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

D3.6 Final Use case specification for Energy and Factories of the Future Services

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Executive Summary

This deliverable is the final document related to the Energy and Factories of the Future services and falls within the framework of Task 3.3 “Energy and Factories of the Future”. The different requirements of each 5G-VICTORI Use Case (UC) [1] were investigated, and the Key Performance Indicators (KPIs) associated to each provided service were initially described in deliverable D3.5 [2].

The considered services comprise characteristics from all the three different 5G service classes (eMBB, uRLLC, mMTC), due to the nature of their relevant vertical applications. These services include:

i. real-time monitoring of critical industrial equipment at power utilities and electric train stations, related to **UC #2** and **UC #4.1**,

ii. CCTV facility monitoring, related to **UC #2**, and

iii. collection of massive data from sensing devices spread in a LV power network of a city, related to **UC #4.2**.

To evaluate the performance of these services, necessary test cases and KPI assessment methodologies in their preliminary form were also described in deliverable D3.5. These necessary guidelines followed by the 5G-VICTORI Consortium in the preparation of the test cases, along with KPI evaluation procedures, were established in deliverable D4.1 [3].

This deliverable presents the services and testing procedures in their final form, compliant with the guidelines defined in deliverable D4.1, in order to assess the vertical services stemming from the UCs descriptions reported in deliverable D2.1 prior to the 5G-VICTORI trials. The final test cases and services comply with the 5G network deployment option of each 5G-VICTORI facility as defined in deliverable D2.4 [4].

Specifically, deliverable D3.6 describes the test cases that can be rolled out by the 5G-VICTORI platforms, based on first KPI validation and evaluation results that have been collected through both lab and field testing. The deliverable provides lab results for the vertical applications and the network deployment through specific 5G performance indicators and a testing procedure agreed among the different tasks of WP3.

This deliverable provides input to the upcoming project activities within WP4 “Trials of Coexisting Vertical Services, validation and KPI evaluation”. The outcomes of this task will feed Task 4.2 and Task 4.5, where the extension of the related testbed infrastructures will take place and the enabling network services for the inter- and intra-field trials will be integrated and validated. In addition, the various and diverse vertical applications described in [6] and summarized in the Appendix, will be also deployed and evaluated. In this sense, final results and conclusions stemming from the 5G-VICTORI trials will be addressed by WP4.

Acronyms

General

Acronym	Description
3GPP	Third Generation Partnership Project
5G	Fifth Generation cellular system (3GPP related)
5G CN	5G Core Network
5GC	5G Core
5G-SA	5G Stand Alone
AMF	Access and Mobility Management Function
AUSF	Authentication Server Function
AW2S	Advanced Wireless Solutions and Services
BBU	Base Band Unit
BSCW	The document server used in the 5G-VICTORI project
CPE	Customer Premises Equipment
CPU	Central Processing Unit
CU/DU	Centralized Unit/Distributed Unit
DL/UL	Downlink/Uplink
E2E	End to end
eMBB	eMBB Enhanced Mobile Broadband - enhanced MBB
EMS	Energy Management System
gNB	gNodeB
GPU	Graphics processing unit
IoT	Internet of Things
iPerf	Measurement tool, can be downloaded here.
LTE-M	Long Term Evolution Machine Type Communication.
MBB	Mobile BroadBand
MEC	Multi-Access Edge Computing
MIMO	Multiple input, Multiple output
mMTC	Massive Machine Type Communications
mmWave	Milimetre Wave
N6/SGi	3GPP: Interface between the Evolved Packet Core (EPC) and the Public IP network
NR	New Radio (3GPP term)
PDU	Protocol Data Unit
QoS	Quality of Service
RAM	Random Access Memory
RHU	Radio Hub Unit
RMS	Railway Management System
RRH/RRU	Remote Radio Head/Remote Radio Unit
RTT	Round-Trip-Time (=two times the latency in both directions)
SIM	Subscriber Identity Module
SMF	Session Management Function
TOC	Table Of Content

UC	Use-Case
UDM	Unified Data Management
UDR	Unified Data Repository
UE	User Equipment
UPF	User Plane Function
URL	Uniform Resource Locator
URLCC	Ultra-Reliable Low Latency Communications
vEPC	Virtual Evolved Packet Core

5G-VICTORI related

Acronym	Description
5G-VINNI	The Patras ICT-19 Cluster (v)
5G-EVE	Alba Iulia ICT-19 Cluster (e)
5G-PPP	5G infrastructure Public Private Partnership
ADMIE	Independent Power Transmission Operator (IPTO) (5G-VICTORI Partner)
D2.4	Deliverable D2.4 (within **WP2**)
D3.5	Deliverable D3.5 (within T3.3)
EUR	Eurecom (5G-VICTORI Partner)
IASA	Institute of Accelerated Systems and Applications (5G-VICTORI Partner)
ICT-17	The 5G experimental platforms developed under 5G-PPP/EC that were the seed of most of the facilities in 5G-VICTORI
ICT-19	The 5G platform developed for the 5G-VICTORI
IR	Interim Review (done 2020-10-08)
ORO	Orange Romania (5G-VICTORI Partner)
T3.3	Task 3.3 (within WP3)
UoP	University of Patras (5G-VICTORI Partner)
WP2	Work Package 2: Description – Use cases/ Specifications
WP3	Work Package 3: Vertical Services to be demonstrated
WP4	Work Package 4: Trials of Coexisting Vertical Services, validation and KPI evaluation

1 Introduction

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

This document is the second and final release of Task 3.3, and it defines energy metering related services that will be tested and evaluated independently or together with other services on one or more of the 5G VICTORI facilities using the 5G infrastructure as specified in **WP2** and implemented as part of the **WP4** activities.

More specifically, the Energy and Factories of the Future services related UCs that this deliverable concentrates on include:

i. real-time monitoring of critical industrial equipment at power utilities and electric train stations, related to **UC #2** and **UC #4.1**,

ii. CCTV facility monitoring, related to **UC #2**, and

iii. collection of massive data from sensing devices spread in a LV power network of a city, related to **UC #4.2**.

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

1.1 Objectives

The objective of the deliverable is to define detailed final test case specifications for Factories of the Future and Energy related services that can be demonstrated by the 5G-VICTORI platforms (see Figure 1-1 for an overview), address KPIs and provide evaluation results from lab tests.

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

Figure 1-1 below provides an overview of the Factories of the Future and Energy services, which are described in detail in D2.1 [1], and covered in this document as well.

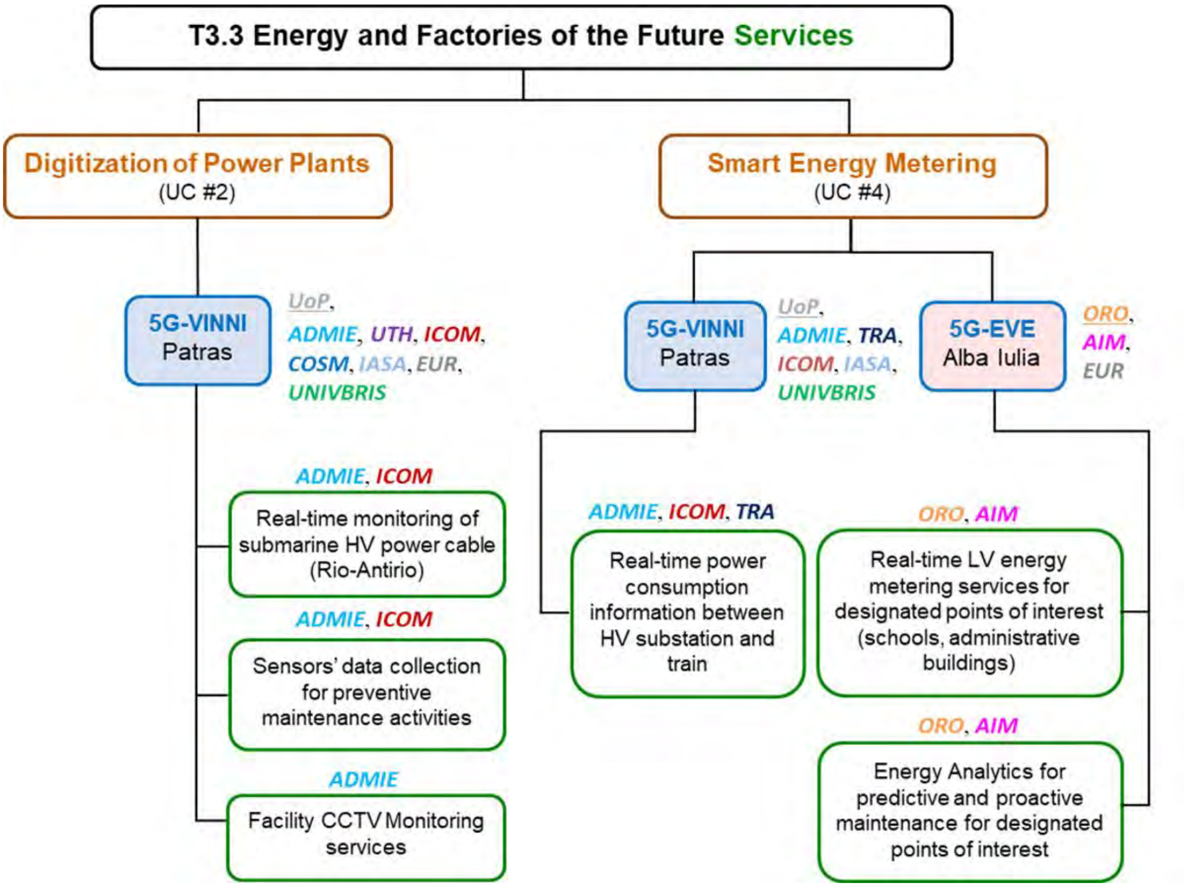


Figure 1-1 Factories of the Future and Energy UCs, Clusters and Services

1.1.1 Digitization of Power Plants at the 5G-VICTORI facility in Patras

The services offered in Patras aim at demonstrating critical infrastructure 1) real-time monitoring, 2) predictive maintenance and 3) CCTV – optical inspection related services, under the umbrella of a unified 5G-enabled solution compliant with Industry 4.0 standards (latency, capacity, reliability).

The solution supports on-premise 5G Private Network deployment and complies with the needs of the different vertical applications by adopting a customizable and expandable architecture, with cloud and edge computing capabilities. The UC investigates the different deployments options offered by the 5G-VICTORI facility in Patras and leverages the Multi-access Edge Computing (MEC) and slicing capabilities offered by the solution, in order to serve vertical applications with diverse needs over a common underlying infrastructure.

The objectives of this UC is to showcase that the specific Industry 4.0 related services can be enhanced by the available 5G-VICTORI infrastructure, which provides mechanisms for ease of customization and maintenance by the vertical operator, thus providing an attractive solution for a smooth transition of legacy facilities to smart factories, especially at remote and secluded areas where existing network infrastructures cannot support the required functionality.

1.1.2 Smart Energy Metering at the 5G-VICTORI facilities in Patras and Alba Iulia

The Smart Energy related services offered in Patras focus on cross-vertical High Voltage (HV) scenarios and specifically for services facilitating real-time power consumption information exchange between HV substations and electric trains. A 5G Private Network with edge-cloud capabilities, operating near the train station and the HV feeder, is used for the real-time collection and local processing of measurements originating from the moving train and the HV substation.

The objective of this UC is to showcase that both Energy and Railway Operators can build on top of this solution to gain full view of their systems in real time. Moreover, through information exchange between the two systems, the interaction of electric trains with the power grid will be also monitored, providing valuable input to power quality improvement algorithms.

The Alba Iulia services, on the other hand, focus on Low Voltage (LV) scenarios. Their objective is to provide smart energy metering services for public buildings and street lighting in the Alba Iulia Smart City environment in Romania.

The UC will evaluate interconnection of energy metering devices/ infrastructure with the data control and management platform through a multi-tenant and resource sharing slice infrastructure providing the required intelligence for smart grid operation.

The UC is deployed in a multi-domain and multi-orchestrator network infrastructure provided by 5G-EVE project through a 5G-VICTORI portal named the 5G-VICTORI Infrastructure Operation System (5G-VIOS). Via this platform verticals can register, deploy, experiment and monitor the UCs [2].

1.2 Structure of the document

This document comprises seven sections. Following the Executive Summary and Introduction sections:

Section 2 describes in detail the testing methodology that is used for the assessment of energy and factory of the future services that will be rolled out by the 5G-VICTORI platform.

Sections 3 describes Factories of the Future services to be demonstrated at the 5G-VICTORI facilities in Patras.

Section 4 provides a detailed description of the Smart Energy services (focusing on a HV scenario) to be demonstrated at the 5G-VICTORI facilities in Patras.

Section 5 describes the LV scenario of the Smart Energy services to be demonstrated at the 5G VICTORI facility in Alba Iulia Municipality.

In each of the sections 3-5, a description of the vertical UC and the 5G network topology (described in detail in **D2.4**) is provided. This is followed by a general description of the test cases including the individual tables containing detailed information for each final test case. This is followed by a detailed description of lab results and, if available, field results including 5G performance measurements. In the provided test cases, each service is assessed independently. The last part of each chapter is dedicated to suggested test combinations, which will evaluate the performance of each service when it coexists with other services under the same infrastructure.

Finally, Section 6 concludes the deliverable.

2 Testing methodology

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

The assessment procedure contains the following tasks:

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

2.1 Testing Methodology Description

The testing methodology is in accordance with the relevant 3GPP standard [7] and includes the following steps.

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

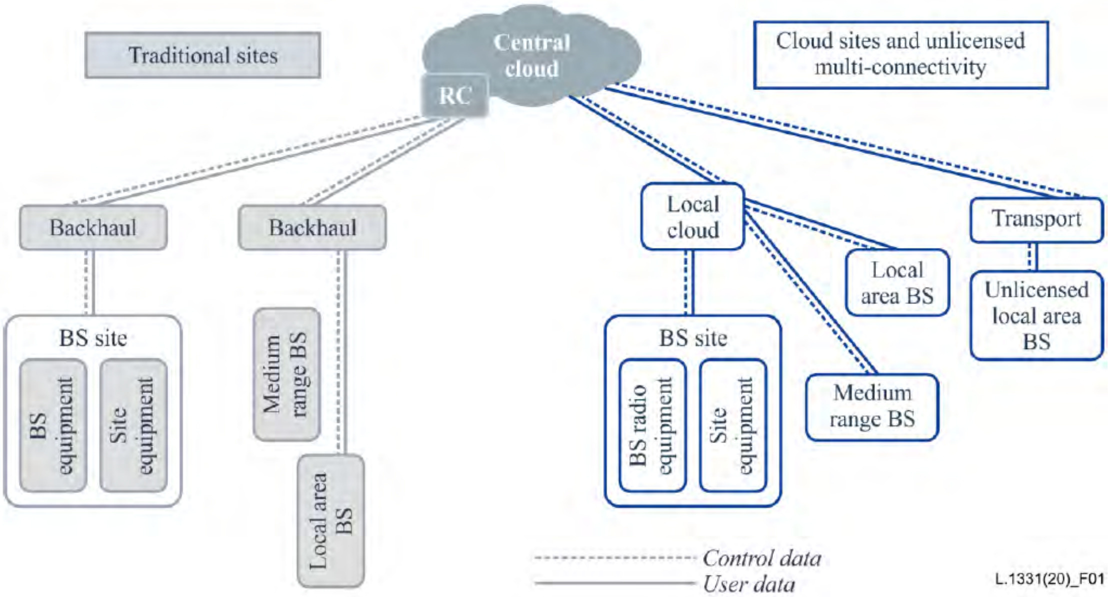


Figure 2-1 Deployment option topology/configuration [8]

2. **Identification of the main building blocks per network.** For each topology deployed the main building blocks will be listed providing a high level description of software (virtualized 5G NFs) and hardware (networking equipment and servers) equipment and their specifications (see Table 2-1).

Table 2-1 Network Topology

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

2.2 Performance measurements

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

Table 2-2 Measurement and traffic details

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

2.2.1 Evaluation of individual building blocks

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

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

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

Table 2-4 Performance measurements for SMF

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

	Max time of PDU session establishment	This measurement provides the max time of PDU session establishment during each granularity period
QoS flow monitoring	Number of QoS flows requested to create	This measurement provides the number of QoS flows requested to create
	Number of QoS flows successfully created	This measurement provides the number of QoS flows successfully created
	Number of QoS flows failed to create	This measurement provides the number of QoS flows failed to create

Table 2-5 Performance measurements for UPF

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

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

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

2.2.2 E2E Performance Metrics per 5G slice.

Table 2-7 E2E (per slice metrics)

E2E (per slice metrics)	
Metric	**Description**
Average e2e delay for a network slice	This KPI describes the average e2e UL packet delay between the PSA UPF and the UE for a network slice.
Throughput for Single Network Slice Instance	This KPI describes the downstream throughput of one single network slice instance by computing the packet size for each successfully transmitted DL IP packet through the network slice instance during each observing granularity period and is used to evaluate integrity performance of the end-to-end network slice instance. It is obtained by downstream throughput provided by N3 interface from all UPFs to NG-RAN which are related to the single network slice.
QoS flow Retainability	This KPI shows how often an end-user abnormally loses a QoS flow during the time the QoS flow is used.
Packet transmission reliability KPI in DL on Uu	This KPI describes the Reliability based on Packet Success Rate (PSR) Percentage between gNB and UE.
Average network jitter for the network slice	This KPI describes the differential time between the packet actual arrival time and its expected arrival time according to a standard clock.

2.3 Reporting template

A template for the reporting table that is being used to extract the evaluation results is indicated in Table 2-8 [3].

Table 2-8 Test Case template

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

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

3 Digitization of Power Plants at the 5G-VICTORI facility in Patras

3.1 Overview

In a Smart Factory, data from various sensors that are spread at the facilities, are combined to provide faster, more reliable, and cost-efficient monitoring and control of the system. Applications in a Smart Factory can be divided into three broad categories: operation, maintenance and security. As described in deliverables **D2.1** [1] and **D2.2** [9], the 5G-VICTORI "Digitization of Power Plants" UC will demonstrate how the requirements of the different applications in a Smart Factory can be efficiently supported with the adoption of 5G technologies and the deployment of a private 5G network.

The objective of the following test cases is to validate the appropriate setup and deployment of different applications, the fulfillment of their specific requirements, and their coexistence under a unified 5G-enabled monitoring solution. A brief list of the applications that will be demonstrated per category is given below, while more details can be found in the relevant sections:

- Operation: Operation related applications refer to applications involved in the real-time control of the system and are characterized by guaranteed low latency and high reliability requirements. In our case, certain HV cable sensors collect readings that can be fed to future power protection controllers and emit trip signals in case of fault detection. The collection and correlation of the specific readings from each site must be performed in the short time frame dictated by the controller, and so the specific service will be given the highest priority.
- Maintenance: Maintenance related applications refer to applications using live and history measurements for analytics. They do not impose strict latency requirements as they usually feed post fault analysis or predictive maintenance related algorithms. Nevertheless, this category requires collection of massive data originating from different types of sensors. The specific use case includes collection of measurements related to the maintenance of the HV cable, and also the monitoring and configuration of the overall ICT infrastructure.
- Security: In our case, security related applications refer to transmission of UHD video from CCTV cameras ensuring the security of critical infrastructure against theft, fire, etc.

To ensure that all services described in this UC can be delivered, different deployment options of Patras5G (UoP's 5G lab) will be examined. Patras5G offers 3 deployment options, described in detail in the relevant chapter of D2.4 [4]. This use case will leverage deployment option #1, which regards a monolithic 5G Core (5GC) solution, and option #2 that is based on a decentralized core.

3.1.1 Deployment Option #1: SA 5G architecture based on Amarisoft solutions

The monolithic 5GC solution is ideal for testing and providing non-public networks (NPNs). In Patras5G we have deployed the Amarisoft solution that although architecturally follows the 3GPP standards, it has all of its functionalities integrated on the same hardware. Combined with the Autonomous Edge solution offered by Patras5G, this solution offers a standalone (SA) portable 5G solution with cloud capabilities at the edge. Figure 3-1 illustrates the monolithic architecture, where all 5GC functionality is offered by the Amarisoft solution.

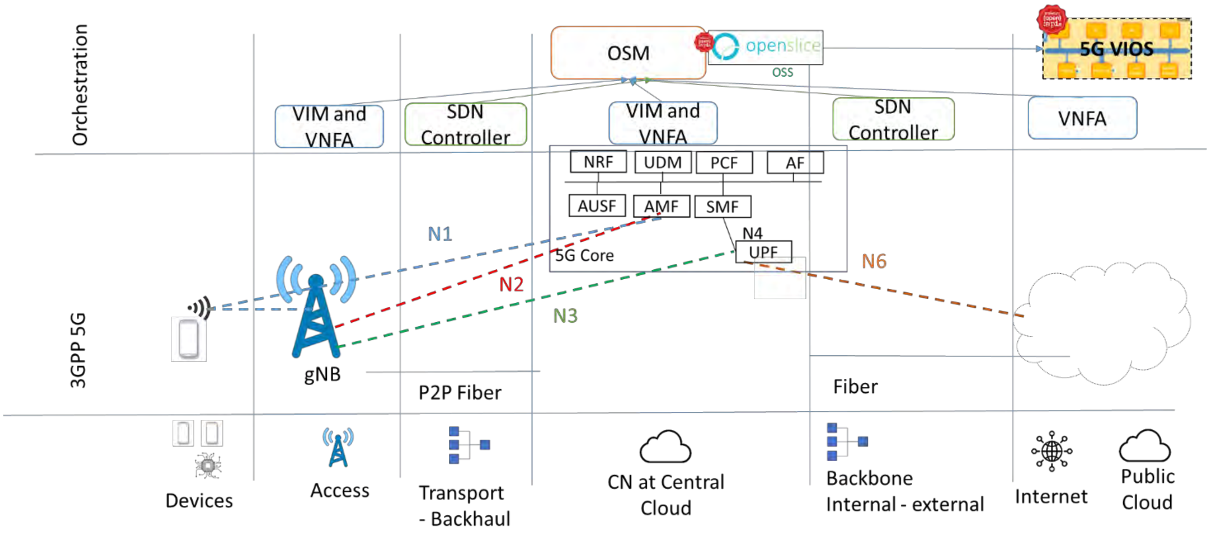


Figure 3-1 5G architecture based on aggregated solutions at Patras5G

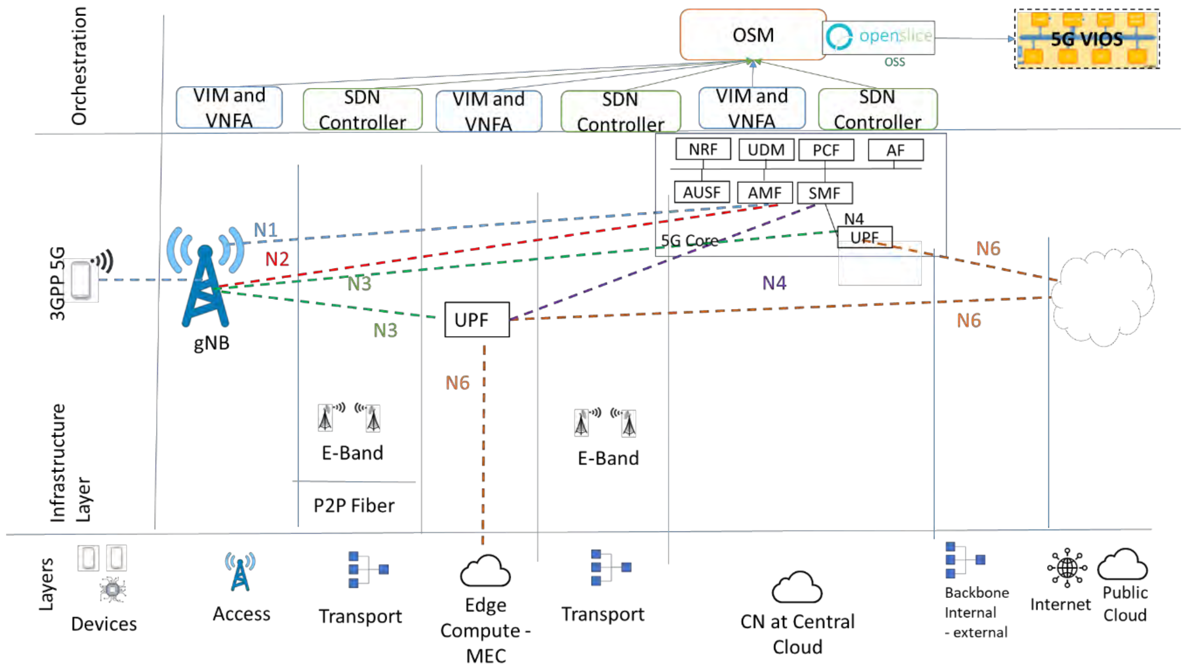


Figure 3-2: 5G architecture based on disaggregated solutions at Patras5G

3.1.2 Deployment Option #2: SA 5G architecture based on decentralized 5G Core

Patras5G is following the architectural approach of the 5G Service Based Architecture (SBA), which breaks apart the monolithic core and implements each function so that it can run independently on common, off-the-self hardware. By leveraging the 5G-VICTORI architecture, 5GC functions can be co-located with application functions (AFs) at an edge datacenter (e.g., Autonomous Edge) or the cloud according to the requirements of the service.

Figure 3-2 illustrates the general architectural approach where a User Plane Function (UPF) instance may be deployed at the edge, or the cloud.

Performance measurements, as defined in section 2 will be carried out to assess the performance of the different deployment options. As deployment option #1 is based on a commercial aggregated solution, E2E metrics will be collected to assess the performance of the network. Deployment option #2 provides the capability to host different NFs at different nodes in a decentralized architecture. Thus, it is essential to assess the performance of different 5GC NFs separately, in order to detect possible bottlenecks and conclude to the most suitable deployment for each service.

During lab testing, deployment option #1 is used to validate the requirements of different vertical services. For field trials, where the UoP testbed is extended to the ADMIE facilities, different variants of deployment option #2 will be investigated.

3.2 Energy and factories – Digitization of Power Plants – Patras – Real-time monitoring of HV power cable test cases (EDHv)

3.2.1 Service Description

Figure 3-3 illustrates the high-level architecture of **UC #2** and the placement of different application and network functions / nodes at the facilities. In this setup, a UPF instance is dedicated at each service, allowing slicing- implementation of services with numerous UPF capabilities and distinct performance requirements under the same 5GC. Moreover, UPF is co-located with application functions, thus providing ultra-fast packet forwarding, reducing communication delay and enabling MEC, which delivers computational resources at the edge to support new low latency services.

For the real-time HV cable monitoring service, only the components in green are involved. This service is responsible for the emission of low latency alarm signals to a real-time controller; thus, it is characterized by low computational and network latency and high reliability requirements. In order to achieve these KPIs, this service is leveraging MEC architecture, and all application functions are placed at the edge. One dedicated UPF instance is also co-located with the application functions of the service (Modbus plugin interface, Real-time monitoring APP), to reduce the datapath and minimize the communication delay. Control plane 5GC functions remain on the UoP cloud and are shared with other services running at Patras5G infrastructure.

