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

D3.5 Preliminary Use case specification for Energy and Factories of the Future Services

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1.0	Last revision and submission of the document	Jesús Gutiérrez (IHP)	2021-07-09

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Executive Summary

This deliverable is the first 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 related 5G-VICTORI Use Case (UC) [2] are investigated, and the Key Performance Indicators (KPIs) associated to each provided service are described.

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

i. real-time monitoring of critical industrial equipment at power utilities and electric train stations, related to **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 have to be described. These necessary guidelines followed by 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 appropriate testing procedures, compliant with the guidelines defined in D4.1, in order to assess the vertical services stemming from the UCs descriptions in D2.1 prior to the 5G-VICTORI trials.

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 [1] and summarized in the Appendix, will also be deployed and evaluated.

An initial assessment of the **Energy and Factories of the Future** services will be part of deliverable **D3.6**, entitled “Final Use case specification for Energy and Factories of the Future services”. Specifically, D3.6 will describe 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. Final results and conclusions stemming from the 5G-VICTORI trials will be the subject of WP4.

1 Acronyms

1.1 General

Acronym	Description
3GPP	Third Generation Partnership Project
5G	Fifth Generation cellular system (3GPP related)
BSCW	The document server used in the 5G-VICTORI project
CPE	Customer Premises Equipment
eMBB	eMBB Enhanced Mobile Broadband - enhanced MBB
iPerf	Measurement tool, can be downloaded here.
MBB	Mobile BroadBand
mMTC	Massive Machine Type Communications
NR	New Radio (3GPP term)
QoS	Quality of Service
RTT	Round-Trip-Time (=two times the latency is both directions)
TOC	Table Of Content
UC	Use-Case
URLCC	Ultra-Reliable Low Latency Communications

1.2 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
D3.5	Delivery 3.5 (within T3.3)
ICT-17	The 5G platform developed for the 5G-PICTURE EU project
ICT-19	The 5G platform developed for the 5G-VICTORI
IR	Interim Review (done 2020-10-08)
T3.3	Task 3.3 (within WP3)
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

The ever-increasing needs of society towards a more efficient way of living calls for a shift towards a more interconnected world. This necessity has led to the ongoing digital transformation of public and private sectors, which ensures the provision of advanced, reliable and secure services to the end users in a direct and user-friendly way. These changes have affected a large number of sectors related to ICT and verticals industries. Verticals such as **Transportation**, **Energy**, **Media** and **Factories of the Future** have received increasing attention lately, due to their importance and impact on society. Their ubiquitous effect in everyday lives dictates the need for their transformation, from legacy services into smart and flexible processes.

The evolution of cellular technologies towards 5G is an important milestone, as it opens the path towards digital transformation. Not only does 5G enable high data rates up to tens of Gbps, end-to-end (E2E) latency in the order of tens of milliseconds and high connection densities, but also it relies on flexible infrastructures and platforms that facilitate the support of different services with diverse Quality of Service (QoS) requirements and Key Performance Indicators (KPIs). Thus, 5G is expected to play an instrumental role in establishing a sustainable environment for advanced vertical and networking services, leading to innovative ideas and new business models that will drive the digital era through collaborations and synergies.

It is obvious that the development of 5G infrastructures and platforms plays an important role in achieving Europe's digital strategy goals, as these will be the foundation on top of which the 5G ecosystem will be established. The 5G-PPP ICT-17 projects, whose purpose was the development of 5G testbeds for verification of UCs in small-scale trials, are vital to this direction. These projects set the basis for the next set of projects under the ICT-19 call, which aim at conducting large-scale trials for advanced UC verification in commercially relevant 5G environments. 5G-VICTORI, which is an ICT-19 project, exploits main sites of 5G-VINNI, 5GENESIS, 5G-EVE (ICT-17 projects) and the 5G UK testbed and modify them, in order to extend their coverage towards the integration of commercially relevant, operational environments. It focuses on the four verticals of interest mentioned earlier, namely **Transportation**, **Energy**, **Media** and **Factories of the Future,** as well as UCs featuring cross-vertical interaction.

Task 3.3 aims at defining the Energy and Factories of the Future related services stemming from their respected UCs that can be tested and evaluated alone or together with other services on top of the underlying 5G infrastructures (work of WP4).

This document defines an initial set of **Energy and Factories of the Future** related test cases – see deliverable **D4.1** [3] for the definition and template of these – that will be used for the preparation and demonstration activities of the project, by assessing the correct operation and performance of advanced vertical services running on top of 5G open infrastructures that are interconnected with the operational vertical premises.

The services considered in Task 3.3 belong to the following categories:

1. Real-time monitoring of critical industrial equipment,
2. CCTV facility monitoring, and
3. Collection of massive data from sensing devices.

Application requirements are related to the WP2 defined ones and some additional ones are defined in WP3. Test-case KPIs are listed in the test-case tables found in this document.

Figure 1-1 provides an overview of the **Energy and Factories of the Future** Services defined in Task 3.3. These services are developed under the scope of the 5G-VICTORI UCs listed in Table 1-1.

Table 1-1 Mapping of Task 3.3 UCs

UC	Title	Targeted 5G-VICTORI facility
UC #2	Digitization of Power Plants	Patras
UC #4	Smart Energy Metering	Patras and Alba Iulia Municipality (AIM)

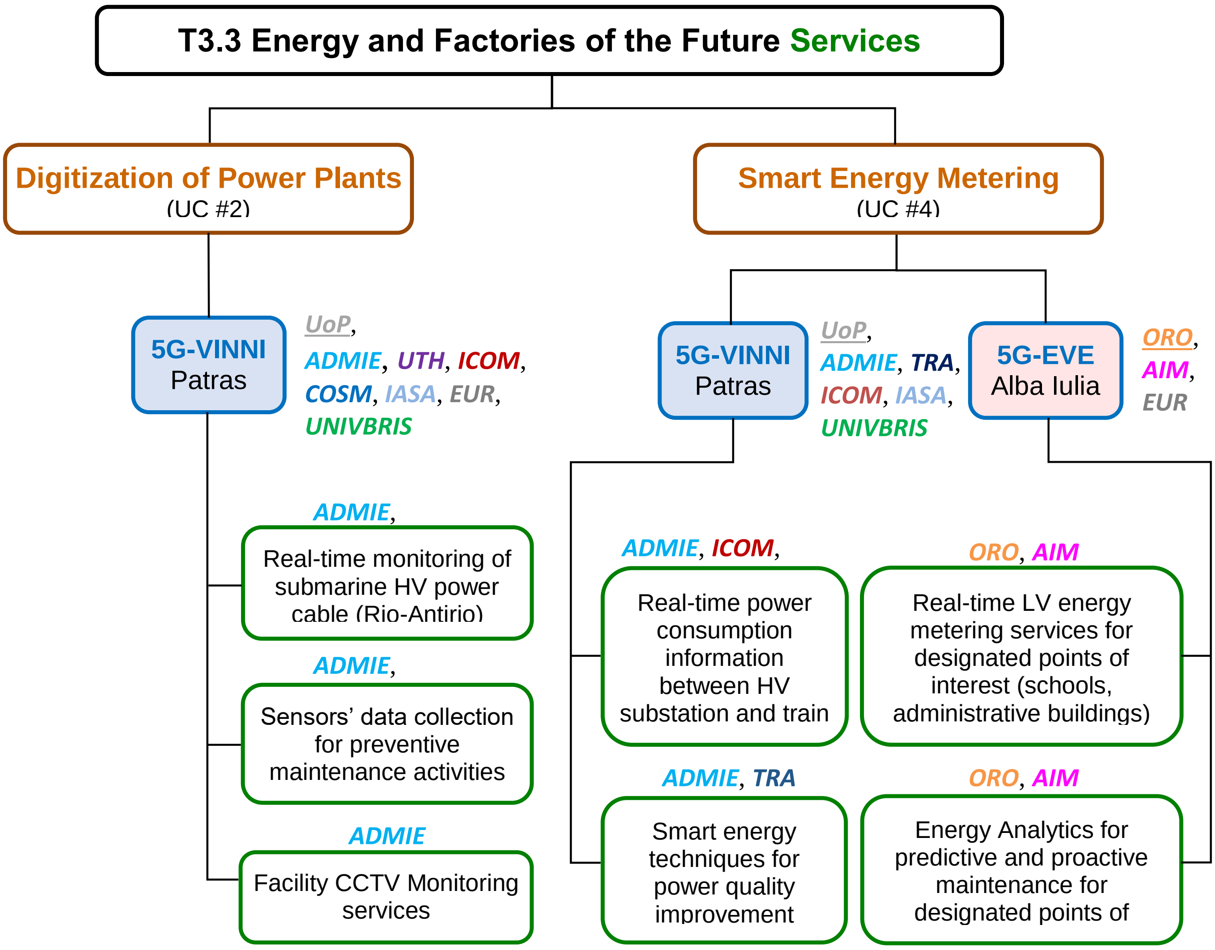

Figure 1-1 T3.3 Energy and Factories of the Future Services - Use Cases, Clusters, Services, *Partners, Demo responsible*.

Figure 1-1 also indicates the partners involved in Task 3.3 and the roles each of them play therein. In general, these include:

- Cluster general content (5G network, servers, backbone links, switches, etc.).
- Delivery of specific vertical services (e.g. asset monitoring, energy analytics).
- Demo responsible partners in WP4 are underlined.

