5G EVE

5G European Validation platform for Extensive trials

Deliverable 2.5:
Final pilot test and validation

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List of acronyms and abbreviations

Acronym	Meaning
3GPP	Third Generation Partnership Project
5G	Fifth Generation
AGV	Automated Guided Vehicle
AI	Artificial Intelligence
AIA	Athens International Airport
AMF	Access and Mobility management Function
API	Application Programming Interface
AR	Augmented Reality
ASOC	Airport Security Operation Centre
AUSF	Authentication Server Function
AWS	Amazon Web Services
BBU	Base Band Unit
CA	Carrier Aggregation
CBR	Constant Bit Rate
CDN	Content Delivery Network
CEE	Cloud Execution (Ericsson) Environment
CIC	Cloud Infrastructure Controller
CM	Corrective Maintennce
CMG	Cloud Mobile Gateway
CMM	Cloud Mobility Management Coordinate Measuring Machine
CMOS	Complementary Metal-Oxide Semiconductor
CNOM	Core Network Operations Manager
CP	Control Plane
CPE	Customer-premises equipment
CPRI	Common Public Radio Interface
C-RAN	Cloud Radio Access Network
CTX	Context Blueprint
CU	Cloud Unit
CUDB	Centralized User Database
DSM	Demand Side Management
DU	Digital Unit
E2E	End-to-End
EC	Enterprise Core
EDA	Ericsson Dynamic Activation
eMBB	Enhanced Mobile Broad Band
eMTC	enhanced Machine Type Communication
ENM	Ericsson Network Manager
EPC	Evolved Packet Core
E-UTRAN	Evolved Terrestrial Radio Access Network
EV	Electric Vehicule
FDD	Frequency Division Duplex
FDIR	Fault Detection, Isolation, and service Restoration
FM	Fault Management
GUI	Graphic User Interface
HD	High Definition
HDR	High Definition Resolution
HMD	Head Mounted display
HSS	Home Subscriber Server
HTTP	Hypertext Transfer Protocol
HW	HardWare
IaaS	Interface as a Service
ICC	Instant Camera Change
IOPS	Input/output operations per second
IoT	Internet of Thing
IRU	Indoor Radio Unit
IUA	Instant Uplink Acces
IWL	Inter-Working Layer
KPI	Key Performance Indicator
KPI-VS	KPI Virtualization Service
LAN	Local Access Network
LIDAR	LIght Detection And Ranging

LTE	Long-Term Evolution
LV	Low Voltage
MaaS	Mobility as a Service
MAC	Medium Access Control
MANO	Management and Orchestration
MCR	Mobile Cloud Robotics
MDB	Media Data Base
MEC	Mobile Edge Computing
MICE	Meetings, Incentives, Conferencing, and Exhibitions
MIMO	Multiple Input Multiple Output
MME	Mobility Management Entity
mMTC	massive Mobile Type Communication
MOB	MOBility tracker VNF
MTTR	Mean Time To Repair
NB-IoT	Narrow Band – Internet of Things
NF	Network Function
NFV	Network Function Virtualization
NFVM	NFV Manager
NFVO	NFV Orchestrator
NFVI PoP	NFV Infrastructure Point of Presence
NR	New Radio
NSA	Non Stand-Alone
NSD	Network Service Descriptor
OAI	Open Air Interface
ODL	OpenDayLight
OSM	Orchestrator Service Manager
OVS	Open Virtual Switch
PaaS	Platform as a Service
PGW	Packet Gateway
PLC	Process Logic Controller
PLMN	Public Land Mobile Network
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
QoE	Quality of Experience
RAN	Radio Access Network
RAT	Radio Access Technology
RAU	Radio Access Unit
RD	Radio Dot
RDS	Radio Dot System
RRH	Remote Radio Head
RRU	Remote Radio Unit
RTMP	Real-Time Messaging Protocol
RTT	Round Trip Time
SA	Stand-Alone
SBA	Service Based Architecture
SD	Standard Definition
SDN	Software Defined Network
SDR	Software Defined Radio
SLA	Service Level Agreement
SM	System Manager
SMF	Session management Function
SSH	Secure SHell
SW	SoftWare
TaaS	Testing as a Service
TCB	Test Case Blueprint
TDD	Time Division Duplexing
THR	Throughput
TRL	Technology Readiness Level
TSO	Transmission System Operator
UAV	Unmanned Aerial Vehicle
UC	Use Case
UDM	Unified Data Management
UDP	User Datagram Protocol
UE	User Equipment
UPF	User Plane Function
uRLLC	Ultra-Reliable Low-Latency Communications
USRP	Universal Software Radio Peripheral
vCPU	virtual Central Processing Units
vEPC	virtual Evolved Packet Core
vEPG	virtual Evolved Packet Gateway
VIM	Virtualized Infrastructure Manager
VIS	VISualization tool VNF

VM	Virtual Machine
VNF	Virtual Network Function
VNF-FGD	VNF Forwarding Graph Descriptor
VNIC	Virtual Network Interface Controller
VPN	Virtual Private Network
VR	Virtual Reality
VSB	Vertical Service Blueprint
VXLAN	Virtual eXtensible LAN
WAN	Wireless Access Network
WHO	World Health Organization
ZDM	Zero Defect Manufacturing

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Executive summary

5G carries out a shift in the way the mobile service is delivered, going beyond current broadband usage. It takes into account the requirements of each vertical industry to provide a tailored service that meets the constraints imposed by the vertical industry. In order to validate that the requirements of the vertical industries are met, it is necessary to identify a set of Vertical Service KPIs that can be used for validation.

This deliverable consolidates the 5G EVE internal Use Cases deployment and execution, and reports the empowerments provided by 5G and specifically by the 5G EVE end-to-end site facility. The 5G EVE internal Use Cases cover the following vertical industries:

- Smart transport in the context of media content delivery on board high-speed railways and in the context of monitoring and steering mobility flows.
- Smart Tourism by delivering enhanced experience for visitors utilizing augmented reality services, as well as improved participation and engagement for professional visitors at events (e.g., fairs, trade shows…).
- Industry 4.0 in the context of autonomous guided vehicles in manufacturing environments.
- Smart Energy in the context of fault management for distributed electricity production, as well as resolving outages thereby preserving stability of the electricity grid.
- Smart Cities in the context of detecting and steering mobility of people in densely visited areas, ambient air quality monitoring and forecasting, using ambulance vehicles as communication hubs for transmitting patients' vital signals and high-resolution medical media content.
- Media & Entertainment in the context of ultra-high-fidelity media at live events, immersive media, virtual visits, and multi-site gaming.

Each performed use case reported back to the site facility operators, which features and capabilities of 5G the involved stakeholders perceived as empowering elements, as well as which additional 5G EVE services facilitated an easy exploitation of the 5G EVE infrastructure capabilities.

Among the most popular empowering 5G capabilities, the use case stakeholders reported that Multi-Access Edge Computing (MEC), Network Slicing, 5G New Radio (5G-NR) and Virtualised Software Functions (VNFs) provided the necessary added value to perform the envisioned use cases.

Beyond the 5G empowering capabilities, 5G EVE offers an intrinsic set of features that enabled vertical stakeholders to easily exploit the 5G potential. Among these features the use case owners appreciated the 5G EVE experimentation portal and its capabilities for intent-based interfacing to the 5G facility services, the performance diagnosis KPI framework, the monitoring as a service feature, as well as service exposure that, albeit being quite a sophisticated capability requiring deep technical understanding, enabled a high degree of flexibility in the use of the 5G EVE facility.

Beyond its own inherent use cases, 5G EVE offered the infrastructure for experimentation to the ICT-19 projects (5G TOURS, 5G VICTORI, 5G!DRONES, 5G-Solutions, 5Growth, and 5G-HEART). Some use cases exhibited similarities with the 5G EVE own use cases, with the difference that a customer-provider business relationship could be simulated, hence the notion of *pilots* in this case. Additional use cases within the ICT-19 pilots included wildfire monitoring and disaster recovery, load balancing of energy distribution, smart charging in mobility scenarios, electricity grid frequency stability, connected worker remote operation and support, as well as aquaculture.

The execution of the pilots allowed 5G EVE to gain insights about how such experimentation services could be provided in the longer term, beyond the duration of the project. These insights are the basis for the sustainability plans defined by the 5G EVE consortium and which will enable further experimentation by verticals for at least 6 months after the end of the project.

1 Introduction

1.1 Purpose of the document

The present document has been produced by WP2, which is in charge of the implementation, pilot execution and validation of the use cases, and it is publicly available. It is addressed to all the H2020 community willing to have the details on the 5G EVE Pilots description, their implementation inside the 5G EVE E2E site facility, their execution results, and the way they have been validated.

The contents of this document aim at contributing to the dissemination activities carried out by the project within the 5G-PPP and beyond. In this way, the template used to describe the Pilots has been largely inspired on the 5G-IA Trials & Pilots brochure [1], [2]. However, extended details are provided in this document, in contrast to the succinct, two pages format used in such 5G-PPP published brochure.

1.2 Scope of the document

The document focuses on the Pilot experimentation results and the way they are validated. The current document should not be considered as an iteration of the D2.4 - *Initial Pilot test and validation* [3]. Depicted in Figure 1 is a summary of the experiment workflow activities defined to carry out the experimentation within the 5G EVE E2E site facility, which is extensively described in D1.3 - *5G EVE end-to-end facility reference architecture for Vertical industries and core applications* [4]:

Figure 1: 5G EVE Portal - The 4-Step Process to 5G Validation

While D2.4 [3] focused on the Test design activities, the current document focuses on the tests results and analysis of the 5G EVE internal Use Cases. More specifically, this document relates to, but also extends, the information provided by D2.4 [3] as follows:

- This document provides the complete report of the UC execution and the result analysis for each pilot at M36.
- This document is a self-contained document reflecting the UC implementation and validation status. However, the details of the UC execution management and the experimentation design are not included. The goal is to improve the UC readability and focus on the experimentation results and vertical services' KPI implementation and evaluation. D2.4 [3] remains the reference for test design activities of the experimentation workflow.
- As opposed to D2.4 [3], this document does not cover the "End to end site facility status", given that D2.3 [5] is released at the same time and provides a complete and updated description of the end to end site facility, including the definition of the infrastructure KPIs and the measurement methodology.
- The structure of the "Pilot execution and results" chapter has been reviewed, and now it is inspired by the 5G-IA Trials WG Trials & Pilots brochure, with the following add-ons:
    - For each Pilot, a section is dedicated to the Vertical service KPI implementation within the 5G EVE deployments.

  - For each Pilot a short resume of the 5G features and 5G EVE added values that have enhanced the experimentations is included.
  - Two 5G EVE pilot Use Cases, namely Use Case 6.4 - Virtual visit over 5G (Section 2.14) and Use Case 6.5 - High-quality multi-site gaming experience (Sect 2.15), have been instantiated in a multi-site environment. Implementation details are provided in the corresponding sections.
- A dedicated chapter has been added, which provides the entry point to the description and results of the Use Cases coming from ICT-19 projects running on top of 5G EVE end to end site facility.
- A forecast of the ongoing and future work after the end of 5G EVE project is provided at the end of the document.

1.3 Structure of the document

The rest of the document is structured as follows:

- **Chapter 2: 5G EVE Pilots execution and results**

  This chapter provides the report about the 5G EVE internal Pilot execution, containing the execution and result analysis of available information related to the experimentation activities carried out inside 5G EVE end to end (E2E) site facility.

- **Chapter 3: ICT-19 Pilot(s) execution**

  This chapter provides for each ICT-19 Use Case: a brief description of the experiment together with the references to the project's deliverable(s) describing the results, the deployment within the 5G EVE facility and the 5G EVE platform added values for the given Use Case.

- **Chapter 4: Conclusions and Future work**

  This chapter provides the overall conclusions from the acquired experiences, describing the work accomplished during the last months of the project. It provides a forecast for ongoing and future activities that will rely upon the 5G EVE infrastructure deployed on each site facility after the end of the project.

2 5G EVE Pilots execution and results

The 5G EVE internal pilot execution and results report structure is based on the template used by the 5G-PPP Trials Working Group to fulfil the Trials & Pilots brochure [1], [2].

An extended version is provided here covering the following additional topics for each Pilot Use Case*:*

- The vertical KPIs implementation for experiments executed on 5G EVE site facilities.
- The references to the Blueprints implementations, results, and any other useful material.
- An evaluation of how the 5G EVE platform added value has enhanced the experiment execution and result analysis.

The Vertical service KPIs relevant to each Pilot Use Case are described based on a common model defined within the project that has led to the definition of a template that can be found in Annex A.

Notice that two pilot Use Cases, namely Use Case 6.4 - Virtual visit over 5G (Section 2.14) and Use Case 6.5 - High-quality multi-site gaming experience (Section 2.15), have been instantiated in a multi-site environment. The details of this multisite instantiation are provided in the corresponding sections.

2.1 Use Case 1.1 - Smart Transport: Intelligent railway for smart mobility: 5G on-boarding media content streaming

2.1.1 Pilot Context

FSTechnology, working as main provider of ICT services for the railway industry, has analysed during the last years how 5G technology adoption can be considered a critical key technology for the development of high quality 5G based services to enhance passengers' comfort and entertainment as well as for the customization and enhancement of passengers on board experience. One of these services is the innovative streaming of on-board rich media contents for entertainment and infotainment for train passengers' segment of the daily High-Speed services, mostly commuters and tourists.

Currently, the quality of the on-board media contents delivery is perceived as one of the most relevant indicators to evaluate the overall trip experience, therefore FSTechnology aims to test in the 5G EVE framework the next opportunity to offer to the passengers an innovative service of data streaming for media contents in Full HD/4K, including movies, TV Shows and Music, that can be delivered through the new generation of 5G mobile connections.

The scenario conceived by FSTechnology has the goal to validate the conditions of real set up of high reliable content delivery of Trenitalia multimedia in Full HD/4K with the 5G connectivity, taking into account the technical difficulties that on-board communication faces in a high-speed environment (e.g., handovers, doppler effect).

With this aim, two series of experiments have been performed in the 5G EVE Italian Site.

The first one relies on media content communication between the 5G EVE Media Content Service front-end and back-end (see top end-to-end grey thick line in Figure 2 through "TIM Field TO"). The front-end application runs on a 5G mobile device and is represented by the train icon on the left; the back-end application runs on the "Media content delivery" component in "PoliTo" site on the right. Preliminary tests have been performed with a content server on a public cloud. With APN (lab and/or field availability), a dedicated VM is created and tested to access the platform considering the introduction of Virtual Content Delivery Network (CDN) Cache functionalities.

The second one consists of an emulation-based experiment. The 5G Prisma network emulator component located in the "TIM LAB" simulates the conditions of 5G connectivity for the media content delivery. The specific conditions of communication that aim to characterize the High-Speed railway framework (see bottom end-to-end grey thick dotted line in Figure 2**,** where the end-to-end connection is represented by the train icon on the left and the "Media content delivery" component in "PoliTo" on the right).

Emulation of 5G connectivity performance in the stressing condition of High Speed provides Trenitalia with basic evidence to support the innovation of the current model of media content delivery towards the provision of on-board media services with Full HD/4K streaming.

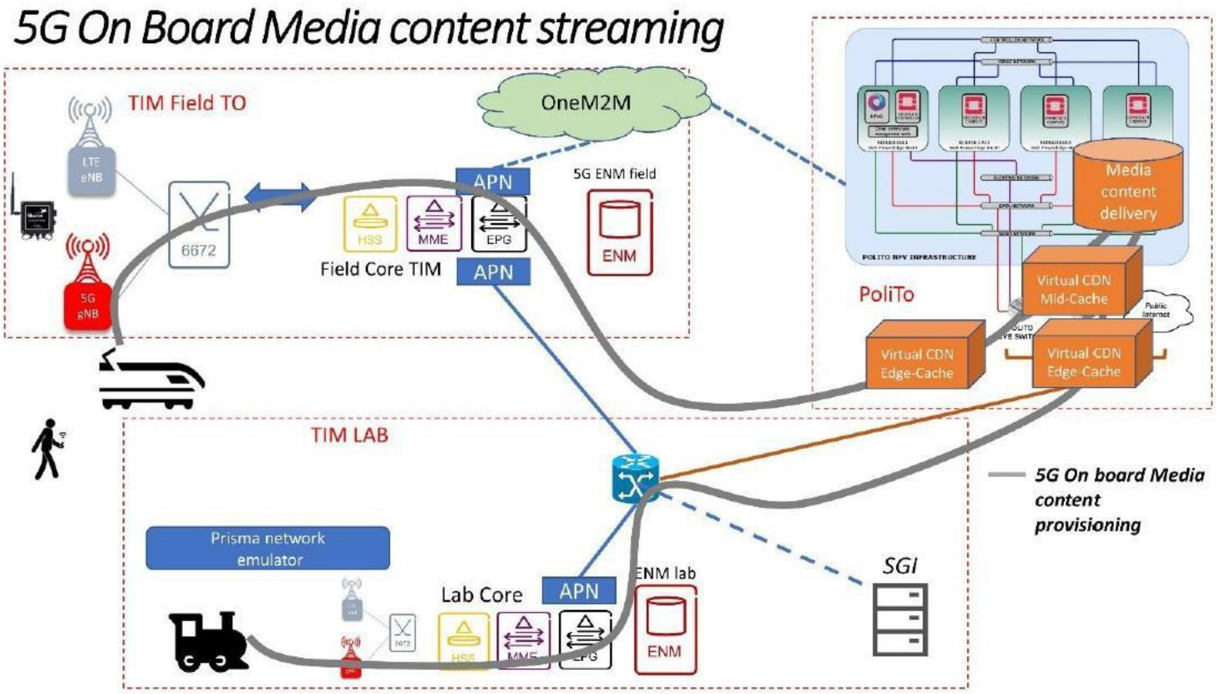


Figure 2: Smart Transport (Italy) UC1.1 - Reference architecture

Experiment test execution results are validated by FST from a service point of view through a QoE (Quality of Experience) questionnaire in order to understand perceived quality of Full HD/4K video performance enabled by 5G in the stressing condition of high-speed railway environment.

Therefore, FST has analysed at which throughput or latency the QoE does not fulfil the network metrics criteria considering the stressing test conditions of the high speed simulated by the 5G Prisma Emulator (e.g., handover effect to be considered for high speed) according to the pre-identified modem simulated features. This is possible by setting the emulator impairment simulating mobility by the timing advance parameter and allows a sensitivity analysis considering throughput and latency. The QoE analysis allows to validate the effects of the variation of throughput and latency on the video quality, considering network stress conditions of specific simulated variations of the train high speed (graphical representation of the behaviour of the network KPIs on different high speed ranges are considered in order to validate the achievement of the QoE threshold). 4G vs 5G differences are tested.

2.1.1.1 Partner's roles

Vertical

FST provides the knowledge of the on-board media service features to be tested considering the communication stress conditions of the railway high speed environment, including the definition of services KPIs and service components. Therefore, FST offers support to the Experiment Developer in the definition of the vertical service blueprints and related experiments.

VNF provider(s)

NXW provides the software components of the media service, as illustrated in Figure 2. Three VNFs are on boarded on the 5G EVE platform:

- the media content delivery (origin server)
- the virtual CDN Mid-Cache
- the virtual CDN Edge-Cache

Experiment developer(s)

NXW and A2T develop the Experiment according to the objectives indicated by the Vertical. They define suitable blueprints for vertical services, experiment contexts and experiments, as well as the necessary NFV Network Service Descriptors (NSD) associated to the experiment blueprints, once defined and validated.

Experimenter(s)

FST underpins the request of an experiment and the evaluation of its results. FST defines, supported by the Experiment Developer and Site Manager, the features of an experiment starting from its blueprints, requesting the deployment of related virtual emulation testing environment, filling the test cases for the experiment execution and analysing results and KPIs.

Site Manager(s)

TIM manages the entire scheduling and execution related to the Experiment.

2.1.1.2 Trials

First trial of the current UC has been performed at the beginning of December 2020 (M30) with the aim to test the E2E connectivity through the APN of the laboratory infrastructure.

In order to proceed with the test, a Virtual Machine (VM) has been created with the content to be streamed. Connected to this VM, there was a radio terminal located in the Lab with 5G connectivity. Moreover, in order to proceed with the test remotely, an application has been used to access the terminal in the Lab.

Finally, the “Plex” platform has been used as reference video-streaming platform for the test execution, as shown in Figure 3. This software has been used in order to simulate the functioning of the Platform owned by Ferrovie dello Stato (“Portale Frecce”) for video streaming on high-speed trains.

The use of this platform for the test does not jeopardize the test itself because the “origin server” can be easily replaced with any other source of video material.

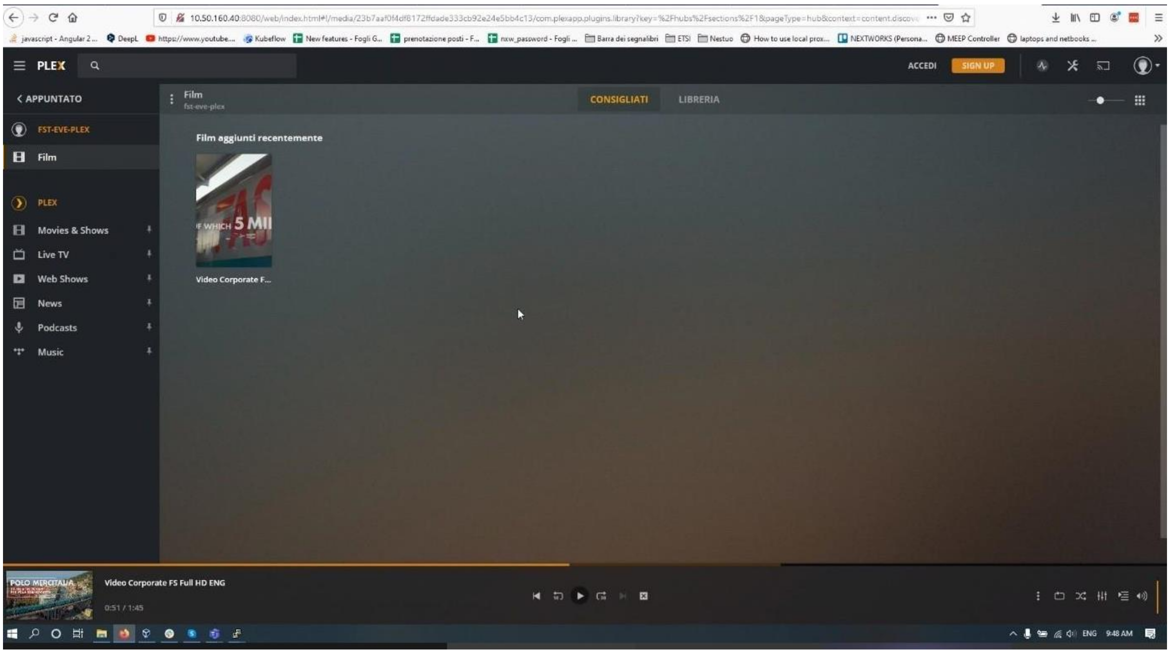


Figure 3: Smart Transport (Italy) UC1.1 - Video streaming platform

In Figure 4, the Vertical Service Blueprint depicts the video-streaming service. From this blueprint it is detectable the possible easy replacement of the “origin server” described above.

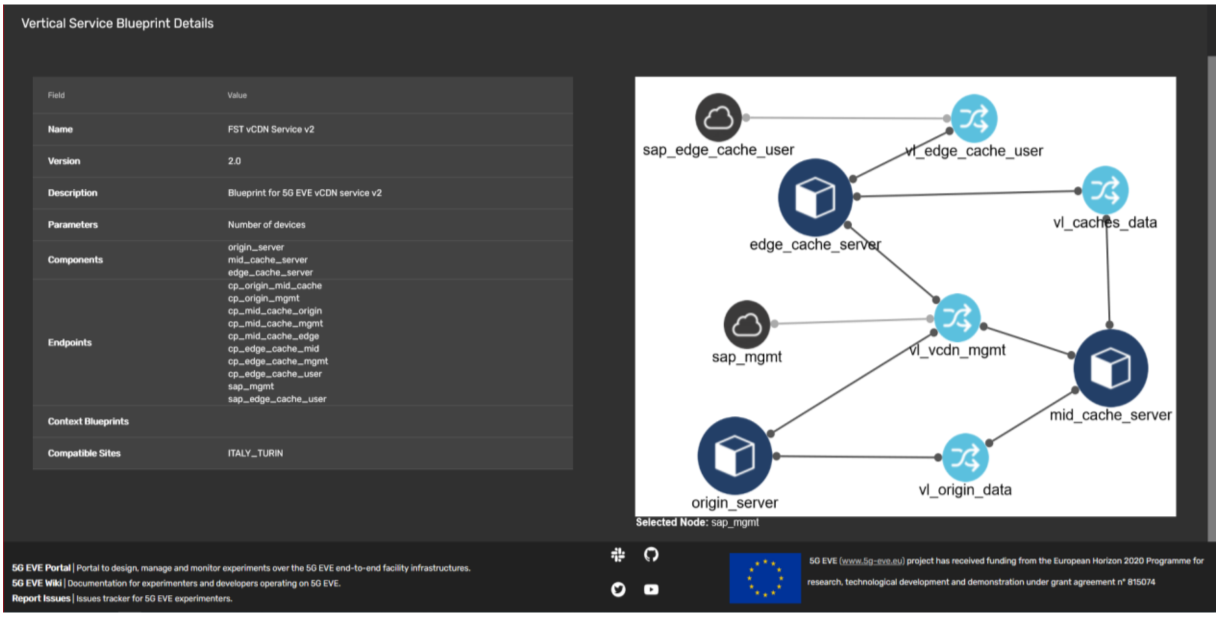


Figure 4: Smart Transport (Italy) UC1.1 - Vertical Service Blueprint

Figure 5 shows that the FST service has been instantiated while Figure 6 shows that the experiment was performed (on a dynamic IP via Application access).

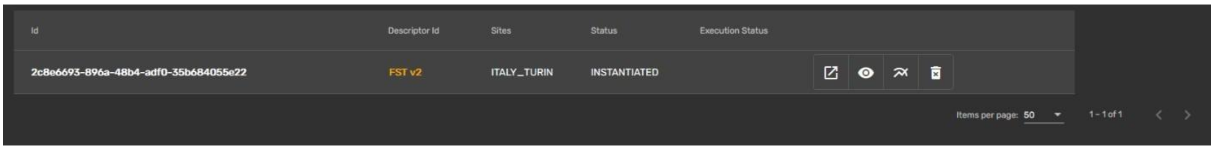


Figure 5: Smart Transport (Italy) UC1.1 - Service status - instantiated

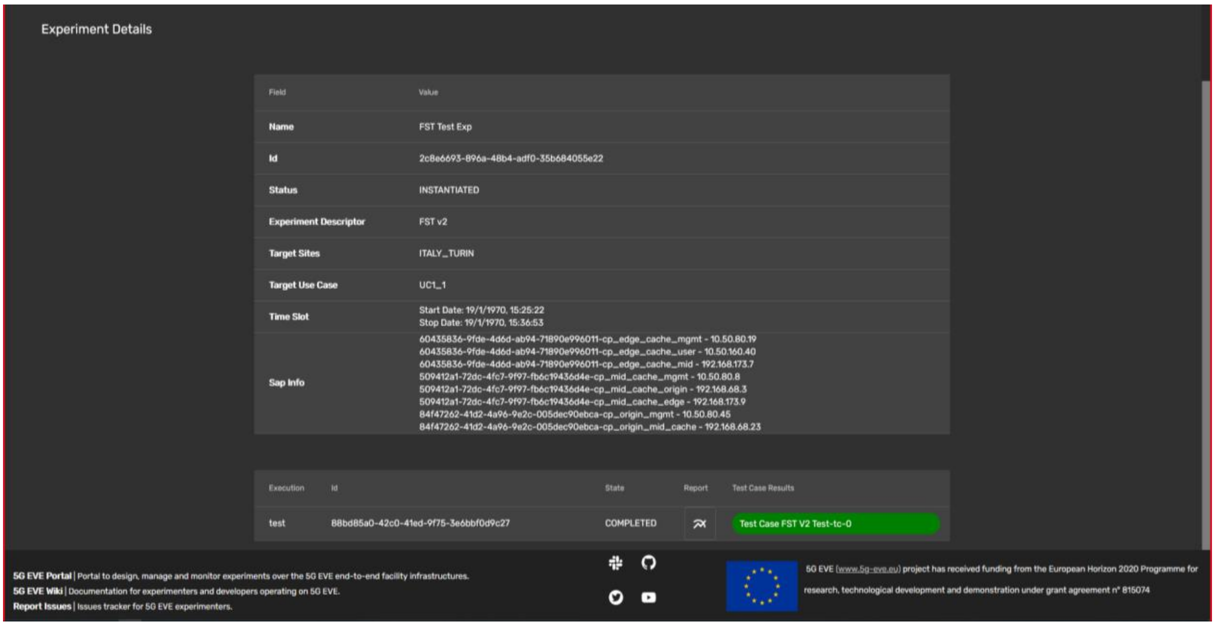


Figure 6: Smart Transport (Italy) UC1.1 - Service status - completed

Finally, we have performed a functional test to evaluate from a qualitative point of view the streaming performance for a 1080p Full-HD video at 16.7Mbps, as shown in Figure 7. The visualization of the video started immediately and proceeded with the expected quality, without any noticeable degradation incurring. This confirmed that the network was able to support the required download speed.

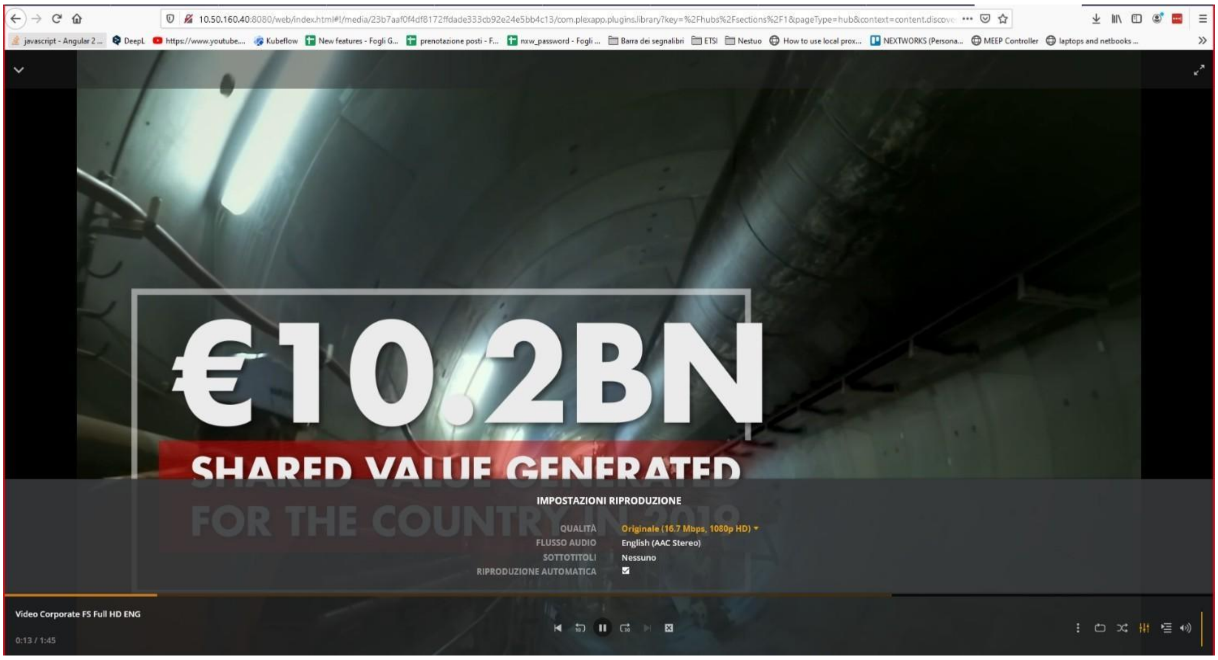


Figure 7: Smart Transport (Italy) UC1.1 - Video streaming test

Second trial of the current UC has been performed in the month of May 2021 (M35) with the aim to test the E2E connectivity through the APN of the laboratory infrastructure in High-Speed stress conditions being simulated with the 5G Prisma Emulator.

2.1.2 Pilot architecture

The *Smart Transport: 5G On-Boarding Media content streaming* pilot leverages on the 5G EVE Framework to validate the reliability of a Full HD/4K vCDN, relying on the 5G connectivity.

The scenario of the pilot for the Use Case is depicted in Figure 3. It describes the VNFs and the infrastructure where the pilot runs. The service contains a vCDN service that is composed of a media content delivery server, a vCDN Mid cache and a vCDN Edge cache.

Table 1 describes all VNFs and PNFs that compose the service and their cardinality.

Table 1: Smart Transport (Italy) UC1.1 - Components of vCDN

Name	Type of function	Cardinality
Media content delivery	PNF	1
Virtual CDN Mid Cache	VNF	1..n
Virtual CDN Edge Cache	VNF	1..n

The media content delivery, or origin server, built on Plex Media Server [6], contains the HD/4K media content available for the end users. The transcoding of the content is performed by this service, which relies on network statistics to auto-adjust the quality of the video in real-time. The vCDN caches provide caching functionality, with the aim to serve the media content near to the user, reducing latency and improving QoS and QoE. The deployment of the caches is based on a hierarchical architecture.

The interconnection among the VNFs and the user equipment on the RAN part is described in the Vertical Service Blueprint, available at [7] and depicted in Figure 4.

As shown above in Figure 4, the service VNFs are reachable from the management network, through the sap_mgmt connection point. This network is used only for configuration purposes. The users access the service only from the user network. The only VNF exposed to the user is the vCDN Edge cache.

In the following Test Plan Template described in Table 2 and Table 3, dataset of relevance for the definition of Context Blueprint and Experiment Blueprint have been defined.

Table 2: Smart Transport (Italy) UC1.1 - Test Case 1

Test Case 1	
Test Name:	**On media content communication between the 5G EVE Media Content Service front-end and back-end**
Target KPI:	User Throughput, E2E Latency, Packet Loss rate (to verify reliability and availability of network service), Video Streaming Vertical Perceived QoE
Measurement Method:	Vertical Application running on 5G mobile devices
Parameters:	The network will change from 4G to 5G, for comparison. QoE will be evaluated on Video in Full HD/4K
Validation Conditions:	Validation of the QoE of Video Streaming with the achievement of the indicated Target KPIs, through the Vertical Application. Perceived QoE would be validated (using Mean Opinion of a score of questionnaires below a threshold) with the assessment of impact of the variations of target KPIs on the video streaming quality in a framework of train urban mobility.

Table 3: Smart Transport (Italy) UC1.1 - Test Case 2

Test Case 2	
Test Name:	**Lab virtual emulation testing**
Target KPI:	User Throughput, E2E Latency, Packet Loss rate (to verify reliability and availability of network service), Video Streaming Vertical QoE
Measurement Method:	5G Prisma Emulator simulating conditions of railway High Speed
Parameters:	The network will change from 4G to 5G, for comparison. QoE will be evaluated on Video in Full HD/4K. High speed stress conditions will be simulated with the 5G Prisma Emulator
Validation Conditions:	Validation of the Perceived QoE of Video Streaming with the achievement of the indicated Target KPIs, considering the stressing conditions of the High speed simulated by the 5G Prisma Emulator (e.g., Handover Effect to be considered for high speed) on the base of pre identified modem simulated features. Perceived QoE would be validated (using Mean Opinion of a score of questionnaires below a threshold) with the assessment of the impact of the variations of target KPIs on the video streaming quality. Network KPIs variations would be specifically simulated considering train high speed stress (Graphical representation to be validated).

The pilot has been fully integrated in the 5G EVE platform. The first versions of the Vertical Service Blueprint, Context Blueprint, Test Case Blueprint and Experiment Blueprint, and the related NSDs, have been tested using the 5G EVE portal and are available in 5G EVE Github repository [7]. These versions have been successfully tested with the 5G Prisma Emulator in the TIM lab.

The Context Blueprint, depicted in Figure 8, describes the service context. It has one VNF connected to three different service access points (called “sap”). The sap *sap_dg_mgmt* is used by the platform for configuration purposes. The other two saps, *sap_dg_in* and *sap_dg_out*, are used respectively for incoming and outgoing traffic.

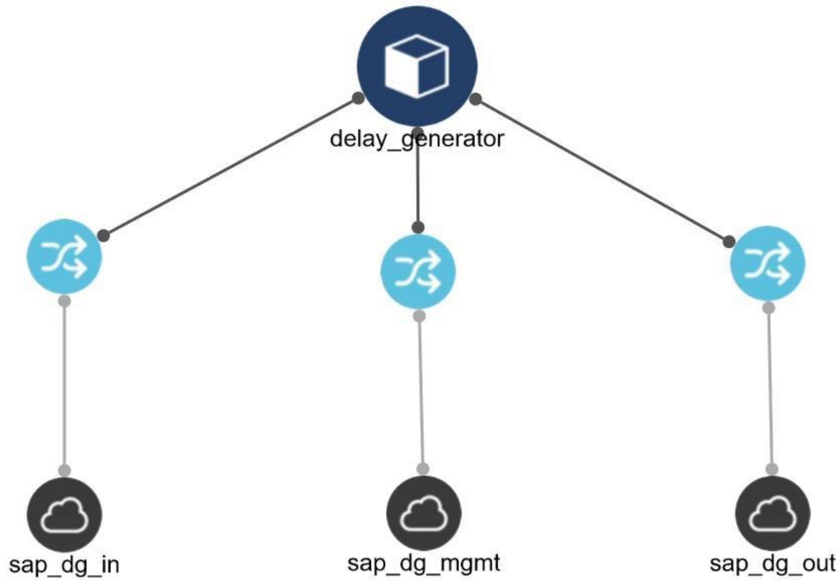


Figure 8: Smart Transport (Italy) UC1.1 - NetEM: Delay Generator Context Blueprint

The Delay Generator VNF allows the experimenter to configure dynamically the emulation of packet loss, delay or packet corruption, as well as bandwidth limit.

The VNF offers a reverse proxy service, built on NGINX [8]. It can be configured as the entry point of the experiment, allowing the traffic generated by the end user to pass through it, applying to that flow the traffic control rules configured for the experiment.

The experiment, depicted in Figure 9, contains three VNFs that compose the service.

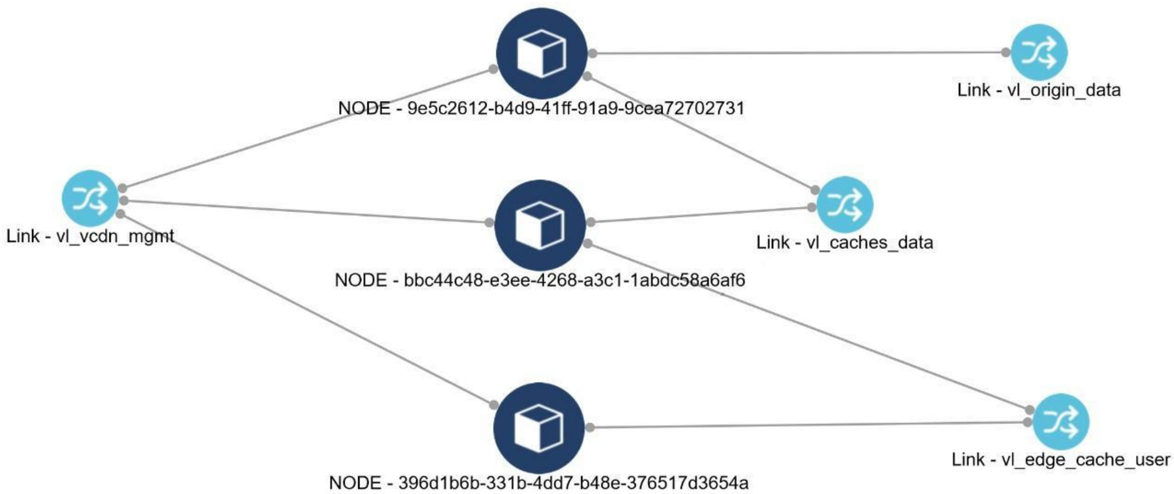


Figure 9: Smart Transport (Italy) UC1.1 - Experiment Blueprint

The three VNFs are:

- edgeCache is the nearest element to the end user. It is usually placed in an edge node. It is connected to three different virtual links:
    - vl_vcdn_mgmt: Management network, used for configuration purposes;
    - vl_edge_cache_user: User network. The vCDN service is bound to this network;
    - vl_caches_data: Intra-cache networking. It is used by the edge cache to connect to the parent cache (midCache).

- midCache is the parent cache for the edge. It is usually placed not far from the end user. It is connected to three different virtual links:
    - vl_vcdn_mgmt: Management network, used for configuration purposes;
    - vl_caches_data: Intra-cache networking. It is used by the midEdge cache to connect to the edge cache;
    - vl_origin_data: This network interconnects the midCache with the MediaContent server, where the video content is stored.
- Context VNF is placed in the edge as the edgeCache. It is connected to two virtual links:
    - vl_vcdn_mgmt: Management network, used for configuration purposes;
    - vl_edge_cache_user: User network. During the execution of the experiment, the end user will contact the context VNF instead of the edgeCache, which will redirect the requests to the edgeCache, applying to that connection all the network degradation configured for the experiment.

2.1.3 Vertical service KPIs implementation

Table 4 summarizes the Vertical Services KPIs for this UC.

Table 4: Smart Transport (Italy) UC1.1 – Vertical Service KPI

Use case title	**Smart Transport: Intelligent railway for smart mobility: 5G on-boarding media content streaming**			
Site facility	**Italian Site**			
Vertical KPI name	User Throughput	End2End (E2E) Latency	Packet Loss rate	Video Streaming Vertical QoE
Vertical KPI definition	average “speed” [bits/second] of data transfer during media content streaming	time that takes to receive the response of the service across the network once it is triggered	number of packets transmitted and not received or dropped during transmission on the total number of packets transmitted	Perceived Quality of Experience
Metric collection tools	Turin Data shipper [10]	Turin Data shipper [10]	Turin Data shipper [10]	Questionnaire (Mean Opinion Score –MOS)
Position of the probes in the reference architecture 1) UE; 2) Public Cloud; 3) Private Cloud; 4) Edge	Private Cloud	Private Cloud	Private Cloud	
Metric collection methodology	Collect metric every 1 second during the experiment executions	Collect metric every 1 second during the experiment executions	Collect metric every 1 second during the experiment executions	Questionnaire compiling by users
Validation tools	5G EVE Portal KPI validation tool	5G EVE Portal KPI validation tool	5G EVE Portal KPI validation tool	Tool evaluating surveys
Validation methodology	Not relevant	Not relevant	Not relevant	Mean Opinion Score – MOS

2.1.4 Pilot deployments

The pilot is deployed at the TIM laboratories where the user's equipment, under 5G coverage, can connect to the service that is running in Politecnico di Torino using the interconnection provided by 5G EVE infrastructure. The service is composed by three main components. A media content delivery server, named origin_server, and two caches, named mid_cache and edge_cache, connected in a hierarchical architecture as described in the Vertical Service Blueprint depicted in Figure 4.

The images and the VNF Descriptors for the caches and the media content delivery have been uploaded in the NFV infrastructure in Politecnico di Torino. All the blueprints and network services, necessary to run the experiment have been onboarded in the 5G EVE portal. They are available in the 5G EVE github [7]. The service experiment is executed through the 5G EVE platform, and instantiates, as described, a media content server and two hierarchical caches in the cloud infrastructure at the Politecnico di Torino lab.

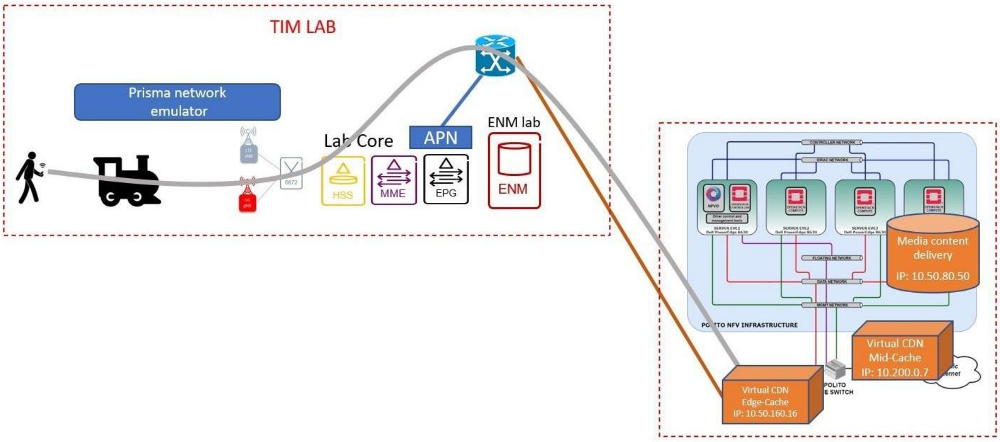


Figure 10: Smart Transport (Italy) UC1.1 - Pilot deployment scenario

The users, as depicted in Figure 10, are located in TIM's laboratories during this pilot execution. Through their 5G terminal, they are connected, via browser, to the video content available in the media content delivery server and they can stream the chosen content.

The vertical KPIs are sent by the data shippers installed and dynamically configured in the cache VNF to the local kafka broker, located in the Politecnico di Torino infrastructure. After that, the metrics and the associated KPIs, calculated by the RAV (Results and Analysis Validator) are shown in the 5G EVE Portal. At the end of the experiment, a questionnaire is sent to the users, related to the perceived quality of experience.

2.1.5 Pilot execution results

The experiment has been carried out in May 2021. The KPI evaluated in the validation campaign has been mostly the user throughput due to the fact that the tests have been performed at the end of the project in the first implementation of the platform. Future tests will check also latency, packet loss and QoE, also in real environments.

The initial setting of the workspace has been done with the following steps:

i. connecting the client laptop to the tool including the Keysight prima emulator

ii. Keysight setup and configuration (selection of the timing advance parameter value). See Figure 11 and Figure 12.

iii. Testing of end-to end connectivity, from the client laptop to the Vertical Service deployed in the 5G EVE facility.

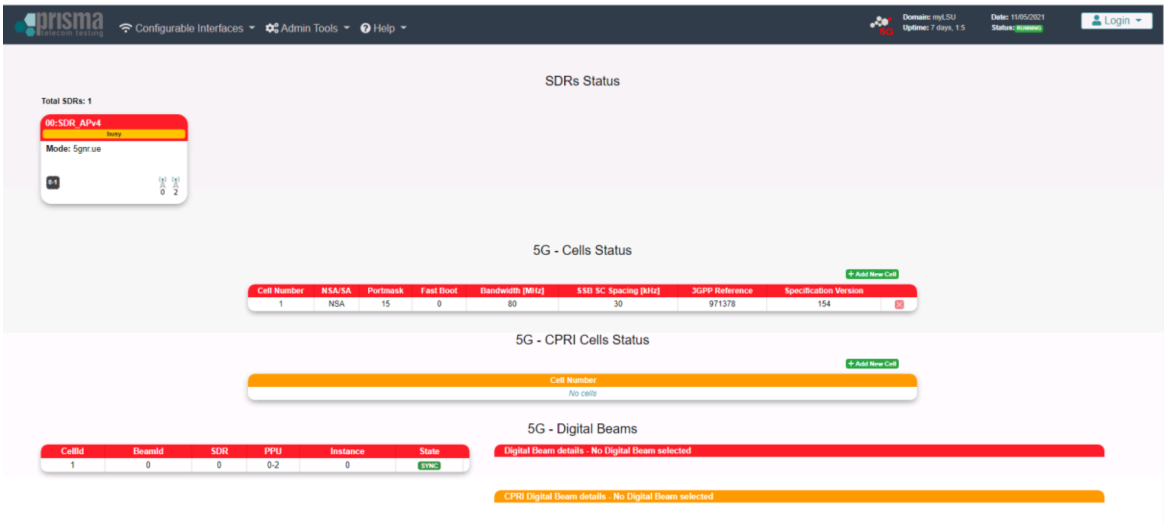


Figure 11: Smart Transport (Italy) UC1.1 - Keysight Prisma emulator set up via User Interface.

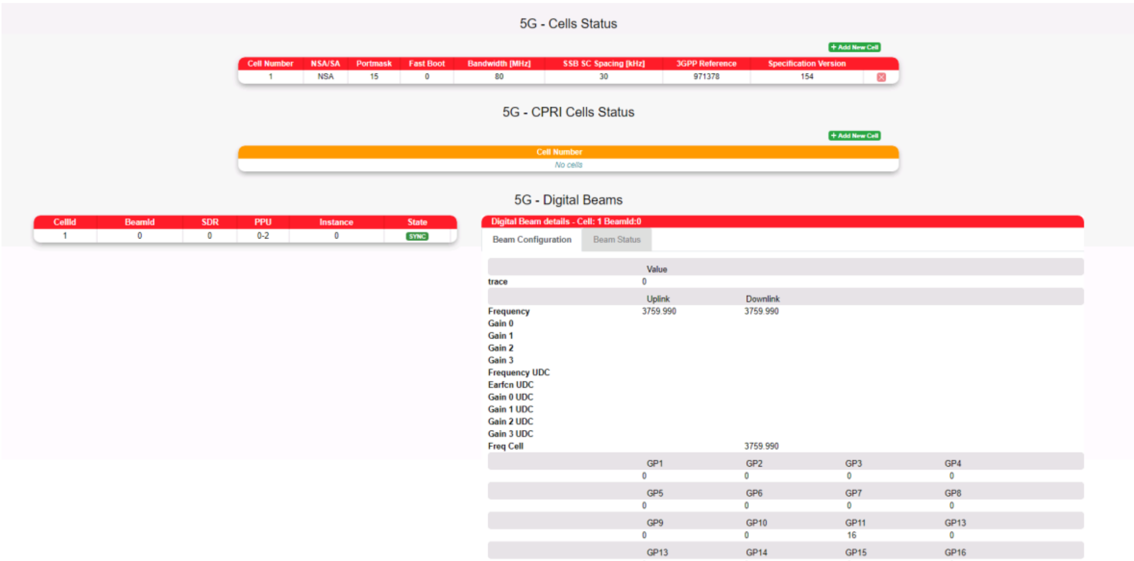


Figure 12: Smart Transport (Italy) UC1.1 - Keysight Prisma emulator configuration via User Interface.

Once the setup finalized, the "Test of the end-to-end video content use" execution has been done with the following outcomes as depicted in Figure 13:

- Video quality required 17Mbps, streamed in HTTP (TCP); therefore, the transfer was done with a buffering mechanism.
- In the absence of impairment, the video was seen correctly; the data traffic was approx. 35Mbps and the content was buffered. No use issues had been detected.
- Background traffic towards another APN (50 Mbps DL on 5 users, 25 Mbps UL on 5 users): there was no effect on video traffic.
- Attempt to activate an IPERF3 E2E flow from video server: in this case the flow could not be transmitted.

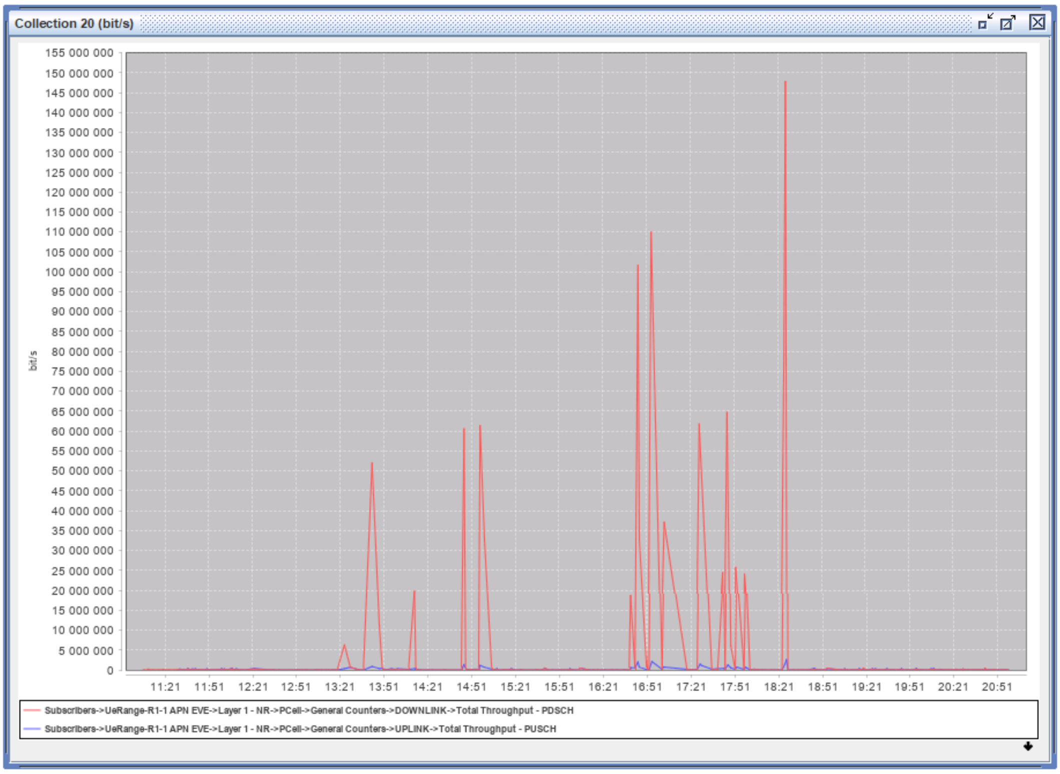


Figure 13: Smart Transport (Italy) UC1.1 - Experiment results - Downlink and Uplink throughput

Moreover, the “Test of the E2E video content use with impairment” (timing advance to simulate movement, from 10 to 150 km/h with increments of 10km/h) has been executed: network performance has decreased considerably, the throughput was oscillating and was lower than 10Mbps, which prevented buffering and use of the video.

The experiment was positive and the Use Case E2E was correctly demonstrated. Figure 14 depicts the experiment result.

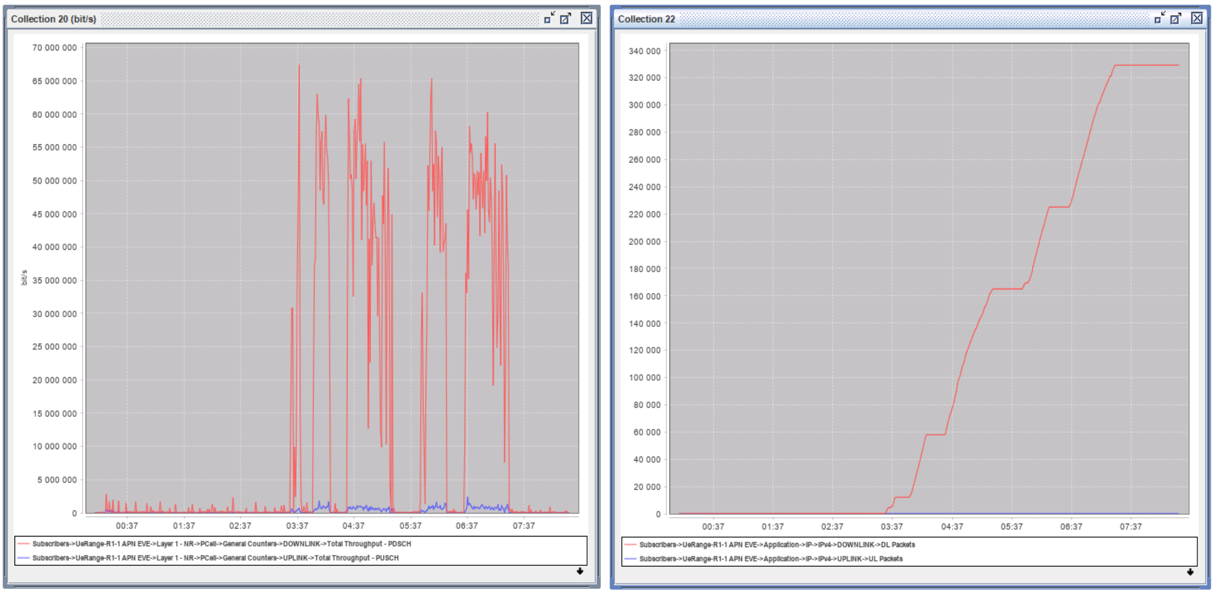


Figure 14: Smart Transport (Italy) UC1.1 - Experiment results - Downlink (left) and Uplink (right) throughput assessment

Therefore, these are the main conclusions at the end of the trial activity:

- The experiment was executed correctly done. No issues had been detected.
- The experiment set up and dynamic configuration allows an interesting range of different test cases simulating different conditions of practical interest from the railway operator's point of view as well as for technology providers and business developers supporting use case of concrete interest.
- Collaboration among partners had been successful. This collaboration has been enabled by the platform and the partners are willing to keep on working together on this topic even after 5G EVE closure.

2.1.6 5G empowerment

This section provides a summary of the 5G features that have improved the experimentation.

Multi-access edge computing (MEC) formally known as mobile edge computing

This technology improves the experiment by bringing the computational capacity close to the mobile user allowing to deploy edge caches closer to where the content is consumed. This improves the QoE perceived by the user and reduce the amount of traffic in the core network.

Network Slicing

It ensures that the Use Case performance requirements described by the Vertical are meet using 5G EVE platform. This service could be assimilated to "Network Slice as-a-service" which provides a concrete answer to Vertical's demand by enabling "à la carte" End-to-End services. A Communication Service Provider (CSP) offers a Network Slice to a Communication Service Customer (CSC) for a communication service that is based on a Network Slice Instance. The Site Manager in 5G EVE would be the CSP and the Vertical/Experimenter would be the CSC.

2.1.7 5G EVE platform added value

The 5G platform has allowed to test in a simulated environment the performance of the HST scenario depicted in this use case, allowing to first estimate the user throughput that would have been reachable onboard of a train at high speed. This is one of the very first experiments of this kind, and despite not being executed in a real environment due to the currently missing coverage of the railways with 5G it helped to start evaluating the performance that could be achieved in such a challenging scenario. This first evaluation will be the basis for future more detailed ones and possible future cooperation of the partners involved. In this context then the added value brought by 5G in general is related to the Performance Diagnosis, allowing to check very preliminarily the user throughput possibly experienced by the users in high-speed emulated scenario, but already with future plans to extend to the other KPIs in the framework. The other added values reported in D1.3 have not been yet analysed.

2.2 Use Case 1.2 - Smart Transport: Intelligent railway for smart mobility: Urban mobility 5G data flows analysis

2.2.1 Pilot context

The Use Case 1.2 Urban mobility 5G data flows analysis aims at demonstrating that, thanks to 5G mobile communications, it is possible to monitor and to analyse real time mobility data through large scale data analytics to provide added value information for decision making in traffic congestion management. Moreover, combining Use Cases 1.1 and 1.2 as Vertical Smart Transport, enriched information about passenger's mobility flows enables E2E on board and off board customized info-mobility services. The Use Case has been developed step-by-step adopting a top-down approach for design, implementation, and deployment.

The perspective of Urban Mobility Planners has been considered. They need advanced tools for enhanced traffic optimization and control in crowdy urban areas as well as an accurate identification of demands in terms of mobility services of heterogeneous nature (private/public, individual/collective, single/combined, and so on) according to the paradigm named "Mobility as a Service" (MaaS) promoted by the European Commission since 2010. Services and tools to automatically identify the actual demand in terms of services and paths (origin-destination) and to induce suitable forecasts of aggregated mobility flows for transport network optimization play a fundamental role in the transition from the traditional mobility paradigm towards a more sustainable, secure, and efficient mobility system. In this perspective, the vertical service presented in this section represents a first step to provide a flexible, large scale (and easy to integrate) 5G based mobility flow monitoring and analysis platform distributed over the end-to-end communication.

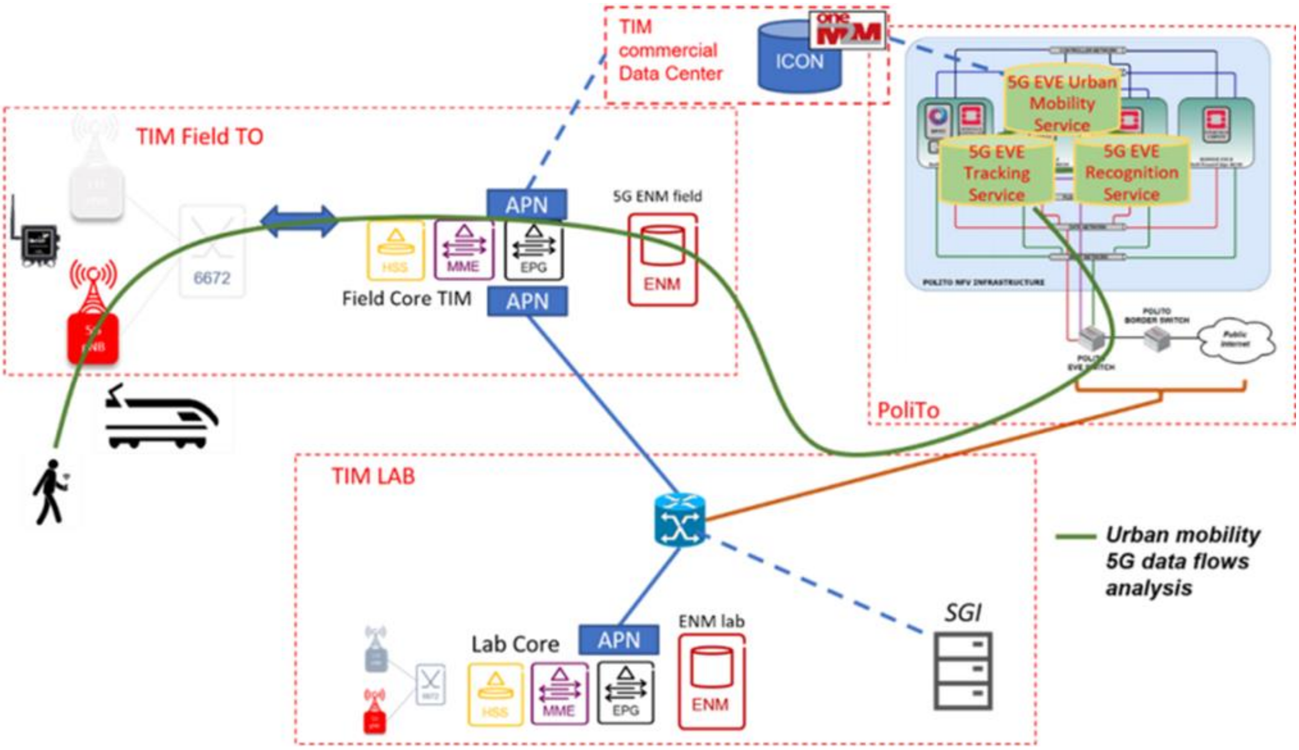


Figure 15: Smart Transport (Italy) UC1.2 - Consolidated reference architecture

In line with the design and implementation activities reported in D2.4 [3], three main services have been developed and deployed to support the experiment execution. With reference to Figure 15, the three services are represented as three distinct VNFs, which have been successfully instantiated in the 5G EVE platform. The 5G EVE Tracking Service collects and transmits data from different sensors from user's 5G mobile device (on the left in the Figure 15) to the 5G EVE Recognition Service (on the right in the Figure 15). The 5G EVE Recognition Service automatically analyses data and identifies user's transportation modality in real time by a suitable machine learning trained on high volume data set collected in the preliminary phase of the Use Case. The 5G EVE Urban Mobility Service automatically aggregates flows as mobility patterns and related transport modalities and publishes added value information on TIM's ICON platform via OneM2M protocol.

In the whole experiment's design and implementation cycle, the main actors, the pilot architecture referring to the Italian Site and the test case advancement, including the Service KPIs and the live experiment execution, are reported in the following sections. The experiment allows an end user equipped with a 5G device to automatically send mobility data to the 5G Tracking Service that manages mobility data. The device receives, in real time, the estimated modality adopted by the end user from the 5G Recognition Service. The enriched data, namely mobility data with estimated modality, are returned to the end user and, at the same time, managed by the 5G Urban Mobility Service: this service sends enriched data to the TIM's platform ICON accessed by mobility operators and transportation system managers as third parties.

The Use Case shows how real time machine learning based recognition can support decision making in traffic congestion management, from the urban and railway operator's point of view. Relevant KPIs from the vertical's point of view include tracking response time and memory usage concerning the 5G Tracking Service and other four KPIs concerning the 5G Recognition Service (recognition accuracy, network time, memory usage and response time). A further purpose of the experiment is to include data from Libelium scanners (on the left in the Figure 15) adopted in the Use Case of vertical Smart City (see Use Case 5.1, Section 2.9) in the analysis of urban mobility flows. The main expectation is that data blending can play a crucial role in automatically refining mobility patterns and favouring synergies between Smart Transport and Smart City scenarios in case of critical and/or risky situations.

2.2.1.1 Partner's roles

The main actors of the experiment in all related activities are the following ones:

Vertical

A2T designs the experiment according to the own knowledge in the field of urban mobility, in line with considerable experience in Electro Mobility and related services in huge urban environments. Moreover, the concept behind the Use Case is based on both scientific literature and market needs relevant in urban mobility.

VNF provider

A2T provides the entire set of VNFs enabling the experiment. Each VNF implements one of the three services described in the previous section, namely:

- *5G EVE Tracking Service* – The VNF collects data from different sensors from end users' 5G mobile devices;
- *5G EVE Recognition Service* – The VNF analyses data and automatically identifies each end user's transportation modality in real time by a learning machine (being part of the service);
- *5G EVE Urban Mobility Service* – The VNF aggregates flows as mobility patterns and related transport modalities and publishes added value information on the TIM's ICON platform via OneM2M protocol.

Experiment developer

A2T is responsible for specifying the blueprints associated to the experiment, as well as the associated NFV Network Services Descriptors. This task has been performed by A2T in cooperation with a site integrator for the Italian site, namely, NXW.

Experimenter

A2T is responsible for the request of the experiment described in the previous section and related assessment of results from the 5G network and the business point of view. A2T has defined the characteristics of the experiment managing blueprints and requests for the deployment of the related virtual environment (CNIT – Polito VNF Infrastructure). During the experiment execution, A2T has been in charge of the actual execution of the experiment to perform the analysis of actual results and service KPIs with respect to tests already performed in laboratory.

Site Manager

TIM is the Site Manager responsible for authorizing and managing the experiment in the Italian site according to requirements and specifications indicated by Vertical and Experimenter. Moreover, during the experiment execution, TIM supported the test activities on the field.

2.2.1.2 Trials

A2T performed the first trial execution on October 14th, 2020, in the form of an internal live event to share the entire set up and execution of the experiment with all partners in 5G EVE. The test execution was performed around the area of Polytechnic University of Turin through the dedicated APN provided by TIM according to the consolidated reference architecture depicted in Figure 15. The user equipment included two 5G mobile devices, namely Samsung Galaxy S10 5G, provided with the Android mobile application developed by A2T as client application of the 5G EVE Tracking Service.