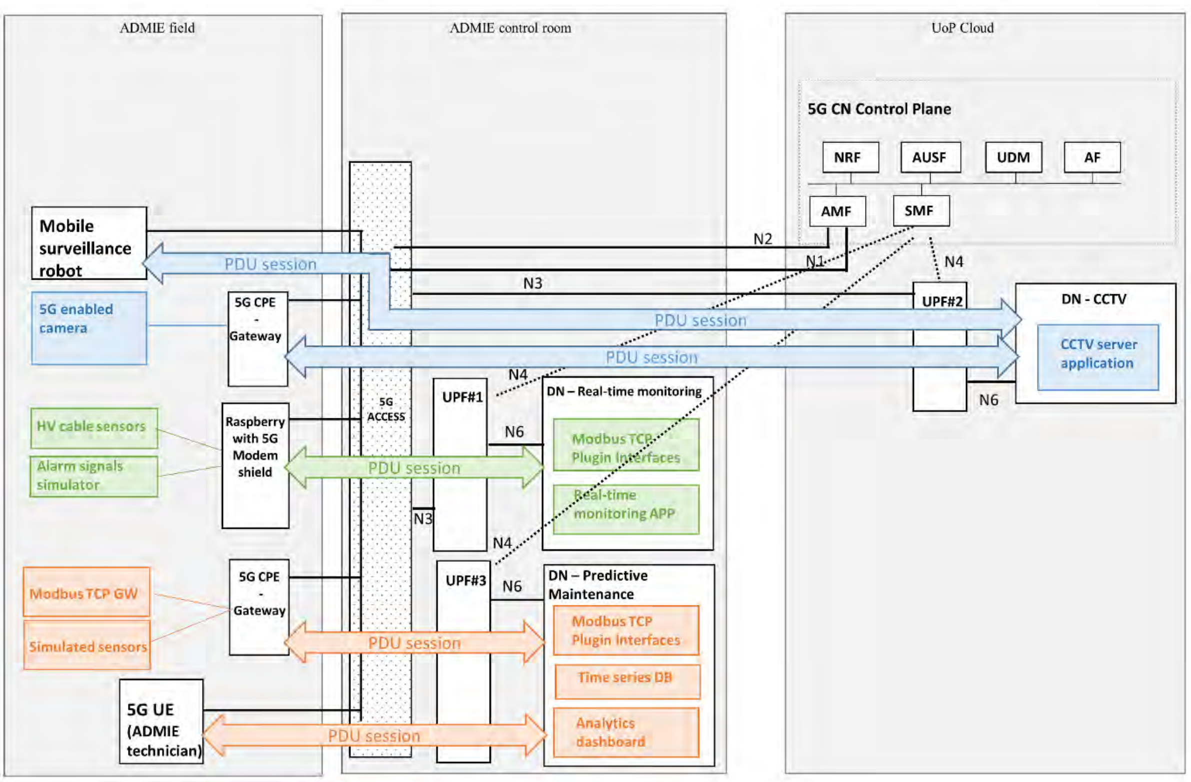


Figure 3-3 High Level architecture of UC #2 components

The next chapters describe in detail the different test cases that will be used to evaluate the performance of the service in the lab and finally at the field. Moreover, they present the results that are currently available after the lab experimentation that took place the previous months.

3.2.2 EDHv01: HV cable sensors data logging over 5G (lab & field test)

The objective of the test case is to showcase that wired connections and legacy sensors can be substituted by wireless new generation sensors and devices and a wireless NPN, which will be able to meet the specified KPIs imposed by the real-time monitoring application.

Table 3-1: EDHv01 - HV cable sensors data logging with 5G connectivity (lab & field test)

EDHv02	HV cable sensors data logging with 5G connectivity (lab & field test)
Testbed	**5G-VINNI Patras**
Description	This test case describes the initial configuration and validation setup that will be deployed. This includes the IoT platform, the legacy industrial sensors, the 5G network slice that will be used for the time-critical measurements collection at each site and the additional equipment needed for the provision of 5G connectivity to the legacy sensors. It is important to validate that the overall solution can be supported by the deployed 5G network in the lab and the field.
Key Use-case requirements and KPIs	N/A
Network performance requirements and KPIs	Latency (min. between user service end-points) User Datarate (Max.) - 0.1 Mbps (per device) Reliability > 99.99% (SIL 2) Availability > 99.99% (SIL 2) Packet Loss Ratio < 10^{-9}
Network Functional requirements and KPIs	**S-FU-5304** (Slicing) **S-FU-5308** (Management & Orchestration of Distributed Pools of Resources) **S-FU-5301** (Air Interface – Access Network) **S-FU-5303** (Multi-Tenancy) **S-FU-5302** (Distributed Pools of (Compute/Network) Resources)
Components and configuration	**- Components:** 1. Sensors' data simulator (virtual Modbus TCP sensors) 2. MEC server (Autonomous Edge) 3. Legacy sensors 4. Modbus TCP interface (Modbus TCP recorder) 5. 5G CPE 6. gNB 7. 5G Core 8. VM running the IoT platform 9. Switch **- Configuration:** 1. Configuration of sensors (physical and virtual) to send data to the platform 2. Appropriate design/configuration of IoT platform plugins for communication with legacy sensors via Modbus TCP protocol 3. Configuration and setup of networking devices and services (gNB, 5G CPE, 5G Core)

Test procedure	**- Preconditions:** 1. 5G connectivity at each site is established. 2. IoT platform and Modbus TCP interfaces configured **- Test Case Steps:** 1. IoT platform Modbus TCP plugin sends “read” request towards the Modbus TCP recorders (physical and virtual). 2. The time-stamp of the “read” request is marked 3. Physical and virtual sensors send raw data as a response 4. Customized plugins receive the data and translate it into meaningful information. 5. Processed data is stored and time at the end of processing is also marked. 6. End-to end latency is measured 7. Network traffic monitoring tools (e.g. iperf) can be used at the device simulator endpoint to measure other KPIs of interest (bandwidth, packet loss, etc.)
Measurements	**- Methodology** 1. Measurements are collected for a number of iterations for the evaluation of each KPI for each set of test conditions. **- Complementary measurements** 1. Network Slicing across the different services is validated. **- Calculation process** 1. For the vertical application, the end-to-end latency is defined as the time passed from the “read” request until the data are available for use. 2. The time difference between the two timestamps is calculated for each case. 3. Max value, Mean average and standard deviation are calculated for the computational latency. 4. Results for each traffic condition are stored.
Expected Result	Application meets the expected KPIs

3.2.3 EDHv02: Data transmission test between different sites (field test)

The UC describes the collection of measurement between two sites. The two sites are an extension to the 5G-VINNI facility. The objective of this test case (Table 3-2) is to evaluate the connectivity between the two sites and to measure the performance of the connection.

Table 3-2: EDHv02 - Data transmission test between Rio and Antirio sites (field test)

EDHv03	Data transmission test between Rio and Antirio sites (field test)
Testbed	**5G-VINNI Patras**
Description	Objective of this test case is to validate the connectivity of the two sites and measure the performance of the connection.
Key Use-case requirements and KPIs	N/A (infrastructure test)
Network performance requirements and KPIs	Latency (min. between user service end-points) User Datarate (Max.) - 0.1 Mbps (per device) Reliability > 99.99% (SIL 2) Availability > 99.99% (SIL 2) Packet Loss Ratio < 10^{-9}
Network Functional requirements and KPIs	N/A

Components and configuration	**- Components:** 1. gNB (Antirio site) 2. 5G CPE (Antirio site) 3. Terminal hosting sensor simulator (Antirio site) 4. Modbus TCP interface (Antirio site) 5. Switch (Rio site) 6. Autonomous Edge (Rio site) **- Configuration:** 1. Connectivity between components performed as in Figure 3-3**Error! Reference source not found.**. 2. Autonomous Edge (AE) connected to the switch 3. Terminal hosting the sensor simulator, and Modbus TCP interface at Antirio connected through the 5G CPE. 4. Setup a network performance measurement tool at each terminal. 5. Configure network traffic generator console application 6. Configure iperf at the two terminals
Test procedure	**- Preconditions:** 1. Connection between the two sites is established. 2. 5G connectivity at each site is established. **- Test Case Steps:** 1. Run ICMP (ping) test from terminal at Antirio site to the terminal at Rio 2. Run iperf from client to server and log KPIs of interest (latency, bandwidth and packet loss) 3. Use the traffic generator application to change the traffic conditions. 4. Measurements are collected for a number of iterations for the evaluation of each KPI for each set of test conditions.
Measurements	**- Methodology** 1. For each traffic condition perform the tests for each KPI **- Complementary measurements** N/A **- Calculation process** 1. For each test, perform the number of iterations needed (e.g. 100 iterations) and log the results. 2. Compute the mean, max and min value for each KPI per traffic condition.
Expected Result	Connectivity between physical / simulated sensors and IoT platform is established Expected KPIs for the interconnection are met

3.2.4 EDHv03: Data Synchronization for measurements correlation of real-time monitoring service (lab & field test)

Real time monitoring of the HV cable status requires measurements from both sites to be collected and stored under the same timestamp in a common time-series database. In order to obtain the full view of the HV power cable, the measurement of a physical value (e.g., oil pressure) for a given timestamp is considered valid only if the measurements from the two sides of the cable have arrived in time. If the timestamp of the measurements differs more than a predefined threshold, then both measurements are discarded as they cannot be used by the system. Moreover, for the support of the real-time requirements of the smart factory “operation”, measurements of each site must be collected within a predefined maximum delay time otherwise they will be discarded. In this sense, the service reliability is related to the number of discarded measurements versus the total number of measurements.

Table 3-3: EDHv03 - Data Synchronization service for measurements correlation between Rio and Antirio sites (lab & field test)

EDHv04	Data Synchronization service for measurements correlation between Rio and Antirio sites (lab & field test)
Testbed	**5G-VINNI Patras**
Description	The objective of this test case is to validate the time synchronization of the measurements originating from the two sites and the maximum latency for their storage at the time-series database.
Key Use-case requirements and KPIs	Service Reliability > 99.99% Guaranteed max End-to-End Latency
Network performance requirements and KPIs	Latency (min. between user service end-points) User Datarate (Max.) - 0.1 Mbps (per device) Reliability > 99.99% (SIL 2) Availability > 99.99% (SIL 2) Packet Loss Ratio < 10^{-9} Guaranteed max Jitter
Network Functional requirements and KPIs	**S-FU-5306** (Synchronization) **S-FU-5304** (Slicing) **S-FU-5308** (Management & Orchestration of Distributed Pools of Resources) **S-FU-5301** (Air Interface – Access Network) **S-FU-5303** (Multi-Tenancy)
Components and configuration	**- Components:** 1. Sensors' data simulator (virtual Modbus TCP sensors) 2. MEC server (Autonomous Edge) 3. Legacy sensors 4. Modbus TCP interface (Modbus TCP recorder) 5. 5G CPE 6. 5G Core Network 7. 5G NR 8. Autonomous Edge 9. VM running the IoT platform 10. 1 Switch per site 11. Edge device (terminal) for the hosting of sensors' data simulator at Antirio site **- Configuration:** 1. IoT platform, devices and device simulators configured as in EDHv02

Test procedure	**- Preconditions:** 1. 5G network at both sites is established 2. Fiber interconnection between the two sites is established 3. IoT Platform is configured and running at Rio Site **- Test Case Steps:** 1. IoT platform Modbus TCP plugin sends “read” request towards the Modbus TCP recorder located at Rio site (physical or virtual) for a specific physical value. 2. IoT platform Modbus TCP plugin sends “read” request towards the Modbus TCP recorder located at Antirio site (physical or virtual) for the sensor measuring the same physical value at Antirio site. 3. Both measurements are stored in the database as described in the previous test cases. 4. The time difference between the associated timestamps of the two measurements is calculated. 5. If the difference bypasses a predefined threshold, the measurements are discarded. 6. The discarded measurements ratio is computed. 7. End-to end latency for the measurements is also computed as in EDHv01. 8. If one of the measurements surpasses the latency limit, the pair is marked as invalid.
Measurements	**- Methodology** 1. The test procedure is repeated for different request rates by the application and different traffic conditions 2. The ratio of “late” measurements to the total measurement is calculated. 3. The ratio of unsynchronized measurements to the total measurements’ pairs is calculated. **- Complementary measurements** 1. Packet loss ratio is measured 2. Data rate per device is measured **- Calculation process** 1. A pair of measurements is defined as the group of one measurement from Rio site and one measurement from Antirio site, referring at the same physical quantity. 2. Pairs of measurements are considered unsynchronized if their timestamps differ more than a predefined threshold 3. Pairs of measurements are considered outdated if at least one measurement of the pair is outdated.
Expected Result	Outdated measurements should be < 99.99% Unsynchronized measurements should be < 99.99%

3.2.5 EDHv04: End-to-end HV cable status reporting application deployment – Normal and abnormal operational conditions (lab & field test)

The services that will be demonstrated for the Smart Factories UC are divided into operation, maintenance, and security related applications. The real time monitoring of the submarine HV cable is an operation related application. The objective of this application is to identify possible abnormal operation conditions in real-time, inform the operator and provide input to future local controllers.

Table 3-4: EDHv04 - End-to-end HV cable status reporting application deployment - Normal and abnormal operational conditions (lab & field test)

EDHv05	End-to-end HV cable status reporting application deployment - Normal and abnormal operational conditions (lab & field test)
Testbed	**5G-VINNI Patras**
Description	The objective of this test case is to validate the end-to-end functionality of the HV submarine cable status monitoring application during normal and abnormal conditions. The collected measurements will be compared against predefined thresholds and relevant signals will be emitted should any abnormal activity be detected. The abnormal events will be reproduced by simulated Modbus TCP devices, instantiated by a Modbus TCP simulator. In this final test, the End2End application latency is measured from the time of the appearance of the abnormal event until the signal emission from the application and includes sensing, network and computational latency.
Key Use-case requirements and KPIs	Abnormal event detection delay < 250ms Service Reliability > 99.99% (SIL 2) Service Availability > 99.99% (SIL 2)
Network performance requirements and KPIs	Reliability > 99.99% (SIL 2) Availability > 99.99% (SIL 2)
Network Functional requirements and KPIs	**S-FU-5304** (Slicing) **S-FU-5301** (Air Interface – Access Network) **S-FU-5303** (Multi-Tenancy)
Components and configuration	**- Components:** 1. Sensors' data simulator (virtual Modbus TCP sensors) 2. MEC server (Autonomous Edge) 3. Legacy sensors 4. Modbus TCP interface (Modbus TCP recorder) 5. 5G CPE 6. 5G Core Network 7. 5G NR 8. Autonomous Edge 9. VM running the IoT platform 10. 1 Switch per site 11. Edge device for the hosting of sensors' data simulator at Antirio site 12. Scenario simulator **- Configuration:** 1. IoT platform sensors and sensors' simulator are configured 2. 5G network is deployed 3. Scenario's simulator is connected to the sensors' simulator and configured to feed it with measurements for normal and abnormal operating conditions.

Test procedure	**- Preconditions:** 1. IoT platform and sensors functionality is validated 2. 5G network and site interconnection is validated **- Test Case Steps:** 1. Use physical sensors and feed virtual sensors with measurements indicating normal operating conditions. 2. Validate the correct execution of the monitoring solution 3. Configure the scenarios' simulator for abnormal scenario production 4. Mark the timestamp of the simulated event (in the simulator) 5. Check that alarm signal is emitted as a response to the abnormal situation 6. Mark the time of the signal emission 7. Calculate the difference between the two time instants.
Measurements	**- Methodology** 1 The test cases steps are repeated several times under different conditions: Number of devices, location of event, network conditions. 2 For each test, perform the number of iterations needed (e.g., 100 iterations) and log the results. 3 Compute the mean, max and min value for each KPI per traffic condition. **- Complementary measurements** 1. Abnormal event is also logged and presented at the dashboard to inform the operator. **- Calculation process** 1. Repeat the test under the same conditions several times (e.g. 100 iterations) and compute the mean, max and min latency value 2. The two time instants are logged at different machines. a. The scenario simulator is executed on a terminal behind the 5G CPE (to replicate the behavior of a physical component) b. The IoT application is hosted on the Autonomous Edge. 3. The two machines must be synchronized under a common reference clock for a valid calculation of the end2end application latency.
Expected Result	Use case KPIs are met regardless of the traffic conditions

3.2.6 Lab KPI results

Prior to the execution at a real industrial environment, testing has been performed in a laboratory environment with the use of sensors simulators. Figure 3-5 illustrates the lab environment, whereas an overview of the exact simplified lab setup used for the Real-time monitoring and Sensor data collection tests over 5G is described in Figure 3-4 and Table 3-5. A laptop and a Raspberry Pi4 (with a 5G shield) were used to host the dockerized sensors simulators and transmit measurements over Modbus TCP protocol. The same simulators will be utilized in the field, along with the physical sensors, to simulate abnormal events. At this time, no mmWave backhauling was in place to use, therefore the whole 5G connectivity was supported inside the UoP lab. The Amarisoft callbox node was used to deploy a 5G Stand Alone (SA) deployment using standard configuration (downlink oriented) and provide connectivity with the Patras5G cloud network. Real-time metrics of the network quality were monitored via Patras5G monitoring solution and displayed on a separated screen (Figure 3-5). The laptop was connected to the 5G network via a 5G-CPE, and inbound traffic was permitted through port forwarding rules. For the real-time monitoring service, we used our custom Modbus TCP adapter (IoT platform VM), which we instantiated at the Patras5G cloud. The adapter was developed in C language, in order to achieve minimum processing delay for the vertical time-critical application.

Table 3-5 EDH / EDS Lab Testing - Network Topology

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

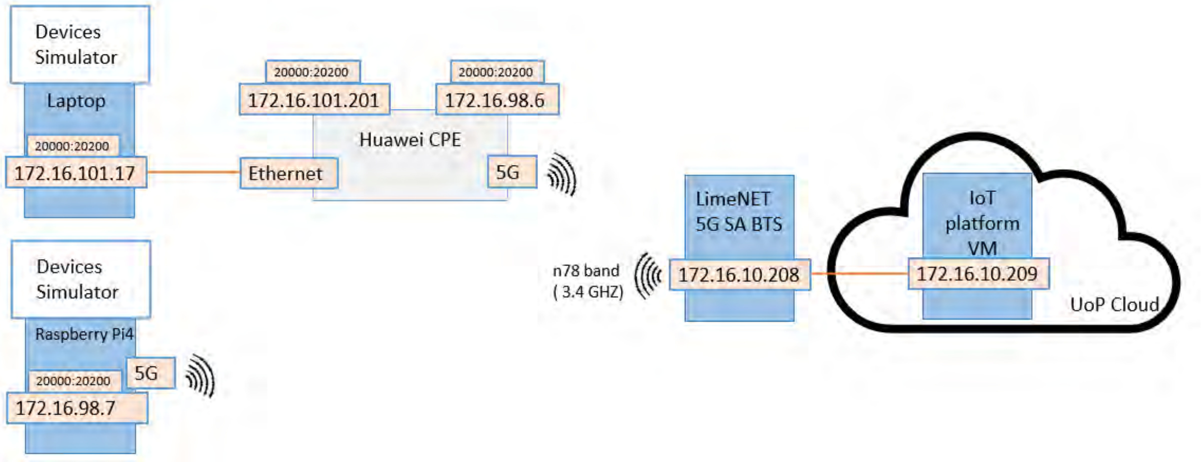


Figure 3-4: Overview of system setup for EDH and EDS services lab experiment

The main objective of lab testing was to validate that the different components forming the vertical solution (sensors, IoT platform, etc.) can be integrated and sufficiently supported by the network and computing resources offered by the 5G-VICTORI platform. In this sense, each service is tested separately and with no additional traffic offered in the site. The measuring process in the lab for EDH related test cases is the following:

Table 3-6 EDH Lab Testing - Process characteristics

Measurement duration	**Time duration of the measurement [T]:** *Not applicable* ***Repetition time:*** *For EDHv01: 1000 Modbus TCP requests* *For EDHv03: 1000 pairs of Modbus TCP requests* ***Granularity of measurements:*** *Deployment times: Not applicable* *Latency: in the order of ms* *Datarates: in the order of Kbps*
Traffic offered in the site	***Traffic Characteristics (rate)*** ***Number of connections:*** *For EDHv01: 1 connection (no additional traffic)* *For EDHv03: 2 connections (no additional traffic)* ***Traffic Pattern and interarrival time:*** *Not applicable*

Figure 3-5: Lab setup of EDH and EDS trials

All tests corresponding to the Real-time monitoring of HV power cable scenario have been performed according to the deployment of Figure 3-4. The results obtained by the lab experimentation are presented below.

For test case **EDHv01: HV cable sensors data logging over 5G**, Modbus TCP traffic was simulated with the use of device simulators and transmitted through the deployed 5G network. At this point, we were interested in the delay and robustness of the end-to-end solution for the transmission of small packets of measurements. Our solution measures the end-to-end latency L_{E2E} of the application, which is the sum of processing latency L_P and network latency L_N. The first step was to calculate L_P imposed by the simulators and IoT application. During the first set of measurements the IoT platform and simulator were hosted at the same laptop, where network latency can be neglected, and L_{E2E} equals L_P. Transaction of 1000 measurements requests provide a mean $L_{E2E} = L_P$ of 1.7 ms with a typical datarate of 54 Kbps. The next step was to perform the same number of transactions, following the setup of Figure 3-4 and transmitting measurements through the deployed 5G network. Transaction of 1000 measurements requests between the end points resulted in min= 13.7 ms / mean 38.5 ms / max 86.8 ms end-to-end latency (L_{E2E}). Moreover, 75% of measurements resulted in end-to-end latency less than 49.6 ms and all measurements are positioned below the 100ms threshold. The network latency between the endpoints was measured through 1000 ping requests. Results are plotted in Figure 3-6.

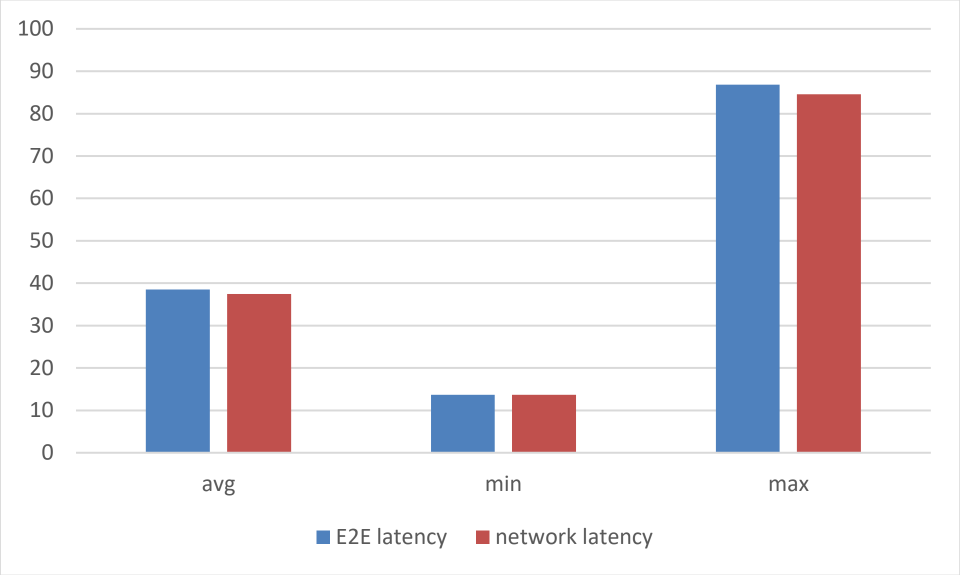


Figure 3-6 Lab testing results: E2E latency between sensor simulator and IoT application through 5G

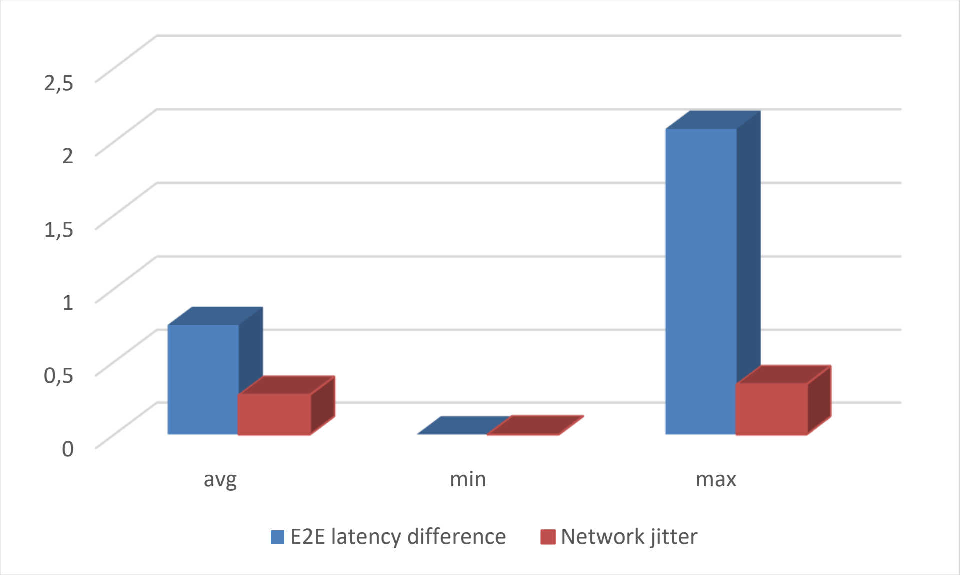


Figure 3-7 Lab testing results: E2E latency difference between pairs of concurrent measurement requests versus Network jitter

The next step of lab experiments is to evaluate the synchronization of measurements. For the lab testing of **EDHv03 Data Synchronization for measurements correlation of real-time monitoring service**, we used one laptop, connected to the 5G network through a CPE and a Raspberry Pi 4 connected through a 5G shield, as illustrated in Figure 3-4. Each device is used to transmit the simulated traffic by one site. We performed 1000 pairs of concurrent requests by the IoT platform VM towards the two simulators. The E2E latency and latency difference for each pair were measured. The experiment resulted in a min= 0.0002 ms / mean 0.7516 ms / max 2.0850 ms. Network jitter was also measured with iperf and resulted to a mean value of 0.272 ms. Results are plotted in Figure 3-7. It is shown that the variations in latency for the measurements pairs are not significant and they are more influenced from processing than network delays.

It must be noted that test were performed with no mmWave connection between the two endpoints and without background traffic in the transmission channel. During field testing, we must validate that there will not be variations in latency when more services will be served by the same deployment. Lab results corresponding to performance metrics for the 5G slice that was deployed are summarized in Table 3-7. Performance measurements for UPF and AMF (as defined in section 2) will be performed during field measurements, where the decentralized architecture of deployment Option #2 will be used.

