Management	Inter-gNB handovers	Number of requested handover resource allocations	N/A, only one gNB
		Number of successful legacy handover resource allocations	N/A, only virtualized resources
QoS flow related measurements	QoS flow setup	Number of QoS flow attempted to setup	Single slice setup, single flow(1 x MSISDN)
		Number of QoS flow successfully established	100%
		Number of QoS flow failed to setup	0%

Performance measurements for SMF			
Metric		**Description**	**Measurements**
Session Management	Number of PDU sessions (Mean)	This measurement provides the mean number of PDU sessions	1 PDU session tested
	Number of PDU sessions (Maximum)	This measurement provides the max number of PDU sessions	1 PDU session
	Number of PDU session creation requests		1 PDU session

Performance measurements for UPF			
Metric		**Description**	**Measurements**
N3 interface related measurements	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	K8s PODs, <0.1ms
One way packet delay between NG-RAN and PSA UP	packet delay between NG-RAN and PSA UPF	This measurement provides the average UL GTP packet delay between PSA UPF and NG-RAN	K8s PODs, <0.1ms
	Average round-trip packet delay between PSA UPF and NG-RAN		K8s PODs, <0.1ms

Common performance measurements for NFs			
Metric		**Description**	**Methodology**
Virtual resource usage	Virtual CPU usage	This measurement provides the mean usage of the underlying virtualized CPUs for a virtualized 3GPP NF	32 vCPUs
	Virtual memory usage	This measurement provides the mean usage of the underlying virtualized memories for a virtualized 3GPP NF	128GB
	Virtual disk usage	This measurement provides the mean usage of the underlying virtualized disks for a virtualized 3GPP NF.	100GB

a) E2E Performance Metrics per 5G slice.

E2E (per slice metrics)		
Metric	**Description**	**Measurements**
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.	LLC Slice: <10ms
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.	30Mbps DL 10Mbps UL
QoS flow Retainability	This KPI shows how often an end-user abnormally loses a QoS flow during the time the QoS flow is used.	1 abnormal case/1.5h
Packet transmission reliability KPI in DL on Uu	This KPI describes the Reliability based on Packet Success Rate (PSR) Percentage between gNB and UE.	99,999%

5.6 Lab Results

5.6.1 5G LAB setup in Orange facility

In the FR/RO cluster we have deployed the 5G SA architecture as described in Figure 5-2, basically running the entire 5G system components into the integrated LAB for the 5G SA Option 2 functionality.