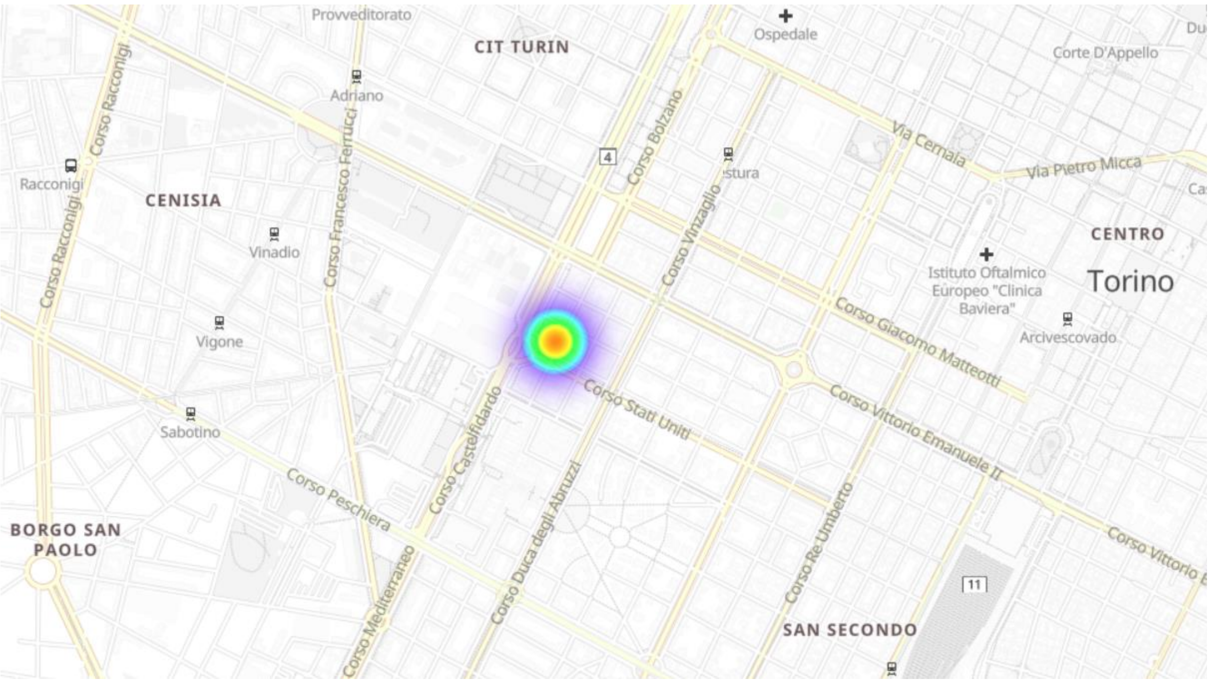


Figure 16: Smart Transport (Italy) UC1.2 - Area of Trial execution

During the experiment execution, two end users performed various transportation modes through the Android mobile application, which had been installed in their smartphones provided with the 5G connectivity in 5G EVE infrastructure. Figure 16 shows the location of the trial deployment. The users were required to perform a transportation mode holding the 5G mobile phones, which were sending all sensor information to the 5G EVE Recognition Service via the 5G EVE Tracking service. The 5G EVE Recognition Service analyses data and automatically identifies the end user's transportation modality or status in real time through a previously trained machine learning based model. The 5G EVE Tracking service is responsible to collect the sensor's data which are useful for further analysis and refinement of the machine learning based model. On this occasion, the end user was able to find out in real time through the Android mobile application the estimated transportation mode, the related probabilities, and other useful information regarding the mobility and the connectivity status. The information is computed and the result send to the user in one second. In this sense, the 5G connectivity enhances the quality of the user experience by providing a fast and reliable service.

2.2.2 Pilot architecture

The software architecture underlying the use case is depicted Figure 17. Four different VMs have been installed. Three of them, namely "VM#1 - BE_Tracker", "VM#2 - Visualizer" and "VM#4 - BE_Recognition", are owned by A2T, while the fourth one, namely "VM#3 - Kafka", has been developed by Telcaria.

The vertical KPIs, which are processed by A2T's VMs, converge to the Kafka Server which is in charge to convey and visualize the KPIs on the 5G EVE Platform. In particular, Figure 17 shows more clearly which VMs are in charge to provide the services mentioned in section 2.2.1 (see Figure 15):

1. The VM#1 - BE_Tracker offers the 5G EVE Tracking Service whose managed data are then visualizable through the VM#2 - Visualizer which ultimately sends two of the vertical KPIs to the Kafka server: tracking_memory_usage and tracking_response_time.
2. The VM#4 - BE_Recognition offers other services the 5G EVE Recognition Service; it sends four vertical KPIs to the Kafka server: recognition_memory_usage, recognition_response_time, recognition_accuracy and recognition_network_time); at the same time, it manages 5G EVE Urban Mobility Service by publishing useful aggregates flows as mobility patterns and related transport modalities on the TIM's ICON platform via OneM2M protocol.

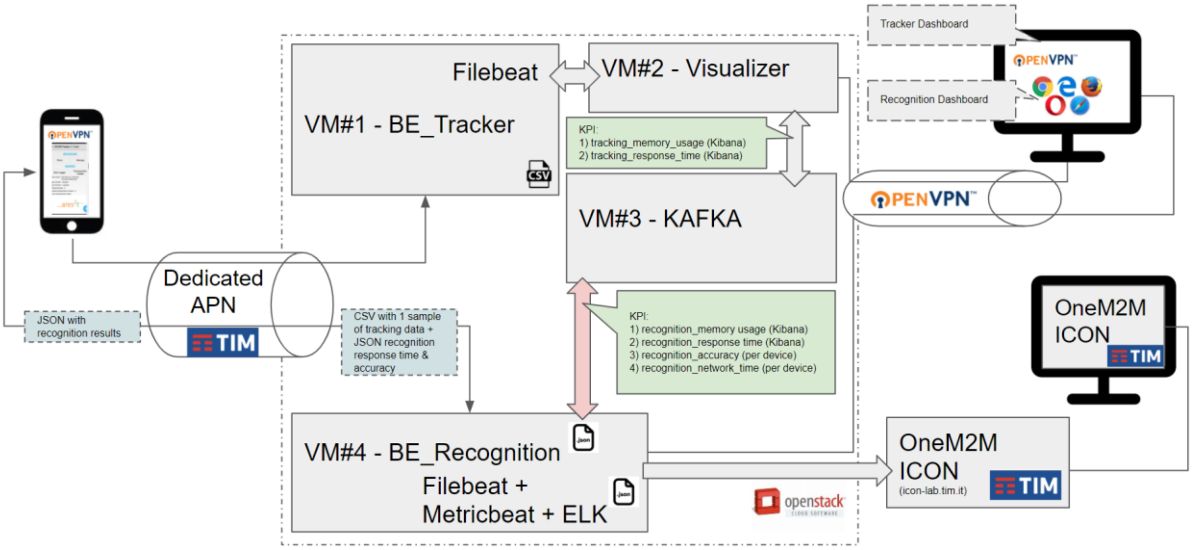


Figure 17: Smart Transport (Italy) UC1.2 - Detailed architecture

2.2.3 Vertical service KPIs implementation

For UC 1.2 six low-level test cases have been defined according to the vertical KPIs of interest for the Experimenter. The first and the second one aim at measuring the vertical KPIs involving the 5G Tracking Service, while the last four ones aim at measuring the vertical KPIs involving the 5G Recognition Service. The six test cases are reported in Table 5.

Table 5: Smart Transport (Italy) UC1.2 - Vertical service KPIs

Use case title	**Smart Transport: Intelligent railway for smart mobility: Urban mobility 5G data flows analysis**
Site facility	**Italy**

Vertical KPI name	Recognition Accuracy	Recognition Network Time	Recognition Response Time	Recognition Memory Usage	Tracking Response Time	Tracking Memory Usage
Vertical KPI definition	It expresses the percentage accuracy of the application to correctly estimate the declared transportation mode.	Time elapsed in ms between an inquiry to the 5G EVE recognition and to its relative response without considering the processing time.	Time spent to evaluate and visualize the data on the Kibana Visualization of the Recognition server.	It shows the percentage of used memory which is computed by the Kibana installed in the Recognition server.	Time spent to evaluate and visualize the data on the Kibana Visualization of the Tracking server.	It shows the percentage of used memory which is computed by the Kibana installed in the Tracking server.
Metric collection tools	Filebeat	Filebeat	Metricbeat	Metricbeat	Metricbeat	Metricbeat
Position of the probes in the reference architecture 1) UE; 2) Public Cloud; 3) Private Cloud; 4) Edge	Recognition Server (Edge)	Recognition Server (Edge)	Recognition Server (Edge)	Recognition Server (Edge)	Tracking Server (Edge)	Tracking Server (Edge)
Metric collection methodology	Each second the Recognition Accuracy is updated, and its value is collected by its Kafka topic	Each second the Recognition Network Time is collected by its Kafka topic	Every 5 seconds the Recognition Response time is collected by its Kafka topic	Every 5 seconds the Recognition Memory Usage is collected by its Kafka topic	Every 5 seconds the Tracking Response time is collected by its Kafka topic	Every 5 seconds the Tracking Memory Usage is collected by its Kafka topic
Validation tools	The 5G EVE platform's KPI validation framework	The 5G EVE platform's KPI validation framework	The 5G EVE platform's KPI validation framework	The 5G EVE platform's KPI validation framework	The 5G EVE platform's KPI validation framework	The 5G EVE platform's KPI validation framework
Validation methodology	Recognition Accuracy	Recognition Network Time should be	Recognition Response Time should	Recognition Memory Usage	Recognition Tracking Time should	Tracking Memory Usage

	should be > 80%	consistently < 100ms	be consistently < 100ms	should be consistentl y < 20%	be consistently < 100ms	should be consistentl y < 20%

2.2.4 Pilot deployments

The dynamic instantiation of the Virtual Machines on the 5G EVE Platform was realized thanks to the configuration of the Blueprints and Descriptors according to the software architecture depicted in Figure 17. In the following figures, the architecture of the Vertical Service Blueprint (VSB) and the Context Blueprint (CTX) are shown. Figure 18 shows the VSB which denotes the presence of the three VNFs, in line with description given in Section 2.2.2. In particular, the circles are represented by the VNFs in dark blue colour, by the Connectivity services in light blue colour, and finally by the Service Access points in dark grey colour. Figure 19 denotes similarly the context blueprint (CTX) which is the Delay Generator. These blueprints describe the main architecture of Use Case 1.2.

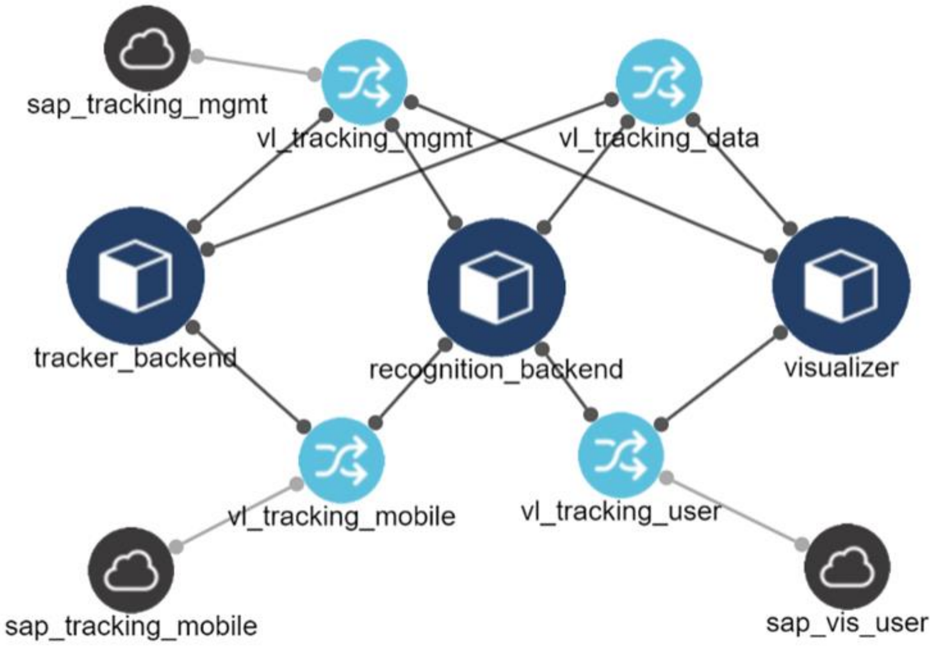


Figure 18: Smart Transport (Italy) UC1.2 - Vertical Service Blueprint

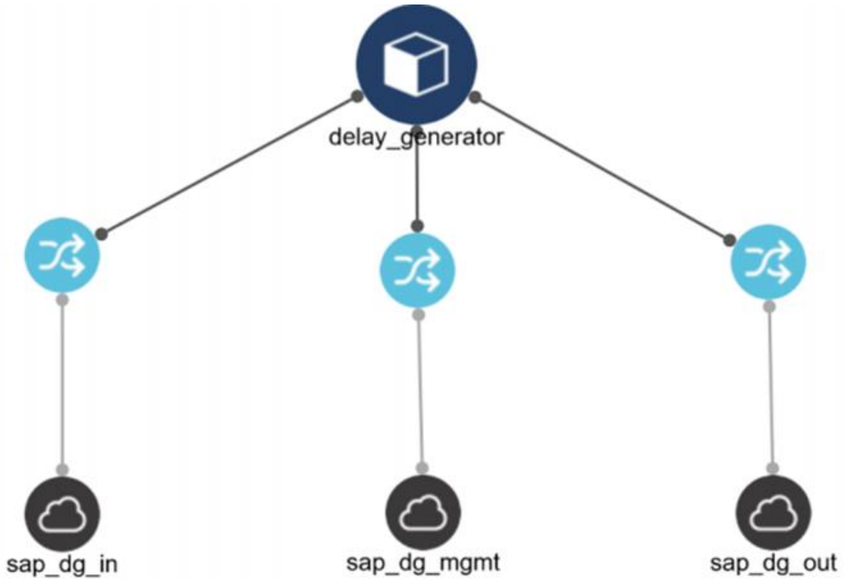


Figure 19: Smart Transport (Italy) UC1.2 - Context Blueprint

2.2.5 Pilot execution results

In January 2021, A2T performed a new set of experiments, in which the vertical KPIs were collected. The tests required the installation of a specific phone app developed by A2T on a Galaxy S10 Android phone. In the initial stages, the user starts a new session by declaring the modality transport he is going to perform (no mechanical transportation means being adopted). The mobile application can recognize up to 10 different transportation modes as Still, Walking, Running, Bicycle, Car, Motorcycle, Bus, Tram, Train, and Metro. During the experiment, the end users performed according to the declared modalities and received in real-time the estimated transport modality or status and the relative probabilities.

The main results registered during the experiment execution are reported in the following figures. Figure 6 shows the results of the most important KPI, from the vertical's point of view, namely the recognition accuracy which shows the percentage of the correctly classified data instances during the experiment execution. The recognition accuracy ranges around 90% as depicted in Figure 20. The second KPI of interest, the Recognition Network Time is shown in Figure 21, which ranges around 300ms. Finally, considering both the 5G EVE Tracking and 5G Recognition services, the KPIs regarding response time and memory usage in the Kibana based monitoring system show a similar trend, in which the former ranges around 50ms and the latter shows a usage of nearly 20% (see Figure 22 and Figure 23). Memory Usage KPI shows a regular trend of nearly 20%. Response Time KPI shows a trend which ranges around 80ms.

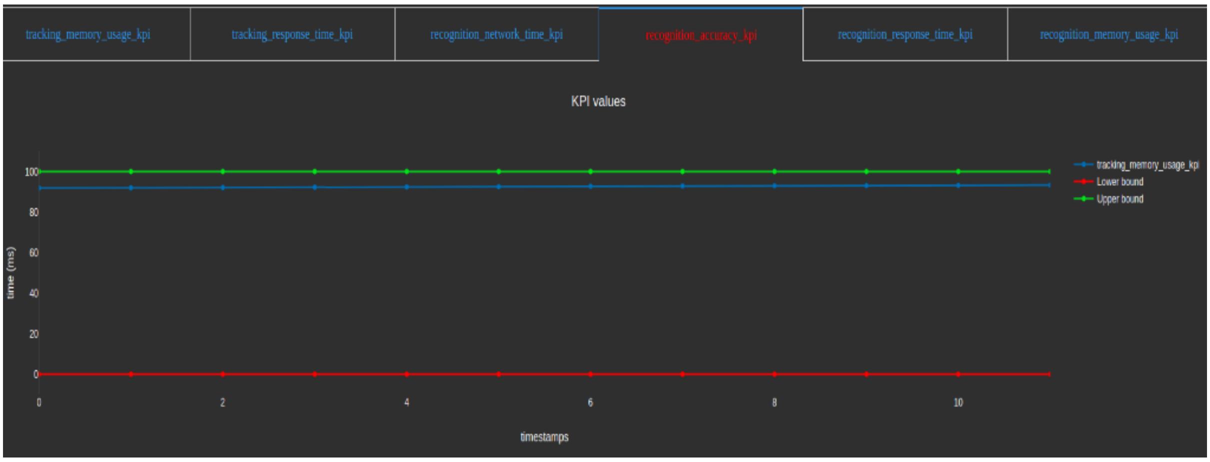


Figure 20: Smart Transport (Italy) UC1.2 - Recognition Service - Recognition accuracy

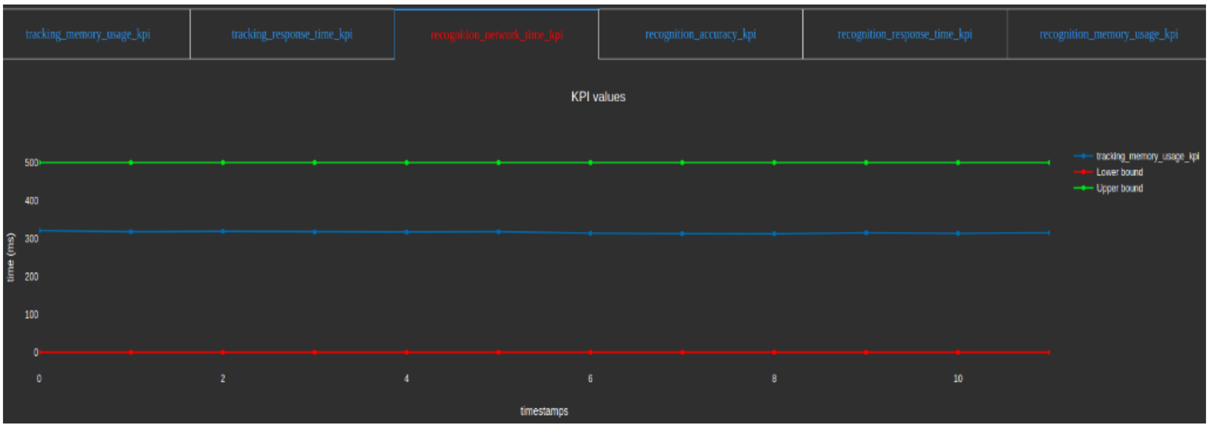


Figure 21: Smart Transport (Italy) UC1.2 - Recognition Service - Recognition network time

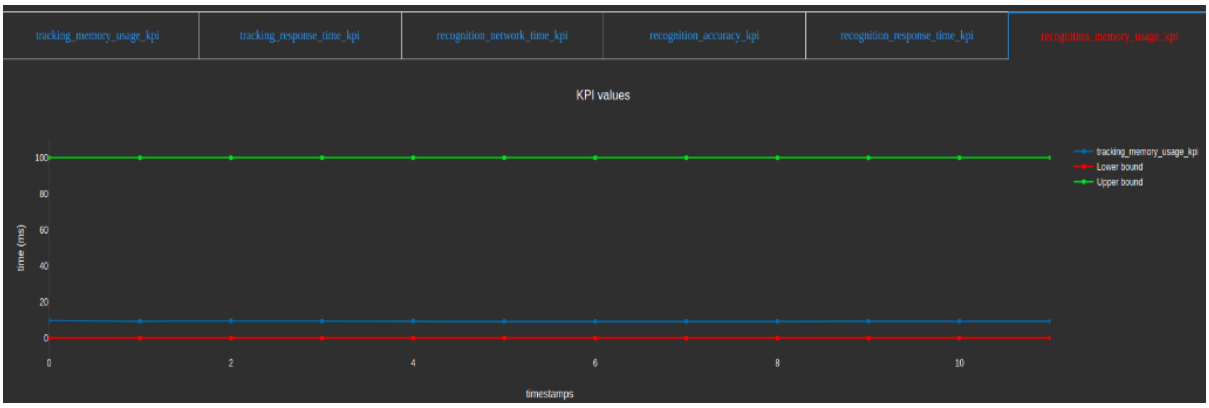


Figure 22: Smart Transport (Italy) UC1.2 - Recognition Service - Recognition memory usage

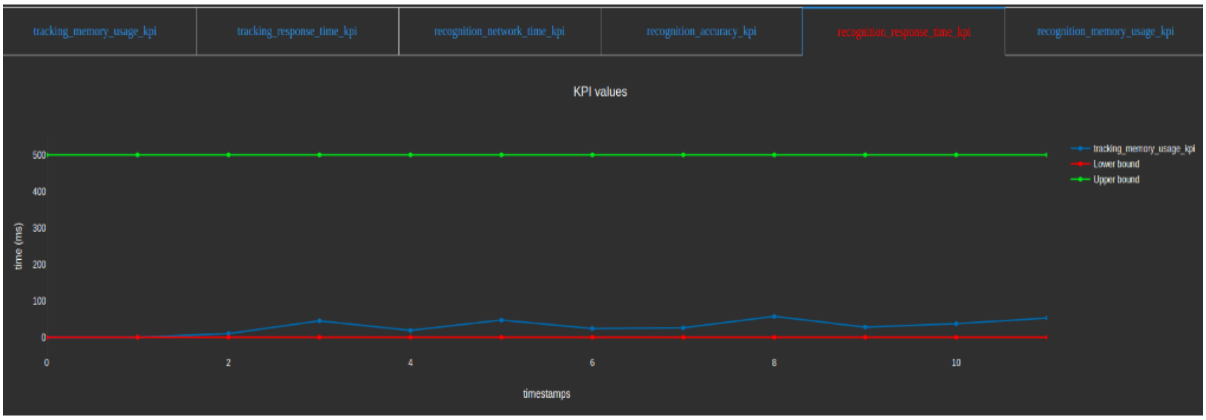


Figure 23: Smart Transport (Italy) UC1.2 - Recognition Service - Recognition response time

2.2.6 Info Mobility Service – one M2M ICON Platform

The ICON Platform is part of the *5G EVE Urban Mobility Service*. A2T exploits the instantiated Recognition VNF to send aggregated flows as mobility patterns and related transport modalities and publishes added value information on the TIM's ICON platform via OneM2M protocol. Initially the Recognition VNF recognizes in real time the transportation mode of the user and simultaneously sends a json file to the platform every 10 seconds through a POST Request. The json file contains information such as id_phone, declared and estimated transportation mode, timestamp and GPS coordinates. On the other side, the ICON platform receives the json files and shows the mobility patterns through its dedicated visualization system. An example is shown in the figures below. Figure 24 and Figure 25show respectively two different commutes through "Walking" and "Tram" transportation modes in Turin.

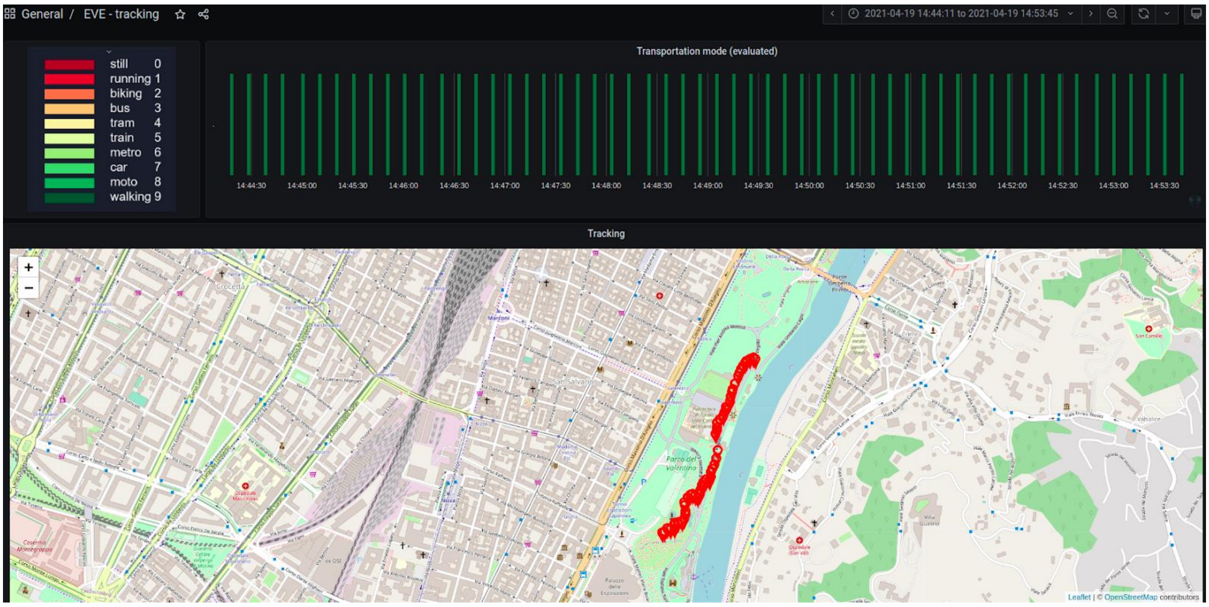


Figure 24: Smart Transport (Italy) UC1.2 - oneM2M ICON Platform - Walking-like pattern monitoring

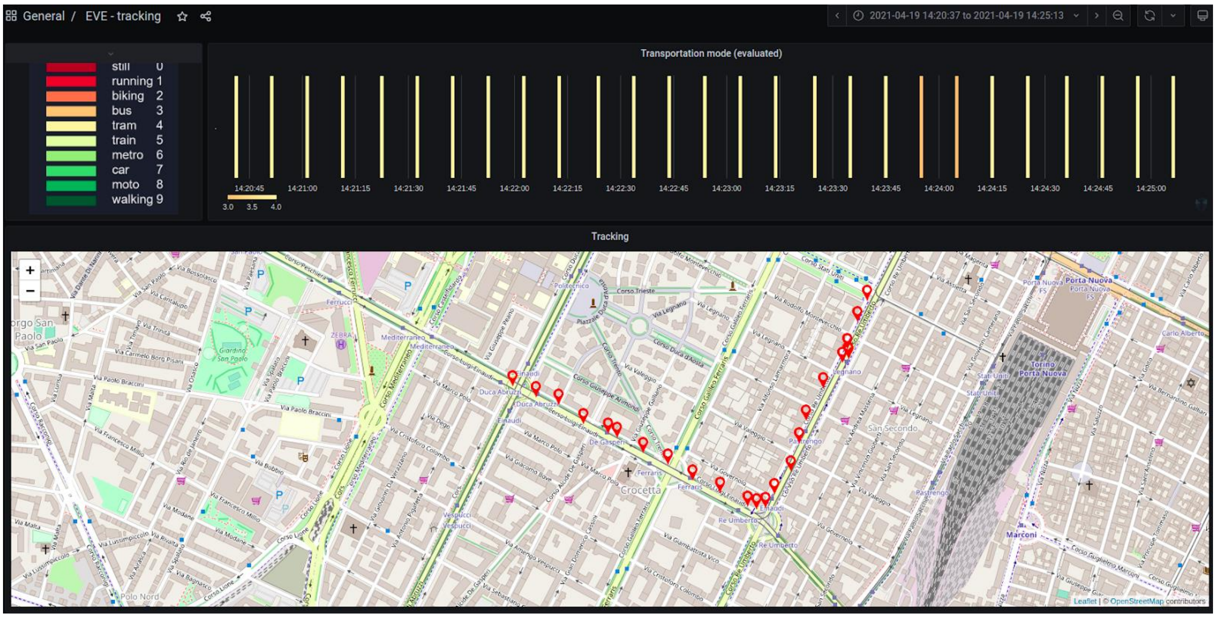


Figure 25: Smart Transport (Italy) UC1.2 - oneM2M ICON Platform - Tramline pattern monitoring

2.2.7 5G empowerment

The main 5G features improving the experiment execution are represented by the adoption and integration of MEC technology and RAN low latency (ref. URLLC). The former provided data storage and processing capabilities in-edge with no involvement of core network for estimating the transportation modality and/or the status of the end user (i.e., “Still”, “Walking” and “Running”). The latter allowed real time communication of the estimated modality/status to the end user. The combined presence of MEC technology and RAN low latency in the 5G EVE platform allowed to assess recognition time and accuracy with previous 4G oriented test.

2.2.8 5G EVE platform added value

The 5G EVE platform provides a flexible and open 5G VNFs environment to set up and configure all necessary vertical components in one vertical service suitably described by a set of blueprints and descriptors. The intent-based interface fostered a smooth onboarding process covering the full set of activities depicted in the Experiment Workflow via 5G EVE web portal. From the Smart Transport Vertical's point of view, the considerable added value offered by the 5G EVE platform is the opportunity to test the vertical service here developed to monitor mobility flows as well as to automatically identify typical patterns in realistic scenarios. The automatic monitoring of passenger mobility patterns and related transport modalities aims at identifying different transportation modality demands, performing optimal spatial planning and enabling efficient trip planning and control for end users. This represents a significant tool to support urban mobility planning and optimization, especially with respect to the above-mentioned transition from traditional mobility means to the paradigm Mobility as a Service (MaaS) in urban areas.

2.3 Use Case 2.1 - Smart Tourism: Augmented Fair experience

2.3.1 Pilot context

5G technologies will allow tourists to enjoy an enhanced experience while visiting historical sites or architectural landmarks in a city. The Smart Tourism UC aims to develop a system of software tools to interactively access information on architectural landmarks, connecting a digital environment and the physical space of the city, overcoming the limitations of traditional information tools, and allowing new interactions with monuments and works of art. The development of these technologies will enable historical and archaeological sites and assets to be seamlessly explored and maintained: from offline browsing to advanced ticketing; from remote monitoring to Augmented Reality (AR) exploration. The UC uses Artificial Intelligence (AI) image recognition techniques and AR applications to enhance the visitor experience and optimize available resources.

A mobile app has been developed by CNIT in support of this UC. The Smart Tourism app recognizes a monument or a work of art just by framing it with the camera from any direction and regardless of its distance. As shown in Figure 26, the interface shows the name of the object and shows the related information with just a touch. From within the app, if an AR extension is available for the monument, AR graphics will be superimposed on the image to allow an AR-enhanced visit of the monument or site. The AR application relies on 3D models and other multimedia files that will be available through the server positioned in the 5G edge cloud, which enables AR Multimedia document retrieval, AR Project document retrieval, AR navigation of 3D models and 3D maps.

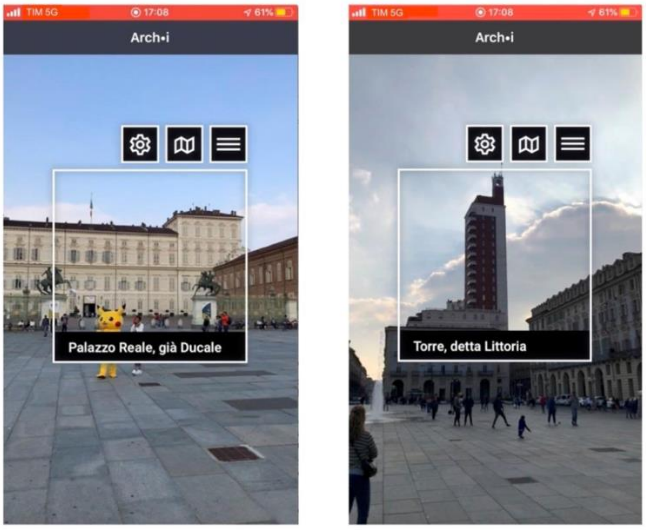


Figure 26: Smart Tourism (Italy) UC2.1 - Application interface

2.3.1.1 Partner's roles

Vertical

CNIT plays the role of the vertical, it has the purpose of testing the AR app it has developed for smart tourism purpose, using the 5G-EVE infrastructure.

VNF provider(s)

CNIT has provided the VNF providing the backend functionality of the Smart Tourism app, to be on boarded with the help of NXW.

Experiment developer(s)

CNIT has developed the experiment with the goal of evaluation of the Use Case.

Experimenter(s)

CNIT is also the experimenter, having set up a test suite that allows the testing of the capability of the Smart Tourism app.

Site Manager(s)

TIM is the site manager in charge of authorizing and securing the schedule and execution for the validation activities.

2.3.1.2 Trials

The UC is operational and can be activated in the area with 5G coverage in the "Innovation Mile" between Politecnico di Torino and the Porta Susa railway station. A trial has been shown publicly in a 5G EVE webinar held on November 18, 2020.

2.3.2 Pilot architecture

The architecture of this UC is shown in Figure 27, where the two main components of the Use Case are the AR Server (ARS) and the Media Database (MDB) Network Functions (NFs) running in the 5G EVE edge cloud. The Smart Tourism app interacts in real time with the 5G EVE Edge Cloud to retrieve the augmented reality content.

The ARS NF is a lightweight web server using the Django Web framework, which interacts with the MDB NF, realized through Mongo DB, to retrieve the multimedia content and the 3D models.

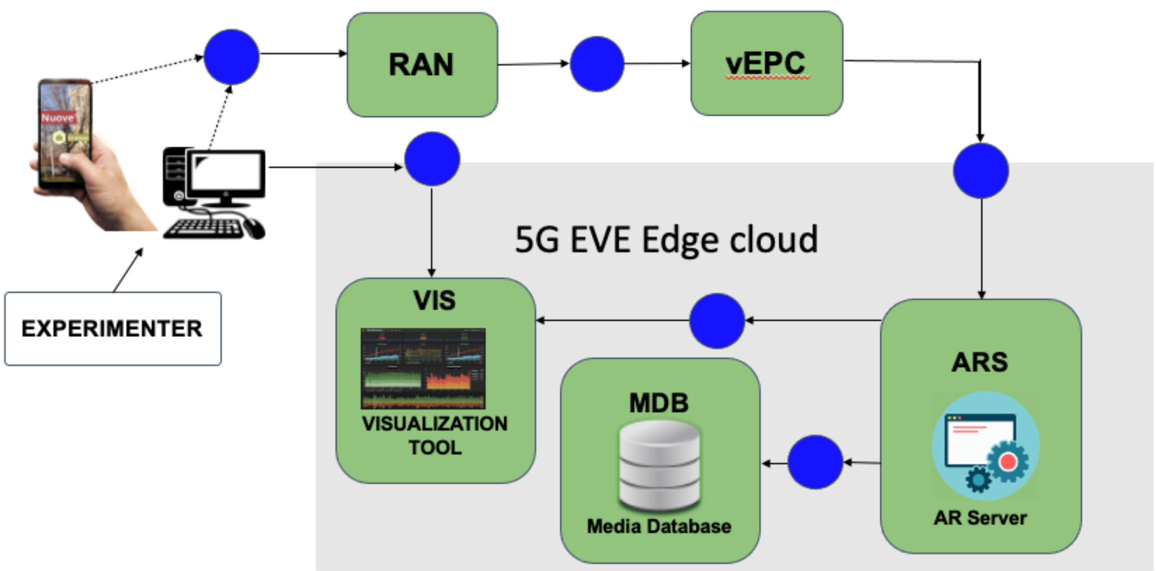


Figure 27: Smart Tourism (Italy) UC2.1 - Pilot architecture

2.3.3 Vertical service KPIs implementation

To collect the metrics, we used the data shipper available at [10]. In Table 6 we report the collected metrics and how we define the corresponding KPI:

Table 6: Smart Tourism (Italy) UC2.1 - Vertical Service KPIs

Use case title	**Smart Tourism: Augmented Fair experience**		
Site facility	**Italy**		
Vertical KPI name	**CPU consumption for the two VNFs**	**Memory consumption for the two VNFs**	**Network Delay Ratio**

Vertical KPI definition	the percentage of the available CPU capacity	the memory consumption of the two VNFs in MB	the ratio of the end-to-end delay due to the network with respect to the delay introduced by the multimedia server VNF, measured in percentage
Metric collection tools	Bash script based on the Linux command mpstat. Details on [25]	Bash script based on the Linux command free. Details on [25]	Custom bash+python script. Details on [25]
Position of the probes in the reference architecture 1) UE; 2) Public Cloud; 3) Private Cloud; 4) Edge	Edge (in VNF)	Edge (in VNF)	UE and Edge (in VNF)
Metric collection methodology	Metrics collected every 1 second	Metrics collected every 1 second	Metrics collected every 1 second
Validation tools	5G EVE Portal KPI validation tool	5G EVE Portal KPI validation tool	5G EVE Portal KPI validation tool
Validation methodology	The KPI is satisfied if the CPU remains < 80% of the maximum available in the edge cloud.	The KPI is satisfied if the memory remains < 80% of the maximum available in the edge cloud server (4GB in our case).	The KPI is satisfied if the ratio of the end-to-end delay due to the network with respect to the delay introduced by the multimedia server VNF, measured in percentage is below 10%.

2.3.4 Pilot deployments

The Use Case configuration is illustrated through the Vertical Service Blueprint (shown in Figure 28 and available in [11]) describing the different components and related connections.

The two dark blue boxes represent the major components (VNF) in the architecture:

1) "VR_server", which is the AR server mentioned above;
2) "VR_DB", which is the Django lightweight web server mentioned above.

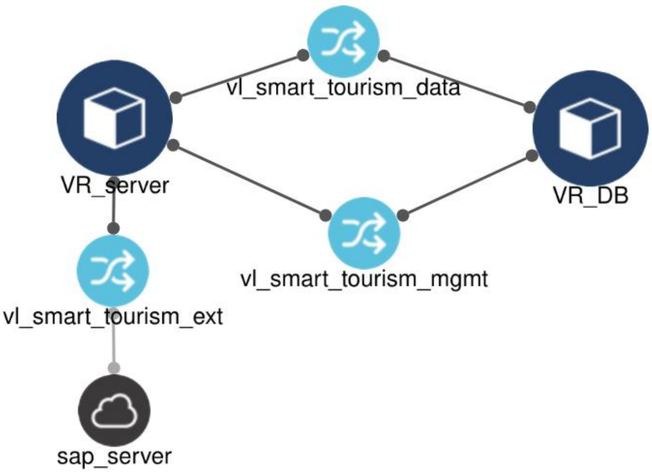


Figure 28: Smart Tourism (Italy) UC2.1 - Vertical Service Blueprint

2.3.5 Pilot execution results

We report below the results recorded with 20 clients simultaneously accessing the use case functionalities (i.e., requesting media content and AR features) over a window of 60 seconds, with no external traffic.

We report screenshots of the dashboard of the use case in Figure 29. In the first set of screenshots, shown below, one can see the CPU consumption of VR_DB (left) and VR_server (right). In both cases, the consumption is below 80%, which means that the first targeted KPI is satisfied.

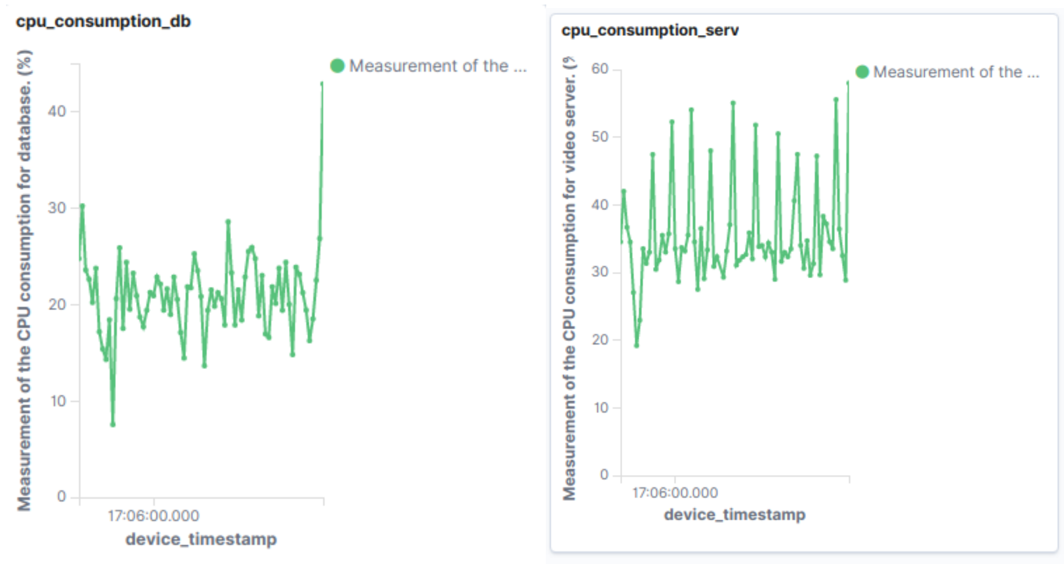


Figure 29: Smart Tourism (Italy) UC2.1 - VR_DB & VR_Server CPU usage

In the second set of screenshots, shown in Figure 30, one can see the memory consumption of VR_DB (left) and VR_server (right), measured in MB. Also, for this case, the targeted KPI is reached, with the maximum consumed memory being around 400MB, which is well below the KPI of <3.2GB (80% of 4GB).

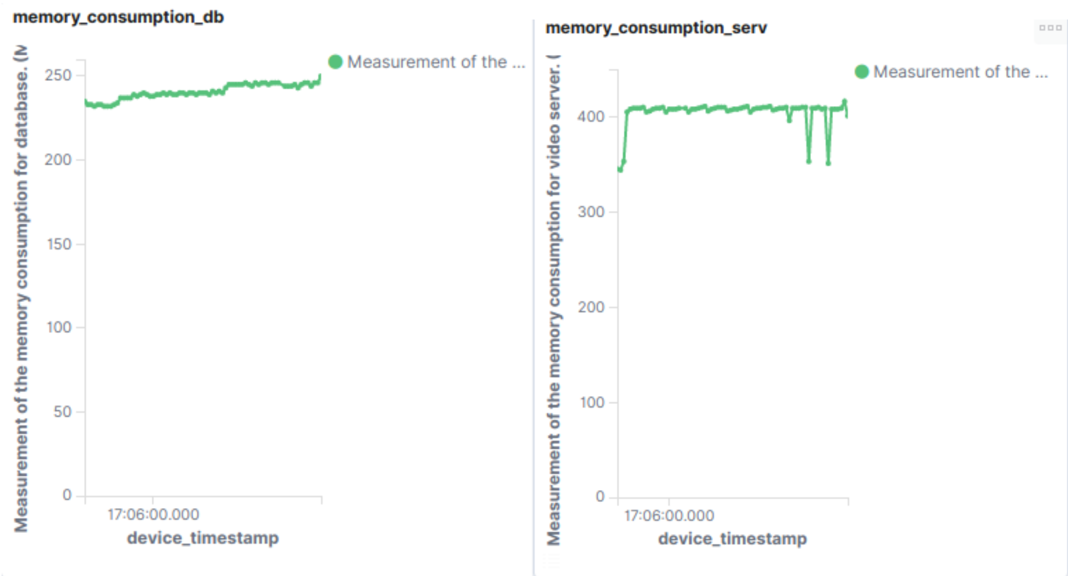


Figure 30: Smart Tourism (Italy) UC2.1 - VR_DB & VR_Server memory

In the last screenshot in Figure 31, we recorded the network delay ratio. So far, the KPI has not been reached, mainly due to the lack of optimization that is needed in the 5G access network, which would guarantee a sizable decrease in the end-to-end network delay.

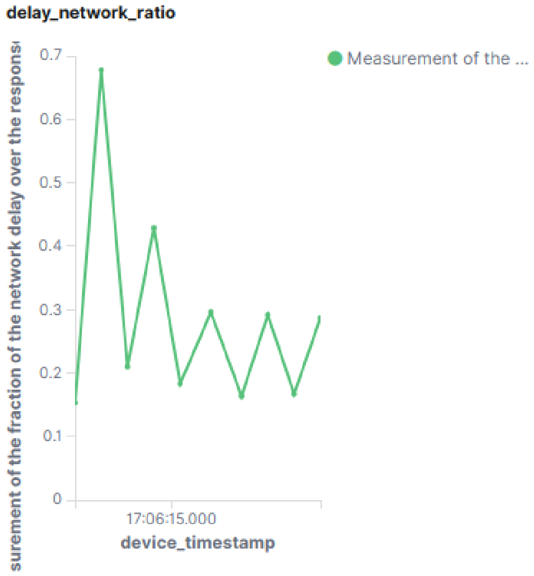


Figure 31: Smart Tourism (Italy) UC2.1 - Network delay

2.3.6 5G empowerment

5G will enable the utilization of computational resources at the edge, which are needed to process a large number of requests coming from user devices that may be concentrated in a small area (e.g., an archaeological site). The eMBB features of the 5G network are stressed as well by the need to provide large multimedia content to mobile devices using the application. Additionally, the low latency (thus leveraging the URLLC) will contribute to dramatically improve the user experience by making the AR features of the app more responsive.

2.3.7 5G EVE platform added value

The main added values of the 5G EVE platform for this use case have been the following:

- **Intent-based interface towards verticals**: the service is integrated with the 5G EVE portal.
- **Performance Diagnosis (KPI Framework)**: the service is integrated with the 5G EVE KPI monitoring system.

2.4 Use Case 2.2 - Smart Tourism: Experiential tourism

2.4.1 Pilot context

The ability to amplify and improve both participation and interaction of professionals, visitors and tourists in events related to tourism businesses, resources and destinations, is of great potential and interest for the tourism industry. Simultaneous organization and demand of events with a large number of users requires easing its organization and assistance, something that is already feasible thanks to the new possibilities of VR technology and real-time 360º video, and which results in an upgraded immersive experience for the attendees.

Validation tests have been fully carried out in two stages: by January 22nd, 2020, for the downlink distribution of 360º video over 5G, also demonstrated live at FITUR 2020 (International Tourism Trade Fair in Madrid) [12]; and by June 23rd, 2020 at 5TONIC premises, for the validation of live 360º video production and transmission over 5G. Trial implementation, execution and validations has involved SEG, YBVR (subcontractor), ERI-ES, TID, UC3M, IMDEA, TELC, NXW and WINGS.

2.4.1.1 Partner's roles

Vertical:

SEG and YBVR are responsible for defining the Use Case.

VNF provider(s):

SEG and YBVR provide the definition of the service to be offered in the Use Case. Note that, in this particular Use Case, both sub-Use Cases adopt over-the-top solutions, so that the services are outside 5G EVE scope and are deployed in a public cloud. In that way, it is not needed to deploy specific VNF(s) in the Spanish site.

Experiment developer(s):

Ericsson Spain supports the operation related to the introduction of this Use Case in the 5G EVE workflow, with the collaboration of TELC for technical support in the usage of the platform.

Experimenter(s):

Ericsson Spain takes care of the experiment execution, under the supervision of TELC, and also with the collaboration of YBVR, which manages the execution of the over-the-top solution.

Site Manager(s):

IMDEA Networks and UC3M, as Spanish site managers, play this role, authorizing and scheduling the execution of the validation campaigns for this use case at 5TONIC lab.

2.4.1.2 Trials

Trial 1 consisted of a two-day live demonstration in the International Conference of Tourism in Madrid FITUR, which was celebrated in January 2020. In the FITUR2020 conference, a 360º camera was installed at SEG`s stand to shoot all the conferences that were planned in the program. The camera was connected to a stitching server to build the spherical video, and then an ingest server was transmitting, in real time, the 360-degree video through the Ericsson 5G network into VR headsets located at a different location in the event, and also made available to the public. The setup is depicted in Figure 32.

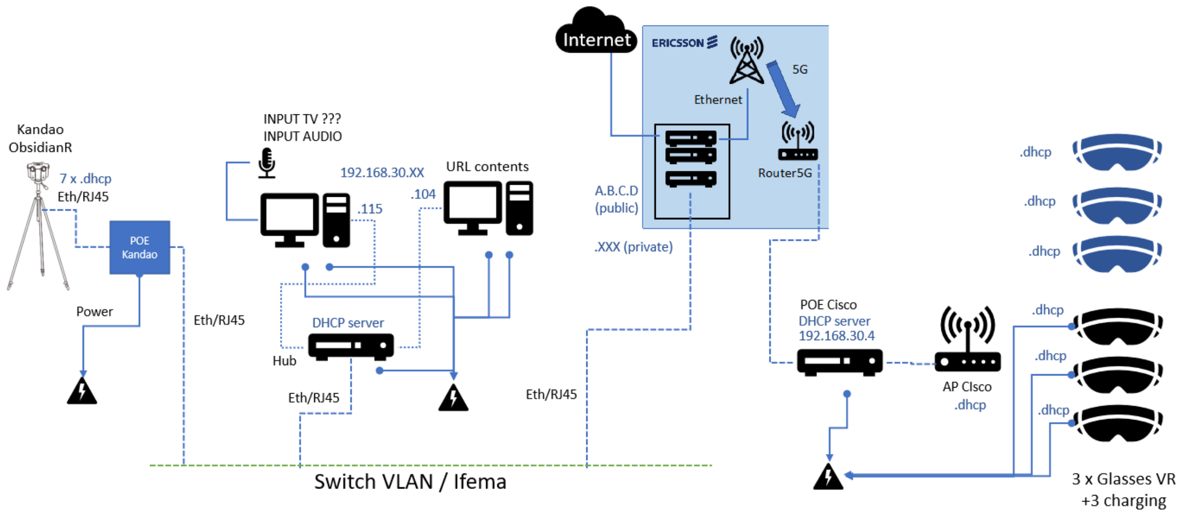


Figure 32: Smart Tourism (Spain) UC2.2 - FITUR Demo scheme

The **second trial** involved extensive validation at 5G EVE site in Madrid (5TONIC lab) proving how 5G network performance enables the delivery of optimal QoE for immersive experiences.

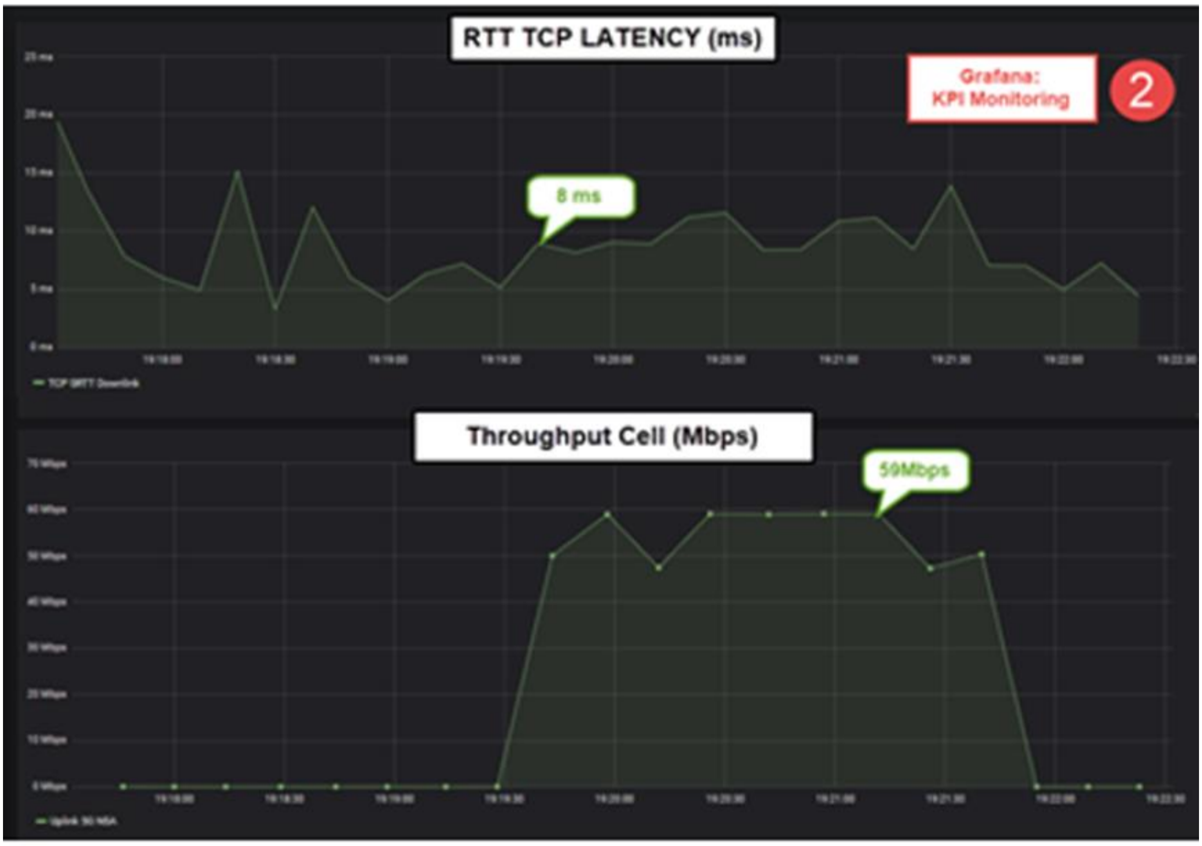


Figure 33: Smart Tourism (Spain) UC2.2 - Latency and UL throughput metrics

The latency of the user plane traffic introduced by the network is around 10 ms and the uplink throughput reaches peaks of 59 Mbps, as depicted in Figure 33.

Under a variety of test conditions, it has been determined that the actual consumption of uplink user data rate by the 360-degree video production system to secure a smooth user experience is within 59 Mbps (upper end) and 25 Mbps (lower end).

Several protocols for 360º video transmission (HTTP, RTMP) were tested and the resulting QoE validated.

Also, a wide range of terminals for accessing 5G network has been tested, from CPEs to low-end 5G pocket devices, all of them meeting the demands of the use case for the selected access network configurations.

Besides the show at FITUR2020, a webinar on this use case experimentation over the 5G EVE platform was held in June 2020 and it is available at [9].

2.4.2 Pilot architecture

Regarding SEG, the following sub-Use Cases can be distinguished:

Immersive events: participation in professional events is usual in the tourism industry, and now it is possible to improve the visibility of these events by providing a differential experience to attendees. Combining VR technology with 360º video it is possible to take the experience of digital immersion to the next level, offering the option of assistance to different events taking place simultaneously in different places, including remote immersive experiences thanks to the streaming of 360º video. Figure 34 depicts the immersive event architecture.

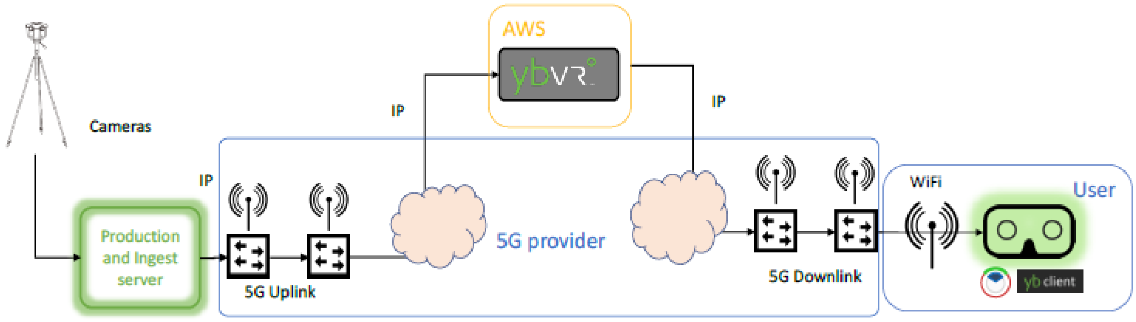


Figure 34: Smart Tourism (Spain) UC2.2 - Immersive events technical architecture

Virtual tickets: the sale of virtual tickets is an opportunity to generate new income sources in any professional event of the tourism industry, especially in the case of the Meetings, Incentives, Conferencing, and Exhibitions (MICE) sector. 5G technology will facilitate the reception of content via streaming concerning any event thanks to the improvement in connectivity and bandwidth. Event organizers could define virtual tickets packaging recorded contents according to multiple market segments, creating on-demand experiences very focused on the interest of the target audience.

The virtual tickets architecture is depicted in Figure 35.

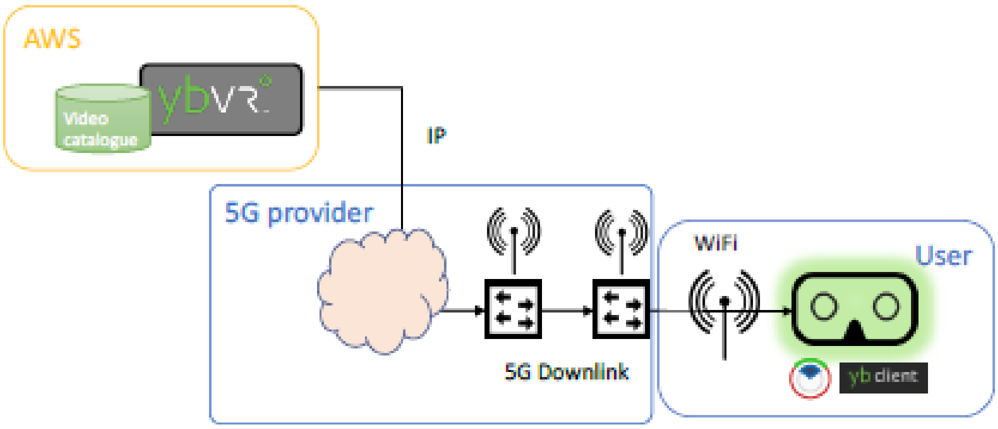


Figure 35: Smart Tourism (Spain) UC2.2 - Virtual tickets technical architecture

The prior trials have validated technical and business feasibility for streaming up of 360-degree live video being recorded at touristic events and locations over a 5G Access network to a remote server (in AWS) responsible, in turn, for world-wide rendering to end-users who enjoy an immersive experience of such event, through VR glasses, connected to the network also via 5G.

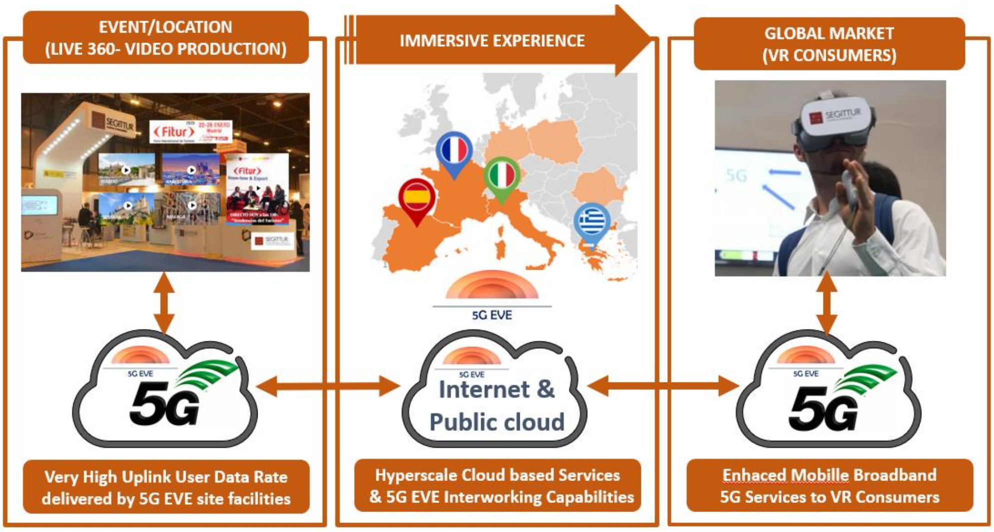


Figure 36: Smart Tourism (Spain) UC2.2 - 5G EVE Smart Tourism Trial - High-level Architecture

In order to enable global market reach for this solution, its architecture is based on three pillars: standards-based protocols and devices for both 360-video recording and visualization, distributed SW architecture for the vertical application fully leveraging internet and public cloud scale and relying on 5G networks for both uplink and downlink communications. So, the beauty of the introduced architecture for this E2E vertical solution lies in its easy to scale Over-The-Top deployment model, compatible with exploiting 5G eMBB service potential at the performance levels expected to be readily available for all early 5G commercial deployments and subscription fees. That secures a huge addressable market for this service, provided that 5G can really live up to the uplink user data rate demands for distribution of live 360 video recorded and transmitted over a 5G. And that is indeed the case for several access network configurations tested for this service at 5G EVE project, delivering superior QoE of 360-degree video.

Accordingly, 5G CSPs can also claim their key role in the value chain, as the actors who can configure, deliver and assure the required uplink user data rate, and offering a premium service.

2.4.3 Vertical service KPIs implementation

The two sub-Use Cases run on top of a 4G/5G network, executing the business logic in a public cloud. In that case, no services or virtual appliances are needed to be deployed within the 5G EVE site facilities, as the only requirement is to have connectivity, with the required performance, between the end-user devices.

The infrastructure implemented in 5TONIC Lab and related to the 5G EVE workflow is depicted in Figure 37 and the KPIs defined in Table 7:

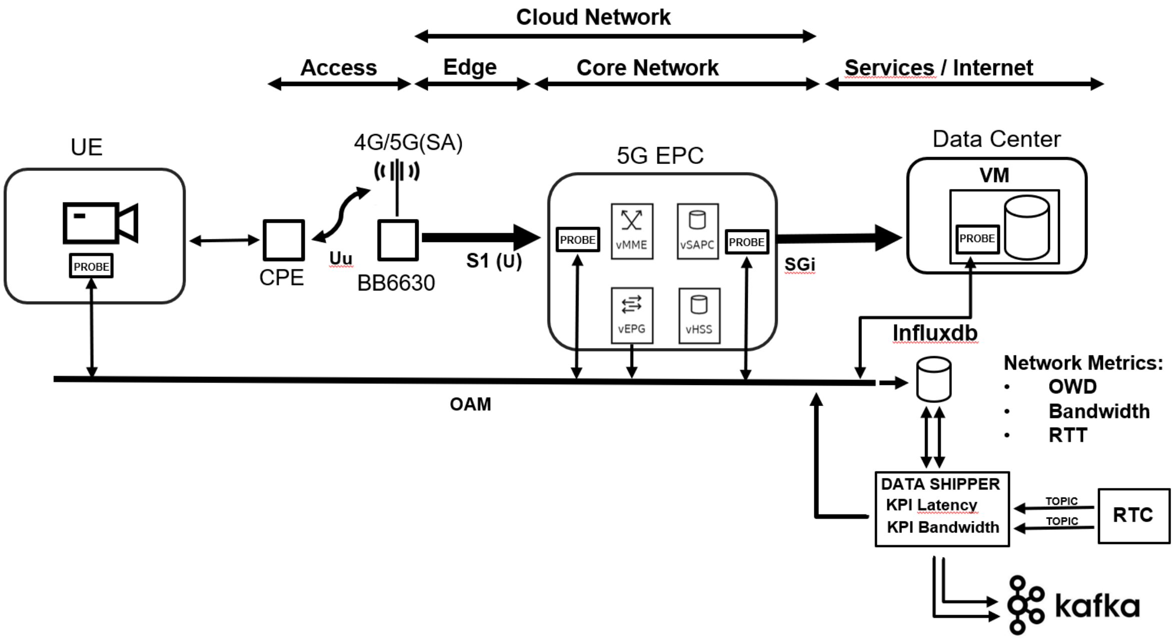


Figure 37: Smart Tourism (Spain) UC2.2 - Network infrastructure implemented in 5TONIC

Table 7: Smart Tourism (Spain) UC2.2 - Vertical service KPIs

Use case title	**Smart Tourism: Experiential tourism**			
Site facility	**5TONIC Madrid**			
Vertical KPI name	Camera changes	Mismatch time	Download bitrate	Upload bitrate
Vertical KPI definition	This metric shows the stress to the FOV adaptation mechanism by the number of completed camera changes	Average time without right frame for the current field of view	Bitrate reached while download	Bitrate reached while upload
Metric collection tools	YBVR counter in client software	YBVR counter in client software	Traces captured in client edge and PROBEs in Ericsson network	Traces captured in client edge and PROBEs in Ericsson network
Position of the probes in the reference architecture	UE	UE	UE	UE
Metric collection methodology	YBVR player simulate camera changes as soon as right frame for the current field of view is played, accounting the number of camera changes performed	YBVR player simulate camera changes and compare requested and reproduced viewport timing	YBVR player will meter regularly download bitrate	YBVR player will meter regularly upload bitrate
Validation tools	YBVR analysis	YBVR analysis	YBVR analysis	YBVR analysis
Validation methodology	Guidance: 5G should get at least 50% more camera changes than 4G	Guidance: 500ms or less during the entire playback; 200ms or less for	Guidance: It should consistently hit the top bitrate mark of 50Mbps.	Guidance: It should consistently hit the top bitrate

		95% of the playback		mark of 200Mbps.

2.4.4 Pilot deployments

Trial #1 Showcased at FITUR 2020. For providing 5G NSA network coverage, a backpack containing the 5G Radio Access and Core equipment was deployed and the required indoor antennas were installed in SEG booth at the fair. During the demonstration, activities carried out in an auditorium were visualized through virtual reality glasses connected to the 5G network, and also broadcasted live. In parallel, people who attended the 5G experience point at SEG booth, were able to travel, virtually, to destinations such as Toledo and Málaga (Spain), Santa Cruz (California), Geneva (Switzerland) or Melbourne (Australia). Figure 38 shows the 5G backpack deployed at the fair.

Figure 38: Smart Tourism (Spain) UC2.2 - FITUR trial and demo, January 2020

Trial #2 Completed in June 2020 and demonstrated at 5G EVE Webinar held on June 23rd, 2020. A 360-degree camera and YBVR production and ingest server were installed in 5Tonic lab and connected to Internet using the existing 5G network in the lab. The available radio band for this trial was TDD 3.5 GHz, using 50 MHz of spectrum. The TDD pattern was configured to 7:3, as it was needed to maximize the UL throughput. The recorded video was both stored in an Internet server and broadcasted live. The users connected to the live video streaming could virtually look around the room, feeling a superior QoE for this immersive experience.

Figure 39 shows the video streaming as visualized by the users (over a flat screen, in this picture). The date highlighted allows to see that is a real time stream. The video application took 3 seconds to process the image, is the difference between the time highlighted in a blue square and the time on the flat screen.

Figure 39: Smart Tourism (Spain) UC2.2 -5Tonic trial and demo, June 2020

Trial #3 The final tests were done in February 2021, in 5tonic lab. The available radio for this trial was similar to the one that we used in the last trial: TDD 3.5 GHz, 50 MHz of spectrum and with 7:3 as TDD pattern. However, in this case, we went one step further as we needed to maximize the UL throughput, configuring RAT (Radio Access Technology) aggregation. This feature takes advantage of having a NSA option 3x deployment [14], where the UE has stablished two legs for the 5G communication; in a standard 5G session the user plane goes only through 5G leg, although with this feature the user plane goes through the LTE leg plus 5G leg. The feature provides reordering buffer handling that avoids the probability of out of order packets and add maximum throughput of LTE plus NR.

In this last session, a UE containing the APPs was used to execute the four UC of this pilot. The UE was connected by ethernet to the CPE NR, which provided the connection to the 5G Ericsson network.

The KPI report was not being successfully shown in 5G-EVE portal, because the portal had some problems and did not executed the experiments, anyway the metrics could be measured using the same probes that the 5G-EVE portal should have used and were obtained the graphs in a Grafana local tool, outside the 5G-EVE portal.

2.4.5 Pilot execution results

Test cases were executed in the 4G and 5G environment. Although 5G measurements are the main goal of these test cases, 4G reference was useful to assess the quality improvements obtained with 5G technology. 4G tests were run in September 2019 and January 2020 test sessions. The results of those 4G tests are presented jointly with 5G test results.

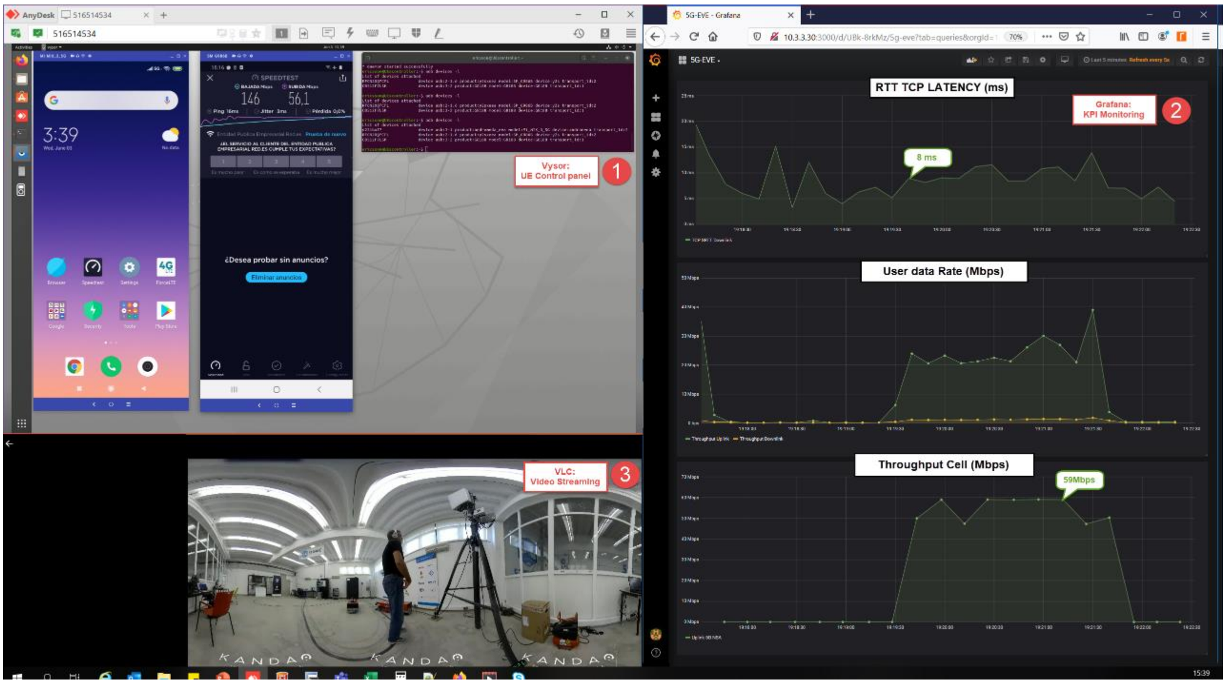


Figure 40: Smart Tourism (Spain) UC2.2 - SEG demo results

The uplink of the 5G network reaches peaks near 60 Mbps as shown in Figure 40, and it has been verified that there is a very good performance and user perception of the video when the camera is demanding a data rate of 25 Mbps.