Table 3-7 EDH Lab Testing: E2E (per slice metrics) Performance Results

E2E (per slice metrics)		
Metric	**Description**	**Measurements**
Average e2e delay for a network slice	This KPI describes the average e2e UL packet delay between the PSA UPF and the UE for a network slice.	Average: 38.5 ms 1000 packets sent through ping request (default packet size – 32 bytes)
Throughput for Single Network Slice Instance	This KPI describes the downstream throughput of one single network slice instance by computing the packet size for each successfully transmitted DL IP packet through the network slice instance during each observing granularity period and is used to evaluate integrity performance of the end-to-end network slice instance. It is obtained by downstream throughput provided by N3 interface from all UPFs to NG-RAN which are related to the single network slice.	Not evaluated at lab testing
QoS flow Retainability	This KPI shows how often an end-user abnormally loses a QoS flow during the time the QoS flow is used.	Not evaluated at lab testing
Packet transmission reliability KPI in DL on Uu	This KPI describes the Reliability based on Packet Success Rate (PSR) Percentage between gNB and UE.	Not evaluated at lab testing
Average network jitter for the network slice	This KPI describes the differential time between the packet actual arrival time and its expected arrival time according to a standard clock.	Average: 0.272 ms 1000 iperf packets sent between a client hosted at the Raspberry PI 4 and a server hosted at the same VM as the IoT platform.

3.2.7 Field Trials

The preliminary field trial of the Real-time monitoring (EDHv) and Sensors' data collection (EDSv) services took place at ADMIE facilities to validate the correct configuration of physical sensors, 5G and non-5G related infrastructure and applications. We deployed a NPN 5G network using the Autonomous Edge solution, hosting also the 5GC and the vertical IoT application for the collection and processing of measurements. Figure 3-8 a) depicts the interior of the control cabin where virtual sensors have been replaced by the physical ones. The 5G NPN was successfully deployed and there was no interference with the electromagnetic field produced by the High Voltage (150kV). The correct communication and interpretation of sensors' reading was also validated. Figure 3-8 b) depicts the installation of the mmWave connection antennas on the HV power pole for the interconnection of ADMIE facilities with the UoP campus and the rest of Patras 5G-VICTORI facilities.

The next step, is to assess the performance of different deployments, leveraging the decentralized architecture of deployment option #2.

a) Interior of ADMIE's HV power cable control cabin at Rio

b) mmWave link between ADMIE and UoP facilities

Figure 3-8 Preliminary field trial for Factories of the Future UCdeployment

3.3 Energy and factories – Digitization of Power Plants – Patras – Sensor data collection test cases (EDSv)

3.3.1 Service Description

Sensor data collection service includes all the necessary actions and applications that can transform the legacy **ADMIE** site located at Rio into a smart factory infrastructure. In order to do this and provide services such as monitoring, data analytics, predictive maintenance, etc., sensors supporting 5G NR connectivity technologies, together with the inclusion of an advanced data management platform integrated at a MEC server at the edge of the network, will be installed at the site. Sensor data will be collected and processed locally at the MEC server, while filtered data will be sent to the **UoP** Cloud for storage and to enable smart applications, through an extension of the 5G-VINNI infrastructure via a mmWave link from UoP to the ADMIE site.

In reference to Figure 3-3, for the sensor data collection service, only the components in orange are involved. This service is characterized by the emission of small measurement data packets in a periodic fashion; thus, it does not require low network latency but high bandwidth and computing resources, which is of course proportional to the number of industrial sensors installed at the site. To reduce those requirements, we leverage the existing MEC capabilities in order to filter and decrease high data volume transmissions at the UoP Cloud, which in most cases involve repetitions of previous measurements. One dedicated UPF instance is also co-located with the application functions of the service to reduce the datapath and minimize the communication delay. Control plane 5GC functions remain on the UoP cloud and are shared with other services running at Patras5G infrastructure.

The next chapters describe in detail the different test cases that will be used to evaluate the performance of the service in the lab and finally at the field. Moreover, they present the results that are currently available after the lab experimentation that took place the previous months.

3.3.2 EDSv01: Heterogeneous industrial sensor data collection on MEC server (lab & field test)

The transformation of legacy industrial facilities into a highly connected smart factory environment necessitates a great number of low-cost sensors installed and integrated to the facilities' private network. However, these prove to be challenging to manage due to their heterogeneity. In addition to this, smart factory services impose multiple data bursts of relatively short time frames in a network, therefore a large number of sensors can strain the network periodically and increase the overall packet loss. To deal with these problems, 5G technology can be used in order to provide a dedicated network slice which will act as the underlying infrastructure for the enablement of efficient data transmissions in a secure and manageable way.

Table 3-8: EDSv01 - Heterogeneous industrial sensor data collection on MEC server (lab & field test)

EDSv01	Heterogeneous industrial sensor data collection on MEC server (lab & field test)
Testbed	**5G-VINNI Patras**
Description	The purpose of this initial test case is to validate the 5G network slice that will be used for the data-burst measurements collection. In this scenario, low-cost industrial sensors will be installed at ADMIE legacy facilities and will provide insightful measurements to an IoT platform hosted at a MEC server through 5G gateways. This test case will run initially with a small number of heterogeneous sensors at the lab and field, for validation of the data management platform used under this service. Finally, when correct data collection has been verified, the next step will be to test the service under real industrial environment conditions, where a large amount of sensing devices will be present. This will be achieved by simulating a large number of industrial sensing devices over 5G.
Key Use-case requirements and KPIs	1-100 Kbps Datarate per sensor 2-10 Mbps Total Datarate 10^{-6} - 10^{-9} Packet Loss Ratio
Network performance requirements and KPIs	**U-CA-5201** (High Connection Density) - number of devices to be supported from a single access node, number of devices to be supported from the 5G core NFs **U-CA-5202** (High Traffic Density) - total capacity offered by a number of access network nodes **S-OTH-5203** (Scalability) - max 100 connections
Network Functional requirements and KPIs	**S-FU-5301** (Air Interface – Access Network) - Antenna operation at 5G, Wi-Fi and/or NB-IoT support **S-FU-4306** - On Demand deployment of network services **S-FU-5304** (Slicing) - on-demand instantiation/ deletion/ configuration of an E2E network slice and delivery of services over it, QoS guarantees (e.g. latency, bandwidth, etc.).
Components and configuration	**- Components:** 1. IoT platform VM 2. Sensors' data simulator (virtual Modbus TCP sensors) 3. MEC server (Autonomous Edge + gNB) 4. 5G CPE gateway 5. Modbus TCP Gateway 6. Legacy sensors **- Configuration:** 1. Configuration of sensors (physical and virtual) 2. Appropriate design/configuration of IoT platform’s plugins for communication with sensors supporting different application protocols (e.g. Modbus TCP) 3. Configuration of IoT platform’s time-series database (type of data, time resolution, etc.) 4. Configuration and setup of networking devices (gNB, 5G CPE, Modbus TCP gateway) 5. Configuration of IoT platform as a VNF

Test procedure	**- Preconditions:** 1. Simulator is connected to the private 5G network and it is configured to create a specific number of virtual sensors 2. IoT platform running on MEC server and configured to request/receive data from a specific numbers of devices (physical and virtual sensors) 3. Appropriate tcpdump command runs at the VM hosting the IoT platform and filters incoming/outgoing packets of interest 4. All sensors (physical and virtual) are ready and connected to the IoT platform **- Test Case Steps:** 1. Deploy IoT platform as a VNF. The platform initializes and starts sending data requests to the sensors. 2. Sensors send raw data to the appropriate plugins of the IoT platform along with sensor simulator. 3. IoT platform's customized plugins receive the data and translate it into meaningful information. 4. Processed data are stored at the corresponding time-series database. 5. With the use of the tcpdump command, we capture all sensor packets for up to 5 minutes and save them to a pcap file. 6. The process is repeated for different number of sensors and different report rates. 7. KPIs are measured for each case.
Measurements	**- Methodology** 1. In order to acquire the service deployment time, we measure the difference between the time of service initialization and the time of the first sensor data request. 2. For each scenario, an associated pcap file containing all filtered sensor packets is created by tcpdump. 3. Pcap files are analyzed offline with the Wireshark traffic analyzer tool. 4. KPIs are measured through Wireshark and exported either in the format of CSV files or PNG images. **- Complementary measurements** 1. N.A. **- Calculation process** 1. Total Datarate can be calculated as the sum of all received data in a time period of 1 second and then it can be converted to (Mbps). 2. Sensor Datarate can be calculated as the sum of received data from a specific sensor in a time period of 1 second and then it can be converted to (Mbps). 3. Packet Loss Ratio can be calculated as the ratio of the number of lost packets to the total number of sent packets over a specific time period. 4. All the above calculations can be done through the Wireshark traffic analyzer tool. 5. Service deployment time is measured as the difference between the time of service initialization and the time of the first sensor data request.
Expected Result	The aim of this test case is to validate the data-burst measurements collection 5G network slice and evaluate its performance in a real industrial environment, while ensuring that performance indicators fall within the thresholds described above.

3.3.3 EDSv02: Infrastructure test between Rio site and 5G-VINNI (field test)

In the context of 5G-VICTORI, the ADMIE site in Rio, along with the respected site in Antirio, is to be integrated with the 5G-VINNI facilities at UoP premises. In order to satisfy this, the two sites will be interconnected via a mmWave link connection. The objective of this test case is to evaluate the connectivity between the two sites and measure the performance of the connection.

Table 3-9: EDSv02 - Infrastructure test between Rio site and 5G-VINNI (field test)

EDSv02	Infrastructure test between Rio site and 5G-VINNI (field test)
Testbed	**5G-VINNI Patras**
Description	Test the performance of the mmWave link connection between ADMIE and UoP sites in terms of latency and throughput.
Key Use-case requirements and KPIs	>1 Gbps Uplink, Downlink <20 ms mmWave link latency
Network performance requirements and KPIs	N/A
Network Functional requirements and KPIs	**S-FU-5305** (Converged Optical – Wireless transport)
Components and configuration	**- Components:** 1. iperf client 2. iperf server 3. MEC server (Autonomous Edge) 4. mmWave 10Gbit Link 5. UoP DC **- Configuration:** 1. Installation and configuration of mmWave 10Gbit Link 2. Configuration and setup of iperf client 3. Configuration and setup of iperf server
Test procedure	**- Preconditions:** 1. Confirm that MEC server and UoP Cloud are configured and are up and running. 2. Confirm that iperf services are ready. **- Test Case Steps:** 1. Firstly, the iperf client is configured to initiate traffic from the MEC server to the iperf server located at the UoP Cloud (uplink). 2. The iperf server monitors the traffic and extracts the necessary information (uplink throughput). 3. Secondly, the iperf services are configured to initiate traffic to the opposite direction, that is, from the UoP Cloud to the MEC server (downlink). 4. The iperf client, which now serves as an iperf server, monitors the traffic and extracts the necessary information (downlink throughput). 5. Lastly, the RTT is measured by initiating a ping request between Rio and UoP Cloud.

Measurements	**- Methodology** 1. Generate the traffic using the iperf services and the ping utility command. 2. Monitor the corresponding metrics. 3. Export them to a CSV file **- Complementary measurements** 1. N.A. **- Calculation process** 1. Measure the uplink/downlink by utilizing the iperf services and converting the results to (Gbps). 2. Measure mmWave link latency using well-established network functions such as Ping
Expected Result	Evaluation of the mmWave link performance, proving that it satisfies the respective performance requirements.

3.3.4 EDSv03: End-to-end Preventive maintenance application deployment (lab & field test)

Having demonstrated the functionality of the services mentioned previously, the next and final step is to deploy all these services in combination with some visualization ones, in order to present an end-to-end vertical application customized for preventive maintenance activities. In this final test case, advanced industrial asset monitoring will be showcased and preventive maintenance applications will be demonstrated via different presentation methods (e.g. automated reports, high-quality diagrams, alarms).

Table 3-10: EDSv03 - End-to-end Preventive maintenance application deployment (lab & field test)

EDSv03	End-to-end Preventive maintenance application deployment (lab & field test)
Testbed	**5G-VINNI Patras**
Description	Test case to verify the correct end-to-end functionality of the application.
Key Use-case requirements and KPIs	Verification of application functionality.
Network performance requirements and KPIs	N/A
Network Functional requirements and KPIs	**S-FU-4306** - On Demand deployment of network services **S-FU-5304** (Slicing) - on-demand instantiation/ deletion/ configuration of an E2E network slice and delivery of services over it, QoS guarantees (e.g. latency, bandwidth, etc.).
Components and configuration	**- Components:** 1. IoT platform in MEC Server 2. Sensors' data simulator (virtual Modbus TCP sensors) 3. MEC server (Autonomous Edge + gNB) 4. 5G CPE gateway 5. Modbus TCP Gateway 6. Legacy sensors 7. mmWave 10Gbit Link 8. UiTOP platform VNF in UoP Cloud 9. UoP DC **- Configuration:** 1. Configuration of sensors and IoT platform as of Test Case EDSv01

Test procedure	**- Preconditions:** 1. Same as of Test Case EDSv01 & EDSv02 **- Test Case Steps:** 1. Deploy IoT platform as a VNF. The platform initializes and starts sending data requests to the IoT platform at the MEC server. The IoT platform at the MEC server forwards the requests to the sensors. 2. Sensors send raw data to the appropriate plugins of the IoT platform along with sensor simulator. 3. IoT platform's customized plugins translate it into meaningful information. 4. Processed data are filtered and stored at the corresponding time-series database. 5. Filtered data are transmitted at the UiTOP instance at UoP Cloud for further use. 6. Incoming data are available to end users via the UiTOP Web UI.
Measurements	**- Methodology** 1. Transmit filtered data at the UiTOP instance at UoP Cloud. 2. Inspect data through the UiTOP Web UI. **- Complementary measurements** 1. N/A **- Calculation process** 1. Confirm that UiTOP instance at UoP Cloud processes and presents data correctly to end users, with good quality reports, graphs, etc. 2. Service deployment time is measured as the difference between the time of service initialization and the time of the first sensor data request.
Expected Result	Evaluation of the end-to-end application.

3.3.5 Lab KPI results

After having described thoroughly the EDS test cases, this section includes a summary of the preliminary results obtained through lab testing at UoP 5G facilities. The lab setup that was used during these lab trials is the same as the one for the lab testing of the EDH service. For more information as well as illustrations of the lab setups, the reader is encouraged to consult section 3.2.6. However, a brief review of the setup is included here for reader's convenience. All in all, for the **EDS service testing**, the experiments took place at the Patras5G lab of UoP, where all the components were deployed locally, including the whole 5G radio connectivity. In order to generate industrial sensor traffic over the 5G network, one laptop and one Raspberry Pi 4 were used, both running a dockerized Modbus TCP simulator app, with 5G-enabled connectivity through a 5G-CPE and a 5G shield from UoP respectively. Both devices were connected with UoP's local gNB and were able to receive data requests from and transmit measurements to a data management platform (IoT platform VM) deployed as VNF in UoP's OpenStack environment. The network conditions were constantly being monitored by a monitoring software provided by UoP and the results were displayed on a separate screen. The described setup for this scenario is summarized in Table 3-11.

Table 3-11 EDS Lab Testing – Network Topology

Network Topology	
Type of sites in the network area	Number of gNBs: 1 Small scale gNB gNB deployment Option: No distributed RAN deployment – all gNB functions deployed on a single HW component

	Type of gNB commercial – for testing purposes
Fronthaul/Backhaul Information	Predominant type of backhauling: Fiber - Ethernet
Cloud Infrastructure	The cloud platform offers a total computing power of 450 CPUs and 1,5 TB of RAM and 50 TB of storage. All servers are interconnected on TOR 10GbE/40GbE NVIDIA Cumulus switches with dual 10GbE NICs DPDK enabled Virtualization software: Openstack, ETSI MANO OSM

At this stage the lab tests were conducted with the aim to validate the network and the vertical applications, so no additional traffic offered in the site. In all tests therefore the measuring process characteristics are those included in Table 3-12.

Table 3-12 EDS Lab Testing – Process characteristics

Measurement duration	**Time duration of the measurement [T]:** *For EDSv01, EDSv03: 5 minutes* ***Repetition time:*** *10 deployment requests* ***Granularity of measurements:*** *Deployment times: in the order of minutes* ***Latency****: in the order of ms* ***Datarates****: in the order of Kbps*
Traffic offered in the site	***Traffic Characteristics (rate)*** ***Number of connections:*** *For EDSv01, EDSv03: 2 connections (no additional traffic)* ***Traffic Pattern and interarrival time:*** *Not applicable*

The results obtained from the experiments for the two lab EDS test cases are presented below.

For the **EDSv01 Heterogeneous industrial sensor data collection on MEC server**, following the testing procedure described earlier in section 3.3.2, we initially create simulated devices and proceed to register and connect them to the IoT platform. Next, we capture the network traffic between the sensors and the platform by using the tcpdump utility command. Lastly, we analyze offline the data with the Wireshark traffic analyzer tool. Some preliminary measurements were captured and are presented below. In this scenario, we have created 100 virtual sensors and inspected the traffic they generate.

Figure 3-9 shows that the data transmissions taking place during the EDSv test cases are indeed of data-burst type. As shown in Figure 3-10, the typical industrial sensor data rate (red line in the Figure 3-9) features an average value of roughly 11 Kbps, with a maximum value of 54 Kbps and a minimum one at 0 Kbps, as presented in the test case tables earlier.

In addition, as shown in Figure 3-11, the total data rate for 100 industrial sensors (blue line in the Figure 3-9) features an average value of 1.07 Mbps, with a maximum value of 5.40 Mbps and a minimum one at 0 Mbps.

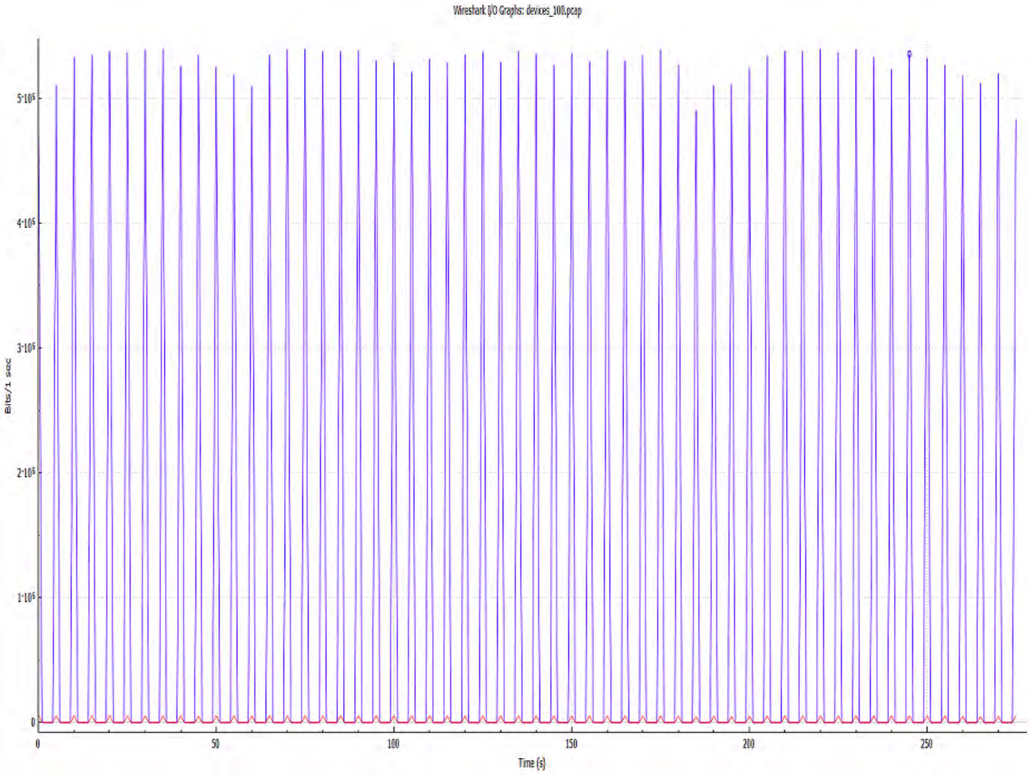


Figure 3-9 Captured traffic between 100 simulated devices and the IoT platform hosted at MEC server with 5G

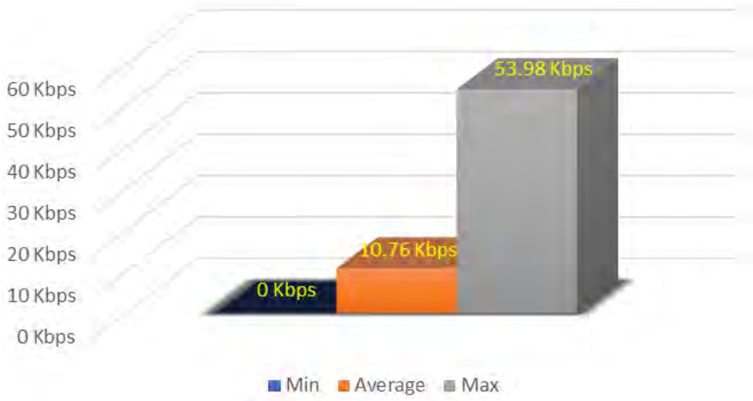


Figure 3-10 Lab testing results: Sensor data rate

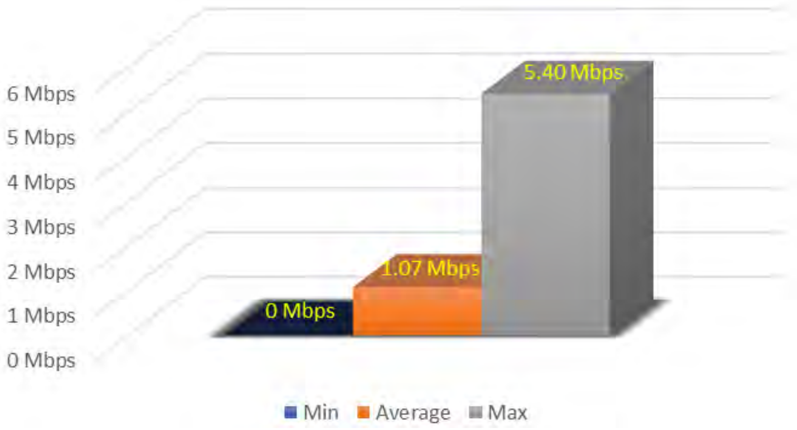


Figure 3-11 Lab testing results: Total device data rate

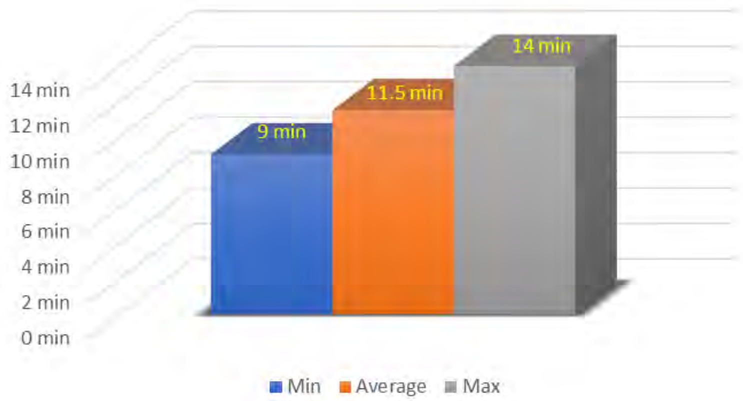


Figure 3-12 Lab testing results: Service deployment time

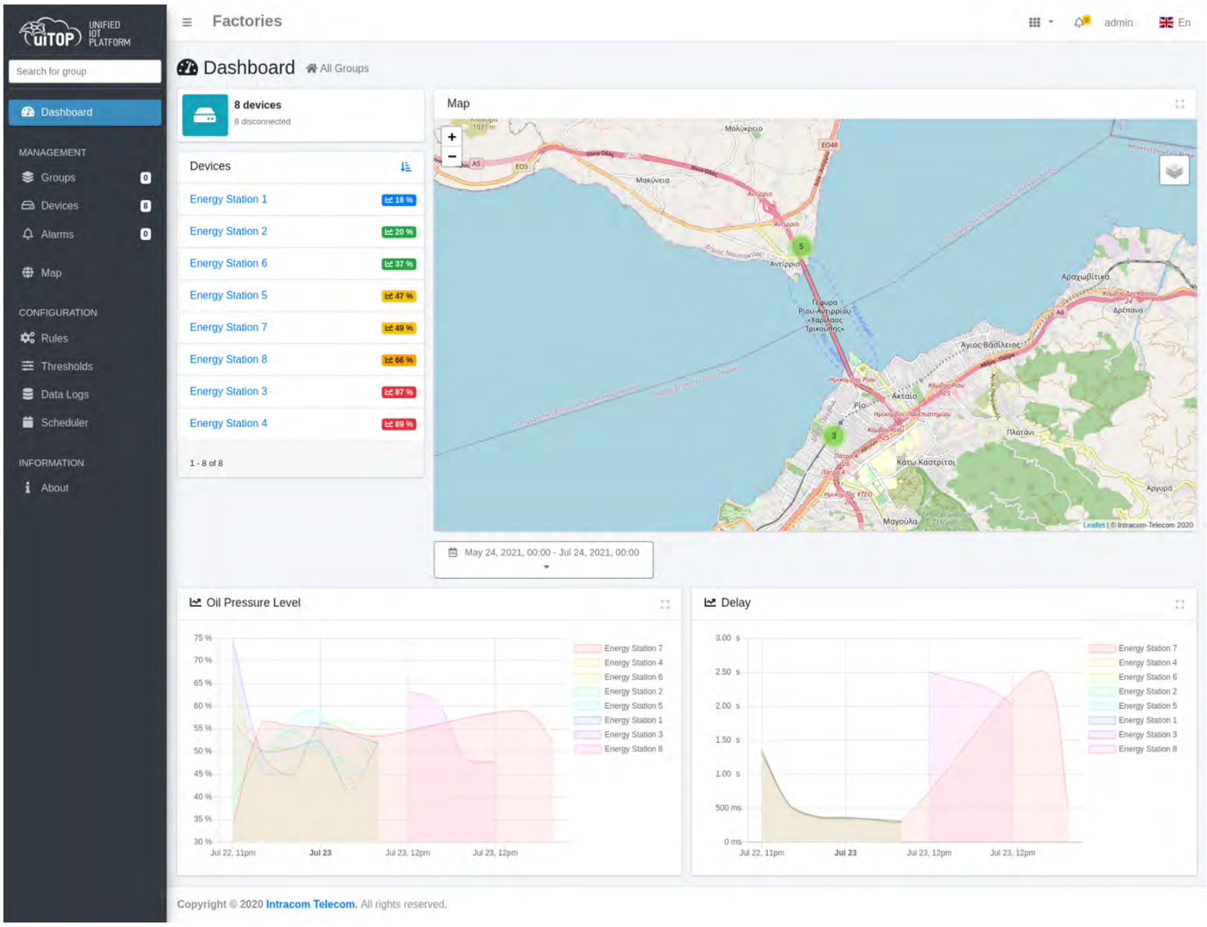
Furthermore, the packet loss ratio (not visible in Figure 3-9) is 0 during this lab test, therefore no graph is shown here.