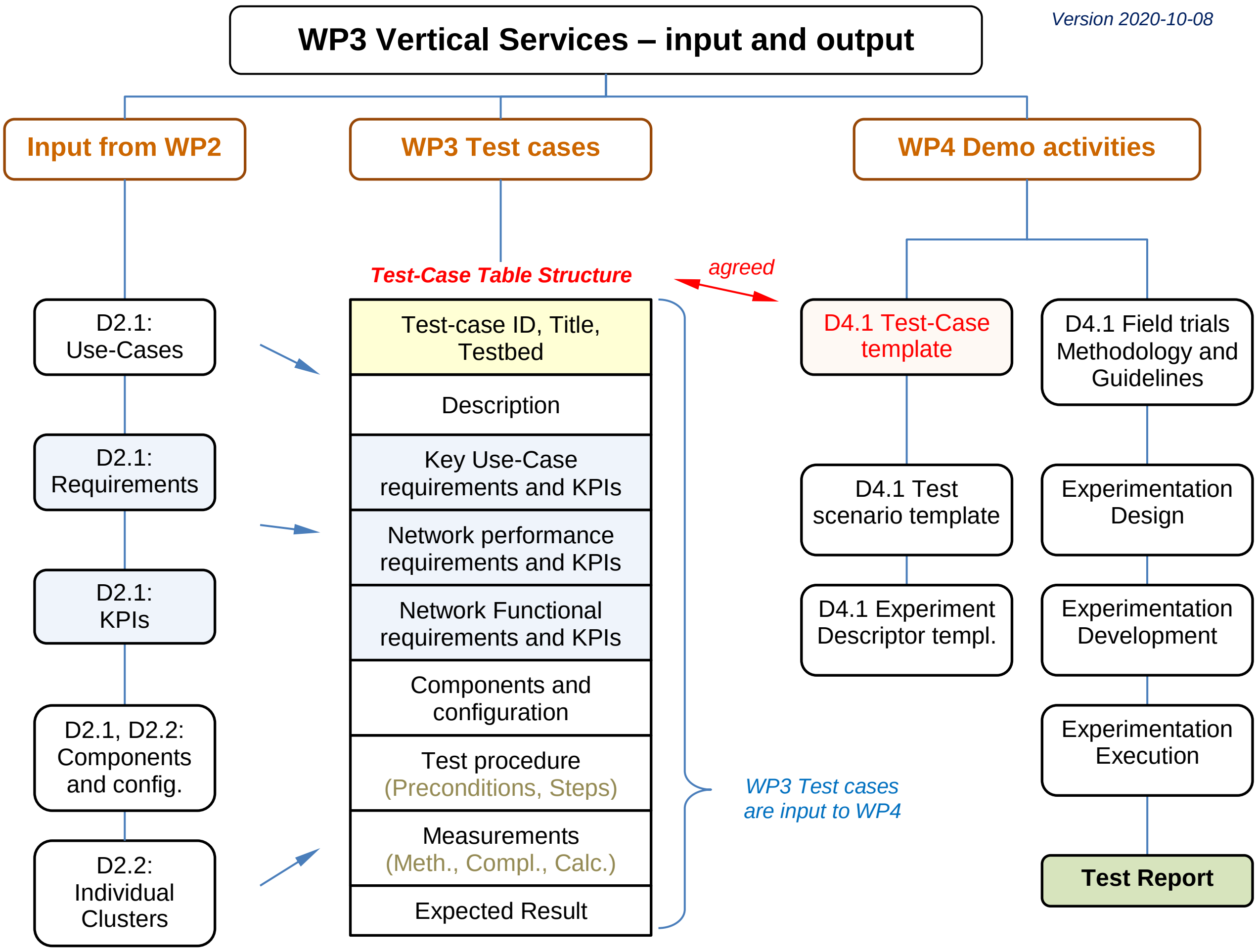

Figure 1-2 Task 3.3 Energy and Factories of the Future Services – Input from WP2, WP3 Test Cases, WP4 Demo activities.

Figure 1-2 describes:

- **WP2** output to WP3 UCs and test cases, where D2.1 contains UC, requirements and KPIs, plus components and cluster configurations in D2.2.
- **WP3** test case tables, the content of which has been agreed with WP4. The WP3 test cases are fed to the WP4 Demo activities
- **WP4** includes a document, deliverable **D4.1** [3], which defines the content in each field of a test case table.

1.1 Objectives and Content

The objectives for the different clusters and vertical services in T3.3 differ according to the characteristics and needs of the vertical industry they are applied to. The different test cases are divided into groups according to the respective cluster and vertical use case. A high-level view of the objectives and content for each group is given below:

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

The services offered in Patras are to demonstrate critical infrastructure real-time monitoring, predictive maintenance and CCTV related services, under the umbrella of a unified 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 and radio slicing support (5G air interface, NB-IoT).

The objectives of this UC is to showcase that the specific Industry 4.0 related services can be sufficiently supported by the available 5G portable platform, 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 infrastructure cannot be relied on.

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 to 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, will be used for the real-time collection and local processing of measurements originating from the moving train and the HV substation.

The objective of this use case 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 the electric train 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 use case 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 the vertical can register, deploy, experiment and monitor the UCs [2].

1.2 Organization of the document

This document comprises three main sections according to the 3 different Use Cases planned for demonstration in 5G-VICTORI, which fall under the category of the Energy and Factories of the Future.

Following the Executive Summary and Introduction sections, section 3 refers to the Digitization of Power Plants Use Case, running at the 5G-VINNI cluster.

Section 4 describes the HV scenario of the Smart Energy Metering Use Case, also running at the 5G-VINNI cluster.

Section 5 discusses the LV scenario of the Smart Energy Metering Use Case, running at the 5G-EVE cluster.

Finally, section **Error! Reference source not found.** concludes the deliverable.

2 Testing methodology

2.1 Testing Methodology Description

The objective of this D3.5 "test specification" is to describe the demonstration scenarios and the relevant test cases of the UC that are planned to be demonstrated. These will be used as input to the WP4 activities in the demonstrations execution. UCs are taken as input from the WP2 documents D2.1, D2.2, D2.3, and are further analyzed and extended in WP3 as detailed test cases.

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

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

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

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

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

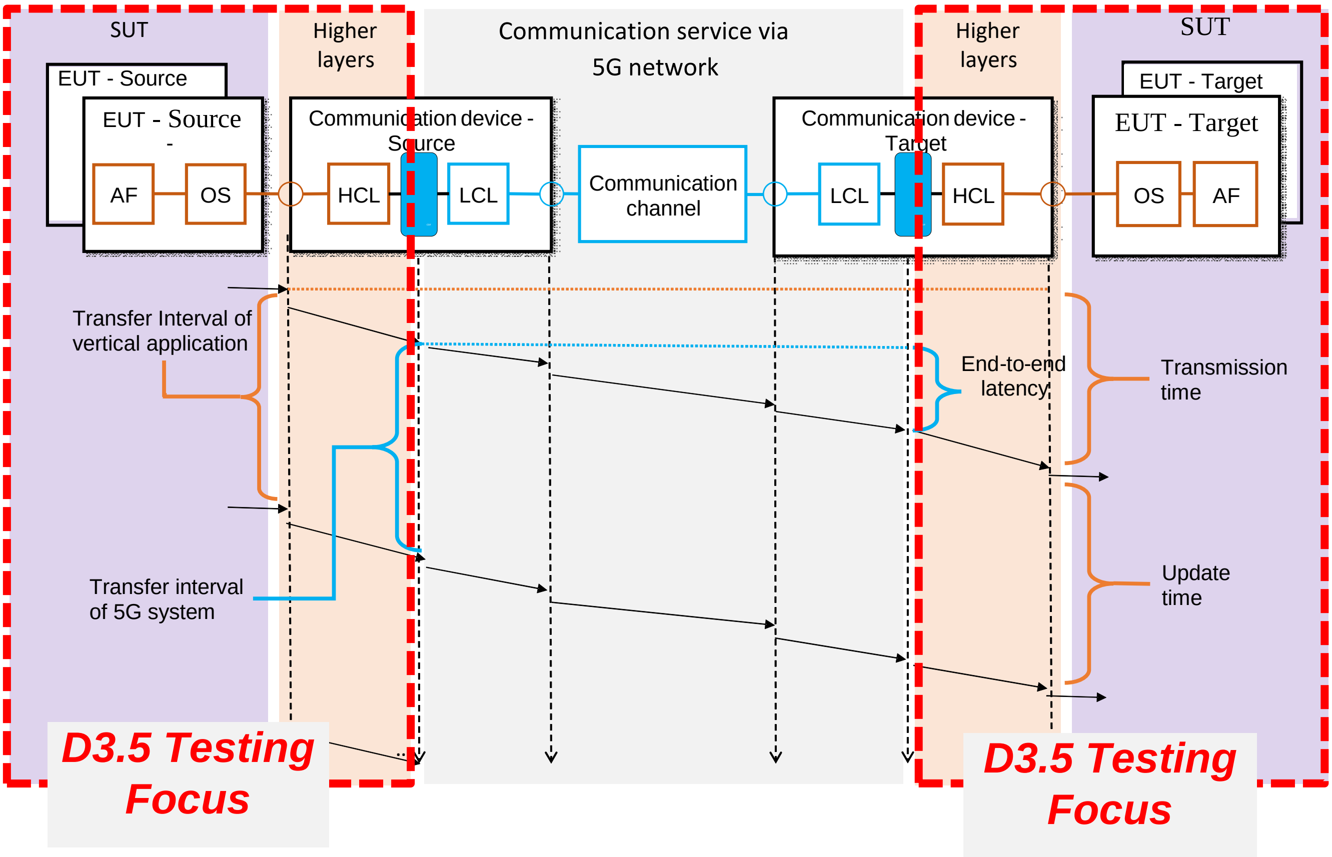

Figure 2-1: Services to be tested and parameters to be evaluated [19]

As deliverable D3.5 focuses on testing of services, the corresponding analysis is limited to the upper layers of the communication system including the applications and the HCL. As the testing results for the services need to be reproducible, the 5G system providing lower communication services will be considered as fixed. Although the various parameters of the 5G communication network influence the performance of the services, it will be not be examined in the present deliverable, as these aspects have been addressed by deliverable D4.1 [3]. However, all services will be tested under a precisely described and controlled 5G environment indicating parameters related to i) the environment where the network will be deployed (spatial extent of the real-world facilitates), ii) propagation environment in which the application operates during testing, iii) background network traffic including the number of wireless devices, number of virtual links established in the cloud environment hosting the 5G platform, iii) Positions of wireless devices and distances between them, iv) type of 5G user equipment and Customer Premises Equipments (CPEs), v) Time during which tests were conducted on the system under test, vi) network topology and network devices, vii) type of servers hosting the 5G platform.

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

Performance testing will be carried over multiple test groups. Each test group investigates the performance parameter(s) of interest and consists of one or multiple test cases. For each test case, each baseline parameter (e. g. number of devices, 5G network topology, compute resources allocated to the RAN and Core functions,) has a single specified value. However, the value of one or more baseline parameters is altered within a test group, i. e. from one test case to the next, in order to assess the impact of the altered baseline parameter(s) on the performance parameter(s).

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

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

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

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

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

2.2 Test case development

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

To facilitate the specification of test cases, test description tables contain the following information:

- *Test-case ID*: A detailed description of the test IDs used to distinguish the various use cases and services to be tested. The ID number is unique 6-character string of letters and number providing a specific piece of information about the type of use case, the group where this use case belongs, the 5G cluster that this service belongs etc. The test-case ID structure in WP3 follows a set of specific principles. These principles, customized for T3.3 test cases, are described below:
  - The first prefix letter **E** stands for **Energy** and factories - reflects T3.3, with "Energy and Factories of the Future Services".
  - The second prefix letter represents a use case group within each vertical service:
    - E**D** = Energy and factories **Digitization** of power plants services

  - E**S** = Energy and factories **Smart** energy metering services
- The third prefix letter is used to group types of services or network-related services.
- The fourth prefix letter is a lower case one, which indicates the 5G cluster:
  - **v**: 5G-VINNI, Patras
  - **e**: 5G-EVE, Alba Iulia
- The trailing number 01..99 in the test-case ID gives room for up to 99 test cases in each category.
- This gives a list of test-case IDs for T3.3 and D3.5 looking like this:
  - EDHv - Energy and factories Digitization of power plants Patras Real-time monitoring of HV power cable test cases.
  - EDSv - Energy and factories Digitization of power plants Patras Sensor data collection test cases.
  - EDCv - Energy and factories Digitization of power plants Patras Facility CCTV monitoring test cases.
  - ESCv - Energy and factories Smart energy metering Patras Real-time power consumption test cases.
  - ESMe - Energy and factories Smart energy metering Alba Iulia Real-time LV energy metering services functionality test cases.
  - ESAe - Energy and factories Smart energy metering Alba Iulia Energy Analytics test cases

- *Title, Testbed name*: Title of the use case and facility over which the testing process will be conducted.
- *Description of test* in concise manner explaining the purpose of the test. The description is also used to distinguish this test from any other test in the document
- *Key use-case requirements and KPIs*: The requirements and KPIs listed in the test case tables with a label come from **WP2** deliverable D2.1, which uses a unique numbering, being an example **S-FU-5301** (Smart Factory and Functional related and a number). These are categorized with:
  - User = vertical service related, Facility = network related
  - Type: Functional (FU), Performance (PE), Capacity (CA), or Other (OTH).
- *Network performance and KPIs*
- *Network functional requirements and KPIs*
- *Listing and configuration of all components used in the testing process*. This includes a list of test specific pre-conditions including information about equipment configuration, the initial state of the SUT, etc.
- *Test procedure specification*. This section defines a sequence of elementary actions and checks being executed on different test entities.
- *Measurements*: This section provides information for the results to be obtained per test
- *Expected results* giving emphasis on tests that failed or the performance achieved didn't met performance the associated KPIs. For this case, description where the test case has failed, as well as the location where the error/unexpected performance has been observed will be highlighted.