The 5G results are an average of two rounds done during the last test session in February 2021. These results show exceptional performance for the YBVR service and prove the 5G capabilities to deliver a steady streaming service with real low latency (8ms average). The 5G radio setup for this latest session, where we used the feature RAT UL aggregation, improved UL throughput performance on the 5G network and reached peaks of 122 Mbps as shown in the results from UC 4.

The network KPIs: Latency, jitter, and throughput; they were measured with the probe at the core input and the graphs were generated in a local Grafana.

Camera changes evaluation

In Figure 41, the first set of measurements (Measurement A - Viewport adaptation speed) for 4G and 5G cases are shown. It is noticeable that the curve of 5G provides the best results closer to the ideal case and surpassing 90% of viewports changes under 400 ms.

Results under 4G show lower performance and the distribution curve does not reach 100%. This behavior is due to consecutive viewport changes during the playback sessions where the player does not have enough time to perform all viewport changes successfully.

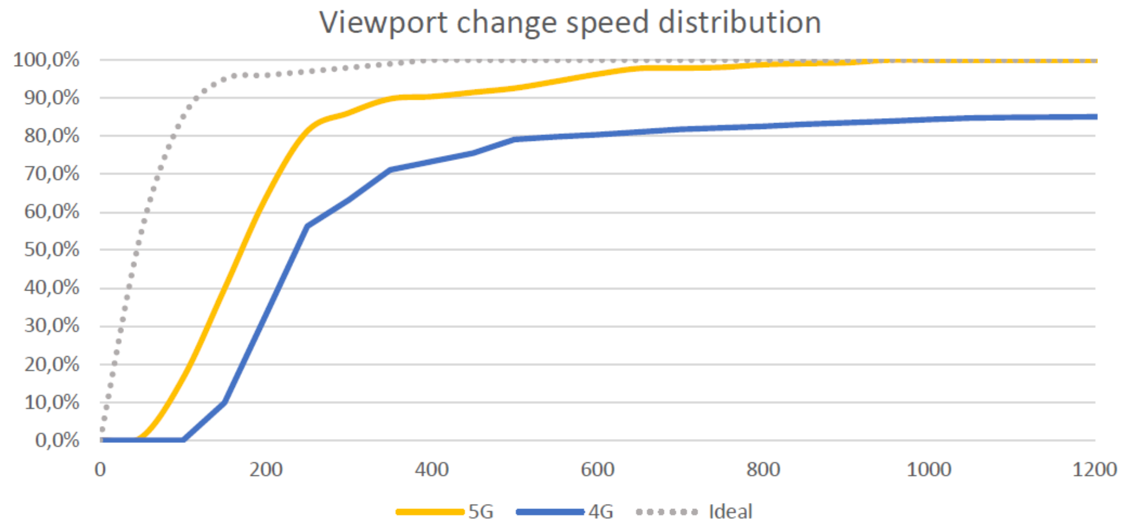


Figure 41: Smart Tourism (Spain) UC2.2 -Viewport change time distribution (viewport change)

Figure 42 shows the results for Measurement B (Mismatch Time). This parameter is depicted for both 4G and 5G cases. Again, the 5G case provides better results.

In this case, the curves are not as good as those seen before because the simulated head turn by the player generates fast viewport changes where the mismatch time is cumulative, so it usually involves more time. This means that the user spends more time gazing at a wrong viewport representation, than the time that it takes to execute the viewport change.

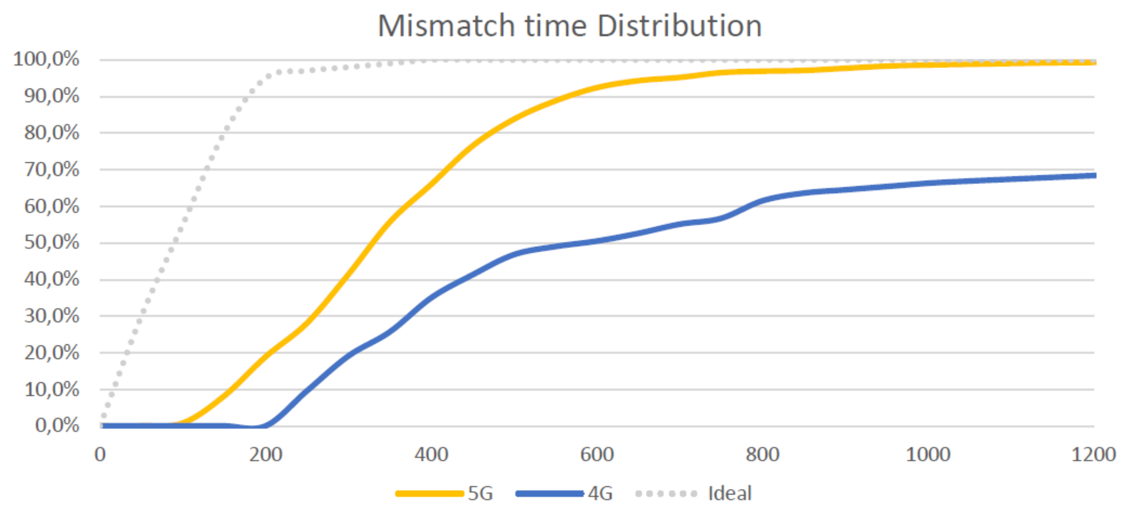


Figure 42: Smart Tourism (Spain) UC2.2 - Mismatch time distribution (viewport change)

Figure 43 depicts the RTT TCP downlink latency measured during the experiment. The Fluctuating measurements between 4 and 17 ms, being the average of 11 ms.

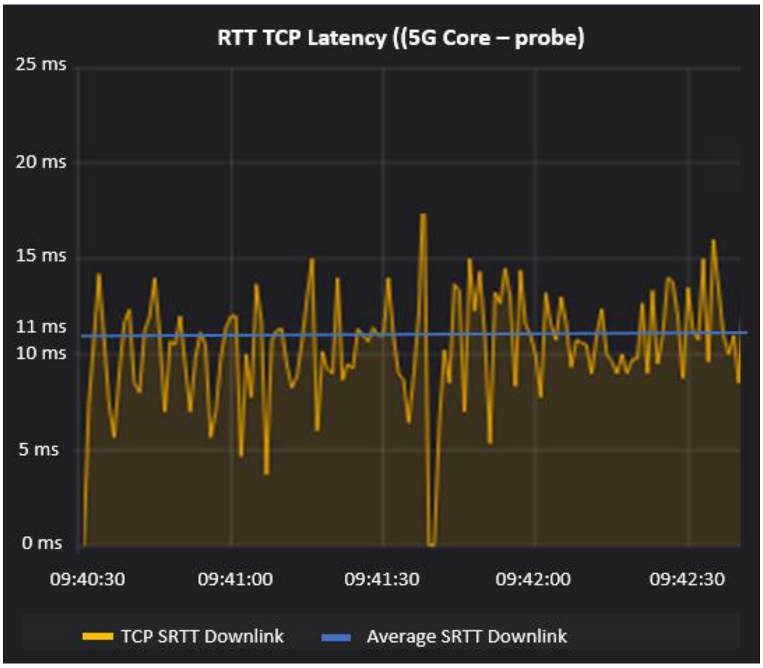


Figure 43: Smart Tourism (Spain) UC2.2 - RTT TCP Downlink Latency - 5G (viewport change)

For this period the jitter average was 6ms for downlink as show in Figure 44.

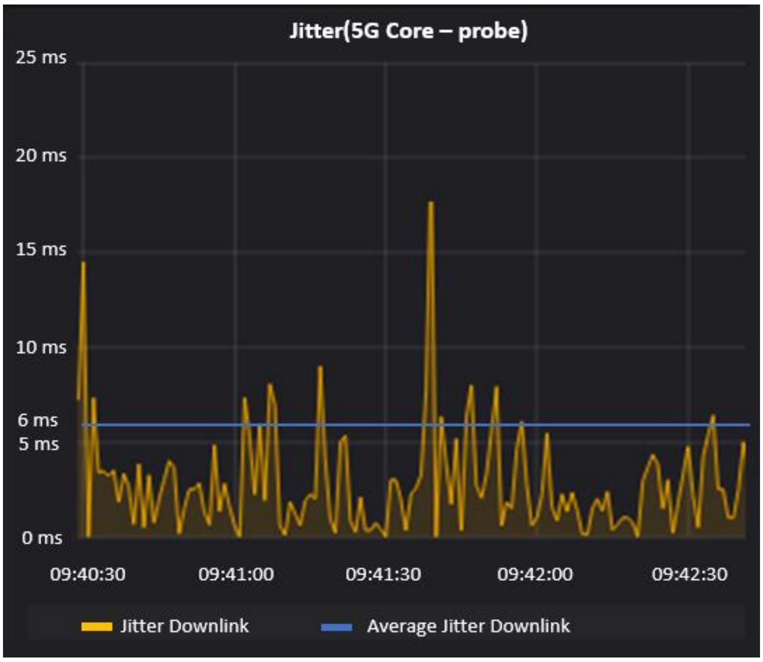


Figure 44: Smart Tourism (Spain) UC2.2 - Downlink Jitter - 5G (viewport change)

This radio configuration can provide 450 Mbps for downlink instant throughput. The peak demand during the test was 43 Mbps while the average was 28.1 Mbps (as depicted in Figure 45), including the period when no traffic was demanded.

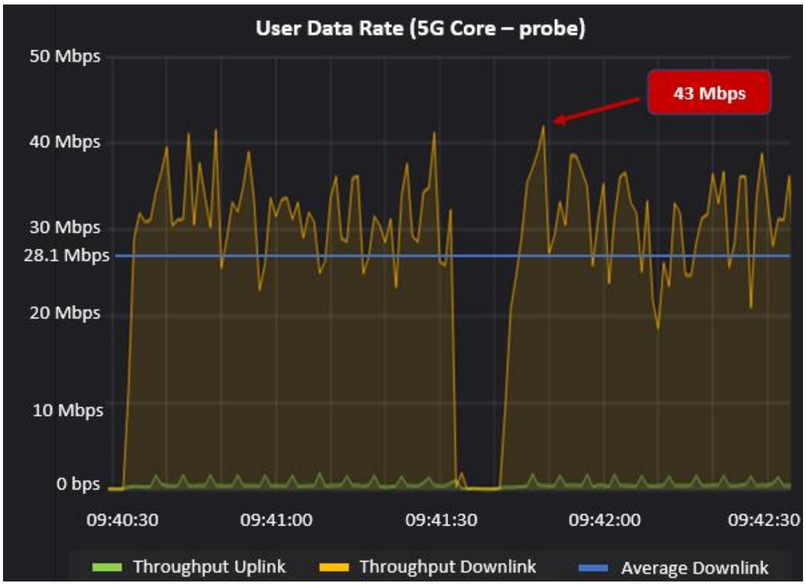


Figure 45: Smart Tourism (Spain) UC2.2 - User Data Rate Throughput - 5G (viewport change)

Mismatch time evaluation

Figure 46 shows the camera speed distribution. For this parameter, the change speed is more linear than it was seen in the viewport change because the camera change implies a clear order while viewport changes depend on the head position of the user and changes according to the player behaviour.

These results meet 5G technology expectations since Instant Camera Change (ICC) technology provided by YBVR is expected to last up to 1 second. As seen in Figure 4, most of the camera changes lasted between 150 and 250 milliseconds. Average results for 4G takes more time but are also good.

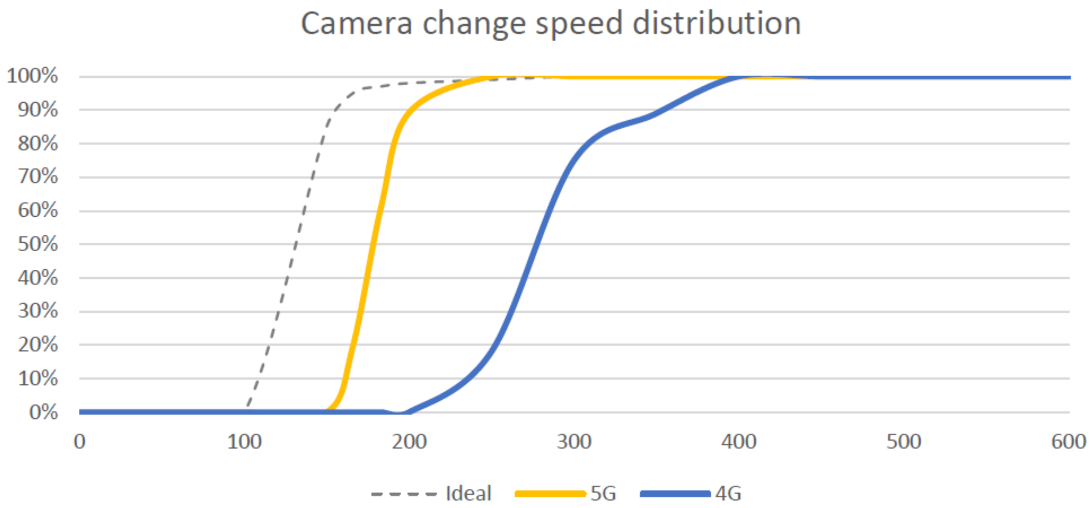


Figure 46: Smart Tourism (Spain) UC2.2 - Camera change speed distribution (camara change)

As expected, mismatch time distribution (depicted in Figure 47) is really close to camera change speed curves due to the differences between this measure and a viewport change as explained before.

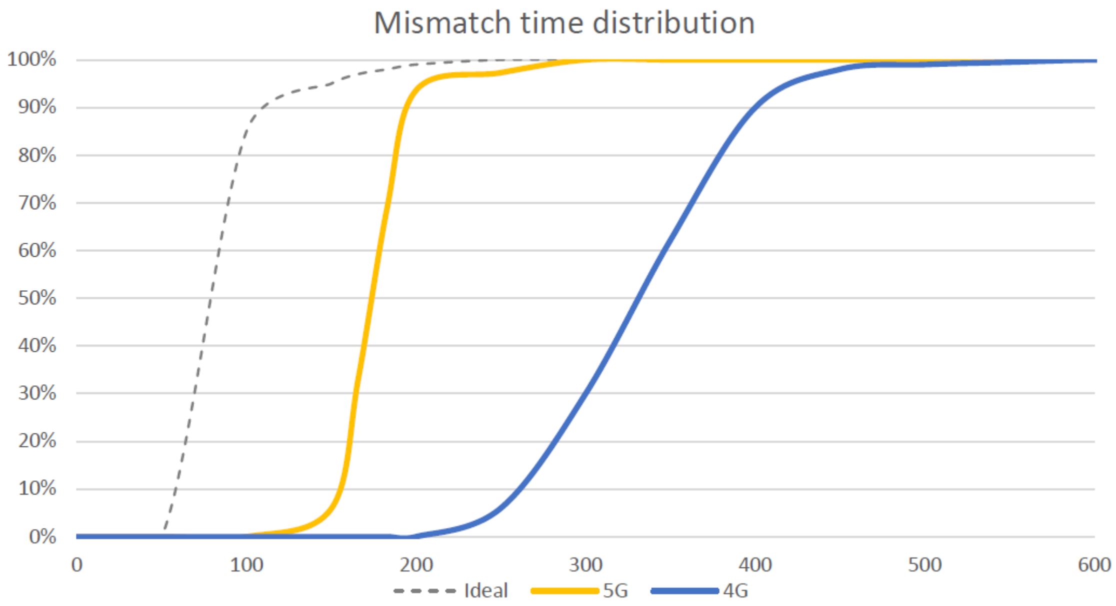


Figure 47: Smart Tourism (Spain) UC2.2 - Mismatch time distribution (camara change)

The latency in the camera change, depicted in Figure 48, is very similar with the viewport change, and the average is 10 ms, 1 ms less than viewport changes.

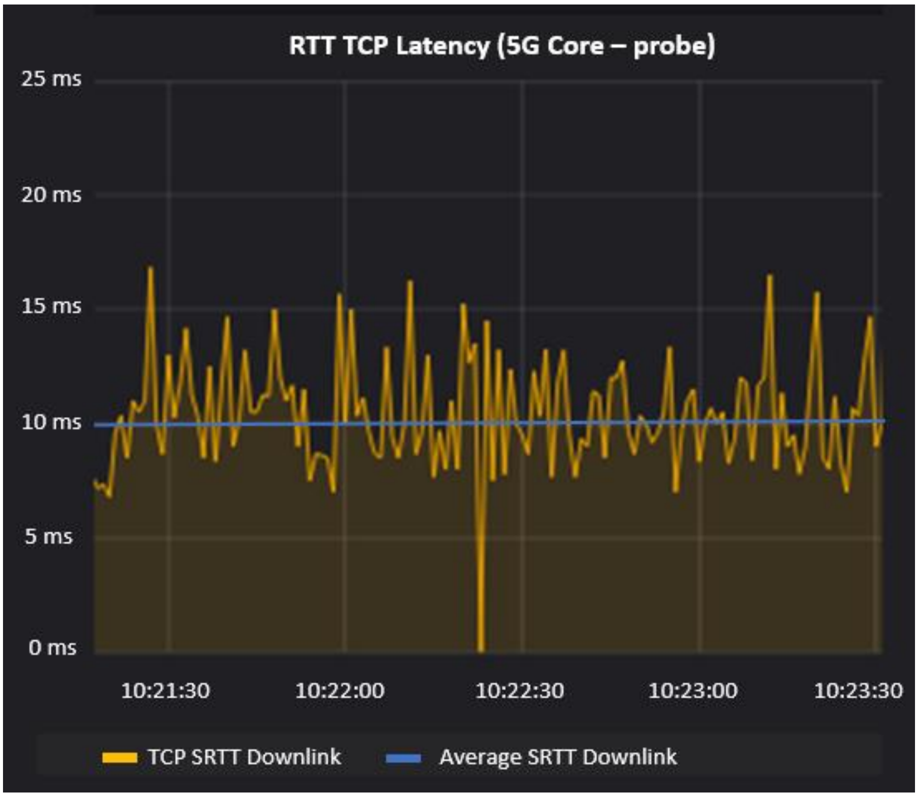


Figure 48: Smart Tourism (Spain) UC2.2 - RTT TCP Downlink Latency - 5G (camara change)

Figure 49 shows the jitter measurements where the average was 4ms for downlink, which was lower than the viewport changes average jitter (6 ms).

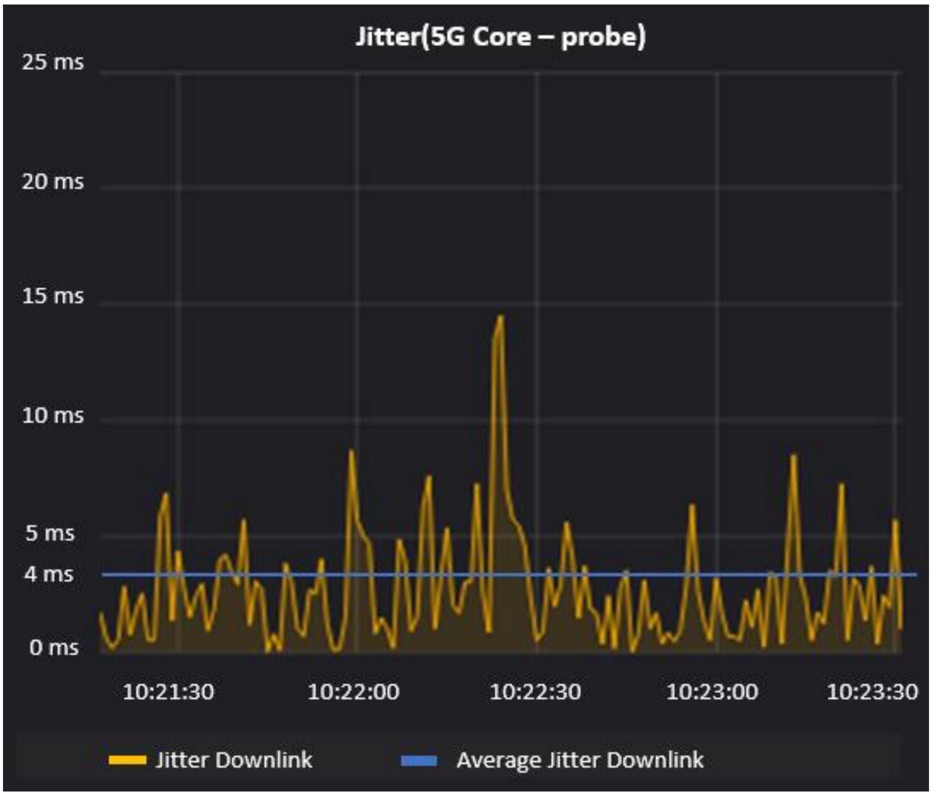


Figure 49: Smart Tourism (Spain) UC2.2 - Downlink Jitter - 5G (camera change)

Regarding instant throughput downlink, the test reached 45 Mbps peaks, which is still far from the maximum capacity of 5G radio (450 Mbps). The average measurement for the camera change test was 45 Mbps, as depicted in Figure 50.

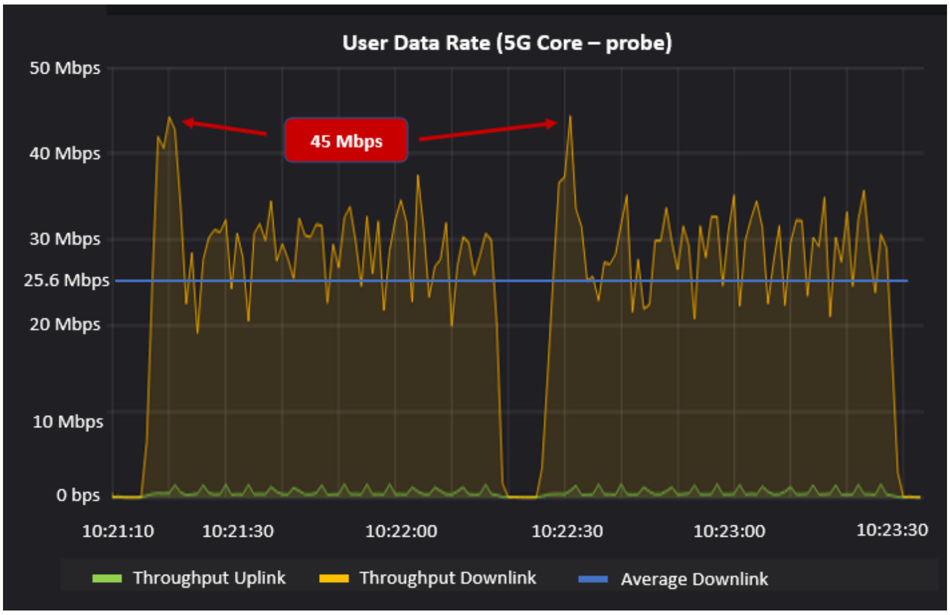


Figure 50: Smart Tourism (Spain) UC2.2 - User Data Rate Throughput - 5G (camera change)

Download bitrate evaluation

The first difference to consider is the stability between the downlink for both deployments. 5G network was tested with a device connected to the 5G modem in ethernet, so the bitrate was steady and close to 50 Mbps during the whole test despite small drops. On the other hand, 4G tests were made with a device connected to the 4G modem using a WiFi link, which could explain some of the instability and the final average of over 25 Mbps. The results over time are depicted in Figure 51, while the average bitrate is depicted in Figure 52.

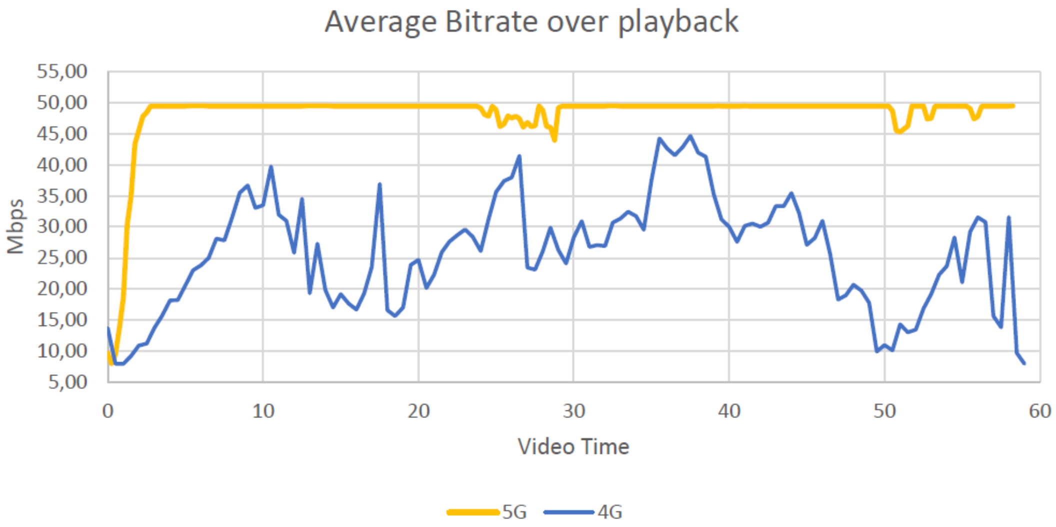


Figure 51: Smart Tourism (Spain) UC2.2 - Bitrate over playback on 5G vs 4G (downstream distribution)

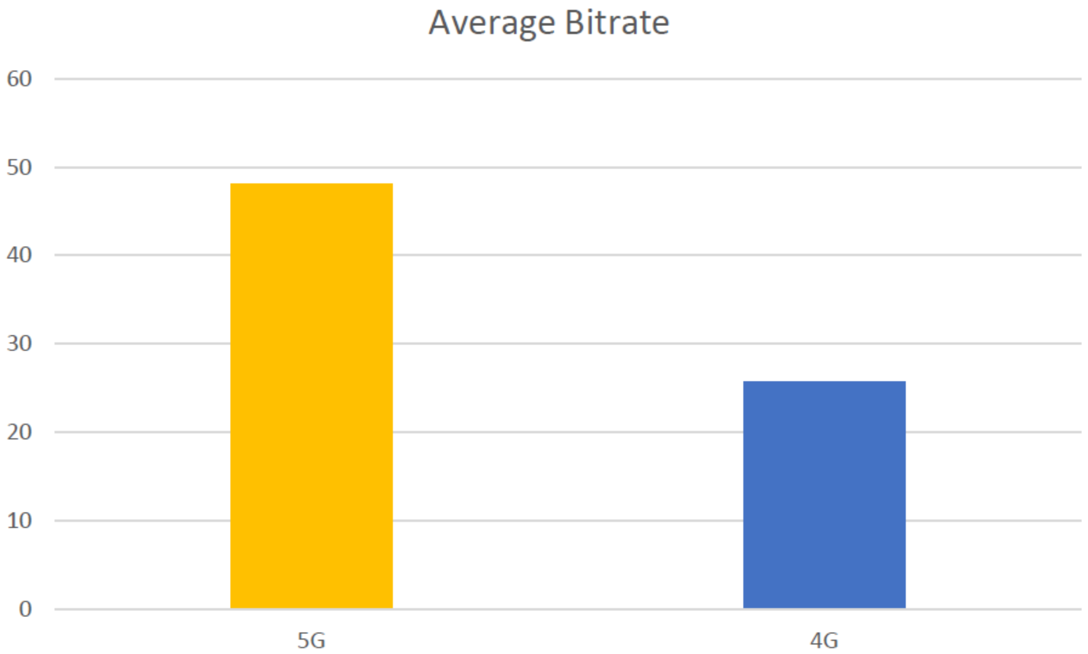


Figure 52: Smart Tourism (Spain) UC2.2 - Average Bitrate 5G vs 4G (downstream distribution)

The instant throughput downlink measurement with the probe in the 5G core shows peaks of 140 Mbps and a 66 Mbps average in layer 2, as depicted in Figure 53.

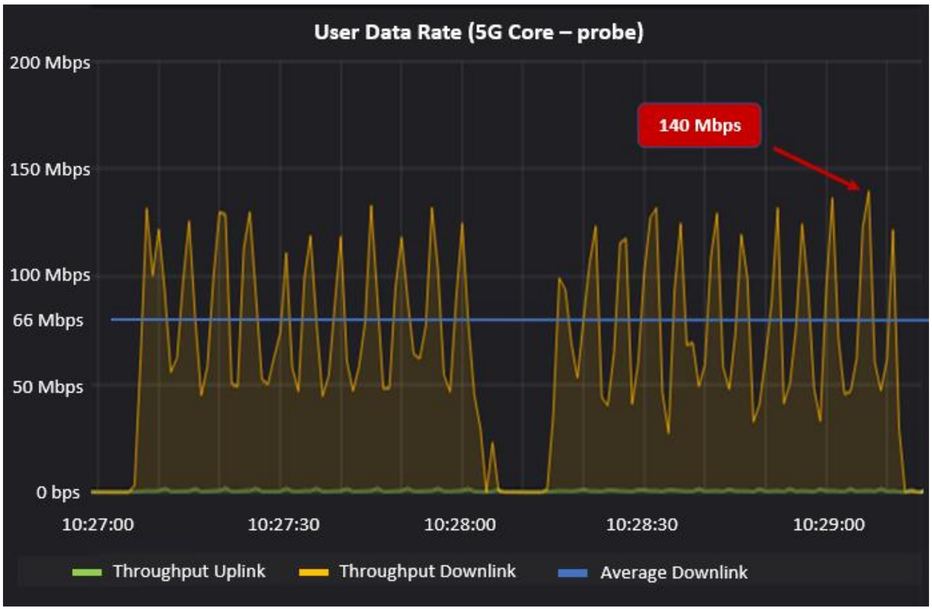


Figure 53: Smart Tourism (Spain) UC2.2 - User Data Rate Throughput - 5G (downstream distribution)

The latency of RTT TCP was 10 ms on average and a jitter of 4.5 ms, very close to the data obtained in the UC1 and UC2, as depicted in Figure 54 and Figure 55 respectively.

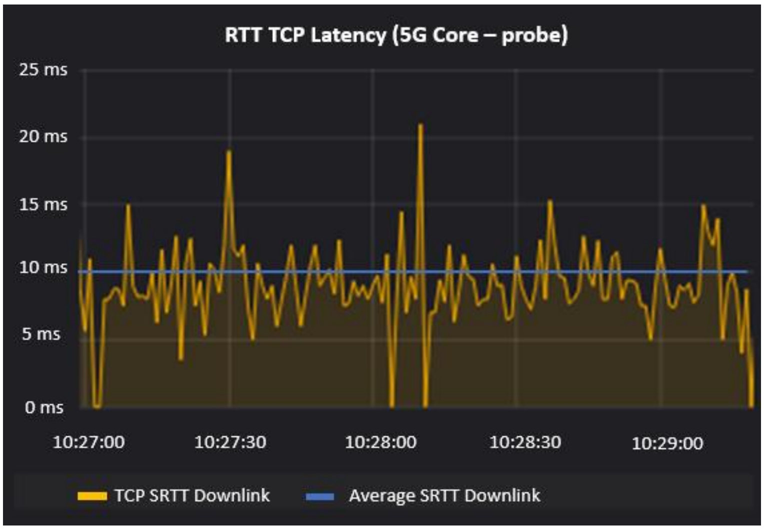


Figure 54: Smart Tourism (Spain) UC2.2 - RTT TCP Downlink Latency - 5G (downstream distribution)

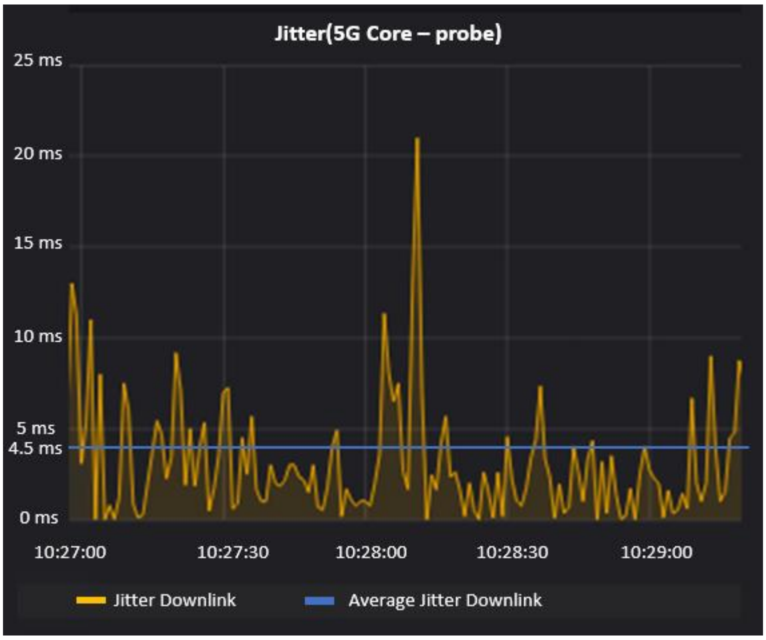


Figure 55: Smart Tourism (Spain) UC2.2 - Downlink Jitter - 5G (downstream distribution)

Upload bitrate evaluation

The results for 5G speeds were as expected: a sustained value of approx. 100 Mbps. This was the limit for the setup we currently had but it shows that with the bandwidth available, we were able to consistently use the full bandwidth to upload segments.

However, we saw a behaviour with all the tests we performed: a slow-start or maybe a “window” negotiation, which caused the first few seconds of upload to be a ramp-up phase, as verified with iperf as depicted in Figure 56. Since the tests consist of uploading 6-second video files, the slow start caused files to accumulate since every new file also needed a ramp-up until it used the full bandwidth available.

```
❯ iperf3 -c 34.250.43.37
Connecting to host 34.250.43.37, port 5201
[  4] local 172.22.49.198 port 55532 connected to 34.250.43.37 port 5201
[ ID] Interval           Transfer     Bandwidth       Retr  Cwnd
[  4]   0.00-1.00   sec  2.53 MBytes  21.2 Mbits/sec    0    192 Kbytes
[  4]   1.00-2.00   sec  5.42 MBytes  45.5 Mbits/sec    0    428 Kbytes
[  4]   2.00-3.00   sec  8.99 MBytes  75.5 Mbits/sec    0    825 Kbytes
[  4]   3.00-4.00   sec  11.8 MBytes  98.9 Mbits/sec    0   1.33 Mbytes
[  4]   4.00-5.00   sec  11.2 MBytes  94.4 Mbits/sec    0   1.58 Mbytes
[  4]   5.00-6.00   sec  12.5 MBytes   105 Mbits/sec    0   1.58 Mbytes
[  4]   6.00-7.00   sec  12.4 MBytes   104 Mbits/sec    0   1.58 Mbytes
[  4]   7.00-8.00   sec  12.2 MBytes   102 Mbits/sec    0   1.58 Mbytes
[  4]   8.00-9.00   sec  12.5 MBytes   105 Mbits/sec    0   1.58 Mbytes
[  4]   9.00-10.00  sec  12.5 MBytes   105 Mbits/sec    0   1.58 Mbytes
- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bandwidth       Retr
[  4]   0.00-10.00  sec   102 MBytes  85.7 Mbits/sec    0             sender
[  4]   0.00-10.00  sec  99.8 MBytes  83.7 Mbits/sec                  receiver
```

Figure 56: Smart Tourism (Spain) UC2.2 - iPerf results from 5G to AWS Cloud (upstream distribution)

As we can see, it took 3 seconds to achieve 75% of the bandwidth and then 3 more to fully utilize the 100 Mbps that were available. We performed a longer iperf to make sure the sustained speeds would be maintained in a longer session as seen in Figure 57.

```
Accepted connection from 193.145.14.196, port 1206
[  5] local 10.0.10.4 port 5201 connected to 193.145.14.196 port 1208
[ ID] Interval           Transfer     Bandwidth
[  5]   0.00-1.00   sec  2.63 MBytes  22.1 Mbits/sec
[  5]   1.00-2.00   sec  6.22 MBytes  52.2 Mbits/sec
[  5]   2.00-3.00   sec  10.7 MBytes  90.2 Mbits/sec
[  5]   3.00-4.00   sec  13.5 MBytes   113 Mbits/sec
[  5]   4.00-5.00   sec  12.9 MBytes   108 Mbits/sec
[  5]   5.00-6.00   sec  12.9 MBytes   109 Mbits/sec
[  5]   6.00-7.00   sec  13.0 MBytes   109 Mbits/sec
[  5]   7.00-8.00   sec  13.0 MBytes   109 Mbits/sec
[  5]   8.00-9.00   sec  13.5 MBytes   114 Mbits/sec

...

[  5]  53.00-54.00  sec  12.8 MBytes   107 Mbits/sec
[  5]  54.00-55.00  sec  13.3 MBytes   112 Mbits/sec
[  5]  55.00-56.00  sec  13.0 MBytes   109 Mbits/sec
[  5]  56.00-57.00  sec  12.9 MBytes   108 Mbits/sec
[  5]  57.00-58.00  sec  12.8 MBytes   107 Mbits/sec
[  5]  58.00-59.00  sec  12.7 MBytes   107 Mbits/sec
[  5]  59.00-60.00  sec  12.9 MBytes   108 Mbits/sec
[  5]  60.00-60.12  sec  1.50 MBytes   102 Mbits/sec

- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bandwidth
[  5]   0.00-60.12  sec  0.00 Bytes  0.00 bits/sec                  sender
[  5]   0.00-60.12  sec   760 MBytes   106 Mbits/sec                  receiver
```

Figure 57: Smart Tourism (Spain) UC2.2 - iPerf results for 1 minute session (upstream distribution)

As expected, a longer session utilises the full 100 Mbps of available bandwidth required which would for this KPI evaluation. However, a few more adjustments would go a long way in ensuring that the slow start is minimized.

Figure 58 shows this behaviour when establishing new sessions: the 5G total bandwidth dips and starts climbing until it reaches ~100Mbps while the 4G is less susceptible to this “window negotiation” or handshake, albeit with lower speeds.

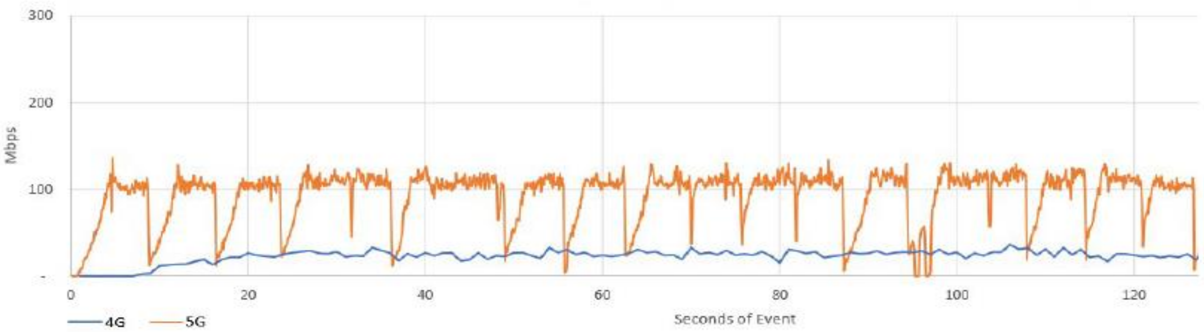


Figure 58: Smart Tourism (Spain) UC2.2 - Total bandwidth per seconds of event (upstream distribution)

This KPI evaluation demanded all 5G uplink capability configured in the radio setup. The instant throughput Uplink in this measurement with the probe in the 5G core shows peaks of 122 Mbps and a 95.2 Mbps average in layer 2, as shown in Figure 59.

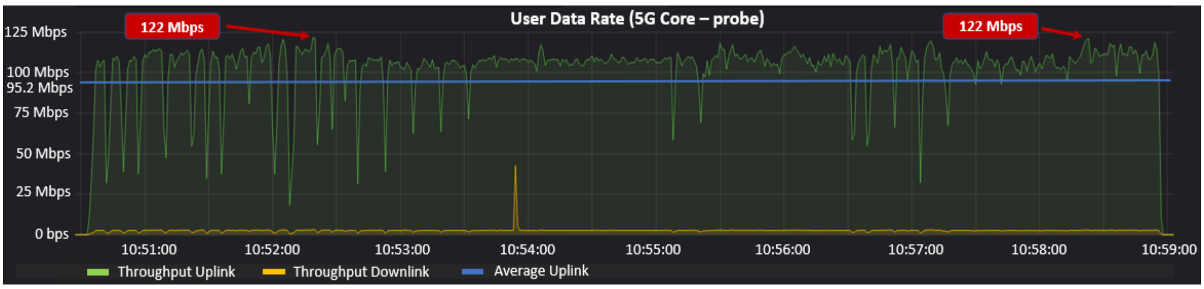


Figure 59: Smart Tourism (Spain) UC2.2 - User Data Rate Throughput - 5G (upstream distribution)

2.4.6 5G empowerment

High-definition contents (4K/8K) in the 360-degree video format allow the surround view, to different angles and from different cameras. It is here where 5G technology plays a fundamental role and introduces new features giving a big push to video VR streaming implementation.

- 5G uplink user data rate of over 50 Mbps allows to perform live VR streaming from whatever place with 5G coverage. Otherwise, the solution is limited to fibre reach.
- 5G low latency is a valuable help for adaptive field of view technologies, improving video VR quality for the users.
- 5G downlink user data rate will improve users experience and operational deployment of VR experiences.

5G technology supports this Smart Tourism system trialled at 5G EVE platform in two complementary ways:

1. 5G high-reliability and high-throughput performance of over 50 Mbps for uplink communications (for 50 MHz bandwidth available in mid bands spectrum) are the key enablers for this solution, since they allow for transmission of the vast amount of data being recorded with 180- or 360-degree cameras. This differential KPI of 5G removes the painful dependency of this type of remote live production video with wired infrastructure (not flexible and very expensive, if available at all at the location) or satellite communications. It also overcomes the limitations of previous mobile communication standards, which were not designed for allowing the high uplink data rate demanded for this solution in standard coverage models.
2. 5G eMBB not only copes with the capacity and downlink user data rate needs for distribution of 360-degree video to users enjoying it in a variety of devices, but also secures a rapid market uptake and viable business model for this type of services being the standard service available to all subscribers of 5G commercial networks.

2.4.7 5G EVE platform added value

5GEVE platform allows not only to easily execute testing but to maximize control all over the process from beginning to end. The platform allows verticals and experiment developers to easily configure experiments, selecting a target 5G environment, browsing a wide portfolio of tools and service components to build each experiment and creating new blueprints to easily reproduce testing with different operational conditions.

Once the experiment settings are configured, the experimenter has just to schedule a time slot to run the experiment and wait for the environment preparation. 5GEVE platform test execution and monitoring environment has a transparent and self-explanatory interface which has granted us to monitor the experiment progress and visualize monitoring graphs for every metrics, logs and KPIs.

2.5 Use Case 3.1 - Industry 4.0: Autonomous vehicles in manufacturing environments (Spain)

2.5.1 Pilot context

The objective of this use case is to assess the viability of operating 5G connected Autonomous Guided Vehicles (AGVs) in factories, with the control of the vehicle virtualized at the edge of the network. In particular, the vehicle's control is moved out of the physical unit, implementing it in a computing node that meets the latency requirements for the AGV operation. The AGV collects the information from its sensors and sends it to the virtual controller through a wireless connection. This information from the sensors is processed in the virtual process logic controller (vPLC) that generates the commands to be executed by the AGV actuators. These orders are sent again through the wireless connection to the AGV, where they direct the different actuators' actions in the next action period.

2.5.1.1 Partner’s roles

Vertical:

ASTI is in charge of defining its high-level service requirements and vertical service KPIs to the experiment developers.

VNF provider(s):

ASTI, UC3M, ERI-ES

UC3M is providing the VNFs for both the virtualized controller (i.e., Virtual PLC) and context conditions (i.e., delay and packet loss).

ASTI has installed and configured the MasterPLC software on the provided Master PLC VNF.

ERI-ES is providing and configuring the 5G NSA network, i.e., both VNFs and PNFs.

Experiment developer(s):

UC3M, ASTI & ERI-ES

UC3M is in charge of designing and defining all blueprints (VSB, CtxBs, ExpB, TCB) related to the UC.

UC3M and ASTI are responsible for defining mechanisms to collect the application metrics from the AGVs and to define the Vertical Service KPIs.

ERI-ES is responsible for the infrastructure metrics (i.e., Network KPIs) collection related to the UC (Latency and Packet loss).

Experimenter(s):

UC3M & ASTI

UC3M and ASTI are in charge of preparing and scheduling the experiment.

UC3M is in charge of ensuring that the experiment is running correctly.

UC3M is responsible for ensuring that the defined UC Metrics & KPIs are being collected and received by the 5G EVE Data Collection, Storage, and Visualization tools.

Site Manager(s):

IMDEA, ERI-ES & UC3M

IMDEA Networks Institute and Ericsson are responsible for managing a subset of the UC experiment components (i.e., AGVs, 5G CPE, 5G NR RAN, and 5G NSA vEPC).

UC3M is in charge of managing the virtual components of the UC that will be under the control of the 5G EVE platform (i.e., MasterPLC and Context VNFs).

2.5.1.2 Trials

The vertical service KPIs for this use case, as defined by the vertical, are guide error and power consumption and they are described in Table 8. The guide error is computed as the difference between the current AGV position and the targeted path. In contrast, the power consumption is obtained as the amount of current that the AGV is using while in transit. These two KPIs are highly correlated, i.e., the bigger the guide error, the more power the AGV consumes while correcting its path deviation. For this use case, it is also worth noting that these vertical service KPIs, i.e., guide error and power consumption, are equivalent to the application metrics. Subsequently, the following tests were executed to evaluate the indicated vertical service KPIs:

a) Evaluation of the AGV performance with 5G NSA without any network impairments versus 4G; this test was carried out to obtain the best-case scenario performance of the AGV with 5G NSA. This 5G best-case scenario performance was compared to 4G under the same conditions.

b) Evaluation of the AGV performance with 5G NSA experiencing forced discrete packet losses; this test was undertaken to analyse the AGV performance when served by hazardous factory radio channels of varying degrees.

c) Evaluation of the AGV performance with 5G NSA experiencing forced discrete delays; this test was conducted to analyse the effect on AGV performance due to the different deployment locations of the virtualized controller.

2.5.2 Pilot architecture

The trial architecture for the use case is depicted in the Figure 60:

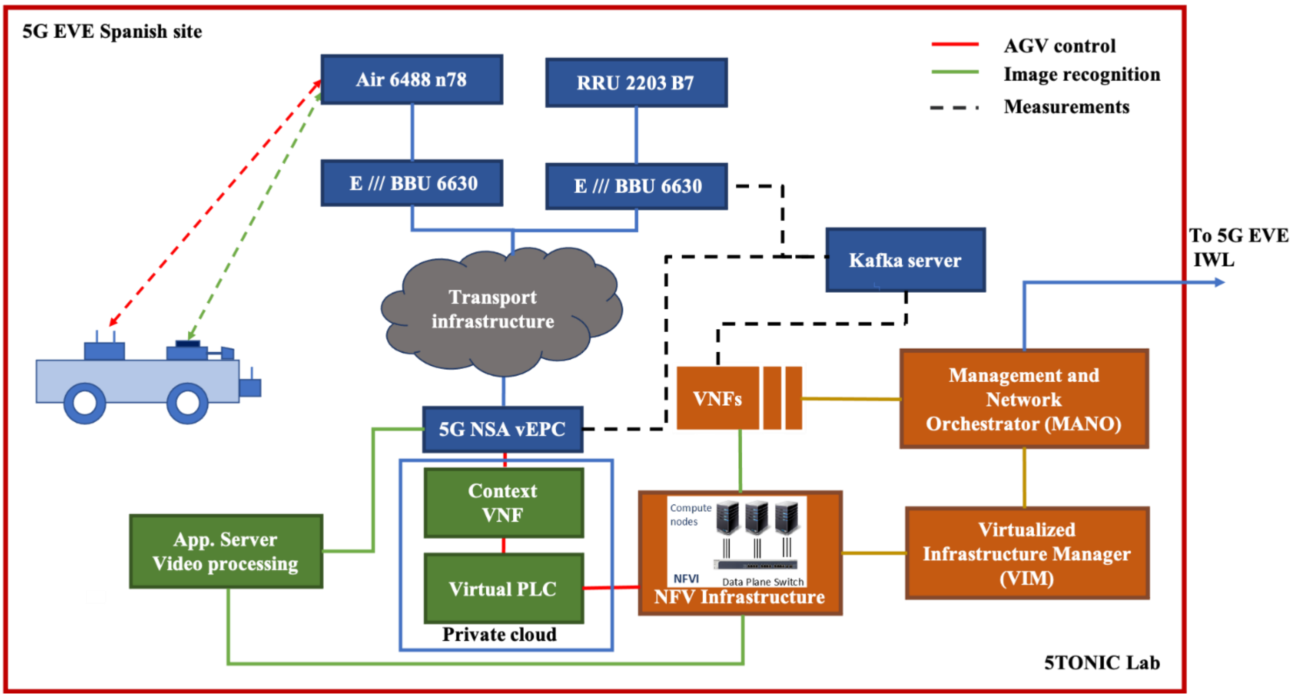


Figure 60: Industry 4.0 (Spain) UC3.1 - Pilot architecture

The system encompasses:

- Radio Access network supporting high performance 5G NSA access.
- Virtual EPC supporting NSA access.
- Virtualized processing platforms, implementing the functionalities required to host the virtualized controller (Virtual PLC) and the context conditions (Context VNF) VNFs.

- NFV infrastructure is composed of both the management and network orchestration (MANO) and virtualized infrastructure manager (VIMs) platforms.
- The MANO platform is based on OSM and is in charge of configuring and instantiating the VNFs associated with the use case, i.e., Virtual PLC and Context VNF.
- The VIM platform is in charge of managing all the compute nodes hosting the VNFs and is based on OpenStack.
- The 5G EVE data collection manager (i.e., Kafka server) is responsible for the application and infrastructure metrics collection to derive vertical service and network KPIs, respectively.

The 5G EVE Spanish site is connected to the Interworking Layer (IWL) in Turin to facilitate the vertical use case's instantiation and execution from the 5G EVE portal.

2.5.3 Vertical service KPIs implementation

For this use case, the vertical service KPIs are guide error and power consumption, whereas the relevant network KPIs are latency and packet loss.

For these trials, only the vertical service KPIs were collected and analysed; however, we plan to collect and analyse the network KPIs in the upcoming trials which are out of the scope of 5G EVE project. To collect the vertical service KPIs, the packets were captured from the context VNF using the Linux “tcpdump” tool [15]. Filebeat [16] was used to ship the application metrics to the 5G EVE data collection manager (indicated as the Kafka server in UC architecture). Filebeat was installed in the context VNF attached to the virtualized controller.

Therefore, we processed the received application metrics from the 5G EVE monitoring platform and validated the vertical service KPIs described in Table 8.

The use case KPI collection schema following the 5G-PPP 5G general schema (see Annex A) is presented in the Figure 61.

Table 8. Industry 4.0 (Spain) UC3.1 - Vertical service KPIs

Use case title	**Industry 4.0: Autonomous vehicles in manufacturing environments**	
Site facility	**5TONIC**	
Vertical KPI name	**Guide error**	**Power consumption**
Vertical KPI definition	The guide error is computed as the difference between the current AGV position and the targeted path.	The power consumption is obtained as the amount of current that the AGV is using while in transit
Metric collection tools	Tool provided by the vertical	Tool provided by the vertical
Position of the probes in the reference architecture	UE	UE
Metric collection methodology	The test case Blueprints includes commands to modify the artificial delay and packet loss. Metrics are collected for each impairment.	The test case Blueprints includes commands to modify the artificial delay and packet loss. Metrics are collected for each impairment.
Validation tools	Proprietary script used to compute the variation of the guide error and comparing it with the maximum acceptable guide error deviation.	Proprietary script used to compute the energy consumption and comparing it with the the battery capacity to compute its duration.
Validation methodology	Validation is just a comparison between the resulting value and a maximum threshold value.	Validation is just a comparison between the resulting value and a maximum threshold value.

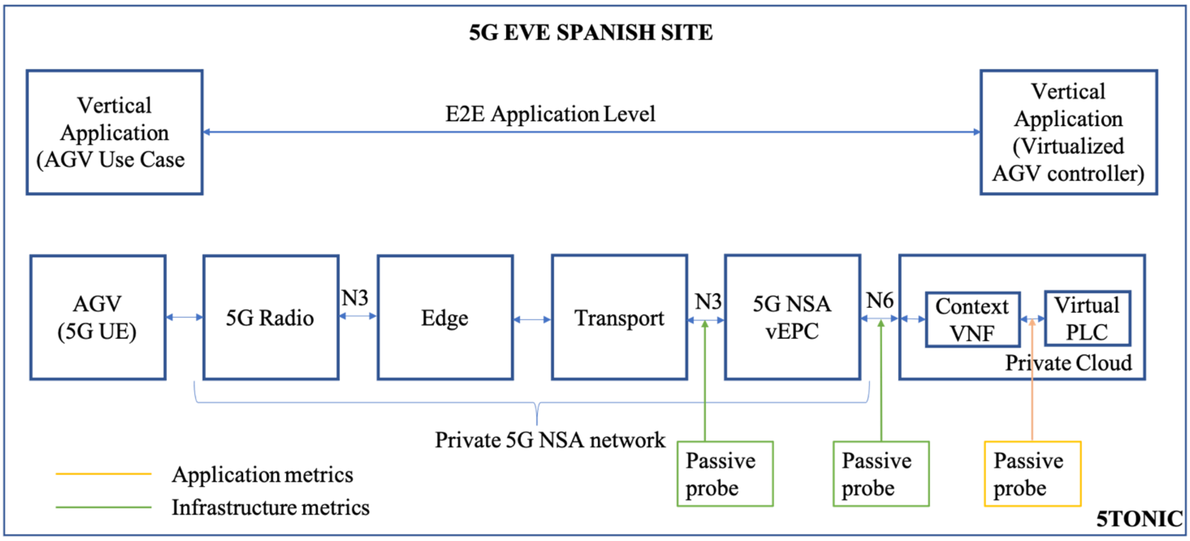


Figure 61: Industry 4.0 (Spain) UC3.1 - KPI collection functional architecture

2.5.4 Pilot deployments

The trial has been implemented in the 5TONIC laboratory, where a circuit to support two AGVs has been installed. The deployment of the use case inside the 5TONIC laboratory is depicted in Figure 62 Figure 62.

Figure 62: Industry 4.0 (Spain) UC3.1 - Deployment architecture

5G NSA coverage is provided in the laboratory, and it is operating in frequency bands seven and n78.

The AGVs incorporate a 4G/5G router that supports connectivity to 4G and 5G NSA networks.

The 5G EVE platform was used to install and manage the virtualized controller (Virtual PLC) and context VNFs. The AGV collects the sensor information, and through the use of the 5G NSA network, it sends this information to the virtualized controller in the cloud. This virtualized controller performs the following functions:

- Tracking of the AGV route and correcting the difference accordingly.
- Collision avoidance with obstacles in the AGV path.

- Actions associated with tracking marks deployed in the route (e.g., stopping the AGV for loading).

The AGV used for the trials is the Easybot model and is currently used in factories worldwide. This AGV is designed and manufactured by ASTI Mobile robotics (5G EVE vertical partner).

To execute the use case, the following steps were followed:

- Prepare the use case VNF images for the Virtual PLC and Context VNFs and upload them to the NFV Infrastructure VIM at 5TONIC.
- Design the blueprints (i.e., VSB, CtxB, TCB, and ExpB) and network service descriptors for the use case virtual components, i.e., Virtual PLC and Context VNFs and finally onboard them to the 5G EVE platform.
- Instantiate the use case through the 5G EVE platform.
- Execute the UC test trials provided above, and collect the relevant application metrics.
- Process the collected application metrics, and finally validate the associated vertical service KPIs.

The blueprints and network service descriptors used for this use case can be accessed at [17].

2.5.5 Pilot execution results

This section provides the results for each of the test trials presented in sub-section 2.5.1.2 above.

a) ***Evaluation of the AGV performance with 5G NSA without any network impairments versus 4G***

In this test, we present the results for the vertical service KPIs, i.e., guide error and current consumption.

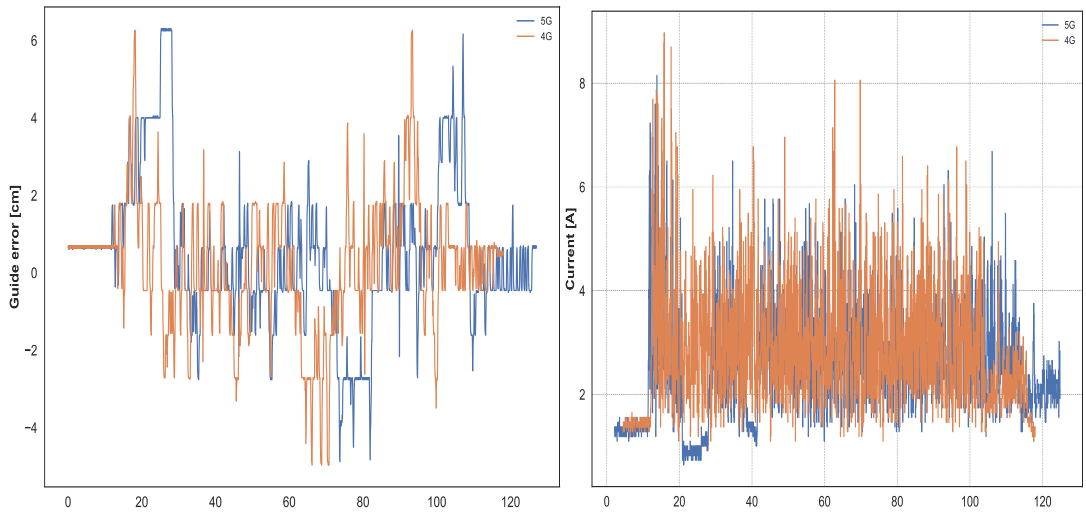


Figure 63: Industry 4.0 (Spain) UC3.1 - AGV performance comparison in 5G NSA and 4G (without impairments)

As observed from the above graphs in Figure 63, on average, 5G produces slightly better results than 4G for both KPIs.

b) ***Evaluation of the AGV performance with 5G NSA experiencing discrete packet losses***

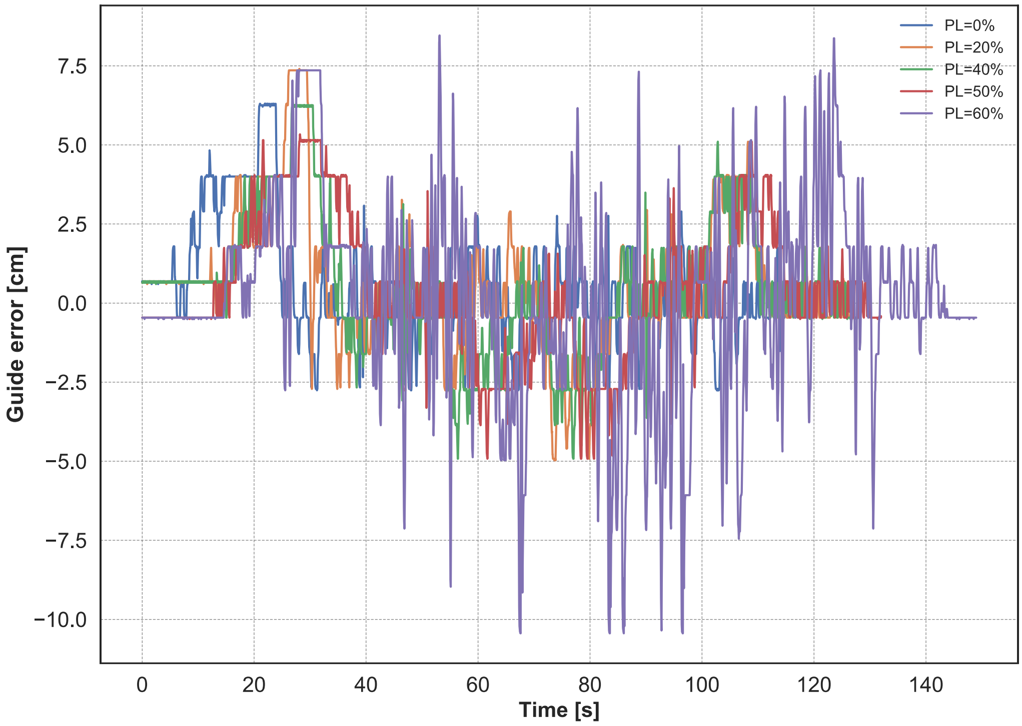


Figure 64: Industry 4.0 (Spain) UC3.1 - AGV performance in 5G NSA (discrete packet losses)

Figure 64 represents the guide error experienced by the AGV, starting with no packet loss (0%) and modifying this value to 20%, 40%, 50%, and finally 60%. From our tests, we noticed that even with 60% packet loss, the AGV can still move, although the guide error is too much (as can be seen from the graphs). We recommend that the maximum packet loss should not exceed 20% for this use case to function within acceptable latency bounds.

c) *Evaluation of the AGV performance with 5G NSA experiencing discrete delays*

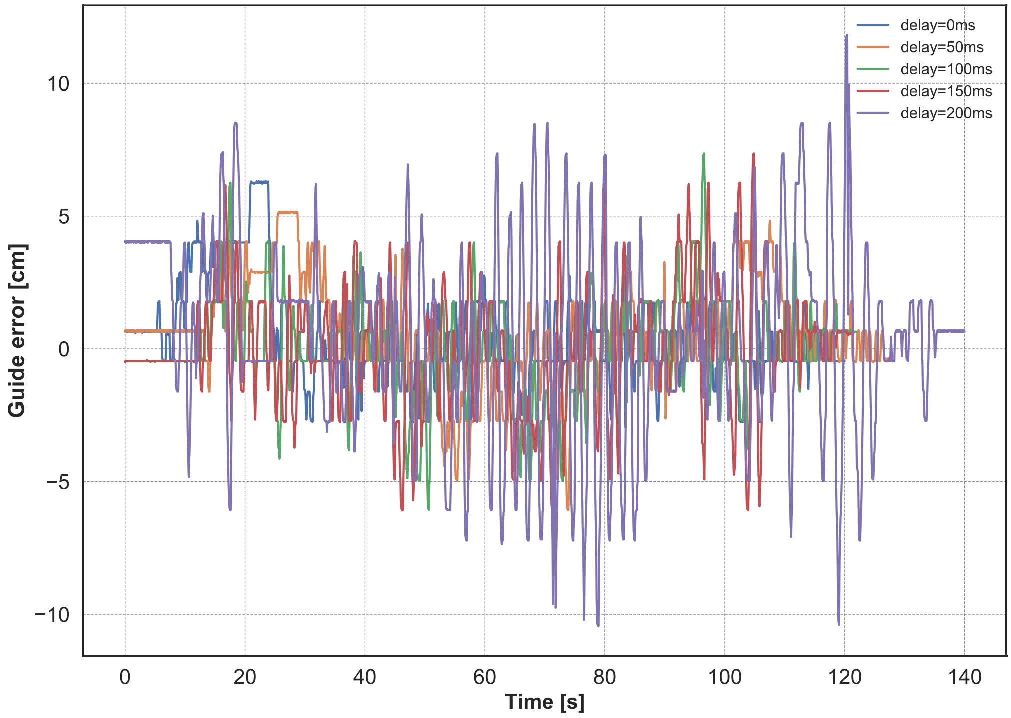


Figure 65: Industry 4.0 (Spain) UC3.1 - AGV performance in 5G NSA (discrete delays)

For these tests, we examined the effect that different virtual PLC locations would have on the AGV performance by varying the delay between the AGV and virtual PLC from 0 ms to 200 ms in intervals of 50 ms. From our observations, as indicated in the above graphs in Figure 65, delay/latency has a significant impact on AGV performance, as can be seen by the difference in the guide error when there is no delay (0 ms) and when the delay increases by 50 ms. In conclusion, the maximum acceptable delay/latency for this use case should not exceed 10 ms.

2.5.6 5G empowerment

- 5G NR: enhanced features for traffic support and prioritization; hence we were able to carry out the trials within the acceptable latency bounds for the UC.
- 5G NSA: we were able to test the use case performance with 5G using this network.
- Monitoring as a Service: to be used in the next trial to collect the UC infrastructure metrics.

2.5.7 5G EVE platform added value

- Intent-based interface was used to: design and onboard the UC blueprints and network service descriptors, instantiate, and execute the UC.
- The KPI Framework was used to collect and validate the vertical service KPIs.

2.6 Use Case 3.2 - Industry 4.0: Autonomous vehicles in manufacturing environments (Greece)

2.6.1 Pilot context

This use case refers to the use of autonomous vehicles for logistics and manufacturing. In the first case the vehicles are used in warehouses for shuttling freights between places. In the second case they replace also conveyors in the assembly line. The target scenarios foresee the use of a fleet of vehicles controlled remotely by applications running in a local cloud to have the possibility of introducing sophisticated control and navigation systems without affecting the vehicle. On the vehicle just low-level control, sensors data collection and connectivity are implemented.

The vehicles are connected to the remote control via LTE or 5G. The navigation of the vehicle is based on cameras and LIght Detection And Ranging (LIDAR). The LIDAR is mainly used for detecting objects in front of the vehicle and for collision avoidance. Cameras are used for vision-based navigation. These control functions run remotely in the local cloud in real time.

A smart facility management system in the cloud coordinates all operations and controls the vehicles in real time.

The staff interacts with the facility management system and the vehicles using a specific App running on a Tablet/smartphone.

2.6.1.1 Partner's roles

Vertical

- WINGS: Smart city and Advanced smart city applications
- COMAU: AGV supplier

VNF provider(s)

- ERI-GR: Core network VNFs

Experiment developer(s)

- ERI-GR: 4G/5G network, eMBB application server, AGV- control system management
- WINGS: Smart city/smart power applications
- COMAU: AGV low-level controller application

Experimenter(s)

- ERI-GR
- OTE/Cosmote
- WINGS

Site Manager(s)

- OTE/Cosmote

2.6.1.2 Trials

The trials at the 5G EVE site in Athens (COSMOTE lab) have the purpose of verifying and validating the behaviour of the implemented logistic solution and how LTE first and 5G later can support it efficiently. The logistic solution involves the use of a vision-based guided AGV, as shown in Figure 66, remotely controlled in the edge cloud in real-time. The vehicle sends a continuous data stream to the remote servers including three video streams, one per camera, and odometry information to the remote controller, that sends back movement data. The vehicle controller in cloud is a multi-layer controller including video processing, high-level and low-level motion control. The vehicle controller is managed by the AI-based main control system located in the edge cloud. The latter manages all the logistics requests and operations. The interaction with the whole system occurs through a dedicated set of Apps hosted on tablets connected to the management functionalities via the mobile network. The purpose of the trial is to verify that the vehicle, relying on the mobile network for communication, can perform its mission of shuttling objects between three different places representing a reception, a warehouse and a loading bay area, moving in the test area using the real-time remote vision-based navigation following its optimal track and reaching the destination smoothly and precisely. Mobile network throughput or latency issues can reduce or impair the behaviour of the vehicle causing lower accuracy, instability in the trajectory and potentially collisions.

Figure 66: Industry 4.0 (Greece) UC3.2 - AGV component

A first trial was executed using the 4G LTE infrastructure. Video streams sent in uplink direction were reduced in terms of bandwidth with respect to what was possible to achieve with 5G due to the lower uplink throughput. The limitation in uplink bandwidth was mainly due to the cat4 dongle used on the vehicle. The 4G dongle was limiting the uplink rate to 40 Mbps. Since the LTE RTT is on average about 20 ms, the vehicle controller was set to guarantee larger margins for deciding the next actions in order to keep the complete control loop reactive enough.

In the second trial with 5G NR, thanks to the higher uplink rate of 75 Mbps, video streams in uplink can operate at higher rate and resolution, improving the movement accuracy of the vehicle. Thanks to a lower RTT than LTE (about 10 ms with the pre-scheduler active) the reactivity of the control loop was also improved. In this second trial the dongle was replaced by a smartphone tethered to the vehicle PC acting as gateway.

In both trials, communication between the vehicle sub-network and the edge cloud was made using a VXLAN tunnel to make the mobile network transparent to the application layer.