Finally, the IoT platform VM was deployed over the 5G-VINNI facility through the orchestration layer of OSM at UoP's testbed. The average time required for the VNF's deployment was measured. An average duration of 11.5 minutes was measured as the required time for the VNFs deployment, illustrated in the graph below.

For the **EDSv03 End-to-end Preventive maintenance application deployment**, following the testing procedure described earlier in sections 3.3.2 and 3.3.4, we deployed an instance of the UiTOP platform at a server at the lab. Then, we used one laptop and one Raspberry Pi 4 in order to simulate a number of virtual devices and connected them to the platform via 5G. Lastly, we inspected the incoming data as well as some KPIs of interest through the UiTOP dashboard, as shown in Figure 3-14. With these initial tests, we showcased the correct operation of the UiTOP platform.

Figure 3-13 Lab tests of UiTOP platform. The laptop shown here operates as an industrial sensor connected to the platform through 5G.

Lab results corresponding to performance metrics for the 5G slice that was deployed are summarized in Table 3-13. Performance measurements for UPF and AMF (as defined in section 2) will be performed during field measurements, where the decentralized architecture of deployment Option #2 will be used.



Devices	
Energy Station 1	18 %
Energy Station 2	20 %
Energy Station 6	37 %
Energy Station 5	47 %
Energy Station 7	49 %
Energy Station 8	66 %
Energy Station 3	87 %
Energy Station 4	89 %

1 - 8 of 8

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Figure 3-14 UiTOP dashboard with captured data.

Table 3-13 EDS Lab Testing: E2E (per slice metrics) Performance Results

E2E (per slice metrics)		
Metric	**Description**	**Measurements**
Throughput for Single Network Slice Instance	This KPI describes the downstream throughput of one single network slice instance by computing the packet size for each successfully transmitted DL IP packet through the network slice instance during each observing granularity period and is used to evaluate integrity performance of the end-to-end network slice instance. It is obtained by downstream throughput provided by N3 interface from all UPFs to NG-RAN which are related to the single network slice.	Average: 1.07 Mbps Min: 0 Mbps Max: 5.4 Mbps 100 industrial sensors with sensor report rate = 0.5 Hz, receiving data requests from and sending measurement data to UoP cloud for a 5-minute time period.
QoS flow Retainability	This KPI shows how often an end-user abnormally loses a QoS flow during the time the QoS flow is used.	Not evaluated at lab testing
Packet transmission reliability KPI in DL on Uu	This KPI describes the Reliability based on Packet Success Rate (PSR) Percentage between gNB and UE.	Not evaluated at lab testing

3.3.6 Field Trials

In addition to lab results, some first field trials have successfully taken place during this period for the **EDSv02**. These are also included below. Two different field setups were followed for the trials. The first one was presented earlier in section 3.2.7 and is not included here. Please refer to section 3.2.7 for more information. The second one refers to the testing and verification of the mmWave link installed between the ADMIE facilities at Rio and the 5G-VINNI facilities at UoP campus. For this test, the system setup is illustrated in Figure 3-15 and follows precisely the EDSv02 testing procedure:

Two iperf services, one acting as an iperf client and the other acting as an iperf server, were set up to test the capacity of the mmWave link. One iperf service run at a laptop at ADMIE premises and the other run at UoP Cloud. Some preliminary TCP downlink measurements were measured and are presented in Figure 3-16.

By inspecting the photo, it is clear that the mmWave link can support TCP uplink capacity up to 10 Gbps. Similar results were obtained when we measured the uplink capacity of the link. Finally, we proceeded with testing the round-trip time (RTT) between ADMIE and UoP facilities by using the well-known ping utility command. The results showed that the RTT is less than 1ms, therefore it can be neglected. Overall, all KPIs of interest are satisfied.

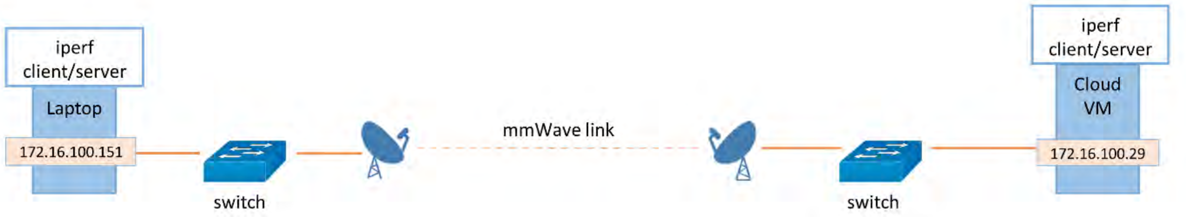
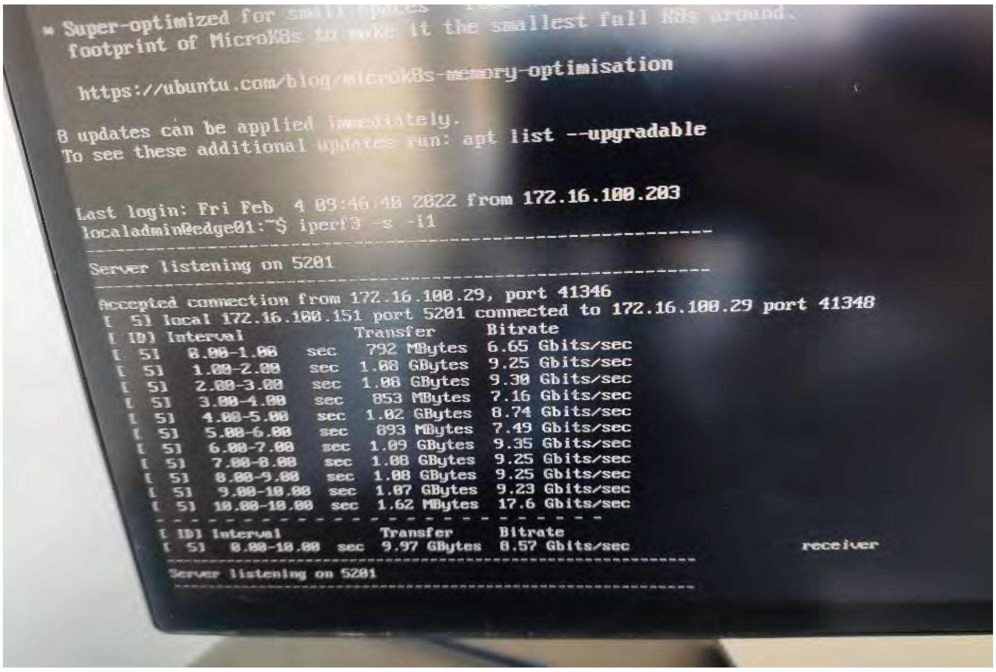


Figure 3-15 Overview of system setup for EDS services field experiment



```
* Super-optimized for small spaces [illegible]
  footprint of MicroK8s to make it the smallest full K8s around.

  https://ubuntu.com/blog/microk8s-memory-optimisation

8 updates can be applied immediately.
To see these additional updates run: apt list --upgradable


Last login: Fri Feb  4 09:46:40 2022 from 172.16.100.203
localadmin@edge01:~$ iperf3 -s -i1
-----------------------------------------------------------
Server listening on 5201
-----------------------------------------------------------
Accepted connection from 172.16.100.29, port 41346
[  5] local 172.16.100.151 port 5201 connected to 172.16.100.29 port 41348
[ ID] Interval           Transfer     Bitrate
[  5]   0.00-1.00   sec   792 MBytes  6.65 Gbits/sec
[  5]   1.00-2.00   sec  1.08 GBytes  9.25 Gbits/sec
[  5]   2.00-3.00   sec  1.08 GBytes  9.30 Gbits/sec
[  5]   3.00-4.00   sec   853 MBytes  7.16 Gbits/sec
[  5]   4.00-5.00   sec  1.02 GBytes  8.74 Gbits/sec
[  5]   5.00-6.00   sec   893 MBytes  7.49 Gbits/sec
[  5]   6.00-7.00   sec  1.09 GBytes  9.35 Gbits/sec
[  5]   7.00-8.00   sec  1.08 GBytes  9.25 Gbits/sec
[  5]   8.00-9.00   sec  1.08 GBytes  9.25 Gbits/sec
[  5]   9.00-10.00  sec  1.07 GBytes  9.23 Gbits/sec
[  5]  10.00-10.00  sec  1.62 MBytes  17.6 Gbits/sec
- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bitrate
[  5]   0.00-10.00  sec  9.97 GBytes  8.57 Gbits/sec                  receiver
-----------------------------------------------------------
Server listening on 5201
-----------------------------------------------------------
```

Figure 3-16 Preliminary TCP downlink measurements over mmWave link

3.4 Energy and factories – Digitization of Power Plants – Patras – Facility CCTV monitoring test cases (EDCv)

3.4.1 Service Description

Industrial infrastructures must be monitored, not only for the security of the facilities themselves but also for the technical personnel to ensure their physical wellbeing and protect them from multiple safety hazards. Power utilities is a special case of such a harsh environment where not only does a high safety risk exists but it is also a critical infrastructure with direct impact on society. Therefore, power utilities need to secure their installed equipment to prolong their health and eliminate any chances for work accidents. To this end, CCTV monitoring of facilities over 5G will provide a solution to this problem by providing live video feed when technical personnel is present or an event occurs, while not compromising other Industry 4.0 applications running in the background.

For the demonstration of this service, one UHD CCTV camera is installed inside the HV cable control room, while a mobile surveillance robot with 5G-enabled connectivity is patrolling outdoors. The components and network setup can be seen in Figure 3-3, where the CCTV slice is indicated with blue color. In the application layer, the cameras and the robot capture images from the interior of the control room and the outdoor facilities respectively and forward them to the MEC server for preprocessing. In case an event is detected (e.g. technical personnel in the room or intruder at the facilities), the video feed will be forwarded towards the UoP Cloud. From there, an alarm will be raised in order to notify the responsible security administrator of ADMIE.

3.4.2 EDCv01: Smart CCTV surveillance over 5G connectivity (lab & field test)

Smart CCTV services involve preprocessing of live video feed at the edge of the network, both from indoors and outdoors through the use of a CCTV camera and a mobile surveillance robot respectively, and transmission of video stream to the cloud only when an event is detected and for the time period it lasts.

Table 3-14: EDCv01 - Smart CCTV surveillance over 5G connectivity (lab & field test)

EDCv01	Smart CCTV surveillance over 5G connectivity (lab & field test)
Testbed	**5G-VINNI Patras**
Description	In this test case, the monitoring equipment located at the ADMIE facility in Rio will be connected through 5G with the MEC server, where dedicated algorithms for personnel/intruder detection will be running. In case any distress signal is raised, an alarm is generated and sent to the UoP cloud in order to notify the responsible security administrator, who can then access the live video feed.
Key Use-case requirements and KPIs	Successful implementation of smart CCTV services CCTV datarate over network around 15 Mbps/camera CCTV streaming latency 150 ms CCTV maximum packet loss ratio 0.5%
Network performance requirements and KPIs	**U-CA-5202** (High Traffic Density) - total capacity offered by a number of access network nodes
Network Functional requirements and KPIs	**S-FU-5303** (Multi-Tenancy) - Delivery of services with the requested QoS to multiple tenants over a single network deployment **S-FU-5307** (On Demand deployment of network services) - Show on demand eMBB service deployment

Components and configuration	**- Components:** 1. MEC server (Autonomous Edge + gNB) 2. CCTV camera 3. Mobile surveillance robot with 5G connectivity 4. Network switch 5. mmWave 10Gbit Link 6. UoP DC **- Configuration:** 1. Configuration of CCTV camera and mobile surveillance robot at ADMIE site and establishing 5G connectivity with the MEC server. 2. Configuration of smart CCTV surveillance service running at the MEC server to listen to video feeds coming from the equipment 3. Setup UoP DC to receive distress signals and notify the security administrator
Test procedure	**- Preconditions:** 1. CCTV camera and mobile surveillance robot up and running 2. Smart CCTV surveillance service up and running **- Test Case Steps:** 1. Start streaming video feed. Configure settings to e.g. reach 15 Mbps. 2. View result. The processed video should contain high information content, meaning events in the control room or outdoors, i.e. technical personnel entering the room, intruder at the facilities.
Measurements	**- Methodology** 1. The CCTV camera and the mobile surveillance robot send pictures to the Smart CCTV surveillance service running on the MEC server. The video streams are processed and alarm signals are sent to UoP DC, in case of an event. The live video feeds' datarates are measured. **- Complementary measurements** 1. Tools like iperf can be used for comparison. **- Calculation process** 1. The video streams' bitrates are measured as the raw video payload stream, not including any network transportation overhead protocols.
Expected Result	The aim is to showcase that smart CCTV surveillance services on an Industry 4.0 environment can be effectively supported by 5G technology.

3.4.3 Lab KPI Results

As a first step for the assessment of CCTV and the mobile surveillance robot, we focused on video latency and uplink bitrate requirements of the service in the lab. The Amarisoft callbox node was used as a gNB using standard configuration (downlink oriented) and 5GC was hosted at the Patras5G cloud network. As it is shown in Figure 3-17, we also used a 5G mobile phone with a video streamer App and adjusted the video bitrate in order to replicate the surveillance robot camera bitrate. The tables below describe the lab network topology and lab testing process characteristics.

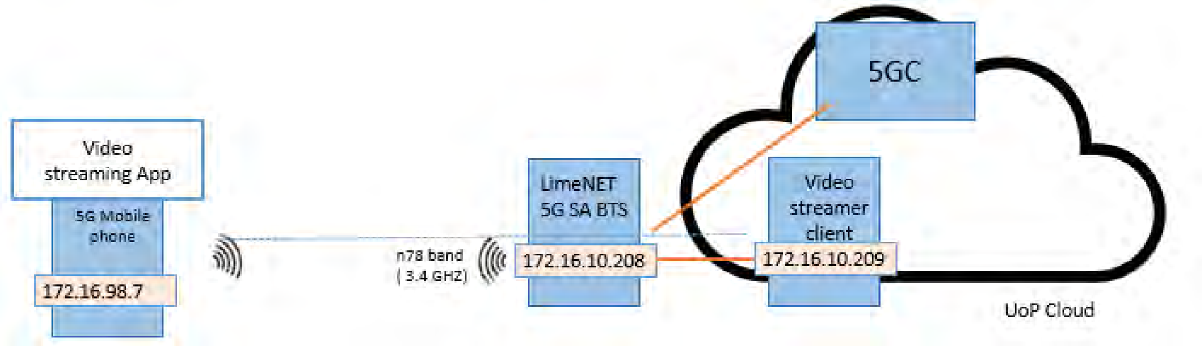


Figure 3-17 Overview of system setup for EDC service lab experiment

Table 3-15 EDV Lab Testing - Network Topology

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

Table 3-16 EDC Lab Testing - Process characteristics

Measurement duration	**Time duration of the measurement [T]:** *10 minutes* ***Repetition time:*** *Not applicable* ***Granularity of measurements:*** *Deployment times: Not applicable* *Latency: in the order of seconds* *Datarates: in the order of Mbps*
Traffic offered in the site	***Traffic Characteristics (rate)*** ***Number of connections:*** *For EDCv01: 1 connection (no additional traffic)* ***Traffic Pattern and interarrival time:*** *Not applicable*

To calculate the video streaming latency between the endpoints, we streamed a live feed from the camera of the mobile phone to a client hosted on the cloud for 10 minutes. We captured the timestamp of a video frame transmitted from the mobile phone and the respective timestamp when it was received by the client application. The experiment resulted in a Min = 0.9 s/ avg = 2.32 s / max latency = 5.01 s which is larger than the target 150 ms. Nevertheless, it must be noted that this metric refers to the E2E delay and incorporates the application processing delay. Different streaming applications and deployment setups will be used during field testing so as to reduce the E2E video streaming delay.

During the experimentation, the uplink bitrate of the channel was also monitored via the Patras5G monitoring tools. The results show a Min = 0.75 Mbps / avg = 7.33 Mbps / max bitrate usage = 12.78 Mbps at the channel and a snapshot of the metric during experimentation (as captured by Netdata monitoring tool) is shown in Figure 3-18. During experimentation there was no available mmWave link. Our next steps are to validate the solution at the field where both static (CCTV camera) and mobile (surveillance robot) 5G endpoints will be used and traffic will be transmitted to the Patras5G facilities through the mmWave connection.

Figure 3-18 ESC Lab Testing - Uplink bitrate usage of the channel

3.4.4 Field Trials

Some preliminary measurements were performed after the establishment of the mmWave link between the University of Patras and ADMIE facilities at Rio. Figure 3-19 depicts footage from the CCTV camera at Rio facilities, accessed through the mmWave link, and Figure 3-20 depicts the bandwidth usage for the one-camera setup.

Figure 3-19 Capture from the CCTV camera accessed by UoP

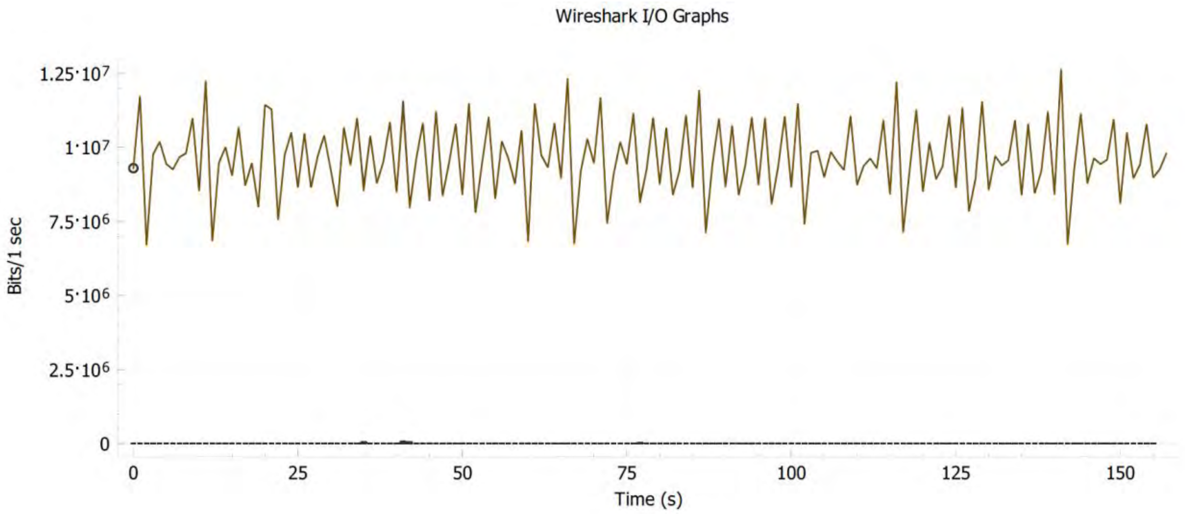


Figure 3-20 Bandwidth usage for one camera setup

3.5 Test combinations at 5G-VICTORI facility in Patras

During the delivery of D3.6 no test combinations were performed for Smart Factory services. In order to test the sustainability of the UC, it is planned that all Smart Factory services will run simultaneously in order to demonstrate how multiple slices dedicated to different services will be deployed over the same private 5G access network. The services considered in the Patras test combinations are the following:

- Real-time monitoring of HV power cable test cases (EDHv).
- Sensor data collection test cases (EDSv).
- Facility CCTV monitoring test cases (EDCv).

The Patras test combinations considered are listed in **Table 3-17**.

Table 3-17 Patras Test-combinations over CDN deployment

Resources and type of services	Resources		Services		
Test Combinations	Network Slicing supported	QoS enabled	EDHv	EDSv	EDCv
REComb01			X	X	
REComb02			X	X	X
REComb03		X	X	X	X
REComb04	X	X	X	X	X

The aim of these test combinations is to evaluate the performance of performance-demanding/ performance-critical applications simultaneously and in various network configurations, namely in configurations where no QoS nor Network Slicing is used and in configurations where QoS and Network Slicing is available.

REComb01 will assume that two out of three services with various performance characteristics will simultaneously be present. Here there is no QoS differentiation, nor any other type of NS configuration for any of the services. Then in RECpmb02 the effect of inserting the third service is being assessed.

For **REComb03**, QoS setting is tailored to the three services/ service categories, and the way that these affect the service performance is assessed.

For **REComb04**, NS configuration over 5G SA will be set and tailored to the specific services, and their performance will be assessed especially when all services are run simultaneously.

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

- NS 1: Facility CCTV monitoring test cases (EDCv)
- NS 2: Real-time monitoring of HV power cable test cases (EDHv) and Sensor data collection test cases (EDSv)

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

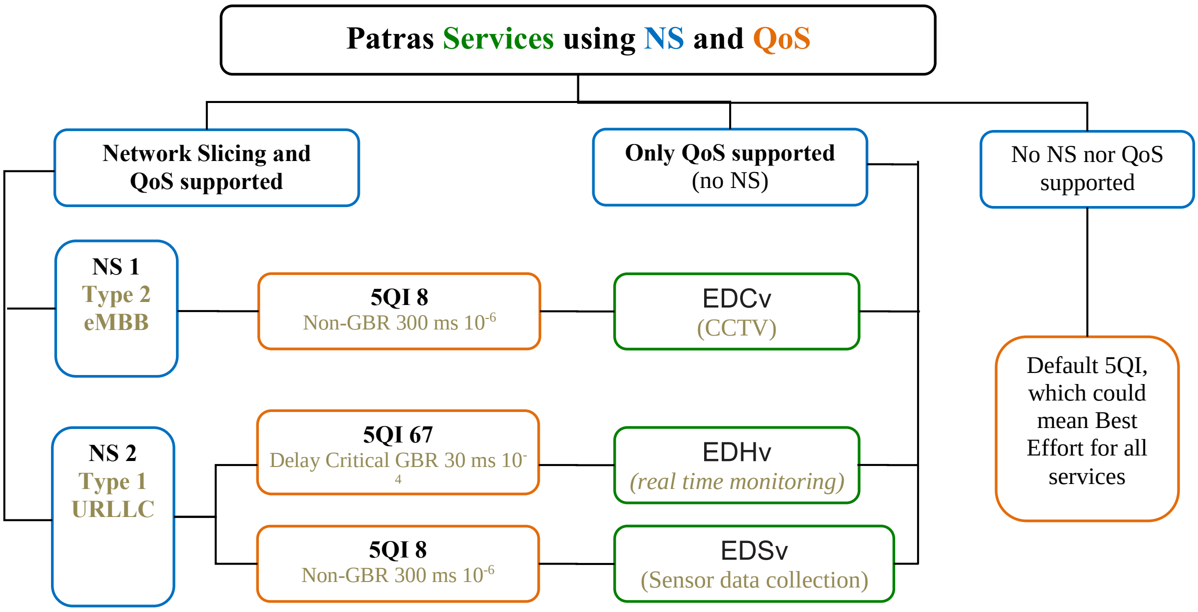


Figure 3-21: Patras Services with and without Network Slicing, plus QoS support.

4 Smart Energy Metering at the 5G-VICTORI facility in Patras

4.1 Description of 5G infrastructure at 5G-VICTORI facility in Patras cluster (Korinthos)

The main aim of the UC is to achieve connectivity between the onboard network and the station server though NR access. When the train approaches the station there is a NR connection between the train station Autonomous Edge and the train. In the meantime, the time series data base at the Autonomous Edge collects data from the relevant metering devices at the **ADMIE** (IPTO) premises, which lies close to the **TRAINOSE** train station.

The diagram in Figure 4-1 provides an overview of the HV Energy use case services and the way they are mapped to 5G and non-5G infrastructure at Korinthos railway station area. Deployment Option #1 is deployed which is based on Autonomous Edge deployment:

- **ADMIE HV substation**: The HV substation located in the vicinity of the railway station, hosts the HV/MV transformer which feeds the Electric Railway with electric power. A Modbus TCP gateway (Honeywell recorder) is used to transform analog electrical readings to digital packets and transmit them over Modbus TCP protocol. A 5G Gateway is used to provide 5G connectivity to the Modbus TCP gateway.
- The deployment architecture comprises a **5G gNB** (access), which will be installed close to the Korinthos substation to provide the required coverage to the train and the HV substation.
- **5G Autonomous Edge deployment**: A mobile box, built for on-demand 5G deployments depending on the verticals' UC requirements [4]. 5G Autonomous Edge comprises 1) the 5G gNB (access) and 2) cloud resources which are able to host the 5GCN and the vertical services. The vertical services (EMS, RMS) may use their own UPF instance to ensure privacy and specific service related KPIs. The network topology is based on the 5G-VICTORI SBA and follows Patras5G deployment option #2, as described in section 3.1.2.
- **Energy Management System (EMS) / Railway Management System (RMS)**: the set of functions and databases supporting the two verticals. Measurements originating from the train and HV substation are collected, stored, and processed by these systems through the underlying 5G NR network deployment.

The following sections present the set of test cases that will assess the performance of different components and functions constituting the deployment and finally the E2E performance of the HV scenario of Smart Energy Metering UC.