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

3.1 Description

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** [2] and **D2.2** [4], the 5G-VICTORI "Digitization of Power Plants" UC will demonstrate how the requirements of the different applications in a Smart Factory can be sufficiently supported with the adoption of 5G technologies and the deployment of a private 5G network.

The trial will take place at the **ADMIE** facilities located in Patras, Greece, near the University of Patras campus and will serve as an extension to the 5G-VINNI facility. As depicted in Figure 3-1 which presents a high-level view of the UC, **ADMIE** facilities consist of two sites, in Rio and Antirio, separated by 4 km of sea and electrically interconnected via a High Voltage (HV) power cable. Each site serves as termination point for the HV power cable and comprises one control room and several sensors for the monitoring of the termination equipment status at this site. Sensor measurements are displayed on 7-segment displays at each site with no storage or communication capabilities.

With respect to deliverable D2.3 [5], for the needs of this UC, **ADMIE** facilities will be enhanced with new types of sensors, gateways, and monitoring devices. Firstly, dedicated Modbus TCP gateway devices are used to provide networking capabilities to the already planted sensors, thus enabling their integration to the 5G network. In addition, NB-IoT sensors will be installed on the sites along with 5G-enabled sensors for the collection of temperature, humidity etc. Lastly, cameras will also be installed at the Rio site to enable CCTV applications that will connect to the 5G air interface via 5G gateways. All these devices will be interconnected through a multi-RAT private network with the MEC server located inside the HV cable control room.

A data management platform (UiTOP) provided by **ICOM** will operate on top of the MEC server. UiTOP is a cloud-hosted multi-tenant IoT solution that is developed in a containerized micro-services based architecture. It comprises all the features of a complete IoT solution, from the most basic core functionalities such as data storage and control services, to some optional modules which can be customized on demand to satisfy the specific needs of each application. Due to its containerized architecture, UiTOP can be executed on the cloud or at the edge, providing capabilities of distributed processing and storage. Last but not least, it includes a rich and customizable dashboard for monitoring purposes, along with a northbound API for easy information exchange with third party applications, such as services for sensor data analytics.

The IoT solution will be able to collect measurements originating from sensors using different application level communication protocols (Modbus TCP, MQTT, etc.) and over different over-the-air interfaces (NB-IoT, 5G NR, etc.), and transform them into meaningful information for further use (reports, alarms, etc.). The sensor data from Rio and Antirio sites will be transmitted to the same destination, which is the MEC server where UiTOP will be executed. For that purpose, the two **ADMIE** sites will be interconnected via a fiber optic link, while the overall infrastructure will be interconnected with the 5G-VINNI facility at UoP through a millimeter wave (mmWave) link, for further processing and permanent storage.

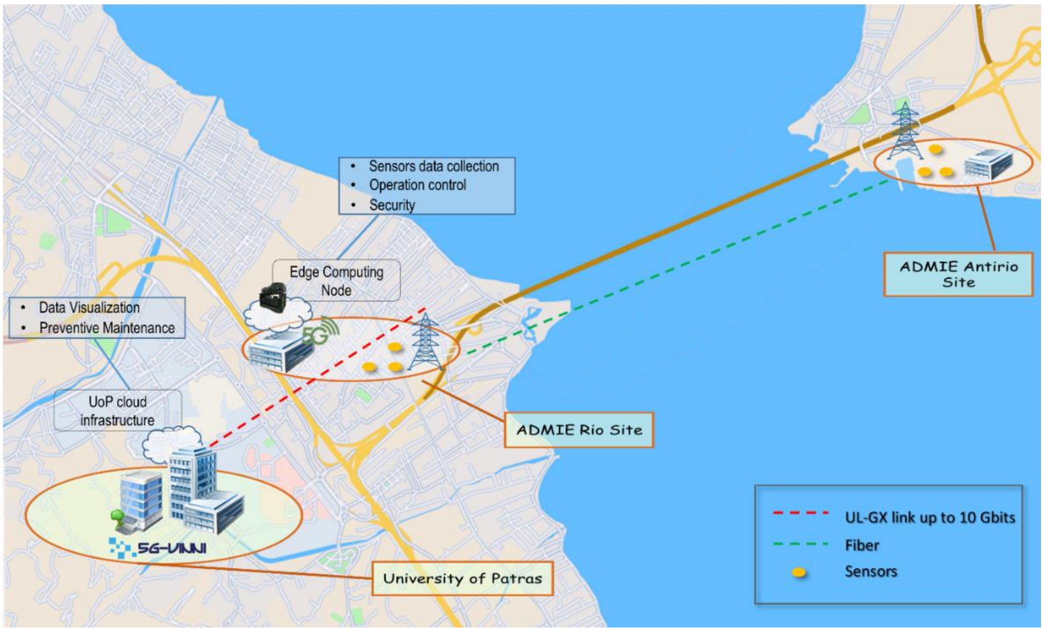

Figure 3-1: High-level network design Rio-Antirio site

With the deployment of a private 5G network, the facility operator (ADMIE) will be able to configure the network, computing and storage resources according to the requirements of the specific applications. Through the network and computing performance monitoring tools provisioned by UoP, the facility operator will be also able to collect communication, storage and processing related metrics, and thus gain the end-to-end view and control over the facilities (e.g. ensure priority to time-critical applications). Moreover, the use of a private network enhances data privacy, security and expandability, and thus satisfies some of the major quality performance indicators in the energy domain.

The objective of the following test cases is to validate the correct setup and deployment of the different applications, the fulfillment of their specific requirements, and their coexistence under a unified 5G-enabled monitoring solution. A brief reference 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 UC 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.

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

3.2.1 Description

Real-time monitoring of HV power cable refers to real-time synchronization of measurements from **ADMIE** sites in Rio and Antirio. The two sites are interconnected via a submarine HV cable whose status is monitored via sensors planted in both sites. The measurements from both sites will be collected, synchronized and stored in a common time-series database. Then the status of the cable will be estimated and control signals will be emitted in case of emergency. In order to support the low latency requirements imposed by the nature of the application, storage and computation will be performed at an edge server in one of the two sites. The test cases in this section will determine the latency between an abnormal event and its identification by the monitoring solution.

The elements used for demonstration of this service are spread into three different locations (Rio and Antirio **ADMIE** sites, **UoP** Campus) and depicted in Figure 3-2. **ADMIE** facilities are enhanced with new types of sensors, gateways, and monitoring devices. Firstly, dedicated Modbus TCP gateway devices are installed used to provide networking capabilities to the already planted sensors. Modbus TCP is an open industrial protocol stack where typical Modbus RTU messages are transmitted with a TCP/IP wrapper over an IP network. The installed Modbus TCP gateways are integrated to the private 5G network through a 5G gateway. A laptop is also connected to the 5G, where a Modbus TCP simulator is used to simulate different types and number of Modbus devices and abnormal scenarios. Measurements are collected through a private 5G network established on the Autonomous Edge solution provided by **UoP**, which provides also provides MEC capabilities.

On top of the MEC server, UiTOP will be used as the IoT platform. UiTOP is a cloud-hosted multi-tenant IoT solution that is developed in a containerized micro-services based architecture. It comprises all the features of a complete IoT solution, from the most basic core functionalities such as data storage (MongoDB) and control services, to some optional modules which can be customized on demand to satisfy the specific needs of each application. For the needs of this vertical application, a custom Modbus TCP adapter, able to collect measurements from the aforementioned devices, has been developed. Measurements from Rio and Antirio devices will be collected, synchronized and stored at the Rio MEC server.

These measurements will be compared against predefined thresholds and trigger real-time alarms and reports in case of an abnormal event. Alarms and measurements are also collected at the UoP campus Cloud, which is connected with ADMIE Rio site through MmWave Connection, also established by **ICOM**. At the UoP cloud, several VMs facilitating the monitoring of the communication network and the cloud resources, along with the energy related measurements, are available.

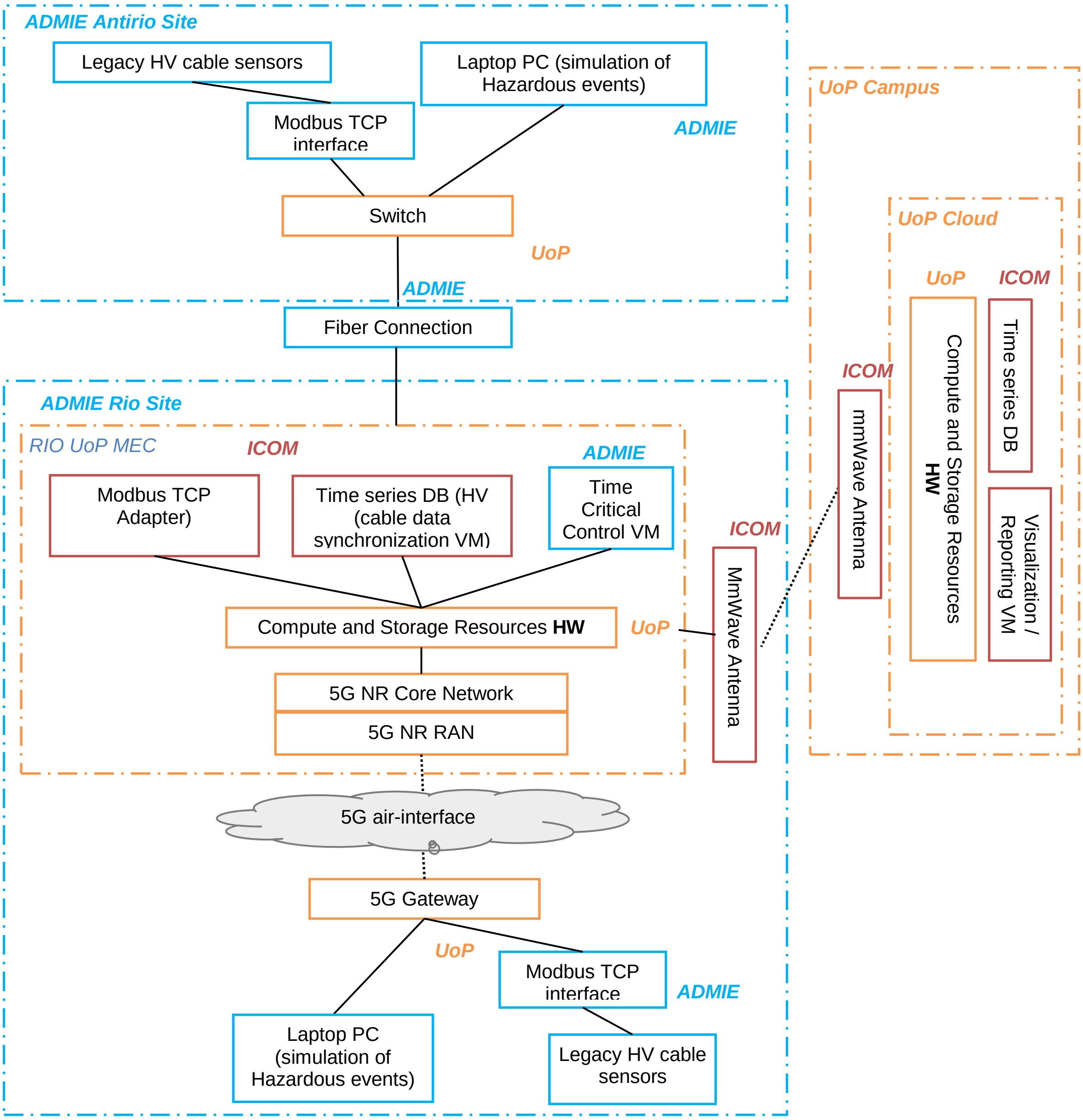

Figure 3-2: Digitization of Power Plants in Patras – Real-time monitoring of HV power cable – High-level deployment architecture