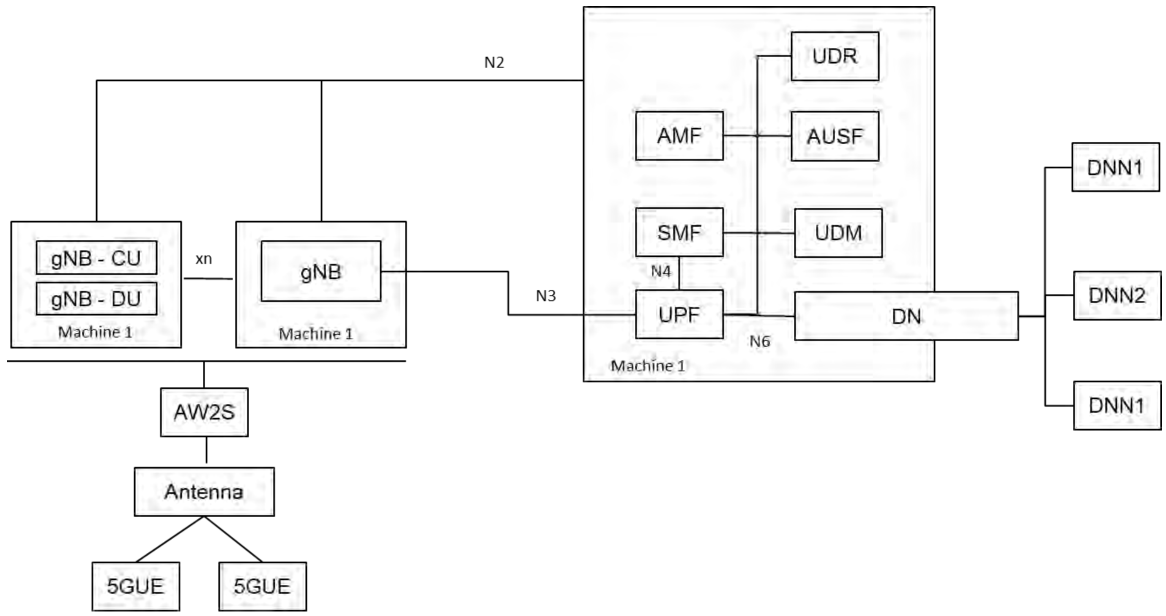


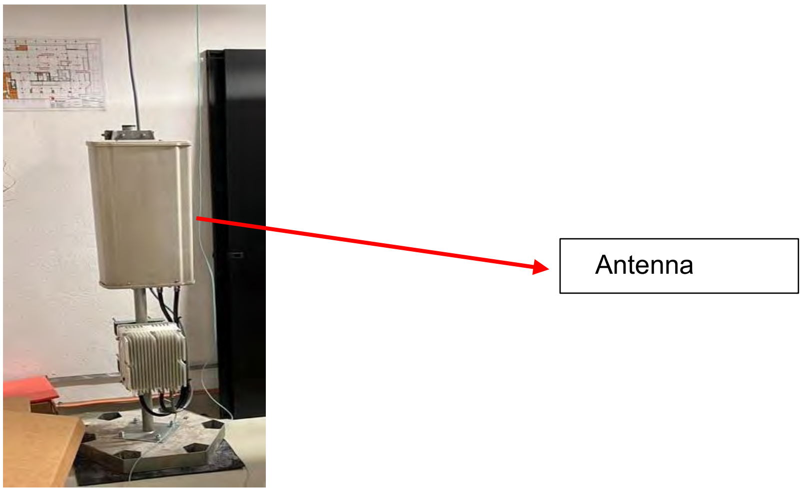
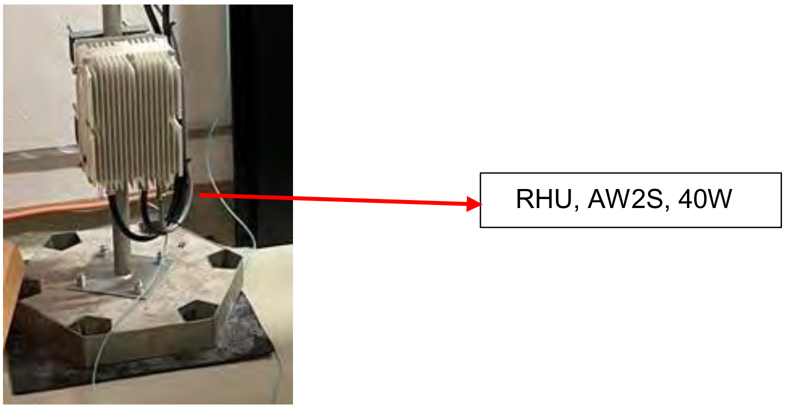
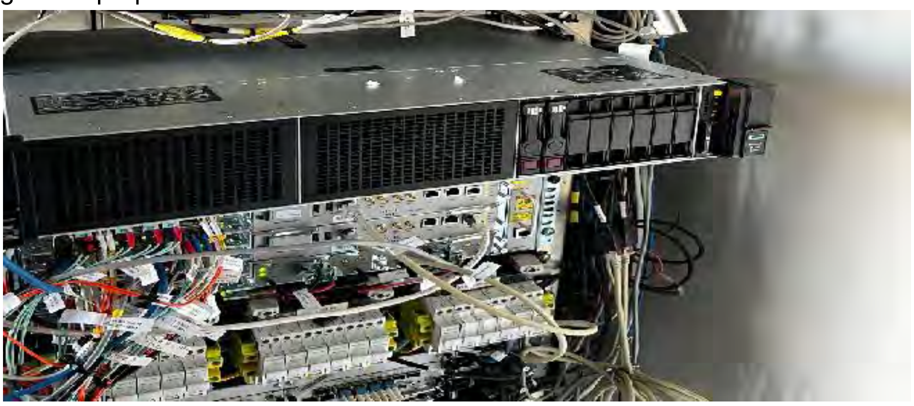
Figure 5-2 FR/RO cluster 5G SA architecture