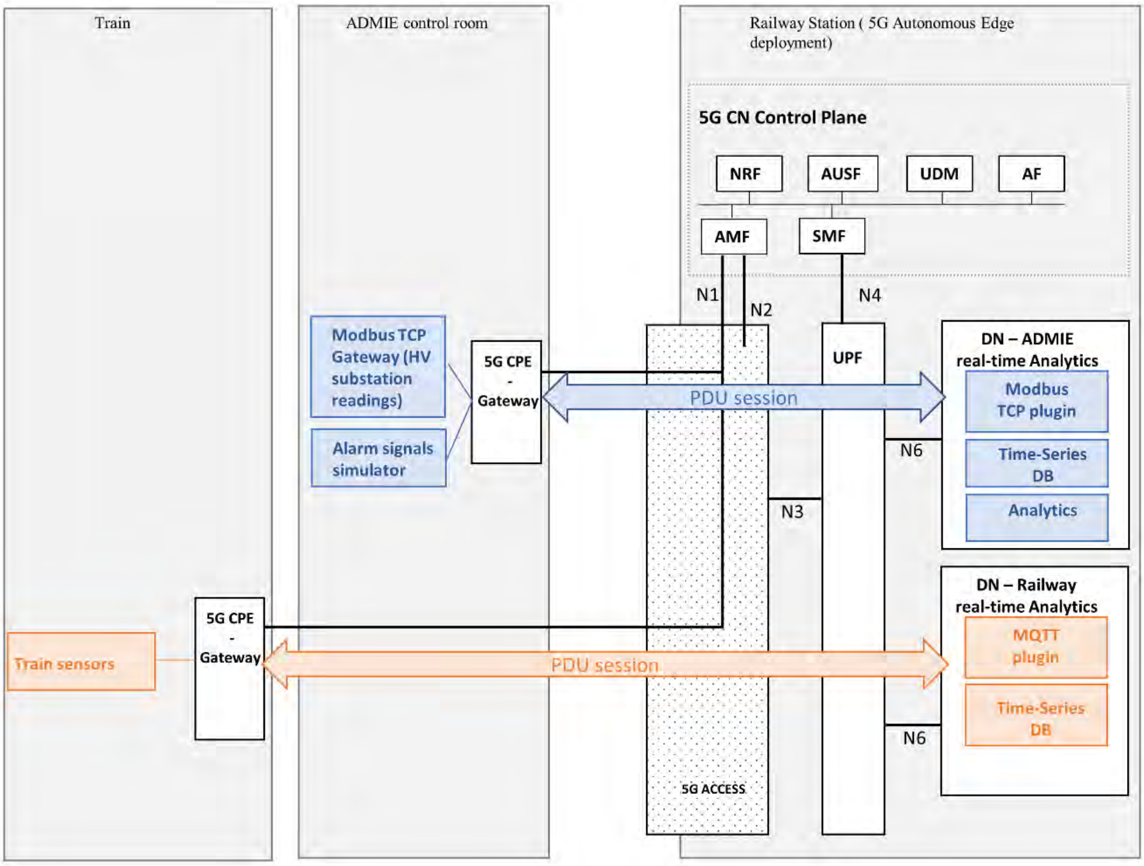


Figure 4-1 HV Energy UC services mapped to Patras-5G infrastructure

4.2 Energy and factories – Smart Energy Metering – Patras – Real-time power consumption test cases

4.2.1 Service Description

Real-time monitoring of power consumption over the traction subsystem is of crucial importance, both for the railway operator and the power transmission system operator. This is due to the nature of the traction system, whose power demand profile exhibits various changes, with constant power surges that stress the traction power network, and consequently the power grid. Thus, it is necessary for railway operators to mitigate these intense power surges, as not only are they able to secure the wellbeing of their equipment, but they can also release the stress of the power network and/or provide auxiliary service to the power grid transmission operator. To this respect, by monitoring the power flows in these subsystems, the railway and power utility operators will be able to identify voltage fluctuations and develop specific energy profiles in order to mitigate them. Moreover, by leveraging the information regarding the current status and profile of the railway system, the power utility operator will be able to perform more accurate prediction on the energy demand (energy forecasting) or even use the railway system as flexible load. The objective of the specific test cases is to verify that 5G technology can sufficiently support the networking requirements of such a railway/energy management system and is compatible with both FRMCS and smart grid standards.

4.2.2 ESCv01: Energy Management System (EMS) integration at the MEC server (lab test)

From the Transmission Operator point of view (**ADMIE**), an IoT solution service must be deployed for the collection of measurements, originating from the HV substation. The IoT solution must be customized according to HV substation equipment requirements and satisfy the UC KPIs. The test case is described in Table 4-1.

Table 4-1: ESCv01 - Energy Management System (EMS) integration at the MEC server (lab test)

ESCv01	Energy Management System (EMS) integration at the MEC server (lab test)
Testbed	**5G-VINNI Patras**
Description	The initial test case aims at the preparation and the correct configuration for the integration of the chosen data management solution (UiTOP) as a VNF over the Patras5G facility. It will verify the functionality of the platform by testing it in a lab setup through virtual sensors with Ethernet interface and will also validate the easiness and speed of deployment.
Key Use-case requirements and KPIs	Guaranteed max End-to-End Latency
Network performance requirements and KPIs	**U-PE-4201** - E2E latency for HV Energy Metering service (in ms) - measures packet round trip time from IoT platform to device sensor. <20 ms **U-PE-4202** - Packet loss – shows the percentage of packets lost during transfer between sensors and IoT platform. $<10^{-5}$
Network Functional requirements and KPIs	**S-FU-4302** - Mobile Edge Computing Capabilities **S-FU-4303** - Multi-Tenancy **S-FU-4304** - Slicing **S-FU-4306** - On Demand deployment of network services
Components and configuration	**- Components:** 1. UiTOP platform 2. Autonomous Edge (MEC) 3. Modbus TCP client simulator providing the needed data (kV, A, MW, MVar) and replicating the device's message format **- Configuration:** 1. Configure the data management platform time-series database for the specific recorder (type of data, time resolution etc.) 2. Configure the custom plugins for communication with the specific recorder used in the HV substation (Honeywell). Protocol used is Modbus TCP. 3. Deploy data management platform (UiTOP) as VNF over the Edge Cloud hosted on Autonomous Edge. 4. Configure a Modbus TCP recorder simulator to replicate Honeywell setup and message format.

Test procedure	**- Preconditions:** 1. UiTOP platform is pre-configured with the Use Case specific databases and device plugins and packed as a VM. 2. Autonomous Edge is configured **- Test Case Steps:** 1. User logs in to the 5G-VINNI Orchestration Platform 2. User requests application on-boarding to the Autonomous Edge. 3. The deployment time is measured 4. User requests the deployment of the Honeywell recorder simulator 5. Honeywell recorder simulator sends raw data to the data management platform via Ethernet link 6. Modbus TCP plugin translates raw data to meaningful time-stamped information 7. Time-stamped information is stored at the corresponding time-series databases 8. Datarate and time difference between the measurement time-stamp and time of storage to the database are measured.
Measurements	**- Methodology** 1. For the estimation of the on-boarding time, UoP will provide their network monitoring tools which will analyze the network state to capture the necessary information. 2. For the estimation of the latency imposed by the application, total latency can be measured as the difference of the measurement timestamp originating from the device (and captured as a field of the measurement) and the current time of saving to the time-series database **- Complementary measurements** 1. N/A **- Calculation process** 1. For the estimation of the on-boarding time, the monitoring tools will measure the time between the instant the vertical user asked for the service instantiation until the instant the service is in operating state. 2. For the estimation of the latency imposed by the application, total latency can be measured as the difference of the measurement timestamp originating from the device (and captured as a field of the measurement) and the current time of saving to the time-series database 3. For the calculation of network latency, sets of ping requests will be performed between the endpoints
Expected Result	The aim of this test case is to validate the platform's functionality and evaluate its performance, while ensuring that performance indicators fall within the thresholds described above.

4.2.3 ESCv02: HV substation physical sensors integration (field test)

As a continuation of the previous test case, the integration of the sensing equipment located at the HV substation to the IoT solution service must be also tested and verified. Table 4-2 presents the test case.

Table 4-2: ESCv02 - HV substation physical sensors integration (field test)

ESCv02	HV substation physical sensors integration (field test)
Testbed	**5G-VINNI Patras**
Description	In this test case the physical measurement devices located at the HV substation at Korinthos will be connected with the Autonomous Edge and the

	EMS. The objective of this test case is to validate that the platform is compatible with the legacy equipment of the HV substation, and then measure the communication latency imposed by the physical network interfaces and the deployed 5G private network. Since the 5G private network shall be available only when the train approaches the train station, 5G network deployment time will be also assessed.
Key Use-case requirements and KPIs	Guaranteed max End-to-End Latency Reliability > 99.99% (SIL 2) Availability > 99.99% (SIL 2)
Network performance requirements and KPIs	**U-PE-4201** - E2E latency for HV Energy Metering service (in ms) - measures packet round trip time from IoT platform to device sensor <40 ms **U-PE-4202** - Packet loss – shows the percentage of packets lost during transfer between sensors and IoT platform <10^{-5}
Network Functional requirements and KPIs	**S-FU-4302** - Mobile Edge Computing Capabilities **S-FU-4303** - Multi-Tenancy **S-FU-4304** - Slicing **S-FU-4306** - On Demand deployment of network services
Components and configuration	**- Components:** 1. UiTOP platform 2. Autonomous Edge (MEC) 3. Honeywell Recorder at HV substation 4. Ethernet Switch 5. Huawei 5G CPE **- Configuration:** 1. Connectivity between components performed as in Figure 4-1 a. 5G network deployed b. Honeywell Recorder connected to the Huawei 5G CPE 2. Deploy UiTOP VNF on the Autonomous Edge 3. Configure UiTOP to request data from the Honeywell Recorder (specify IP, port, datarates).
Test procedure	**- Preconditions:** 1. UiTOP platform is pre-configured with the Use Case specific databases and device plugins and packed as a VM. 2. Autonomous Edge is configured. 3. UiTOP is deployed 4. 5G network is deployed. **- Test Case Steps:** 1. Through the customized Modbus TCP plugin, UiTOP performs measurement collection request to the Honeywell recorder. 2. The recorder sends back a Modbus TCP response. 3. The response payload is transformed to meaningful data, stored at the time-series database and plotted on the UiTOP customized dashboard. 4. UiTOP Modbus TCP plugin is configured for different datarates.
Measurements	**- Methodology**

	1. Test procedure is repeated several times with different report datarates. 2. Measurements are collected for a number of iterations (~5 iterations need) for the evaluation of each KPI for each set of test conditions. 3. Erroneous measurements to be discarded from the measurements. **- Complementary measurements** 1. Reliability (%) - 99.99 % 2. Availability (%) - 99.99 % **- Calculation process** 1. For the validation of the correction in measurements collection: a. measurements presented in the UiTOP dashboard can be easily compared against the values presented on the Honeywell screen. 2. For the latency measurements: a. UiTOP creates and stores a timestamp during the measurement data request. b. UiTOP attaches a measurement collection timestamp during the measurement saving to the database. c. Latency can be calculated as the time difference between the two timestamps
Expected Result	The aim of this test case is to show that the EMS platform is compatible with the legacy equipment of the HV substation, while ensuring that performance indicators fall within the thresholds described above.

4.2.4 ESCv03: RMS platform integration and deployment (lab & field test)

This set of test cases focuses on the testing of the RMS platform under realistic conditions. The main objective of the selected UCs is to verify that the system complies with KPIs set by the railway operator and the services offered are reliable and operate as expected. In addition to this, another important aspect that will be also addressed is associated with evaluation of the performance range (minimum and maximum values) of the system to ensure that the service will be offered to the users with specific capabilities performance guarantees.

To achieve this, we initially identify the basic functional and performance parameters relevant to the RMS platform that will be tested. We also define parameters that will be kept constant throughout the testing process as well as parameters that cannot be controlled (i.e. propagation conditions) and introduce uncertainty in the results obtained. Finally, a detailed description of the testing methodology followed covering all aspects of the service to be provided (including on-board HW installation, 5G network specifications, network topologies, etc.) will be provided allowing reproducibility of the results obtained.

Table 4-3: ESCv03 – RMS platform integration and deployment (lab & field test)

ESCv03	RMS platform integration and deployment (lab & field test)
Testbed	**5G-VINNI Patras**
Description	This test case focuses on the functional and performance evaluation of the RMS system under various network settings and traffic conditions. To achieve this, a variety of sensors will be installed on-board measuring energy and kinematic parameters of the train. These measurements will be transmitted to the trackside over a private 5G network hosted in the autonomous edge. For performance stress testing purposes, measurements from emulated sensors (implementing the full protocol stack used in the actual hardware sensors) will be also transmitted allowing the functional and performance testing of the system. Functional testing will validate that network connections are

	appropriately established (devices can be registered to the appropriate network slice, PDU sessions can be established and information can be transmitted) whereas performing testing will focus on the measurement of parameters related to packet transmission delay, throughput, packet loss ratio and jitter.
Key Use-case requirements and KPIs	Services offered by the RMS have strict requirement in terms of latency and reliability as it is used in the development of intelligent train systems. The relevant KPIs to be evaluated include: Max. allowed end-to-end latency < 20ms Reliability > 99.9999% (SIL 4) Availability > 99.9999% (SIL 4) Data rate per measurement point > 10 Mbps Density >400 sensors per train (depending on the train, expected to exceed 1000 in the next 5 years)
Network performance requirements and KPIs	**U-PE-4201** - E2E latency for the RMS (in ms) - measures packet round trip time from IoT platform to device sensor. <20 ms **U-PE-4202** - Packet loss – shows the percentage of packets lost during transfer between sensors and IoT platform. $<10^{-5}$
Network Functional requirements and KPIs	**S-FU-4302** - Mobile Edge Computing Capabilities **S-FU-4303** - Multi-Tenancy **S-FU-4304** - Slicing **S-FU-4306** - On Demand deployment of network services
Components and configuration	**- Components:** 1. IASA and/or UiTOP metering/monitoring platform 2. Hardware sensors: High Performance Data acquisition platform monitoring power consumption, train kinematic parameters, 3-axis acceleration, vibration, track condition 3. Emulated sensors: Software emulated devices implementing the same protocol stack with the HW sensors. Emulated sensors are hosted in VMs or physical machines (x86 CPUs) 4. On-board MEC platform 5. Ethernet switch aggregating traffic flows from sensors 6. 5G gateway 7. Trackside installed Autonomous Edge (MEC) **- Configuration:** 1. Connectivity between components performed as in Figure 4-1 a. 5G network deployed b. HW and emulated sensors connected to the 5G gateway 2. Deploy metering platform as VNF on the Autonomous Edge 3. Assign RMS -related connections to appropriate slice 4. Configure PDU sessions interconnecting on-board 5G gateway with the 5G network installed at the trackside using the appropriate QoS specifications (QFI values) 5. Establish end-to-end connections between the installed sensors and the MEC where metering/monitoring platform is hosted. This requires configuration of the physically installed sensors and emulated devices to transmit measurements to specific IP, port (where UiTOP listens), VLAN etc and with specific sampling rates/data rates.
Test procedure	**- Preconditions:** 1. 5G network (5G-RAN/5G-CORE) is deployed and pre-configured. 2. 5G CPE has been registered in the database (UDR), AMF/SMF has been configured, QoS rules have been ported at the UPF. Network slices have been created.

	3. Connection establishment between the 5G network and the MEC platform hosting the metering/monitoring platform (UiTOP or platform provided by IASA) 4. The metering/monitoring platform is pre-configured with the Use Case specific databases and device plugins and packed as a VM/container. 5. The application server (metering platform) is deployed and ready to receive connection requests. 6. Different traffic conditions and data rates are defined. **- Test Case Steps:** *Basic Functionality Testing* 1. Test network connectivity between the on-board sensors and the 5G access network. Validate if the on-board 5G-CPE has been successfully associated with the trackside gNB and information is exchanged correctly 2. Test network connection between the 5G-CPE and the application server (i.e. UiTOP) 3. Test network connection to the synchronization server 4. Test connectivity between the sensors and the measurement server installed at autonomous edge 5. Start transmission of measurements to the autonomous and verify that the payload is decoded, stored and successfully visualized to the monitoring platform. 6. Test that sensor connectivity has been established through the appropriate tunnels and information flow is marked with the suitable QoS indicators (QFI) 7. Test that connections between the sensors and the application server can be successfully terminated. 8. Test that resources used during PDU session have been successfully released. *Performance testing: System stress testing* 1. Evaluate the performance of the system (in terms of latency, throughput, jitter, session establishment time, session release time, network availability) under different number of sensors keeping all other parameters constant 2. Evaluate the performance of the system under different sensor payloads (number of measurements transmitted using a single message) 3. Evaluate the performance of the system under different sensor sampling rate 4. Evaluate the performance of the system under different traffic models (period, aperiodic traffic) 5. Evaluate the performance of the system under different distances between the 5G-CPE and the 5G-RAN 6. Evaluate the performance of the system under different distances between the 5G-CPE and the 5G-RAN and different mobility speeds
Measurements	**- Methodology** Performance testing is carried out over two differing testing environments: • Laboratory environment over which all components of the system are installed at IASA/NKUA lab using the same network topology, HW and SW components. Propagation models between gNBs and 5G-CPE are emulated using programmable RF-signal attenuators. • Close to Real world environment testing where all components are installed and evaluated over an actual train. The relevant measurement campaign is performed at TRAINOSE main testing facilities (specific tracks used for testing train performance after maintenance)

	Test procedures are repeated several times with different traffic conditions, train speeds and system configurations (data rate). Results are collected and based on their variability additional tests are performed. **- Complementary measurements** • Reliability (%) - 99.9999 % • Availability (%) - 99.9999 % **- Calculation process** Measurements are collected using appropriate network monitoring tools, i.e. Wireshark, for network monitoring, Prometheus for cloud monitoring, dedicated 5G network monitoring platform Parameters are calculated following the relevant standards including [ETSI TS 128 554] • the mean number of PDU sessions that are successfully established in a network slice. • Virtualised Resource Utilization of Network Slice Instance • PDU session establishment time • QoS flow Retainability • Downlink, uplink throughput Average packet transmission delay through the RAN part to the UE.
Expected Result	The aim of this test case is to show that the RMS can be used to facilitate the operation of future intelligent railway transportation systems.

4.2.5 ESCv04: EMS / RMS interconnection (lab & field test)

After having tested the EMS and RMS platforms individually, the next step is to verify their operation over a shared MEC infrastructure, showcasing multi-tenancy capabilities and isolated interaction between the vertical owner and their own VNF. In addition, appropriate APIs must be established to enable the interconnection of the two platforms – VNFs during operation in real-time, with well-defined message formats, for the exchange of important information such as power consumption data and commands.

Table 4-4: ESCv04 - EMS / RMS interconnection (lab & field test)

ESCv04	EMS / RMS interconnection (lab & field test)
Testbed	**5G-VINNI Patras**
Description	The 5G facility needs to support simultaneously multiple tenants and multiple services, with various QoS, requirements, etc., over a single infrastructure. The objective of this test case is to demonstrate that both management systems (EMS and RMS), owned by different departments can be hosted at the same cloud infrastructure as isolated vertical applications. - Data privacy must be validated as each Operator has access only at his own Management System - Data correlation and Information exchange between the two vertical industries is executed via well-defined APIs and rules
Key Use-case requirements and KPIs	Guaranteed max End-to-End Latency Enabling multi-tenancy over shared MEC infrastructure
Network performance requirements and KPIs	N/A
Network Functional requirements and KPIs	**S-FU-4303** - Multi-Tenancy **S-FU-4302** - Mobile Edge Computing Capabilities **S-FU-4304** – Slicing **S-FU-4307** – Synchronization

Components and configuration	**- Components:** 1. UiTOP platform 2. IASA IoT platform 3. Autonomous Edge (MEC) 4. Honeywell Recorder at HV substation 5. Ethernet Switch 6. Huawei 5G CPE 7. High Performance Data acquisition platform monitoring power consumption, train kinematic parameters, 3-axis acceleration, vibration, catenary 8. On-board MEC platform with integrated gateway **- Configuration:** 1. Connectivity between components performed as in Figure 4-1 a. 5G network deployed b. Connectivity between all sensing devices installed on-board and the acquisition system. c. Connectivity of the acquisition platform with the on-board gateway. d. Honeywell Recorder connected to the Huawei 5G CPE 2. Deploy UiTOP platform for each vertical tenant on the Autonomous Edge 3. Configure acquisition devices to transmit to specific IP, port (where UiTOP listens), and with specific data rates using the MQTT protocol. 4. Configure EMS to request data from the Honeywell Recorder (specify IP, port, datarates).
Test procedure	**- Preconditions:** 1. On-board installation of the data acquisition system including installation of sensors to the appropriate locations (Status: completed, sensors have been installed at a Siemens Desiro Train operated by TRAINOSE) 2. Honeywell recorder is installed and operational at the HV substation, where the trial takes place 3. UiTOP platform is pre-configured with the Use Case specific databases and device plugins and packed as a VM (registration of sensors and metering parameters 4. Autonomous Edge is configured. 5. 5G network is deployed. 6. Different sampling rates are defined. **- Test Case Steps:** 1. Initial field testing over LTE • Transmission of measurements from the train to the ground (MEC node provided by IASA/NKUA) over LTE • Information is stored on a cloud based data management system provided by IASA/NKUA and plotted on Grafana dashboard. • Testing of the system over the line interconnecting Piraeus Port with the Athens International Airport (El. Venizelos) 2. Actual field testing over 5G • Transmission of measurements to the autonomous edge node provided by UoP hosting UiTOP • Testing of train to ground transmission using the 5G system provided by UoP • Compare the performance of the 5G system with the LTE in terms of packet latency and throughput

Measurements	**- Methodology** 1. Test procedure (in the fields): Multiple message transmissions over multiple train routes. 2. All packet traces are preserved to calculate packets delays, throughput, packet loss rate, etc. **- Complementary measurements** 1. Reliability (%) - 99.99 % 2. Availability (%) - 99.99 % **- Calculation process** 1. To calculate the performance of the control plane packets involved in the relevant processes (i.e. gNB association, UE association, etc) are preserved and the relevant KPIs are estimated. The analysis of the packet traces is performed using tShark (a CLI version of Wireshark) 2. Data plane analysis in terms of throughput, PDU session establishment time, packet latency, etc. using Prometheus and tShark 3. Validation of transmitted measurements throughout the comparison of a local copy of the database (installed on-board) and a copy of database hosted MEC nodes placed at the ground
Expected Result	The two platforms should be completely isolated, ensuring data privacy and fulfilling their specific QoS and requirements over the same 5G infrastructure.

4.2.6 Lab KPI results

Prior to the execution at a real industrial environment, testing has been performed in a laboratory environment with the use of simulated data. For the Smart Energy use case, the solution comprises two platforms (RMS, EMS), which must be able to operate independently over a common infrastructure (network / computing resources) and exchange information when needed. As a first step, the two platforms are validated in the lab, using different 5G deployments (offered by Patras5G and IASA respectively).

4.2.6.1 EMS lab experimentation

The EMS lab experimentation was performed at Patras5G laboratory and follows the deployment option #1 (SA 5G architecture based on Amarisoft solutions). The Patras5G Autonomous Edge solution used in the lab (which will be used also in the final field deployment), comprises a 5G gNB and an edge-cloud where 5GC and the EMS are instantiated. Table 4-5 and Figure 4-2 below describe the lab setup.

Table 4-5 ESC Lab Testing - Network Topology for EMS

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

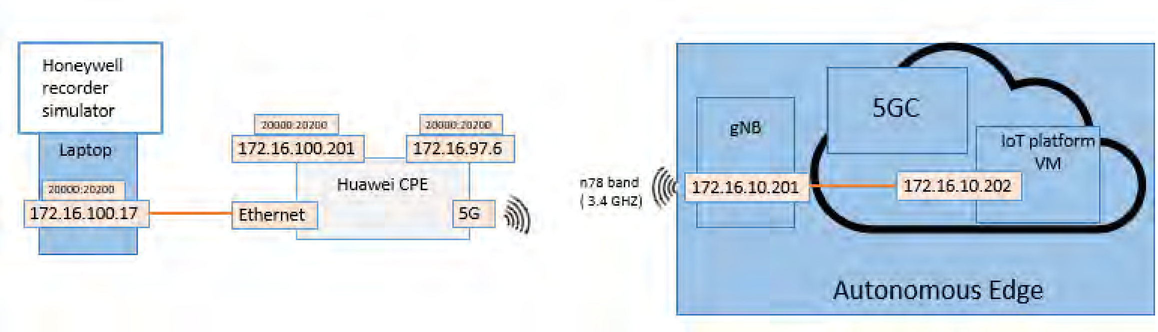


Figure 4-2 Overview of system setup for ESC EMS lab experiment

Table 4-6 EMS Lab Testing - Process characteristics

Measurement duration	**Time duration of the measurement [T]:** *N/A* ***Repetition time:*** *For ESCv01: 1000 Modbus TCP requests* *100 repetitions of 5G slice deployment time* ***Granularity of measurements:*** *Deployment time: In the order of seconds, Latency: in the order of ms, Data rates: in the order of Kbps*
Traffic offered in the site	***Traffic Characteristics (rate)*** ***Number of connections:*** *For ESCv01: 1 connection with multiple measurements (no additional traffic)* ***Traffic Pattern and inter-arrival time:*** *Frequent data bursts*

The main objective of lab testing was to validate that the different components forming the EMS solution can be supported sufficiently by the Autonomous Edge solution. Since we rely on deployment option #1 for the lab experimentation of EMS, the measuring process is detailed in Table 4-6.

For the test case **ESCv01: Energy Management System (EMS) integration at the MEC server**, firstly, we measured the data rate of a typical Honeywell recorder. In this sense, we replicated the traffic pattern of the recorder and reproduced it with a Modbus TCP simulator. The traffic pattern follows a pattern of frequent data bursts of small size (~100Kbps). Network latency was measured through 1000 ping requests between the endpoints and resulted in min= 14.2 ms / mean 37.4 ms / max 75.8 ms network latency. The E2E latency of the EMS monitoring application resulted to a mean value of 246 ms, but it is mostly impacted by processing delays during measurements interpretation and storage.

For the HV scenario, the EMS application must be always up and running in order to perform analytics to the received measurements and adjust the energy profile of the substation. On the contrary, HV substation measurements are useful only if they are correlated with train related measurements. So, the 5G network is useful only when the train approaches the HV substation. The second important metric for this use case is to measure the deployment time of the 5G network. By using the previous setup, we perform 100 start requests to the gNB and measure the time difference between the start request and the time instant at which the endpoint (laptop hosting the simulator) answers to ping requests. For 100 start requests the endpoint was reconnected and replied to the ping request after min=9.52 s / mean 10.21 s / max 10.48 s.

Table 4-7 ESC Lab Testing: E2E (per slice metrics) Performance Results - Patras5G deployment option #1

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

Average e2e delay for a network slice	This KPI describes the average e2e UL packet delay between the PSA UPF and the UE for a network slice.	Average: 37.4 ms, 1000 packets sent through ping request (default packet size – 32 bytes)
Throughput for Single Network Slice Instance	This KPI describes the downstream throughput of one single network slice instance by computing the packet size for each successfully transmitted DL IP packet through the network slice instance during each observing granularity period and is used to evaluate integrity performance of the end-to-end network slice instance. It is obtained by downstream throughput provided by N3 interface from all UPFs to NG-RAN which are related to the single network slice.	102 Kbps
QoS flow Retainability	This KPI shows how often an end-user abnormally loses a QoS flow during the time the QoS flow is used.	Not evaluated at lab testing
Packet transmission reliability KPI in DL on Uu	This KPI describes the Reliability based on Packet Success Rate (PSR) Percentage between gNB and UE.	Not evaluated at lab testing
Average network jitter for the network slice	This KPI describes the differential time between the packet actual arrival time and its expected arrival time according to a standard clock.	Not evaluated at lab testing

4.2.6.2 RMS lab experimentation

To perform the relevant experiments at IASA's laboratory, a 5G testbed has been deployed over a virtualized cloud environment allowing accurate estimation of network and compute resources consumed during the establishment of new User Equipment (UE) connections. The 5G SA version of OpenAirInterface (OAI) provided by EUR has been deployed in the private cloud infrastructure, as shown in Figure 4-3.