3.2.2 EDHv01: HV cable sensors data logging without 5G connectivity (lab & field test)

The legacy HV cable sensors at each site are not connected to the corporate network and only provide alarms regarding the system state (at each site) via a 7-segment display. The first step towards a real-time monitoring system is to:

a) enhance the sensors with networking capabilities,

b) configure the platform for the specific type of sensors and communication protocols,

c) integrate the legacy sensors to the platform, and

d) validate the performance of the solution via Ethernet connectivity.

Table 3-1: EDHv01 - HV cable sensors data logging without 5G connectivity (lab & field test)

EDHv01	HV cable sensors data logging without 5G connectivity (lab & field test)
Testbed	**5G-VINNI Patras**
Description	The objective of this test case is the configuration and testing of sensors and platform for the real-time acquisition of measurements at each site via Ethernet connectivity. It will be validated that the platform can be hosted at the cloud or at the edge, communicate with the sensors and translate their messages to meaningful information. It must be validated that the sensors, industrial communication protocol and platform can support the functional KPIs of the vertical application prior to the 5G network deployment. The industrial communication protocol that will be used is Modbus TCP.
Key Use-case requirements and KPIs	1. IoT Platform functionality can be successfully hosted at the edge. 2. Sensors specific industrial protocol is supported by the solution. 3. Measurements are translated and displayed correctly at the dashboard.
Network performance requirements and KPIs	Latency for measurement acquisition below 10 ms (It refers to the sum of sensing, networking and computation latency)
Network Functional requirements and KPIs	**S-FU-5302** (Distributed Pools of (Compute/Network) Resources)
Components and configuration	**- Components:** 1. VM running the IoT platform 2. Sensor's simulator (virtual Modbus TCP sensors) 3. MEC server (Autonomous Edge) 4. Legacy sensors 5. Modbus TCP interface (Modbus TCP recorder) 6. Ethernet 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 of IoT platform time-series database (type of data, time resolution, etc.)
Test procedure	**- Preconditions:** 1. IoT platform VM is running and Modbus TCP plugins are configured. 2. Modbus TCP recorders are installed at the ADMIE sites and 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 at the corresponding time-series database and time at the end of processing is also marked. 6. It is checked that the stored value complies with the sent value (e.g., by using predefined measurements at the sensors’ simulator / or by cross checking with the legacy displays of the facilities) 7. End-to end latency is measured

Measurements	**- Methodology**
	• Test procedure will be repeated with different number of physical and virtual sensors and for different plugin configuration (e.g. read requests / second)
	    o To validate the correct measurements translation and storage at the IoT platform, a great number of predefined measurements will be sent by the sensors' simulator and the physical devices
	    o For the evaluation of network KPIs, measurements for each configuration are collected for a number of iterations.
	
	1. The initial data logging timestamp is recorded and sent to the plugins as part of the message, along with the sensor data.
	2. Processed data are timestamped again prior to their storing to the database.
	3. Both timestamps for each case are exported to a CSV file.
	4. Process is repeated for a significant amount of messages
	- Complementary measurements
	1. Max. Number of read requests
	- Calculation process
	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 read in the database.
	1. The time difference between the two timestamps is calculated for each case.
	2. Max value, Mean average and standard deviation are calculated for the computational latency.
	3. Results are stored in a CSV file.

Expected Result	• IoT platform successfully hosted at the edge resources • Measurements are correctly translated to meaningful information and stored in the correct format • Latency according to the KPIs

3.2.3 EDHv02: HV cable sensors data logging with 5G connectivity (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 non-public wireless network (NPN) which will be able to meet the specified KPIs.

Table 3-2: EDHv02 - 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	Following the initial configuration of the legacy sensors at each site and the one for the IoT platform's specific plugins, the actual field setup will be deployed and validated. This includes 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 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 > 99.9999999% (SIL 7) Availability > 99.9999999% (SIL 7) 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 and IoT platform as of Test Case EDHv01 2. 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 as in EDHv01 **- 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 at the corresponding time-series database and time at the end of processing is also marked. 6. End-to end latency is measured 7. Traffic generator application is used to simulate different traffic conditions. 8. 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 read in the database. 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, regardless of the traffic generated by the other services running simultaneously at the facilities.

3.2.4 EDHv03: Data transmission test between Rio and Antirio sites (field test)

The two sites are separated by a canal and will be interconnected via a fiber connection. The two sites are an extension to the 5G-VINNI facility. The objective of this test case is to evaluate the connectivity between the two sites and measure the performance of the connection. The IoT platform is hosted at the Rio facilities, so it must be validated that measurements originating from Antirio site can be collected as well.

Table 3-3: EDHv03 - 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 (fiber + 5G RAN).
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 > 99.9999999% (SIL 7) Availability > 99.9999999% (SIL 7) 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 3-2. 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. Fiber 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 Antirio sensors and Autonomous Edge is established Expected KPIs for the interconnection are met

3.2.5 EDHv04: Data Synchronization service for measurements correlation between Rio and Antirio sites (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 and have been stored 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 3-4: EDHv04 - 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 > 99.9999999% 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 > 99.9999999% (SIL 7) Availability > 99.9999999% (SIL 7) 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 < 99.9999999% Unsynchronized measurements should be 99.9999999%

3.2.6 EDHv05: 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 (see Table 3-5).

Table 3-5: EDHv05 - 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 > 99.9999999% (SIL 7) Service Availability > 99.9999999% (SIL 7)
Network performance requirements and KPIs	Reliability > 99.9999999% (SIL 7) Availability > 99.9999999% (SIL 7)
Network Functional requirements and KPIs	**S-FU-5304** (Slicing) **S-FU-5301** (Air Interface – Access Network) **S-FU-5303** (Multi-Tenancy)

<table>
<tr><td>Components and configuration</td><td>- 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.</td></tr>
<tr><td>Test procedure</td><td>- 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.</td></tr>
<tr><td>Measurements</td><td>- 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.</td></tr>
<tr><td>Expected Result</td><td>Use case KPIs are met regardless of the traffic conditions</td></tr>
</table>

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

3.3.1 Description

Sensor data collection service includes all the necessary actions and applications that are able to transform the legacy **ADMIE** site located at Rio into a smart and automated infrastructure. The Rio site consists of a simple control room without any type of remote access. In order to provide this capability, as well as additional services such as monitoring, data analytics, predictive maintenance, etc., sensors supporting 5G NR and other 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.

As depicted in Figure 3-3, for the demonstration of this service, in addition to Modbus TCP gateways, NB-IoT sensors will be distributed across the Rio facility for the collection of non-time-critical quantities, such as environment temperature, humidity etc. In order to support Radio slicing NB-IoT will be provided by a second LimeNET Mini, also installed at Rio site. In this sense, the different sensors and devices will be interconnected through a multi-RAT private network supported by the MEC server located inside the HV cable control room. The sensor measurements will be transmitted in JSON format through a REST API adapter to the UiTOP filtering service running on the MEC. Filtered data will be transmitted to the UoP Cloud through mmWave antennas in order to be further processed by data analytic algorithms and provide valuable information regarding equipment health, expected lifetime etc.

The objective of the specific test cases is to ensure that the below demonstrations will take place:

i. Demonstrate MEC capabilities by applying an advanced sensor management system at the edge for handling multiple devices supporting 5G NR or different access technologies,

ii. Demonstrate mmWave link backhaul connectivity with 5G-VINNI infrastructure,

iii. Demonstrate advanced Industry 4.0 applications over power utilities.

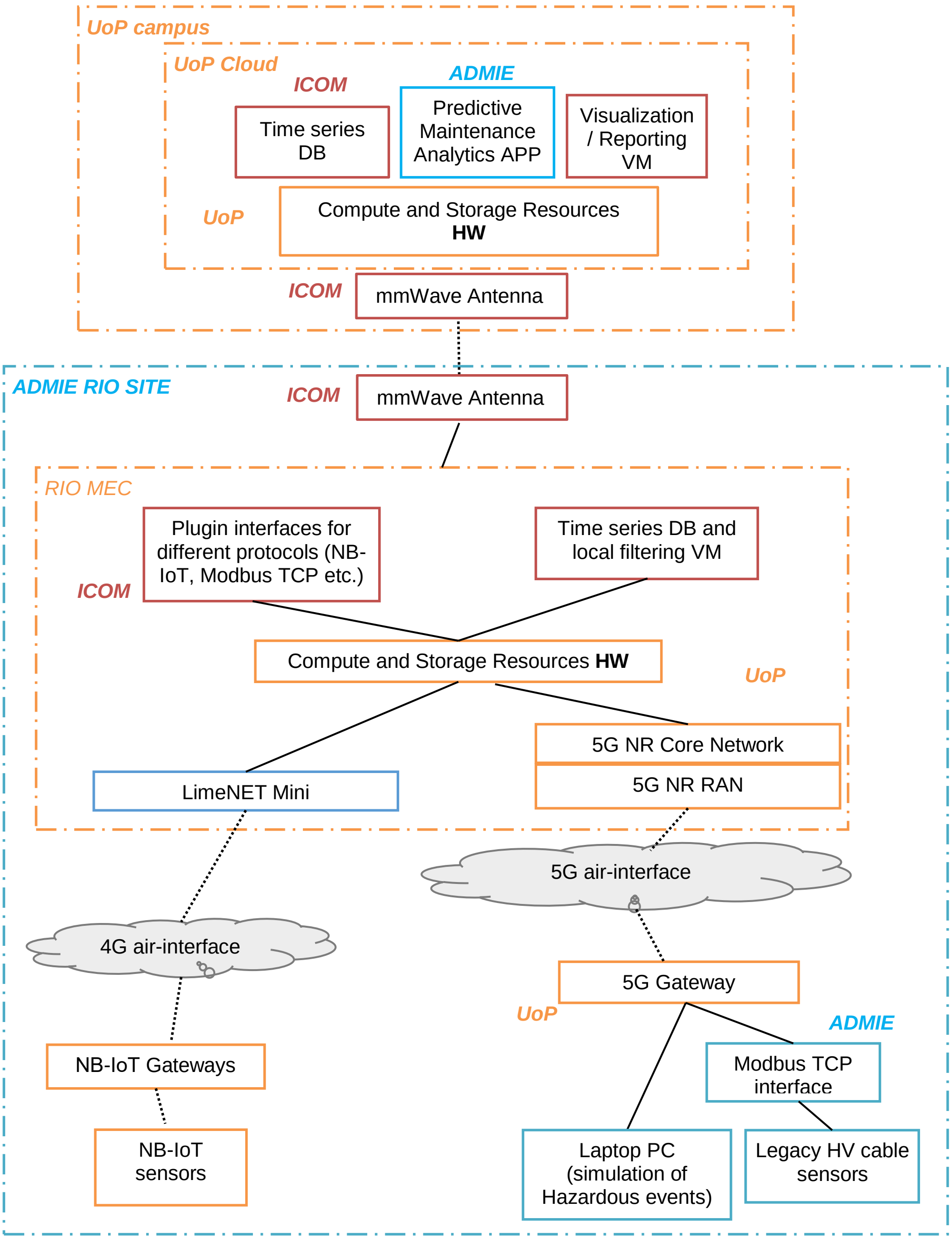

Figure 3-3: Digitization of Power Plants in Patras – Sensor data collection – High-level deployment architecture