2.6.2 Pilot architecture

To setup the experiment at the 5G EVE Portal, a specific Test Case Blueprint (TCB) is defined. The TCB contains a command to launch a python script located on a VM on the application server in the local cloud in Athens. The TCB doesn’t require the use of parameters for configuring the script.

The python script implements the operation of asking the main control system for the transfer of a freight from one place to another, as it can be done also manually using the App provided on site for managing the whole system. When the TCB is selected in the 5G EVE Portal, this is communicated to the interworking layer (IWL) that implements the command execution. The IWL is connected to Server 1 as shown in Figure 67 in red.

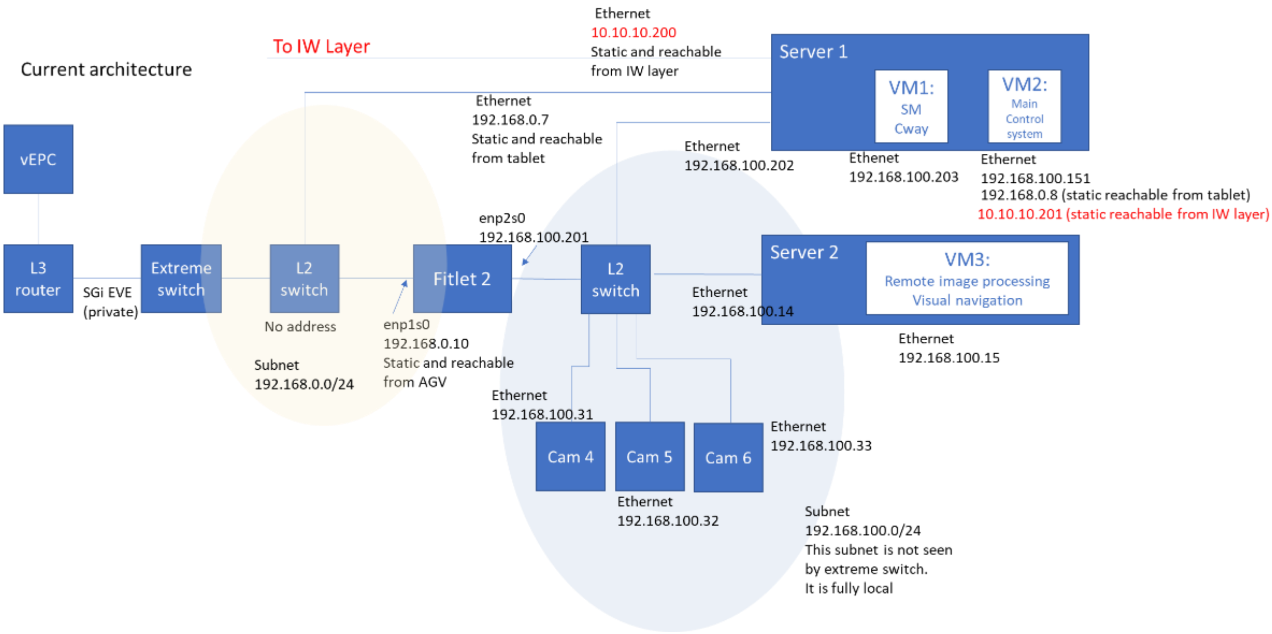


Figure 67: Industry 4.0 (Greece) UC3.2 - Pilot architecture

On VM2 in server 1 an SSH service is installed. The SSH service allows the IWL to interconnect to the VM2 as an SSH client. The SSH connectivity is used by the IWL to launch the python script as requested in the TCB. Then, the launched script interfaces the main control system starting the new mission. The script emulates the behaviour of the tablet when asking for the transfer of a freight, first registering a freight in the relational DB used for the inventory and then it asks to move the freight from the reception to the warehouse.

2.6.3 Vertical service KPIs implementation

The Vertical service KPIs for this Use Case are described in Table 9 right below:

Table 9: Industry 4.0 (Greece) UC3.2 - Vertical service KPIs

Use case title	**Industry 4.0: Autonomous vehicles in manufacturing environments**			
Site facility	**OTE ACADEMY- GREECE**			
Vertical KPI name	Latency	Throughput	Reliability	Availability
Vertical KPI definition	crossing time between the 2 tunnel endpoints	Throughput measured between the remote control and the AGV	failure probability within time t in years	steady state availability when considering only the corrective maintenance (CM) downtime of the system.
Metric collection tools	Wireshark/Mini-PC	Wireshark/Mini-PC	Wireshark/Mini-PC	Wireshark/Mini-PC
Position of the probes in the	1, 3 and 4	1, 3 and 4	1, 3 and 4	1, 3 and 4

reference architecture **1) UE; 2) Public Cloud; 3) Private Cloud; 4) Edge**				
Metric collection methodology	Collect metric every 1 second	Collect metric every 1 second	Collect metric every day	Collect metric every day
Validation tools	miniPC	miniPC	miniPC	miniPC
Validation methodology	Fault detection, isolation and service restoration	Fault detection, isolation and service restoration	Fault detection, isolation and service restoration	Fault detection, isolation and service restoration

Measurements for characterizing the mobile network throughput are made using UDP because the tunnel used to establish communication between the remote control and the AGV is a UDP VXLAN. All data traffic passes through the tunnel.

- Traffic at application level is monitored and characterized with a PC equipped with Wireshark, mirroring data from the AGV and the control servers.
- Data are processed with a dedicated python program using Pandas library.
- MiniPCs contribute with a variable delay to delay variation at application level.
- A dedicated test characterized their behaviour.

Figure 68 illustrates the Testing Architecture and the positioning of the probes.

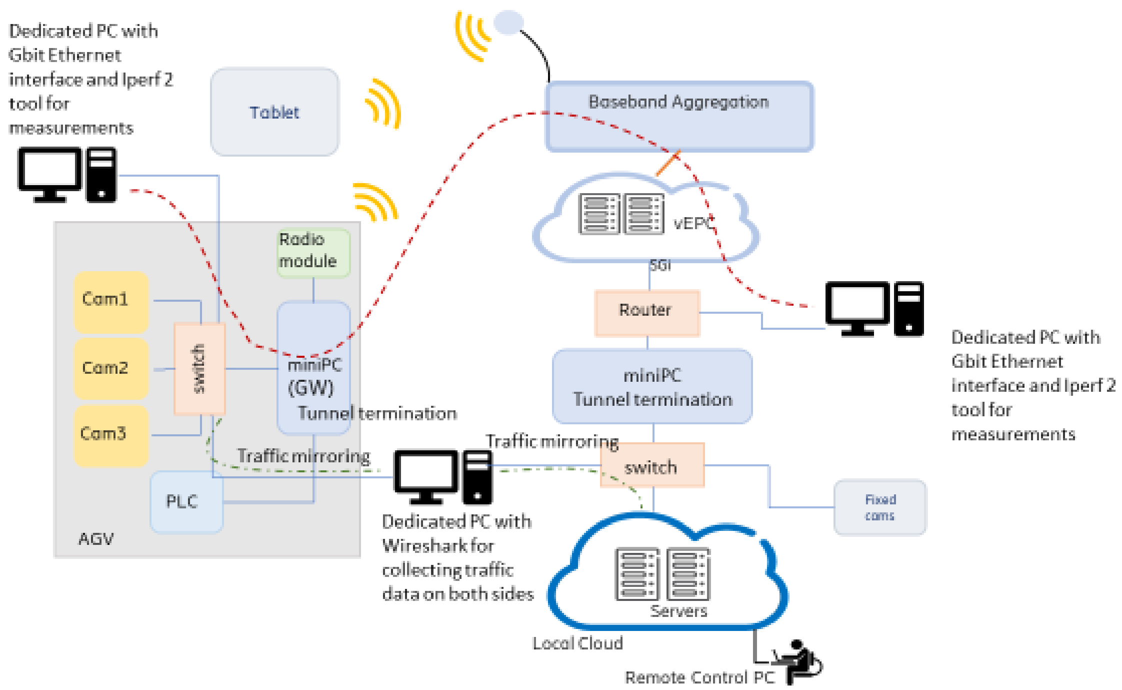


Figure 68: Industry 4.0 (Greece) UC3.2 - Testing architecture

2.6.4 Pilot deployments

The Psalidi facility deployment is illustrated in Figure 69.

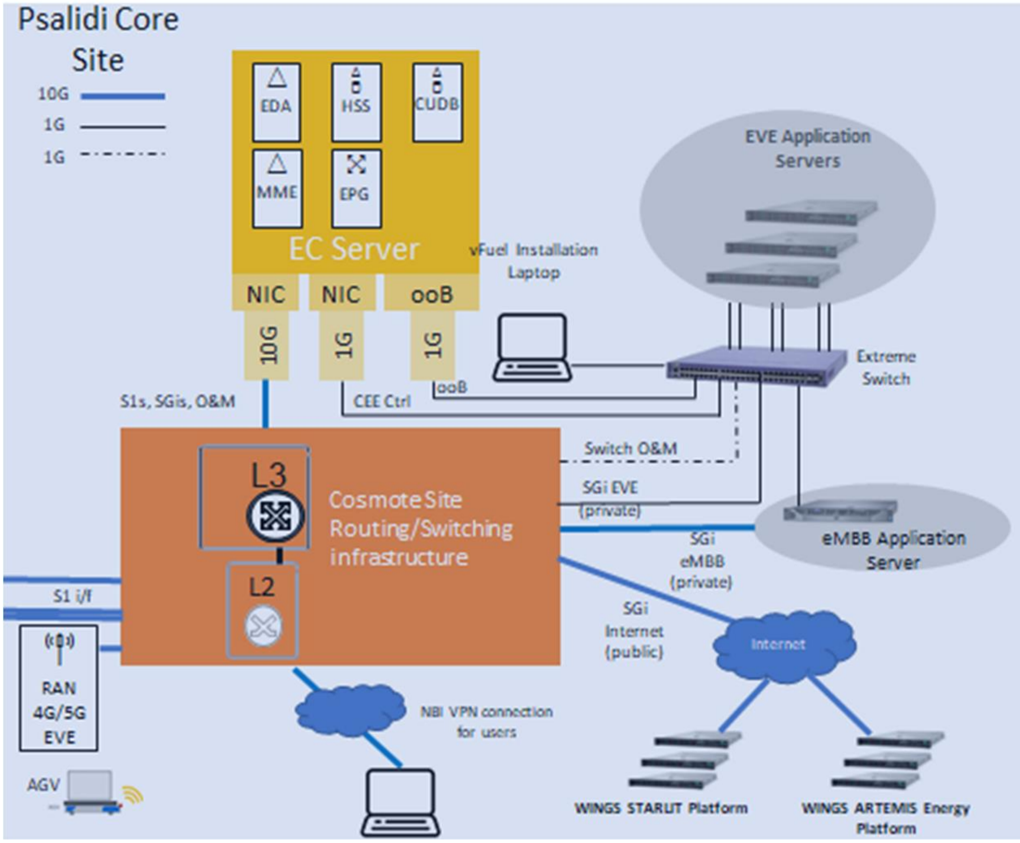


Figure 69: Industry 4.0 (Greece) UC3.2 - Psalidi facility deployment

The implementation consists of the following components:

1. Ericsson 4G/5G Access Network: Provides 4G/5G private wireless access, compatible to 3GPP R14/R15, to the AGV and WINGS smart energy and advanced city IoT use cases.
2. Ericsson Cloud-based EPC (vEPC Enterprise Core): Enterprise based vEPC solution designed to run on top of Ericsson Openstack IaaS i.e., Cloud Execution Environment (CEE) and use Dell PowerEdge R640 server. vEPC provides, functionality for vMME (Virtual Mobility Management Entity), vPGW (Virtual Evolved Packet Gateway), vCUDB (Virtual Centralized User Database), vHSS-FE (Virtual Home Subscriber Server – Front End), v-EDA (Virtual Ericsson Dynamic Activation) and CNOM. Figure 70 depicts the mobile network architecture.

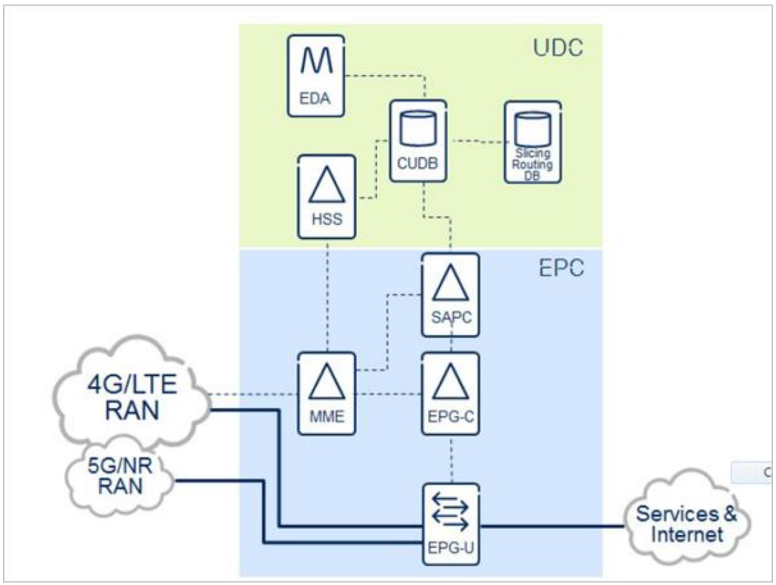


Figure 70: Industry 4.0 (Greece) UC3.2 - Mobile network architecture

3. eMBB Application Server: Dedicated mobile broadband application servers based on Dell Precision 3930 HW used for 4G/5G wireless throughput and E2E delay local capability testing.
4. 5G EVE application servers: Local cloud XEN servers based on Intel processor cores. The servers are interfacing the Enterprise Core (EC) through SGi interface sharing the same sub-network of SGi and are performing main control system management and the AGV system control. Figure 71 illustrates the functions implemented in the local cloud.

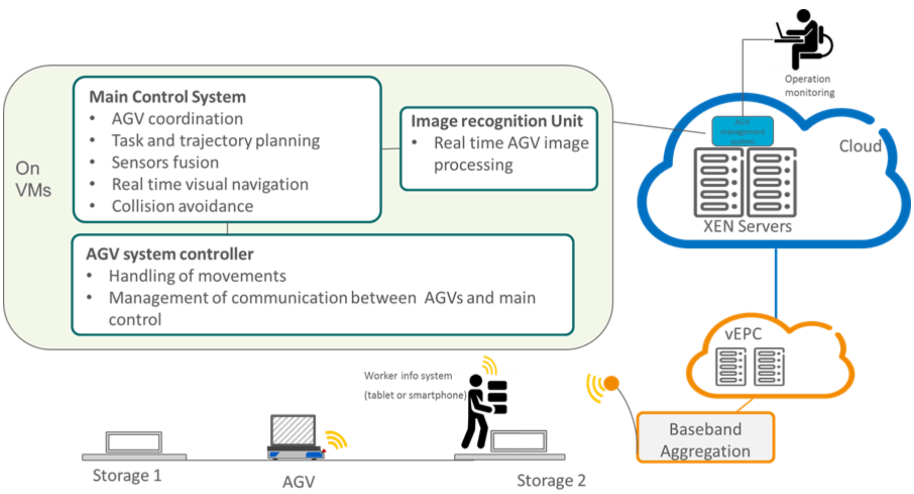


Figure 71: Industry 4.0 (Greece) UC3.2 - Functions implemented in the local cloud

5. WINGS Starlit & Artemis energy platforms: Smart energy and advanced smart city applications cloud servers.
6. Automatic Guided Vehicle (AGV- AGILE 1500): Autonomous robotic vehicle manufactured by COMAU used for the shuttling of freights between reception, storage and shipment areas in a warehouse/logistics environment. The vehicle is connected via the 5G NSA deployment using EN-DC with LTE as anchor plane for control and signalling information. Remote motion control will rely on cloud-based server control in real time with no fixed infrastructure needed to drive the vehicle. Figure 72 contains a picture of the AVG.

Figure 72: Industry 4.0 (Greece) UC3.2 - AGV component

The use case refers to the shuttling of freights between places in a warehouse or a manufacturing plant using an AGV. Missions can be launched remotely from the portal and locally by the staff. In Figure 73 the overall high-level architecture from the portal to the control application of the vehicle in cloud is shown.

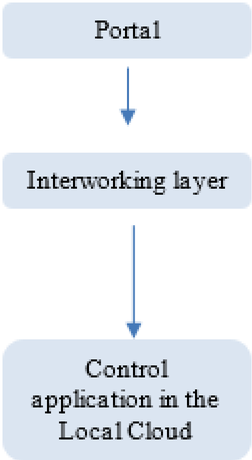


Figure 73: Industry 4.0 (Greece) UC3.2 - Overall high-level Architecture

The portal is used to launch and monitor the application in the local cloud using blueprints. The interworking layer interacts with the portal and the local cloud, issuing the commands described in the blueprints. The application in the local cloud manages the warehouse/manufacturing plant, launches and controls the mission of a vehicle shuttling freights, and reports the results of the operations. Missions can be started either through the portal, using the proper TCB, or manually by the workers using a dedicated App running on a tablet. Monitoring functions can also run in the local cloud to provide feedbacks on performance. Once a new request is received by the portal or by the staff, using the tablet App, the main control system checks which vehicle can be used and determines the route it must follow to reach its destination. Then, the navigation function controls, in real time, the travel of the vehicle along its route. Using the cameras, the remote-control system in the local cloud localizes the vehicle in the environment. The video streams coming from the vehicle are processed to detect and recognize objects and to determine the position and orientation of the vehicle with respect to them. At each movement step, the main control system decides the next step to be executed using the motion control function also implemented in the local cloud.

In the context diagram in Figure 74 the green boxes represent the actors interacting externally with the system. For each of them the dataflows exchanged with the system are shown. The round-bounded orange block represents the process. At this level it represents the whole logistics control system.

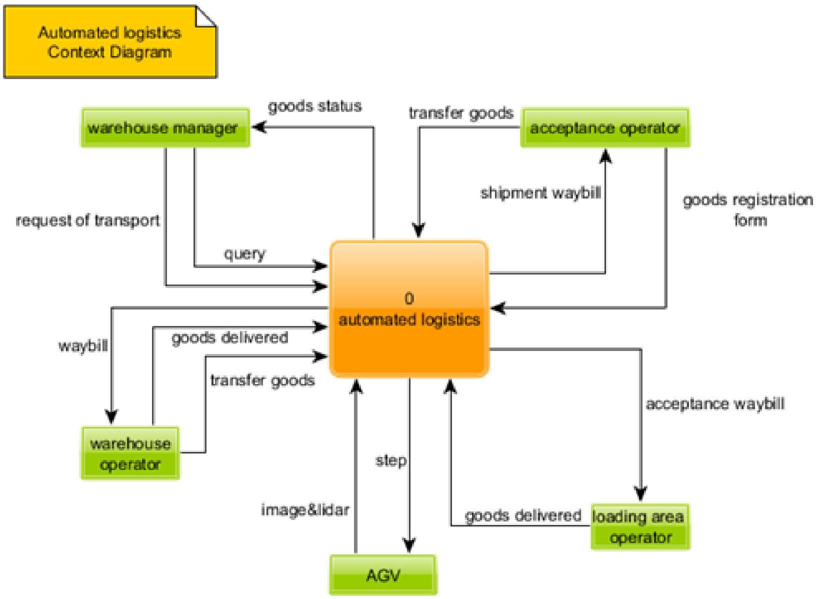


Figure 74: Industry 4.0 (Greece) UC3.2 - Context diagram of the logistics use case

The details of process execution depicted in Figure 74 are beyond the scope of this document.

2.6.5 Pilot execution results

__**Latency 5G NR results**__

- Iperf 2 was used to measure the throughput with UDP packets with a payload size of 1000 Bytes
  - DL average throughput: 1.15 Gbps
  - UL average throughput: 75 Mbps
- Timings were measured from the traffic traces of the mirrored traffic from the AGV and the cloud servers
  - Wireshark was used to capture and synchronize the traces
  - An in-house developed python SW using the pandas library was used to compute and analyze timings
- The measured RTT was 15 ms on average with a standard deviation of 3 ms (measured without pre-scheduler)
- Average DL latency 8 ms
- Average UL latency 10 ms

__**Throughput**__

- Motion control traffic trace of the AGV shown during normal operation
  - red trace traffic from the AMR to the System Manager (SM)
  - black one from the SM to the AMR
- The AGV demands high capacity only for vision-based navigation.
  - Each vehicle is equipped with 3 cameras
  - 1920x1080 resolution B&W frames with a refresh rate of 10 Hz
  - Each WDR HD camera streams an MJPEG video flow with rate of 1 Mbps (max 10 Mbps) → total traffic 3Mbps to 30 Mbps

- The AGV requires few hundreds kbps in UL (typ. 100-150 kbps according to measurements on field).

Table 10, Table 11 and Table 12 provide the characterization of the traffic linked to the AGV operation.

Table 10: Industry 4.0 (Greece) UC3.2 - Total IPcam max traffic

Parameter	Value
Stream type	CBR
Peak rate	30 Mbps
Packet size (av.)	1522 bytes
Packets rate	2464 pkts/s

Table 11: Industry 4.0 (Greece) UC3.2 - SM traffic per vehicle

Parameter	Value
Stream type	CBR
Peak rate	9 kbps
Packet size (av.)	54 bytes
Packets rate	20.7 pkts/s

Table 12: Industry 4.0 (Greece) UC3.2 - AMR control traffic

Parameter	Value
Stream type	CBR
Peak rate	135 kbps
Packet size (av.)	699 bytes
Packets rate	24 pkts/s

Reliability and availability

- System MTBF= $\frac{1}{\frac{1}{MTBF1}+\frac{1}{MTBF2}+\ldots+\frac{1}{MTBFn}}$ computed in years.
  - Where MTBFi is the MTBF of the considered elements.
- Reliability: failure probability within time t in years
- $F(t) = e^{-t/MTBF}$.
- The 5G/LTE system reliability calculated from MTBFs is 97.5% over 1 year (probability of not having a failure in a 1-year timeframe without considering protection mechanisms).
- Inherent availability: it is the steady state availability when considering only the corrective maintenance (CM) downtime of the system.
- The 5G/LTE system availability calculated is 99.999% (see Table 13).

Table 13: Industry 4.0 (Greece) UC3.2 - Five nines availability downtime

Availability %	Downtime per year	Downtime per month	Downtime per week	Downtime per day
99.999% ("five nines")	5.26 minutes	25.9 seconds	6.05 seconds	864.3 milliseconds

2.6.6 5G empowerment

5G features used:

- 5G NSA offering high bandwidth and low latency capabilities.
- Monitoring as a Service: to be used for metrics collection.

2.6.7 5G EVE platform added value

The main added values of 5G EVE platform have been the following:

- **Intent-based interface towards verticals**: the service is integrated with the 5G EVE portal.
- **Performance Diagnosis (KPI Framework)**: the service is integrated with the 5G EVE KPI monitoring system.

2.7 Use Case 4.1 - Smart Energy: Fault management for distributed electricity generation in smart grids (France)

2.7.1 Pilot context

Good communication technologies are vital for fault management of distributed electricity generation in smart grids. The use of fixed networks based on optical fibres for this communication is very expensive and becomes complex to manage. The obvious solution is the use of wireless connections, but the smart grid control system has special requirements on the underlying communication network in terms of latency, reliability and performance. The main requirements for this use-case are being fulfilled by existing 4G/LTE network technologies (latency). 5G NR allows new services and applications requiring lower latency, improved energy efficiency, better reliability and massive connection density.

The Use Case "Smart Energy" proposed by EDF focuses on fault management in distributed electricity generation grids:

- Due to the high variability of renewable energy generation (sun, wind…), voltage variations happen that require tight control to avoid system cascaded failures;
- Local security systems detect voltage loss and react immediately by switching off from the grid;
- Temporary and local decrease may be sustainable, and they can be due to external factors (branches touching cables…). These temporary cases are not related to current energy production variations and need to be treated differently from more regional and persistent decreases due to real energy variations. In that case, we want to keep the local producer connected to avoid more serious energy losses;
- Local security systems are unable to detect the difference between a normal and an abnormal case, these are known only by the regional controllers. Therefore, a tight control of security process is needed by which the regional controller can supersede the local security system decision.

The proposed test environment supports real security boxes connected to a simulated electrical network, based on a grid simulator. This set up enables to test the various use-cases, creating conditions where security systems need or don't need to be activated. To control local systems behavior, an "out-of-band" network (separate from the electric system) is used for communication instructions to local security boxes. The information is transmitted using GOOSE protocol [17], a layer 2 multicast protocol usually operating over a local Ethernet network within the substation. The layer 2 protocol is relayed over a 5G NR network.

2.7.1.1 Partner's roles

Vertical

EDF provides:

- The smart protection system (control node).
- An electric network simulator controlled by a laptop.

VNF provider(s)

NOK-FR provides:

- 4G/5G CORE network functions.
- 4G/5G RAN functions.
- Platform for collecting KPIs and monitoring.
- Layer 2 virtual switch to carry GOOSE protocol.

- Open vSwitch virtual switches VNFs supporting the tunnelling mechanism. They are deployed on devices located on each part of the network.
- Test tools called MAAS for measuring the KPIs.

Experiment developer(s)

EDF & NOKIA

Experimenter(s)

EDF & NOKIA

Site Manager(s)

NOKIA

2.7.1.2 Trials

5G EVE site in Paris (Nokia lab) is providing an end-to-end L2 connectivity to carry GOOSE messages between smart grid devices. The Layer 2 to end connection instantiated is automated through the usage of a blueprint comprising an end-to-end LTE/5G network (RAN, Packet core and application server) as depicted in Figure 75.

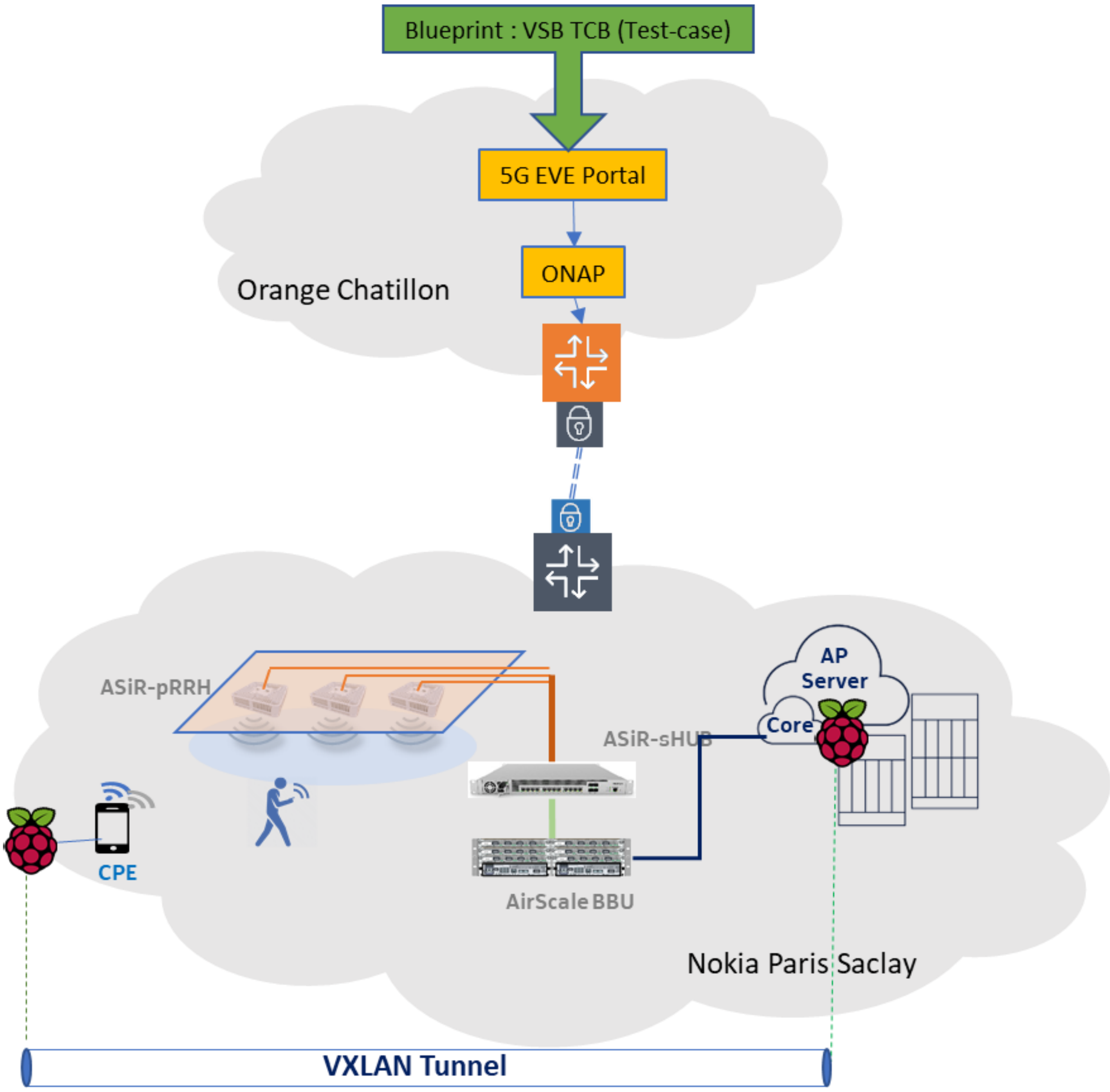


Figure 75: Smart Energy (France) UC4.1 - Service instantiation

Through the course of the project different integration sessions between Nokia and EDF have been performed; first to validate the use case and then to evaluate the role of 5G in this kind of scenario.

2.7.2 Pilot architecture

The figures below present the architecture from two perspectives. Figure 76 illustrates the Smart Grid emulator:

- all equipment is physically co-localized with the CPE;
- the use-cases are controlled from a laptop;
- the electric emulator generates electrical events and propagates an electrical signal (specific voltage) to a Raspberry Pi;
- the latter sends a GOOSE message to the network infrastructure.

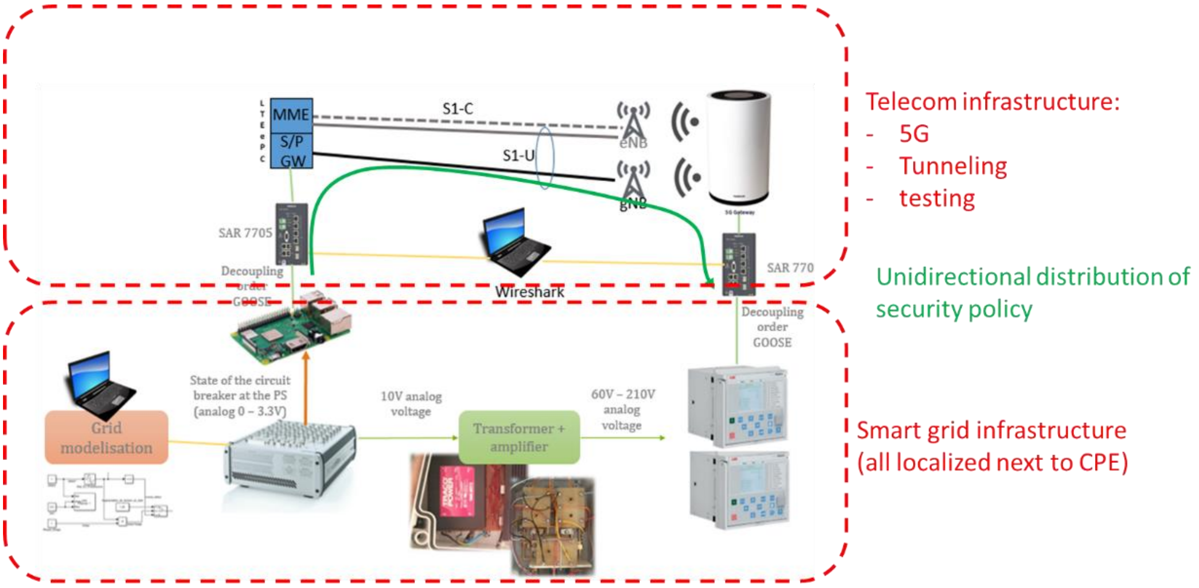


Figure 76: Smart Energy (France) UC4.1 - Smart Grid architecture (zoom on grid simulator located next to CPE)

Figure 76 depicts the network infrastructure, which is made of two parts:

- The tunnelling part between two routers encapsulates in IP the GOOSE packets. An ePipe tunnelling mechanism allows to exchange GOOSE traffic between the distributed electrical devices. The ePipe tunnel encapsulates Ethernet frames generated by Raspberry Pi control node according to the GOOSE protocol into IP packets and forwards them over the 5G data network. The receiving device at the end of the tunnel decapsulates the packets to obtain the initial Ethernet frames and forwards them to their destination;
- The cellular system distributes wirelessly the packets. The communication between tunnel end points is provided by an end-to-end 5G solution including a 4G/5G capable CPE with Ethernet port, a 4G/5G RAN on NSA mode and an EPC.

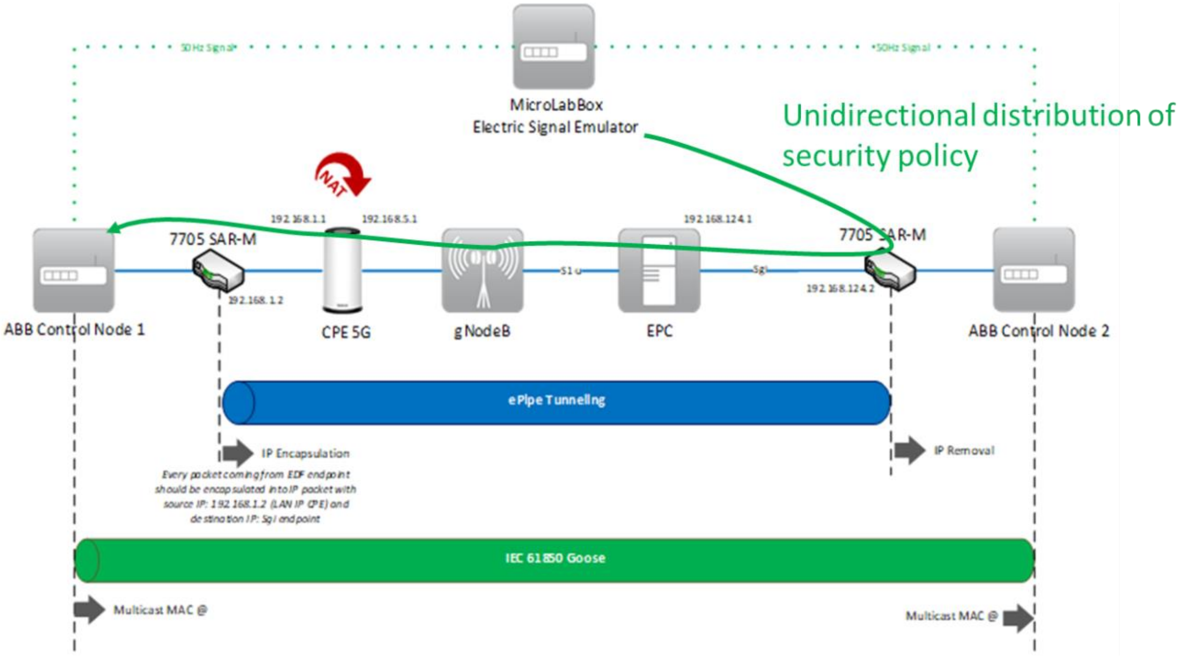


Figure 77: Smart Energy (France) UC4.1 - Smart Grid architecture (zoom on network infrastructure)

The 7705 SAR switches are virtualized as Open vSwitches [19], which can be instantiated automatically on demand. Open vSwitch (OVS) [19] is multilayer software-based switch providing a programmable and production quality switching platform with support for standard management interfaces (e.g., OpenFlow [20]). Open vSwitch does not support the ePipe tunnelling protocol but it offers other alternatives. Two possible tunnelling protocols have been studied:

- **Virtual eXtensible Local Area Network** (VXLAN) as specified in RFC 7348 [21] is the most suitable in our case. However, Openvswitch's implementation of VXLAN does not support multicast, which can be a limitation in the case of GOOSE multicast traffic. Nevertheless, other software-based switches (e.g.., Linux bridges) do support multicast over VXLAN. This and other alternatives are being evaluated.
- **Generic Routing Encapsulation** (GRE) [22] doesn't seem to be a suitable fit for the proposed architecture as it performs layer 3 encapsulation, and has not been tested in the given context.

Different deployment options are possible:

- At the server side (close to the EPC), the switch can be deployed on the same physical host as the EPC or any other collocated server.
- On the client side, one possibility is to initialize it on the CPE but this was subject to some technical constraints due to possible low resources available on the CPE. A better scenario is to deploy the switch on a router on the client premises, offloading the CPE to a more powerful and easily managed processing hardware.

2.7.3 Vertical service KPIs implementation

A proprietary monitoring framework is deployed to retrieve metrics from the radio equipment and from probes running on different interfaces. The collected metrics are processed to be used internally and shared externally using the 5G EVE monitoring framework.

The Monitoring Framework is deployed on demand on the network using an internal Nokia tool. This starts several modules on a Kubernetes cluster, among others, an Elastic Search (ELK) stack, a Kafka server, a GUI, and a probe controller. The GUI allows to manually select the targeted radio equipment and the desired metrics. Once this is done, the probes corresponding to the selected metrics are deployed on the specified device and begin to send their data metrics towards the internal Kafka server. The metrics are then processed and displayed locally for analysis by the operator, but they are also modified to match the 5G EVE needs and sent towards the Kafka server in Orange Chatillon, then to the Central 5G EVE Kafka server as depicted in Figure 78.

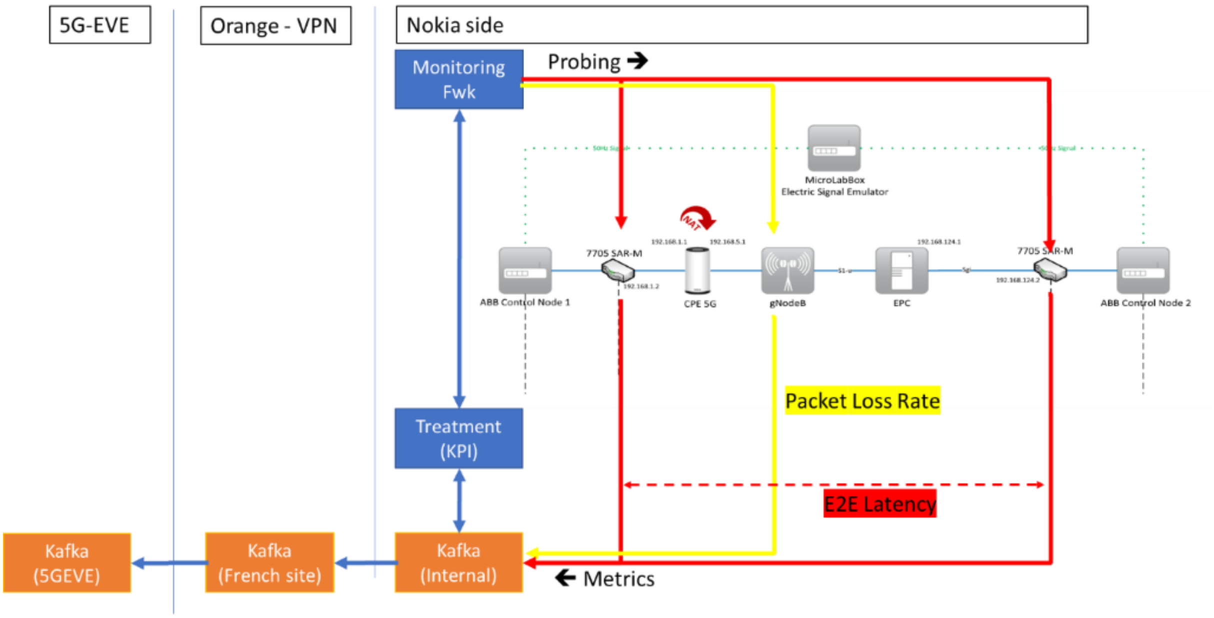


Figure 78: Smart Energy (France) UC4.1 - Metrics collection schema

The different KPIs collected are defined in Table 14.

Table 14: Smart Energy (France) UC4.1 - Vertical service KPIs

Use case title	**Smart Energy**	
Site facility	**Nokia Paris Saclay**	
Vertical KPI name	**Latency**	**Packet Loss rate**
Vertical KPI definition	crossing time between the 2 tunnel endpoints	service reliability to avoid losing the GOOSE alarm packet
Metric collection tools	Tshark	Tshark
Position of the probes in the reference architecture 1) UE; 2) Public Cloud; 3) Private Cloud; 4) Edge	1, 3 and 4	1, 3 and 4
Metric collection methodology	Measurements are made: • on routers by port mirroring & wireshark • on device for packet error rate Step 1: Initial system is “normal” => switch on the abnormal condition 1 (local decrease) => only the non-supervised security boxes are switches off Step 2: Initial system is “normal” => switch on the abnormal condition 2 (regional decrease) => all security boxes are switched-off During Step 2, we measure various KPIs	
Validation tools	Smart grid simulator	Smart grid simulator

Validation methodology	Fault detection, isolation and service restoration	Fault detection, isolation and service restoration

2.7.4 Pilot deployments

Two blueprints are proposed to support the use cases, including Smart Energy use case and proprietary monitoring framework. These two blueprints are onboarded on the 5G EVE portal and registered in the site orchestrator, i.e., an ONAP instance running in Chatillon (France). The OpenStack Heat templates with the environment parameters have been packaged as "ONAP VNF packages" to support these two blueprints. The VPN connection between Orange Chatillon and Nokia Paris-Saclay has been updated accordingly allowing the Smart Energy blueprint instantiation via 5G EVE Portal. Once the requests arrive at Nokia Paris-Saclay via ONAP Chatillon, the layer 2 tunnel between a raspberry Pi connected with CPE and a server behind the core network is automatically established. This tunnel allows the smart energy devices to communicate through layer 2 GOOSE protocol over 5G network. The proprietary monitoring framework is executed and collects the metrics. The KPIs are processed and pushed to 5G EVE Kafka clusters.

5G is non-standalone (NSA) compliant with 3GPP R15 September 2019. The 5G radio operates an eMBB radio configuration in TDD band n78 (3500MHz) with a bandwidth of 100MHz. The 4G radio is in FDD band b1 (2100MHz) with a bandwidth of 10MHz. The core is NOKIA 5G Core operating in NSA mode. User equipment (UE) is a NOKIA Fixed Wireless device.

Figure 79 depicts the implemented 5G architecture at Nokia Paris Saclay site.

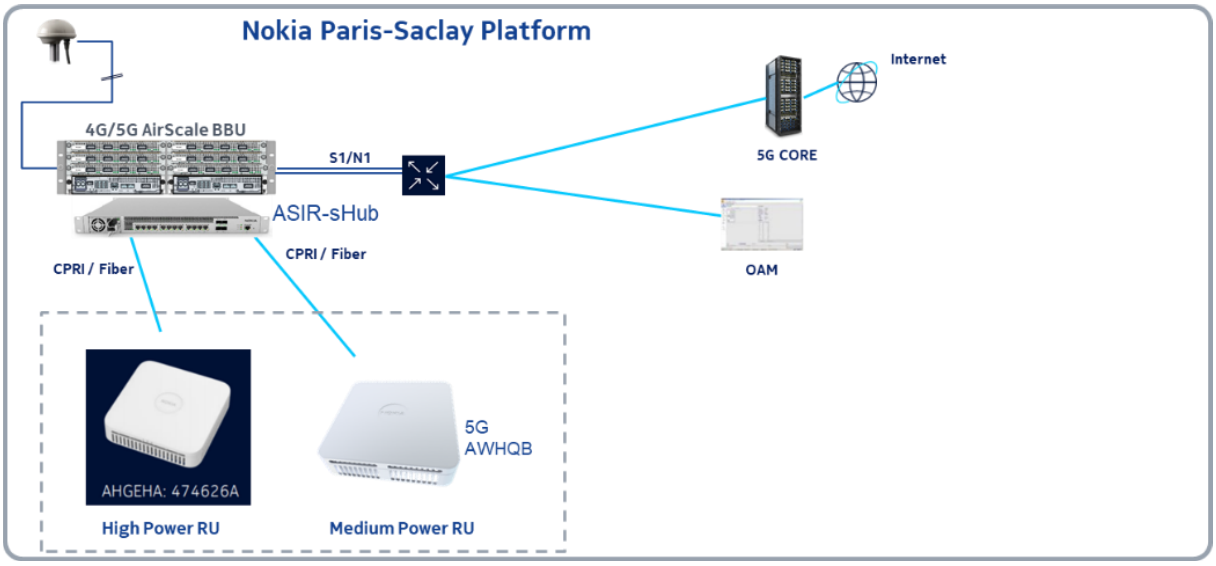


Figure 79: Smart Energy (France) UC4.1 - Physical 5G network architecture deployed in Nokia-Paris Saclay site

2.7.5 Pilot execution results

The functional tests that we performed are as follows:

i) Voltage drop occurs following a Transmission System Operator (TSO) fault simulation: the protection relay with instantaneous settings trips unlike the 5G-connected one with delayed settings that remains closed;

ii) Voltage drop occurs following a simulation of the FCB opening: both protection relays trip. The one opens because of the instantaneous settings due to voltage measurements, and the 5G-connected one reacts due to the reception of a GOOSE decoupling command.

The one-way latency measurements were repeated several times to obtain statistical data of operating time measurements. According to the obtained results, the one-way latency did exhibit low variance and in line with the use case requirement.

2.7.6 5G empowerment

The main 5G features improving the experiment execution are represented by the adoption and integration of RAN low latency (ref. URLLC) features. 5G improves the next generation power protection schemes to become more efficient, quicker, and less expensive. Therefore, the execution time of such Fault Detection, Isolation, and service Restoration (FDIR) system is reduced from a few minutes to only a few seconds, and it will possibly embed advanced protection functionalities. The outage risk is mitigated, and thus supply quality is improved considerably.

This section provides a resume of the 5G features as shown in [5] and Table 15 that have improved the experimentations in Paris-Saclay.

Table 15: Smart Energy (France) UC4.1 - 5G empowerment

Features	Integrated	Benefits
Monitoring as a Service (MaaS)	X	Automate the measurements and collection of data/log from heterogeneous environments (virtualized, RAN product based) using a unified framework. The MaaS collects KPIs using Robot framework.
5G-NR	X	New Radio offers a higher throughput and Low Latency
5G CORE NSA/SA	X	Control plane is faster than 4G allowing to meet the latency requirements of EDF use-case
Micro-Services	X	Agility, Support of CI/CD, easy evolution to support new features.
URLLC	Available in Rel 16 of the RAN product	New Radio offer
Service exposition	X	Integration in 5G EVE Portal and facilitate the use-case execution from a vertical perspective
Slicing	Available in Rel 16 of the RAN product	A network multi-tenancy support to provide an isolated and customized network settings

2.7.7 5G EVE platform added value

Table 16 summarizes the 5G EVE platform added values that enhanced the experiment execution and results in Paris-Saclay.

Table 16: Smart Energy (France) UC4.1 - 5G EVE platform added value

Features	Integrated	Benefits
Portal	X	Centralize the blueprints management and provide a unique access entry to the partners in 5G EVE
Multi-Site Multi-domain slicing and orchestration	X	Extend the capacity and scalability of network slicing management to connect Nokia-Paris Saclay site to 5G EVE French node (Orange Chatillon)
Performance Diagnosis (KPI Framework)	X	Have a real-time insight view of network status for maintaining a high network availability: this is done thanks to the MaaS and the monitoring framework of 5G EVE

5G VNFs (Openness Framework)	X	Ease the integration of different vendors and accelerate the network evolution: this is done by connecting the RAN to either Nokia 5G CORE or to B-COM 5G Core, as planned in the framework of ICT-19 5G TOURS project.

2.8 Use Case 4.2 - Smart Energy: Resolving Outages and Ensuring the Stability of Smart Grids by means of 5G (Greece)

2.8.1 Pilot context

This Use Case considers the small/medium scale experimentation of distributed electricity generation and management in smart grids. This Use Case comprises the following elements:

- **A network of distributed energy sources,** which can be batteries, but also solar panels combined with sensors to measure the current energy level. Panels represent the prosumers.
- **A network of distributed energy consumers,** which can be actuators, like lamps, fans, heaters etc. combined with sensors to measure the energy consumption.
- **The distribution network**, connecting sources with consumers, combined with sensors measuring the energy flow (e.g., voltage, current).

This Use Case comprises the following steps/phases, representing different conditions in the network.

1. At the beginning, there exists a specific configuration (NORMAL phase);
2. A fault situation occurs (ALERT/ALARM phase);
3. The topology of the grid is restructured so that power restoration can happen as fast as possible (RESTORATION phase).

The challenges that the Use Case targets to address relate to:

- Longevity of technology, deploy once and operate “forever”;
- Worst case latency thus delivers a single message within its guaranteed delivery time;
- Ongoing evolution of the power grid into a grid supporting a much more distributed generation and storage of power, being a dynamic and unpredictable environment where intermittent and variable power sources are replacing dispatchable and controllable base load generation;
- Predictive maintenance and prompt reaction.

Moreover, considering the area of **Smart Utilities** in general, an extension of this pilot included also the operation of smart water meters, which are being controlled and managed from a cloud platform. The smart water meters installed on the field are transmitting consumption measurements over Wireless M-Bus (short-range) towards a 5G gateway that is deployed by WINGS. Wireless M-Bus communication is a European Open Standard for remote readings of gas, water, heat, electricity and other types of consumption meters. Using the European ISM band 868 MHz, it fulfils the special requirements of remotely powered or battery-driven systems, including consumer utility meters. In particular, the Sensus iPerl water meters (shown in Figure 80), are installed in the Greek site. They are high-performance, solid-state smart water meters with integrated Wireless M-Bus communication capabilities in T1 mode and 15-year expected operational life. They are programmed to provide data at 15-minute intervals, helping water utilities to manage distribution networks more efficiently, to conserve water, and to provide accurate billing to their customers. Beside total water volume and current water flow, iPerl provide information about possible alarming conditions, such as leaks, tampering, flow direction and the status of the device itself.

Figure 80: Smart Energy (Greece) UC4.2 - The smart water meter

The 5G gateway (shown in Figure 81), collects data from the smart water meters and transmits them over the 5G network towards the cloud platform. More specifically, the 5G gateway provides a robust, stand-alone, battery-powered solution that periodically listens and concentrates data frames from nearby Wireless M-Bus meters in T1 mode (versions with S1, C1 mode are also available), and forwards them through 5G technology to the cloud. There, each data frame is parsed analytically, and information is extracted about the identity, status, and measurements of the meter device. Finally, conclusions about consumption, alarming-abnormal situations (e.g., leakage detection, reverse flow, low battery, tampering attempt), as well as the raw measurements from each meter device are plotted and presented in detail in the corresponding dashboard.

Figure 81: Smart Energy (Greece) UC4.2 - The 5G-enabled smart gateway

2.8.1.1 Partner's roles

Vertical:

WINGS provides the emulated smart grid that includes the power grid network, the power suppliers (e.g., solar panels), as well as the corresponding consumers. In addition, WINGS supports the use case with the ARTEMIS-Energy cloud platform that includes mechanisms for managing, storing, and analysing data. In addition, for the Smart Utilities extension, WINGS provides the water meters and the 5G gateway.

VNF provider(s):

1) WINGS: Node controlling VNFs.

2) ERI-GR: Core network VNFs.

3) NOK-GR: Core network VNFs.

Experiment developer(s):

WINGS takes care of all necessary actions for the realization of the experiments.

Experimenter(s):

WINGS drives the experiment execution as well as the collection and analysis of the corresponding results.

Site Manager(s):

OTE

2.8.1.2 Trials

The trials are being performed at OTE Academy premises, Athens. Table 17 summarizes all the Use Case related components that are included in the trials.

Table 17: Smart Energy (Greece) UC4.2 - Components

Component Name	Description	Deployment requirements
Voltage/Current Sensor	Sensor measuring the values of voltage and current.	Deployed in the distributed power grid infrastructure.
Relay Node	Node in the power grid infrastructure capable of relaying current to other nodes of the power grid infrastructure.	Deployed in the distributed power grid infrastructure.
Smart water meters	Sensors measuring water consumption.	Deployed/installed in OTE premises.
5G Gateway	Node close to the sensors/cameras responsible to collect data from the sensors/cameras or send data to relay nodes. It communicates with the 5G RAN (acting as 5G terminal).	Deployed close to sensors, relay nodes and cameras to provide 5G connectivity.
ARTEMIS Utilities Platform	Cloud platform in which the Utilities Services are deployed.	Deployed in a centralized server as Virtual Machine or in a distributed manner in the cloud continuum (edge/MEC, cloud).

2.8.2 Pilot architecture

As depicted in Figure 82, this trial is totally controlled through the 5G EVE's framework and more specifically, through the modules / mechanisms that are deployed in three layers (portal, interworking layer, Greek site).

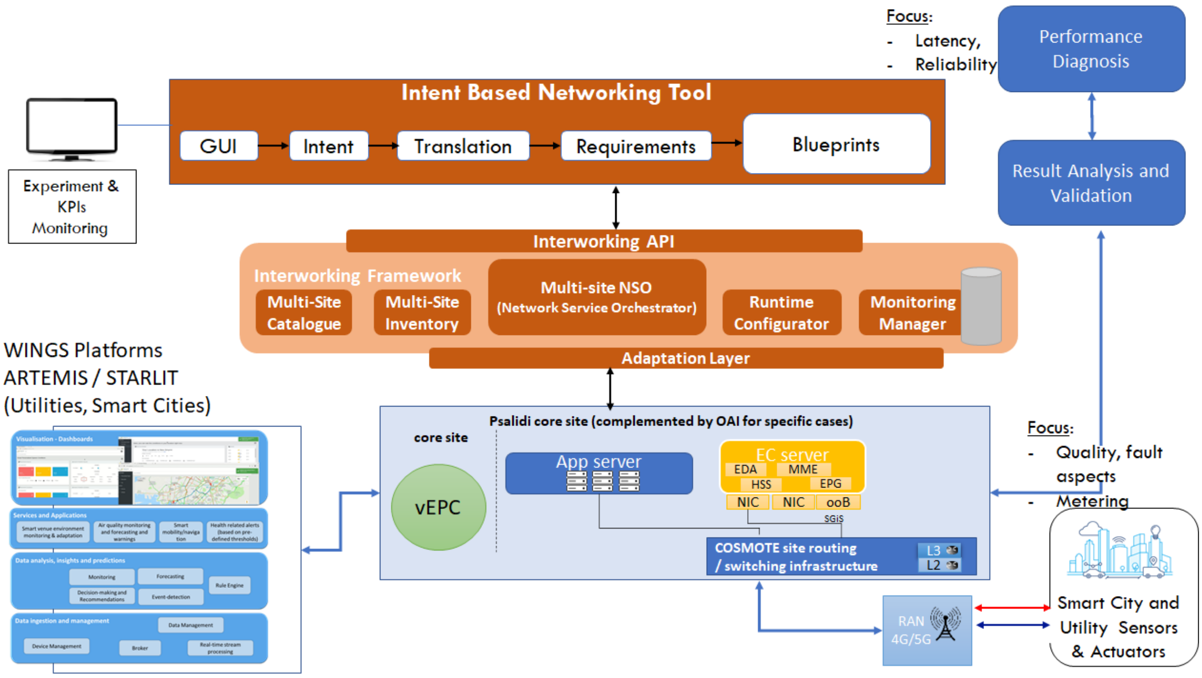


Figure 82: Smart Energy (Greece) UC4.2 - Architecture

2.8.3 Vertical service KPIs implementation

A set of application layer vertical KPIs are collected and validated as illustrated in the Table 18.

Table 18: Smart Energy (Greece) UC 4.2 - Vertical Service KPIs

Use case title	**Smart Energy: Resolving Outages and Ensuring the Stability of Smart Grids**	
Site facility	**Greece**	
Vertical KPI name	Power Restoration Time	Power Restoration Decision Time
Vertical KPI definition	The time from the moment a voltage drop is detected on a smart node to the time the voltage is restored to the correct value	The time from the moment a problematic node reports its status to the time a decision for new power route to that node is decided
Metric collection tools	Custom tool inside the smart node	This value is calculated internally at the Platform
Position of the probes in the reference architecture 1) UE; 2) Public Cloud; 3) Private Cloud; 4) Edge	Probes are located at the UE and the Server on the public/private Cloud (depending on the deployment)	Probe is located at the Server on the public/private Cloud (depending on the deployment)
Metric collection methodology	For each problematic node the time from the request to resolve outage to the reconfiguration is measured as a sum of the reconfiguration time of the node and the response time for that request minus the processing time of the platform	The decision time is a sum of the latency for the status update requests for the available power routes and the platform internal algorithm decision time
Validation tools	The 5G EVE platform's KPI validation framework	The 5G EVE platform's KPI validation framework
Validation methodology	Specific time limits have been calculated for the time that a node can operate during a voltage drop. When those limits are crossed, the smart node's operation is prone to errors and as such is marked as dangerous and needs to be shut down thus destabilizing part of the grid. The total time it takes to restore the voltage of this problematic node is compared to these values to decide on the validation results	This KPI comprises of the time it takes to get the status of all the available power routes and decide on the optimal one to restore the voltage on the afflicted node. It is the sum of the processing time and the response times for the various requests to update the status of the routes. The required processing time is calculated as a factor of the grid size and the CPU utilization of the platform and the response time for all the requests is again a factor of the grid size and the network latency. Finally, this value is compared to the acceptable thresholds provided by profiling this service for various grid sizes and network access technologies

In addition, a set of network related KPIs are collected and validated on the vertical side as illustrated Table 19.

Table 19: Smart Energy (Greece) UC 4.2 - Network KPIs

Use case title	**Smart Energy: Resolving Outages and Ensuring the Stability of Smart Grids**
Site facility	**Greece**

Vertical KPI name	End-to-end RTT latency	Bandwidth (UE side)	Bandwidth (Server side)
Vertical KPI definition	The end-to-end RTT latency between the gateway (UE) and the server located in Edge cloud	The bandwidth experienced on the gateway (UE) side	The bandwidth experienced on the server side
Metric collection tools	fping + appropriate Data shipper	Tools bmon / bwm-ng + appropriate Data shipper	Tools bmon / bwm-ng + appropriate Data shipper
Position of the probes in the reference architecture 1) UE; 2) Public Cloud; 3) Private Cloud; 4) Edge	Gateway (in UE)	Gateway (in UE)	Edge Cloud (in VNF)
Metric collection methodology	Collect metric every 60 second	Collect metric every 60 seconds	Collect metric every 60 seconds
Validation tools	5G EVE Portal KPI validation tool	5G EVE Portal KPI validation tool	5G EVE Portal KPI validation tool
Validation methodology	AVG values among the collected metrics	AVG values among the collected metrics	AVG values among the collected metrics

2.8.4 Pilot deployments

The pilot deployment is illustrated in Figure 83. The voltage/current sensors and relay nodes are connected to the 5G gateway. Then, the 5G gateway is connected to the 5G RAN. For the current deployment the 5G gateway is connected to the Ericsson 5G NSA network. Then the traffic enters/exits the Internet through the N6 interface of the 5G Core. Two deployments were carried out. In the first the WINGS ARTEMIS Energy Platform is deployed in the public Cloud, while in the second deployment it is deployed in a private Cloud (local server) connected just after the N6 interface.

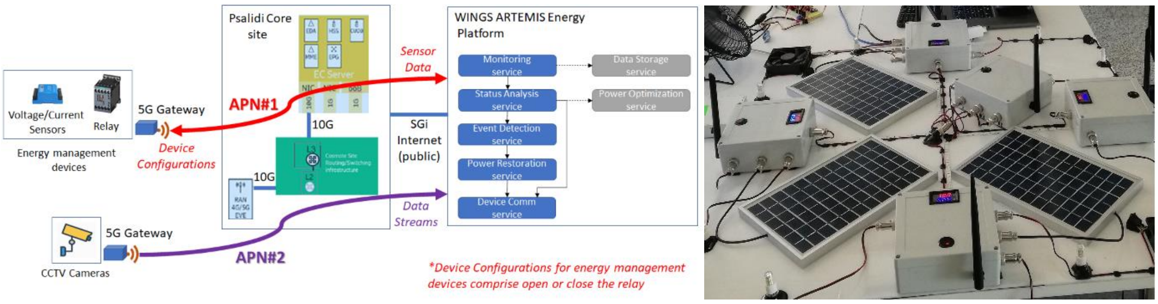


Figure 83: Smart Energy (Greece) UC4.2 - Pilot deployment

To validate the experiments thought the 5G EVE platform, as set of blueprints and descriptors were generated describing the VNFs, NSD, KPI, metrics and test parameters.

2.8.5 Pilot execution results

Table 20 summarizes some KPIs of interest for the specific use case. From network perspective RTT latency has been identified as most important, while power restoration time and power restoration decision time are the most significant vertical KPIs.

Table 20: Smart Energy (Greece) UC4.2 - Vertical service KPIs measurement

5G related KPIs	**Comments**
RTT Latency	Target: 20 ms

Vertical KPIs	Is it measurable during experimentation?	Can it be mathematically derived from 5G related KPIs?
Power Restoration Time	Yes, it is measured in the 5G Gateway node. Target: 200 ms	End-to-end latency plus an offset time of relay node's activation
Power Restoration Decision Time	Yes, it is measured in the Power Restoration service. Target 50 ms	No

More detailed experiments were conducted focusing on the evaluation of the use of the 5G network. For this purpose, in addition to the installation of IoT devices (energy meters and water meters), a high number of IoT devices, ranging from tens to hundreds, were emulated using specialised software. Scenarios with different number of IoT devices and different transmission rates per device (e.g., every 5 seconds, every 10 seconds) were executed and the metrics were analysed. By using the 5G testbed of Ericsson that is deployed on the Greek site average latencies of 9.79 msec were achieved. At the application level, for the smart energy use case, the average end-to-end latency of a service request was around 60 msec (also including the required processing time of the information at the local cloud). The 5G testbed of NOKIA was also used for experimentations. In this case, network latencies of around 12 msec were observed in the scenarios with the best wireless channel conditions (e.g., device positions with high coverage and low interference). Finally, both 5G testbeds guaranteed the requested data rates while application layer packet losses were not observed.

As depicted in Figure 84, through the KPI validation tool, roundtrip latencies around 10 ms were validated. The targets for the two vertical KPIs, 200 ms for Power Restoration Time and 50 ms for Power Restoration Decision Time, respectively, shown in Figure 85 and Figure 86, were also achieved.

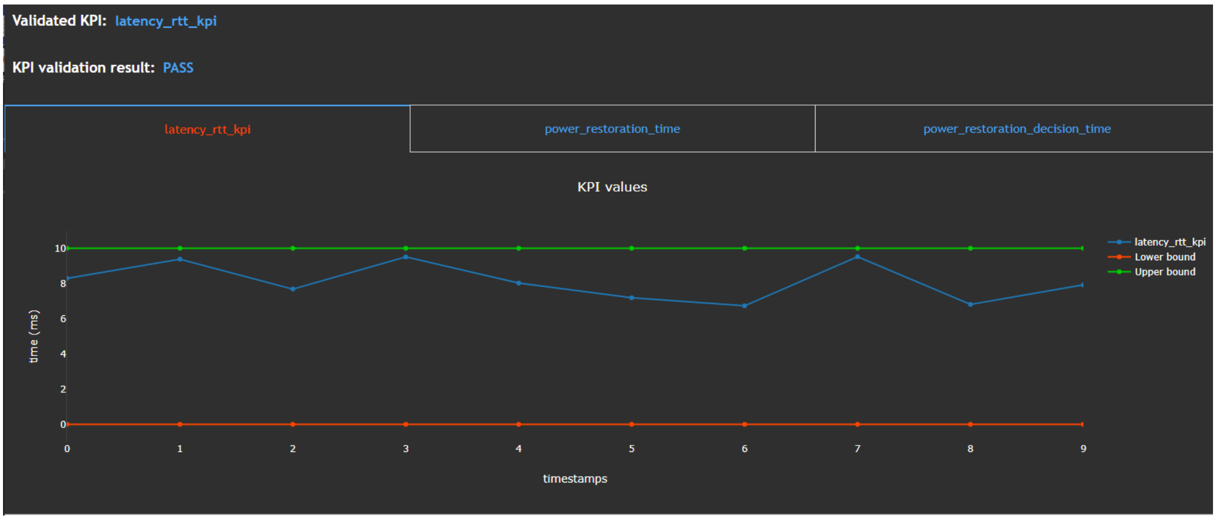


Figure 84: Smart Energy (Greece) UC4.2 - RTT Latency KPI

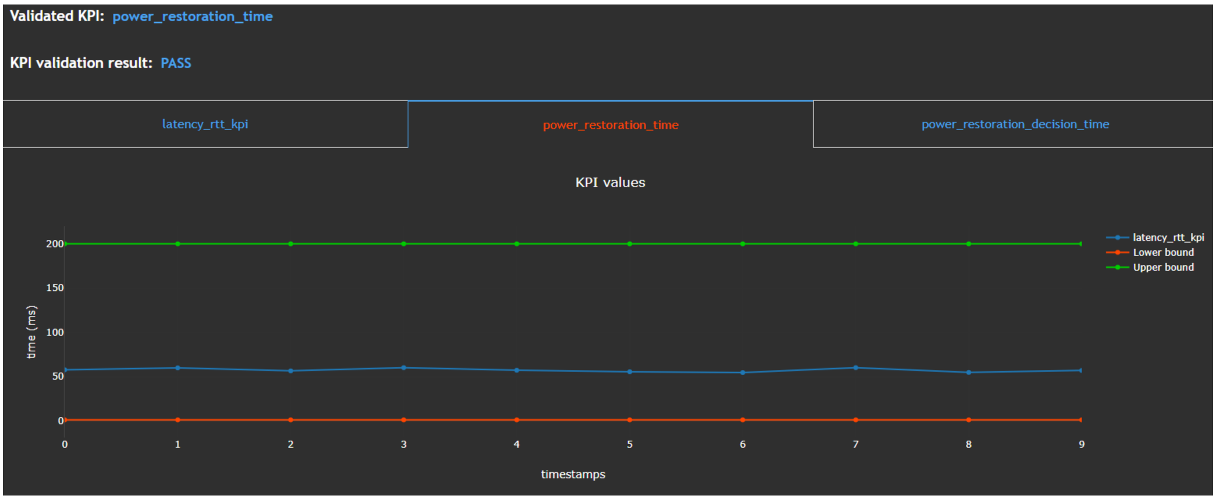


Figure 85: Smart Energy (Greece) UC4.2 - Power Restoration Time KPI

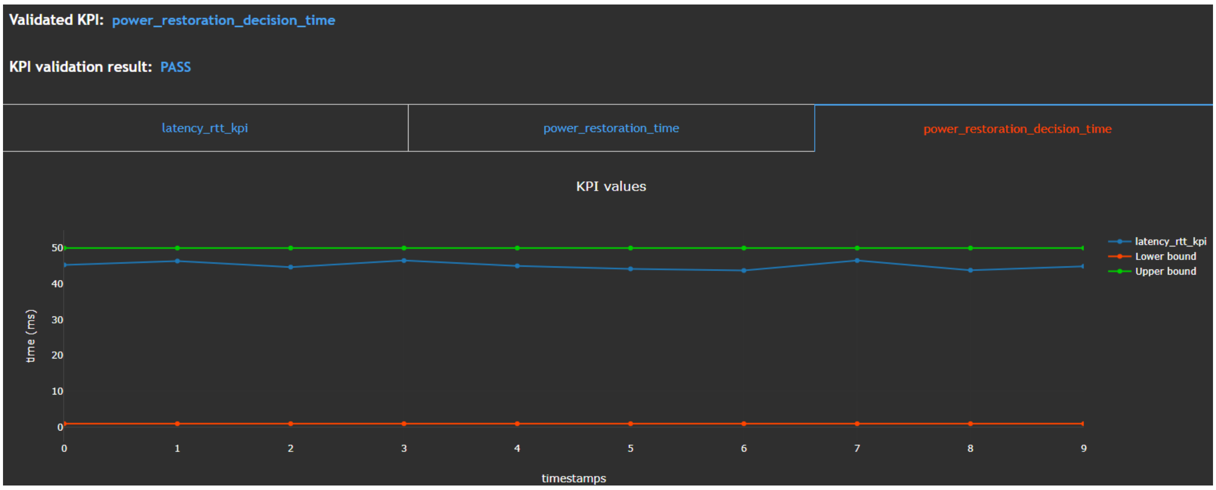


Figure 86: Smart Energy (Greece) UC4.2 - Power Restoration Decision Time KPI

2.8.6 5G empowerment

In this trial, (energy-related) measurements from the devices are sent to the WINGS ARTEMIS Energy platform, over an mMTC slice, and then the platform processes these measurements and reacts in cases of power outages with proper remediation actions for power restoration. The key objective of the trial is the accurate, reliable and extremely fast transmission of the data through the 5G network in both directions.