As described, the 5G SA architecture implemented in the lab is built on:

- Physical:
  - server(x86), a capable computing element (RAM, storage, CPU and network), where all the system software components are running (5G gNB, Core)
  - Remote Radio Head, AW2S MIMO 2x2 RRH supporting NR
  - 5G Antenna, band N78 MIMO 2x2
  - Cisco NX-OS switch with high bandwidth interfaces

- Radio resources: 5G TDD spectrum N78(100MHz)
- Software components: gNB CU/DU, AMF, SMF, UDR, UDM and UPF, deployed in containers on the server
- 5G SA UE/rm500q module
- Camera for video traffic x& LV devices

Table 5-11 5G SA network elements in LAB

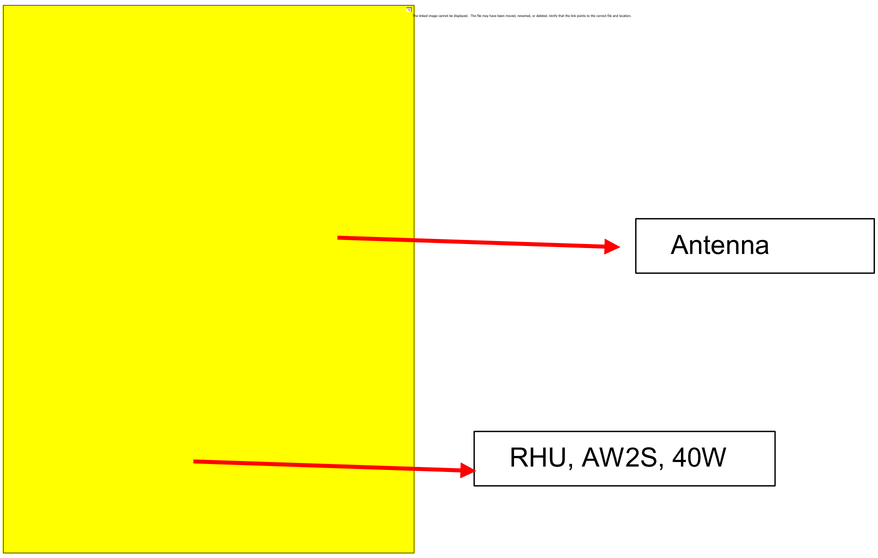
No	5G LAB element
1	Antenna, connected through coaxial cable to the RHU 
2	RHU, AW2S, N78 capable, connected to the server with Optical Fiber, OM3, 10Gbps interface 
3	Compute server, running the 5G SA software components, connected to the RHU with Optical Fiber, OM3, 10Gbps and also connected to ORO switches NX-OS for management purpose 