3.3.2 EDSv01: Data management platform pre-test on MEC server without support of multi-RAT connectivity (lab test)

The first step towards the transformation of the legacy ADMIE site at Rio into a highly-connected industrial facility is to address the connectivity issues that are present and install additional low-cost IoT sensors for the needed data generation that will drive the advanced monitoring applications planned in the context of the EDS services. For that purpose, this initial test case will focus on: a) the provision and installation of various IoT sensors throughout the Rio site, b) the data collection from legacy sensors with no previous networking capabilities, c) the necessary modifications / enhancements to the IoT platform located at the MEC server, to accommodate for the different IoT and industrial protocols used and d) the evaluation of the platform's performance on the management of high-volume network traffic when sensors are directly connected to the platform via Ethernet. See Table 3-6 for the test case.

Table 3-6: EDSv01 - Data management platform pre-test on MEC server without support of multi-RAT connectivity (lab test)

EDSv01	Data management platform pre-test on MEC server without support of multi-RAT connectivity (lab test)
Testbed	**5G-VINNI Patras**
Description	The initial test case aims at the preparation and the needed configurations for the integration of the data management platform at the MEC server. It will verify the functionality of the platform by testing it in a lab setup for different number of sensors and network traffic, through both virtual sensors and simple data sources via direct Ethernet links.
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	**S-OTH-5203** (Scalability - max 100 connections)
Network Functional requirements and KPIs	N/A
Components and configuration	**- Components:** 1. VM running UiTOP platform 2. Sensors' data simulator (virtual Modbus TCP/MQTT sensors) 3. MEC server (Autonomous Edge) 4. Modbus TCP/MQTT sensors with Ethernet connectivity **- Configuration:** 1. Configuration of sensors (physical and virtual) to send data to the platform (endpoints, report rate etc.) 2. Appropriate design/configuration of UiTOP plugins for communication with sensors supporting different application protocols (e.g. Modbus TCP, MQTT) 3. Configuration of UiTOP's time-series database (type of data, time resolution, etc.)
Test procedure	**- Preconditions:** 1. UiTOP running on MEC server 2. Simulator running on MEC server 3. All sensors (physical and virtual) are ready, configured with a specific report rate and connected to UiTOP 4. UiTOP plugins are configured with their maximum report rate **- Test Case Steps:** 1. Physical and virtual sensors send raw data at a specific report rate to the appropriate plugins. 2. UiTOP's customized plugins receive the data and translate it into meaningful information. 3. Processed data is stored at the corresponding time-series database. 4. The process is repeated for different number of sensors and different report rates. 5. KPIs are measured for each case and a boundary one is identified, as the combination of the maximum number of sensors the platform can manage and the highest data rate / sensor.

Measurements	**- Methodology** 1. Measurements are collected for a number of iterations for the evaluation of each KPI for each set of test conditions. 2. Data collected for each test case (e.g. sensor report rates, total datarate, number of devices) is exported to a CSV file. 3. A final CSV file, containing the expected results for each case and the information regarding the respected UiTOP configuration, is exported and can be used as a guide for future tests. **- Complementary measurements** 1. N.A. **- Calculation process** 1. Total Datarate can be calculated as the sum of received data in a time period of 1 second and then it can be converted to (Mbps). 2. The expected results for each set of test conditions is calculated by combining the data for each iteration into the computation of the mean value of each parameter of interest (e.g. total datarate, sensor datarate, number of sensors). 3. Boundary case is identified by appropriate filtering of the results.
Expected Result	The aim is to showcase UiTOP's capability to be used as a middleware software in order to provide advanced data management services and support MEC applications, while ensuring that performance indicators fall within the thresholds described above.

3.3.3 EDSv02: Data management platform with support of multi-RAT connectivity on MEC server (lab & field test)

Having validated the IoT platform’s performance and data management capabilities when installed at the MEC server, the next step is to deploy the platform and test it in a real industrial environment. In this case, the low-cost IoT sensors will be spread into the HV power cable control room and connect to the MEC server wirelessly though different RATs. The purpose of this specific test case is to validate the platform under scenarios where multiple sensors supporting different physical interfaces are present, without arising any issues on the overall operation. This scenario also includes the validation of the 5G network slice that will be used for the high-volume measurements collection and the additional equipment needed for the provision of 5G connectivity to the legacy sensors.

Table 3-7: EDSv02 - Data management platform with support of multi-RAT connectivity on MEC server (lab & field test)

EDSv02	Data management platform with support of multi-RAT connectivity on MEC server (lab & field test)
Testbed	**5G-VINNI Patras**
Description	In this test case, the data management platform which was previously integrated successfully at the MEC server, will be tested in scenarios where multiple sensors of heterogeneous access technologies (e.g. 5G NR, NB-IoT) coexist in the same space.
Key Use-case requirements and KPIs	1-100 Kbps Datarate per sensor 2-10 Mbps Total Datarate 1000 Mbps/ 2000 m2 Traffic Density 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-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. VM running UiTOP platform 2. Sensors' data simulator (virtual Modbus TCP/MQTT sensors) 3. MEC server (Autonomous Edge + gNB) 4. LimeNET Mini 5. 5G CPE gateway 6. Modbus TCP Gateway 7. NB-IoT Gateway(s) 8. 5G-enabled/NB-IoT Sensors 9. Legacy sensors **- Configuration:** 1. Configuration of sensors and IoT platform as of Test Case EDSv01 2. Configuration and setup of networking devices (gNB, 5G CPE, LimeNET Mini, Modbus TCP gateway) 3. Configuration and setup of 5G/NB-IoT and legacy sensors
Test procedure	**- Preconditions:** 1. Same as of Test Case EDSv01 **- Test Case Steps:** 1. Sensors send raw data at a specific report rate to the appropriate plugins of UiTOP via different networking interfaces (e.g. 5G NR, NB-IoT), along with sensor simulator. 2. UiTOP's customized plugins receive the data and translate it into meaningful information. 3. Processed data is stored at the corresponding time-series database. 4. Information regarding transmitted and lost packets are stored in UiTOP. 5. The process is repeated for different number of sensors and different report rates. 6. KPIs are measured for each case and best case is identified.

Measurements	**- Methodology** 1. Measurements are collected for a number of iterations for the evaluation of each KPI for each set of test conditions. 2. Data collected for each test case (e.g. sensor report rates, total datarate, number of devices) is exported to a CSV file. 3. A final CSV file, containing the expected results for each case and the information regarding the respected UiTOP configuration, is exported and can be used as a guide for future tests. **- Complementary measurements** 1. N.A. **- Calculation process** 1. Total Datarate can be calculated as the sum of received data in a time period of 1 second and then it can be converted to (Mbps). 2. The expected results for each set of test conditions is calculated by combining the data for each iteration into the computation of the mean value of each parameter of interest (e.g. total datarate, sensor datarate, number of sensors). 3. Boundary case is identified by appropriate filtering of the results.
Expected Result	The aim of this test case is to validate the platform's functionality and evaluate its performance in a real industrial environment, while ensuring that performance indicators fall within the thresholds described above.

3.3.4 EDSv03: 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 3-8: EDSv03 - Infrastructure test between Rio site and 5G-VINNI (field test)

EDSv03	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 service 2. iperf server service 3. ICMP client service 4. ICMP server service 5. MEC server (Autonomous Edge) 6. mmWave 10Gbit Link 7. UoP DC 8. Traffic Analyzer service **- Configuration:** 1. Installation and configuration of mmWave 10Gbit Link 2. Configuration and setup of iperf client service 3. Configuration and setup of iperf server service 4. Configuration and setup of ICMP client service 5. Configuration and setup of ICMP server service
Test procedure	**- Preconditions:** 1. Confirm that MEC server and UoP Cloud are configured and are up and running. 2. Create a network slice for mmWave link testing, comprising 4 VNFs. Two for traffic generation (iperf/ICMP client) and two for receiving the traffic (iperf/ICMP server). **- Test Case Steps:** 1. Firstly, the iperf client service is configured to initiate traffic from the MEC server to the iperf server service located at the UoP Cloud (uplink). 2. The iperf server service 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 the ICMP client service at Rio and the ICMP server service at UoP Cloud.
Measurements	**- Methodology** 1. Generate the traffic using the iperf and ICMP client services. 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.

3.3.5 EDSv04: 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 3-9: EDSv04 - End-to-end Preventive maintenance application deployment (lab & field test)

EDSv04	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	N/A
Components and configuration	**- Components:** 1. UiTOP VM #1 in MEC Server 2. Sensors' data simulator (virtual Modbus TCP/MQTT sensors) 3. MEC server (Autonomous Edge + gNB) 4. LimeNET Mini 5. 5G CPE gateway 6. Modbus TCP Gateway 7. NB-IoT Gateway(s) 8. 5G-enabled/NB-IoT Sensors 9. Legacy sensors 10. mmWave 10Gbit Link 11. UiTOP VM #2 in UoP Cloud 12. UoP DC **- Configuration:** 1. Configuration of sensors and IoT platform as of Test Case EDSv02 & EDSv03
Test procedure	**- Preconditions:** 1. Same as of Test Case EDSv02 & EDSv03 **- Test Case Steps:** 1. Sensors send raw data to the appropriate plugins of UiTOP via different networking interfaces (e.g. 5G NR, NB-IoT), along with sensor simulator. 2. UiTOP's customized plugins translate it into meaningful information. 3. Processed data is stored at the corresponding time-series database and then it is forwarded to the Data Fusion service. 4. Filtered data are transmitted at the UiTOP instance at UoP Cloud for further use. 5. 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.
Expected Result	Evaluation of the end-to-end application.

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

3.4.1 Description

Industrial infrastructures contain multiple safety hazards that can threaten the physical wellbeing of the workers. Power utilities is a special case of such a harsh environment where not only does a high safety risk exist but also it is a critical infrastructure with direct impact on society. It is easy to understand that a simple fault in an HV substation control room could mean the loss of monitoring and observability of the power grid, even leading to instability in the grid. 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, two UHD CCTV cameras are installed inside the HV cable control room. The components setup is quite similar with that of EDHv test case group, in terms of network connectivity. In the application layer, these cameras will capture images from the interior of the control room and forward them to the MEC server for preprocessing. In case an event is detected (e.g. technical personnel in the room), the UHD camera 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**. The cameras' application part is generating the CCTV monitoring frames that are sent and monitored at the MEC server and UoP Cloud. At application layer, the session is established over a H.264 session layer, and the traffic is of UDP type.