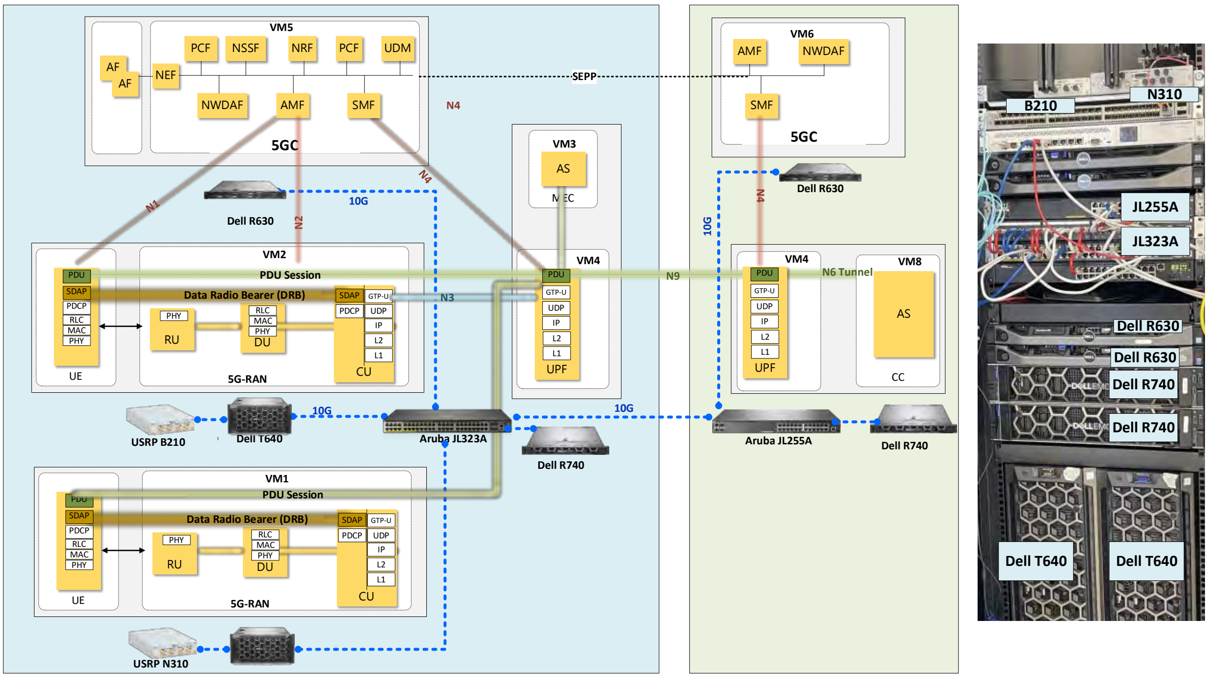


Figure 4-3 IASA 5G-SA experimental platform

In this environment, we consider the private 5G platform (shown in the blue box) comprising a set of softwarized RAN and core elements. These are hosted at physically separated servers. An Application Server (AS) has been also deployed at a different server. 5G UEs based on the Rel.16 RM500Q sub-6GHz module have been used to request access to the AS. The RUs has been implemented using N310 and B210 USRPs. All compute nodes are physically interconnected with an Aruba JL323A. An OAI based 5G SA Core platform has been also deployed having some basic 5G functionality (for our experimental purposes we deployed only AMF, SMF and UPF elements). These elements are hosted in physically separated machines through an Aruba JL255A. Both switches are interconnected using a 10G point to point link. Network/compute resource utilization metrics have been collected through the monitoring platform Prometheus and have been visualized using Grafana.

Typical samples of the traffic generated by each metering device, reaching the UPF in VM4 and, finally terminated at the AS in VM 3 is shown in Figure 4-4. The relevant measurements have been carried out under different number of connected devices and different payload per transmitted message (depending on the sampling rate and the number of channels monitored per device).

In the following tables (Table 4-8, Table 4-9) the performance of the different components of the 5G system under different metrics are provided.

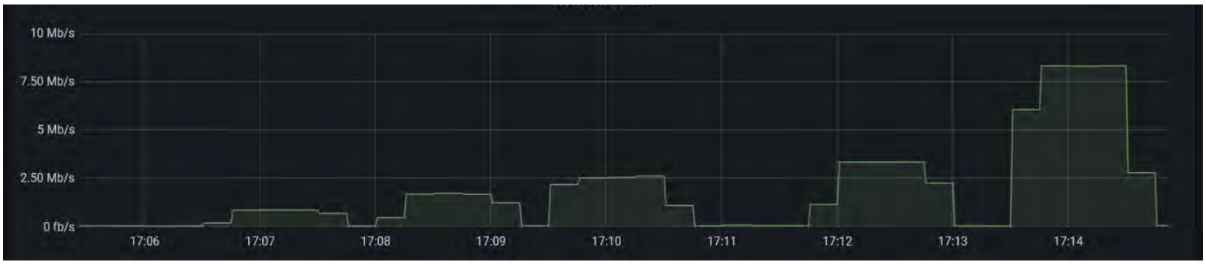
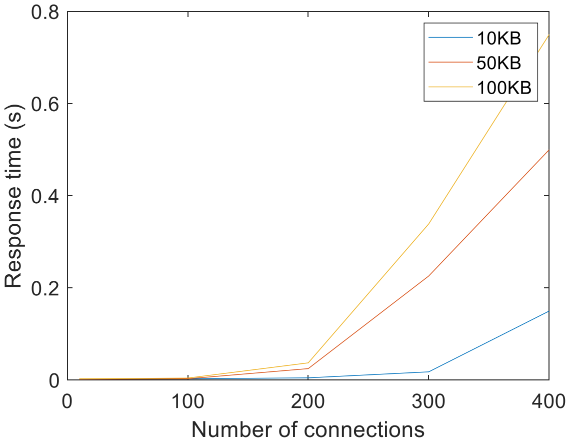


Figure 4-4 Traffic patterns

Table 4-8 Performance measurements for gNB under different deployment options

Performance measurements for gNB under different deployment options			
Metric		**Description**	**Measurements**
Delay	Average message UL delya over-the-air interface	This measurement provides the average (arithmetic mean) over-the-air packet delay on the uplink. It calculates under different number of measuring devices (connections) and payload size (volume of measurements collected over a period of 1s) the average message delay.	

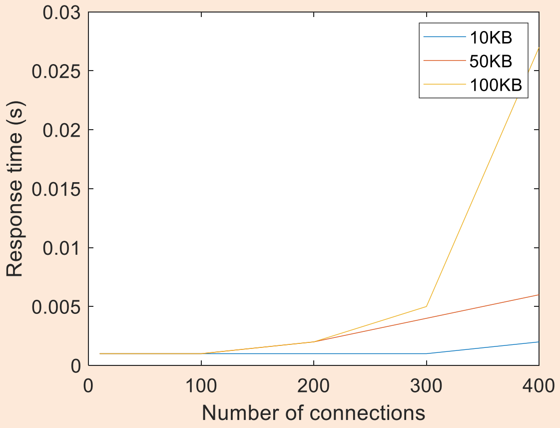
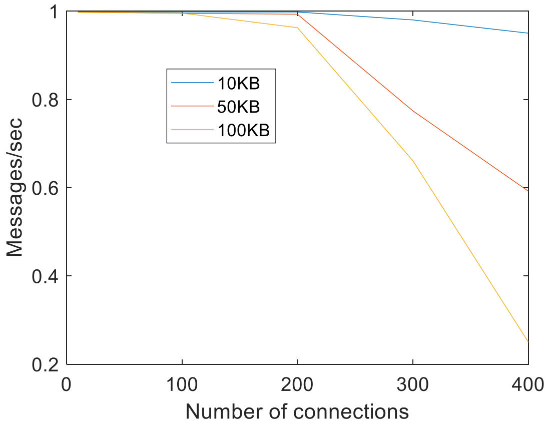
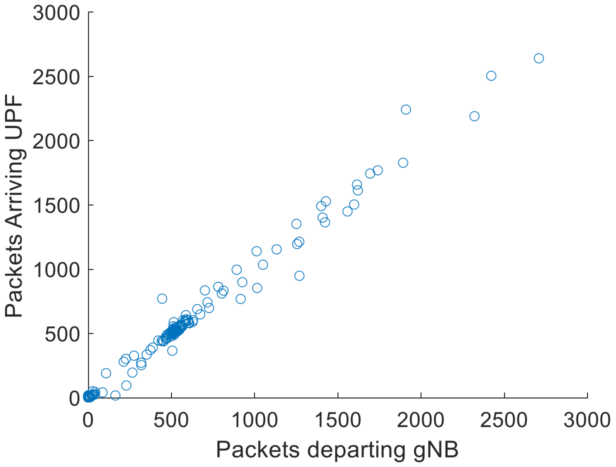
	Average message UL delay between NG-RAN and UPF	This measurement provides the average (arithmetic mean) message delay from the gNB to the UPF.	
UE throughput	Average DL UE throughput in gNB	This measurement provides the average UE throughput in downlink for different message size	

Table 4-9 Performance measurements for UPF

Performance measurements for UPF			
Metric		**Description**	**Measurements**
N3 interface related measurements	Number of incoming GTP data packets on the N3 interface, from (R)AN to UPF	This measurement provides the number of GTP data PDUs on the N3 interface which have been accepted and processed by the GTP-U protocol entity in UPF on the N3 interface	

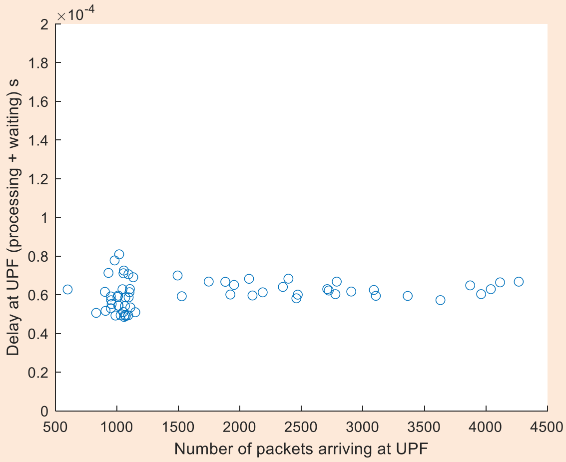
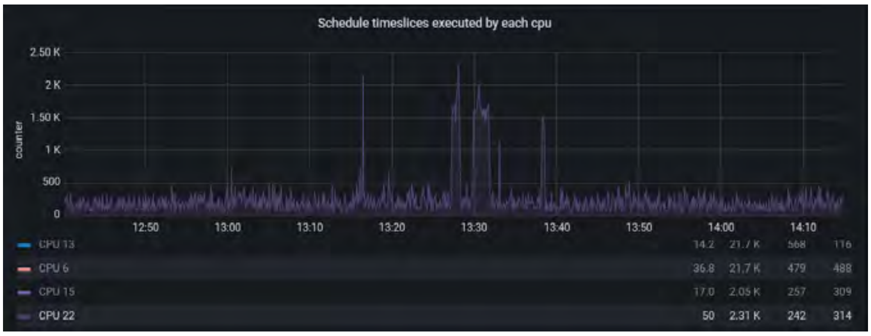
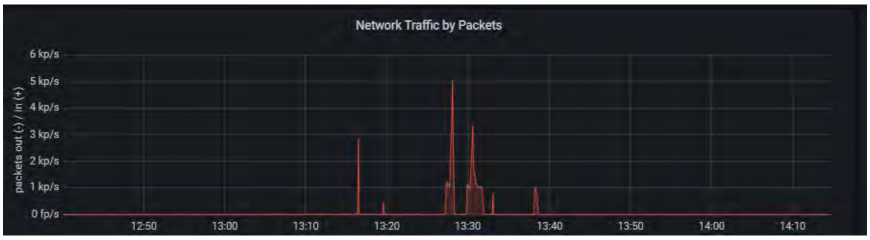
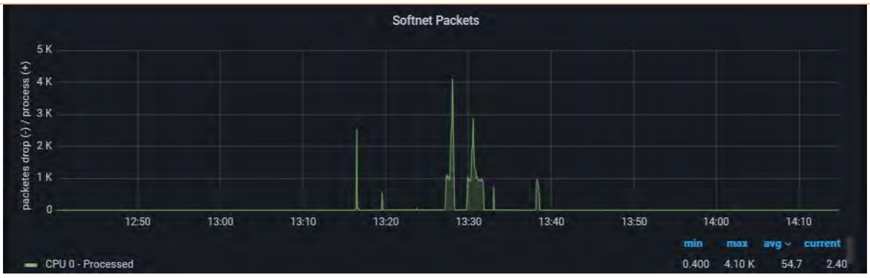
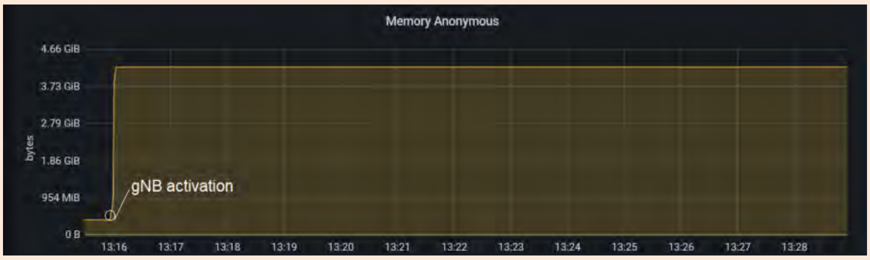
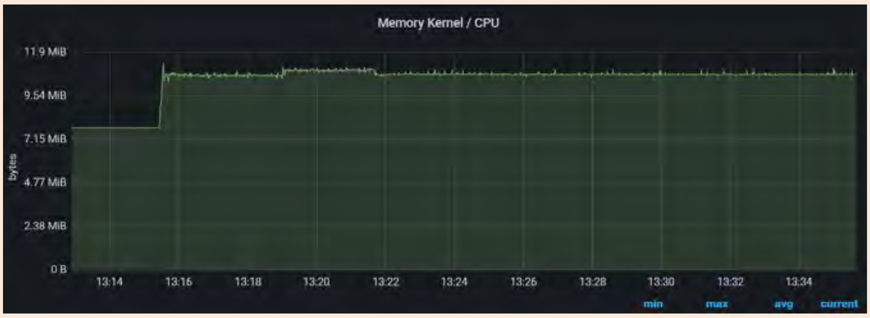
		UPF delay: Processing + waiting time per packet at the UPF	

Table 4-10 Common performance measurements for NFs

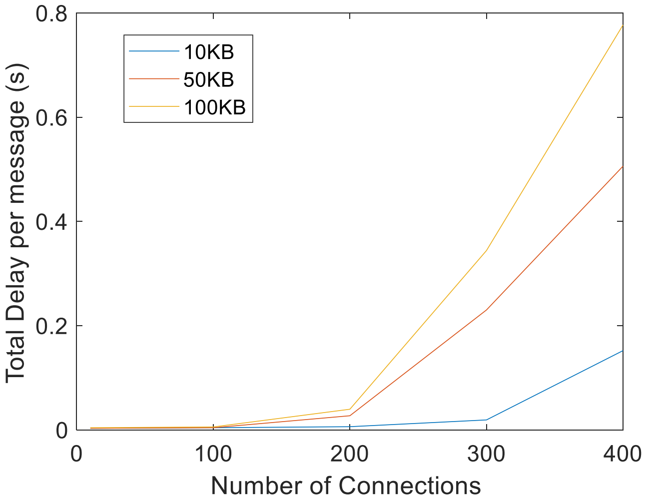
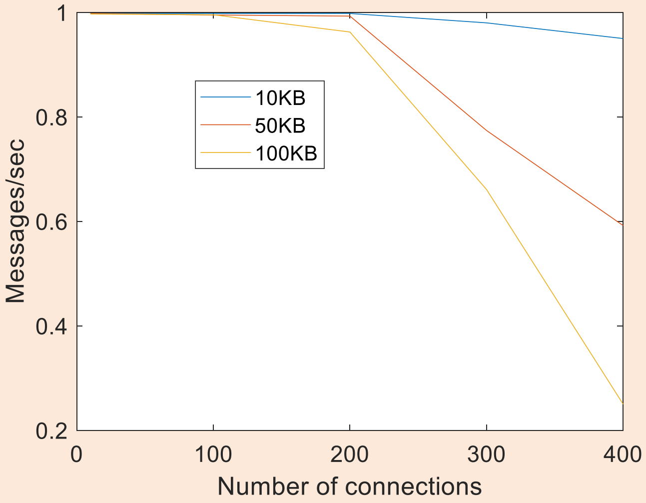
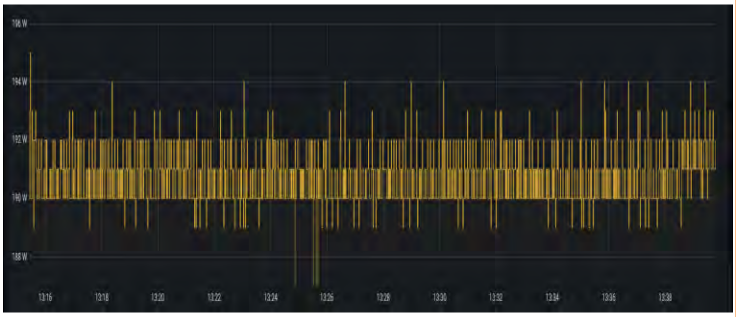
Common performance measurements for NFs			
Metric		**Description**	**Measurements**
Virtual resource usage	Virtual CPU usage	This measurement provides the mean usage of the underlying virtualized CPUs for a virtualized 3GPP NF	CPU resources allocated for lower layer BBU functions: resources are fixed and independent on the traffic load  CPU resources for upper layer protocols (packet based):  The screenshot above has been captured for the following packet stream  UPF: Packets processed at CPU0 of the servers used for the UPF

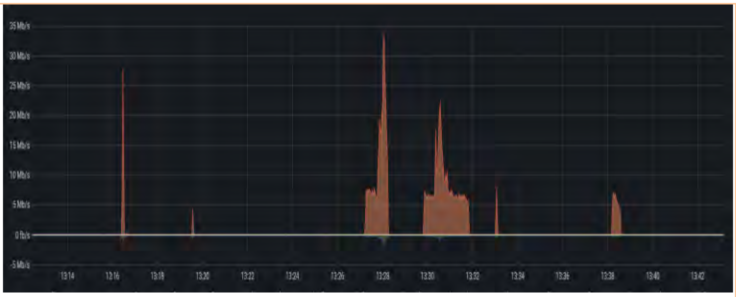
			
	Virtual memory usage	This measurement provides the mean usage of the underlying virtualized memories for a virtualized 3GPP NF	gNB Memory requirements:  UPF memory requirements after gNB activation and session establishment  UPF memory requirements at the CPU kernel after gNB activation and session establishment 

a) E2E Performance Metrics per 5G slice.

Table 4-11 E2E (per slice metrics)

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

Average e2e delay for a network slice	This KPI describes the average e2e UL packet delay between the PSA UPF and the UE for a network slice.	
Throughput for Single Network Slice Instance	This KPI describes the downstream throughput of one single network slice instance by computing the packet size for each successfully transmitted DL IP packet through the network slice instance during each observing granularity period and is used to evaluate integrity performance of the end-to-end network slice instance. It is obtained by downstream throughput provided by N3 interface from all UPFs to NG-RAN which are related to the single network slice.	
Power Consumption	gNB power consumption (excluding RU power consumption): stepwise increase of power consumption when gNB is activated. Power consumption depends on lower layer function processing – load-independent UPF power consumption: system is underutilized	gNB Power consumption (Watt)  UPF Power consumption (Watt)  Traffic Mbps

4.2.7 Field Trials

To validate the integration of the physical HV substation sensors with the UiTOP platform deployed at the lab, a 4G modem was installed at ADMIE premises (Korinthos). A new Modbus TCP adapter was developed for UiTOP, and it was configured to perform requests to the Honeywell recorder over public internet. Figure 4-5 and Figure 4-6 depict readings at the same timespans captured by the official Honeywell software and our developed adapter respectively. Historical measurements are collected to a time-series database and are used to create a power profile of the HV substation and identify future abnormalities in real-time.

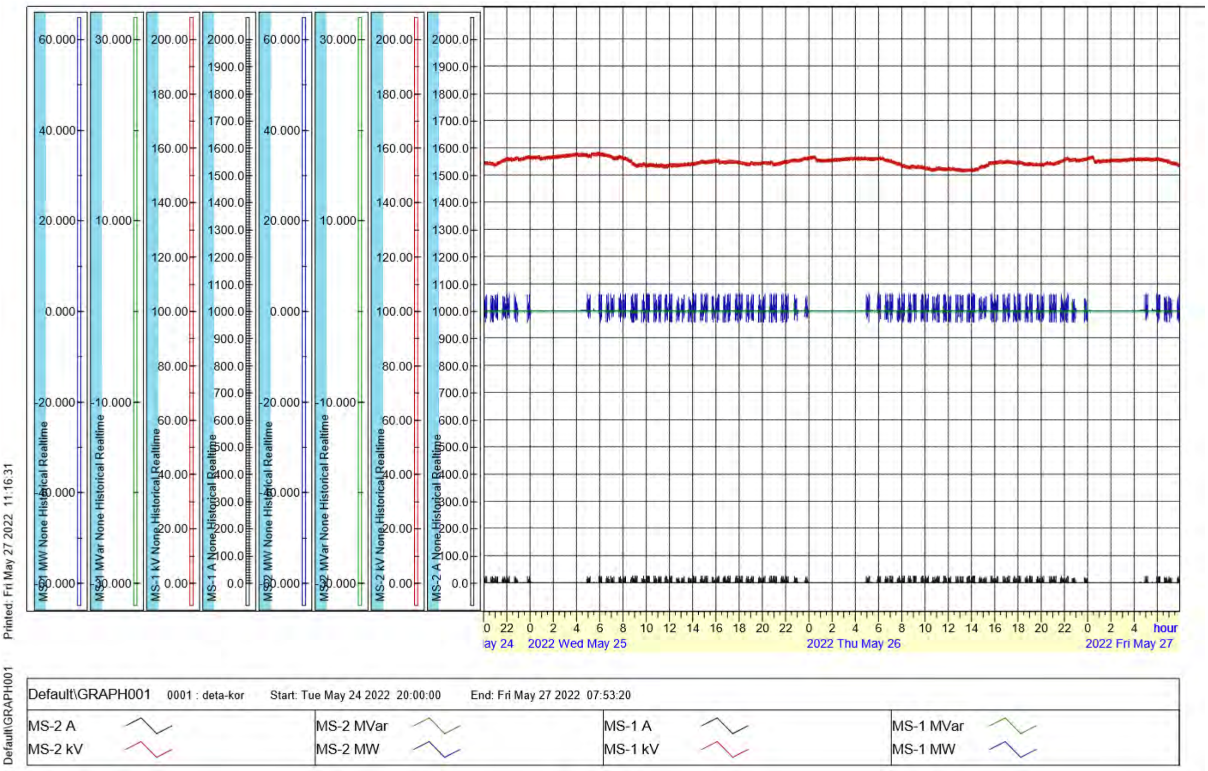


Figure 4-5: Data from Honeywell recorder at Korinthos, captured via a commercial software

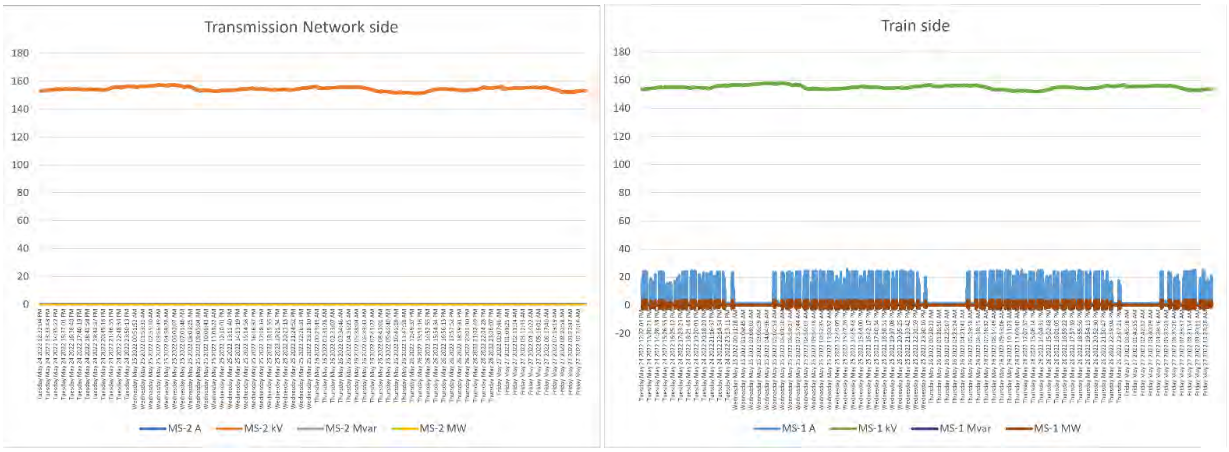


Figure 4-6: Data from Honeywell recorder at Korinthos, captured via our IoT platform

4.3 Test combinations at 5G-VICTORI facility in Patras

This UC is being demonstrated at Korinthos using a NPN isolated 5G network. (Autonomous Edge solution). There are no other services hosted at the same infrastructure so there is no need for Test-combinations.

5 Smart Energy Metering at the 5G-VICTORI facility in Alba Iulia

5.1 Overview (mapping of services on 5G-SA infrastructure)

The architecture in Figure 5-1 provides an overview of the Energy UC FR/RO cluster in Alba Iulia, as the 5G solution described is based on the two IoT flavors, based on OAI vEPC (LTE-M 4G access) and 5G SA mMTC network slice (linked to the device availability).

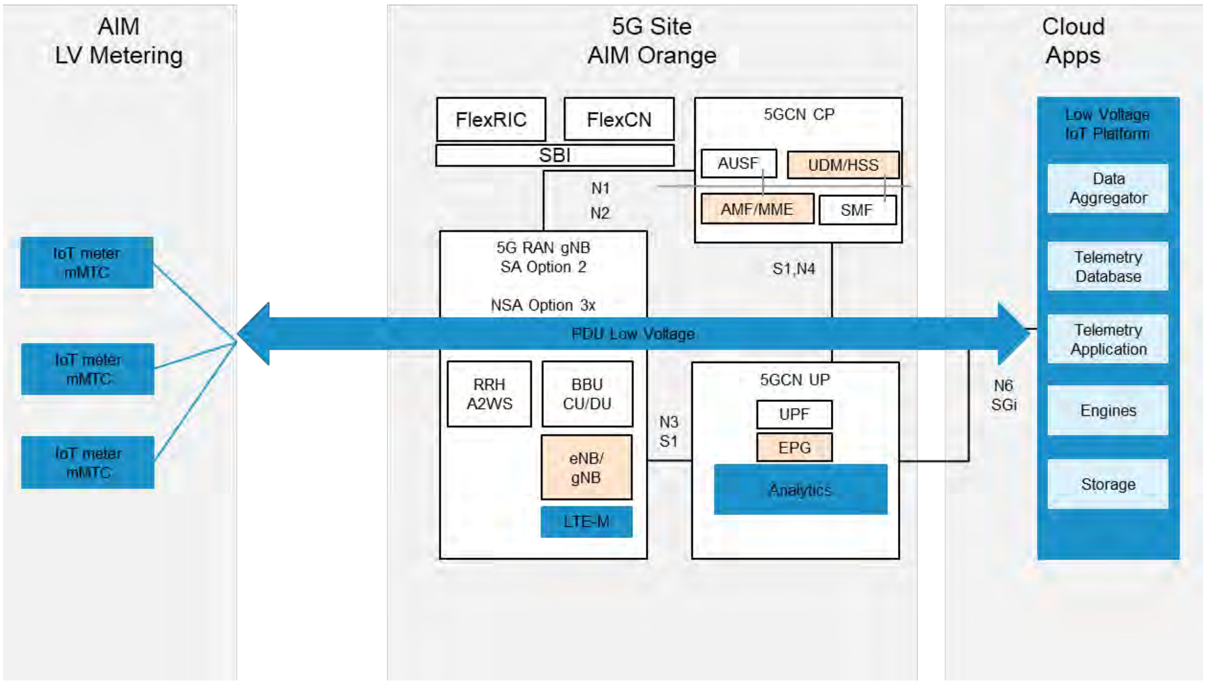


Figure 5-1 FR/RO cluster use case services mapped to 5G infrastructure at Alba Iulia

Energy services UC components are:

- **IoT end device**: the IoT metering device, connected to the IoT Telemetry analytics server, acting as aggregating component, the communication component is provided over the Low Latency PDN slice
- **5G NSA/SA Network**: it is the component installed in Orange 5G site, as RRH/BBU, vEPC/5GCN core network components, network interfaces and local processing servers.
- **Telemetry platform**: it is the cloud telemetry platform, acting as Telemetry Data Aggregator, Telemetry Database, Telemetry Application and engines and telemetry data storage, connected through N6/SGi interface to the IoT devices

5.2 Energy and factories – Smart Energy Metering – Alba Iulia – Real-time LV energy metering services functionality test cases

5.2.1 Service Description

For the UC deployment, low cost/ low energy consuming devices are installed across the city on three public institutions, which will operate through LTE-M / 5G-NR access layers. Collected measurements are transferred to the 5G-VICTORI central cloud facilities to be stored, processed and analyzed by the Telemetry platform, through a single network mMTC slice.