2.8.7 5G EVE platform added value

The use of the 5G EVE platform enhanced the use case's testing repeatability by allowing experiment reconfiguration and test repeatability on the fly. Modifications and redeployment of the service are possible remotely, without the need for physical presence in the site facilities, and in combination with the platform's analysis and validation capabilities provide a valuable testing mechanism for any service. The implemented Performance Diagnosis tool which is part of the 5G EVE platform was also used in this use case. The Performance Diagnosis provided an insightful look into the operational behaviour of the elements of the service regarding their performance as well as the dependencies between the various elements. Building on that, fine-tuning the service while removing detected performance bottlenecks at the same time became possible and consequently so did the validation of the services KPIs targets as well. Finally, the service profiles generated during the Performance Diagnosis provide valuable information regarding the correlation of scaling resources and their cost with the corresponding performance hit.

2.9 Use Case 5.1 - Smart City: Safety and Environment – Smart Turin Wi-Fi Scanner

2.9.1 Pilot context

This Use Case collects data from commercial Wi-Fi probe-detection sensors, henceforth referred to as "scanners", and infers flow densities and direction of transit of people on city streets. The scanners detect the *probe-request* messages sent periodically by all the active Wi-Fi (Rel.5) interfaces and thus by the mobile devices (typically, smartphones) carried by the people moving in the area. The source MAC address of such messages (even if randomized and anonymized) allows to infer the mobility of each mobile device. The Use Case is hosted by the Italian Site in the City of Turin and is developed by CNIT.

The 5G EVE Flow Mobility Service is available as Vertical Service in the 5G EVE Platform.

2.9.1.1 Partner's roles

Vertical

CNIT plays the role of the vertical, it has the purpose of testing crowd management algorithms using the 5G EVE infrastructure.

VNF provider(s)

CNIT has provided the VNF to be on boarded with the help of NXW.

Experiment developer(s)

CNIT has developed the experiments with the goal of evaluation of the Use Case.

Experimenter(s)

CNIT is also the experimenter, processing the probe data collected through the Wi-Fi scanners to feed them into the algorithms to detect the flow of people.

Site Manager(s)

TIM is the site manager, and it has collaborated with CNIT for the installation and maintenance of Wi-Fi scanners connected to the 5G architecture.

2.9.1.2 Trials

The UC is fully operational on 5 WiFi scanners covering the area between Politecnico di Torino and Porta Susa Train Station; such area is one of the main transport backbones from the campus area and one of the main Torino train stations. Figure 87 illustrates the coverage area for the Trial.

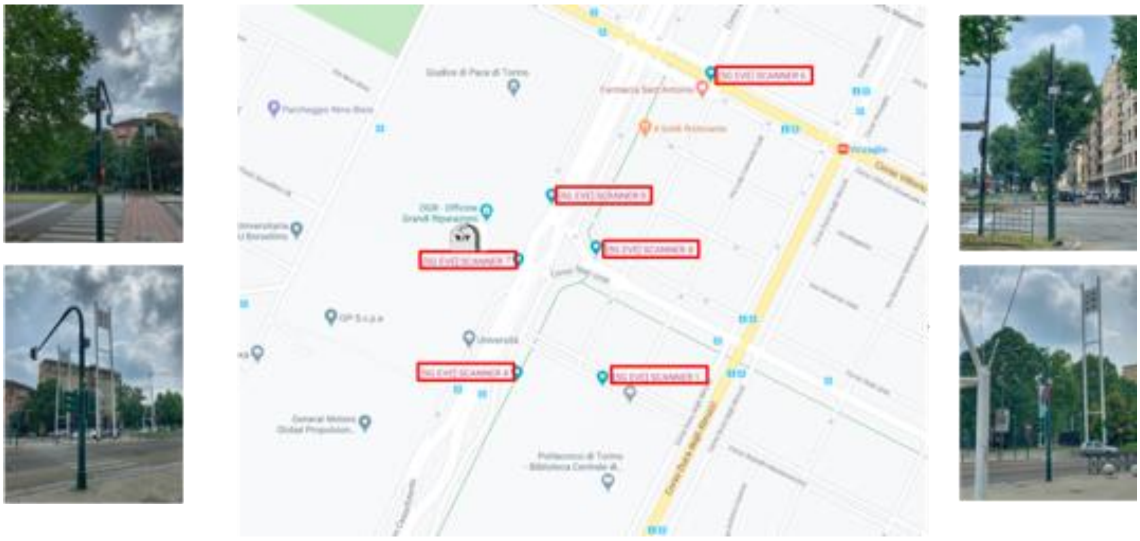


Figure 87: Smart City (Italy) UC5.1 - Coverage area map

2.9.2 Pilot architecture

The Pilot architecture is defined through the following components:

1. The **Wi-Fi scanners** record the time at which the MAC address of a device was observed and publish the corresponding data. The MAC address is anonymized.
2. The **One-M2M platform** collects the data received by all the Wi-Fi scanners.
3. The **Mobility tracker** gets real-time data from the One-M2M platform using MQTT [23] protocol.
4. The **Visualization Tool,** based on Grafana [24]**,** allows the experimenter to display customized dashboards showing the real-time number of devices under each scanner.

Figure 88 illustrates the architecture for **5G EVE Flow Mobility Service**.

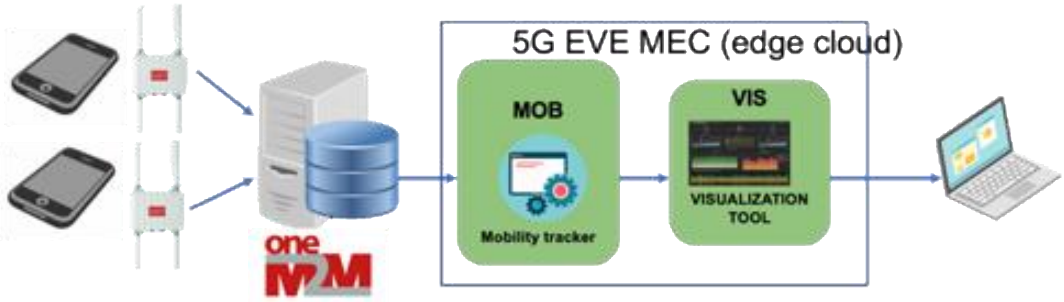


Figure 88: Smart City (Italy) UC5.1 - Pilot architecture

The Mobility Tracker is implemented through a VNF denoted as MOB, and the Visualization tool through a VNF denoted as VIS. Both VNFs are orchestrated within the edge cloud.

2.9.3 Vertical service KPIs implementation

To collect the metrics, we used the data shipper available at [25]. In Table 21 and Table 22, we report the metrics that we collect and how we define the corresponding KPI:

Table 21: Smart City (Italy) UC5.1 - Vertical Service KPIs

Use case title	**Smart City: Safety and Environment – Smart Turin Wi-Fi Scanner**
Site facility	**Italy**

Vertical KPI name	CPU consumption MOB VNF	Memory consumption MOB VNF	Storage consumption MOB VNF
Vertical KPI definition	The resources remain < 70% maximum available in the edge cloud	The resources remain < 70% maximum available in the edge cloud	The resources remain < 70% maximum available in the edge cloud
Metric collection tools	https://github.com/5GEVE/datashipper-turin	https://github.com/5GEVE/datashipper-turin	https://github.com/5GEVE/datashipper-turin
Position of the probes in the reference architecture 1) UE; 2) Public Cloud; 3) Private Cloud; 4) Edge	Edge (in VNF)	Edge (in VNF)	Edge (in VNF)
Metric collection methodology	Collect metric every 1 second	Collect metric every 1 second	Collect metric every 60 second
Validation tools	5G EVE Portal KPI validation tool	5G EVE Portal KPI validation tool	5G EVE Portal KPI validation tool
Validation methodology	AVG values among the collected metrics	AVG values among the collected metrics	AVG values among the collected metrics

Table 22: Smart City (Italy) UC5.1 - Vertical Service KPIs (cont.)

Use case title	**Smart City: Safety and Environment – Smart Turin Wi-Fi Scanner (cont)**		
Site facility	**Italy**		
Vertical KPI name	Number of active sensors tracked by MOB VNF	CPU consumption VIS VNF	Bandwidth between MOB VNF and OneM2M server
Vertical KPI definition	The sensors remain > 70% maximum available	The resources remain < 70% maximum available in the edge cloud	The bandwidth grown no more than linearly with the number of scanners
Metric collection tools	Custom bash+python script	https://github.com/5GEVE/datashipper-turin	https://github.com/5GEVE/datashipper-turin
Position of the probes in the reference architecture 1) UE; 2) Public Cloud; 3) Private Cloud; 4) Edge	Edge (in VNF)	Edge (in VNF)	5G Core
Metric collection methodology	Collect metric every 1 second	Collect metric every 1 second	Collect metric every 1 second
Validation tools	5G EVE Portal KPI validation tool	5G EVE Portal KPI validation tool	5G EVE Portal KPI validation tool

Validation methodology	MIN value among the collected metrics	AVG values among the collected metrics	AVG values among the collected metrics

2.9.4 Pilot deployments

The Use Case configuration is illustrated through the Vertical Service Blueprint (shown in the Figure 89 and available in [26]) describing different components and related connections.

The big blue boxes represent the two major components (VNF) in the architecture:

1. "visualization_tool", with visualization and analysis purposes;
2. "mobility_tracker", which processes the data received by the One-M2M from the WiFi scanners.

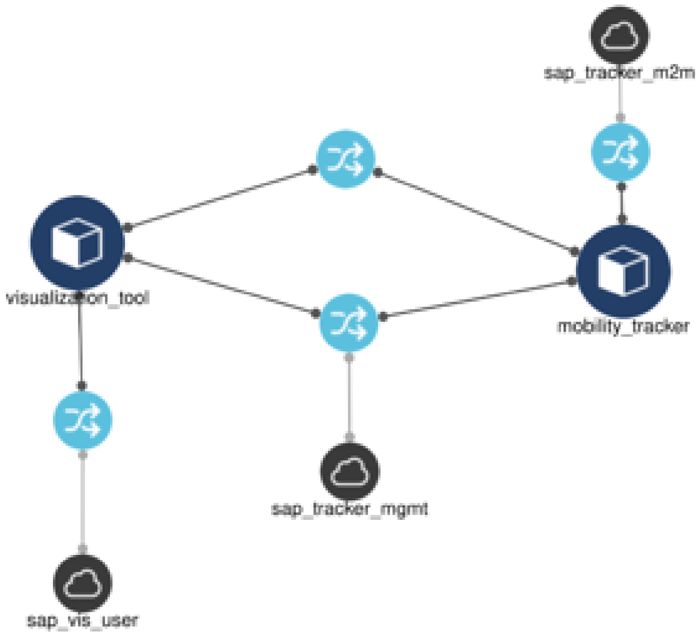


Figure 89: Smart City (Italy) UC5.1 - Vertical Service Blueprint

We provide two main dashboards:

Device density dashboard (Figure 90): This dashboard provides the number of devices over time under each Wi-Fi scanner in function of a given time interval. Six graphs are presented:

- Graph #1 shows the number of distinct MAC addresses that were captured in a given sampling period. Even if this number is affected by randomization, it clearly shows from a qualitative point of view some high-level effects related to the mobility. E.g., from the graph it is possible to observe the effects of COVID restrictions and of holidays.
- Graph #2 represents the same information as in the first graph but represented through a heatmap in function of the day and the hour, useful to identity periodic patterns (as day/night, weekly, etc.).
- Graph #3 and #4 are identical to graph#1 and #2 but they refer to MAC addresses of faculty members and Politecnico employees. These MAC addresses have not been randomized and allow to have a ground truth evaluation of the number of people under the coverage of each WiFi scanner, restricted on a particular social condition (i.e., being affiliated to Politecnico).
- Graph #5 and #6 are identical to graph #3 and #4 but refer to Politecnico students. The main difference with respect to the graphs #3 and #4 is that the population of samples is larger (by a factor 10, roughly speaking) and the habits are different. Thus, from the graphs it is possible to get insight on the different habits of students and faculty/employees commuting from/to Politecnico to/from Porta Susa train station.

Figure 90: Smart City (Italy) UC5.1 - Device density dashboard

Mobility flow patterns (Figure 91): This dashboard reports the most frequent mobility patterns identified in the area. A mobility pattern is defined as the sequence of WiFi scanner traversed by the same MAC address, thus represents a mobility path across the area covered by the WiFi scanners. Each pattern is identified by a string describing the temporal sequence of WiFi scanners along the path, e.g., a pattern XYZ means that the device moved from X to Y and then to Z. Given an observation window, the dashboard produces two outputs, as shown in the following picture:

- A map showing graphically the main mobility patterns with arrows that are coloured based on the observed popularity.
- A histogram showing all the most popular patterns ranked in decreasing order.

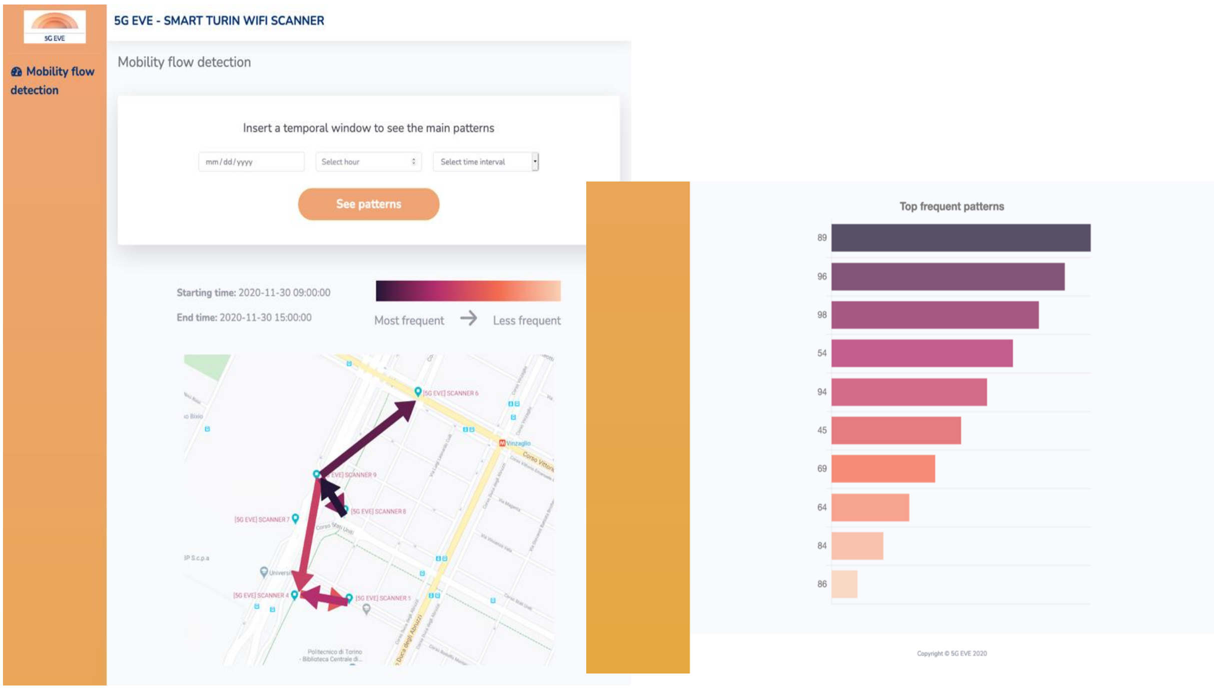


Figure 91: Smart City (Italy) UC5.1 - Mobility flow patterns

2.9.5 Pilot execution results

The collected data spans a time period starting from Oct. 2019 up to today, and comprises almost 15 million distinct MAC addresses, observed in about 40 million observations.

The following KPIs were observed for the two VNFs implementing the mobility tracking service:

- MOB VNF: average CPU utilization < 5%, cumulative storage 5.50 GB (cumulative), average RAM 2.7GB. Thus, all the corresponding KPIs are satisfied.
- VIS VNF: average CPU utilization <1% (but higher peaks when the user interacts with the dashboard). Thus, the corresponding KPI is satisfied.
- The number of active sensors has been observed following the downtime of some of them during some exceptional failure events, i.e., power loss or WiFi sensor freeze. This metric has been very useful to identify possible failures and to react promptly to them.
- The bandwidth between the MOB VNF and the OneM2M platform has been observed proportional to the number of MAC addresses detected by each WiFi scanner. Thus, the overall bandwidth does not grow more than linearly with respect to the number of running WiFi scanners and the corresponding KPI is satisfied.

2.9.6 5G empowerment

The main 5G feature that has improved the experimentation has been MEC. The service exploits the intrinsic spatial correlation of mobile users and distributes the mobility tracking application across multiple edge clouds. Thus, the pervasive nature of edge clouds in 5G networks enables a scalable solution for the mobility tracking application.

2.9.7 5G EVE platform added value

The main added values of 5G EVE platform have been the following:

- **Intent-based interface towards verticals**: the service is integrated with the 5G EVE portal.
- **Performance Diagnosis (KPI Framework)**: the service is integrated with the 5G EVE KPI monitoring system.

2.10 Use Case 5.2 - Smart City: Safety and Environment

2.10.1 Pilot context

According to the World Health Organisation (WHO): “Air pollution poses a major threat to health and climate”. The combined effects of ambient (outdoor) and household (indoor) air pollution cause about 7 million premature deaths every year [27]. More than 80% of people living in urban areas that monitor air pollution are exposed to air quality levels that exceed the WHO guideline levels. Considering the above, the “**Smart City: Safety and Environment**” use case addresses ambient air quality monitoring and forecasting in outdoor environments. Air quality monitoring is achieved through WINGS’ low-cost multi-sensor station that measures: O_3, CO, SO_2, NO, NO_2, PM1, PM2.5, PM10, noise, temperature and humidity. Using an integrated 5G modem, the station connects to the 5G network that is deployed in the Greek site and transmits real-time measurements to WINGS’ STARLIT cloud platform as shown in Figure 92.

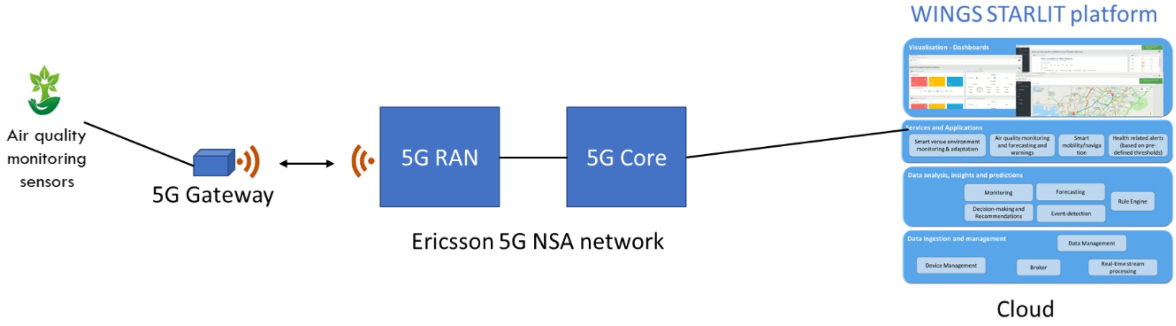


Figure 92: Smart City (Greece) UC5.2 - Components

In addition, food safety is also considered in this pilot. WINGS provided a food quality platform, a system comprised by a food scanner device and a supporting software platform for on the spot real-time food quality assessment. The system comprises two main parts, the sensing device (AGNES food scanner – Figure 93) and the software platform (AGNES dashboard – Figure 94). The sensing device consists of a sensing subunit containing sensors and light sources, and of an electronics subunit containing the integrated board and interfaces to the user and database. The software platform reaches from the embedded software deployed on the main electronics board, to the web user interface and finally the cloud database. The system covers (1) Mycotoxin detection, (2) Fraud detection and (3) Food identification and analysis (e.g., fat, moisture, proteins %).

Figure 93: Smart City (Greece) UC5.2 - The 5G-enabled AGNES food scanner

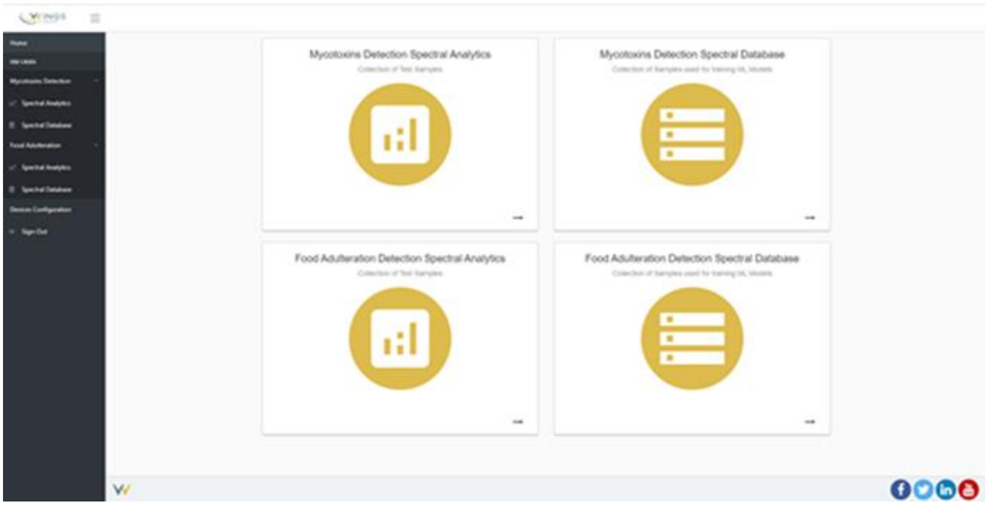


Figure 94: Smart City (Greece) UC5.2 - The AGNES food quality platform dashboard home screen

The **AGNES food scanner** incorporates an Ultraviolet – Visible (UV-VIS) spectrometer (C12880MA - Hamamatsu.), a Complementary Metal-Oxide Semiconductor (CMOS) camera and all the light sources needed for performing the above measurement methods. The sensors are configured and controlled by the device's control unit which can control the operation of the sensing subsystem and communicating with the end-user's web interface to collect the sensory measurements and send them to the cloud platform.

The **software platform** spans across the following system levels:

- **Embedded software** residing on the sensing device. The embedded software is responsible for operating the integrated sensing device, driving sensors and lighting sources, performing measurement procedures, performing data pre-processing and communicating with the web-based user interface.
- **Cloud platform** deployed on selected Infrastructure as a Service. The cloud platform hosts the cloud database for all sensory and contextual data sets necessary for performing food analysis required by the project use cases. The cloud platform provides web dashboard (**AGNES dashboard**) as the interface for managing the devices, the cloud database, measurements visualization and retrieval, and decision making procedures.

The **5G connectivity** allows AGNES devices to be connected with the cloud platform at all times with **low latency and high-speed rates (**Figure 95**)**. Such a fast and reliable connection gives the ability for fast and real time **control of the devices** from the web interface along with the quick data uploads. In addition, with the 5G connectivity a larger number of devices can be connected simultaneously to the cloud platform without overloading the network, thus providing large volumes of measurement data for analysis and giving its users a unique experience.

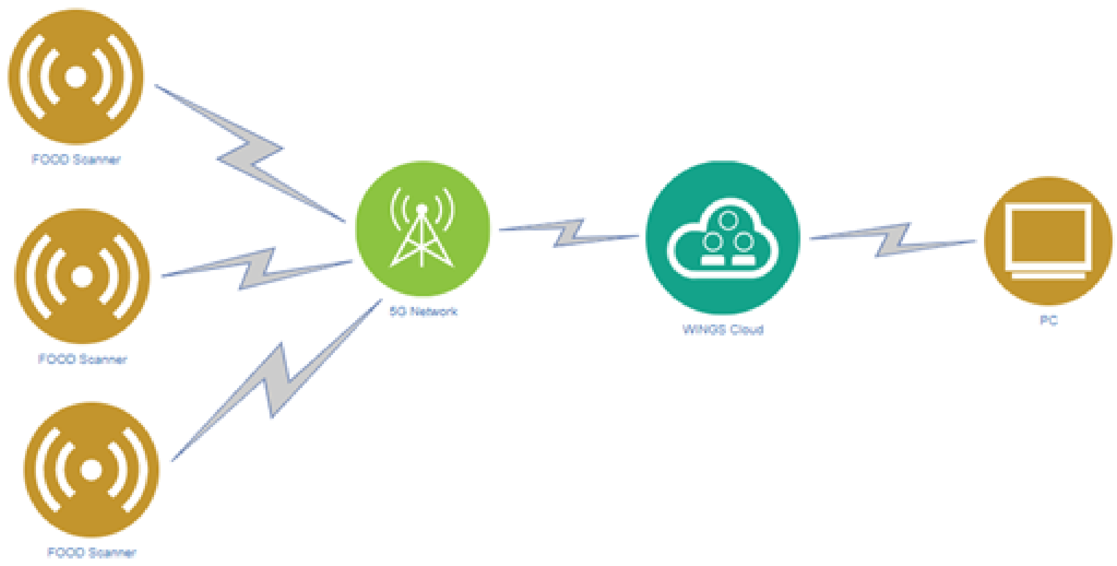


Figure 95: Smart City (Greece) UC5.2 - AGNES 5G connectivity

2.10.1.1 Partner's roles

Vertical:

WINGS provides the STARLIT platform, as well as the necessary sensors (low-cost multi-sensor station) that support the Smart City applications that are included in this Use Case.

VNF provider(s):

1) WINGS: Node controlling VNFs.

2) Ericsson-Greece: Core network VNFs.

3) NOKIA-Greece: Core network VNFs.

Experiment developer(s):

WINGS takes care of all necessary actions for the realization of the experiments.

Experimenter(s):

WINGS drives the experiment execution as well as the collection and analysis of the corresponding results.

Site Manager(s):

OTE.

2.10.1.2 Trials

The trials are being performed at OTE Academy premises, Athens. The air quality station is installed there as part of the Smart City infrastructure. A 5G Gateway is deployed close to the sensors and is responsible to collect data from them and to communicate with the 5G RAN and therefore, acting as a 5G terminal. The purpose of the 5G Gateway is to provide the required connectivity. The WINGS STARLIT platform, in which the Monitoring Services are deployed, is also available on site and hosted by a cloud server. AGNES food scanners are also available on site. Table 23 lists the components included in the Use Case.

Table 23: Smart City (Greece) UC5.2 - Components

Component Name	Description	Deployment requirements
Air Quality Sensor	Sensor measuring the air quality.	Deployed as part of the Smart City infrastructure
AGNES food scanner	Device measuring food quality.	Available on site for testing purposes.
5G Gateway	Node close to the sensors responsible to collect data from the sensors. It communicates with the 5G RAN (acting as 5G terminal).	Deployed close to sensors to provide 5G connectivity.
WINGS STARLIT platform	Cloud platform in which the Monitoring Services are deployed.	Deployed in a cloud server as Virtual Machine.

2.10.2 Pilot architecture

As depicted in the Figure 96, the trial is totally controlled through the 5G EVE's framework and more specifically, through the modules / mechanisms that are deployed in three layers (portal, interworking layer, Greek site).

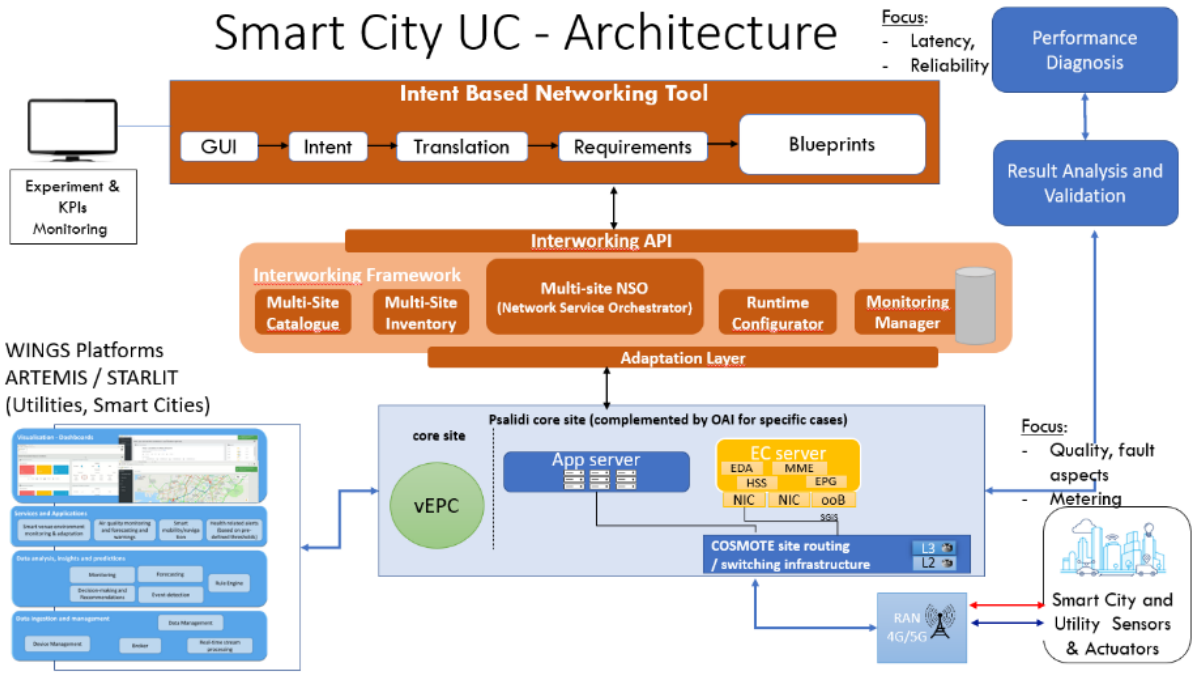


Figure 96: Smart City (Greece) UC5.2 - Architecture

2.10.3 Vertical service KPIs implementation

A set of application layer vertical KPIs are collected and validated as illustrated in Table 24.

Table 24: Smart City (Greece) UC 5.2 - Vertical Service KPIs

Use case title	**Smart City: Safety and Environment**	
Site facility	**Greece**	
Vertical KPI name	Request response time	Number of sensors supported
Vertical KPI definition	The response time of the requests from the smart nodes	The number of sensors supported by the platform based on the network performance

Metric collection tools	Custom tool inside the smart node	Value calculated internally at the Platform
Position of the probes in the reference architecture 1) UE; 2) Public Cloud; 3) Private Cloud; 4) Edge	Probes are located at the UE and the Server on the private Cloud	Probes are located at the UE and the Server on the private Cloud
Metric collection methodology	For each request the response is measured and published on the corresponding Kafka topic received in the data shipper configuration	The number of sensors is calculated based on the attainable data rate measured on the UE and the Server and is published on the corresponding Kafka topic received in the data shipper configuration
Validation tools	The 5G EVE platform's KPI validation framework	The 5G EVE platform's KPI validation framework
Validation methodology	The request response time at the UE (sensor) is calculated by subtracting the processing time at the Server in order to get the response time solely from the network latency. Afterwards it is compared to the Service target values	The aggregated data rate of the traffic that is generated during the service operation from all the sensors is measured. Afterwards it is divided with the average data rate for one sensor and compared to the Service target values

In addition, a set of network related KPIs are collected and validated on the vertical side as illustrated in the Table 25.

Table 25: Smart City (Greece) UC 5.2 - Network KPIs

Use case title	**Smart City: Safety and Environment**		
Site facility	**Greece**		
Vertical KPI name	End-to-end RTT latency	Bandwidth (UE side)	Bandwidth (Server side)
Vertical KPI definition	The end-to-end RTT latency between the gateway (UE) and the server located in Edge cloud	The bandwidth experienced on the gateway (UE) side	The bandwidth experienced on the server side
Metric collection tools	fping + appropriate Data shipper	Tools bmon / bwm-ng + appropriate Data shipper	Tools bmon / bwm-ng + appropriate Data shipper
Position of the probes in the reference architecture 1) UE; 2) Public Cloud; 3) Private Cloud; 4) Edge	Gateway (in UE)	Gateway (in UE)	Edge Cloud (in VNF)
Metric collection methodology	Collect metric every 60 second	Collect metric every 60 seconds	Collect metric every 60 seconds
Validation tools	5G EVE Portal KPI validation tool	5G EVE Portal KPI validation tool	5G EVE Portal KPI validation tool

Validation methodology	AVG values among the collected metrics	AVG values among the collected metrics	AVG values among the collected metrics

In the following Figure 97 the deployment architecture is illustrated together with the probes for the collection of the KPIs. Currently 3 probes are already deployed:

- Probe 1: On the 5G gateway collecting RTT latency metrics and throughput metrics.
- Probe 2: On the N6 interface collecting throughput metrics.
- Probe 3: On the Application Server RTT latency metrics and throughput metrics.

These probes collect metrics in a real time manner. In addition, two probes are deployed which collect metrics in a not real time manner.

- Probe 4: 5G RAN related metrics collected from the Ericsson NMS system (Radio ENM).
- Probe 5: 5G Core related metrics collected from the Ericsson NMS system (SINOM).

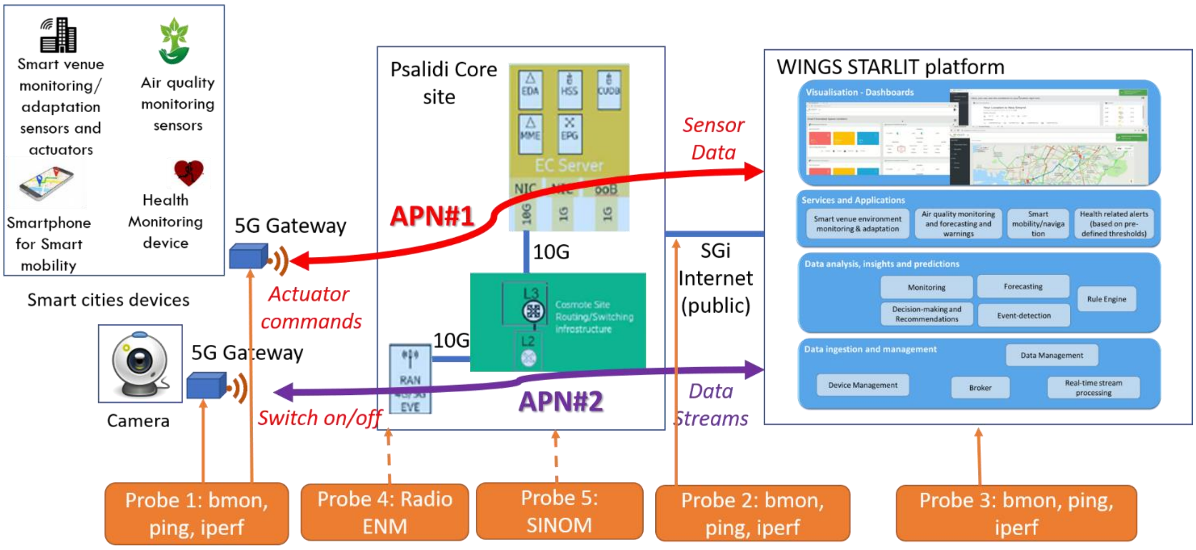


Figure 97: Smart City (Greece) UC5.2 - Probes placement

2.10.4 Pilot deployments

The trial has been implemented on the OTE Academy premises, where several AIR WINGS smart nodes have been deployed inside and around the lab. The individual components of the trial are depicted in the Figure 98.

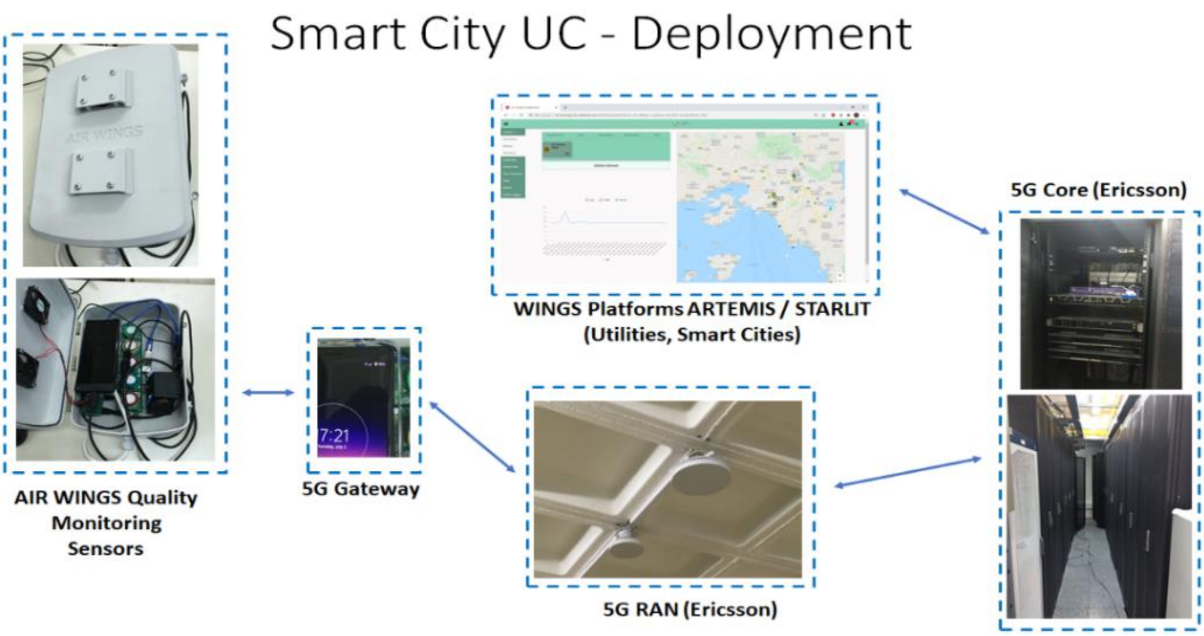


Figure 98: Smart City (Greece) UC5.2 - Pilot deployment at OTE academy premises (Athens)

5G NSA coverage is provided to the smart nodes, and it is operating over the n78 band.

The 5G EVE platform was used to deploy the STARLIT platform as well as a smart node emulator, to emulate additional background traffic, for the different tests of the trial. The smart nodes collect the various measurements using multiple sensors, and over the 5G NSA network, send these measurements to the STARLIT platform. The platform performs the following functionalities:

- Monitoring of all the sensors;
- Using the collected measurements to feed the AI models tasked with deciding any necessary actions based on the available actuators;
- Predict changes in the measurement values and recalibrate the models when necessary.

The AIR WINGS smart nodes, used in this trial, are custom built and provided by WINGS ICT Solutions and the UE, used as the 5G Gateway in this trial, is a smart phone provided by ERICSSON.

To execute this use case trial the following steps were performed:

- Preparing the necessary VNFs for the STARLIT platform and the smart node emulator and uploading them on the VIM of the Greek site;
- Creating the required blueprints and descriptors for the trial (VSB, TCB, ExpB and NSD) for the virtualized components of the experiment;
- Onboarding these blueprints and descriptors on the 5G EVE platform;
- Creation, scheduling, and instantiation of an experiment for the specific use case from the 5G EVE portal;
- Execution of the experiment and collection of the requested metrics;
- Analysis of the collected metrics and validation of the requested KPIs.

The blueprints and descriptors that were used for this use case can be found in [29].

2.10.5 Pilot execution results

The trial is supported by visualization dashboards that are included in the STARLIT platform, as shown in Figure 99.

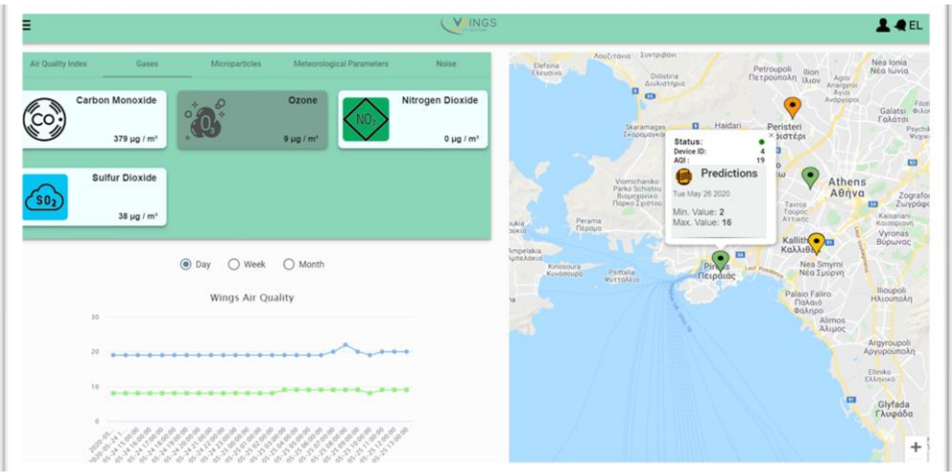


Figure 99: Smart City (Greece) UC5.2 - STARLIT platform dashboard

A few selected KPIs are closely monitored during the trial. Particularly, there were vertical KPIs such as the “Request response time”, shown in Figure 100, the “Number of sensors supported”, shown in Figure 101, as well as network KPIs such as the “RTT latency”, seen in Figure 102.

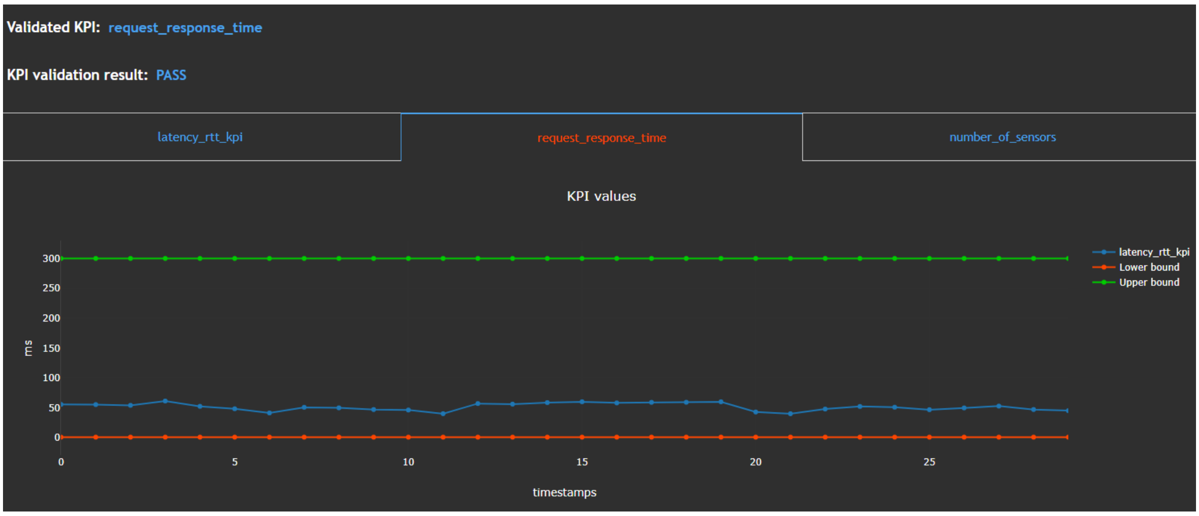


Figure 100: Smart City (Greece) UC 5.2 - Request Response Time KPI

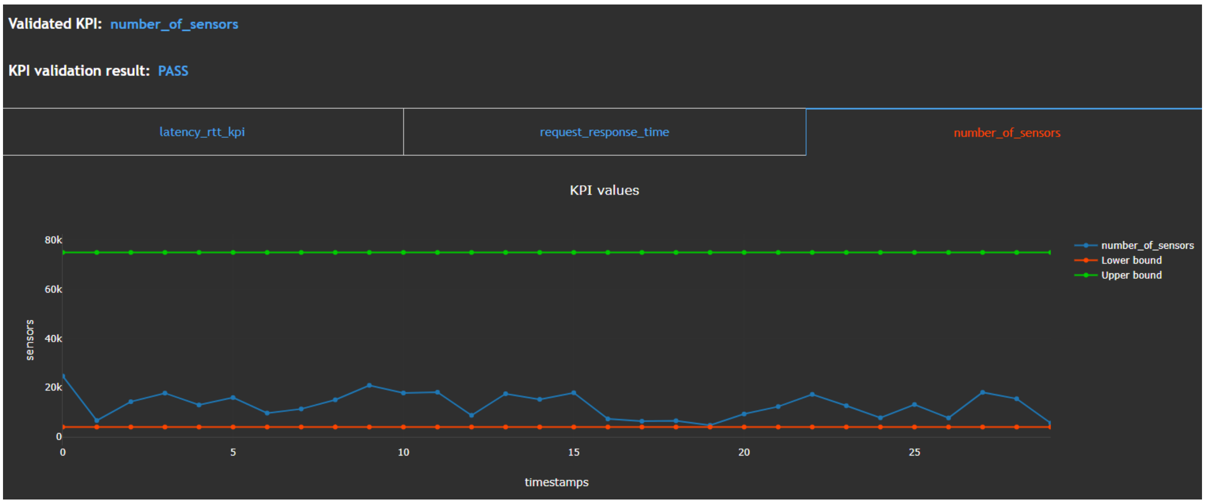


Figure 101: Smart City (Greece) UC 5.2 - Number of Sensors KPI

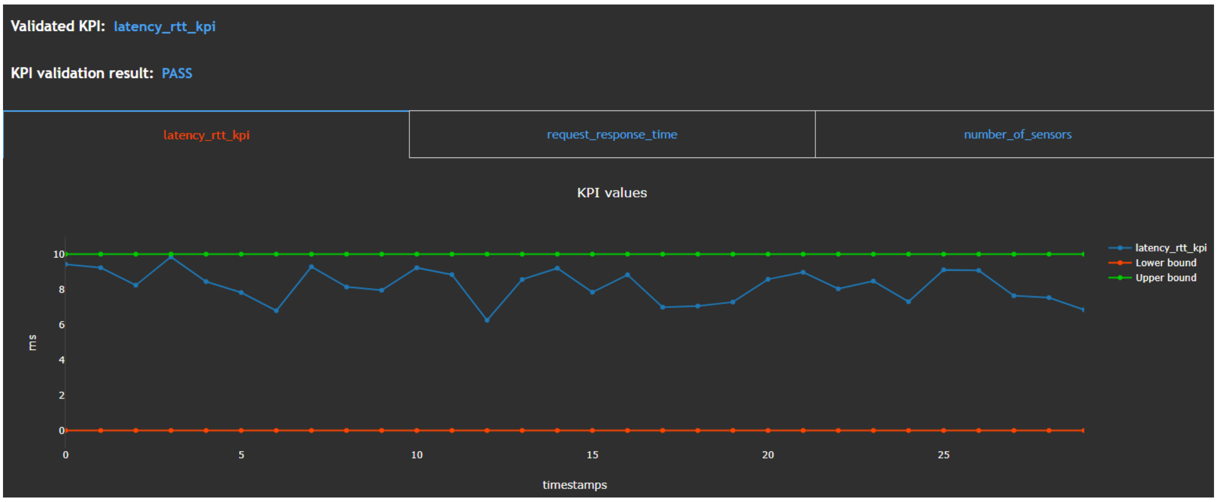


Figure 102: Smart City (Greece) UC 5.2 - RTT Latency

More detailed experiments were conducted focusing on the evaluation of the use of the 5G network. For this purpose, varying numbers of IoT devices (air quality monitoring, food scanners) were either installed or emulated, and set to transmit frames with variations in the transmission rates (e.g., every 5 seconds, every 10 seconds). Scenarios with different number of IoT devices (10, 100 and 500) and different transmission rates per device (e.g., every 5 seconds, every 10 seconds) were executed and the metrics were collected and analysed.

By using the 5G testbed of NOKIA that is deployed in the Greek site latencies of around 12 ms were observed in the scenarios with the best wireless channel conditions (e.g device positions with high coverage and low interference). At the application level, for the smart city use case, the average end-to-end latency was around 58 msec (including the required processing time of the information at the cloud). By using the 5G testbed of Ericsson that is deployed in the Greek site average latencies of around 9 msec were achieved. Both 5G testbeds guaranteed the successful transmission of low data rate requested by the application, while packet losses were not observed.

2.10.6 5G empowerment

In this trial, measurements from the station are sent to the STARLIT platform, over an mMTC slice, and then the platform processes these measurements, generates forecasts on the status of various parameters and triggers actions related to air quality monitoring and health recommendations. The key point for the success of the trial is the accurate, reliable and extremely fast transmission of the data through the 5G network. This allows for immediate reactions in cases of air quality degradation. In general, 5G fuels IoT applications through the mMTC services and the ability to interwork with URLLC and, where relevant, with eMBB. This brings further applications that change the way we work and live.

2.10.7 5G EVE platform added value

The use of the 5G EVE platform enhanced the use case's testing repeatability by allowing experiment reconfiguration and test repeatability on the fly. Modifications and redeployment of the service are possible remotely, without the need for physical presence in the site facilities, and in combination with the platform's analysis and validation capabilities provide a valuable testing mechanism for any service. The 5G EVE Performance Diagnosis tool was used during the use case test executions. It provided an insightful look into the operational behaviour of the elements of the service regarding their performance as well as the dependencies between the various elements. Building on that, fine-tuning the service while removing detected performance bottlenecks on the same time became possible and consequently so did the validation of the services KPIs targets as well. Finally, the service profiles generated during the Performance Diagnosis provide valuable information regarding the correlation of scaling resources and their cost with the corresponding performance hit.

2.11 Use Case 5.3 - Smart City: Safety and Environment – Connected Ambulance patient metrics

2.11.1 Pilot context

The scope of the "Connected Ambulance" use case is to convert the ambulance into a communication hub that is used to transmit the patient vital data, video and audio signals both from the accident scene and while the ambulance is on route to the hospital. 5G connectivity is required to properly support this use case, due to the massive capacity, reliability, low latency features needed for 4K video transmission and for remote diagnostic as well as the reliability and low latency needed for patient monitoring and some basic control.

2.11.1.1 Partner's roles

Vertical:

Nokia Greece.

VNF provider(s):

NOKIA Greece is the VNF provider.

1. Core network functionality (CMM, CMG, SMF, UPF, UDM, AUSF, AMF).
2. PNF supporting IoT platform functionality.

Experiment developer(s):

Nokia Greece takes care all necessary Use Case actions.

Experimenter(s):

Nokia Greece takes care all necessary Use Case actions.

Site Manager(s):

OTE.

2.11.1.2 Trials

The connected Ambulance use case was initially demonstrated during the trial for the Greek site webinar on the 7th of July 2020. In this trial the use case was not shown end to end, however IMPACT IoT platform was connected to the vEPC via S/P Gateway. Patient metrics flow was scheduled to be performed via the same gateway as the one used for the 4K video data flow. Information is to be conveyed to the vEPC via this gateway, and from there to the IMPACT platform. Installation of the vEPC, IoT platform and Radio, at OTE labs is depicted in Figure 103.

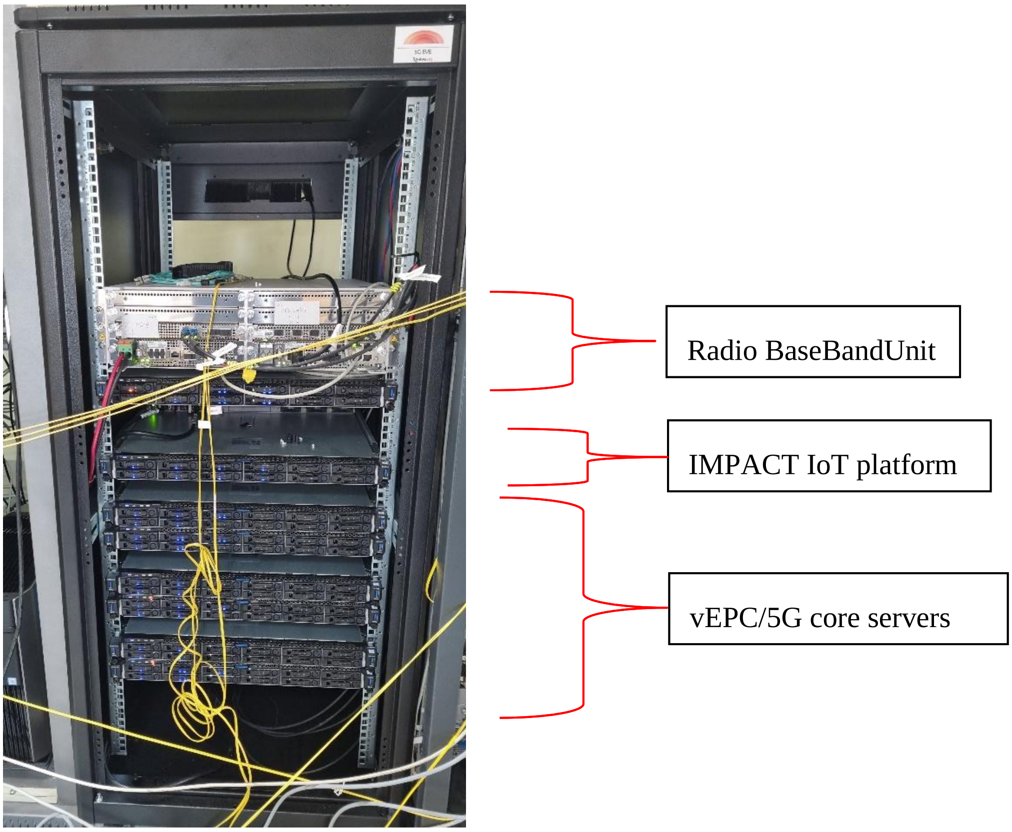


Figure 103: Smart City (Greece) UC5.3 - Trial equipment

2.11.2 Pilot architecture

Vital measurements are conveyed via the 5G gateway (Nokia Fastmile) to vEPC core and then via S/P gateway to the Nokia IoT platform (IMPACT). The platform then conveys the data to an application dashboard. Platform-application connection is performed via REST API. The vital metrics watch like device (see Figure 109), which takes the patient metrics, is connected to the 5G gateway via WiFi. Data is forwarded to IMPACT using HTTP protocol functions, which are relayed on the HTTP protocol adapter of the IMPACT IoT platform. Data flow is shown in Figure 104.

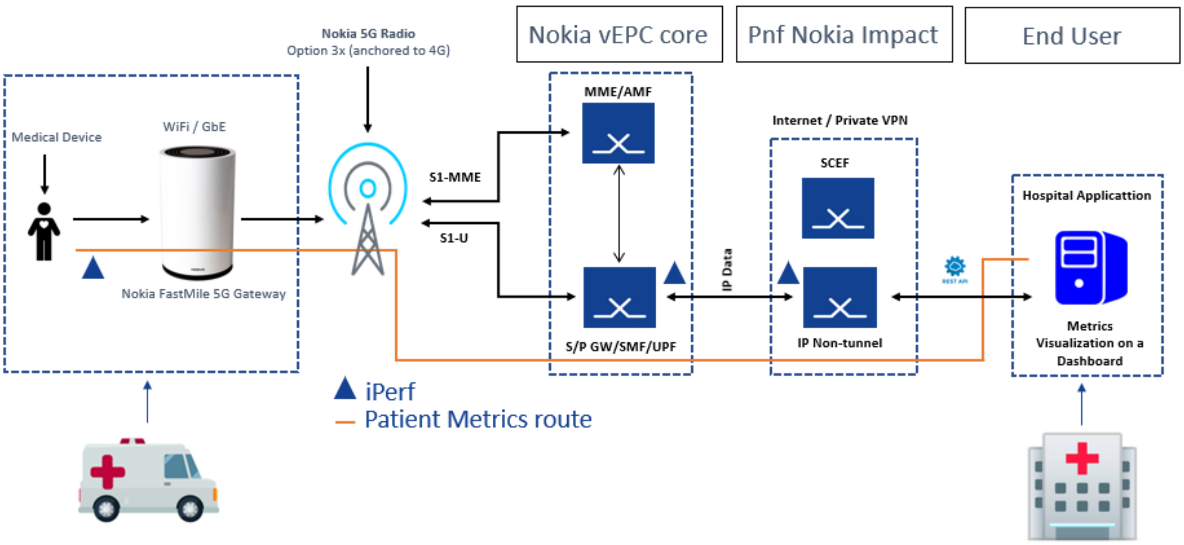


Figure 104: Smart City (Greece) UC5.3 - Pilot architecture, components, interfaces

Data collected during the use-case execution is shipped via a Kafka Publisher to the Greek site Kafka Broker (residing at local OSM-maintained by WINGS), which then conveys the data towards the Interworking Layer, according to the standard site-IWL architecture scheme, is depicted in Figure 105:

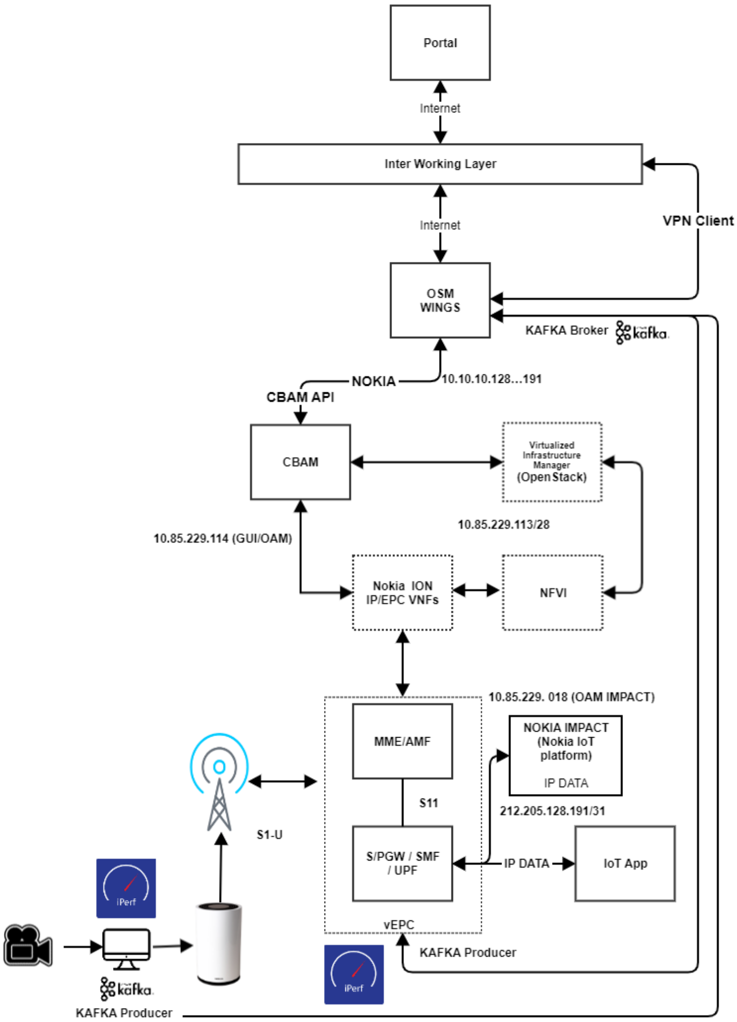


Figure 105: Smart City (Greece) UC5.3 - Data collection architecture

Currently vEPC is running on 4G cloud core elements [CMM-CMG], supporting 5G NSA Radio. There is a parallel deployment of 5G core elements, to support 5G SA. Currently SMF, UPF, UDM, AUSF, AMF have been installed, together with the relevant network changes.

Network components, apart from core:

- VNFM: All vEPC VNFs are handled by CBAM which acts as NFV MANO. As per architectural diagram, OSM is a NFV MANO communicating with CBAM via API. A predefined set of MANO commands has been selected for the OSM/CBAM interface:

Termination (and subsequently) Instantiation commands refer to the Gateway part of the core. CMM is treated as a PNF.

This set of commands is depicted in the Service and Vertical Blueprints [30], where the VNF deployments are initiated from the interworking layer.

- Core can be configured using two APNs in 2 slicing modes for low latency, or throughput.
- IoT platform (IMPACT) is defined as a PNF, as due to its design it can’t be deployed as a VNF.
- Radio deployed for all “Connected Ambulance” sub use cases using 2 Nokia Airscale mRRH pair of cells.

Figure 106 and Figure 107 depict the 4G anchor overview and the 5G NSA connectivity overview, used for this use case.

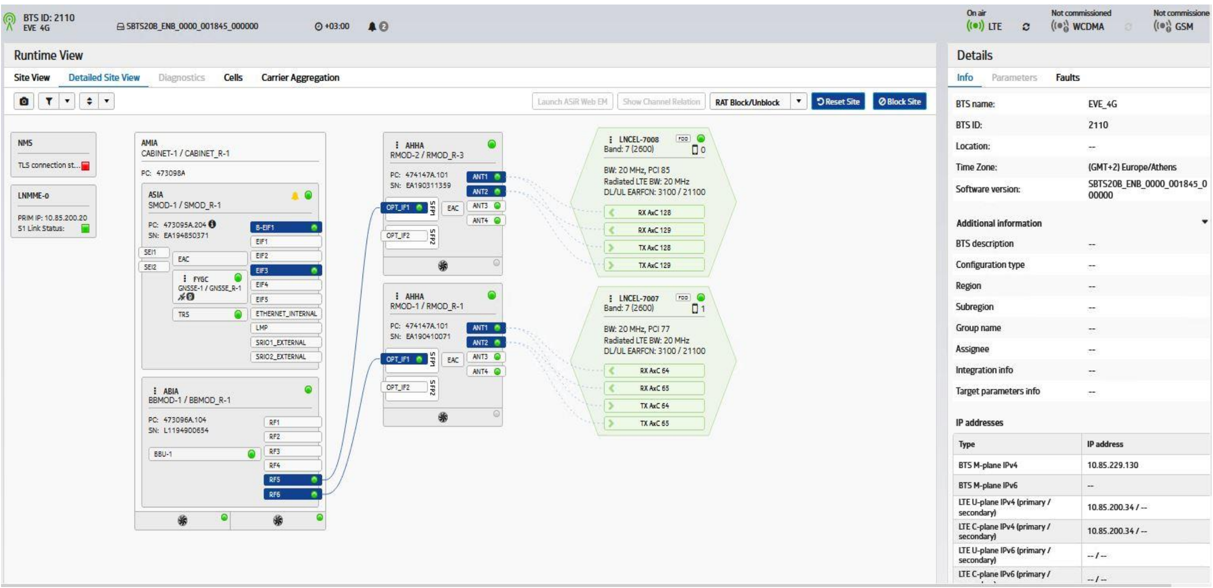


Figure 106: Smart City (Greece) UC5.3 - 4G anchor

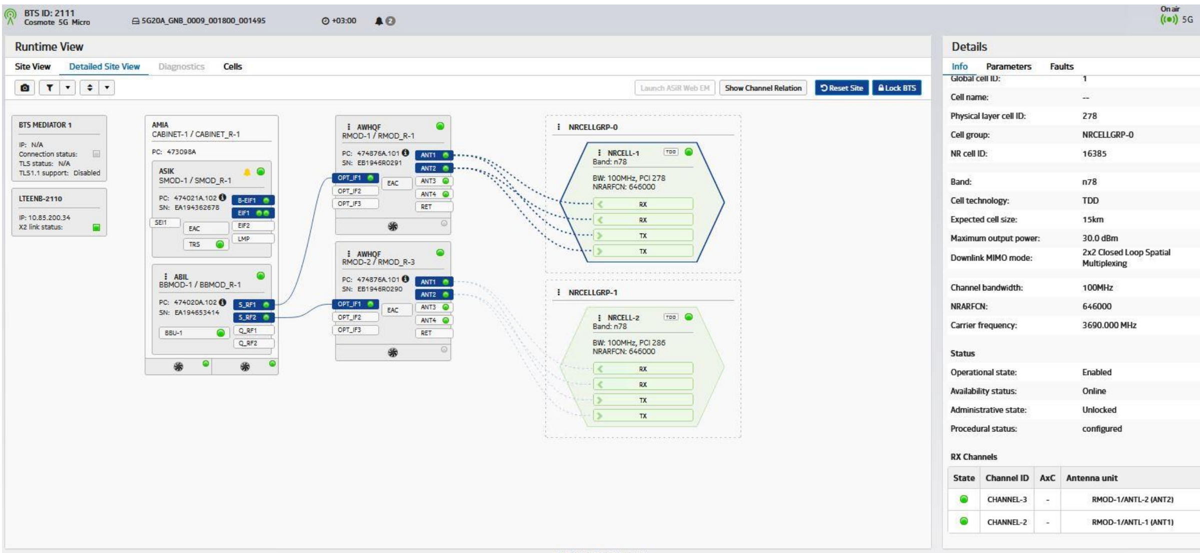


Figure 107: Smart City (Greece) UC5.3 - 5G NSA

OOKLA Speedtest throughput result using an external server (via internet) are depicted in Figure 108

Figure 108: Smart City (Greece) UC5.3 - OOKLA throughput test to external server over 4G (left) and 5G (right)

2.11.3 Vertical service KPIs implementation

As the traffic caused by the flow of patient metrics data are relatively small (within the range of kbps) the important KPI on this sub use case is latency. The KPIs consists of RTT time and iPerf jitter reporting. iPerf can produce data in JSON format, which can be compatible with the Interworking layer requirements. Out of the KPIs defined for the "Connected Ambulance" use case the Tracking response time is relevant to this sub-use case. Table 26 depicts the vertical service KPIs used for this use case.

Table 26: Smart City (Greece) UC5.3 - Vertical Service KPIs

Use case title	**Connected Ambulance patient metrics**		
Site facility	**Greek Site**		
Vertical KPI name	**Up Stream Throughput**	**Tracking Response time**	**Downstream Throughput**
Vertical KPI definition	Minimum user experience upstream data rate required for the user to get a quality experience of the use case	Time spent to evaluate selected amount of data and visualize them	Minimum user experience downstream data rate required for the user to get a quality experience of the use case
Metric collection tools	iPerf	iPerf, ping	iPerf
Position of the probes in the reference architecture 1) UE; 2) Public Cloud; 3) Private Cloud; 4) Edge	1,3 (VNF)	1,3 (VNF)	1,3 (VNF)
Metric collection methodology	Collect metric per 1s. The value is the average upstream throughput during this period	Monitoring metric collection as the experiment runs. Collect every 5 seconds	Collect metric per 1s. The value is the average upstream throughput during this period
Validation tools	5G EVE Portal KPI validation tool	5G EVE Portal KPI validation tool	5G EVE Portal KPI validation tool
Validation methodology	Remove the low values during service inactive periods. Select the minimum value of all remaining values	Comparison of min and max values during the experiment in 4G and 5G	Remove the low values during service inactive periods. Select the minimum value of all remaining values

2.11.4 Pilot deployments

The trial has been implemented on the OTE Academy premises. Core and Radio have been deployed as depicted in Figure 103. vEPC is running on 4G cloud core elements [CMM-CMG], supporting 5G NSA Radio. Radio deployed uses 2 Nokia Airscale mRRH pair (4G-5G) of cells. 5G core is deployed with the respective elements. A server (using Windows) is also used to serve video for the 4K video transmission and a NOKIA Fastmile 5G gateway is connected to the 5G Radio on site, as shown in Figure 114. Moreover, for the vitals metrics a watch-like device (see Figure 109), collecting the metrics is used. The device is connected to the 5G gateway via WiFi. Moreover, IoT platform has been deployed to aggregate the data from the Vitals measuring device. The device, as well as its output are shown in the image below. Use case Blueprints are stored in 5G EVE test case blueprints repo [30].