The purpose of the Facility CCTV Monitoring service on high-level is the following:

- Provide network slice customized for CCTV monitoring.
- Demonstrate that CCTV Streaming is conveyed over 5G with the required characteristics, regardless of other services and background traffic.

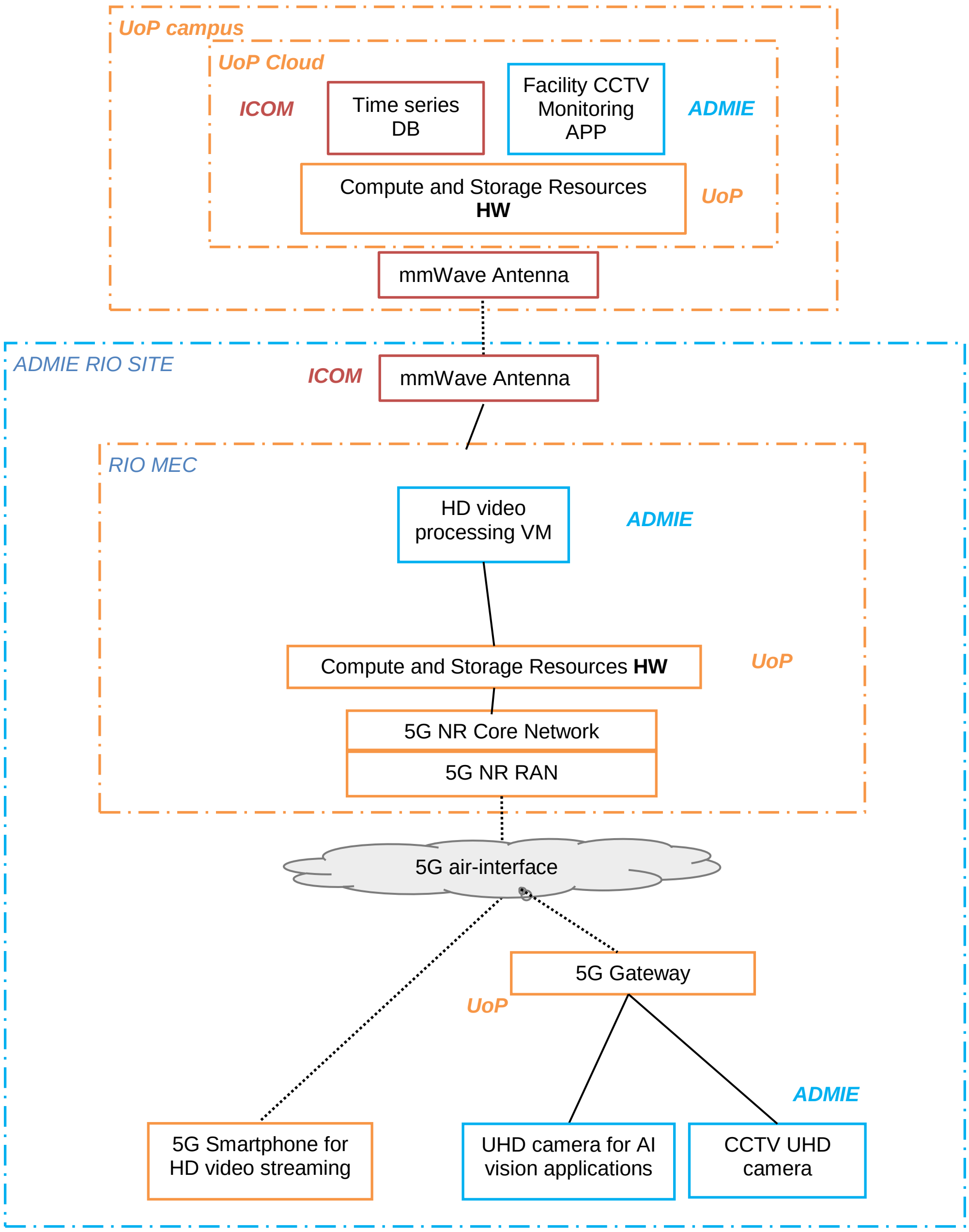

Figure 3-4: Digitization of Power Plants in Patras – Facility CCTV Monitoring – High-level deployment architecture

3.4.2 EDCv01: Smart CCTV surveillance pre-test without 5G connectivity (lab & field test)

Smart CCTV services involve preprocessing of live video feed at the edge of the network and transmission of video stream to the cloud only when an event is detected and for the time period it lasts. These services are made possible through the application of appropriate Computer Vision (CV) algorithms. These algorithms will not only help reduce bandwidth usage of CCTV surveillance equipment but also provide appropriate distress signals for alarm reporting. The test case is described in Table 3-10.

Table 3-10: EDCv01 - Smart CCTV surveillance pre-test without 5G connectivity (lab & field test)

EDCv01	Smart CCTV surveillance pre-test without 5G connectivity (lab & field test)
Testbed	**5G-VINNI Patras**
Description	In this test case, an initial setup will be deployed in which CCTV equipment located at the ADMIE facility in Rio will be tested, along with CV algorithms running on a server at the corporate network of ADMIE. The processed video feed will be stored there, along with any distress signals.
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. Server 2. CCTV cameras (2 UHD cameras) 3. Network switch 4. (Optional) Network traffic generator module **- Configuration:** 1. Configuration of CCTV equipment at ADMIE site and establishing connectivity with the server. 2. Configuration of smart CCTV surveillance service running at the server to listen to video feed coming from the CCTV equipment 3. Configuration of network traffic generator module
Test procedure	**- Preconditions:** 1. CCTV equipment up and running 2. Smart CCTV surveillance service up and running 3. Traffic generator module 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, i.e. technical personnel entering the room. 3. Optionally setup additional traffic between Rio site and the server, with the purpose of measuring additional KPIs such as latency, and to view bitrates on different abstraction levels.

Measurements	**- Methodology** 1. The CCTV camera sends pictures to the Smart CCTV surveillance service running on the server. The camera video stream is processed and its datarate is measured after exiting the service, prior to storage. **- Complementary measurements** 1. Tools like iperf can be used for comparison. 2. If additional network traffic is used, the bitrate on different abstraction levels can be measured, e.g. using different codec bitrate or including UDP/IP, etc. Setup a connection of 1 Mbps or so between the traffic generator module and the server. In this way, latency etc. can be studied. **- Calculation process** 1. The camera video stream bitrate is measured as the raw video payload stream, not including any network transportation overhead protocols.
Expected Result	The aim of this test case is to showcase the successful deployment of smart CCTV surveillance services.

3.4.3 EDCv02: Smart CCTV surveillance over 5G connectivity (field test)

Smart CCTV services in a highly connected industrial environment, where an abundance of wireless sensors is installed, can create bottlenecks in the network traffic, even hinder the normal operation of other applications. 5G technology is expected to solve these problems by providing dedicated network slices that will ensure CCTV applications meet their QoS without interfering with other critical operations.

Table 3-11: EDCv02 - Smart CCTV surveillance over 5G connectivity (field test)

EDCv02	Smart CCTV surveillance over 5G connectivity (field test)
Testbed	**5G-VINNI Patras**
Description	In this test case, the CCTV equipment located at the ADMIE facility in Rio will be connected through 5G with the MEC server, where the CV algorithms 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 cameras (2 UHD cameras) 3. Network switch 4. mmWave 10Gbit Link 5. UoP DC 6. (Optional) Network traffic generator module **- Configuration:** 1. Configuration of CCTV equipment 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 feed coming from the CCTV equipment 3. Setup UoP DC to receive distress signals and notify the security administrator 4. Configuration of network traffic generator module
Test procedure	**- Preconditions:** 1. Same as of Test Case EDCv01 **- 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, i.e. technical personnel entering the room. 3. Optionally setup additional traffic between Rio site and the server, with the purpose of measuring additional KPIs such as latency, and to view bitrates on different abstraction levels.
Measurements	**- Methodology** 1. The CCTV camera sends pictures to the Smart CCTV surveillance service running on the MEC server. The camera video stream is processed and alarm signals are sent to UoP DC, in case of an event. The live video feed datarate is measured. **- Complementary measurements** 1. Tools like iperf can be used for comparison. 2. If additional network traffic is used, the bitrate on different abstraction levels can be measured, e.g. using different codec bitrate or including UDP/IP, etc. Setup a connection of 1 Mbps or so between the traffic generator module and the server. In this way, latency etc. can be studied. **- Calculation process** 1. The camera video stream bitrate is 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.

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

4.1 Description

This UC focuses on the development of a smart energy metering system covering the whole railway system. Through the monitoring and analysis of the overall railway systems comprising the power grid, the sub-stations, the stations as well as the rolling stock, significant power benefits can be achieved. A typical example of a unified energy management system for railways considered in the 5G-VICTORI project is provided in Figure 4-1.