The proposed energy test-cases will evaluate the interconnection of energy metering devices/ infrastructure with the data control and management platform through a multi-tenant and resource sharing slice infrastructure providing the required intelligence for smart grid operation.

5.2.2 ESMe01: Establishment of basic E2E connectivity over mMTC smart energy slice

The aim of the proposed test case is to evaluate the site connectivity between 5G-VICTORI facilities. The purpose of the test case is to validate the end-to-end slice connectivity between different components/facilities involved: low voltage metering device - 5G IoT device - 5G radio access - 5G core networks – 5G-VIOS – Bucharest Orange Datacenter / Telemetry platform.

Table 5-1: ESMe01 – Establishment of basic E2E connectivity over mMTC smart energy slice

ESMe01	Establishment of basic E2E connectivity over mMTC smart energy slice (between AIM LV sensor simulator and Bucharest Orange Datacenter Telemetry platform)
Testbed	**5G-EVE FR/RO**
Description	Dedicated slice configured in the network. Connect LV metering device over 5G radio and test connectivity over slice towards test IP.
Key Use-case requirements and KPIs	N/A
Network performance requirements and KPIs	N/A
Network Functional requirements and KPIs	Testing e2e connectivity over the mMTC preconfigured slice, no specific KPIs defined.
Components and configuration	**- Components:** 1. LV metering device 2. 5G / LTE-M IoT device 3. Telemetry platform 4. mMTC slice configured over 5G network **- Configuration:** 1. Configure and connect LV metering device to 5G/LTE-M IoT platform. 2. The backhaul between LV device and the Telemetry platform is assured by mMTC slice
Test procedure	**- Preconditions:** N/A **- Test Case Steps:** 1. The LV metering device connects to the 5G IoT / LTE-M device and further on to the telemetry platform 2. The LV metering device is registered to the Telemetry platform 3. Raw data packets are sent by LV metering device toward the Telemetry platform

Measurements	**- Methodology** Raw data packets are sent toward Telemetry platform. Check if the procedure is successful. If it is failed investigation are performed to identify the breaking point. **- Complementary measurements** N/A **- Calculation process** N/A
Expected Result	The raw data sent by LV metering device are confirmed on the Telemetry platform.

5.2.3 ESMe02: Establishment of advanced E2E connectivity over smart energy slice with different QoS metrics configured

The goal of the second test case is to check the QoS performance of the smart energy network slice. In order to have enough samples for relevant statistics, the traffic is generated by a sensor simulator.

Table 5-2: ESMe02 - Establishment of advanced E2E connectivity over smart energy slice with different QoS metrics configured

ESMe2	Establishment of advanced E2E connectivity over smart energy slice with different QoS metrics configured
Testbed	**5G-EVE FR/RO**
Description	The purpose of the test case is to check the QoS performance of the smart energy network slice. In order to have enough samples for relevant statistics, the traffic is generated by a sensor simulator
Key Use-case requirements and KPIs	N/A
Network performance requirements and KPIs	Service Availability > 99.9% E2E latency for smart metering service < 100 ms Packet loss rate < 0.01%
Network Functional requirements and KPIs	N/A
Components and configuration	**- Components:** 1. LV sensor simulator 2. 5G / LTE-M IoT device 3. Telemetry platform 4. mMTC slice configured over 5G network **- Configuration:** 1. Configure and connect the sensor simulator to 5G/LTE-M IoT platform. 2. A negative/positive script and sensor command emulator will be configured on the Telemetry platform 3. The backhaul between LV device and the Telemetry platform is assured by mMTC slice.

Test procedure	**- Preconditions:** 1. LV sensor attached to the network/slice 2. No congestion in the network (5G) **- Test Case Steps:** 1. Configure the slice 2. Attach LV sensor simulator to the IoT platform 3. Activate command is send toward from Telemetry platform toward sensor simulator 4. Run connectivity test, write down the results
Measurements	**- Methodology** Test executed every hour for 1 day **- Complementary measurements** N/A **- Calculation process** 1. Connectivity Availability - Calculated as network tunnel up time/total time, reflects in percentage the availability/stability performance. 2. E2E latency - calculate packet round trip time from Telemetry platform to device sensor simulator 3. E2E packet loss rate - calculate percentage of packets lost during transfer between sensors and Telemetry platform
Expected Result	The connectivity is successfully configured and network performance KPI's are achieved.

5.2.4 ESMe03: Establishment of simultaneous 5G raw data transfer to process the traffic generated simultaneously by 3000 LV metering devices

The density of devices in a specific area can be high, mainly in urban zones, increasing the probability that at a certain time multiple devices send/ receive traffic towards/ from the IoT platform. The third test case evaluates the establishment of simultaneous 5G raw data transfer to process the traffic generated simultaneously by 3000 LV metering devices over Alba-Iulia – 5G VIOS mMTC slice.

Table 5-3: ESMe03 - Establishment of simultaneous 5G raw data transfer to process the traffic generated simultaneously by 3000 LV metering devices

ESMe03	Establishment of simultaneous 5G raw data transfer to process the traffic generated simultaneously by 3000 LV metering devices
Testbed	**5G-EVE FR/RO**
Description	The purpose of the test case is to verify high data rates capabilities over the 5G end to end slice of generated simultaneously by 3000 LV metering devices.
Key Use-case requirements and KPIs	N/A
Network performance requirements and KPIs	Raw data received from all 3000 LV metering simulated devices.
Network Functional requirements and KPIs	High data rates capacity for simultaneously transfers of large raw data volumes of LV metering devices.

Components and configuration	**Components:** 1. 3000 5G/ LTE-M IoT devices displaced over 300 square meters using IoT simulators, to collect low voltage metering information 2. RAN – physical USRPs & RAN - containerized software installed in Alba Iulia location nearby AIM public buildings, offering coverage to the IoT low voltage devices 3. AIM Edges - hosting the RAN & Core Network components 4. Bucharest Data center - hosting the Telemetry platform components, engines and compute/storage to provide e provide LV raw data processing, smart metering analytics and 5G VIOS interconnect **- Configuration:** 1. Configure and connect the sensor simulator to 5G/LTE-M IoT platform 2. A negative/positive script and sensor command emulator will be configured on the Telemetry platform 3. The backhaul between LV device and the Telemetry platform is assured by mMTC slice. 4. Transport the raw data from IoT devices towards Telemetry platform
Test procedure	**- Preconditions:** 1. LV sensor simulator attached to the network/slice. **- Test Case Steps:** 1. Configure sensor simulators to simulate data transfer of 3000 LV smart devices simultaneously towards IoT platform. 2. Transfer rate KPIs is calculated on the Telemetry platform based on raw data sent/received to the IoT platform. 3. Test-case KPIs are reported
Measurements	**- Methodology** 3000 tests performed simultaneously. **- Complementary measurements** N/A **- Calculation process** 1. Evaluates the transfer capacity volume of aggregated information from sensors to IoT platform.
Expected Result	Raw data received successfully by the Telemetry platform from all 3000 simulated devices.

5.2.5 ESMe04: Dynamic resource allocation 5G capability against service stability

This test case checks the deployment of four different network slices having four different quality of service metrics: one slice for interactive service, one slice to transport video, one slice with URLLC capability and one slice for mMTC. For each slice performance measurement is performed from network (bandwidth, jitter, latency) and Telemetry (SR%) perspective.

Table 5-4: ESMe04 - Dynamic resource allocation 5G capability against service stability

ESMe4	Dynamic resource allocation 5G capability against service stability.
Testbed	**5G-EVE FR/RO**
Description	Iperf_1 connected over eMBB slice. Congest radio cell by pushing traffic. Iperf_32 connected over URLLC slice push 100kb stream of traffic. Check QoS parameters for each of the slice. E2E connectivity over mMTC smart energy slice (between AIM 3000 LV sensor simulators and Bucharest Orange Datacenter Telemetry platform)
Key Use-case requirements and KPIs	N/A
Network performance requirements and KPIs	Up to three 5G slices (eMBB, URLLC, mMTC) running in parallel over Alba-Iulia – 5G VIOS slice.
Network Functional requirements and KPIs	Concurrent service infrastructure computing and transport network for simultaneous transfers of raw data volumes on multiple 5G slices.
Components and configuration	**Components:** 1. Three laptops/tablets and Wi-Fi AP 2. 3000 5G/ LTE-M IoT devices displaced over 300 square meters using IoT simulators, to collect low voltage metering information 3. RAN – physical USRPs & RAN - containerized software installed in Alba Iulia location nearby AIM public buildings, offering coverage to the IoT low voltage devices 4. AIM Edges - hosting the RAN & Core Network components 5. Bucharest Data center - hosting the Telemetry platform components, engines and compute/storage to provide e provide LV raw data processing, smart metering analytics and 5G VIOS interconnect **- Configuration:** 1. Configure mMTC slice by connecting the sensor simulators to 5G/LTE-M IoT platform 2. Configure connectivity of three laptops/tablets to the three different slices: for eMBB the connection is performed over the Wi-Fi AP, URLCC the connection is performed directly over 5G using SIM. 3. Three slices configured in total over 5G network: URLCC, eMBB, mMTC (3000 LV sensor simulators and Bucharest Orange Datacenter Telemetry platform)

Test procedure	**- Preconditions:** - LV sensor simulator attached to the network/slice. **- Test Case Steps:** 1. Configure the three slices 2. Attach devices on each of the four slices 3. Check that successful network connectivity is in place for all the slices (ping/traceroute towards the specific IP addresses of the test server) 4. Configure sensor simulators to simulate data transfer of 3000 LV smart devices simultaneously towards IoT platform. 5. Automatic slice deployment 6. Dynamic resource allocation between slices 7. 5G RAN / CORE real time monitoring capability 8. Transport the raw data from IoT devices towards Telemetry platform
Measurements	**- Methodology** 1. Check if all four slices are up 2. The iperf is performed utilizing a test server with connectivity within all three slices. 3. Three tests are performed on all 4 slices simultaneously (one test/slice). For eMBB the traffic flow is configured with a bandwidth of 20Mbps For the URLCC slice, the traffic flow is configured with a bandwidth of 100kbps. Raw data packets are sent toward Telemetry platform over mMTC slice. 4. Check if the procedure is successful. If it is failed investigation are performed to identify the breaking point. 5. The tests are repeated three times, resulting in a total number of 6 tests. The KPIs have to be achieved for each of the tests. **- Complementary measurements** N/A **- Calculation process** 1. Evaluates the transfer capacity volume of aggregated information for all 3 slices.
Expected Result	The slices are successfully configured. Connectivity is up and running over the three slices. The KPIs are achieved, meaning that infrastructure computing and transport network concurrent service are concurrently running to sustain all three 5G slices.

5.2.6 Lab KPI results

5G LAB setup in Orange facility

In the FR/RO cluster we have deployed the 5G SA architecture as described in Figure 5-2, basically running the entire 5G system components into the integrated LAB for the 5G SA Option 2 functionality. More details and pictures from the lab deployment and from the field deployment of the 5G infrastructure can be found in [5].

The configuration and testing in the lab were focused on the 5G-infrastructure. The Smart metering platform was deployed directly in the field (screenshots related to implementation are depicted in 5.3.5) and the integration with the 5G infrastructure and comprehensive tests will be performed only in the field in the last phase of the project.

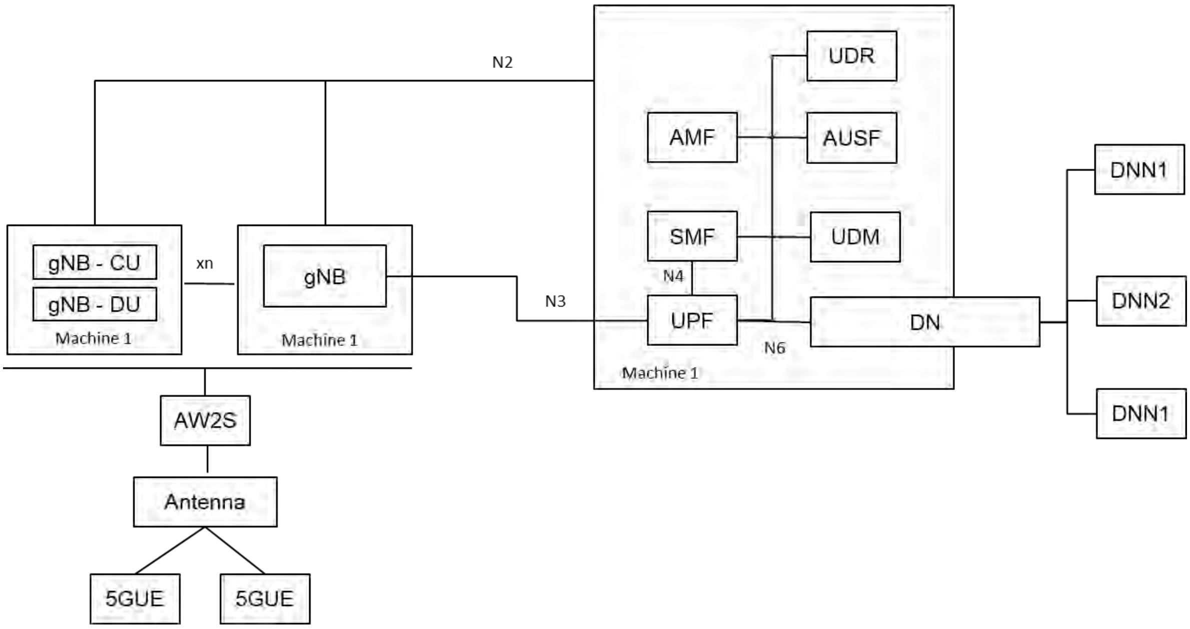


Figure 5-2 FR/RO cluster 5G SA architecture

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

- Physical:
    - server(x86), a capable computing element (RAM, storage, CPU and network), where all the system software components are running (5G gNB, Core)
    - Remote Radio Head, AW2S MIMO 2x2 RRH supporting NR
    - 5G Antenna, band N78 MIMO 2x2
    - Cisco NX-OS switch with high bandwidth interfaces
- Radio resources: 5G TDD spectrum N78(100 MHz)
- Software components: gNB CU/DU, AMF, SMF, UDR, UDM and UPF, deployed in containers on the server
- 5G SA UE/rm500q module
- Camera for video traffic & LV devices

5.2.6.1 ESMe01

All the tests have been performed in LAB by simulating the IoT traffic.

LAB mMTC case values (test periodicity 1min), mMTC packet size <20kB

- E2E Latency < 40ms(emulated telemetry cloud platform).
- Packet loss 0%.

5.2.6.2 ESMe02

All the tests have been performed in LAB by simulating the IoT traffic.

Measured Service Availability > 99.9% in LAB condition (1.5 h availability):

- E2E latency for smart metering service < 60 ms.
- Packet loss rate < 0.01%.

5.2.6.3 ESMe03

All the tests have been performed in LAB by simulating the IoT traffic.

Data sources: bandwidth usage

The results for normal traffic load are captured in Figure 5-3, while the results for 3000 devices traffic load are included in Figure 5-4.

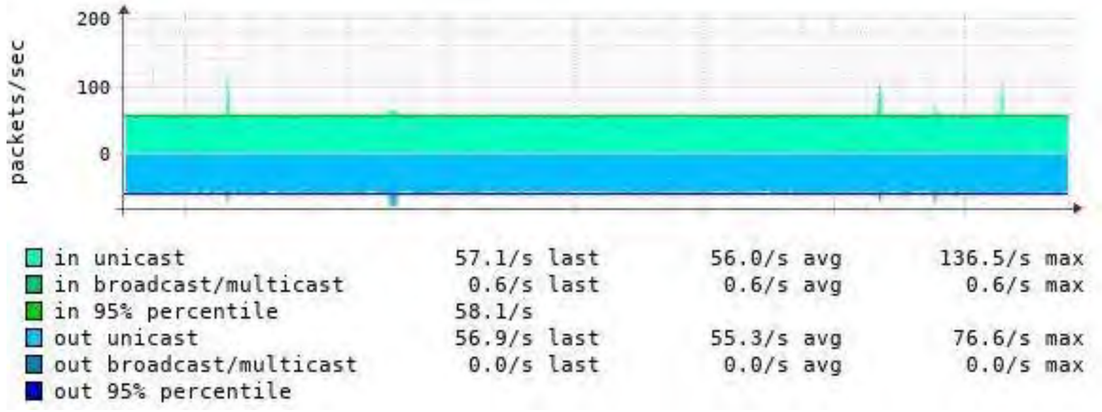


Figure 5-3 Normal traffic load

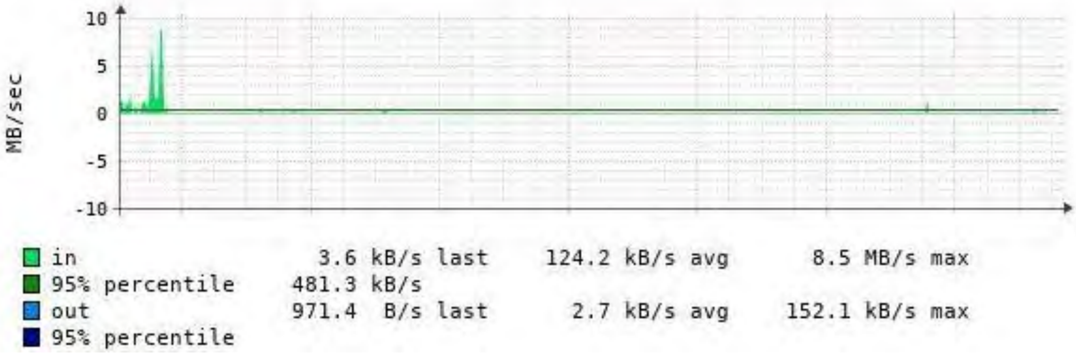


Figure 5-4 Simulated 3000 devices traffic load

5.2.6.4 ESMe04

The test has not been performed in the lab.

5.2.7 Field Trials

The field deployment of the 5G SA infrastructure is described in deliverable D3.4 [5], but no specific configuration and tests were performed for LV Energy metering UC as the focus was on preparing the demonstration of the Media UC related to public safety scenarios.

5.3 Energy and factories Smart Energy Metering Alba Iulia Energy Analytics test cases

5.3.1 Service Description

The second component of the Telemetry platform is the Advanced Analytics, which is used for operational performance follow-up and consumption monitoring. Two test-cases were proposed to evaluate the functionality and performance of the analytics component.

1. Check smart energy consumption monitoring accuracy.
2. Check preventive maintenance alerting accuracy by sending maintenance alerts on the email service, to multiple recipients. Consumption value expected after test case should to be 100% identical with the one measured manually on-prem.

5.3.2 ESAe01: Smart energy consumption monitoring accuracy

The test case is proposing to evaluate the functionality of the Analytics component by testing the accuracy of the data collected from the LV devices and the algorithm used to calculate the energy consumption. Smart metering consumption values calculated with the Analytics component of the Smart Metering Telemetry platform, will be evaluated against the values collected with the manual reading method.

Table 5-5: ESAe01 - Smart metering energy consumption accuracy

ESAe1	Smart energy consumption accuracy
Testbed	**5G-EVE FR/RO**
Description	Evaluate smart metering consumption values registered by LV metering devices calculated with the Telemetry Analytics component against the values collected with the manual reading method.
Key Use-case requirements and KPIs	N/A
Network performance requirements and KPIs	Consumption KPI accuracy = 100%
Network Functional requirements and KPIs	N/A
Components and configuration	**Components:** 1. Three LV metering devices 2. 5G / LTE-M IoT device 3. Telemetry platform 4. mMTC slice configured over 5G network **Configuration:** 1. Configure and connect three LV metering devices to the Telemetry platform 2. The backhaul between LV devices and the Telemetry platform is assured by mMTC slice.
Test procedure	**- Preconditions:** All three LV devices attached to the network. Assure that consumption values associated to all five LV devices are incrementing in the Telemetry platform. **- Test Case Steps:** 1. LV sensor is connected to the Telemetry platform via dedicated slice. 2. LV device send packets towards Telemetry platform 3. Consumption information is stored and timestamped in Telemetry database 4. Raw data is processed by Backend aggregator and delivered to Front end module 5. Consumption graph is displayed by Front end module for each LV metering device registered
Measurements	**- Methodology** Calculate delta between Analytics platform recorded consumption values vs values collected with manual method **- Complementary measurements** N/A **- Calculation process** Consumption accuracy % - cloud consumption raw data value / manual consumption data collected data from energy measurement device
Expected Result	Consumption value is expected to be 100% identical with the one measured manually on-prem.

5.3.3 ESAe02: Preventive maintenance alerting accuracy test

The aim is to check the alerting accuracy performance related to monitored elements by sending maintenance alerts on the email service to multiple recipients.

Table 5-6: ESAe02 - Preventive maintenance alerting accuracy test

ESAe2	Preventive maintenance/reporting accuracy test
Testbed	**5G-EVE FR/RO**
Description	Track LV metering device disconnect events as they occur. If disconnect events occur an alert is triggered and sent by email.
Key Use-case requirements and KPIs	N/A
Network performance requirements and KPIs	Alert accuracy = 100%
Network Functional requirements and KPIs	N/A
Components and configuration	**Components:** 1. Three LV metering devices 2. 5G / LTE-M IoT device 3. Telemetry platform 4. mMTC slice configured over 5G network **Configuration:** 1. Configure and connect three LV metering devices to the Telemetry platform 2. The backhaul between LV devices and the Telemetry platform is assured by mMTC slice.
Test procedure	**- Preconditions:** Three LV devices are attached to the network **- Test Case Steps:** 1. LV metering devices are connected to the Telemetry platform via dedicated slice. 2. LV device send packets towards Telemetry platform 3. Raw data is processed by Backend aggregator 4. Manual randomly disconnect each of the three LV devices 5. No data is received by Backend engine 6. Alarms are triggered by Front end monitoring module 7. LV metering device disconnecting message is sent to a predefined email address

Measurements	**- Methodology** -20 LV disconnection to be performed, evaluated the number of alerts triggered **- Complementary measurements** N/A **- Calculation process** The detection accuracy will be calculated through the comparison of the automatic detections, the ground truth data and the associated email alert received. Alarm accuracy - nb of alarms / nb of LV device disconnection
Expected Result	Alerting accuracy is expected to reach the threshold described above. The aim is to prove that LV network disconnect events fully automated detection can be realized in real-time.

5.3.4 Lab KPI Results

No lab setup was available for the Telemetry platform, as this was implemented directly into the field, and an overall description of the implementation with pictures and screenshots is provided in section 5.3.5 below.

5.3.4.1 ESAe01

The test has not been performed in the lab.

Screenshots from Telemetry Analytics, captured during live operation of the system, were inserted in the section 5.3.5. The captures display some values collected from measurement devices and presented as graphical or tabular reports.

5.3.4.2 ESAe02

The test has not been performed in the lab.

Screenshot captured from Telemetry Analytics is inserted in section 5.3.5, presenting the screen for Alerts set-up (very flexible in setting conditions, communication channels, window time and destinations).

5.3.5 Field Trials

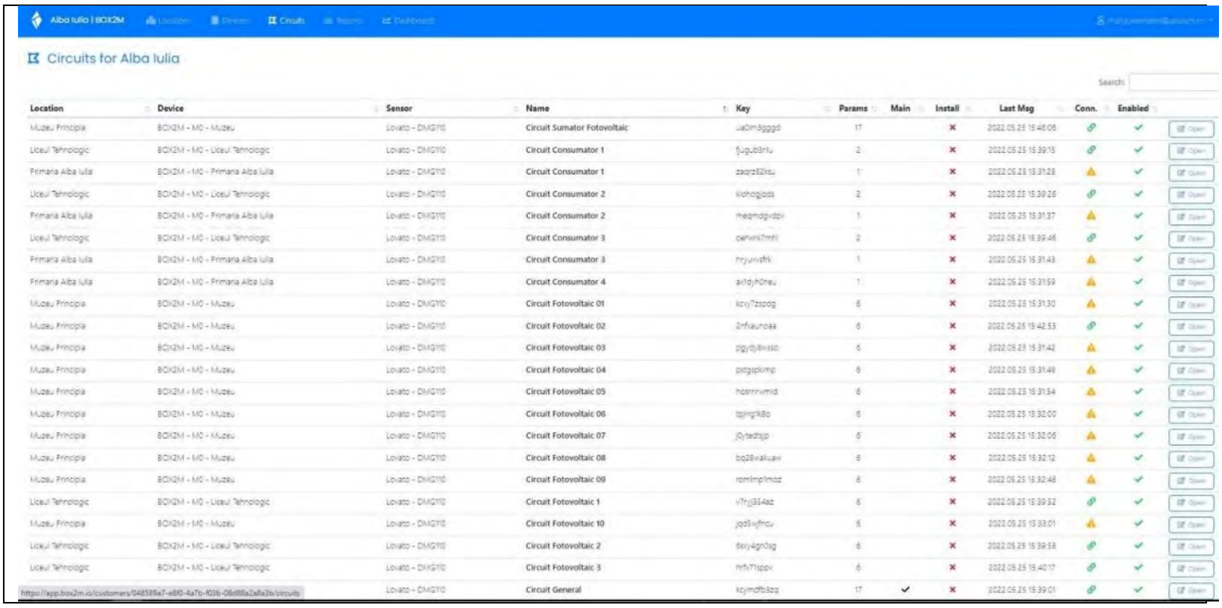
The Telemetry platform was implemented directly into the field, all the needed measurement devices being installed in the 3 sites that will be monitored in this project as presented in D2.3. Moreover, the application was deployed in the cloud infrastructure and configured for the collection of the measurements over LTE-M. The reports and dashboards were defined and implemented according to AIM needs.