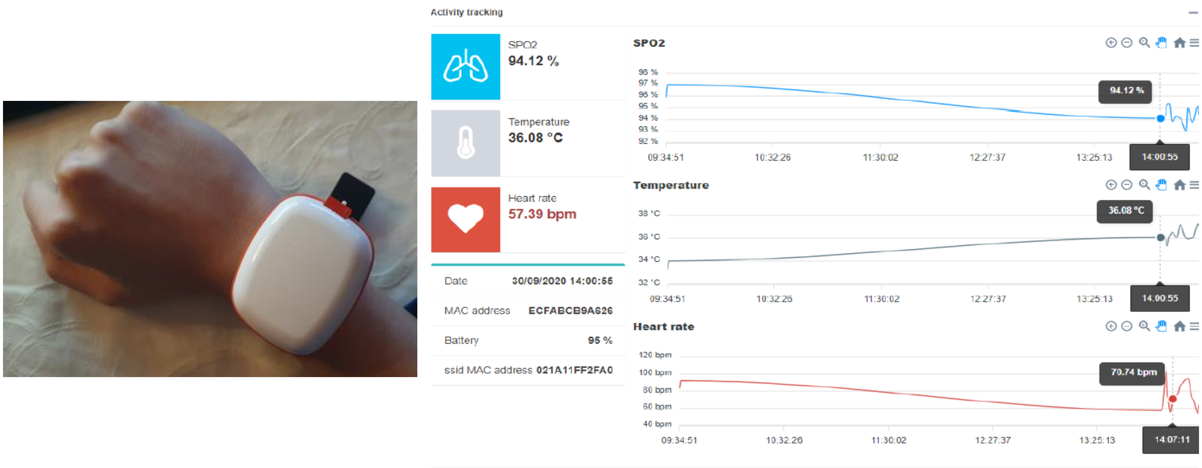


Figure 109: Smart City (Greece) UC5.3 - Vital metrics watch-like device

2.11.5 Pilot execution results

Latency was measured between the 5G Gateway (from a PC connected behind GW) to the S/P gateway of the EPC [towards a VM called ***"content server@10.85.203.2"*** running at the S/P GW].

In this Use case, fast network response time is needed. The 5G network meets this requirement as the RTTs average remains below 100 ms, as show in Figure 110.

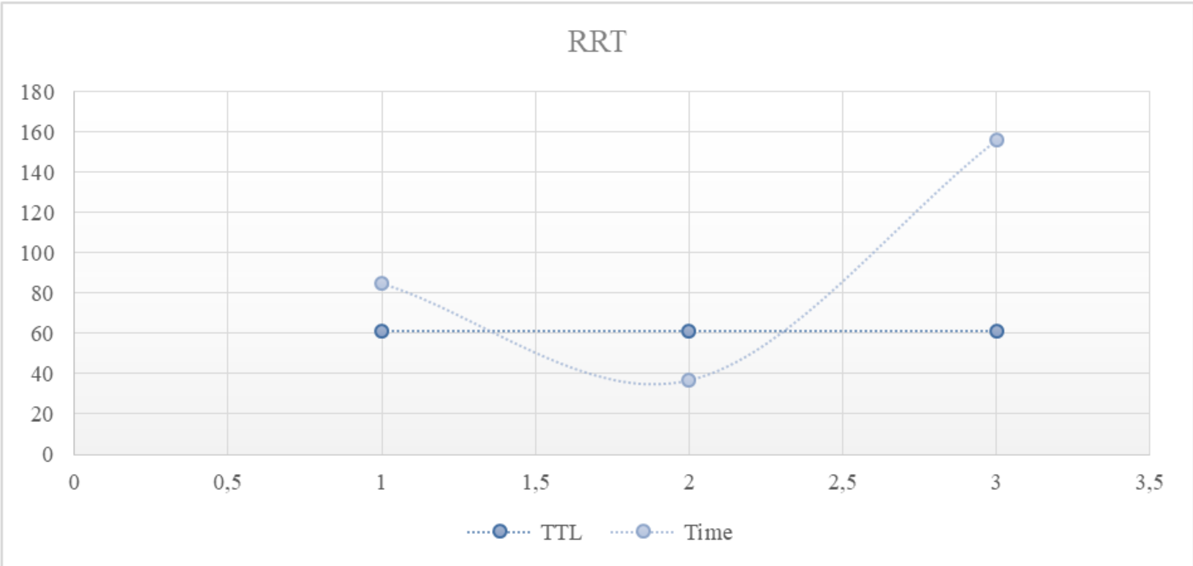


Figure 110: Smart City (Greece) UC5.3 - RTT between 5G Gateway to the S/P gateway

Figure 111 shows Throughput/Packet Loss and Jitter from the CPE to the IMPACT IoT Platform, where the use case data are being consumed:

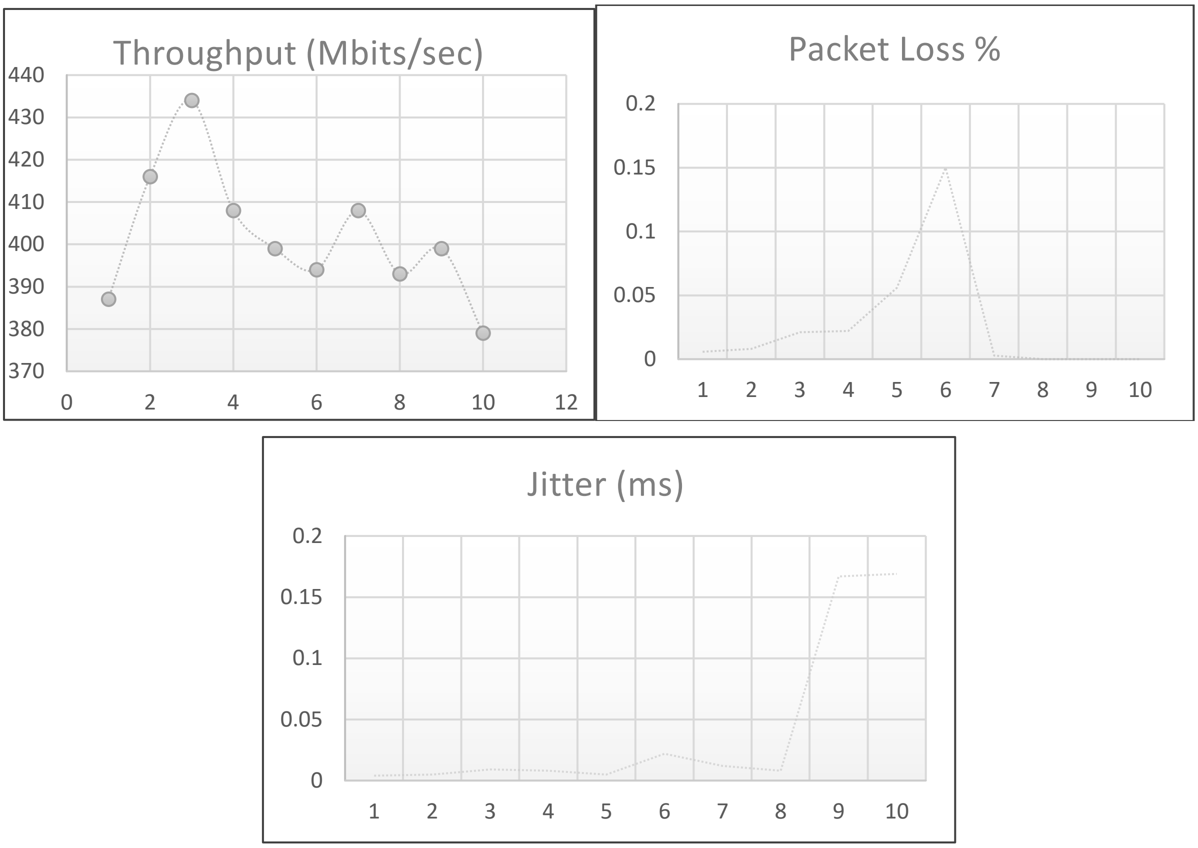


Figure 111: Smart City (Greece) UC5.3 - Throughput/Error Rate/Jitter from CPE to IMPACT IoT platform

We have attached an iperf3 server on the CPE's Qualcomm modem. While by attaching the tracer directly to the modem, we only avoided the internal hops within the CPE (3 hops) and the software stack of the CPE, the difference was impressive. On a 10h run we took results near 3 Gbps:

0.0-36000.0 sec 11.9 TBytes 2.90 Gbps

Moreover, handover was tested. The CPE was connected to a car power supply and travelled around the OTE research building where the two cells are installed as depicted in Figure 112:

Figure 112: Smart City (Greece) UC5.3 - OTE research building outdoor cells

Influence of handover to iperf metrics was minimal. A slight increase of error rate was observed (~20%) during the handover.

2.11.6 5G empowerment

5G features used:

- 5G NSA offering high bandwidth and low latency capabilities.
- 5G SA upgrade taking place: SMF, UPF, UDM, AUSF, AMF are installed, and network changes are also being implemented.
- Monitoring as a Service: to be used for metrics collection.

2.11.7 5G EVE platform added value

The main added values of 5G EVE platform for this use case have been the following:

- **Intent-based interface** towards verticals: the service is integrated with the 5G EVE portal
- **Performance Diagnosis** (KPI Framework): the service is integrated with the 5G EVE KPI monitoring system

2.12 Use Case 5.4 - Smart City: Safety and Environment – Connected Ambulance 4k Video from site

2.12.1 Pilot context

The scope of the "Connected Ambulance" use case is to convert the ambulance into a communication hub that is used to transmit the patient vital data, video and audio signals both from the accident scene as well as while the ambulance is on route to the hospital. 5G connectivity is required to properly support this use case, due to the massive capacity, reliability, low latency features needed for 4K video transmission and remote diagnostic as well as the reliability and low latency needed for patient monitoring and some basic control. This sub use case concerns the 4K video transmission from Ambulance towards the hospital.

2.12.1.1 Partner's roles

Vertical:

NOK-GR

VNF provider(s):

NOK-GR is the VNF provider.

1. Core network functionality (CMM, CMG, SMF, UPF, UDM, AUSF, AMF)
2. PNF supporting IoT platform functionality

Experiment developer(s):

NOK-GR takes care all necessary Use Case actions.

Experimenter(s):

NOK-GR takes care all necessary Use Case actions.

Site Manager(s):

OTE (DT South).

2.12.1.2 Trials

This use case was shown in end-to-end mode during the trial for the Greek site webinar, held on the 7th of July 2020, with the 4K video data flow sent via the Nokia Fastmile 5G gateway (same used from the patient metrics device, as a gateway).

2.12.2 Pilot architecture

The Pilot architecture is depicted in Figure 113 below.

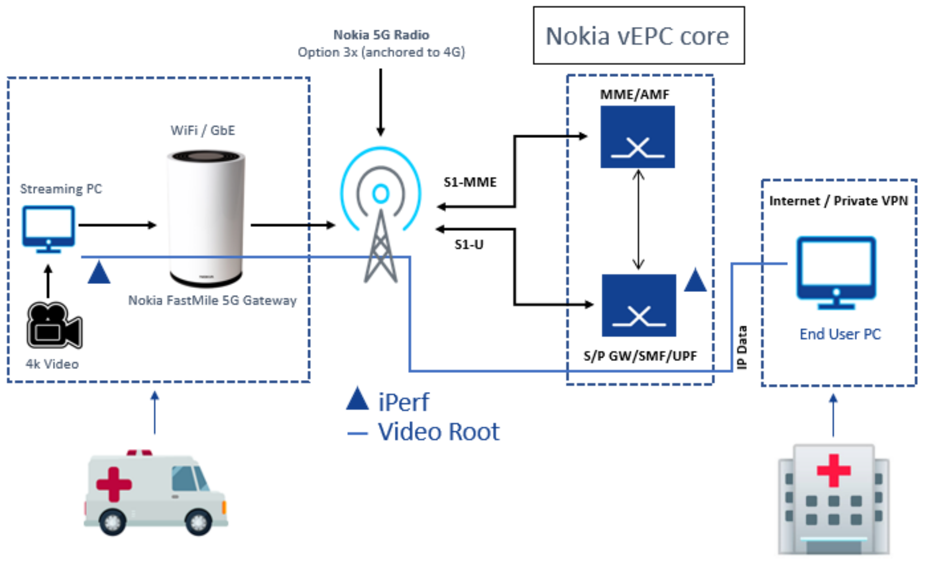


Figure 113: Smart City (Greece) UC5.4 - Pilot architecture, components and interfaces

4K video is encoded in the streaming server, within the hardware card (Blackmagic Design DecLink card [28]), for less added latency. Streaming is performed by OBS streaming software. Streaming data are conveyed via the 5G gateway to the core network and then to the S/P gateway where the viewer is connected (private or public Internet). Iperf3 servers/clients are installed (as shown with the blue triangles in the diagram) along the data transmission path. In Figure 114 the streaming components and 5G Gateway are depicted.

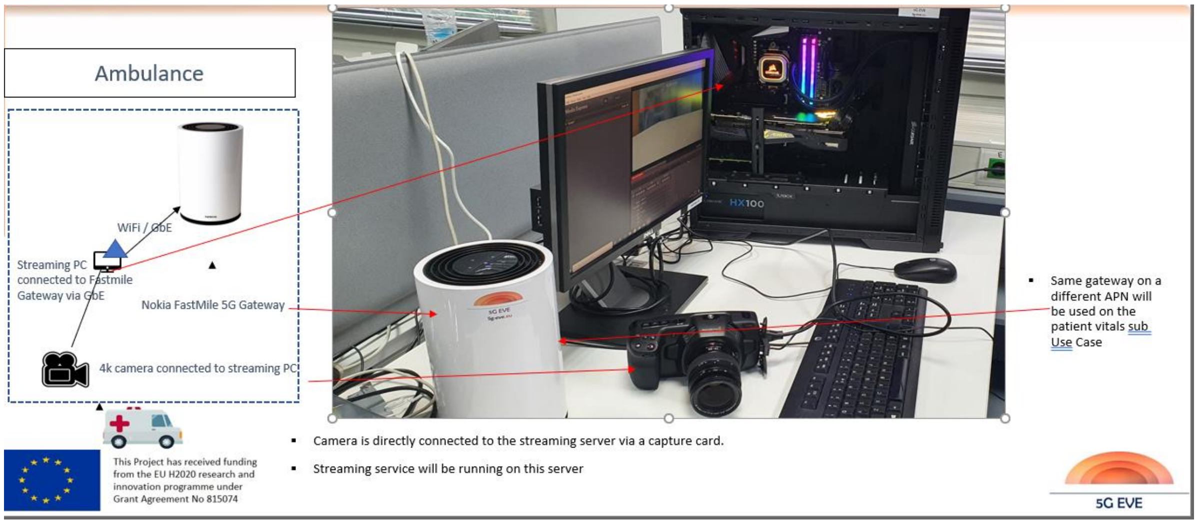


Figure 114: Smart City (Greece) UC5.4 - Streaming components and 5G Gateway

2.12.3 Vertical service KPIs implementation

Data collected during the use-case execution is shipped via a Kafka publisher (through a Python script, developed in house) to the Greek site Kafka broker (residing at local OSM, maintained by WINGS), which then conveys the data towards the Interworking Layer, according to the standard site-IWL architecture scheme (diagram same as the one in Section 2.11.2). KPIs relevant to this UC are all KPIs described in the Vertical KPIs described in Section 2.11.3 i.e., Upstream/Downstream throughput, Tracking Response Time. Their implementation within the current Use Case is depicted in Table 27.

Table 27: Smart City (Greece) UC5.4 - Vertical Service KPIs

Use case title	**Ambulance 4k Video from site**		
Site facility	**Greek Site**		
Vertical KPI name	**Up Stream Throughput**	**Tracking Response time**	**Downstream Throughput**
Vertical KPI definition	Minimum user experience upstream data rate required for the user to get a quality experience of the use case	Time spent to evaluate selected amount of data and visualize them	Minimum user experience downstream data rate required for the user to get a quality experience of the use case
Metric collection tools	iPerf	iPerf, ping	iPerf
Position of the probes in the reference architecture 1) UE; 2) Public Cloud; 3) Private Cloud; 4) Edge	1,3 (VNF)	1,3 (VNF)	1,3 (VNF)
Metric collection methodology	Collect metric per 1s. The value is the average upstream throughput during this period	Monitoring metric collection as the experiment runs. Collect every 5 seconds	Collect metric per 1s. The value is the average upstream throughput during this period
Validation tools	5G EVE Portal KPI validation tool	5G EVE Portal KPI validation tool	5G EVE Portal KPI validation tool
Validation methodology	Remove the low values during service inactive periods. Select the minimum value of all remaining values	Comparison of min and max values during the experiment in 4G and 5G	Remove the low values during service inactive periods. Select the minimum value of all remaining values

2.12.4 Pilot deployments

The trial has been implemented on the OTE Academy premises. Core and Radio have been deployed as depicted in Figure 69. Currently vEPC is running on 4G cloud core elements [CMM-CMG], supporting 5G NSA Radio. 5G core is deployed with the respective elements. Radio deployed uses 2 Nokia Airscale mRRH pair (4G-5G) of cells. A server (using Windows) is also used to serve video for the 4K video transmission and a NOKIA Fastmile 5G gateway is connected to the 5G Radio on site, as shown in Figure 75. Moreover, for the vitals metrics a clock-like device, collecting the metrics is used. The device is connected to the 5G gateway via WiFi. Additionally, IoT platform (IMPACT) has been deployed to aggregate the data from the Vitals measuring device. Vertical service blueprints are stored in 5G EVE test case blueprints repo [31].

2.12.5 Pilot execution results

We measured latency between the 5G Gateway (from the streaming server connected via Ethernet cable on it) to the S/P gateway of the EPC [towards a VM called ***"content server@10.85.203.2"*** running at the S/P GW]. What would matter most in this use case is to serve the ~20 Mbps upload bandwidth. Low latency is needed in order to improve UoE quality. Using iPerf between streaming PC and "content server" we measured the following.

50Mbits/sec are achieved in both uplink and downlink for TCP connections without packet loss as show in Figure 115.

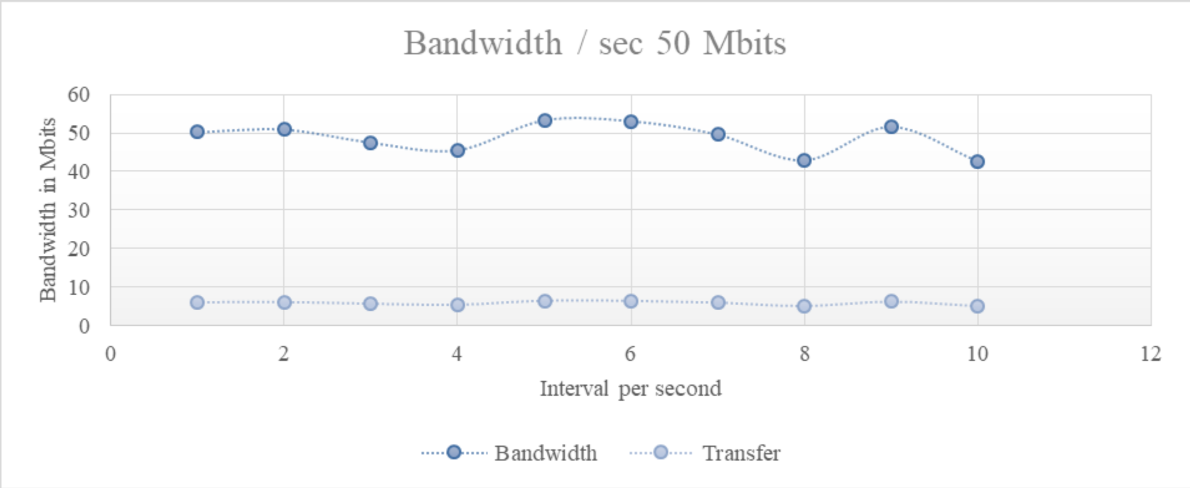


Figure 115: Smart City (Greece) UC5.4 - 50 Mbps bandwidth test

Bandwidth can reach up to 500 Mbps in download for UDP packets, but packet loss becomes apparent as shown in Figure 116 and Figure 117:

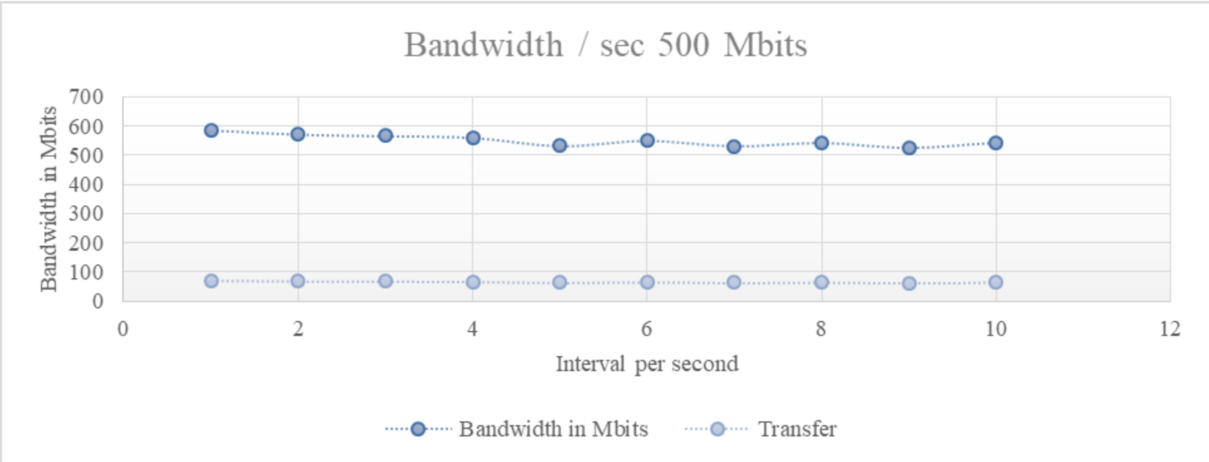


Figure 116: Smart City (Greece) UC5.4 - 500 Mbps bandwidth test

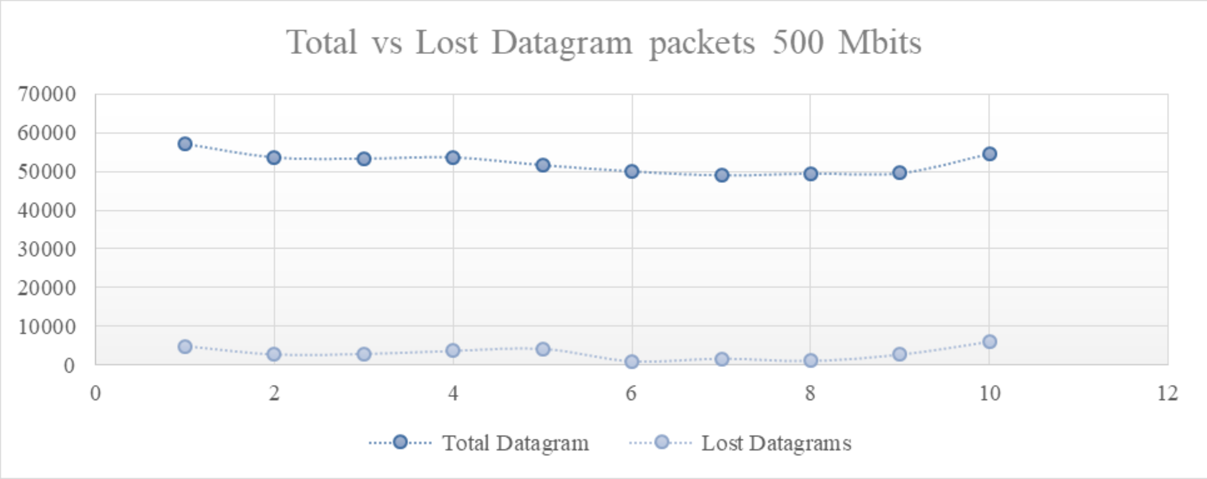


Figure 117: Smart City (Greece) UC5.4 - Packets lost at 500Mbps

At 200 Mbps in download for UDP traffic, data loss is far less, as shown in Figure 118 and Figure 119:

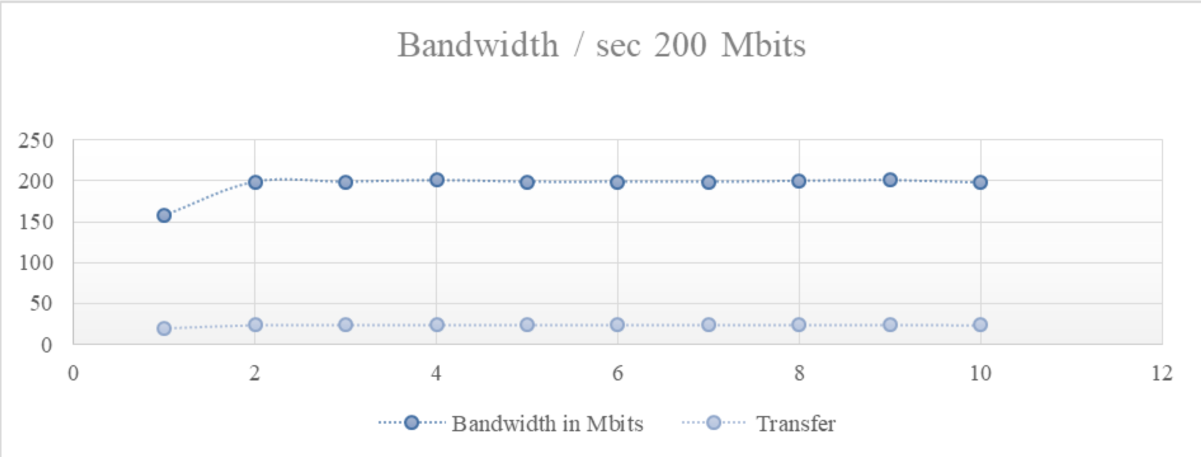


Figure 118: Smart City (Greece) UC5.4 - 200 Mbps bandwidth test

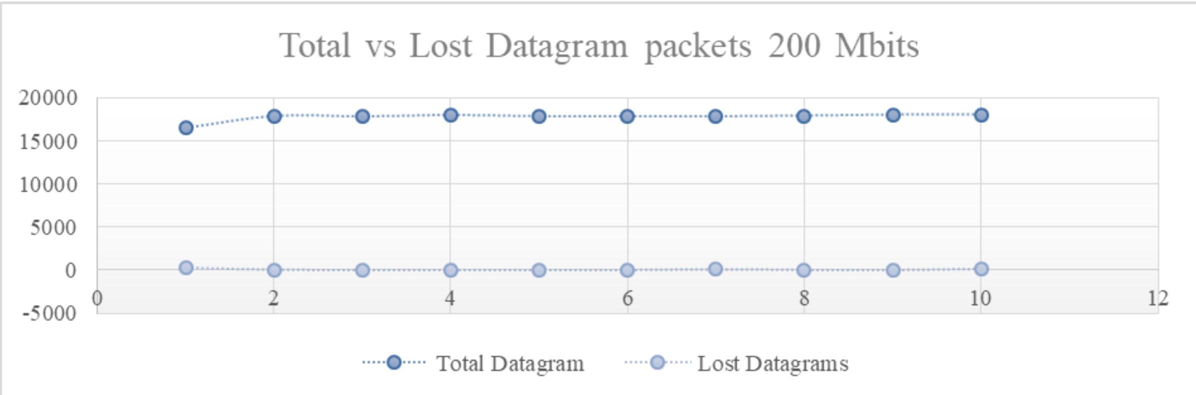


Figure 119: Smart City (Greece) UC5.4 - Packets lost at 200Mbps

2.12.6 5G empowerment

5G features used:

- 5G NSA offering high bandwidth and low latency capabilities;
- 5G SA upgrade taking place: SMF, UPF, UDM, AUSF, AMF are installed, and network changes are also being implemented;

- Monitoring as a Service: to be used for metrics collection.

2.12.7 5G EVE platform added value

The main added values of 5G EVE platform for this use case have been the following:

- **Intent-based interface towards verticals**: the service is integrated with the 5G EVE portal;
- **Performance Diagnosis (KPI Framework)**: the service is integrated with the 5G EVE KPI monitoring system

2.13 Use Case 6.1-3 - Media & Entertainment: Ultra High-Fidelity Media, On-site Live Event Experience, Immersive and Integrated Media

2.13.1 Pilot context

So far OTT video streaming as well as conventional linear channels offered through several IPTV systems has been offered using a fixed access infrastructure at home as an important part of the offer. In fact, even though most operators have their TV streaming applications available to be executed in mobile devices, the reality is that 95% of the time, such devices access the internet using a WI-FI connection and not a mobile connection. With the advent of 5G technology, an increased bandwidth is available for affording a reliable playback of the contents using the mobile network. The scalability issue is in any case present. In this pilot a novel solution is presented. The solution consists on using MEC as a multicast UDP video ingestion point from which several simultaneous HLS live, and VOD connections can be served in parallel without overloading the transport network. Appropriate configuration of the 5G components, i.e., core, radio and MEC, is vital for providing the end user with the right KPIs for visualizing video.

2.13.1.1 Partner's roles

Vertical

The video 360° Use Case is proposed by Telefonica, who provides all the different video content for the case of multicast live video channels.

VNF provider(s)

The video server is provided by Nokia-ES. It is on-boarded using charmed OSM orchestrator and instantiated in a microstack instance, customized by Nokia Bell Labs Spain, capable of dealing with VLANs and multicast and unicast traffic.

The 5G-CORE VNF is provided by Nokia and supports slicing and virtualization integration. It is also onboarded using charmed OSM and microstack.

Experiment developer(s)

Nokia ES is the experiment developer who is in charge of providing all the VSD and NSD files. The NSD files including instantiation of a load generation image which is responsible for generating a background performance video load and coordinating the tests.

Experimenter(s)

Nokia ES is the experimenter too, which is in charge of providing the test case execution context and the analysis of the performance results.

Site Manager(s):

IMDEA Networks Institute, Nokia ES & UC3M.

2.13.1.2 Trials

No public trials have been performed so far.

2.13.2 Pilot architecture

The overall architecture and connectivity of the system can be seen in the Figure 120.

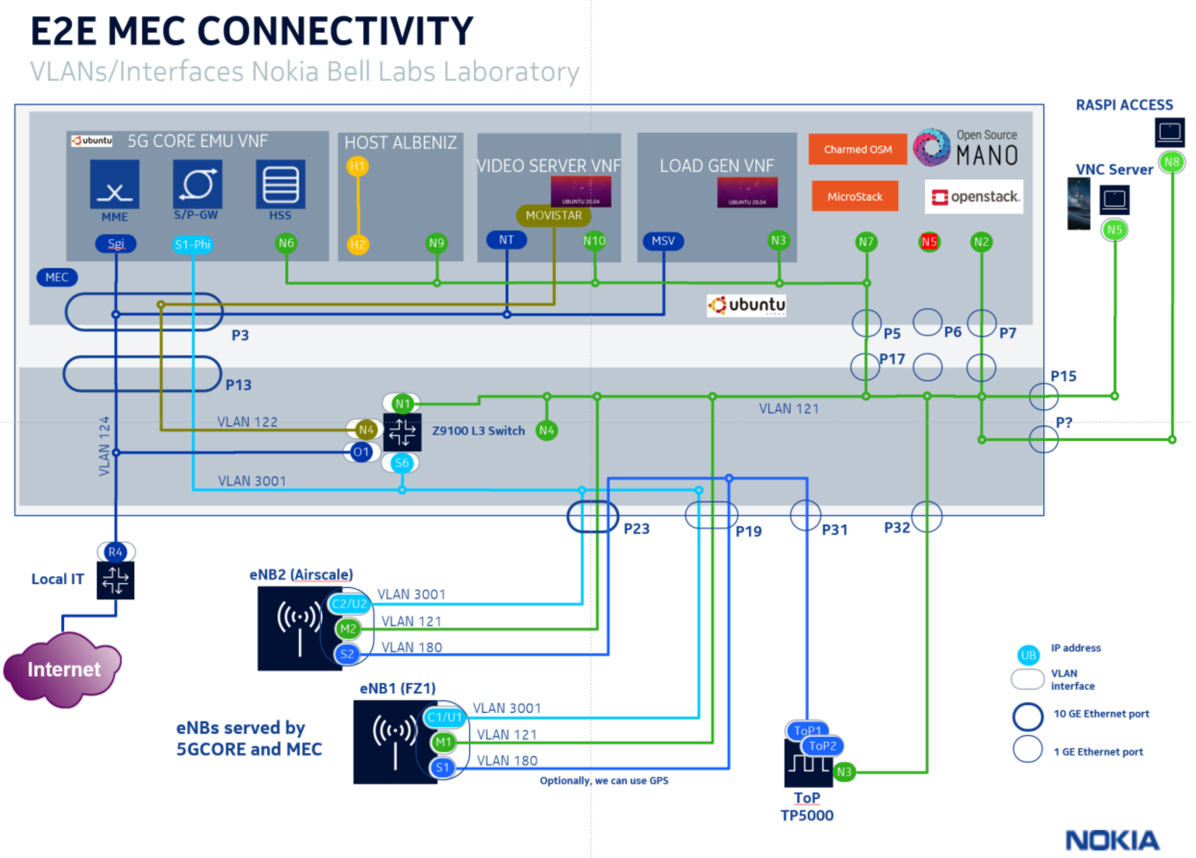


Figure 120: Media & Entertainment (Spain) UC6.1-3 - E2E MEC Connectivity

The MEC part has been specifically developed for this project trying to be OSM compliant and providing a flexible onboarding solution based on Openstack platform (see Figure 121). In order to achieve this target, the microstack snap based platform provided by Canonical has been extended in order to enable multiple VLAN interfaces connectivity using the open virtual switch schema as depicted in Figure 120

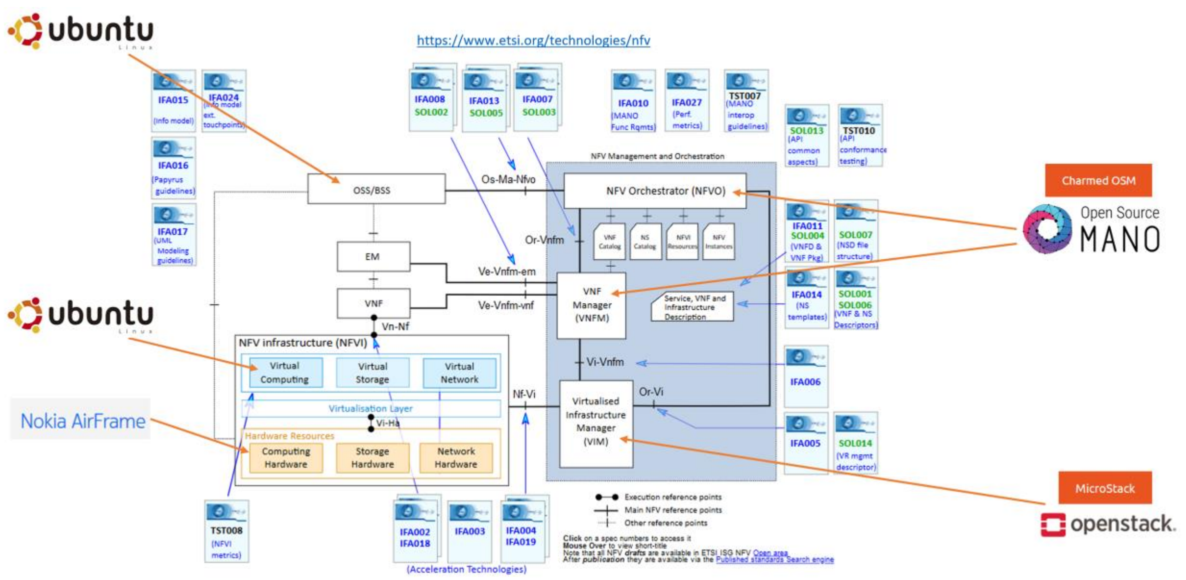


Figure 121: Media & Entertainment (Spain) UC6.1-3 - MANO architecture mapping

Multicast to unicast UDP forwarding was implemented in the BareMetal level to provide access to the HLS live TV channels provided by Movistar TV. Platform. An IGMP Multicast subscription is enabled at BareMetal level and a translation from the multicast UDP addresses to unicast addresses into the video VNF are performed.

2.13.3 Vertical service KPIs implementation

The KPIs measurement points have been established at both the UE behind the radio and the MEC VNF in which the video is directly been served through the SGI network interfaces. For the UE a real player is instantiated into the mobile device which is connected to the 5G network. This player helps the end user to assess the quality being received in the mobile device. At the same time a complex script is repeating the HLS player retrieval actions for a live channel. This process is run under a TERMUX application shell and it is providing real time measurement which are injected into the ELK infrastructure of the video server. A dedicated logstash pipeline continuously parses these stats, converts them into JSON format and sends them to the Elasticsearch instance. Finally, the data is visualized in real time in Kibana as can be seen in the Figure 122.

There is also a script running at the Edge side which is continuously parsing http.log file in order to look for streaming restarts (this is translated into discontinuities in the segment numbering at such file **[B]**). The same script is also triggered as successful 2-hour playback after this time **[D].** Bitrate statistics can be retrieved either from the server or the client point of view **[C]**, regarding to the time to start streaming the content **[A]**, this is obtained from one of the statistical information logged by curl tool.

Table 28 is a summary of the required vertical KPIs. Even though more KPIs are logged, we mainly focused only in these four ones, which are the most relevant for the service.

Table 28: Media & Entertainment (Spain) UC6.1-3 - Vertical service KPIs

Use case title	**4K and Full-HD Video Streaming VOD and Live**			
Site facility	**Spain**			
Vertical KPI name	**Time to startup streaming first frame [A]**	**Numbers of streaming restart events per 5 min [B]**	**Download bit rate [C]**	**Sustained streaming time Full-HD [D]**
Vertical KPI definition	This metric measures the time a player streams the first frame	Number of streaming restarts measured in one hour of playback	Bitrate reached during segment download (different that segment bitrate)	Stability of streaming of VOD and live contents
Metric collection tools	Traces captured in client UE	Traces captured in client UE and Edge video server application	Traces captured in Edge video server application	Traces captured in client UE and Edge video server application
Position of the probes in the reference architecture 1) UE; 2) Public Cloud; 3) Private Cloud; 4) Edge	1) UE	1) UE; 4) Edge	1) UE 4) Edge	1) UE; 4) Edge
Metric collection methodology	The UE measures the time to get the first segment immediately after retrieving the var sub-playlist.	Each 1 hour the Quality probe analyses the traces in the edge and looks for missing segments not served to the user	Each 10 seconds the Quality probe analyses the received content and publish the metric into the Kafka bus	The Edge gathers information using http.log video server traces

				ensuring 2 hours of streaming have been completed for a client.
Validation tools	Nokia tools	Nokia tools	Nokia tools	Nokia tools
Validation methodology	Guidance: Time should be < 5 seconds	Guidance: Less or equal than 2 restarts per hour	Guidance: It should consistently hit the top bitrates for the following contents: 3Mbps(SD), 7Mbps(HD), 20Mbps(4K) and 50Mbps(HQ 4K VOD only)	It should be able to sustain full-HD streaming for 2 hours.

Additionally, an Apache Benchmark instance, which is a tool for measuring the performance of several web servers, is stressing the system simulating hundreds of simultaneous playbacks of channels. Response time in the player side is affected depending on the stress load being executed. A specific VNF for load generation is devoted to coordinate the tests, compile these stats, and launch a background performance load. The VNF is based on an Ubuntu 20.04LTS VM instance, which communicates with the video server and the ELK.

Figure 122: Media & Entertainment (Spain) UC6.1-3 - Video server system metrics

Another point of measurement is the video server itself. In this case TCP statistical data is collected while the segments are being served. TCP stats at OS layer are continuously obtained and dumped into output CSV file which is also ingested into ELK using a custom logstash pipeline. A dedicated Kibana dashboard has been created to register and monitor such statistical data including all the low-level TCP statistics related to video streaming transmission. All the performance stats captured from Apache

Benchmark are also stored in the system for review. They include individual summary files per segment execution as well as GNU plot ready files.

Finally, the CPU, memory, network and Video Server RSS and CPU consumption are also monitored in real time, being ingested to ELK by means of 4 different pipelines as shown in Figure 122.

2.13.4 Pilot deployments

The figures above (Figure 123 and Figure 124) describe the VLAN connectivity across the VNFs and their mapping into the Openstack interfaces. There is also a "Pre-Staging" replica of 5Tonic installation at Nokia site.

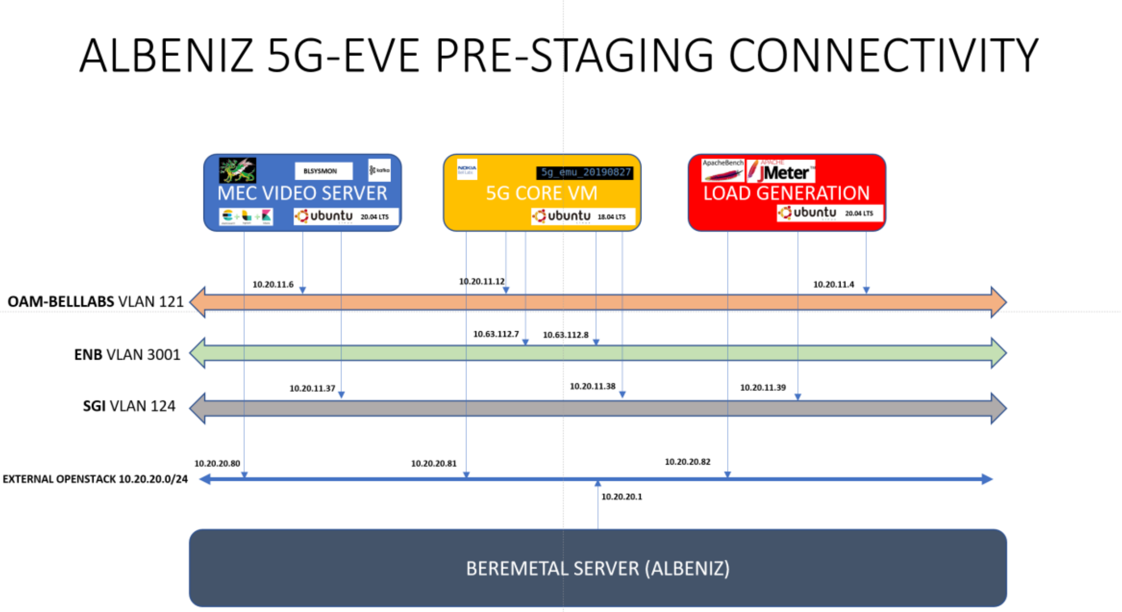


Figure 123: Media & Entertainment (Spain) UC6.1-3 - Pre-staging connectivity

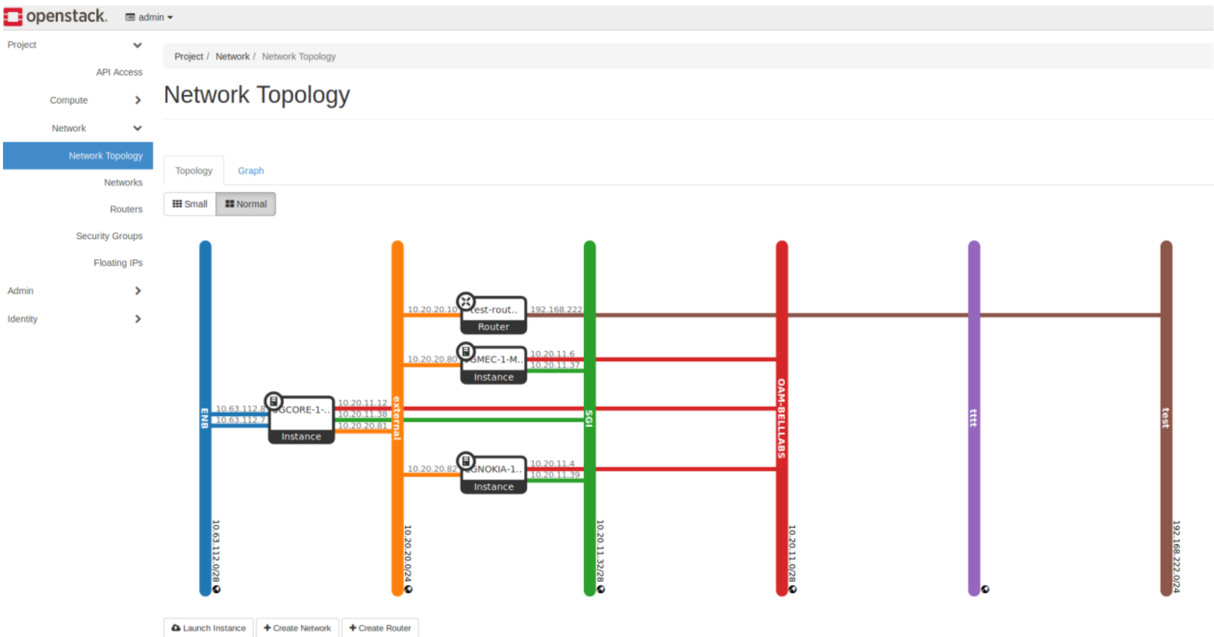


Figure 124: Media & Entertainment (Spain) UC6.1-3 - VIM tenant's network topology

The following VNFS and NSDs, as depicted in Figure 125, have been deployed.

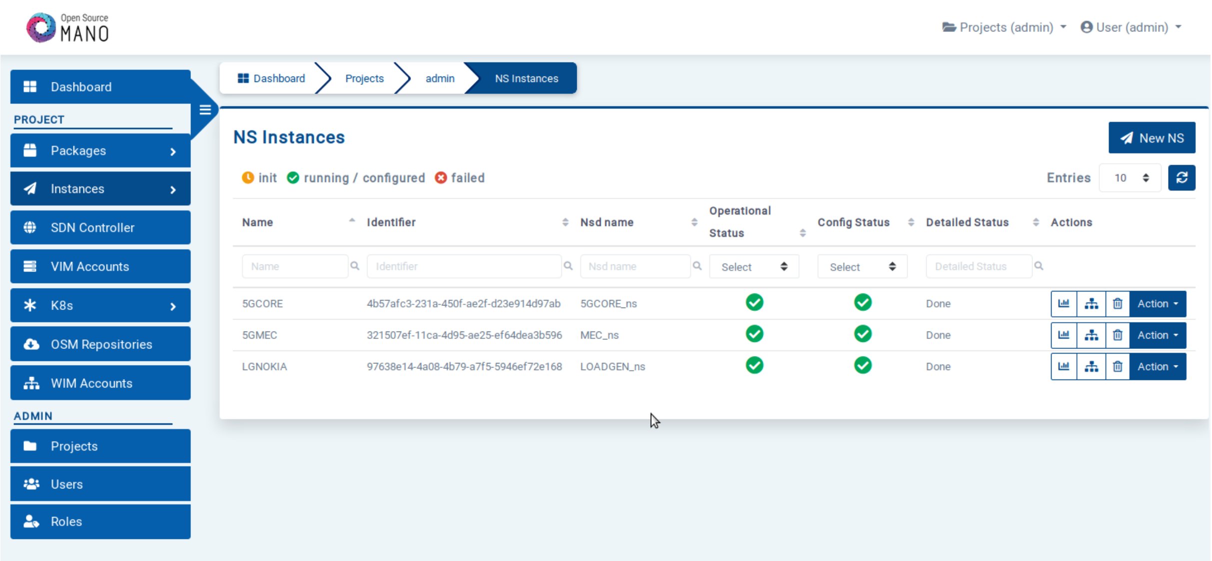


Figure 125: Media & Entertainment (Spain) UC6.1-3 - OSM NSDs

All the VNFs and NSDs can be found at the GitLab repository [32]. Every NSD creation was following the IP Plan. The creation scripts are developed using shell scripting and provide the IP addresses using OSM to interface with the VIM (in this case, Microstack).

The radio configuration part requires both configuring the 4G and 5G as we are using NSA solution in this use case. It has been provisioned using the NOKIA proprietary Element Manager solutions (see Figure 126 and Figure 127).

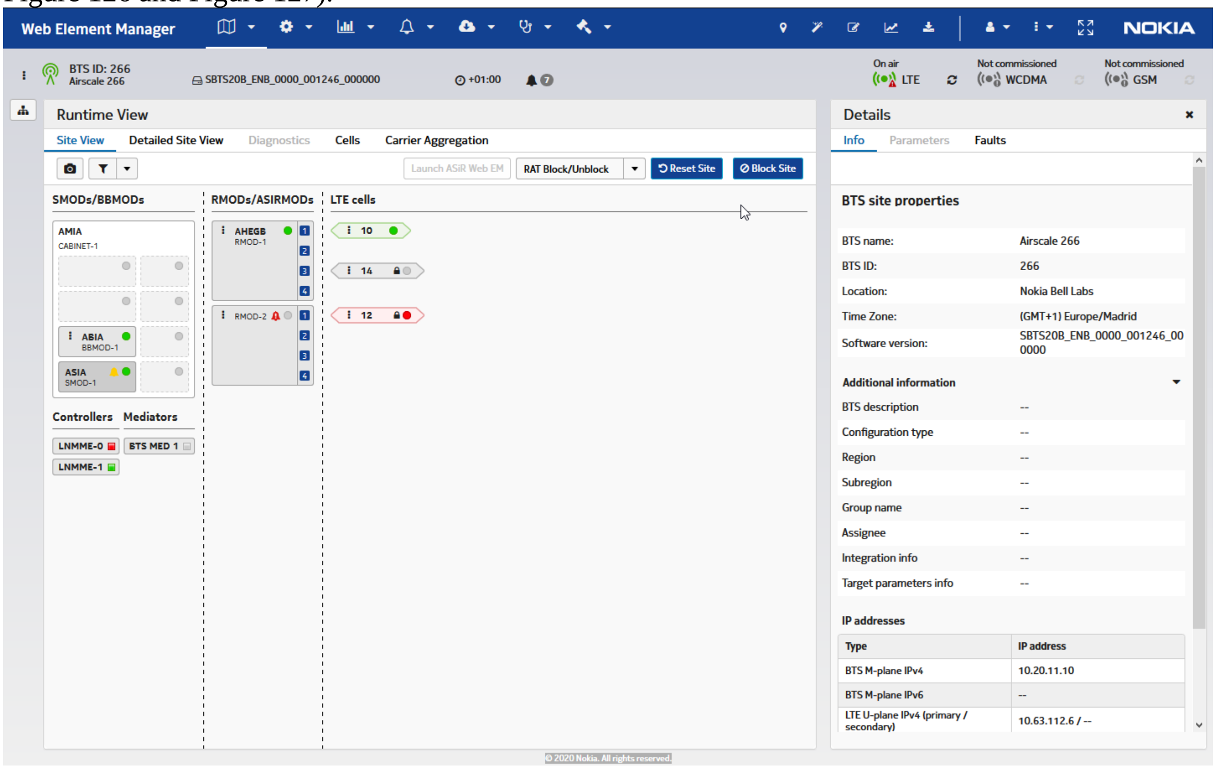


Figure 126: Media & Entertainment (Spain) UC6.1-3 - 4G RAN configuration

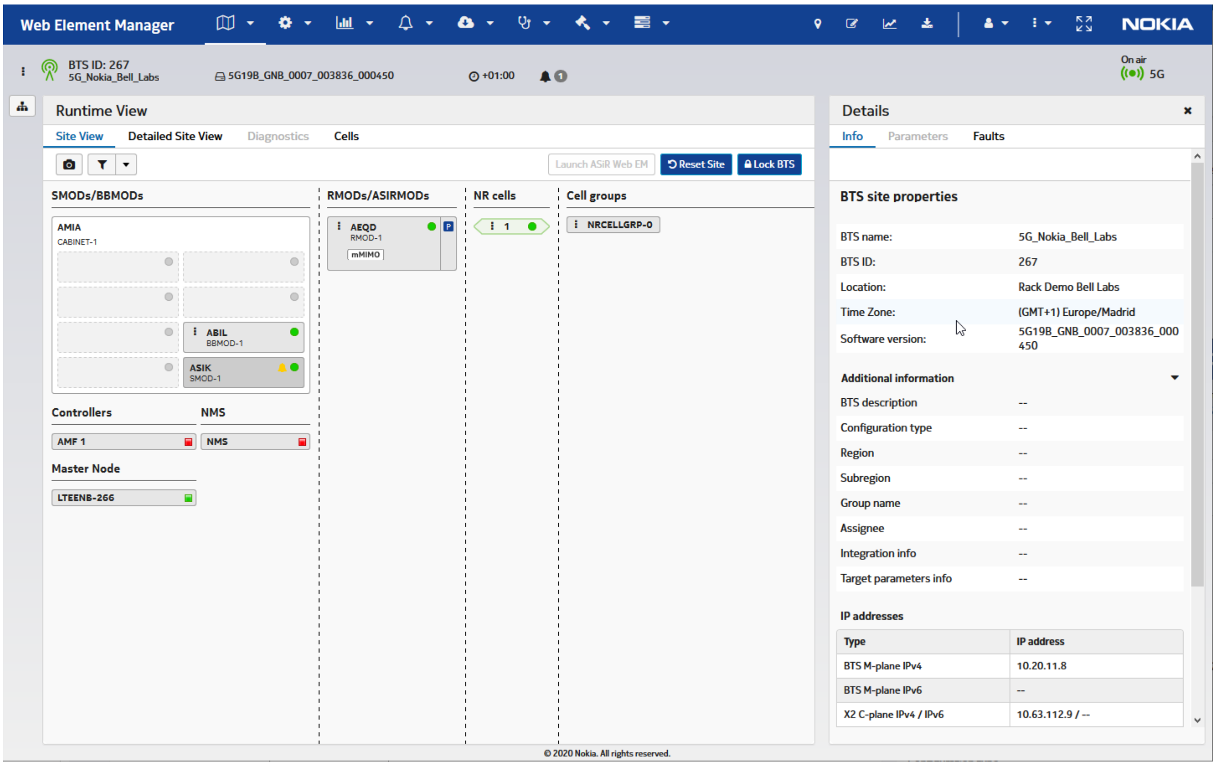


Figure 127: Media & Entertainment (Spain) UC6.1-3 - 5G RAN configuration

Finally, and as explained before, the 5G CORE part of the E2E solution is virtualized and running as a normal VNF instance inside the MEC environment. This tightly coupled installation provides the system with higher flexibility, very low latency, and throughput close to the 25 GBps fibre interfaces allocated.

We can configure the 5G Core in 3 slicing modes depending on whether we want a very low latency, a big throughput or connecting thousands of UEs. The default mode is for throughput and we have tested up to 5 GBps per second service through their virtual interfaces.

2.13.5 Pilot execution results

The tests results are stored under Elasticsearch database and under the multiple data directories, which are enabled for this purpose. One of the most important tests is the one related with the time used to obtain the video segments. Results are shown in Figure 128.

We execute the tests under 5 variants:

- Short test of 5 minutes playback – SD live content playback (snapshot below);
- Short test of 5 minutes playback – full-HD live content playback;
- Sustained playback for 2 hours – SD live content;
- Sustained playback for 2 hours – full-HD live content;
- Single VOD ultra-HD content playback.

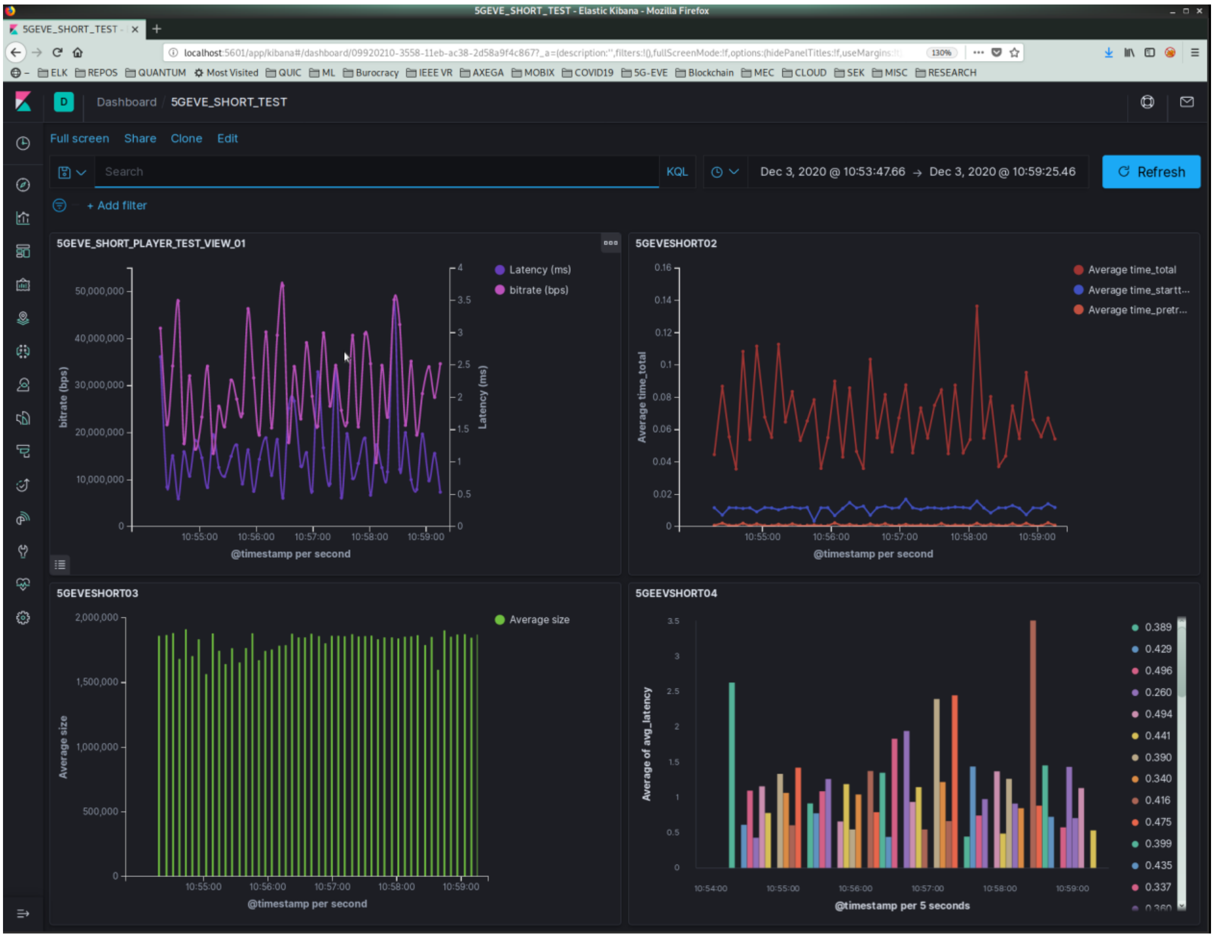


Figure 128: Media & Entertainment (Spain) UC6.1-3 - Video segments test results

Depending on the background performance load, the latency, and the time to download the segments varies. We noticed that for a performance load of 500 simultaneous players retrieving live contents the download time for individual full-HD segments is always below 600 ms and the latency is below 120 ms, which are acceptable values for the end user (we should be able to download a segment in a time which is less than the transport stream segment duration which is currently configured in the system to 6000 ms).The Video Server VNF also registers all the KPIs performance activity daily as shown in Figure 129:

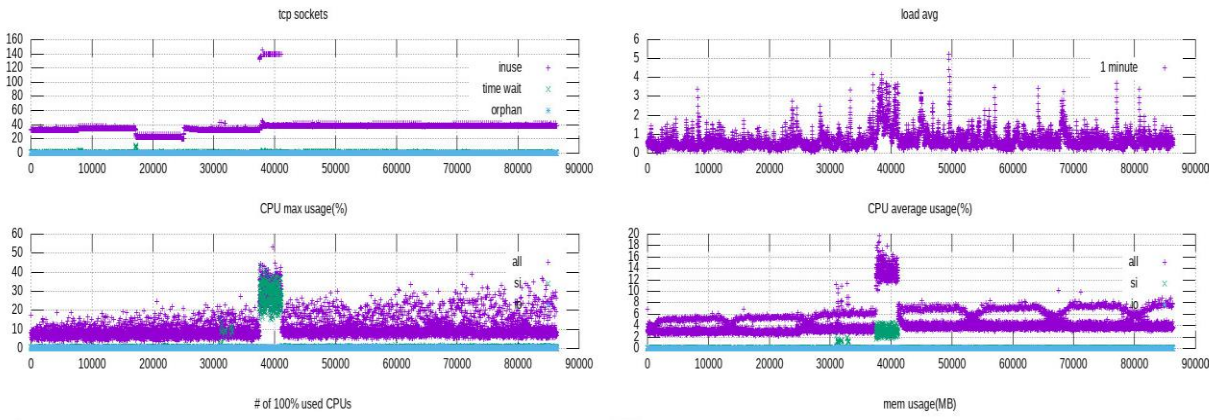


Figure 129: Media & Entertainment (Spain) UC6.1-3 - Video server daily activity

Long running tests have also been performed to verify the stability of the systems, while at the same time saturating the MEC interfaces. Their results are depicted in Figure 130. A simulated load of 2.5 Gbps from the client perspective has been injected into the video server for periods of time ranging from

2 to 12 hours. Ensuring a constant and acceptable latency and moderate resource consumption was the aim of taking these measurements. Apache Benchmark Tool was used to simulate this kind of constant load on existing live video channels. At the same time, visualization of a regular video live streaming TV channel on a real mobile device as well as gathering the statistics at the UE level were done so that the system remains usable from an end user point of view.

Figure 130 -Media & Entertainment (Spain) UC6.1.3 - Long run performance execution

The results are stored under the Logstash database and can be rendered in a specific Kibana dashboard from which the following conclusions can be extracted:

- Latency of the RTT communication is under 200 ms with an average latency close to 100 ms.
- Video segments are always served in less than 1.4 seconds (segments length was 6 seconds).
- Average egress throughput during the test is 2.5 Gbps while the ingress is about 40 Mbps (UDP multicast ingress).

Ensuring that virtualized hardware resources usages while running the test are not exhausted is also a must as can be observed in the figure below Figure 131.

Figure 131: Media & Entertainment (Spain) UC6.1.3 - Virtualized Resources Usage

The conclusions in terms of physical and virtual resources are:

- Less than 50 percent of CPU usage is required at the video server level while running the tests (left).

- Disk IOPS are also under control with a stable trend (right).

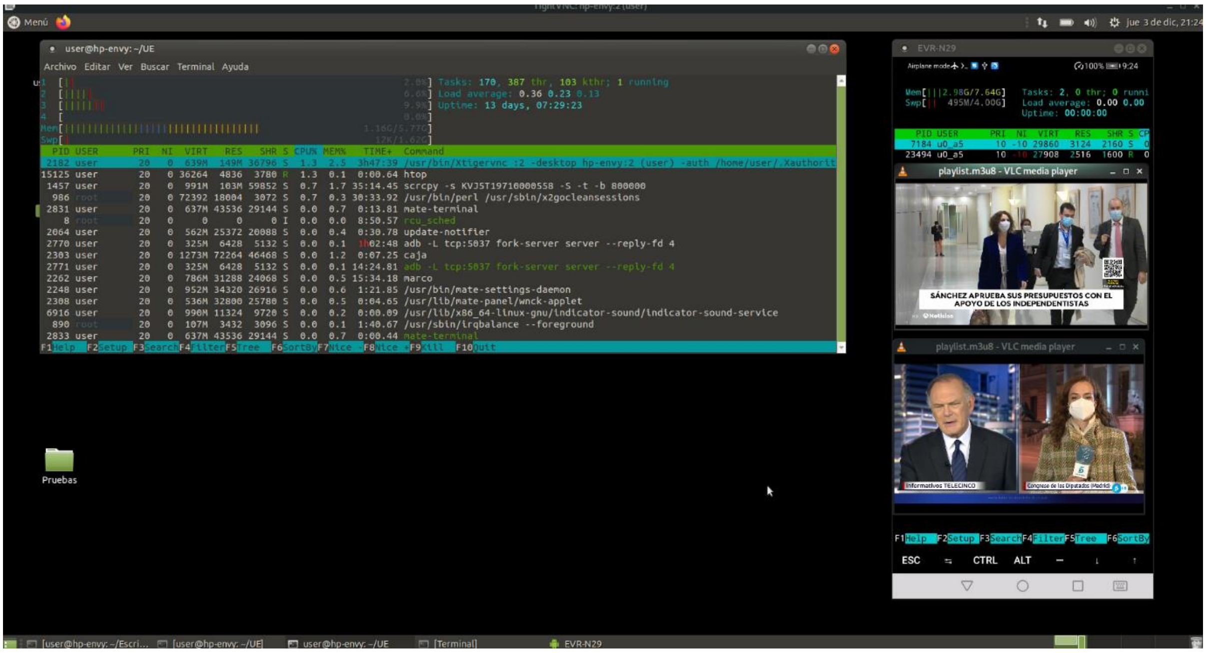


Figure 132: Media & Entertainment (Spain) UC6.1.3 - Stability at the Player Side

Some measurements have been collected at the terminal and pushed to the MEC ELK infrastructure in where they can be stored and shown in a Dashboard. Detailed data is extracted via curl tool and some wrapper scripts running in a custom terminal which is running in the device, while the background performance load is injected into the system. Apart from the command line player client, VLC client playback is tested to ensure that end user video quality does not have any artifacts due to potential problems in bandwidth or latency availability and player remains stable during the period of time in which the tests are executed (see Figure 132).

2.13.6 5G empowerment

Video contents in different formats require different requirements in terms of latency and throughput. Even though latency is an important factor in the case of live video transmission, it is not a critical factor as HLS live video streaming is broadcasted with an initial delay ranging 2-5 seconds.

On the other hand, throughput in the downlink is a key factor for being able to provide several users with the service. Avoiding congestion in the edge for ingestion and serving process should also be taken into consideration.

The 5G NSA setup installed provides the UE with the required bandwidth for receiving SD, full-HD and ultra-HD contents for live, VOD and 360 types. The worst case is for ultra-HD in which 50 Mbps are required.

All terminals tested in 5TONIC premises guaranteed at least 150Mbps in the downlink with most of the terminals providing speeds ranging between 300 and 600 Mbps.

2.13.7 5G EVE platform added value

Unfortunately, the service is not integrated with the 5G EVE portal. Due to the complexity of the UDP multicast video ingestion in the IWL it has not been possible to integrate it in the scope of the project. The Use Case has followed all the guidelines, used the same tools and provided results in the same spirit and schema that the rest of the use cases already integrated with the project.

Thanks to the 5Tonic Madrid site infrastructure, a smooth deployment of the use case has been achieved and it is stable and fully functional from and E2E perspective. However, the setup complexity didn't allow to use 5G EVE Portal to orchestrate the experimentation.

Having the 5G EVE platform as a reference has been an excellent help in other to provide the use case with a consistent and well-suited amount of testing tools and KPI framework.

- Standard VNFs and NSDs design: standard OSM VNFs and NSDs have been developed, even though migration to 5G EVE portal will not be performed.

- Performance Diagnosis (KPI Framework): the service is right now integrated with a complete ELK and KPI tools subsystem in the solution. A commodity script to forward the data into an external or internal Kafka bus is in place and can be integrated with other external systems if required.

2.14 Use Case 6.4 – Media & Entertainment: Virtual visit over 5G

2.14.1 Pilot context

Some physical places, such as houses and popular touristic places provide limited access to potential visitors. In this pilot a virtual visit is proposed to relax this limitation and can be also promoted in case of lockdown period.

Buying or renting houses or apartment is not immediate and visiting many of them is sometimes required before finding the lovely one. This is really time-consuming for the buyers but also for the real estate agency. It also has a cost for going to the location (fuel, train, etc.). This experience is currently very limited and does not really help the visitor to see all what he/she likes, with the many details he/she is interested at. Therefore, we advocate the use of video streaming to quickly start a virtual visit and to quickly swap from one virtual visit to another. 5G network could help to achieve the objective and promote this Video 360° use-case in a popular way. Through this trial, we also propose to measure some specific service KPIs and make some parameters varying (video throughput and/or video latency) to stress the 5G network.

This vertical trial has been presented during the French webinar demo the 9th of July 2020 [9]. It was also demonstrated during the annual Orange event called "Salon de la Recherche" that took place in March 2021 and that was held as a virtual event due to the pandemic period. This event aimed at valorising some Orange projects to partners/customers.

2.14.1.1 Partner's roles

Vertical

The video 360° Use Case is proposed by ORA-FR, who provides all the different video content, the video server as well as the UE equipment.

VNF provider(s)

The video server is provided by ORA-FR and it has been on-boarded by ORA-PL into the ONAP [33] orchestrator.

The WEF (data and control planes) VNFs have been provided by B-COM and on boarded by ORA-FR and ORA-PL ONAP [33] orchestrator.

The OAI vEPC and RAN VNFs have been provided by ORA-RO.

Experiment developer(s)

ORA-FR is the experiment developer in charge of providing all the VSD and NSD files.

Experimenter(s)

ORA-FR is the experimenter too, in charge of providing the test case execution context and the analysis of the performance results.

Site Manager(s)

ORA-FR is the site manager of the French site. It manages the network infrastructure availability and the VNF components deployment with the support of the distant French site. In our video 360° Use Case deployment, the B-COM site is hosting the experiment.

2.14.1.2 Trials

As detailed in D2.4 [3], the objectives of the trials are to evaluate the video 360° service when adapting the video rate and/or the delay at the output of the video server. Indeed, 3 different trials operations have been carried out:

- Video service without any perturbation (putting 9 Mbps as video data throughput) that is used as reference of the 2 others trials;

- Effect of the throughput in the video service quality;
- Effect of delay in the video service quality.