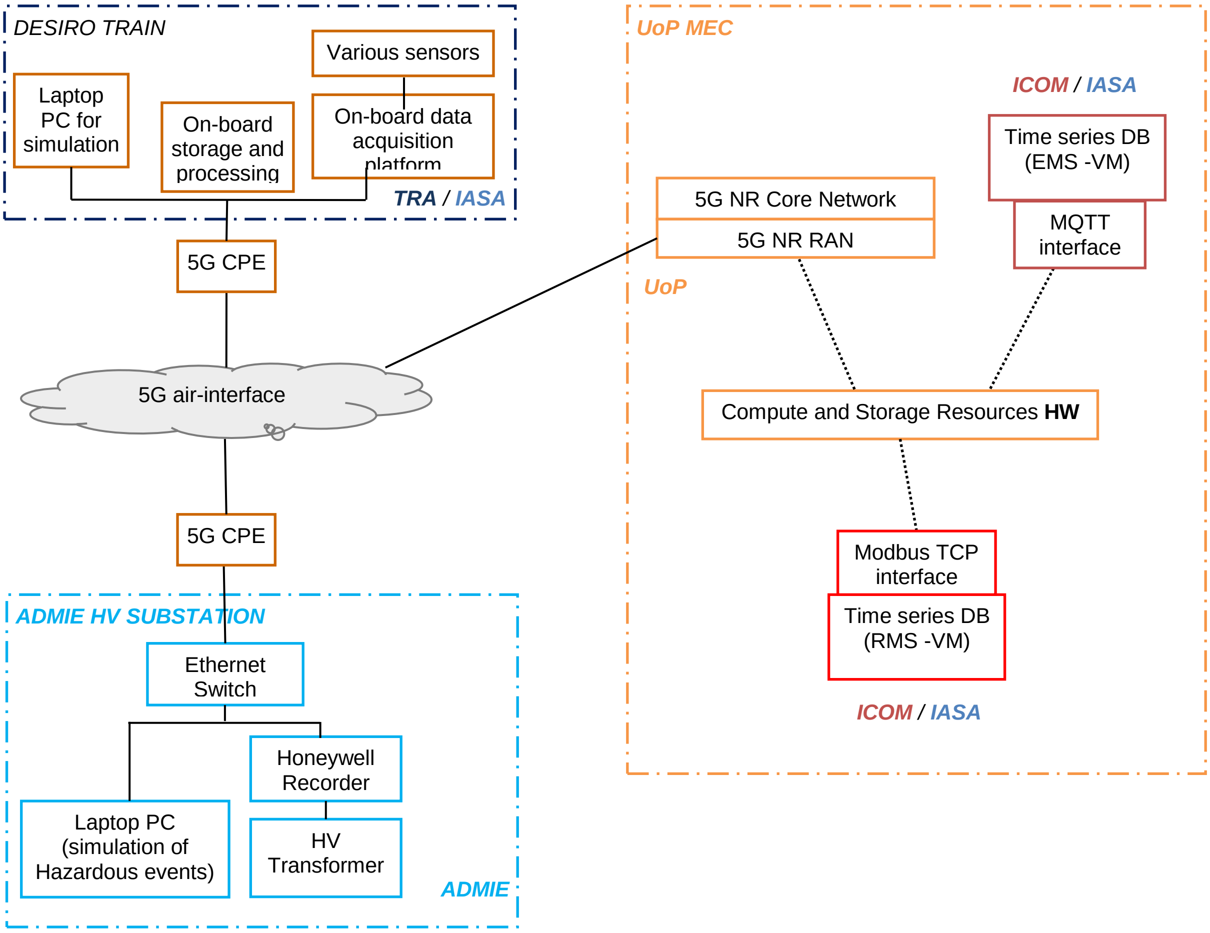

Figure 4-1: Smart Energy Metering in Patras – High-level deployment architecture

Figure 4-2 depicts the high-level view of the proposed system which comprises three main parts, the rolling stocks of **TRAINOSE** (which, in this case is the Desiro Train), the HV substation of **ADMIE** which interconnects with the railway system and the MEC server, provided by **UoP**, on top of which all the services run. The Desiro train is enhanced with various sensors that collect useful data from the train, such as its kinetic parameters, which are forwarded to an onboard high-rate data acquisition platform for preprocessing and storage. In the **ADMIE** facility, voltage, current and active power data from the HV transformer feeding the railway system are captured via specialized Honeywell recorders. Data from both sides are transmitted over-the-air via 5G to the MEC server which is located in the vicinity of the railway station. Two data management platforms are instantiated over the MEC server, one for each vertical user. Each user operates at their own network slice, thus ensuring privacy and security, while using the same underlying resources, therefore exhibiting multi-tenancy. In addition, data from different vertical owners are transmitted to the MEC server via different application protocols, specifically Honeywell measurements are using the Modbus TCP protocol whereas train measurements are using the MQTT one. For this reason, each data management platform at the MEC server incorporates appropriate network adapters to translate measurements into meaningful data. Data from both platforms are stored and analyzed at the MEC server in order to support advanced smart energy applications, such as train time-scheduling optimization algorithms etc. Lastly, data between vertical users are exchanged via appropriate APIs to enable cross-vertical interaction.

Figure 4-2: TRAINOSE – ADMIE High-level Facility plan at Corinthos

The main objective of the specific demonstration is to monitor the power consumed in the traction subsystem. **Traction** that accounts for the power required to operate the rolling stock (vehicles that move on a railway) across the system. The traction system consists of the following subsystems: substations, the traction power network and the traction power system return. To monitor the power flows in these subsystems, energy metering devices will be installed, recording and transmitting in real time all collected measurements. Once these measurements are available, the power consumed in these subsystems can be reduced through the development of a suitable decision support framework that can help towards the:

- **Maximization of regenerative braking utilization.** Through this approach braking energy can be recovered and reused in the form of electricity. To maximize the efficiency of this subsystem, the following approaches have been developed including:
    - Service Timetable Optimization
    - Installation of on-board and wayside energy storage element for the regenerative power. Alternatively, the regenerated power is returned back to the power grid through the traction power return system.
- **Development of Eco-driving strategies** aiming at identifying the optimal speed and acceleration profiles with the objective to minimize energy consumption.
- **Minimization of traction losses.** This can be achieved through reduction of the energy losses in the power grid. Given that losses in the power distribution network are a quadratic function of current, limiting power peaks caused by the simultaneous acceleration of different trains in the network can bring significant benefits. Timetable optimization and the use of regenerative braking technologies are key measures for this purpose.

- **Reduction of the energy demand of comfort** e.g., through the development of smart control for the HVAC and lighting systems.
- **Smart energy metering and management.** This requires the installation of:
  - *Automated metering systems* to collect energy consumption data from vehicles and other rail subsystems. Through this approach, network operators can identify energy flows and evaluate the effectiveness of the implemented measurements. Furthermore, it will enable the development of billing platforms, allowing users to be charged on a pay as you go basis, giving them the incentives to apply energy efficient strategies.
  - *Renewable power systems*
  - *Smart energy management systems* taking into account the stochastic nature of both renewable power sources and the regenerative braking subsystem.

To reduce power consumption in railway systems, real time connectivity with very low latency between all railway subsystem is required. In the following subsection, a detailed methodology is presented explaining all steps required in order to deploy, test and operate a fully functional railway smart energy metering system.

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

4.2.1 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 use case 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 needed for the integration of the chosen data management solution (UiTOP) as a VNF over the 5G-VINNI 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, MVa) 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 and CSV plugins translate 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
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 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.
Key Use-case requirements and KPIs	Guaranteed max End-to-End Latency Reliability > 99.9999% (SIL 4) Availability > 99.9999% (SIL 4)
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. 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 Honeywell Recorder to transmit to specific IP, port (where UiTOP listens), and with specific datarates. 4. Configure traffic generating tool to emulate traffic conditions.
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. 5. Different traffic conditions and datarates are defined. **- 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. Traffic generation tool is used to emulate different traffic conditions. 5. UiTOP Modbus TCP plugin and Recorders are configured for different datarates.
Measurements	**- Methodology** 1. Test procedure is repeated several times with different traffic conditions and Honeywell configurations (datarate) 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 (%) - 99.9999 % 2. Availability (%) - 99.9999 % **- 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. Honeywell Recorder and UiTOP are synchronized to a common clock (e.g. with the use of NTP protocol) b. Honeywell recorder attaches a timestamp at each measurement. c. UiTOP attaches a measurement collection timestamp during the measurement saving to the database. d. 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 use cases 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 in order 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 Honeywell Recorder to transmit to specific IP, port (where UiTOP listens), and with specific data rates.
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 (%) - 99.9999 % 2. Availability (%) - 99.9999 % **- 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.

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

5.1 Description

Smart energy metering is one of 5G-VICTORI's use cases, as extension of 5G-EVE (ICT 17) capabilities hosted in Alba Iulia Municipality (AIM). The energy use case will be demonstrated in the aforementioned infrastructure with the objective to provide smart energy metering services for public buildings and street lighting in the Alba Iulia Smart City environment in Romania. Smart energy metering UC over 5G will address multiple challenges of energy monitoring field:

- lack of monitoring/ no real time monitoring or location dependable monitoring for substations and energy infrastructure.
- rigid, closed, with limited scalability and highly expensive existing solutions mostly based on SCADA technology
- dependency by supplying vendor from technical and operational perspective (by sensing, data gathering, processing, communication, interfacing, integration knowledge and access to information)

The proposed energy use 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. To achieve this, low cost/ low energy consuming devices are installed across the city that will operate through LTE-M / 5G-NR access layers. Several AIM public institution buildings have been selected for energy metering use case demonstrations. The use case is addressing energy low voltage application deployment, instantiation orchestration and low voltage metering data collection from AIM public building endpoints scattered across a city. Collected measurements will be transferred to the 5G-VICTORI central cloud facilities to be stored, processed and analyzed by the Telemetry platform. Advanced analytics will be used for operational performance follow-up and consumption monitoring. Figure 5-1 depicts the high-level view of the UC network setup.

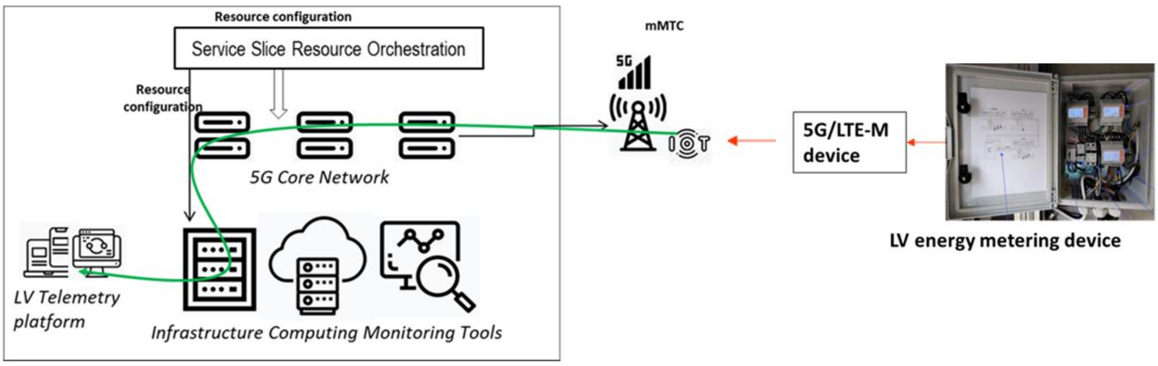

Figure 5-1 Smart Energy Metering in Alba Iulia – Descriptive diagram of UC #4 (LV scenario)

The UC is deployed on a multi-domain and multi-orchestrator network infrastructure provided by 5G-EVE project thru through a 5G-VICTORI portal named the 5G-VICTORI Infrastructure Operation System (5G-VIOS). Via this platform the vertical can register, deploy, experiment and monitor the UCs [2]. The French cluster of the 5G-EVE has extended in Romania with another two site facilities: Bucharest and Alba Iulia. The aforementioned portal is deployed in Bucharest, connected via an IPSec tunnel with Chatillon cluster.

The architecture of the solution contains another four components:

1. Low voltage infrastructure – comprises the 5G IoT devices (installed on AIM premises) necessary to collect low voltage metering information also to transport the raw data from IoT devices towards Telemetry platform.
2. 5G RAN – the USRPs are installed in Alba Iulia location nearby AIM public buildings, offering 5G coverage to the 5G IoT low voltage IoT devices.
3. AIM Edges – hosting the 5G Core Network components.
4. Bucharest Data center – hosts the Telemetry platform components, engines and compute/storage to provide e provide LV raw data processing and smart metering analytics.

For the use case deployment, a single network slice is instantiated providing connectivity from the IoT devices through the deployed infrastructure to the Telemetry platform hosted in Orange network. Bucharest and AIM locations are connected through Orange IP/MPLS network 10 Gbps interfaces, all the 5G RAN/Core and servers installed in AIM being connected through 10Gbps interfaces. The energy use case will make use of the compute infrastructure at the edge and core in AIM and Bucharest.