Telemetry Platform comprises the whole set of energetic dispatcher functions as monitoring the consumptions for measured circuits, the import and export energies, the production of electrical energy, the behavior of consumers and producers and the quality of the energy produced or consumed.

The Telemetry Analytics component implements real-time and historical reports for energy consumption and QoS, carbon footprint and energy cost, on spot audit and historical checks, circuits virtual clustering. Also, real time alerts for device status or parameter deviation, based on measured parameters and predefined threshold are available.

Some screenshots from live operation of the Analytics component are inserted below (Figure 5-7 to Figure 5-10). The list of all circuits deployed and integrated into Telemetry application could be retrieved on a specific section as it could be seen in the Figure 5-6 below.

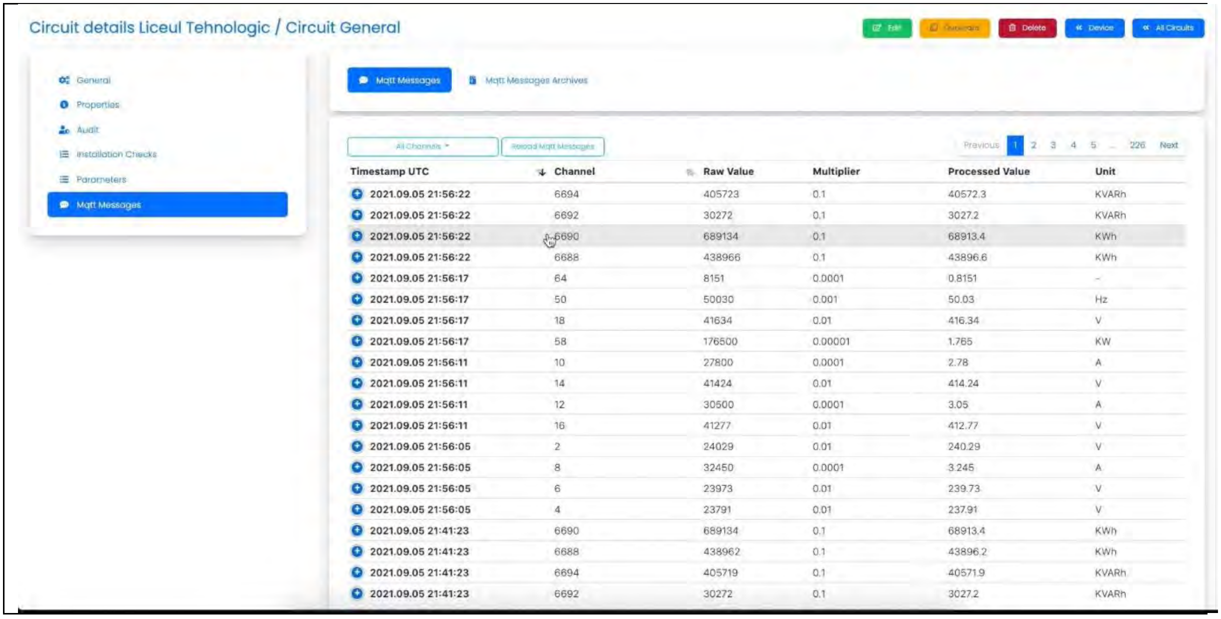
Figure 5-5 Measurement devices installed on 3 sites from Alba Iulia



Circuits for Alba Iulia

Location	Device	Sensor	Name	Key	Params	Main	Install	Last Msg	Conn.	Enabled	
Muzeu Principia	BOX2M - M0 - Muzeu	Lovato - DMG110	Circuit Sumator Fotovoltaic	ua0im3gggd	17		✗	2022.05.25 15:46:06	🔗	✓	Open
Liceul Tehnologic	BOX2M - M0 - Liceul Tehnologic	Lovato - DMG110	Circuit Consumator 1	fjugub3nlu	2		✗	2022.05.25 15:39:15	🔗	✓	Open
Primaria Alba Iulia	BOX2M - M0 - Primaria Alba Iulia	Lovato - DMG110	Circuit Consumator 1	zaqrz82ksu	1		✗	2022.05.25 15:31:28	⚠	✓	Open
Liceul Tehnologic	BOX2M - M0 - Liceul Tehnologic	Lovato - DMG110	Circuit Consumator 2	klohogjodz	2		✗	2022.05.25 15:39:26	🔗	✓	Open
Primaria Alba Iulia	BOX2M - M0 - Primaria Alba Iulia	Lovato - DMG110	Circuit Consumator 2	meqmdgvdpi	1		✗	2022.05.25 15:31:37	⚠	✓	Open
Liceul Tehnologic	BOX2M - M0 - Liceul Tehnologic	Lovato - DMG110	Circuit Consumator 3	oehwnl7mhl	2		✗	2022.05.25 15:39:46	🔗	✓	Open
Primaria Alba Iulia	BOX2M - M0 - Primaria Alba Iulia	Lovato - DMG110	Circuit Consumator 3	nryuwsfrk	1		✗	2022.05.25 15:31:43	⚠	✓	Open
Primaria Alba Iulia	BOX2M - M0 - Primaria Alba Iulia	Lovato - DMG110	Circuit Consumator 4	ax1dyh0neu	1		✗	2022.05.25 15:31:59	⚠	✓	Open
Muzeu Principia	BOX2M - M0 - Muzeu	Lovato - DMG110	Circuit Fotovoltaic 01	kcxy7zspdg	6		✗	2022.05.25 15:31:30	⚠	✓	Open
Muzeu Principia	BOX2M - M0 - Muzeu	Lovato - DMG110	Circuit Fotovoltaic 02	2nfxaunoaa	6		✗	2022.05.25 15:42:53	🔗	✓	Open
Muzeu Principia	BOX2M - M0 - Muzeu	Lovato - DMG110	Circuit Fotovoltaic 03	pgydy8wsso	6		✗	2022.05.25 15:31:42	⚠	✓	Open
Muzeu Principia	BOX2M - M0 - Muzeu	Lovato - DMG110	Circuit Fotovoltaic 04	pstgspkmp	6		✗	2022.05.25 15:31:48	⚠	✓	Open
Muzeu Principia	BOX2M - M0 - Muzeu	Lovato - DMG110	Circuit Fotovoltaic 05	hosrnrwmid	6		✗	2022.05.25 15:31:54	⚠	✓	Open
Muzeu Principia	BOX2M - M0 - Muzeu	Lovato - DMG110	Circuit Fotovoltaic 06	tpjrrg1k8o	6		✗	2022.05.25 15:32:00	⚠	✓	Open
Muzeu Principia	BOX2M - M0 - Muzeu	Lovato - DMG110	Circuit Fotovoltaic 07	j0ytedtsjp	6		✗	2022.05.25 15:32:06	⚠	✓	Open
Muzeu Principia	BOX2M - M0 - Muzeu	Lovato - DMG110	Circuit Fotovoltaic 08	bq28wakuaw	6		✗	2022.05.25 15:32:12	⚠	✓	Open
Muzeu Principia	BOX2M - M0 - Muzeu	Lovato - DMG110	Circuit Fotovoltaic 09	romlmp1moz	6		✗	2022.05.25 15:32:46	⚠	✓	Open
Liceul Tehnologic	BOX2M - M0 - Liceul Tehnologic	Lovato - DMG110	Circuit Fotovoltaic 1	v7ryj354az	6		✗	2022.05.25 15:39:52	🔗	✓	Open
Muzeu Principia	BOX2M - M0 - Muzeu	Lovato - DMG110	Circuit Fotovoltaic 10	jqd5wjfncv	6		✗	2022.05.25 15:33:01	⚠	✓	Open
Liceul Tehnologic	BOX2M - M0 - Liceul Tehnologic	Lovato - DMG110	Circuit Fotovoltaic 2	6sxy4gn0sg	6		✗	2022.05.25 15:39:58	🔗	✓	Open
Liceul Tehnologic	BOX2M - M0 - Liceul Tehnologic	Lovato - DMG110	Circuit Fotovoltaic 3	nrfx71sppx	6		✗	2022.05.25 15:40:17	🔗	✓	Open
		Lovato - DMG110	Circuit General	kcymdfb3zq	17	✓	✗	2022.05.25 15:39:01	🔗	✓	Open

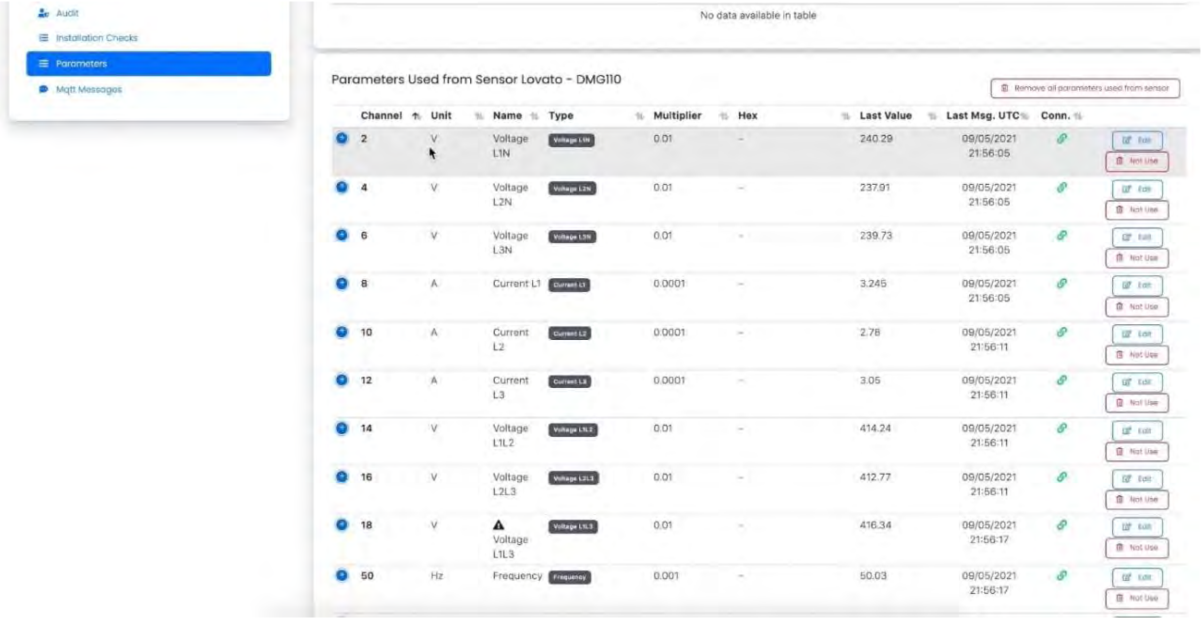
https://app.box2m.io/customers/048589a7-e8f0-4a7b-f03b-08d88a2a8a3b/circuits



Circuit details Liceul Tehnologic / Circuit General

Timestamp UTC	Channel	Raw Value	Multiplier	Processed Value	Unit
2021.09.05 21:56:22	6694	405723	0.1	40572.3	KVARh
2021.09.05 21:56:22	6692	30272	0.1	3027.2	KVARh
2021.09.05 21:56:22	6690	689134	0.1	68913.4	KWh
2021.09.05 21:56:22	6688	438966	0.1	43896.6	KWh
2021.09.05 21:56:17	64	8151	0.0001	0.8151	-
2021.09.05 21:56:17	50	50030	0.001	50.03	Hz
2021.09.05 21:56:17	18	41634	0.01	416.34	V
2021.09.05 21:56:17	58	176500	0.00001	1.765	KW
2021.09.05 21:56:11	10	27800	0.0001	2.78	A
2021.09.05 21:56:11	14	41424	0.01	414.24	V
2021.09.05 21:56:11	12	30500	0.0001	3.05	A
2021.09.05 21:56:11	16	41277	0.01	412.77	V
2021.09.05 21:56:05	2	24029	0.01	240.29	V
2021.09.05 21:56:05	8	32450	0.0001	3.245	A
2021.09.05 21:56:05	6	23973	0.01	239.73	V
2021.09.05 21:56:05	4	23791	0.01	237.91	V
2021.09.05 21:41:23	6690	689134	0.1	68913.4	KWh
2021.09.05 21:41:23	6688	438962	0.1	43896.2	KWh
2021.09.05 21:41:23	6694	405719	0.1	40571.9	KVARh
2021.09.05 21:41:23	6692	30272	0.1	3027.2	KVARh

Figure 5-6 List of all deployed circuits

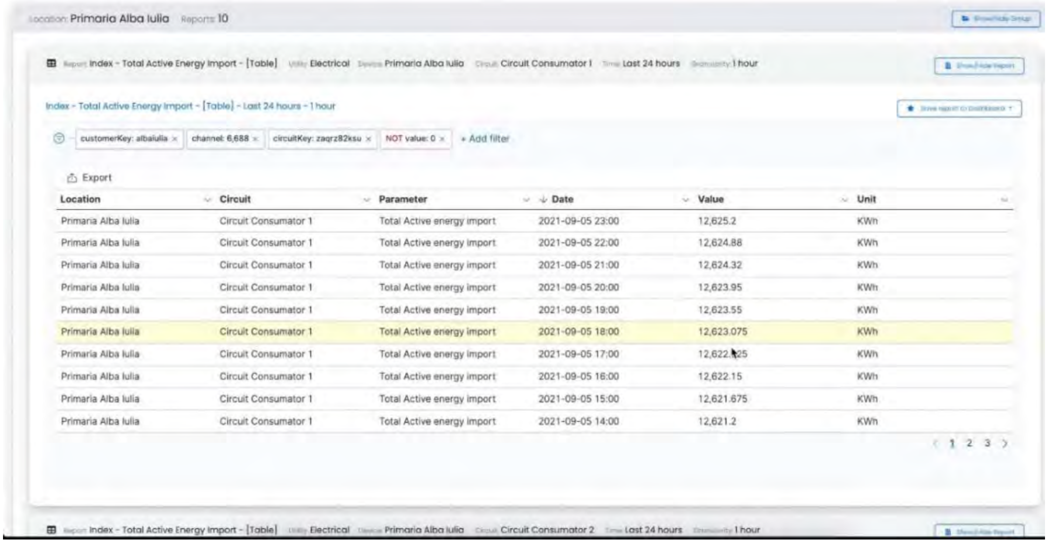


No data available in table

Parameters Used from Sensor Lovato - DMG110

Channel	Unit	Name	Type	Multiplier	Hex	Last Value	Last Msg. UTC	Conn.	
2	V	Voltage L1N	Voltage L1N	0.01	-	240.29	09/05/2021 21:56:05	🔗	Edit Not Use
4	V	Voltage L2N	Voltage L2N	0.01	-	237.91	09/05/2021 21:56:05	🔗	Edit Not Use
6	V	Voltage L3N	Voltage L3N	0.01	-	239.73	09/05/2021 21:56:05	🔗	Edit Not Use
8	A	Current L1	Current L1	0.0001	-	3.245	09/05/2021 21:56:05	🔗	Edit Not Use
10	A	Current L2	Current L2	0.0001	-	2.78	09/05/2021 21:56:11	🔗	Edit Not Use
12	A	Current L3	Current L3	0.0001	-	3.05	09/05/2021 21:56:11	🔗	Edit Not Use
14	V	Voltage L1L2	Voltage L1L2	0.01	-	414.24	09/05/2021 21:56:11	🔗	Edit Not Use
16	V	Voltage L2L3	Voltage L2L3	0.01	-	412.77	09/05/2021 21:56:11	🔗	Edit Not Use
18	V	⚠ Voltage L1L3	Voltage L1L3	0.01	-	416.34	09/05/2021 21:56:17	🔗	Edit Not Use
50	Hz	Frequency	Frequency	0.001	-	50.03	09/05/2021 21:56:17	🔗	Edit Not Use

Figure 5-7 Display of measurements recorded for a specific circuit



Location: Primaria Alba Iulia Reports: 10

Report: Index - Total Active Energy Import - [Table] Utility: Electrical Device: Primaria Alba Iulia Circuit: Circuit Consumator 1 Time: Last 24 hours Granularity: 1 hour

Index - Total Active Energy Import - [Table] - Last 24 hours - 1 hour

customerKey: albaiulia × channel: 6,688 × circuitKey: zaqrz82ksu × NOT value: 0 × + Add filter

Export

Location	Circuit	Parameter	Date	Value	Unit
Primaria Alba Iulia	Circuit Consumator 1	Total Active energy import	2021-09-05 23:00	12,625.2	KWh
Primaria Alba Iulia	Circuit Consumator 1	Total Active energy import	2021-09-05 22:00	12,624.88	KWh
Primaria Alba Iulia	Circuit Consumator 1	Total Active energy import	2021-09-05 21:00	12,624.32	KWh
Primaria Alba Iulia	Circuit Consumator 1	Total Active energy import	2021-09-05 20:00	12,623.95	KWh
Primaria Alba Iulia	Circuit Consumator 1	Total Active energy import	2021-09-05 19:00	12,623.55	KWh
Primaria Alba Iulia	Circuit Consumator 1	Total Active energy import	2021-09-05 18:00	12,623.075	KWh
Primaria Alba Iulia	Circuit Consumator 1	Total Active energy import	2021-09-05 17:00	12,622.[illegible]25	KWh
Primaria Alba Iulia	Circuit Consumator 1	Total Active energy import	2021-09-05 16:00	12,622.15	KWh
Primaria Alba Iulia	Circuit Consumator 1	Total Active energy import	2021-09-05 15:00	12,621.675	KWh
Primaria Alba Iulia	Circuit Consumator 1	Total Active energy import	2021-09-05 14:00	12,621.2	KWh

Report: Index - Total Active Energy Import - [Table] Utility: Electrical Device: Primaria Alba Iulia Circuit: Circuit Consumator 2 Time: Last 24 hours Granularity: 1 hour

Figure 5-8 Display of the parameters set for a specific circuit

Report: Index - Total Active Energy Import - [Table] Utility: Electrical Device: Primaria Alba Iulia Circuit: Circuit General Main Circuit Time: Last 24 hours Granularity: 1 hour

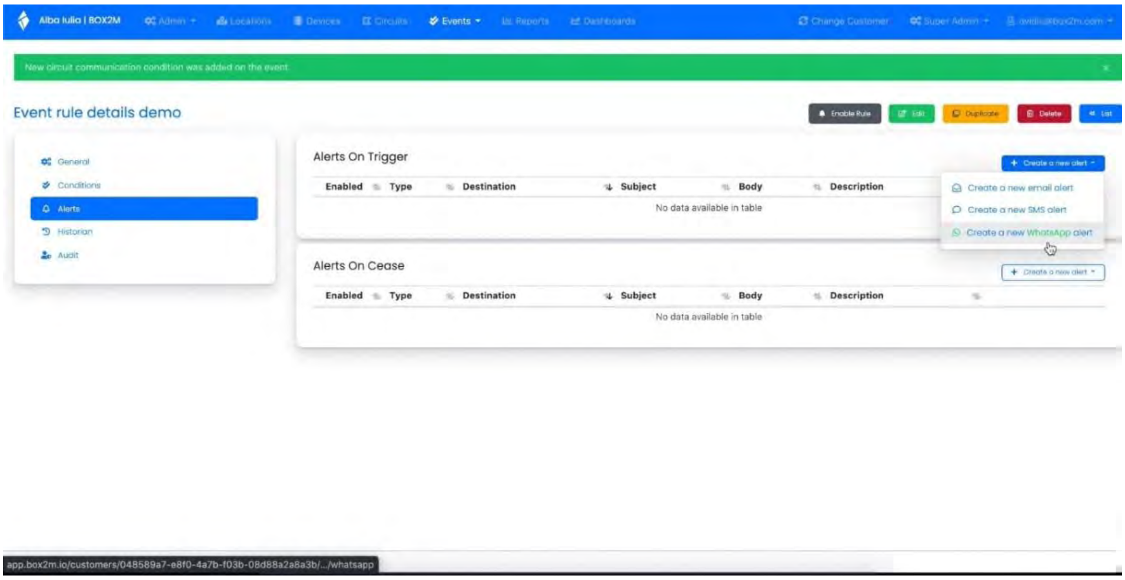
Report: Consumption - Total Active Energy Import - [Graph] Utility: Electrical Device: Primaria Alba Iulia Circuit: Circuit Consumator 1 Time: Last 24 hours Granularity: 1 hour

Consumption - Total Active Energy Import - [Graph] - Last 24 hours - 1 hour

customerKey: albaiulia × channel: 6,688 × circuitKey: zaqrz82ksu × + Add filter

Report: Consumption - Total Active Energy Import - [Graph] Utility: Electrical Device: Primaria Alba Iulia Circuit: Circuit Consumator 2 Time: Last 24 hours Granularity: 1 hour

Figure 5-9 Tabular and graphical report for Energy consumption on specific device



New circuit communication condition was added on the event.

Event rule details demo

Alerts On Trigger

Enabled	Type	Destination	Subject	Body	Description
No data available in table					

Alerts On Cease

Enabled	Type	Destination	Subject	Body	Description
No data available in table					

app.box2m.io/customers/048589a7-e8f0-4a7b-f03b-08d88a2a8a3b/.../whatsapp

Figure 5-10 Set-up alert with specific condition

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

5.4.1 ESeComb01

For the LV Energy Metering UC we can consider one combination of test-cases, starting from some simple test-cases defined in section 5.2, as it is presented below.

- Simple tests (according to the description of ESMe02 and ESMe03): running mMTC network slice, ~30 IoT devices running in parallel or 3000 simulated devices sending data to the Telemetry application; network load measurements
- Combined test (ESeComb01), running mMTC network slice, 30 IoT devices running in parallel with 3000 devices simulated traffic in the network in parallel; network load measurements

The document D3.4 [5] comprises also a definition of the intra-cluster combined test cases, taking into consideration simple 2 simple test cases for each UC and the most demanding combinations/parallel tests, from the network point of view.

6 Conclusions

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

In this context this document defines **Energy and Factories of the Future related services** that will be validated, tested and evaluated independently or together with other services on the various 5G VICTORI facilities in the planned field trials. These field trials will exploit the 5G-VICTORI infrastructure deployments available at the different facility locations (Patras and Alba Iulia) as specified by the overall project architectural activities of **WP2** and implemented as part of the WP4 activities. The different vertical services presented in this document belong to three major categories, which are summarized as follows:

- Real-time monitoring of critical industrial equipment,
- CCTV facility monitoring, and
- Collection of heterogeneous data from multiple sensing devices for data analytics.

More specifically, the Energy and Factories of the Future related UCs that this deliverable concentrates on include:

- Smart Factory services offered in Patras that demonstrate different vertical applications with diverse requirements (critical infrastructure real-time monitoring, predictive maintenance and CCTV – optical inspection) over a unified 5G-enabled solution compliant with Industry 4.0 standards,
- Smart Energy services offered in Patras that demonstrate cross-vertical HV scenarios between the energy domain and the railway domain, with the deployment of a 5G Private Network with edge-cloud capabilities for real-time power consumption measurement collection and data analytics,
- Smart Energy services offered in Alba Iulia for LV scenarios, providing smart energy metering services for public buildings and street lighting with utilization of the 5G-VIOS orchestrator platform for service deployment over multi-domain and multi-orchestrator network infrastructure.

For each service to be demonstrated several test cases were defined and evaluated under laboratory conditions and in some cases initial field trials were also assessed. The test cases described in the document aim to assess the performance capabilities and the efficiency of the 5G-VICTORI infrastructure deployment options, while focusing on different vertical services with diverse characteristics from all the three different 5G service classes (eMBB, uRLLC, mMTC). This deliverable provides a description of the test cases and presents the proposed testing methodology. This includes identification of a set of relevant KPIs that will be monitored and assessed per test case and a description of the proposed KPI measurement/calculation approach that will be taken to facilitate service level assessment, considering the specificities of the underlying 5G infrastructure.

In this context, this document reports a total of 17 detailed test cases. Each test case has started being robustly tested and results from laboratory experiments and in some cases early field tests are documented.

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

7 References

[1] 5G-VICTORI deliverable D2.1 (T2.1) 5G-VICTORI Use-case and requirements definition and reference architecture for vertical services (ORO)

[2] D3.5 (T3.3) Preliminary Use case specification for Energy and Factories of the Future Services (ADMIE, 31 May 2021)

[3] 5G-VICTORI deliverable D4.1 (WP4) Field trials methodology and guidelines (v1.0, 2020-09-24)

[4] 5G-VICTORI deliverable D2.4 (T2.3) 5G-VICTORI end-to-end reference architecture (UNIVBRIS)

[5] 5G-VICTORI deliverable D3.4 (T2.3), “Final Use case specification for Media Services” (RBB, 30 Nov 2021)

[6] 5G-VICTORI Project Proposal (describes partners, objectives, WPs and Tasks, etc.).

[7] 5G; Management and orchestration; 5G performance measurements, 3GPP TS 28.552 version 17.6.0 Release 17, 05/2022

[8] “SERIES L: ENVIRONMENT AND ICTS, CLIMATE CHANGE, E-WASTE, ENERGY EFFICIENCY; CONSTRUCTION, INSTALLATION AND PROTECTION OF CABLES AND OTHER ELEMENTS OF OUTSIDE PLANT”, L1331, ITU-T, 09/2020

[9] 5G-VICTORI deliverable D2.2 (T2.2) Preliminary individual site facility planning (FhG)

8 Appendix

8.1 Proposal Definition of Task 3.3 Energy and Factories of the Future – Project Proposal Definition

This text is fetched from the Proposal document of 5G-VICTORI:

This task involves on-site execution of demonstration activities, which will be carried out by demonstrators in their premises, like HV substations, electric trains. Intra-field trials will be developed vertically between different actors using their infrastructure. The objective is to show the full set of 5G capabilities engaging in a new way of real time exchange of information.

Several use cases will be examined taking into account the type of data to be exchanged, the data that is required by end users and how data will be processed. This will include:

- **provisioning of energy metering services** for HV and LV distributions grids addressing **demand-response scenarios** for
    i. industrial (electrification of large infrastructures such as railways operating in HV), and
    ii. city stakeholders (i.e. electrification of street or public building operating in LV).
- A second use case focusing on the **digitalization of public utilities (power plant)** will be also examined focusing on
    i. the deployment of a massive number of sensors and actuators enabling process automation and optimization and,
    ii. connectivity between the monitored utility and the enterprise. Moreover,
    iii. emergency scenarios will be applied to demonstrate the advantages of 5G technology under extreme conditions that the monitored facilities may encounter.
    iv. Cybersecurity issues could also arise since the exchanged data could be regarded as sensitive especially if they are related to critical infrastructures related to power supply, as well as market procedures (calculation of energy, logistics, market clearance, etc.). The issue of cybersecurity will require a potential comparison to the traditional techniques that are already employed.

This task will serve as input to **WP4** for validation and KPI evaluation.

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