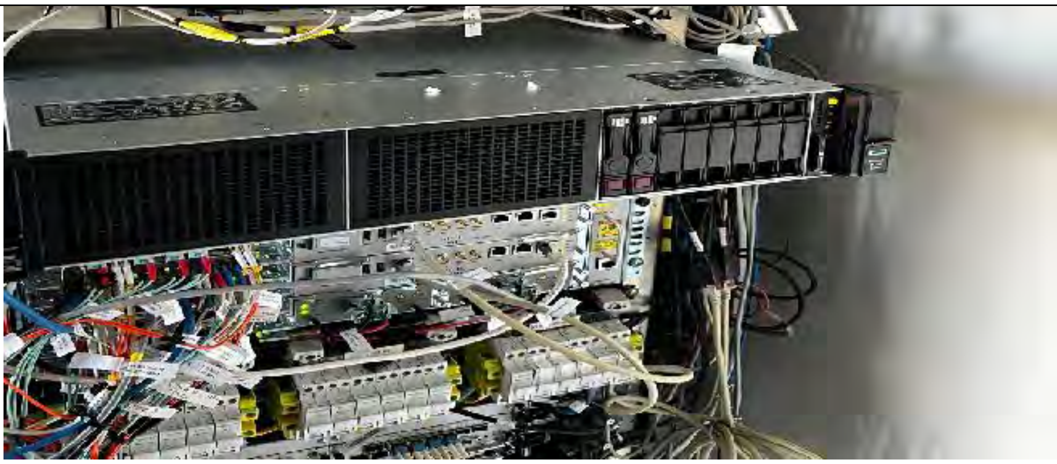
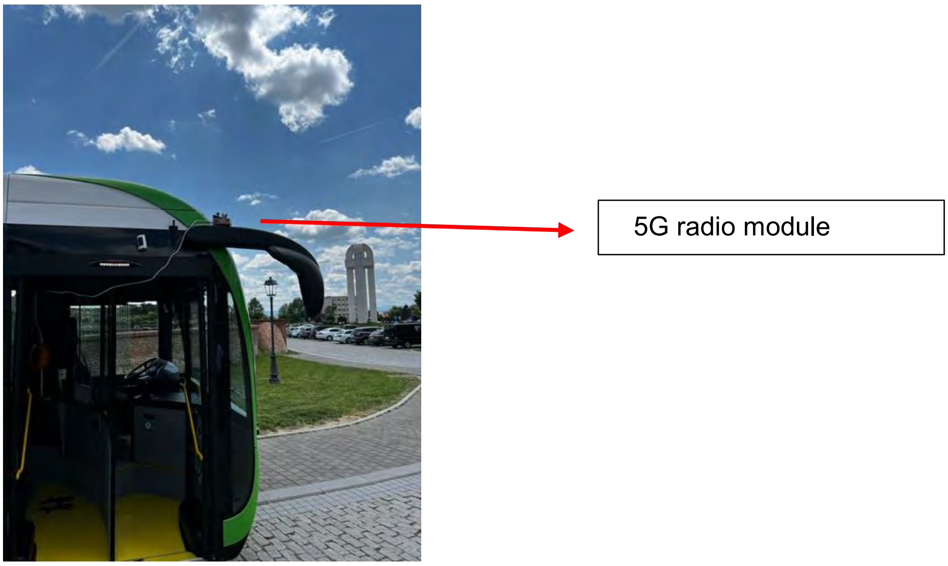
4	Device, 5G SA, RM500Q, 5G module  Smartphone Huawei Mate 5G SA

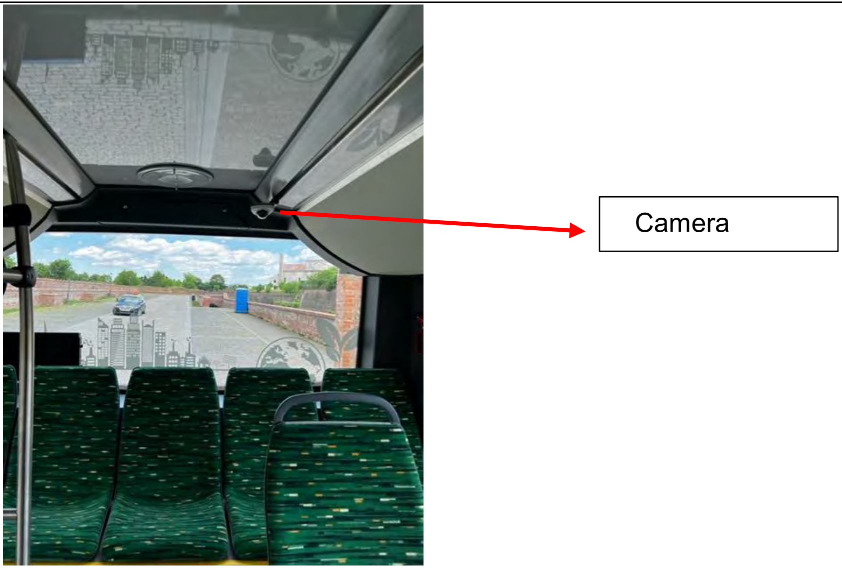
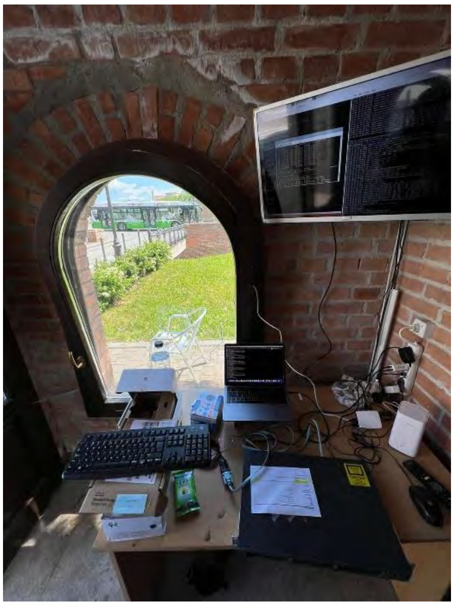
For the LAB purpose, several testing software applications have been used, such as: iperf3, Ookla, video channels for real time transmission and parallel sessions, ICMP tools and Wireshark captures.