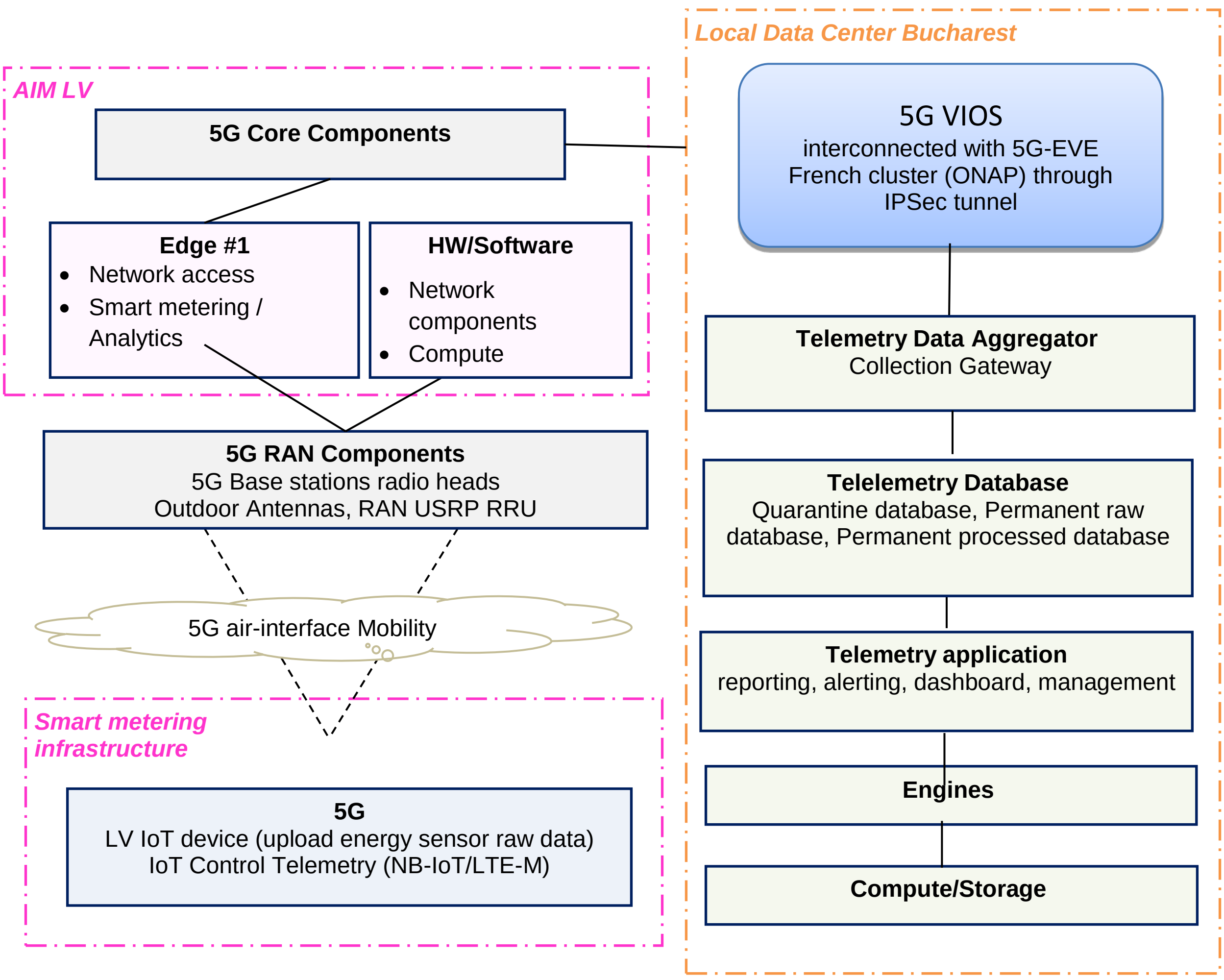

Figure 5-2: Smart Energy Metering in Alba Iulia – High-level deployment architecture

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

5.2.1 Description

Three test cases are developed in order to verify low voltage energy metering service functionality and performance:

1. To check Establishment of basic E2E connectivity over mMTC smart energy slice between different components/facilities involved: low voltage metering device - 5G IoT device - 5G radio access - 5G core networks – 5G-VIOS – Telemetry platform.
2. To check advanced E2E connectivity over smart energy slice with different QoS metrics configured.
3. To check the capacity of the management platform to process the traffic generated simultaneously by multiple LV metering devices.

The aim through the proposed test cases is to validate the deployment of a 5G Smart energy use case with automated capabilities for E2E deployment and in-life management over network virtualized infrastructures. The goal is to create and implement an E2E operational service framework for the Smart Energy metering solution starting from design and development to E2E orchestration over a 5G infrastructure assuring the E2E management, control and orchestration of the slice. The UCs make use of OpenAirInterface (OAI) (5G software alliance), Mosaic-5G (first ecosystem of 5G R&D open source platforms ranging from the centralized network control to the mobile edge network deployment), Open Networking Automation Platform (ONAP) and capable virtualized infrastructure.

The proposed UCs will be validated and demonstrated in Alba Iulia Municipality (AIM), using open source SW components for RAN and core, management and orchestration tools available through the 5G-EVE cluster facility developments, including network elements and physical network devices within an interconnection framework. These components comprise:

- Mosaic5g project, as a set of functions providing 5G connectivity from the UE level, 5G RAN and Core to the application.
- Management, monitoring and orchestration tools.
- Web Portal for service design.
- Inter-working layer for 5G-VICTORI framework orchestration.
- Physical infrastructure, already existing components or cluster facility extension to AIM.
- Site network element in AIM, power, cabinets, antennas.
- End-user device for UCs demonstration: AIM IoT device components, LV simulator.

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 checks the quality of service 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: ESMe2 - 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 quality of service 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:** 3. Configure the slice 4. Attach LV sensor simulator to the IoT platform 5. Activate command is send toward from Telemetry platform toward sensor simulator 6. 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 ESMe3: Establishment of simultaneous raw data transfer of multiple LV energy 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 measures the capacity of the management platform to process the traffic generated from multiple devices.

Table 5-3: ESMe3 - Real-time raw data transfer from Alba Iulia LV metering devices

ESMe3	Real-time raw data transfer from Alba Iulia LV metering devices
Testbed	**5G-EVE FR/RO**
Description	The purpose of the test case is to verify high data rates capabilities for high number of LV simultaneous transfer scenarios.
Key Use-case requirements and KPIs	N/A
Network performance requirements and KPIs	Raw data received from all LV metering simulated devices.
Network Functional requirements and KPIs	High data rates capacity for transfer simultaneously of large raw data volumes of LV metering devices.
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 simulator attached to the network/slice. **- Test Case Steps:** 1. Configure sensor simulator to simulate data transfer of 100 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** 100 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 100 simulated devices.

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

5.3.1 Description

The second component of the Smart metering test case is the Analytics part. Two use cases were proposed to evaluate the component functionality and performance:

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 5-4: 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 5-5: 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:** 5. Configure and connect three LV metering devices to the Telemetry platform 6. 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** NA **- 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.

6 Conclusions

6.1 Findings

This deliverable presented testing procedures compliant with the **D4.1** guidelines [3] that will be used for the validation and evaluation of the services under development in the scope of the vertical applications planned for demonstration in the **Energy and Factories of the Future** UCs. These procedures will be followed in WP4 during the 5G-VICTORI trials and help establishing a new set of verified KPIs under 5G technology related to the Energy and Smart Factory sectors.

This deliverable provided an analytic presentation of all the vertical services, focusing on detailed definitions of services testing. The testing procedures and the corresponding analysis are described from the application point of view, giving the end-to-end perspective of the services and their corresponding vertical applications. All the planned tests in 5G-VICTORI include:

- Real world environment testing,
- Physically emulated environment, and
- Laboratory environment.

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 massive data from sensing devices.

All the different vertical services described in **D3.5** feature diverse characteristics from all the three different 5G service classes (eMBB, uRLLC, mMTC), with requirements of high data rates, minimum end-to-end (E2E) latency and high connection densities, due to the nature of their parent vertical applications.

6.2 Remarks

This preliminary document is a collection of all the different test cases related to the **Energy and Factories of the Future** services under consideration for demonstration during the 5G-VICTORI project. The successor of this document is deliverable **D3.6**, entitled "Final Use case specification for Energy and Factories of the Future services", which includes the final set of test cases to be demonstrated in 5G-VICTORI, after an initial assessment of the planned services. Specifically, D3.6 will present the test cases that can be deployed under the 5G-VICTORI platforms, based on first KPI validation and evaluation results.

Final results and conclusions stemming from the 5G-VICTORI trials will be presented as part of WP4 activities.

7 References

7.1 5G-VICTORI BSCW Documents

[1] 5G-VICTORI Project Proposal (describes partners, objectives, WPs and Tasks, etc.).

[2] 5G-VICTORI deliverable D2.1 (T2.1) 5G-VICTORI Use-case and requirements definition and reference architecture for vertical services (ORO)

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

[4] 5G-VICTORI deliverable D2.2 (T2.2) Preliminary individual site facility planning (FhG)

[5] 5G-VICTORI deliverable D2.3 (T2.2) Final individual site facility planning (UoP)

[6] 5G-VICTORI deliverable D2.4 (T2.3) 5G-VICTORI end-to-end reference architecture (UNIVBRIS)

[7] 5G-VICTORI deliverable D2.5 (T2.4) 5G-VICTORI Infrastructure Operating System – Initial Design Specification (DCAT)

[8] 5G-VICTORI deliverable D2.6 (T2.4) 5G-VICTORI Infrastructure Operating System – Final Design Specification (DCAT)

[9] 5G-VICTORI deliverable D3.1 (T3.1) Preliminary Use case specification for transportation services (BT, 31 May 2021)

[10] 5G-VICTORI deliverable D3.2 (T3.1) "Final Use case specification for transportation service (DBH, 30 Nov 2021)

[11] D3.3 (T3.2) Preliminary Use case specification for Media Services (RBB, 31 May 2021)

[12] D3.4 (T3.2) Final Use case specification for Media Services (RBB, 30 Nov 2021)

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

[14] D3.6 (T3.3) Final Use case specification for Energy and Factories of the Future Services (ADMIE, 30 Nov 2021)

[15] D3.7 (T3.4) Use Case Assessment (IZT, 30 Nov 2021)

7.2 5G-VICTORI BSCW Presentations

[16] 2020-02-05 WP3 Services Coordinators – Patras Tech 2 Meeting (Jesús and Anna)

[17] 2020-02-04 WP3 Presentation – Patras Tech 2 Meeting (Miggi)

7.3 Standards references

[18] ETSI EG 202 810 V1.1.1 (2010-03). ETSI Guide. Methods for Testing and Specification (MTS);. Automated Interoperability Testing

[19] 3GPP TS 22.104 V18.1.0 (2021-06): Technical Specification Group Services and System Aspects; Service requirements for cyber-physical control applications in vertical domains; Stage 1 (Release 18)

7.4 Other references

[20] ACIA White Paper, Performance Testing of 5G Systems for Industrial Automation, [Online]. Available at: https://5g-acia.org/whitepapers/performance-testing-of-5g-systems-for-industrial-automation-2/. Feb, 2021.

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 high voltage 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
    1. industrial (electrification of large infrastructures such as railways operating in HV) and
    2. 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
    1. the deployment of a massive number of sensors and actuators enabling process automation and optimization and,
    2. connectivity between the monitored utility and the enterprise. Moreover,
    3. emergency scenarios will be applied to demonstrate the advantages of 5G technology under extreme conditions that the monitored facilities may encounter.
    4. 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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