In any case, the user’s acceptance is evaluated (Nausea Level feeling) or the operational video service quality delivery. To analyse the performance and compared it with the users’ acceptance and video QoS, some service KPIs are measured (see Section 2.14.3).

2.14.2 Pilot architecture

As illustrated in Figure 133, the French site facility is composed of one cluster of 3 distant network infrastructures (B-COM, ECOM and NOK-FR) connected by VPN to Orange network infrastructure where the ONAP [33] orchestrator is integrated

Figure 134 shows that, on its north bound, the Orange infrastructure is connected to the rest of the 5G EVE platform, given access to the InterWorking Layer (IWL) and to the 5G EVE portal where verticals can register and ask for using the 5G EVE facility for operating their use-case.

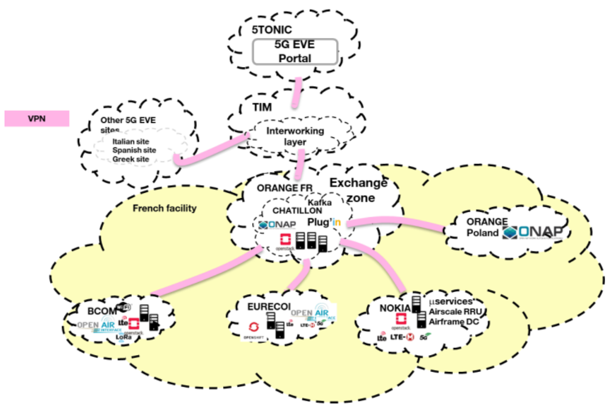


Figure 133: Media & Entertainment (France) UC6.4 - General French facility architecture

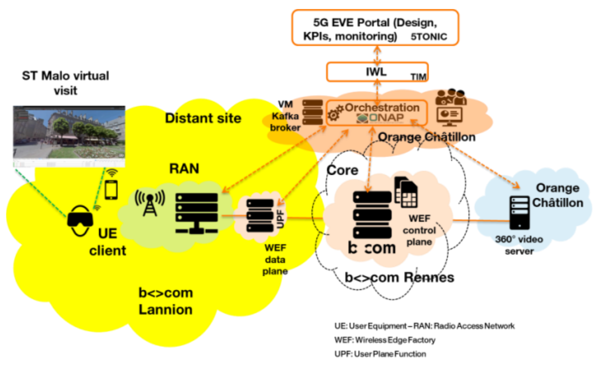


Figure 134: Media & Entertainment (France) UC6.4 - Vertical service architecture deployment

To be more specific to our set-up, we propose to firstly deploy the video 360° use-case in the b<>com site facility. We keep the video server at Orange Châtillon in order to be able to share it with the other sites. The Figure 135 gives a more accurate architecture of the location of the different parts of the network infrastructure, mainly based on OpenSource code. As described in [5], the video 360° was deployed automatically from the 5G EVE portal in multi-site environment leading to develop the corresponding VSB and NSD (see 2.14.4).

The system encompasses of

- Radio Access network supporting LTE or 5G NSA access based either on Amarisoft [34] or Open Air Interface.
- Virtual EPC supporting GW-u (data plane) and GW-c (Control plane).
- Virtualized processing platforms, implementing the functionalities required to support the trial.
- Orchestration platform, based on ONAP, in charge of instantiating the processing functions, as well as configuring the VNFs.
- Measurement infrastructure based on Kafka bus that collects measurements from network and processing functions to derive network and service KPIs.

The system is connected to the IWL in Turin to allow the launch of tests from the 5G EVE portal.

2.14.3 Vertical service KPIs implementation

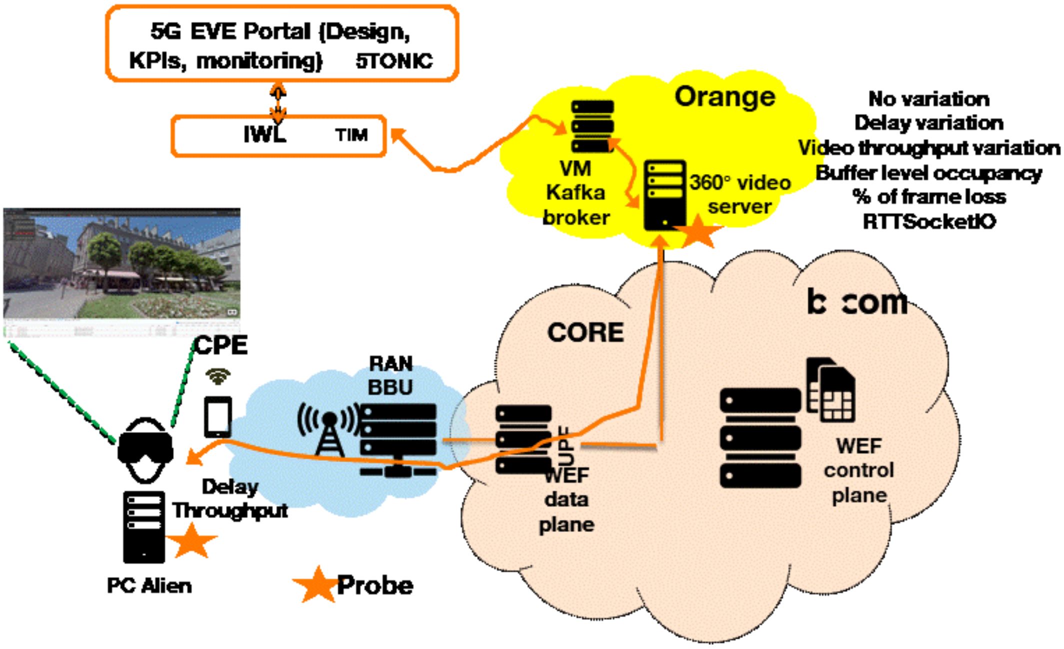


Figure 135: Media & Entertainment (France) UC6.4 - Vertical service architecture including probes location

Figure 135 illustrates the collection of the service KPIs. The probes are located at the video server and at the UE terminal (PC alien) processing the video content. Table 29 gives the main information about video 360° KPIs such as: probes location, KPIs definition, methodology and tools for measurements. The percentage of video frames lost, can be seeing in the screen of the video (see Figure 140). This parameter counts the number of packs lost directly from the HTML page in the local trial screen.

Table 29: Media & Entertainment (France) UC6.4 - Vertical service KPIs

Use case title	**Virtual Visit: Video 360° use-case**			
Site facility	**France**			
Vertical KPI name	**Throughput**	**Adddelay**	**RTTSocketIO**	**BufferLevel**
Vertical KPI definition	Throughput in Kbits measured each second at the video server output interface	Delay measured between the video Server VM and its gateway	This is the round-trip time duration between the video server and the UE in ms.	Video buffer occupancy time duration in seconds
Metric collection tools	Linux dstat command	Ping command	soketIO messages exchange between the node js server (on the video server) and the HTML page (on the terminal)	Value measured by the dash video player used by the HTML page
Position of the probes in the reference architecture 1) UE; 2) Public Cloud; 3) Private Cloud; 4) Edge	The probe is directly integrated at the video server location. At the time being, the server is located in	The probe is directly integrated at the video server location. At the time being, the server is located in	Probes are put in 1) and in 3)	The probe is directly integrated at the video server location. At the time being, the server is located

	3) but should be put in 4)	3) but should be put in 4)		in 3) but should be put in 4)
Metric collection methodology	Each second, via the dstat command, the throughput is measured and the Kafka topic is collected inside the « Throughput-config-day2.xml » file sent by the portal.	This specific use-case metric is used for adding delay at the video server VM output. The delay variation is managed by "Netem" command. Collection of the Kafka topic via the « Adddelay-config-day2.xml file sent by the portal	Kafka topic is collected inside the «RTTSocketIO-config-day2.xml » file and sent to the portal	the Kafka topic is collected inside the «BufferLevel-config-day2.xml » file sent by the portal
Validation tools	The experience aims at limiting the data throughput at the video server output and to evaluate the threshold of throughput that leads to a bad QoE (user acceptance). The video throughput should be compared to the data throughput network KPI in order to see the coherence between both metrics	Variation of the delay at the video server output and comparison with the measured latency network KPI.	Comparison between the collected value and infrastructure KPI latency value (adding of 3 to 7 ms compared to RTT network value involved by Websocket)	Dash player integrated in the HTML page
Validation methodology	In order to limit the egress bandwidth (throughput), we use the following command: tc qdisc add dev eth0 root tbf rate 1mbit burst 32kbit latency 400ms. tbf: use the token buffer filter to manipulate traffic rates. rate: sustained maximum rate. burst: maximum allowed burst. latency: packets with higher latency get dropped	Adding of delay at the video server Ethernet interface via netem command. Example of delay variation: 1st run with 100ms of latency: sudo tc qdisc add dev eth0 root netem delay 100ms. - Change of the latence at 10ms: sudo tc qdisc change dev eth0 root netem delay 10ms - Suppress of the artificial adding latency : sudo tc qdisc change dev eth0 root netem delay 0ms	The user's acceptance (QoE) is used for validating the amount of latency that could be supported in order not to feel some nausea phenomena	This metric is a good indicator and directly depends on the throughput and delay values. More the throughput is, more the buffer occupancy is. Typically, a value of 30 ms of the buffer occupancy allows to have some "stock" of video service. When the buffer occupancy is below 2 ms then the video becomes fixed and perturbed.

2.14.4 Pilot deployments

The trial has been implemented at Orange Châtillon (for the ONAP [33] orchestration, the video server, the Kafka broker for KPIs collection, the VPN management and connection with the IWL and the portal) and at b<>com (Rennes and Lannion) for the hosting of the network infrastructure and the user's experiment, as shown in Figure 136.

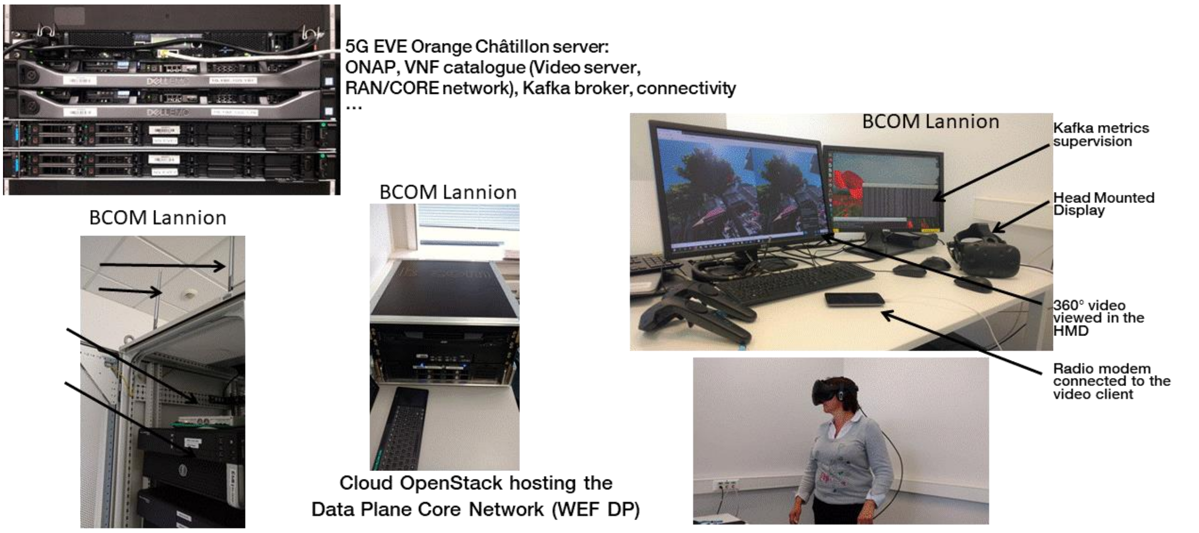


Figure 136: Media & Entertainment (France) UC6.4 - Pilot deployment

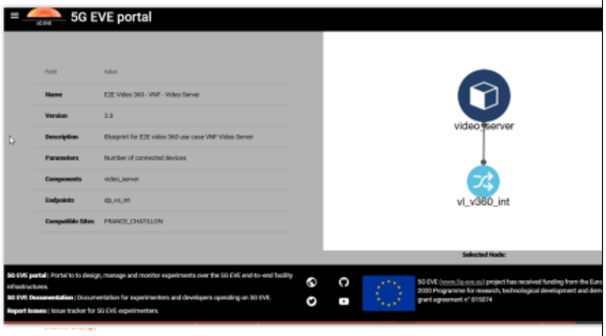
At the time being, we can either implement the Amarisoft or Open Source OpenAirInterface [36] (OAI) in 4G coverage that is ensured in B38 band in the Lab. For 5G coverage, we aim at using either FR1 (N38 / B28) or FR2 (N258) in 5G NSA mode.

The UE terminal is composed of:

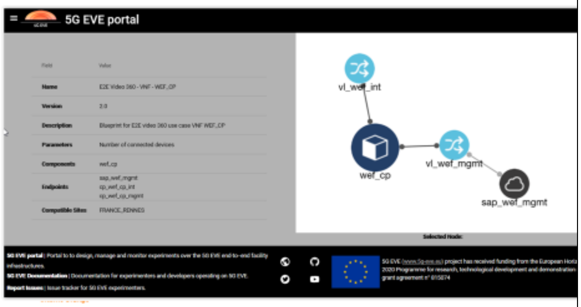
- The HTC Vive HMD client that is connected to one gamer PC integrating one graphical card. The HMD is plugged to the PC via its HDMI port (for the video streaming content) and to the USB port (for the feedback on positioning information of the user in the room). We can also visualize the video content on a PC screen that is the same content of the scene shown in the HMD (Right and left eyes).
- The PC alien is connected to the Ethernet port 4G/5G router via its Ethernet connector making the "bridge" with the radio 4G/5G.
- The LTE/5G router receives via radio the video content transmitted from the RAN gNodeB, itself connected to the WEF control plane and the Video Server (VS).

The PC alien is also used to measure metrics at the UE side, like throughput, delay, buffer occupancy, etc. The measurements are pulled-up to the Kafka broker, located in Orange Châtillon in a specific VM, via the video server using the radio UL transmission.

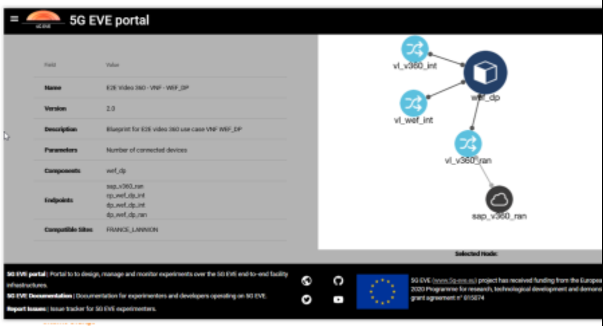
The E2E operation process defined in 5G EVE has been applied as specified in [3] Section 1.2. The different blueprint files are available in the common gitlab repository [37]. We deployed the multi-site approach that needs to split the VSB according to the VNF location deployment and then merge inside VSB composite. The Figure 137 illustrates how and where the VNF components are deployed (a/ Video server in Orange Châtillon, b/ Wef_cp at b<>com Rennes, c/ Wef_dp at b<>com Lannion and d/ Composite multi-site VSB).



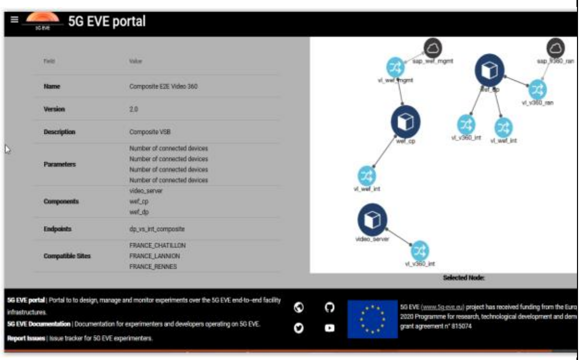
a/ Video service VSB at Orange Châtillon



b/ Wef_cp VSB at b<>com Rennes



c/ Wef_dp VSB at b<>com Lannion



d/ Composite French multi-site VSB

Figure 137: Media & Entertainment (France) UC6.4 - Vertical Service BluePrint for multi-site deployment

The Figure 138 shows the 3 VNFs used in the video 360° service deployment and ONAP onboarded in the portal catalogue. These VNF can be deployed in each of the French site facility.

videoserver_VF	1.0	Michal-Vendor	ENABLED	ONBOARDED	FRANCE_CHATILLON -> ONBOARDED FRANCE_LANNION -> ONBOARDED FRANCE_RENNES -> ONBOARDED FRANCE_SACLAY -> ONBOARDED FRANCE_SOPHIA_ANTIPOLIS -> ONBOARDED
wefcp13_VF	1.0	Michal-Vendor	ENABLED	ONBOARDED	FRANCE_CHATILLON -> ONBOARDED FRANCE_LANNION -> ONBOARDED FRANCE_RENNES -> ONBOARDED FRANCE_SACLAY -> ONBOARDED FRANCE_SOPHIA_ANTIPOLIS -> ONBOARDED
wefdp13_VF	1.0	Michal-Vendor	DISABLED	ONBOARDED	FRANCE_CHATILLON -> ONBOARDED FRANCE_LANNION -> ONBOARDED FRANCE_RENNES -> ONBOARDED FRANCE_SACLAY -> ONBOARDED FRANCE_SOPHIA_ANTIPOLIS -> ONBOARDED

Figure 138: Media & Entertainment (France) UC6.4 - onboarded VNF in the portal VNF catalogue

Figure 139 recaps the details of the Experiment Blueprint mentioning that 3 facilities are involved in the experiment.

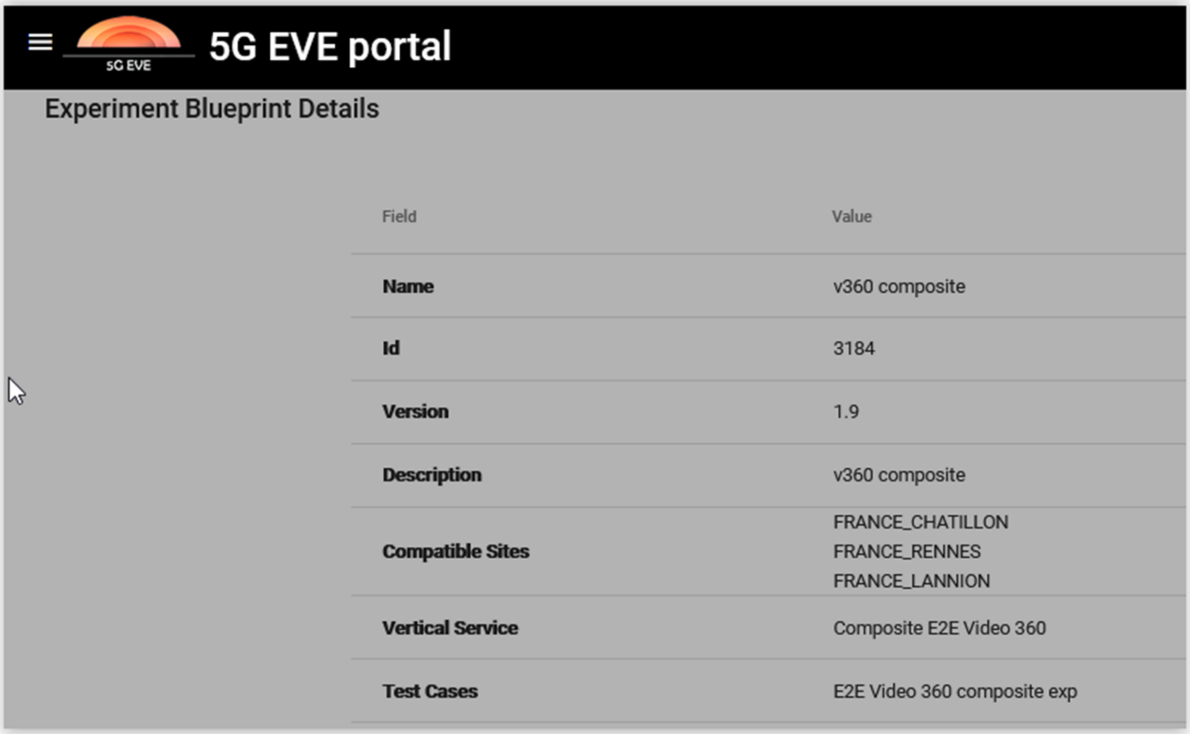


Figure 139: Media & Entertainment (France) UC6.4 - Experiment BP details

2.14.5 Pilot execution results

The different tests cases have been executed from the portal. We can either monitor the KPIs from the portal or from the local screen.

We first experiment the video 360° test case by accessing directly to the virtual video content without any disturbance applied at the video server level. Then this test case is only affected by the network infrastructure behaviour; it is used as reference. In this situation, we can see that the radio link is always matching the video data throughput scheduled at the cadence imposed by the video stream depending on the video coding rate, namely 9 Mbps. At the beginning of the video transmission, the buffer level occupancy being null, the service is asking the network to provide high data throughput in order to fill in the buffer to have some "resource reserve" to avoid jerky video image; typically a buffer level of 30 seconds allows a good QoS. To buffer as much as possible the video stream, the transmit data *throughput* must be higher than the service video stream of the video content. Experience n°1 doesn't add any delay on the video service, that's why the *adddelay* value is null. The *rttsockeio* metric corresponds to the RTT duration between the video server and the UE. It directly depends on the location of the video server in the cloud. In our case, the distance between the UE and the video server is around 500 kms that leads to inherent 3.5 ms. The obtained *rttsocketio* value deporting the video server from radio location is 12 ms including the inherent time duration. This is illustrated in Figure 140.

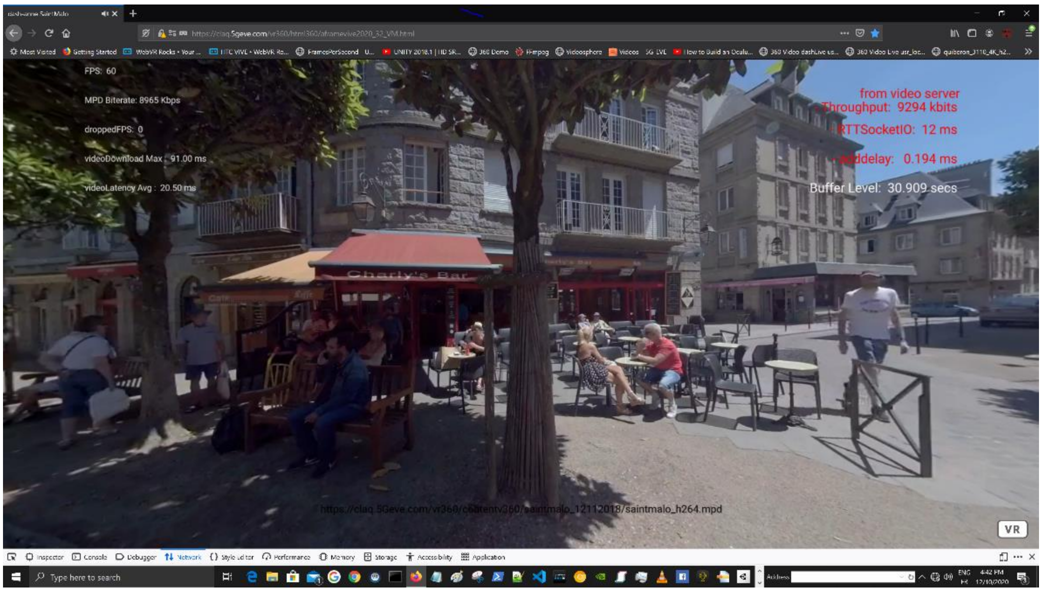


Figure 140: Media & Entertainment (France) UC6.4 - Experiment n°1 without any disturbance

We can see on the left side of the Figure 140 some other metrics such as the FPS (Frame per Seconds) and the number of dropped frames.

In the Figure 141, we can see that the buffer level is rapidly at its maximum because the data throughput link is able to deliver more than the video service. In Figure 142, we illustrated the throughput. After a data rate peak, around 170 Mbps, that load the buffer, the data throughput is in average around 10 Mbps with a range between 4 Mbps and 20 Mbps, allowing to maintain the 30 s of buffer level.

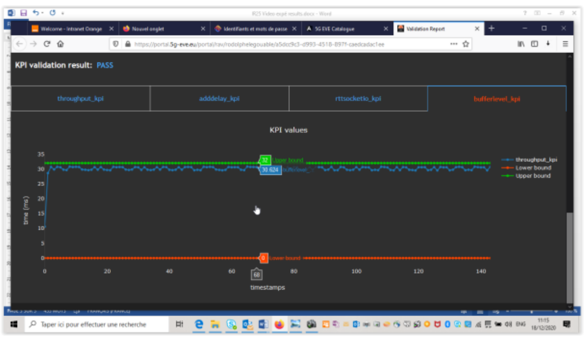


Figure 141: Media & Entertainment (France) UC6.4 – buffer level metrics w/o disturbance

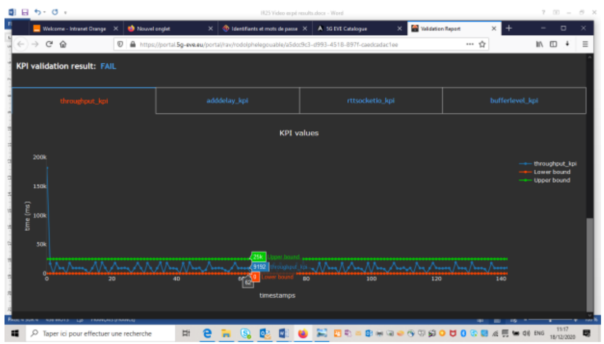


Figure 142: Media & Entertainment (France) UC6.4 - Throughput variation depending on buffer load

Then, we performed the experiment n°2 by making variation of the service video *throughput limitation* from 9 Mbps to 2 Mbps (Figure 143). More the video service throughput is limited, more the *BufferLevel* (video player buffer occupancy) decrease from 30 s to less than 2 s and the video freeze as shown in Figure 144. No direct impact appears on the *rttsocketio* and *adddelay* values when decreasing the video service throughput; this is shown in Figure 145 and Figure 146. For <u>one video stream</u>, for one good quality of the video immersion, we need at least between 4 and 6 Mbps.

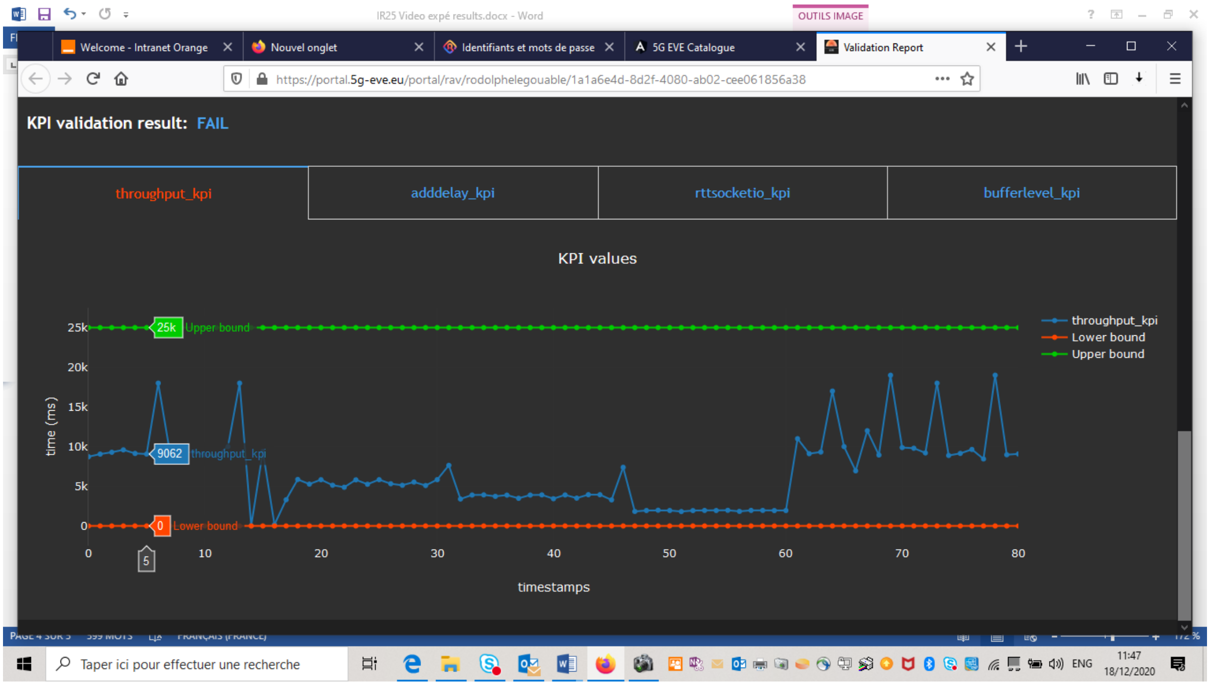


Figure 143: Media & Entertainment (France) UC6.4 - Video throughput with bandwidth limitation – after 60s the limitation is relaxed

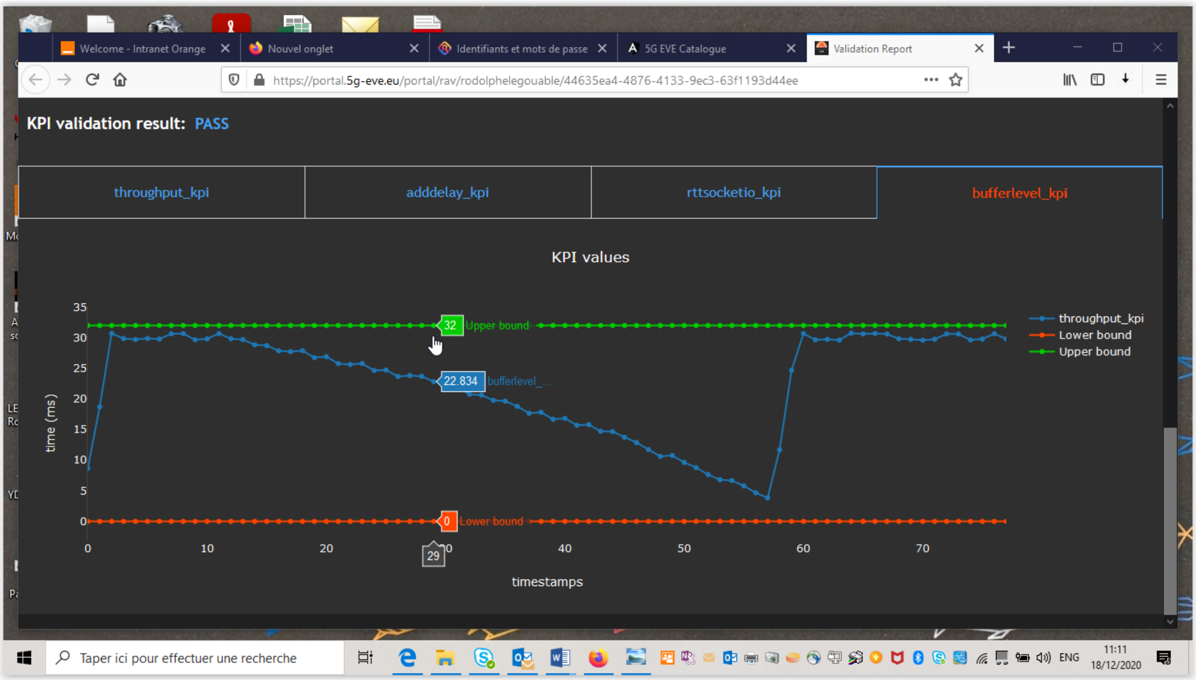


Figure 144: Media & Entertainment (France) UC6.4 - Buffer level when decreasing the throughput showing the buffer load decrease

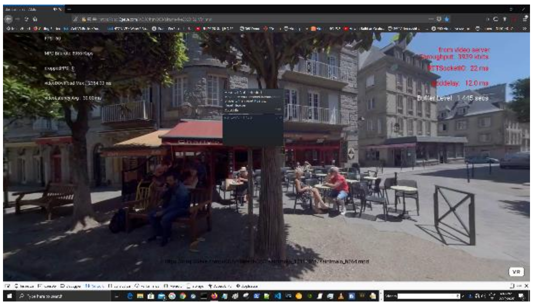


Figure 145: Media & Entertainment (France) UC6.4 - Local screen monitor in case of bandwidth experiment limitation

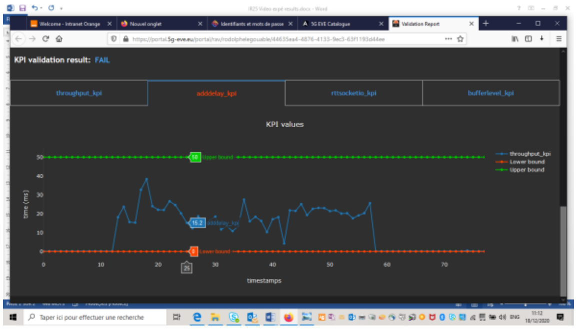


Figure 146: Media & Entertainment (France) UC6.4 – add delay variation with bandwidth limitation

The 3rd experiment consists in adding delay variation on the video output. Of course, in that case the *rttsocketio* is varying accordingly making some intolerable latency between the video image and the users leading to nausea feeling. No change appears around data *throughput* that is fixed at 9 Mbps ensuring good quality on the video (no jerky image and no frame error). So, ensuring RTT latency below 100 ms and 6 Mbps video *throughput* is the couple metrics that allows a good QoE.

2.14.6 5G empowerment

This video use-case is not so greedy in data throughput because one video stream only uses around 12 Mbps to have a good quality of experience. When scaling the use-case in real environment (typically virtual museum visit) where around 50 persons are sharing the virtual visit, then the network throughput is increasing significantly. In that case, NR 5G is mandatory. However, visiting one house for renting doesn't need 5G. In terms of latency, if the users' data plane is located very close to the RAN, in that case, the users are not too much affected by the service latency and the user is not affected by nausea, especially if the link quality between the video server and the users' data plane is of good quality. On the contrary, the need to also put the video server close to the users' data plane is important.

Also, the service KPIs monitoring in our case were important to collect for its analysis.

So, the 5G podium shortlist components for this use-case are: 1/ Infrastructure virtualisation; 2/ Ease infrastructure orchestration deployment; 3/ Monitoring as a service (equality with 5G NR for some type of experiment involving more than 15 persons). However, promotion of such use-case needs that 5G chipset are directly integrating inside the Virtual Reality Head Mounted Display (HMD), for removing dependencies on wired infrastructure or WiFi connectivity (autonomous 5G HMD), that will lead to the business motivation of the virtual reality (in general).

2.14.7 5G EVE platform added value

The main 5G EVE facility added values for the video 360° vertical are (in relation with the above section):

5G facility openness with the automated VNF deployment, allowing to distribute the network functions in different location in an ease way, the platform orchestration that is directly linked to the previous advantage and that allows to save time during the network deployment procedure and also the performance Diagnosis of service KPIs that allows the vertical to rapidly makes conclusion about the optimization of the network deployment and the main components to implement.

2.15 Use Case 6.5 - Media & Entertainment: High-quality multi-site gaming experience

2.15.1 Pilot context

This Use Case demonstrates the multi-site deployment of a live media application, through which game players and spectators participate in a common cloud gaming environment through a virtualized representation.

Given the nature of the media streams (i.e., full 3D), with spectators that use mobile phones, head-mounted displays and headsets, or even traditional desktop PCs, heterogeneity in the delivery of the streams can be large. This type of next-generation media applications comes with new varying consumer requirements that, in turn, necessitate new functionalities and capabilities at the time of deployment and operation.

Purely from a media perspective, the volumetric appearance representation of live performance comprises a diversity of multimedia streams. On one hand, the 3D geometry needs to be streamed. This is usually represented in the form of a 3D triangle mesh, which because of modern real-time 3D capturing and reconstruction technologies is of time-varying nature. On the other hand, the 3D media stream is further accompanied by a multi-view video stream, which is used to reconstruct the coloured appearance of the users through multi-view mesh texturing.

Finally, it is important to clarify that the focus of the UC in the scope of 5G EVE is on the spectators as end users (representing a very popular kind of service as today represented by OTT providers like Twitch). In that respect, it is assumed a fixed quality of experience and service cost for the players, while we try to optimize the experience for the spectators under cost constraints, by leveraging on proper 5G EVE platform design decisions and tools, taking advantage of them.

Fundamentally, the objective of the Use Case is to optimize a streaming gaming service in real-time. The key parameter for decision-making is the quality of the experience perceived by the spectator (end-user), taking image quality parameters such as blockiness or block loss as a reference. To make this possible, a Deep Reinforcement Learning algorithm capable of training in real-time was developed to create a model that optimizes the transmitted video bitrate flow according to reward functions. As we are talking about a gaming scenario, one of the initial requirements was to guarantee 60 frames per second in the transmission.

2.15.1.1 Partner's roles

Vertical:

TID will provide to the experiment the telecom operator view, i.e., the requirements needed to be taken into account to make sure that the conclusion of the experiment is meaningful for future deployment of gaming-related services.

VNF provider(s):

Two VNFs are provided by UPM as part of this Use Case: the vTranscoder and the vProbe. UPM will also provide the Game engine, which will act as a PNF since it is not virtualized.

Experiment developer(s):

Both UPM and TID have jointly elaborated the required blueprints, descriptors and configuration/execution scripts in order to be integrated with the 5G EVE platform.

Experimenter(s):

Again, both UPM and TID have jointly executed the experiments and participate in the evaluation of the obtained results, starting from the KPI validation and visualization procedures supported by the 5G EVE platform.

Site Manager(s):

IMDEA Networks and Universidad Carlos III de Madrid (UC3M)

The site managers of 5TONIC perform the monitoring and scheduling tasks for the Gaming Use Case.

2.15.2 Pilot architecture

The pilot has been implemented as a multi-site experiment running on Spain and Greece 5G EVE sites.

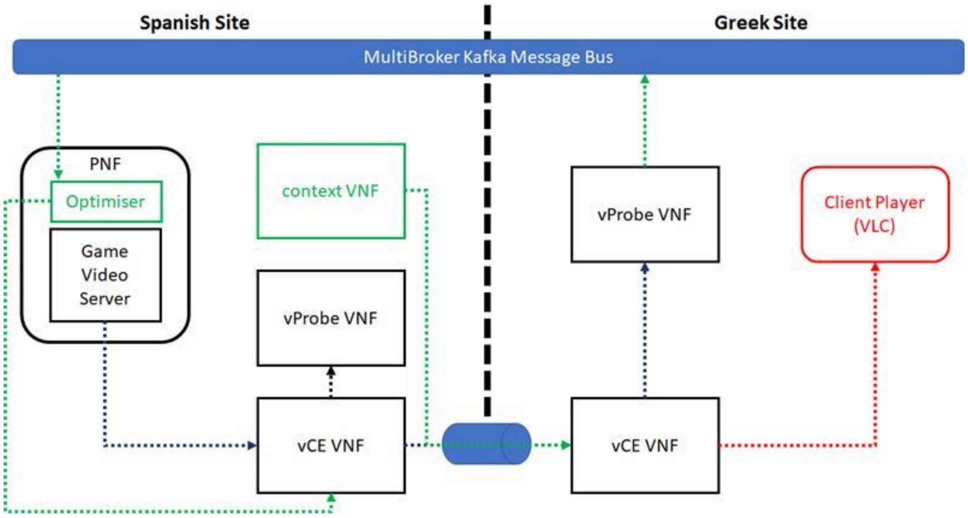


Figure 147: Media & Entertainment (Spain) UC6.5 - Pilot architecture

As seen in Figure 147, and due to the multi-site nature of the experiment, the game server is located in one site (potentially together with some players and/or spectators), while some other spectators are located on other sites. QoE is measured on all client devices and measurements are provided to be consumed by the Service Optimisation component, which in turn executes corrective actions over the video compressor to adapting the bitrate according to the optimiser decision.

2.15.3 Vertical service KPIs implementation

The collection of metrics for this UC (as depicted in Table 30) is a combination between the use of the Kafka bus (vProbe) and the REST API (vCE).

Table 30: Media & Entertainment (Spain) UC6.5 - Vertical service KPIs

Use case title	**High-quality multi-site gaming experience**		
Site facility	**Spain**		
Vertical KPI name	**Quality of Experience (QoE)**	**Service Monitoring**	**Bitrate profile**
Vertical KPI definition	Metric to trace the perceived quality by the users.	Ability to define service metrics to monitor performances	Bitrate value used in transmission
Metric collection tools	Value measured by the VNF vProbe	Internal FFmpeg process computes necessary information	
Position of the probes in the reference architecture	The probe is integrated directly in the VNF, therefore, in parallel to the end-user, being the UE 1) UE.	2) Public Cloud	2) Public Cloud

1) UE; 2) Public Cloud; 3) Private Cloud; 4) Edge			
Metric collection methodology	Approximately every 10 seconds an analysis of the received content is performed and the metrics are published on the Kafka bus	At the moment of making decisions by the optimizer, it collects the data received from the probe, and, via REST API, receives the data from the vCE	The optimizer will make decisions each time it collects information from the quality probe and video compressor. This bitrate profile will later be published on the corresponding Kafka bus
Validation tools	Prior to deployment, an analysis of the transmitted video was performed, obtaining the optimal QoE ranges. This previous analysis serves as a comparison to validate the metrics obtained once deployed	The vCE should transmit the maximum bitrate flow allowed by the UC at full performance. That is, by transmitting the game video at the highest quality, it must support maintaining the previously preset bitrate according to the UC, avoiding constant drops in service or buffering.	Mostly, it will be the subjective opinion of the end-user who values that the maximum selection of the profile is adequate for the available bandwidth of the link.
Validation methodology	With lossless transmission, the probe must return metrics in the range of previously obtained in a controlled environment. Subsequently, adding losses with the iperf tool, anomalous values must be obtained to obtain the QoE KPI, such as blockiness and block loss metrics. In this case, there should be a decrease in blockiness, and the value of block loss should increase notably.	With the UC running and transmitting the video output to their respective destinations, the stream should be received normally. This means that we receive a continuous video without interruptions and that we do not receive image errors.	Being a multisite scenario, the maximum amount of bitrate must be adapted with the bandwidth available in the links. The validation of the selection of profiles is carried out observing visually that without intentionally disturbing the channel, the video is received at the remote site with good quality. As a subsequent act, the iperf tool will be activated to transmit data through the same link and verify that additional losses actually occur in the UC.

2.15.4 Pilot deployments

Descriptors (VSD, CD or ExpD) have been generated for the UC and the initial validation activities.

As seen in the Pilot architecture (Section 2.15.2), the Use Case is made up of three different parts.

- Game Server. Component where most of the UC resources power of the Use Case is integrated. It was designed as a physical function since a dedicated graphic was required for the UC, since it is in charge of both the game engine and the starting point of the video transmission, as well as the training and activation of the DRL model.
- vCE. VNF video compressor, capable of reducing the bitrate of the incoming video and transmitting it to the bitrate transmission profile that the optimizer considers optimal according to the state of the metrics.

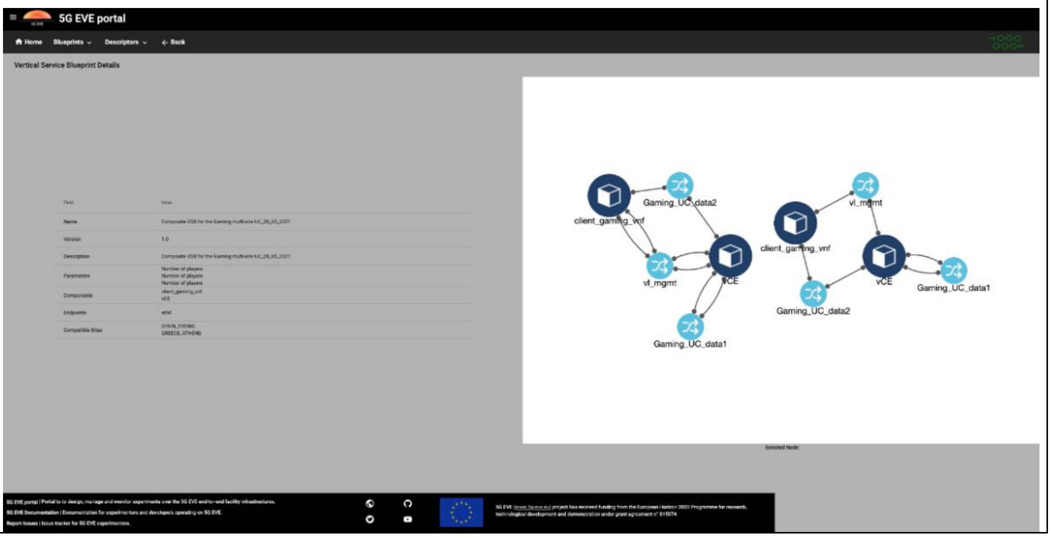
- vProbe. VNF component that evaluates the video received in terms of quality of the experience, and returns the corresponding metrics.

The initial validation of the activities between the different components was carried out in the laboratories of UPM. A Kafka server was included to make it possible to publish and consume metrics.

The deployment of the components on the 5G EVE portal was carried out later, deploying machines at different sites:

- The PNF was deployed in Spain, specifically in the TID Island at 5TONIC laboratories. The game is recorded in real time through a content creation tool, and the video stream is transmitted to the next VNF, in this case, the vCE deployed also in Spain, at 5TONIC (in this case, deployed in the UC3M Island there).
- vCE. Due to the gaming nature of streaming, and therefore, as an objective to have 60 frames per second, the vCE must adapt the incoming streaming received from the PNF to the bitrate that in this Use Case we define through network profiles. One of the outputs is transmitted to a quality probe (VNF) deployed in Spain, while the other output is sent to the vCE VNF located in Greece.
- In Greece, another vCE VNF is deployed, in this case limited to functioning solely as a video router, forwarding the received video. The input is connected to the streaming output of the Spanish vCE, and the outputs are transmitted both to the VNF vProbe and to an IP address that serves to visually observe the streaming.
- The quality probe, vProbe VNF, is deployed in Greece, in parallel to the reception of the content by the viewer, as its function is to evaluate the quality of the image. It receives the streaming from the Greek vCE.
- Additionally, a vProbe VNF is included, receiving the streaming directly from the Spanish vCE. Its objective is to guarantee and confirm that, in case of receiving problems in the Greek probe, it is due to the little bandwidth available between Greece and Spain, and not in the initial creation of the streaming itself.
- Furthermore, the screenshots shown in Table 31 and Table 32 present the deployment of the UC in both Spain and Greece 5G EVE sites, respectively.
- Screenshots from Spanish site

Table 31: Media & Entertainment (Spain) UC6.5 - Spanish site deployment screenshots

Vertical service blueprint	

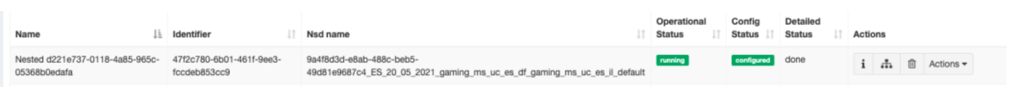
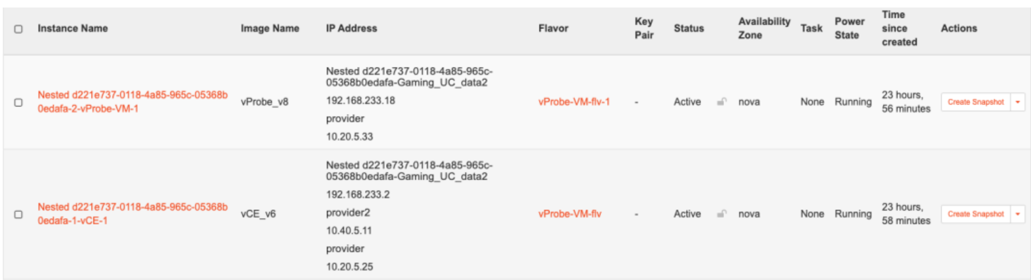
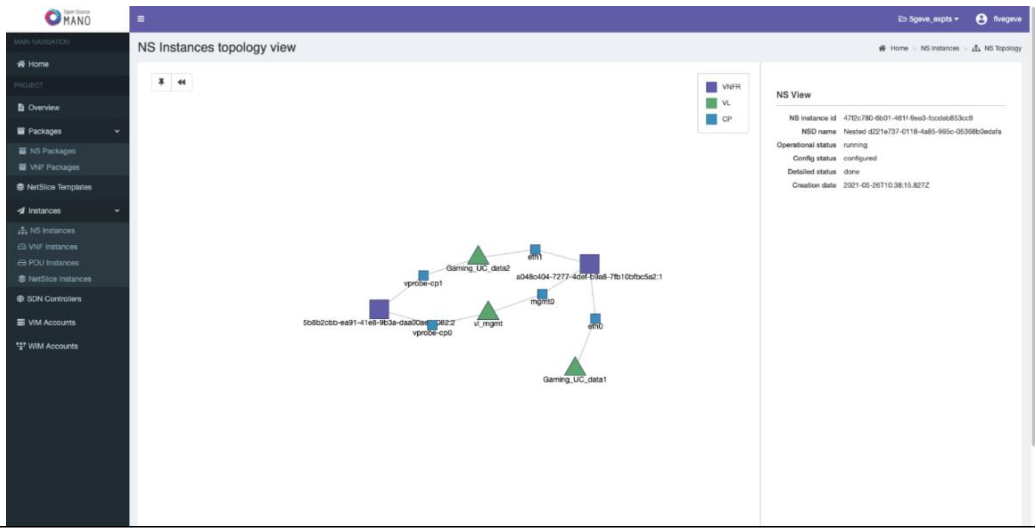
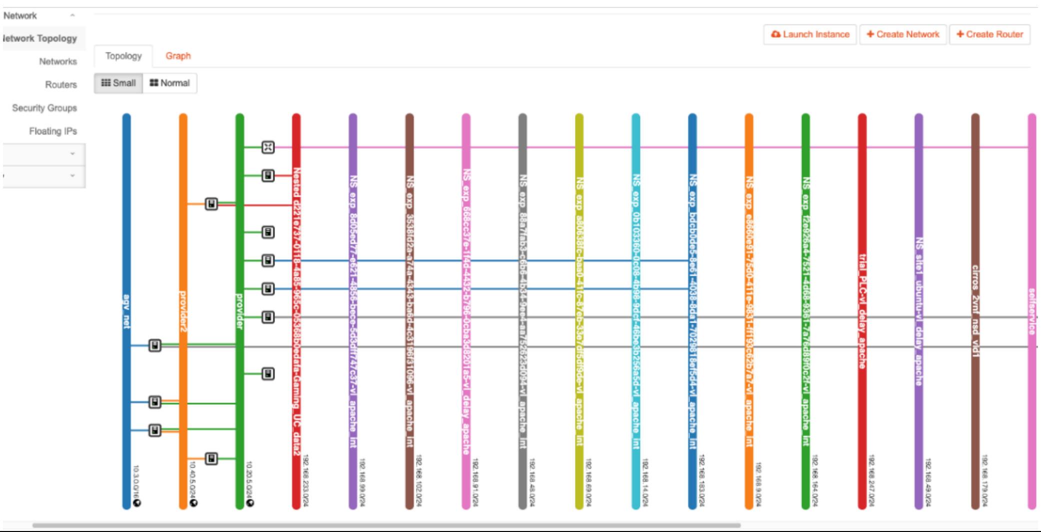
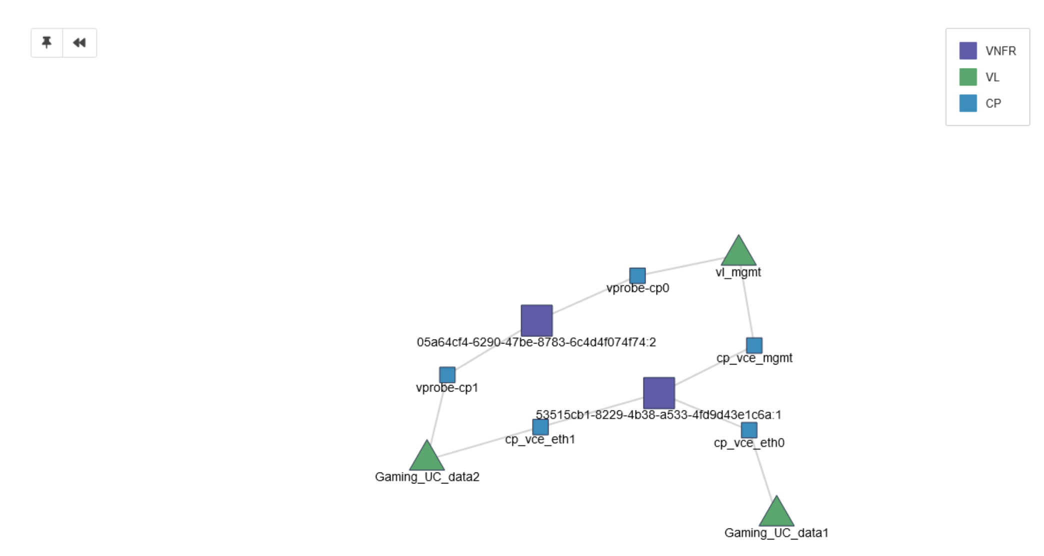
Network Service Instance	
OpenStack instances	
OSM Network Service graph	
OpenStack Network topology	

Table 32: Media & Entertainment (Spain) UC6.5 - Greek site deployment screenshots

OSM Network Service Instance	

<table>
<tr><td>OpenStack instances</td><td>
</td></tr>
<tr><td>OSM Network Service graph</td><td>
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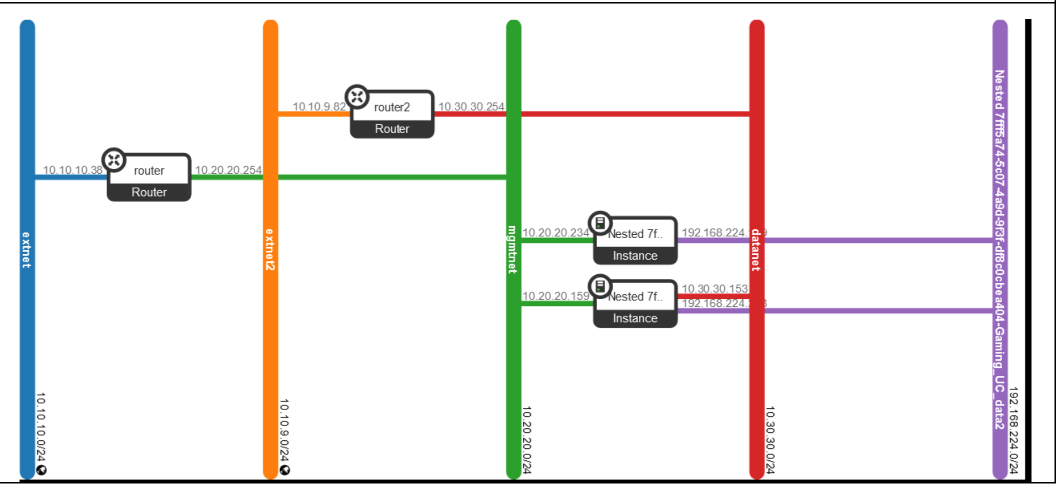
<tr><td>OpenStack Network topology</td><td>
</td></tr>
</table>

2.15.5 Pilot execution results

This Use Case was not part of the initial set of use cases defined in the project proposal, and it was added at the time of project execution precisely to validate the multi-site features of 5G-EVE. The development of multisite support at the platform level is one of the key elements for the operation of this UC facilitating the operation of a complete multi-site environment, on which vertical service delivery can be made between different sites. All this includes, apart from the connection, polishing technical aspects such as available bandwidth and a lossless link. In this particular case this applies to the link connecting Spain and Greece.

The idea of the UC is to first carry out a training with all the instantiated and deployed components (VNFs and PNFs), on which any kind of conditions are produced. During the training stage, part of the available bandwidth in the link is consumed with an external factor, which has impacts on video transmission losses. According to the evaluation of the quality probe, it should return some metrics that the optimizer must learn to handle. Once the model is trained under these conditions, it is deployed and demonstrated under realistic conditions (e.g., producing link losses), with the optimizer being able to adapt the content to offer the best Quality of Experience.

These are an example of results obtained in the local laboratory. It can be observed along the time how the reward obtained can be improved automatically.

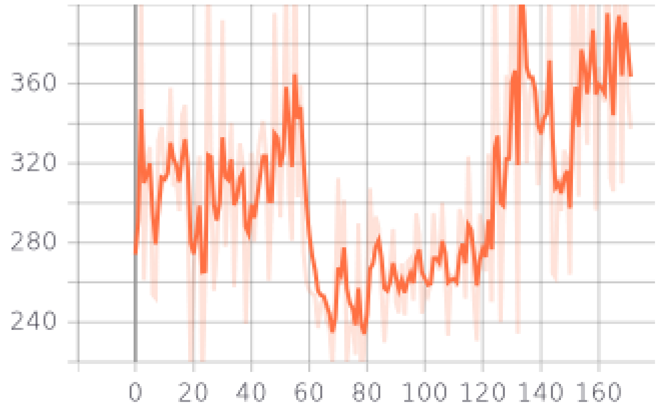


Figure 148: Media & Entertainment (Spain) UC6.5 - Reward optimization over the time

Figure 148 only shows training in early stages, so by polishing the different components of the UC, it is possible to reach higher levels of training efficiency.

2.15.6 5G empowerment

Given the gaming approach, big requirements were needed in terms of the network, which would allow smooth transmission. The advantages of 5G make it possible to maintain a wide bandwidth.

2.15.7 5G EVE platform added value

The possibilities of the 5GEVE project to allow multisite communication makes the development of the UC possible. The origin and end of UC is to be able to generate content on a specific site and be able to receive it anywhere else, independent of location. In this case, the project allows an automatic deployment and execution of all the components involved in remote sites.

3 ICT-19 Pilot(s) execution

This chapter provide the description of the ICT 19 pilot Use Cases that have chosen to perform their experiment on top of 5G EVE E2E site facility. The complete description of each Use Case is provided in the corresponding project deliverables.

The goal of this chapter is to provide for each ICT 19 Use Case:

- A brief Pilot context description including the references to the deliverables in the ICT 19 projects describing the Use Case architecture, execution and results;
- A description of the pilot integration in the 5G EVE site facilities;
- A description of the added value provided by 5G EVE to the given Use Case.

3.1 5G TOURS

The 5G-TOURS project [38] aims at deploying 13 use cases related to the themes of the touristic city in Turin, the safe city in Rennes and the mobility-efficient city in Athens. The ultimate goal is to trial the use cases in a real environment by continuously collecting network, service and vertical KPIs. Two use cases are here detailed as examples of using the network architecture from the 5G EVE: Connected ambulance (UC7) and Wireless Operating Room (UC8).

3.1.1 Use Case 1: Augmented tourism experience

3.1.1.1 Pilot context

The 5G-TOURS UC1 "Augmented tourism experience" aims to provide visitors of targeted museums with an improved and more engaging visit experience. The UC1 consists of two different sub-UCs taking place in Palazzo Madama (UC1.a "In the very heart of Turin") and Galleria d'Arte Moderna - GAM (UC1.b "Gamification, let's play artist") respectively. More in detail [39]:

- UC1.a aims to create an integrated immersive visit of Palazzo Madama and surrounding areas using a mobile application based on beacon localization technology. Through the application the visitors will be provided by context aware information such as personalized tours, level of crowding in museum rooms, maps of the museum and related points of interest as well as have access to more contents related to specific rooms (images, videos, text, etc.) and artworks (3D scans of ceramics) by means of Augmented Reality (AR) features. Visitors will be also able to participate to an educational Virtual Reality (VR) experience based on a puzzle game. In addition, through sensors networks installed in the museum (IoT service), visitors will be able to receive directly on their devices alarm signals in case of fire and heart quake showing the shortest path towards the emergency exits.
- UC1.b aims to allow users to enter into the life of De Maria contemporary artist and to directly test the art creation process. The experience mixes Extended Reality (XR) and gamification allowing children to work together on an interactive wall reproducing the artist canvas by choosing shape and colours contents and imitating the artist "movements" with motion controllers.

3.1.1.2 Pilot deployment in 5G EVE

As reported in [40], the 5G network deployment in the Turin site has been structured along two phases. While in the phase 1 the 5G indoor and outdoor coverage of Palazzo Madama was connected to the TIM commercial network, phase 2 will move towards the integration with the 5G EVE infrastructure through two parallel, independent, and complementary activities to cover the objectives of the UCs implementation (on field) and testing the 5G-TOURS innovations (experimental).

A possible instantiation of the architecture for the phase 2 based on UC1.a and the different 5G network slices it requires (eMBB slice for the AR experience, URLLC slice devoted to the VR gamification part, and mMTC-like slice for the IoT service) is depicted in Figure 149 and described in [41].

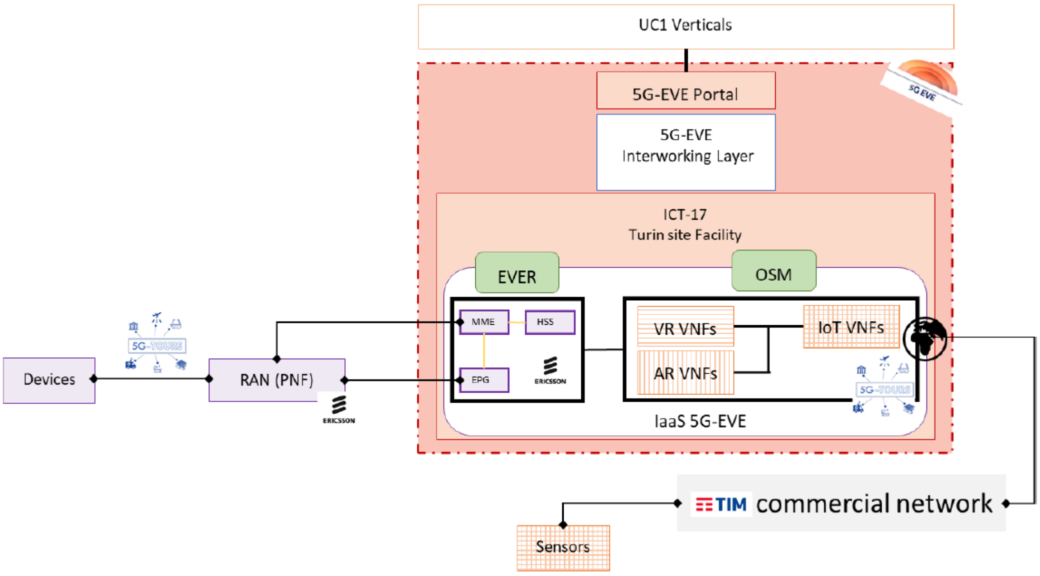


Figure 149: 5G-TOURS UC1.a - Architectural instantiation in Turin site

The Turin site overall infrastructure consists of hardware, software and transport network assets. Among the hardware we can identify the 5G EVE Infrastructure as a Service (IaaS) platform deployed between the TIM Laboratory and Politecnico of Turin and the 5G-TOURS radio access network based on Ericsson solutions. In particular, the radio access network providing the 5G coverage for the use cases will be deployed both at the museum's sites (Palazzo Madama and GAM) and TIM Laboratory premises (as part of the 5G EVE infrastructure). In terms of software components, a substantial number of components are inherited from the 5G EVE platform. Most importantly, the management and orchestration framework developed by the 5G EVE project, including the 5G EVE portal, that will be used to onboard the VNFs implementing the UC1.a application through the 5G EVE Interworking Layer and the two orchestrators available in the Turin site: the OSM-based service orchestrator in charge of deploying the specific VNFs related to services (deployed at the Politecnico of Turin) and the Ericsson EVER Orchestration (deployed at TIM Laboratory) that takes care of the RAN and Core Network Functions.

3.1.1.3 5G EVE platform added value

The integration with the 5G EVE infrastructure will allow to setup UC1.a experimentations on-demand by the definition of the proper blueprints, running the experiment and collecting the relevant KPIs to be analysed in order to check if the UC1.a requirements in terms of throughputs and latencies have been met. While for the OSM-based service orchestrator integration of UC1.a no particular issues have been identified, at the time of writing, studies are still ongoing in order to find the most efficient and effective solution to use EVER Orchestrator in support of the experimentation of the 5G-TOURS innovation related to slicing management based on AI (Artificial Intelligence) and ML (Machine Learning).

3.1.2 Use Case 4: HQ video service distribution

3.1.2.1 Pilot context

In the context of UC4 "HQ video service distribution", the sub-use case UC4.c "5G Core Multicast" which activities are carried out at UPV laboratory aims to design, develop, implement and validate a set of new enhancements to the 5G Core Network that enables multicast communication, focused on the high-quality video distribution and delivery. In particular, UC4.c will enhance the existing 5G Core with two new multicast functions, MCF (Multicast Control Function) and MUF (Multicast Use Function), allowing and performing multicast sessions in both the control plane and user plan. An ad-hoc Service Layer will be developed in order to provide multimedia content to the mobile device through the above mentioned 5G Core and related radio access infrastructure.

3.1.2.2 Pilot deployment in 5G EVE

At the moment of writing this document, right before the end of 5G EVE project, an initial discussion on the integration aspects of UC4.c with the 5G EVE infrastructure is currently ongoing. The proposal from 5G-TOURS is to onboard, configure and run the Service Layer functions on the NFV infrastructure at the Politecnico of Turin. The multicast traffic will be then tunnelled over an IP connection towards UPV laboratory where the 5G Core Multicast is deployed.

3.1.2.3 5G EVE platform added value

The 5G EVE platform will enable the onboarding of the multicast Service Layer in a seamless way through the 5G EVE portal. The 5G EVE Interworking Layer will enable a cross-site experimentation providing the connection towards UPV laboratory.

3.1.3 Use Case 7 & 8: Connected ambulance & Connected surgery room

3.1.3.1 Pilot context

The goal of the use case 7 is to develop a deep understanding on how 5G can be used to improve emergency care, and how 5G can improve the communication between care givers in the ambulance, the medical regulator, remote experts, and emergency department staff [42]. Use case 8 demonstrates the impact of 5G inside the operating room and has very low latency requirements and important amount of video data to be transferred [42].

3.1.3.2 Pilot deployment in 5G EVE

UC7 and UC8 leverage on the 5G EVE Platform to deploy BCOM's Wireless Edge Factory (WEF) Core network [35]. To this purpose, Orange provides an ONAP orchestrator as part of the 5G EVE infrastructure of the French site which enables the user or the experimenter to deploy and configure the WEF Core Network in the BCOM infrastructure [35]. The Service Layer interacts with the 5G EVE Portal through a programmable REST API to request the deployment and instantiation of the whole vertical service by the 5G EVE platform. The 5G EVE Portal API enables a programmable interaction between 5G-TOURS and 5G EVE, which supports experiment lifecycle management operations, whilst all the experiment design operations are available only through the 5G EVE Portal GUI. A preliminary offline step is needed through the 5G EVE Portal GUI to create blueprints and descriptors for the experiments associated to the vertical (sub-) service in 5G EVE platform. Figure 150 depicts the integration of those 2 use cases in 5G EVE platform.