The deployed 5G SA infrastructure in LAB was integrated in Alba Iulia for real trials in the project reviews' demos, as are depicted further in the Table 5-12, with remark that all the LAB configuration is replicated in live for the trial sessions.

Table 5-12 5G SA network deployment in field

No	5G LAB element
1	Antenna, installed in ORO site, connected through coaxial cable to the RHU RHU, AW2S, N78 capable, connected to the server with Optical Fiber, OM3, 10Gbps interface in the demo area 
2	Compute server, running the 5G SA software components, connected to the RHU with Optical Fiber, OM3, 10Gbps and also connected to ORO switches NX-OS for management purpose

	
3	Bus Running experiments, demo area  5G module installed in the bus 
4	Video camera in the BUS for analytics, demo area

	
5	Command and Control Center 

5.6.2 Laboratory measurement results

The laboratory measurement results are captured in Table 5-13.

Table 5-13 Laboratory measurements results

Test Case	Result
MDIe01 *User authentication using captive portal*	*Single user network slice, 5G SA, Radio BW 20MHz in N78* Results: • DL: 28Mbps • UL: 10Mbps • RTT external server (8.8.8.8) 40ms • RTT internal server (edge computing) 20ms [5] 69.00-70.00 sec 643 KBytes 5.27 Mbits/sec [7] 69.00-70.00 sec 871 KBytes 7.14 Mbits/sec [9] 69.00-70.00 sec 568 KBytes 4.65 Mbits/sec [11] 69.00-70.00 sec 1.19 MBytes 10.0 Mbits/sec The following summative result is most relevant:

	[SUM] 69.00-70.00 sec 3.23 MBytes 27.1 Mbits/sec
MDIe02 Captive portal data availability	*eMBB slice is enabled in the network* Results: • www.gsp.ro • Browsing time (latency) – time to display the requested information < 3 s; • Service availability>99% • tcpdump ~ 1.8s
MDCe01 Establishment of basic E2E connectivity over a specific slice	Results: • Ping towards DNS 8.8.8.8 ~40 ms • Ping towards internal DNS (ORO) ~ 28 ms • Ping towards EDGE C&C (through ORO) ~ 29 ms

MDCe02 *Establishment of advanced E2E connectivity over two different slices with different QoS metrics configured*	Results:
	• Network slice capabilities/management (Yes/No);
	  o The two network slices are manually configured (eMBB/Low Latency)
	• E2E latency for interactive service (in ms) < 30 ms;
	  o ~28 ms
	• E2E latency for public safety service (in ms) < 5 ms;
	  o ~12 ms (expected to improve, due to some radio interferences)
	• High bandwidth required for data intensive public safety applications and HD video streaming > 20 Mbps;
	  o Test performed in the N78 20 MHz context
	  o 29 Mbps DL throughput
	• Jitter for URLLC < 1ms
	  o < 0.070-5 ms

MDCe03 *Load test for observing the QoS prioritization among slices with congestion on radio part*	Results:
	• Slices configured
	• E2E latency for interactive service (in ms) < 30 ms
	  o ~28 ms
	• E2E latency for public safety service (in ms) < 5 ms
	  o ~ 12ms
	• High bandwidth required for data intensive public safety applications and HD video streaming > 10 Mbps
	  o 9Mbps
	• Jitter for URLLC < 1 ms
	  o ~0.05 – 0.5 ms
	Comment: proper optimization resource allocation will be performed in LAB condition

MDCe04 *Stability test - injecting traffic over one slice for 7 consecutive days*	Results: • Network availability reached is for 2h, highly traffic load • E2E latency for interactive service (in ms) < 27 ms; Comment: 5G SA RAN will be optimized for improved stability and performance (high radio interferences in the LAB)
MDAe01-MDAe04 (for all AI recognition and identification of emergency situation test-cases)	Results (measurements performed from the device level): • 20 Mbps DL/5 Mbps UL, • RTT ~25 ms

	Comment: AI app KPIs measurements in laboratory were not available, the implementation of the AI app, integration in 5G network and tests will be performed directly into the field for live demonstration

5.7 Test combinations at 5G-VICTORI facility in Alba Iulia

The architecture depicted in Figure 5-3 provides an overview of the combined test-cases description for Media and LV Energy metering UCs. The envisioned parallel tests are described and are grouped as Media UC tests, LV Energy Metering UC tests and Combined UC tests, as referred in Figure 5-3.

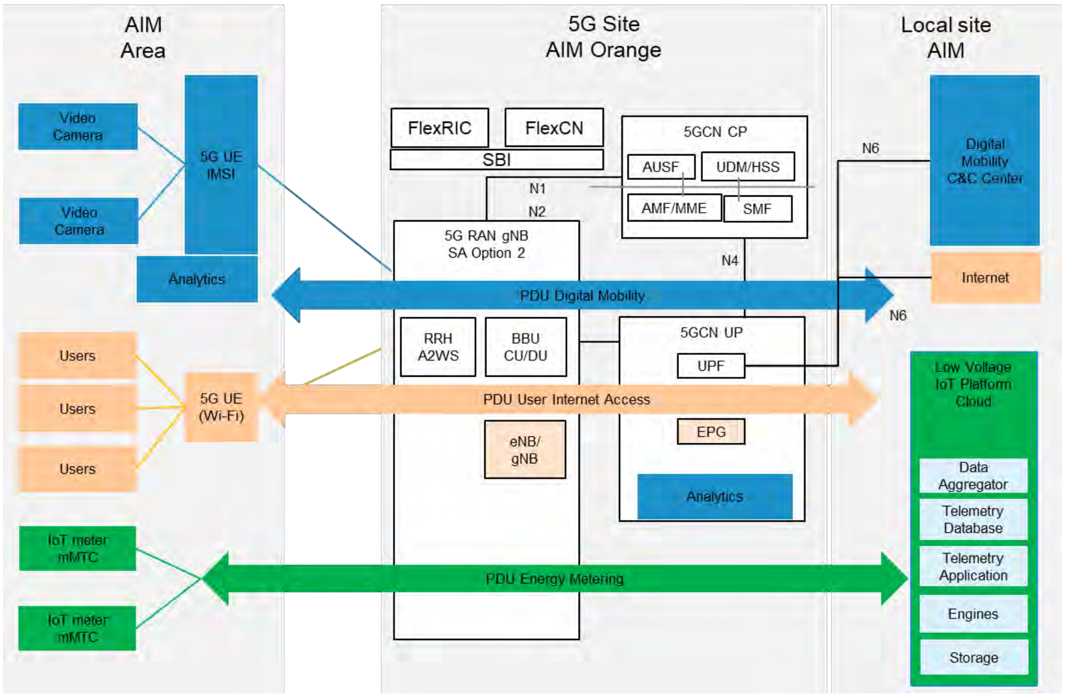


Figure 5-3 FR/RO cluster UC services combined tests description

5.7.1 UC MEDIA

The Media UC tests are split in: Case 1 – Simple tests, and Case 2- Combined tests, as described in Table 5-14.