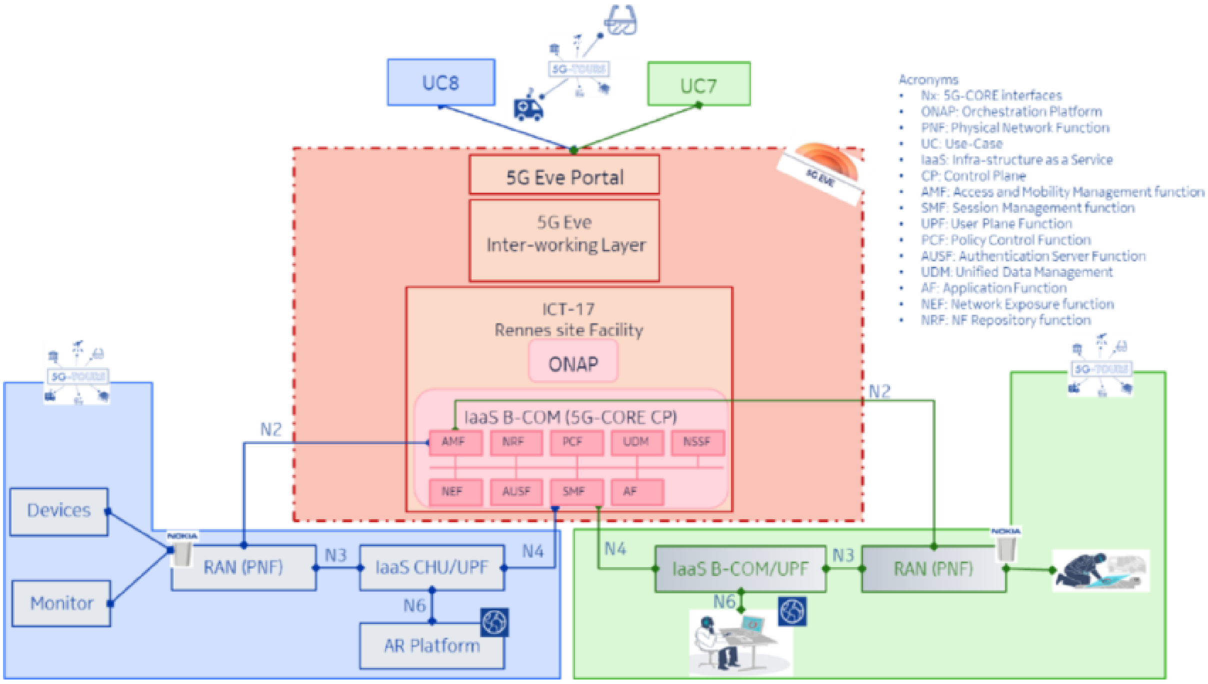


Figure 150: 5G-TOURS UC7 & UC8 - Integration with 5G EVE platform

3.1.3.3 5G EVE platform added value

UC7 and UC8 benefit from 5G EVE monitoring functionalities, by providing the collection and visualization functionalities for the monitoring of data of the entire vertical service. The 5G EVE platform supports the visualization of monitoring data through the 5G EVE portal GUI and provides internal functionalities for performance validation and evaluation based on KPIs.

3.1.4 Use Cases 6, 9, 10, 11, 12 & 13 running in the Greek Site

3.1.4.1 Pilot context

The different use cases from 5G-TOURS running in Greek Site will be deployed in the AIA (Athens International Airport). 5G-TOURS utilizes only the NOKIA's Greek site 5G platform. It should also be noted that the use cases running in Athens will now also include the WP5 Safe City UC6 "Remote health monitoring and emergency situation notification" and UC9 "Optimal Ambulance routing". The 5G coverage extension of the Athens site is already deployed, and its architecture is depicted in Figure 151. The 5G EVE Greek facility is now enhanced by a new location in AIA connected to the 5G-CORE (part of 5G EVE platform) running in OTE Labs. As illustrated in the Figure 151, 4 indoor and 2 outdoor pair antennas (3.5-3.6GHz) are connected to 2 BBUs (BBU1 and BBU2) inside different buildings (B2 and B11 of AIA). The 2 BBUs are connected directly to a switch at AIA. Also, Small form-Factor Pluggable (SFP) probes are connected into the same switch for the need of real time measurements. A Streaming Server is connected also for the need of UC11 for transmitting emergency 4K video. The OSN switch at AIA is connected through a 10 Gbps line to another OSN switch at OTE Labs, where the 5G EVE infrastructure is developed. All the 6 5G-TOURS UCs of Greek site will use in a second phase the E2E service of 5G EVE project: blueprints -> portal-> IWL-> OSM -> 5G-EVE NOKIA's EPC (see section 3.3 and 4.3 in [43]).

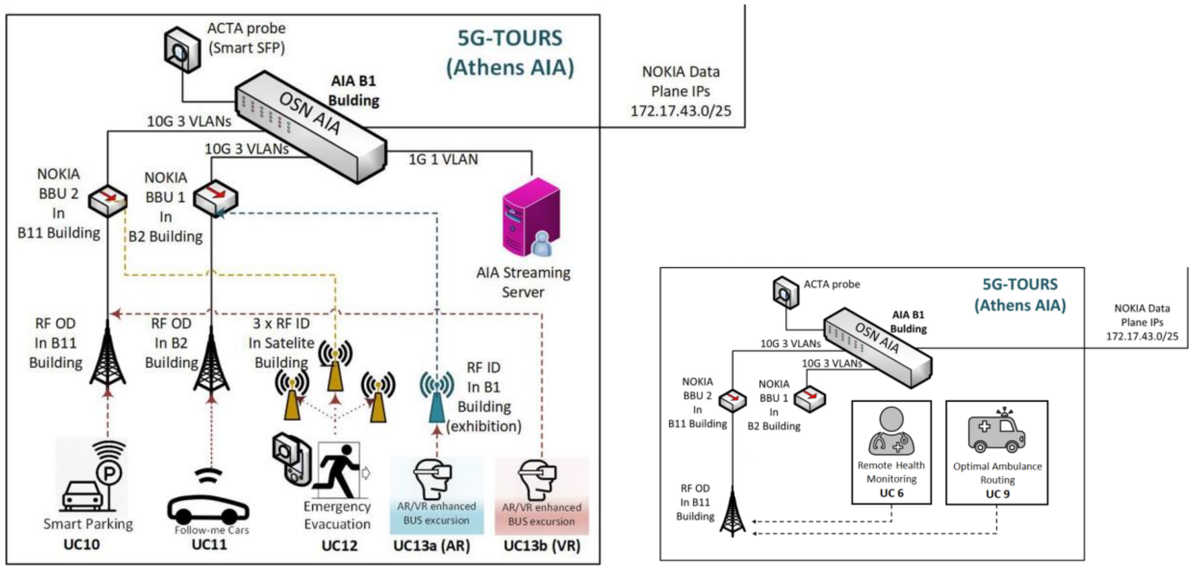


Figure 151: 5G-TOURS – AIA extension location of Athens site for use cases a) 10, 11, 12 and 13 and b) 6 & 9.

<u>**UC6 & 9**</u>

UC6 Remote Health Monitoring: The 5G-TOURS Remote Health monitoring and Emergency situation notification (UC6) addresses solutions for remote health monitoring of people, especially when already diagnosed with a critical disease still compatible with home care (e.g., some forms of cardiovascular disease, hypertension, diabetes, etc.). The main features offered, utilising the WINGS STARLIT platform, include: (a) real time remote health monitoring services of main vital-signs, and (b) quick, reliable notifications to users, family members and health care professionals in case of a health incident or a health emergency prediction.

- The E2E network path for this UC is the following: UC6 works with outdoor antenna in B11 AIA building, BBU2, OSN at AIA, OSN at OTE, 5G EVE NOKIA’s EPC infrastructure (see Figure 151, Figure 152 and section 3 in [40]).

UC9 Optimal Ambulance Routing: The 5G-TOURS Optimal ambulance routing (UC9) addresses real time navigation of the ambulance, both to the site of the emergency and back to the hospital, to ensure the timely provision of medical help and immediate patient transfer. While optimal ambulance routing has been addressed extensively from a more theoretical aspect, the emergence of technologies such as 5G enables the fast and reliable acquisition of data on changing factors of an urban or suburban environment such as traffic flow, changing road graph, population mobility, and hospital capabilities, to be exploited by AI powered decision making.

- The E2E network path for this UC is the following: UC9 works with outdoor antenna in B11 AIA building, BBU2, OSN at AIA, OSN at OTE, 5G EVE NOKIA’s EPC infrastructure (see Figure 151, Figure 152 and section 6 in [40]).

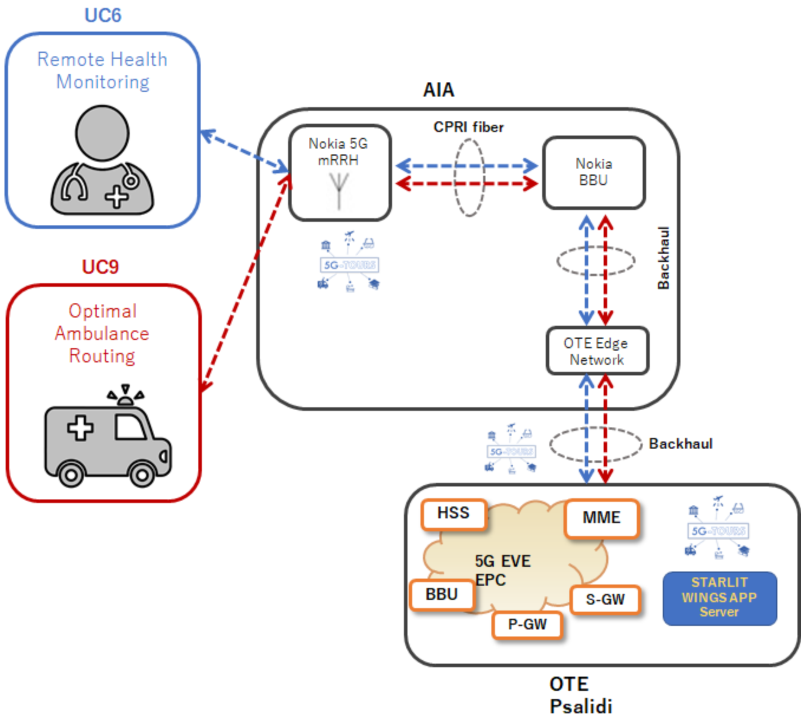


Figure 152: 5G-TOURS UC6 & UC9 -Integration into 5G-EVE Greek Site.

While these two use cases where initially scheduled to be trialled in Rennes, due to only commercial network availability in Rennes for these two use cases, their trialling will be now done in the Athens site. Figure 151 and Figure 152 depict the connection and integration of the 5G-TOURS Safe city UC6 and UC9 hosted at the Athens site respectively. As can be seen in Figure 152, the main back-end functionality for both use cases will be deployed at the WINGS OSM at OTE premises in Psalidi. This is currently work in progress. Once this deployment has been completed, the front-end for both UC6 and UC9 will run on mobile phones or laptops, connected to the 5G-TOURS experimental infrastructure at AIA premises in Athens, where the tests will be performed, along with the wearable devices for UC6. Metrics will be recorded at the application layer as part of the testing and validation activities within 5G-TOURS.

UC10, 11, 12, & 13 (Figure 153)

UC10 Smart Parking Management: This use case will allow the AIA parking users to obtain real time information on available and occupied spaces. This will be achieved by the installation of around 100 5G-enabled parking sensors. This way the drivers will be able to locate available parking spaces directly through a mobile application and will be guided there via the optimal route. The smart parking management will contribute to the emission reduction by reducing unnecessary vehicle movements to locate a parking space.

- E2E configuration of the network is completed (5G EVE infrastructure and AIA extension). All the needed equipment has been installed and configured (sensors, chipsets, EU devices, servers). 15 sensor spots and the needed SIMs cards are ready. Driver app, dashboard management app, and a needed cloud called “WINGSPARK”. E2E tests have been took place at AIA for the e2e network as well as for the apps.
- The E2E network path for this UC is the following: UC10 works with outdoor antenna in B11 AIA building, BBU2, OSN at AIA, OSN at OTE, 5G EVE NOKIA’s EPC infrastructure (see Figure 151, Figure 152 and section 2 in [40]).

UC11 Video enhanced ground-based moving vehicles: This UC focuses on installation of high-definition cameras on the Athens airport follow-me vehicles, which will feed live video feeds to the ASOC (Airport Security Operation Center) as well as to other concerned third parties and stakeholders (emergency resource personnel – Police, Ambulance Services, Fire Brigade) for efficiently responding to emergencies, in order to prevent or quickly respond to incidents that may impact airport operations.

- E2E configuration of the network is completed (5G EVE infrastructure and AIA extension). All the needed equipment has been installed and configured (UHD cameras, 5G routers, Van equipment, Media server, mobile devices, SIM cards). Web app and video transmission app are. E2E tests have been took place at AIA for the network as well as for the apps.
- The E2E network path for this UC is the following: UC11 works with outdoor antenna in B2 building, BBU1, OSN at AIA, OSN at OTE, 5G EVE NOKIA's EPC infrastructure (see Figure 151, Figure 152 and section 3 in [40]).

UC12 Airport Evacuation: This use case focuses on the evacuation of the airport in a quick and organized fashion in case of an emergency, providing automated guidance of emergency routes from the affected area up to the muster areas. This use case focuses on the location accuracy part of 5G technology and the guidance of a user to the nearest exit.

- E2E configuration of the network is completed (5G EVE infrastructure and AIA extension). All the needed equipment has been installed and configured (EU devices, needed server, evacuation application, SIM cards). LBS (location-based services) will be provided by NOKIA's platform and a triangulation (3 indoor antennas are used) algorithm is under development. Also a best route algorithm is ready. E2E tests took place at AIA for the network as well as for the apps.
- The E2E network path for this UC is the following: UC12 works with 3 indoor antennas in Satellite terminal, BBU2, OSN at AIA, OSN at OTE, 5G EVE NOKIA's EPC infrastructure (see Figure 151, Figure 152 and section 4 in [43]).

UC13 AR/VR Student bus excursion: The main goal of this use case is to demonstrate the value offered using 5G technology in cases when groups of people travel, e.g., on a bus, in order to visit a site of interest. The use case focuses particularly on the example of school students travelling to a destination of educational interest during a field trip or excursion. In the trials, a group of 20-25 students from the school of Ellinogermaniki Agogi (EA) will travel on a school bus to Athens International Airport (AIA) to visit an exhibit that will be hosted in a public space of the airport. The fast, reliable wireless connectivity offered by 5G and the smooth streaming of online content that it can enable will be utilized to generate good quality digital learning experiences both during the transportation to and from the destination, and during the visit of the exhibit.

- E2E configuration of the network is completed (5G EVE infrastructure and AIA extension). All the needed equipment has been installed and configured (back-end content servers, EU devices, gear-VR sets, SIM cards). An outdoor antenna is used for the tour and an indoor for the exhibition. 2 VR apps and 2 AR apps are already in final phase of development.
- E2E tests have been took place at AIA for the network as well as for the apps.UC13 scenario A (AR apps - tour) works with indoor antenna in B1 building, BBU1, OSN at AIA, OSN at OTE, 5G EVE NOKIA's EPC infrastructure (see Figure 151, Figure 152 and section 5 in [40]).
- UC13 scenario B (VR apps - exhibition) works with outdoor antenna in B11 building, BBU2, OSN at AIA, OSN at OTE, 5G EVE NOKIA's EPC infrastructure (see Figure 151, Figure 152 and section 5 in [40]).

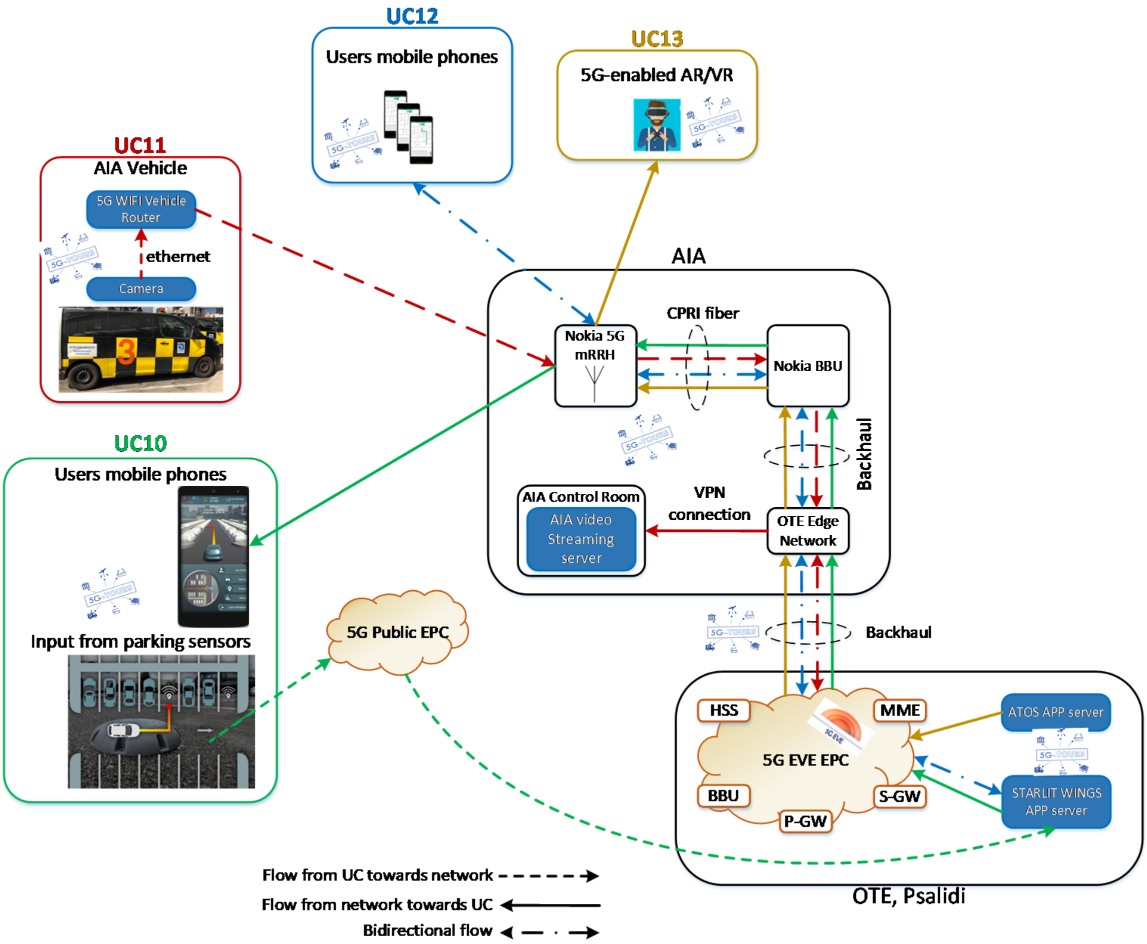


Figure 153: 5G-TOURS UC10, UC11, UC12 and UC13 - Integration into 5G-EVE Greek Site

3.2 5G VICTORI

The 5G-VICTORI project [44] is conducting large scale trials for advanced vertical use case verification focusing on Transportation, Energy, Media and Factories of the Future and cross-vertical use cases. The Romanian testbed proposes to integrate the 5G EVE solution framework to provide 5G network services deployment for the two projects use cases in Alba Iulia Municipality: UC #1.2 Digital Mobility and UC #4.2 LV Energy metering. The demonstration is planned to take place in Alba Iulia Municipality (AIM), in the City Centre, where a dedicated 5G OpenAirInterface RAN and Core site will be deployed as illustrated in the Figure 154.

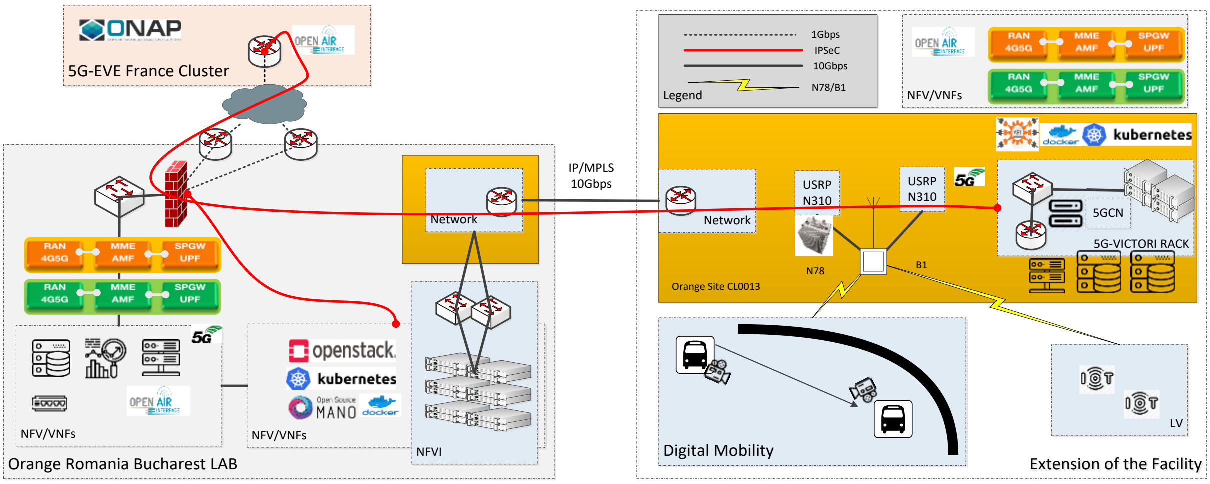


Figure 154: 5G-VICTORI - High level network design with integration in 5G-EVE Romanian facility

3.2.1 Use Case 1.2 & 4.2: Digital Mobility & LV Energy metering

3.2.1.1 Pilot context

UC #1.2 Digital Mobility: it is a real time media service delivery and prioritized communication to the municipality Command and Control Centre, in case of an emergency situation is triggered, detected by AI recognition and identification mechanism, over 5G dedicated slices.

UC #4.2 LV Energy metering, the 2nd use case to be experiment in 5G-VICTORI cluster for Low Voltage (LV) metering and Energy analytics service:

- Real-time Low Voltage (LV) energy metering services for Alba Iulia Municipality infrastructure.
- Energy Analytics for predictive and proactive maintenance for AIM LV infrastructure.

More details about these use-cases are given in [45].

3.2.1.2 Pilot deployment in 5G EVE

In Alba Iulia Facility:

- The entire experiment network infrastructure (RAN/Core and computing) is deployed in Orange Romania site in AIM.
- Hardware available: Outdoor Antennas, RAN USRPs RRU, L2/L3 networking devices, Computes
  - 4G: 5MHz spectrum in B1.
  - 5G: N78; 40 MHz spectrum in N78.
- Software: Virtualization environment (K8s/Docker), 5G RAN and Core OAI.
- IP/MPLS connectivity to Bucharest Cluster.

In Bucharest Facility, Orange Romania:

- Computing cluster, L2/L3 connectivity infrastructure.
- IPSec VPN between Orange France to Orange Romania, for 5G-EVE ONAP Integration.

The planning of deployment is described in [46].

3.2.1.3 5G EVE platform added value

We have already extended the 5G EVE French cluster to Romania by creating one secured VPN in order to be able to use the ONAP framework located in Paris Châtillon Facility for the 5G VICTORI one.

Now, the Romanian facility will be based on the same open source framework that is proposed in 5G EVE by Eurécom partner, also involved in 5G VICTORI project. So, Openshift and Open Air Interface will be part of the facility that will operate both use-cases described above.

3.3 5G!Drones

5G!Drones project [48] aim is to trial several UAV use-cases covering eMBB, URLLC, and mMTC 5G services, and to validate 5G KPIs for supporting such challenging use-cases.

3.3.1 Use Cases: UTM Control and Command - Safety1: Monitoring a Wildfire and Safety2: Disaster recovery

3.3.1.1 Pilot context

These 3 use-cases will operated in the French Eurécom's site facility.

UTM Control and command application

This use case will demonstrate a common functionality for all UAV applications, by providing the necessary safe and secure incorporation of drones into the air traffic. Indeed, the dramatic growth of UAVs over the past decade and the subsequent development of commercial drone activities especially at low altitude have posed the question of drones' safe and secure flight operations in the face of increased air traffic.

Safety1: Monitoring a Wildfire

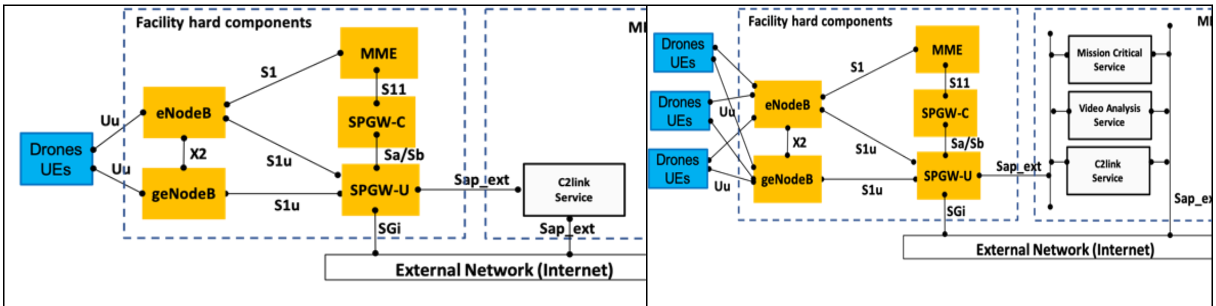
This use-case scenario is known as "Monitoring a wildfire", where UAVs are equipped with HD cameras, which can be used for streaming HD video to a remote application hosted at the edge. Using AI tools, the remote application analyses the video to predict the direction of spreading of wildlife to the firefighters so they can pay immediate attention to those areas and also avoid using the potentially dangerous routes for rescue operation. In such a case, 5G-based eMBB is needed to handle the video traffic volume efficiently.

Safety2: Disaster Recovery

This use-case scenario represents a "Disaster recovery" scenario, where UAVs are considered fitted with WiFi small cells and can be carried close to the disaster area using a mobile ground station. UAVs can interconnect and communicate with the ground station over direct D2D links (WiFi), allowing for the rapid deployment of a wireless backhaul in situations where capacity is needed on an expedited basis, as these networks allow both victims and emergency workers to communicate when it is most important.

3.3.1.2 Pilot deployment in 5G EVE

The 5G!Drones project will only use the computing and 5G infrastructure provided by 5G EVE Sophia Antipolis site. All the necessary software needed to run trials, i.e., Web-portal, Slice Orchestrator, Monitoring collection, NFVO and VIM, are provided by EURECOM for 5G!Drones. 5G!Drones D1.5 [47] details the different components of 5G EVE Sophia Antipolis to be used by 5G!Drones to execute the trials.



(a) UTM Control and Command

(b) Safety1: Monitoring a Wildfire

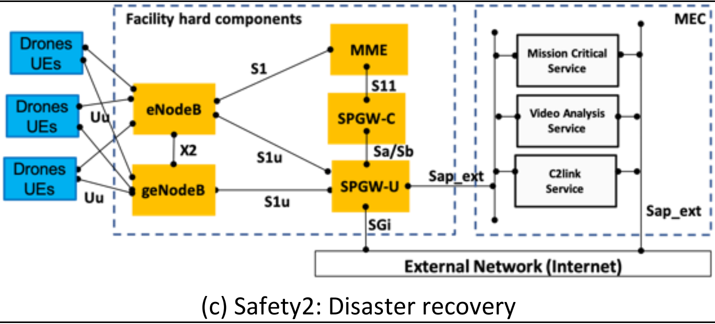


Figure 155: 5G!Drones UTM Control and Command - Safety1 & Safety2 - Functional components and their mapping to 5G EVE Sophia Antipolis facility

Figure 155(a) shows the 1st use-case scenario components and how they are mapped to facility resources in terms of network connectivity and computation requirements. The facility hard components are those already deployed at the 5G EVE facility and enable 5G connectivity via the NSA mode. The UEs are flying drones supporting both 4G and 5G radio access. The service that needs to be instantiated at the MEC is composed only by the C2link service (i.e., one VNF), and requires two network connections to external networks (Sap_ext: Service Access Point external): one to the UE data plane and one to the Internet.

Figure 155(b) illustrates the mapping of the 2nd use-case to facility components. In this scenario, one drone UE and two other "classical" UEs are connected to the 5G RAN. All the UEs have 4G/5G radio. The drone sends video stream to the video analysis service. The service to be instantiated is composed by three VNFs to be deployed at the MEC: one for the MCS service, one for video analysis and one for the C2link service to control the drones. All the three VNFs have two external connections, one for to the UE data plane and one to Internet. The MCS platform uses the first connection to share multimedia and data streams between all the UEs, and the second one to communicate with command centre, in charge of tactical operation (defining subscribers, rights, communications, …) and to load maps tiles.

Figure 155(c) shows the mapping of the 3rd use-case to facility components. In this scenario two drones will be used, one is connected to the 5G network and on-boards a WiFi AP to offload WiFi traffic coming from the second drone, through the 5G connectivity. The second drone uses the WiFi connection to stream a video to the streaming service. The UAV service will be instantiated at the MEC with two VNFs, one containing the C2link service to control the drones, and another VNF hosting a streaming service that gathers video stream sent by the second drone. In term of connectivity, both VNFs need two connections, one to the Internet and one to the UEs (i.e., drones).

3.3.1.3 5G EVE platform added value

The main added values coming from the 5G EVE facility are those that have been implemented in the 5G EVE Eurécom's facility:

- HW and SW infrastructure (RAN and Core parts);
- Openshift cluster;
- OAI open source components.

3.4 5G-Solutions

5G Solutions for European Citizens (namely, *5G-Solutions*) [49] is a H2020 ICT19 project supporting EC 5G policy by implementing the last phase of the 5G-PPP roadmap. The project aims at experimenting and validating 5G capabilities as key enablers to forward-looking services in prominent industry verticals, thus bringing the 5G vision closer to realisation. Advanced field trials of innovative use cases are expected to involve end users across five significant industry vertical domains, namely "Factories of the Future", "Smart Energy", "Smart Cities", "Smart Ports", and "Media & Entertainment". An additional scenario of interest in the project will be that of concurrent execution of use cases from different vertical domains, so to take advantage from the realistic use cases by observing vertical and network KPIs driving a more complete evaluation of potential added value of 5G technologies.

Among all vertical domains, organized in the so called "Living Lab", **Smart Energy** is the vertical industry which is expected to run three use-cases in the **5G EVE platform**, involving the **Italian Site** infrastructure located in Turin. The three use cases are developed in the context of Demand Side Management and are of interests of Energy as well as Energy Service Operators as Verticals.

Main definitions and detailed analysis of the 5G-SOLUTIONS use cases, including analysis and justification of the need for 5G from business and technical point of view, are reported in deliverable D1.1A *Definition and analysis of use cases/scenarios and corresponding KPIs based on LLs* [49], while preliminary design activities (focusing on architectural aspects) are reported in the initial version of deliverable D2.4A *LLs planning, setup, operational management handbook* [50]. Three cycles are expected for running different levels of integration of each use case. Design, implementation, integration, deployment, and test activities for the three cycles of trials running on the 5G EVE platform will be reported in deliverable D5.2 A/B/C and D5.3 A/B/C. The participation to the so called Multi Living Lab, requiring the concurrent executions of trials from different use cases, will be reported in deliverables D7.1 and D7.2.

3.4.1 Use Case 1: Industrial Demand Side Management

3.4.1.1 Pilot context

Demand Side Management (DSM) at the level of business/not residential users (large, medium, or small enterprises, offices, among others). The focus is on the optimal scheduling of energy loads during normal plant operation, as well as the computation and actuation of flexibilities offered on the Dispatching Market and the control actions needed to keep the peak power consumption limited. The use case is developed by IREN as Vertical and Use Case Owner, and A2T as VNF Producer and Use Case Developer.

3.4.1.2 Pilot deployment in 5G EVE

The Use Case will be completely deployed in the 5G EVE platform to manage the use case execution in the 5G EVE Italian Site covering the testbed in the city of Turin. The Cloud Edge environment located in the Politecnico di Torino premise will host the Vertical Service needed to support the execution of three test cases identified for this Use Case 1. The requirements from the orchestrator's point of view concern start and stop services to control and to monitor the execution of all test cases. With respect to the requirements from the KPI Visualization System (developed in 5G Solutions), this Use Case will rely on 5G network KPIs (with particular attention to network latency and reliability) and vertical KPIs (with particular attention to the response time of the overall load shedding control cycle). While the vertical KPIs will be fed by the controllers developed by A2T (as Use Case Developer), the 5G network KPIs will be collected by the 5G Visualization Tools interacting with the 5G EVE platform facility through proper REST APIs.

3.4.1.3 5G EVE platform added value

The Use Case aims at demonstrating that the current adopted architecture can evolve by moving the energy load controller on the Cloud Edge environment, while guaranteeing the suitable disconnection time (that is the overall reactiveness of the system). 5G EVE platform offers an ideal dedicated 5G radio access network (flexible to support the vertical's legacy monitoring system supporting the business logic of the controller) and a reliable Cloud Edge environment to move the control logic as closer to the field as possible, so to limit the disconnection time and allow for a closed-loop control scheme very efficient as well as effective.

3.4.2 Use Case 2: Electric Vehicle Smart Charging

3.4.2.1 Pilot context

New paradigm in electro-mobility business implies a strong interaction between the Electric Vehicle (EV) and energy ecosystem, creating new challenges and offering significant opportunities in the way the next generation electrical networks will be operated and managed. In this regard, the 5G infrastructure can be used for reliable real time scheduling of charging sessions as well as providing fast reschedule in case of unexpected overload, in case a contractual threshold is overcome due to an excessive number of simultaneous charging sessions, or in case the electric power generated from renewables suddenly falls short of the predictions. The use case deals with the problem of computing real-time the charging power set points for active EV charging sessions taking place in one load area. Currently, charging platforms performing such a task leverage centralized computation schemes, working at the level of charging infrastructure back-end. In this use case the decentralized scheme will be investigated and tested by the 5G infrastructure. In this way, the computational effort will be distributed among session agents communicating each other through 5G communications. The reaction to overloads and dispatching orders will be tested too, as well as the added value brought by 5G technology in terms of reliability will be assessed. The use case is developed by IREN and Enel X as Verticals, by IREN as Use Case Owner, and A2T as VNF Producer and Use Case Developer.

3.4.2.2 Pilot deployment in 5G EVE

The use case will rely on the 5G EVE platform to configure and to manage the use case execution in the 5G EVE Italian Site covering the Test Site in Turin (a coverage extension has been required to support this use case). The requirements from the testbed concern 5G connectivity that will be guaranteed by the 5G EVE platform, as well as the requirements for Cloud Edge server hosting the Vertical Services focused on control and optimization aspects in charging related operations.

The requirements from the orchestrator concern the availability of start and stop services to control and to monitor the execution of the test cases according to the UC owner's needs at the execution time. With respect to the requirements from the visualization system, this use case will rely on 5G network KPIs (with particular attention to network latency and reliability) and several vertical KPIs (dealing with load deviations and aggregated charging power curve evolutions, end-user performances and energy monitoring and control Infrastructure). A2T, as Use Case Developer, will develop the needed software components hosted in the "Remote Controller" that will measure the vertical KPIs and will feed the 5G-Solutions KPI Visualization System (KPI-VS). The data will be pushed from the application to KPI-VS via REST-API. The KPI-VS will retrieve the 5G network KPIs interacting with the facility hosting the experiment by means of suitable APIs.

3.4.2.3 5G EVE platform added value

5G technologies are expected to guarantee high reliability, very low communication latency and, consequently, enable a dedicated low sampling time control framework, which results too expensive if provided by fibre and insufficient if provided with 4G. In this respect, 5G EVE offers a great opportunity to evaluate a highly innovative service for Smart Charging in a flexible 5G radio access network and a reliable Cloud Edge environment completely dedicated to distributing the control logic and to move the added value computation resources as closer to the field as possible, so to improve the charging control in terms of the trade-off between the number of served vehicles and the sampling time with respect to existing solutions.

3.4.3 Use Case 3: Electricity Network Frequency Stability

3.4.3.1 Pilot context

The increase of electricity from intermittent renewable energy sources, such as wind and solar energy, calls for faster responsive adjustments between electricity production and demand. Such imbalances between supply and demand result in irregularities in the grid frequency that may become catastrophic if not suitably addressed. The use case deals with the integration of power network frequency regulation functions in the operation of EV charging infrastructure. This integration implies the installation of 5G modems and the implementation of efficient smart charging modules (embedded in the charging stations) working by real time network frequency measurements. The use case is developed by Enel X as Vertical and Use Case Owner, and A2T as VNF Producer and Use Case Developer.

3.4.3.2 Pilot deployment in 5G EVE

The use case will rely on the 5G EVE platform to manage different trial executions in the 5G EVE Italian Site covering the Turin Test Site, which was achieved by the means of the installation of proper 5G resources in the target area (namely, a parking owned by Enel X). Hard requirements from the testbed include a dedicated Cloud Edge environment hosting use case-oriented services implementing efficient control and management strategies. The requirements from the orchestrator concern the availability of start and stop services to control and to monitor the execution of different trials in the testbed according to the UC owner’s needs at the execution time. With respect to the requirements from the KPI visualization system, the use case will rely on network KPIs (with particular attention to network reliability) and vertical KPIs (with particular attention to the deviations between the actual charging power and the target as well as between the desired and the final state of charge). A use case-oriented service, namely the “Remote Controller”, will measure the vertical KPIs by feeding the KPI to the 5G-Solutions Visualization System (KPI-VS). The Remote Controller will be implemented by the Use Case Developer (A2T) according to system requirements identified by the Use Case Owner (Enel X). 5G network KPIs will be retrieved by the KPI-VS interacting with the facility that will host the experiment, by means of proper APIs.

3.4.3.3 5G EVE platform added value

In this use case, high reliability, very low communication latency and precise as well as secure frequency deviation measurements broadcast to all the involved entities, are considered fundamental and 5G technology is expected to guarantee the correct execution of the data communication flow in a very challenging scenario. In particular, a critical aspect is the assessment of communication reliability impacting on the actual ability of charging infrastructure operator to take commitments on electricity markets of interest.

3.5 5Growth

The vision of the 5Growth project [51] is to empower verticals industries such as Industry 4.0, Transportation, and Energy with an AI-driven automated and sharable 5G end-to-end solution that will allow these industries to achieve simultaneously their respective key performance targets. Towards this vision, 5Growth is automating the process for supporting diverse industry verticals through (i) a vertical portal in charge of interfacing verticals with the 5G End-to-End platforms, receiving their service requests and building the respective network slices on top, (ii) closed-loop automation and SLA control for vertical services lifecycle management and (iii) AI-driven end-to-end network solutions to jointly optimize Access, Transport, Core and Cloud, Edge and Fog resources, across multiple technologies and domains.

The main objective of 5Growth is the technical and business validation of 5G technologies from the verticals’ points of view, following a field-trial-based approach on vertical sites (TRL 6-7). Multiple use cases of vertical industries (Comau, Efacec_S, Efacec_E, Innovalia) are field-trialed on four vertical-owned sites in close collaboration with the vendors (Ericsson, Interdigital, NEC, Nokia) and the operators (Altice, Telecom Italia, Telefonica) in the project [52].

5Growth is leveraging on the results of 5G-PPP Phase 2 projects where slicing, virtualization and multi-domain solutions for the creation and provisioning of vertical services are being developed and validated, e.g., 5G-TRANSFORMER and 5G-MONARCH. Two ICT-17-2018 5G End-to-End platforms, 5G EVE and 5G-VINNI, have been selected for the Trials to demonstrate the 5Growth specific vertical use cases.

3.5.1 Use Case 1: Connected Worker Remote Operation of Quality Equipment

3.5.1.1 Pilot context

Innovalia Metrology is an alliance of high-tech SMEs aiming to provide a holistic solution for dimensional quality control. Innovalia commercializes the Coordinate Measuring Machine (CMM), a device that measures point positions to calculate geometries of physical objects by sensing discrete points on the surface of the object with a probe. Thus, quality measurement processes are highly automated. But experts still need to visit factories to configure machines and design processes, meaning slower, less flexible manufacturing.

With this pilot, Innovalia expects to improve its M3 Zero Defect Manufacturing (ZDM) service portfolio by the introduction of a remote CMM configuration service. This way, one of the most expensive maintenance tasks for the CMM will be significantly reduced thanks to the use of the 5G technologies, which will effectively enable remote control operations, thus avoiding the cost of the in-site human interventions.

3.5.1.2 Pilot deployment in 5G EVE

A metrology expert, located at Innovalia headquarters, interacts with the M3 software, and is able to control a CMM, which is installed at the manufacturing site, to perform a calibration procedure. So, from the headquarters, commands are sent to move the machine on the other end, and also the results of the optical scan are sent back to the headquarters for analysis via M3 software by the metrology expert.

The metrology expert also needs to be able to see how the machine is moving, so for that purpose, a camera is installed at the manufacturing site that sends a video streaming to the Innovalia headquarters and is displayed to provide input to the metrology expert. Figure 156 depicts the pilot main components.

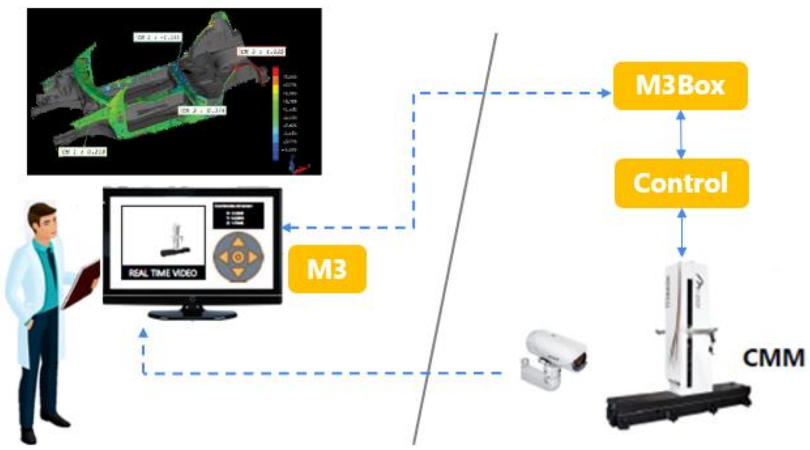


Figure 156: 5Growth UC1 - Connected Worker Remote Operation of Quality Equipment pilot architecture

Regarding the 5G infrastructure, this pilot is using the common 5G network available at 5Tonic lab. The end user devices get connectivity among them and to the applications deployed on the cloud edge over the 5G network.

For the deployment of the applications on the cloud edge, the pilot leverages on the integrated 5Growth and 5G EVE platforms. On the 5G EVE platform, all the required blueprints and descriptors for the experiment are onboarded. On the 5Growth platform, the overall VSB and VSD are onboarded on the Vertical Slicer (5Gr-VS), and the NSD and VNF packages are onboarded on the Service Orchestrator (5Gr-SO). To instantiate the service, the vertical interacts with the 5Gr-VS to request the instantiation. The 5Gr-VS forwards the request towards the 5G EVE Portal. The request reaches then the 5G EVE Interworking Layer (IWL). As the 5Growth platform is defined as a site in 5G EVE platform, the 5Gr-

SO gets the command to instantiate the Network Service and the VNF, which are finally instantiated on the 5Growth servers.

Additionally, the pilot benefits from the monitoring functionalities of 5G EVE. The results of the experiment are collected and exposed by the 5G EVE monitoring platform. Figure 157 provides the integration architecture with 5G EVE platform for the Use Case.

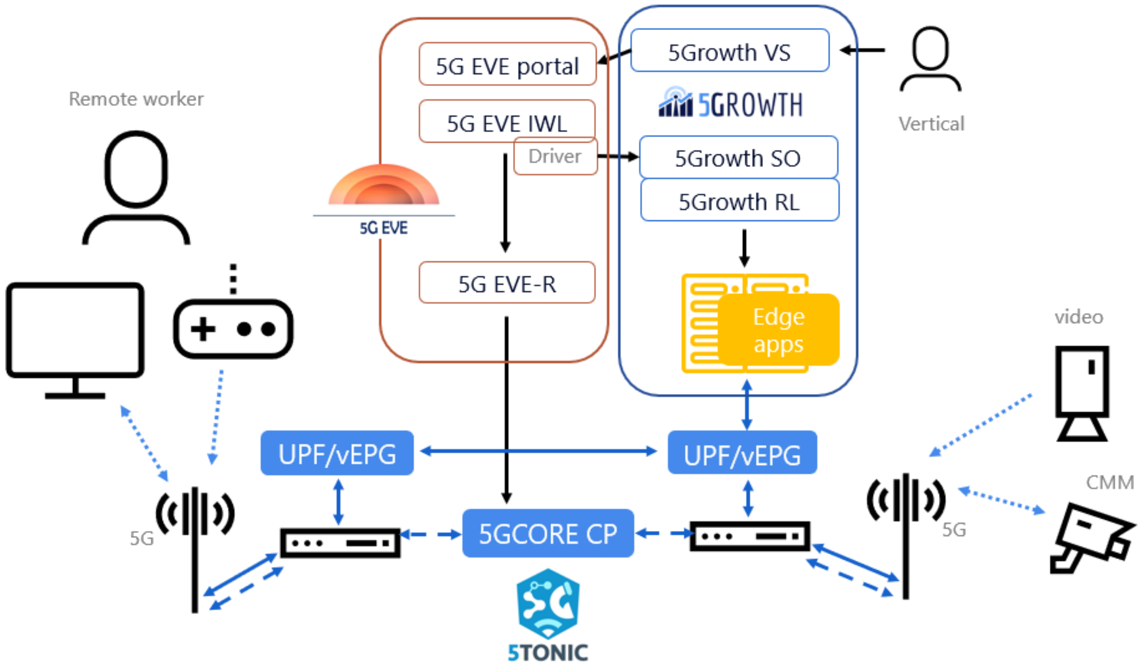


Figure 157: 5Growth UC1 - Integration with the 5G EVE platform

3.5.1.3 5G EVE platform added value

As detailed in the Figure 157, 5G EVE provides an intermediate layer between the 5Gr VS, which is new functionality defined by 5Growth, and it facilitates the onboarding of the NSD and VNF packages and the instantiation of the VNFs at the 5Growth site.

Additionally, the pilot benefits from the monitoring functionalities of 5G EVE. The results of the experiment are collected and exposed by the 5G EVE monitoring platform.

3.5.2 Use Case 3: Digital Tutorial and Remote Support

3.5.2.1 Pilot context

Figure 158 illustrates the logical architecture of the COMAU pilot which is hosted at the COMAU site in Turin, Italy. The use cases deployed in the pilot leverage on a 5G network operating on TIM spectrum and supported by an optical-based transport infrastructure, which connects the baseband (BB) node to the antenna side. This network guarantees stringent industry-grade performance and provides the security level required for critical data. The COMAU site is connected to the TIM site where the 5Growth platform is hosted, including the orchestrator, the HSS, and the COMAU IoT application In.Grid. Specific 5G terminals and 5G pocket routers are used to connect the various components of the pilot (robots, controllers, AR glasses, sensors, etc) to the cellular network.

In this scenario, machinery in a factory is affected by a fault, but the local staff requires advanced support to rapidly fix the problem. In-field technician sent to the remote factory can use a tablet or AR devices connected via 5G. On the other side of the connection, geographically far from the factory where the fault occurred, there is an expert with a remote maintenance application. Such expert has the “full picture” of the fault and can provide remote support to the in-field technician.

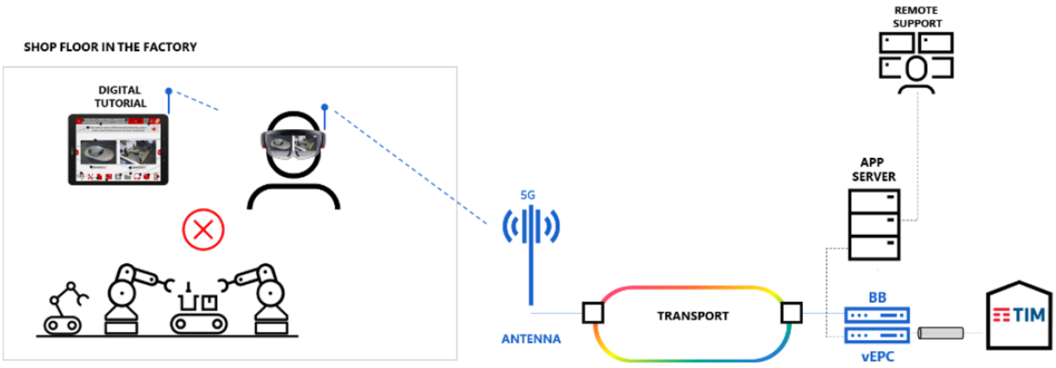


Figure 158: 5Growth UC3 - Connected Worker Remote Operation of Quality Equipment pilot architecture

The use case aims at providing technicians and maintenance staff with remote support and digital tutorials by means of high-definition videos and live connections to remote technical offices. The main objective is to reduce the Mean Time To Repair (MTTR) using real-time streaming with a skilled technician in a remote location to support maintenance and repair operations in the production line of the factory. Another advantage achieved with this use case is the possibility to access to step-by-step digital tutorials and instructions for training purposes.

3.5.2.2 Pilot deployment in 5G EVE

The COMAU pilot with this Use Case will benefit of the interaction with the 5G EVE platform, which is related to the COMAU pilot according to the scheme in Figure 159. Specifically, the 5G EVE lab hosted in the TIM site located in via Borgaro is connected to the TIM site located in via Reiss Romoli where the 5Growth platform is hosted. The COMAU application related with COMAU-UC3 is installed on a server located in the Politecnico di Torino which is similarly part of the mentioned 5G EVE network. Through this setup, it is possible to connect (as indicated by a purple line in figure) the robotic area in COMAU with the application running in Politecnico di Torino, thanks to the interworking of 5G EVE with 5Growth.

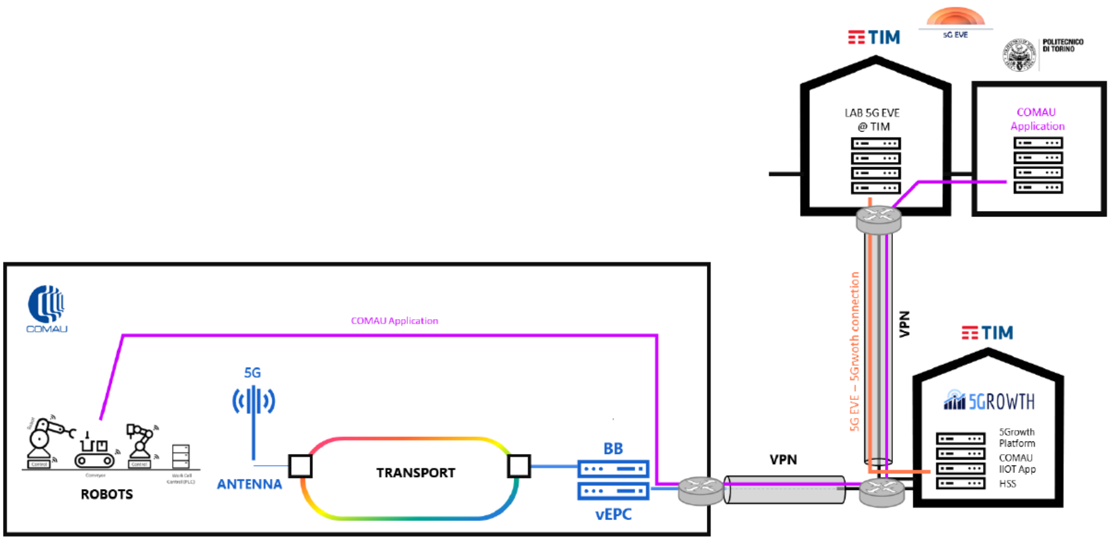


Figure 159: 5Growth UC3 - Integration with the 5G EVE platform

Figure 160 is reporting interworking between 5G EVE and 5Growth platform. For the deployment of the applications on the cloud edge, the pilot leverages on the integrated 5Growth and 5G EVE platforms. On the 5G EVE platform, all the required blueprints and descriptors for the experiment are onboarded. On the 5Growth platform, the overall VSB and VSD are onboarded on the Vertical Slicer (5Gr-VS), and the NSD and VNF packages are onboarded on the Service Orchestrator (5Gr-SO). To instantiate the service, the vertical interacts with the 5Gr-VS to request the instantiation. The 5Gr-VS forwards the request towards the 5G EVE Portal. The request reaches then the 5G EVE Interworking Layer (IWL). As the 5Growth platform is defined as a site in 5G EVE platform, the 5Gr-SO gets the command to instantiate the Network Service and the VNF, which are finally instantiated on the 5Growth servers.

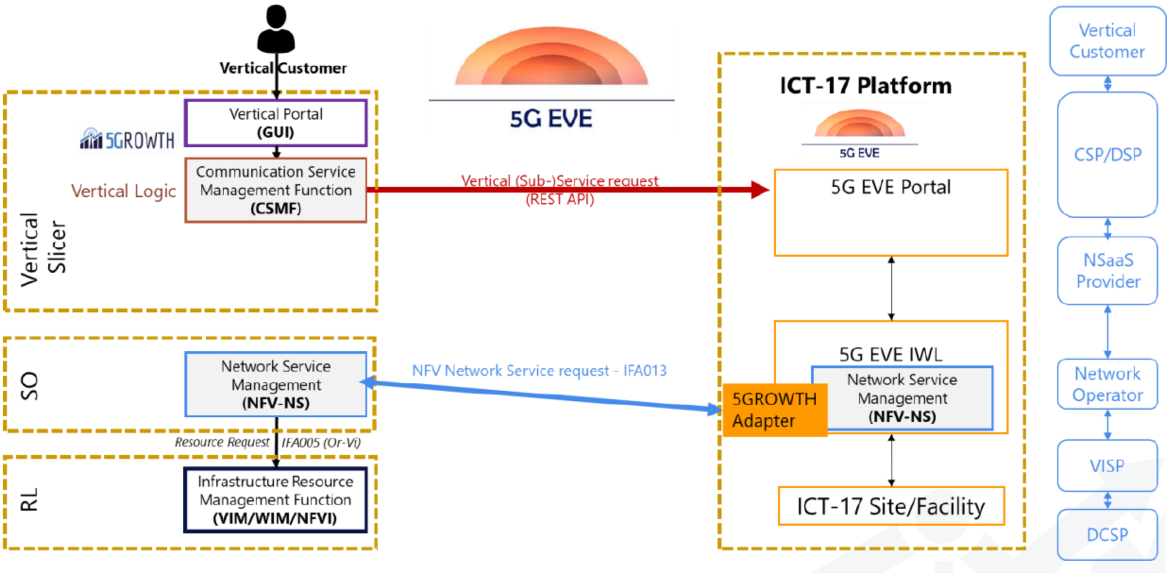


Figure 160: 5Growth UC3 - Interworking with the 5G EVE platform

3.5.2.3 5G EVE platform added value

As detailed in Figure 160, 5G EVE provides an intermediate layer between the 5Growth Vertical Slicer and it facilitates the onboarding of the Network Service Descriptor (NSD) and Virtual Network Function (VNF) packages and the instantiation of the VNFs at the 5Growth site.

The 5G EVE platform exploits the provisioning and monitoring services deployed across multiple sites, enabling location of apps and functions in the cloud, and providing easier remote connectivity on the edge. Fast and timed use of resources enable higher quality and lower cost operations. In addition, the pilot benefits from the monitoring functionalities of both platforms and provides useful data about testing the interworking layer and evaluating end to end performances of virtual maintenance integrated with video streaming and the Augmented Reality in a distributed multiple site environment.

3.6 5G-HEART

5G-HEART [53] focuses on the vital vertical use-cases of healthcare, transport, and aquaculture. In the health area, 5G-HEART will validate pill-cams for automatic detection in screening of colon cancer and vital-sign patches with advanced geo-localization as well as 5G AR/VR paramedic services. In the transport area, 5G-HEART will validate autonomous/assisted/remote driving and vehicle data services. Regarding food, focus will be on 5G-based transformation of aquaculture sector (worldwide importance for Norway, Greece, and Ireland).

Marine aquaculture in Europe has been evolved into a high-tech industry, with many modern aquaculture systems incorporating the collection of heterogeneous data from multiple sources into their daily routines. These procedures are primarily manual and labour intensive, relying on the efforts of the farm staff and regular site visits for monitoring and data collection. The workload on the operator is exacerbated when multiple parameters need to be monitored, such as water quality, fish behaviour and health, feeding, cage structural integrity, etc.

3.6.1 Use Case Aquaculture

3.6.1.1 Pilot context

The 5G-HEART project will provide a much clearer understanding of how the components of the aquaculture industry can interact, and use this knowledge to advance the production by means of targeted intervention to these components (e.g., autonomous feeding, fish health timely examination), in order to obtain total control over farm management. For that purpose, two pilots are deployed on two different environments showcasing the applicability of the solution developed in different locations.

3.6.1.2 Pilot deployment in 5G EVE

The Greek pilot will be deployed in Skironis site in Megara (Figure 161), Attica near Athens where the Greek node of 5G EVE is located and will be exploited to make the 5G network available to the site. 5G-HEART Aquaculture utilizes only the Ericsson's 5G EVE Greek site 5G platform (see [54]).

The 5G-HEART Aquaculture trials is split in five different scenarios which are:

- Sensory Data Monitoring
- Camera Data Monitoring
- Automation and actuation functionalities
- Edge and Cloud-based computing
- Cage to cage – on site communication

In order to execute these scenarios, two pilots are deployed on two different environments showcasing the applicability of the solution developed in different locations.

Figure 161: 5G-HEART UC Aquaculture - Greek pilot site at Megara

Figure 162: 5G Heart UC Aquaculture - Integrated with 5G EVE Greek site.

In the case of the Greek site, the network solution is based in an end-to-end architecture, since the data should be collected and transmitted reliably. The Non-standalone version of deployment is adopted, using both LTE and 5G wireless systems by Ericsson. The Radio Access Network collects the data from the equipment on site, through the baseband node. More specifically, the Skironis Aquaculture site is connected, via the OTE premises at the City of Megara, to the OTE LABs over fiber optics (10 Gbps line), as shown in Figure 162. From there, there is a connection to the Ericsson EPC (5G EVE Greek Site Ericsson' platform) and finally reach the Cloud and the application (WINGS). The installation of the RAN on Skironis site is in progress.

3.6.1.3 5G EVE platform added value

In order to support 5G-HEART Aquaculture UC, the network was designed to meet the UC requirements. These requirements could be summarized as follows:

- The transmission of high data rates (4K+ video resolution transfer) at low latency to enable real-time experience for the user should be supported.
- Video continuity is an important characteristic of the network since it can help avoiding perceived interruptions.
- There will be cases where the video resolution will change from HD video to lower resolution video and vice versa. In these cases, the delay in synchronizing the feeds from the slices used for the different resolution videos should be limited.
- The network should be able to support several device requirements and limitations e.g.., encoding options.

As part of the of the E2E network that will be used in the Aquaculture UC, the 5G EVE testbed will be an important part of the overall implementation, as it will ensure that the UC requirements are met.

4 Conclusion and Sustainability

The 5G EVE end to end site facility reached, until the end of the project in M36 (June 2021), a total amount of 45 validation campaigns for the internal UCs and 21 validation campaigns for UCs issued from the ICT 19 projects, resulting in **a total of 66 validation campaigns until the end of the project**. It is expected that all the ICT 19 hosted UCs will at least drive one extra validation campaign each, which will allow to achieve the objective defined in the DoW targeting 80 validation campaigns within the 5G EVE end to end site facility.

Throughout the above mentioned validation campaigns, 5G EVE internal Pilot Use Cases have reached a high degree of maturity and they have completed the 5G EVE experimentation workflow allowing to collect the metrics, calculate the KPIs and evaluate the results as reported in this document. This information contributes to the dissemination activities related to the Pilot Use Cases execution and results.

The interaction between 5G EVE and the ICT 19 projects Pilot Use Cases that have chosen 5G EVE site facilities has been illustrated. At the time of writing the execution of these pilots is very advanced, and ongoing work continues as planned, at each of the projects. The detailed outcomes and execution results are, and will be further described, in the deliverables of the corresponding projects.

From the 5G EVE perspective, the maintenance of the local infrastructure of the site facilities will be guaranteed. In particular, an internal agreement among the partners involved in the implementation of the four 5G EVE sites ensures that at least until the end of 2021 the facilities that are available in June will be maintained unchanged or will be enhanced and extended in case the interactions with the external users will require so with own resources from the external users themselves.

The following paragraphs provide the details of the activities that are already planned and committed to be supported by each of the site facilities.

The Spanish site, 5TONIC, already existed before the start of 5G EVE and will continue with its activities when the project finishes. However, for 5TONIC is essential to extract value from the deployment of the 5G EVE platform to enhance its objectives as co-creation platform for 5G and beyond 5G use cases.

Among the projects that will use 5TONIC 5G EVE **Spanish site**, are the following:

- 5Growth

  The vision of the 5Growth project is to empower verticals industries such as Industry 4.0, Transportation, and Energy with an AI-driven Automated and Sharable 5G End-to-End Solution that will allow these industries to achieve simultaneously their respective key performance targets. The main objective of 5Growth is the technical and business validation of 5G technologies from the verticals' points of view, following a field-trial-based approach on vertical sites (TRL 6-7). 5G EVE has been selected for the trials to demonstrate the 5Growth specific vertical use cases of Industry 4.0, in 5G EVE Spanish and Italian site facilities, extending to vertical customer premises of Innovalia's Automotive Innovation Center (Bilbao) and COMAU factory (Turin).

  5G EVE Spanish facility (5TONIC) supports 5Growth Innovalia I4.0 pilot. With this pilot, Innovalia expects to improve its M3 Zero Defect Manufacturing (ZDM) service portfolio by the introduction of a remote CMM (Coordinate Measuring Machine) configuration service. In this way, one of the most expensive maintenance tasks for the CMM will be significantly reduced thanks to the use of the 5G technologies, which will effectively enable remote control operations, thus avoiding the cost of the in-site human interventions.

  The participation of 5TONIC is supported by the presence of Ericsson, Telefónica, and UC3M in the 5growth consortium, along with 5TONIC collaborators Innovalia, ASTI Mobile Robotics and Telcaria Ideas.

- AI@ege project [55]

The project will develop a connect-compute fabric – specifically leveraging the serverless paradigm – for creating and managing resilient, elastic, and secure end-to-end slices. The AI@EDGE platform will be validated using four well-chosen use cases with specific requirements that cannot be satisfied by current 5G networks, and one of them, Edge AI assisted monitoring of linear infrastructures using drones in BVLOS operation, will be implemented in 5TONIC.

The participation of 5TONIC is supported by the presence of Ericsson in the Consortium, as well as Aerotools, that will become a 5TONIC collaborator.

- 5G DIVE [56]

  The project, a cooperation between EU and Taiwan, targets end-to-end 5G trials aimed at proving the technical merits and business value proposition of 5G technologies in two vertical pilots, namely (i) Industry 4.0 and (ii) Autonomous Drone Scout. 5TONIC will host the main demo of the project in Europe.

  The project is supported by UC3M, Ericsson, Telcaria and Telefónica.

- 5G-INDUCE [57]

  The project targets the development of an open, ETSI NFV compatible, 5G orchestration platform for the deployment of advanced 5G NetApps. The platform's features provide the capability to the NetApp developers to define and modify the application requirements, while the underlay intelligent OSS can expose the network capabilities to the end users on the application level without revealing any infrastructure related information.

  The project is supported by Ericsson, as well as 5TONIC collaborators Fivecomm, ASTI and YBVR.

- HEXA-X [58]

  Hexa-X is the flagship project aiming to define the European vision of the 6G mobile system that will be deployed by 2030. The project considers 23 use cases, clustered in to 5 families that are enabled by 7 enabling services harnessing new capabilities.

  The involvement of 5TONIC in the project is supported by the participation of UC3M, Ericsson and Telefónica.

Among the ICT-19 projects that will use the 5G EVE **French site**, we can notice:

- 5G-TOURS [38]

For operating the different use-cases that will be deployed in France, especially the connected ambulance and the connected surgery room, the 5G EVE facility has been extended from b<>com to Rennes hospital by secured VPN, b<>com being still connected to the ONAP Orange Châtillon cluster and then to the rest (IWL and portal) of the E2E 5G EVE facility. In others terms the infrastructure network connectivity will be reused. The network core infrastructure will continue to rely on the WEF component, already implemented in 5G EVE with its different releases. For the RAN part, FR2 RAN Nokia's equipment will be integrated for supporting the required services KPIs.

The project is supported by: Orange (France and Poland), b<>com, Nokia-FR

- 5G-VICTORI [44]

The Romania facility in 5G Victori will be directly connected to the French 5G EVE cluster in order to be able to use the ONAP orchestration and also the Opensource VNF/CNF already developed. The Romanian facility will be based on the Eurécom's infrastructure, using Openshift and OAI.

The project is supported by: Orange (France and Romania) and Eurécom.

- 5G!DRONES [48]

The project will mainly reuse the Eurécom’s network infrastructure (HW and SW) based on Openshift and OAI.

The project is supported by: Orange (France) and Eurécom.

There is also one French project called “Engage 5G and Beyond” that will start just after the end of the 5G EVE project (1st of June 2021) that aims at perpetuating the work carried out in 5G EVE. b<>com, Nokia FR, Eurécom, Orange FR are still in the project. The platform will be updated with new features during this project and new verticals will be operated, issued from e-health use-case especially.

Regarding the **Greek site**, two ICT19 projects are hosted with 7 UCs: 5G-TOURS and 5G-HEART. These projects will last over 5G EVE project. So, there is a need to maintain all the 5G EVE infrastructure for more than one year. In Greek Site there are two 5G EPC platforms one from NOKIA and one from Ericsson. Also, there is one OSM and one Kafka by WINGS. So:

- for the needs of 5G-TOURS the Greek Site 5G EVE infrastructure will remain up and running for one year more, till the end of project, since OTE as Site manager, NOKIA-GR as 5G EPC provider and WINGS with OSM and Kafka, participate to the project.
- Also, for the needs of 5G-HEART the Greek Site 5G EVE infrastructure will remain up and running for more than one year, till the end of the project, since OTE as Site manager, ERICSSON as 5G EPC provider, and WINGS supporting OSM and Kafka, they all participate in the project.

In the **Italian site**, three ICT19 projects will be supported: 5G-TOURS, 5Growth, and 5G-SOLUTIONS. These projects will continue after 5G EVE project conclusion for some months.

About the common resources with all the sites, TIM ensures that the Interworking Layer will be maintained and preserved until at least end of 2021, and the SW platform will be unchanged as well.

As stated, in case of enhancements needed in the future months, they will be guaranteed by TIM or by the other partners in the consortia for the needs of the projects that involves them. Just as an example, these enhancements could refer to creating urban connectivity or VPNs with local partners, extending RAN coverage, hosting dedicated servers.

Internal use case UC1.1 will also continue running to collect extra results. There are also ongoing discussions for possible extensions of the Use Cases on Smart City and Smart Transport with the Municipality of Turin, partner of 5G EVE, for a possible wider adoption in the city (meetings with the Municipality occurred in March and April 2021 to promote this opportunity).

The Trial core network will also enable some Edge Cloud innovation activities leveraging on the flexible EVE infrastructure supporting central and edge core 4G and 5G network services with possible future enhancements toward 5G SA solutions.

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Annex A: 5G Reference Architecture for observation and measurement points

The location of the observation and measurement points is based in the following 5G-PPP TMV reference architecture model defined in [59] and depicted in Figure 163.

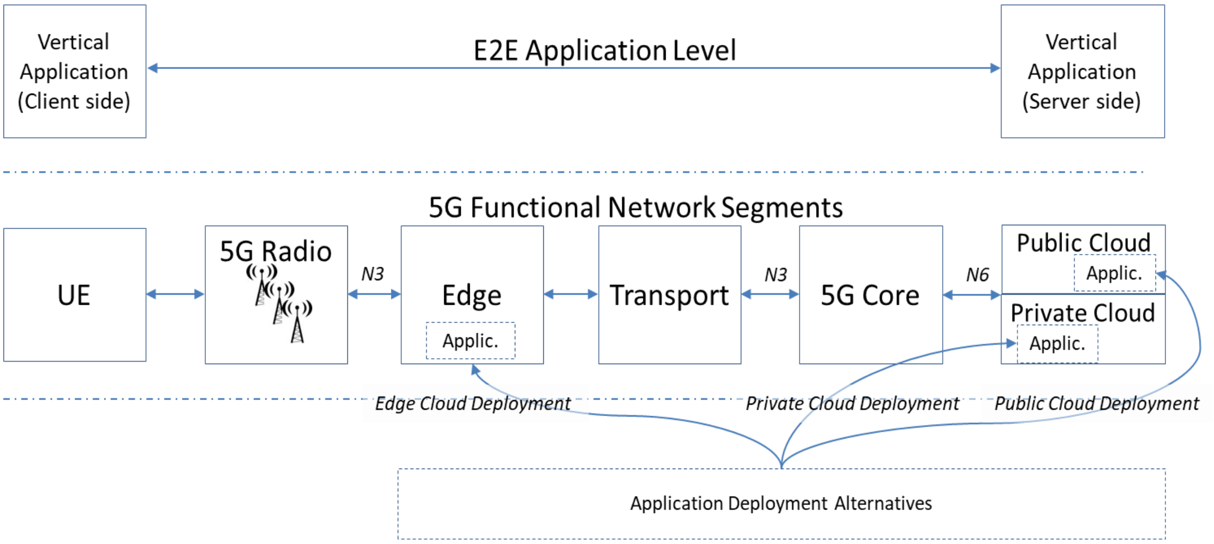

Figure 163: Functional Network Segments of a 5G system