Table 5-14 Media UC combined tests

Case Number	Network Slice	Description
Case 1 - Simple tests (as described in MDCe01 and MDCe02)	*eMBB slice*	• running paralel tests, 3 simultaneous UEs, measuring normal user's data traffic (as users' authentication, internet browsing, video streaming); • throughput tests ookla & iperfv3 performance; network traffic latency;
	LLC slice (non-prioritized)	• single video streaming, non-prioritized Radio environment, single UE/Video cameras streams; • UL data traffic, packet latency and packet loss will be measured

Case 2 - Combined tests (the simple tests comprised in Case 1 will run in parallel)	*LLC slice (prioritized)*	• single video streaming, prioritized Radio environment, single UE/Video cameras streams; • UL data traffic, packet latency and packet loss will be measured
	eMBB and LLC (non-prioritized)	• normal user's data for user's authentication, internet browsing, video streaming • single video streaming, non-prioritized Radio environment, single UE/Video cameras streams; • throughput tests ookla & iperfv3 performance; network traffic latency, UL data traffic, packet latency and packet loss
	eMBB and LLC (prioritized)	• normal user's data for user's authentication, internet browsing, video streaming • single video streaming, prioritized Radio environment, single UE/Video cameras streams; • throughput tests ookla & iperfv3 performance; network traffic latency, UL data traffic, packet latency and packet loss

5.7.2 UC Media and UC LV Energy Metering

For this combined scenario, the most demanding parallel tests have been selected, as defined in Table 5-15. All the results of these combined tests will be evaluated against the required KPIs.

Table 5-15 Definition of FR/RO cluster combined test-cases

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

6 Conclusions

An important part of the 5G-VICTORI activities relates with the execution of large-scale field trials for advanced UC verification in commercial environments deploying 5G infrastructures in support of a number of vertical industries. The planned validation activities will be conducted under real life conditions for the various vertical sectors involved. The vertical industries involved in the 5G-VICTORI demonstration activities include **Transportation, Energy, Media** and **Factories of the Future**.

In this context this document defines media related services that will be validated, tested and evaluated independently or together with other services on the various 5G VICTORI facilities in the planned field trials. These field trials will exploit the 5G-VICTORI infrastructure deployments available at the different facility locations (Berlin, Patras, Alba Iulia and Bristol) as specified by the overall project architectural activities of **WP2** and implemented as part of the **WP4** activities.

More specifically, the Media Services related UCs that this deliverable concentrates on include:

- The Data Shower application that will be tested in the Berlin 5G facility, allowing large quantities of data to be transferred from the station's CDN cache to a train's server for use by passengers.
- The data shower application similar to that of Berlin that will be tested at the Patras 5G-facility. This will provide a train with video-on-demand (VoD) and live content when it arrives at a train station. In addition, a 360° surveillance application will enable a train operator's security personnel to remotely monitor activity at multiple operator facilities. The aforementioned services are all derived from the CDN.
- Services based on the Digital Mobility UC that revolve around infotainment and public safety and will be tested at the 5G-EVE cluster in Alba Iulia Municipality (**AIM**). The infotainment is provided through a portal in public buses, via on-board Wi-Fi and 5G backhauling. Three on-board cameras are used for public safety and Artificial Intelligence (AI) recognition of safety issues and prioritised communication with the Control and Command Centre (CCC) ensures that safety alters can be triggered.

For each service to be demonstrated several test cases were defined and evaluated under laboratory condition and in some cases initial field settings were also assessed. The test cases described in the document aim to assess the performance capabilities and the efficiency of the 5G-VICTORI infrastructure deployment options available at different locations with emphasis on dense and static environments where bandwidth-hungry media content is delivered. This deliverable provides a description of the test cases and presents the proposed testing methodology. This includes identification of a set of relevant KPIs that will be monitored and assessed per test case and a description of the proposed KPI measurement/calculation approach that will be taken to facilitate service level assessment, considering the specificities of the underlying 5G infrastructure.

In this context, this document reports a total of 24 detailed test cases. Each test case has started being robustly tested and results from laboratory experiments and in some cases early field tests are documented. More specifically, some initial field trial results have been produced for the Berlin UCs.

The reported testing methodology will be provided as input to WP4 for the evaluation of the UCs that will be demonstrated as part of the planned field trials focusing on the identified KPIs in support of the relevant evaluation activities.

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List of Figures

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