Smart5Grid

Demonstration of **5G** solutions for **SMART** energy **GRID**s of the future

Deliverable 5.1

Network App integration framework and Smart5Grid roll-out plans for Uninterruptible Smart Grid Operation

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5G PPP
The 5G Infrastructure Public Private Partnership

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D5.1 – Network App integration framework and Smart5Grid roll-out plans for Uninterruptible Smart Grid Operation

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Executive summary

This document describes the preparation of the Smart5Grid platform for UC#1: advanced fault-detection, isolation and self-healing for the power distribution grids and UC#2: enhanced safety tools for maintenance workers in high voltage power substations, with a specific focus on the infrastructure related to Distribution System Operator's (DSO's) facilities and 5G networks and its validation.

Regarding the DSO's facilities:

- For UC#1 the aim is to implement a solution for the real time self-healing of primary substations through sensors that use Cisco routers for connection to 5G network and the monitoring implemented using a Network App.
- For UC#2 the aim is the monitoring of workers for maintenance activities in high voltage substations within a secure area using a Real Time Location System implemented with Ultra-wideband sensors and three-dimension (3D) cameras with Artificial Intelligence (AI) functionalities.

Regarding the 5G networks facilities.

- For UC#1 a commercial network is used, therefore a special focus is put on security through the implementation of a RADIUS to authenticate the SIM cards and secure accesses for the platform building activities.
- For UC#2 a private 5G network is implemented for the connectivity of sensors and cameras.

The validation of the platform is pursued through the definition of a list of metrics ("Field Platform Validation Metrics") and the strategy to measure them.

For UC#1 a near-real environment test is implemented, where the 5G network and the Network App are the field ones whereas the sensors are located in the Enel Milan and Rome test labs.

For UC#2 the infrastructure is tested in the i2CAT lab and later on field.

The conclusions allow to validate the platform for both Use cases.

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1. Introduction

The Task 5.1 is aimed to the preparation of the Smart5Grid field platform to support uninterruptible smart grid operation (M13-M34),

Leader: WI3

• Task inputs: WP2, WP3, and WP4

• Task outputs: Field platform able to support the Network Apps' integration for the targeted use cases

• Contributors: ENEL, ENG, WI3, ATOS, i2CAT, ATH, UW, SID, NOSIA, STAM

Task 5.1 is organized to provide the Smart5Grid field platforms necessary for supporting the demonstration and validation procedures for the Network Apps that are required for the uninterruptible smart grid operation. The support of the Network Apps' integration needed for the use cases will be guaranteed with 5G Network. Furthermore, it is required to organize a detailed test plan for UC#1 & UC#2, to add more details than the initial planning described in WP2. A proof of concept will be defined to test Smart5Grid technologies in scenarios like the automatic fault detection and the remote inspection. The tests will be organized in such a way as to adapt them to the available resources.

1.1. Notations, abbreviations and acronyms

Item	Description
3D	Three-dimensions
AI	Artificial Intelligence
AB	Advisory Board
APN	Access Point Name
CA	Consortium Agreement
CPE	Customer Premises Equipment
DoW	Description of Work
DRES	Distributed renewable energy sources
DSO	Distribution System Operator
DSS	Dynamic Spectrum Sharing
E2E	End-to-End
EDSO	European Distribution System Operators for Smart Grids (non-profit association)
EEGI	European Electricity Grid Initiative
ENTSO-E	European Network of Transmission System Operators for Electricity
EPIA	European Photovoltaic Industry Association
EU	European Union
EWEA	European Wind Energy Association
FDD	Frequency Division Duplex
FP7	Seventh Framework Programme
FPVM	Field Platform Validation Metrics
GA	Grant Agreement
HSS	Home Subscriber Server
IMSI	International Mobile Subscriber Identity

Item	Description
LTE	Long-Term Evolution
LV	Low Voltage
MEC	Multi-access Edge Computing
MME	Mobility Management Entity
MPLS	Multi-Protocol Label Switching
MV	Medium Voltage
MQTT	Message Queuing Telemetry Transport
NAC	Network App Controller
NR	New Radio
NSA	Non-Standalone
PAS IEC	Publicly Available Specification
PoC	Proof Of Concept
PC	Personal Computer
RADIUS	Remote Authentication Dial-In User Service
RTD	Research and Technology Development.
RTLS	Real Time Location System
S/P-GW	Serving/Packet data network -Gateway
T&D	Transmission and Distribution
TDOA	Time Difference of Arrival
TSO	Transmission System Operator
UWB	Ultra-wideband
VPN	Virtual Private Network
WP	Work Package

Table 1 - Acronyms list

2. Preparation of Smart5Grid field platforms

2.1. Use case 1: Italian pilot

The purpose of UC#1 is to verify, in a real scenario, how the 5G network combined with grid applications can provide benefits in the energy sector.

Hence, four medium voltage lines from the Olbia Primary Substation have been chosen to implement real-time self-healing. This advanced feature, currently utilized in the Enel network, swiftly and automatically identifies and isolates electrical faults on the grid within a timeframe of less than one hundred milliseconds. The effectiveness of this process relies on the presence of a highly responsive and dependable communication network.

2.1.1. Power Grid

A key role in this scenario is played by the communication network, composed of the telco and DSO infrastructures; they in fact enable the sensors installed on the power grid to exchange information between each other according to the IEC 61850 standard (https://iec61850.dvl.iec.ch/) and thus to search for and isolate an electrical fault on the grid in a very short time. In Figure 1 below are reported two schemes referred to both domains involved in this use case: the power grid layer and the communication network.

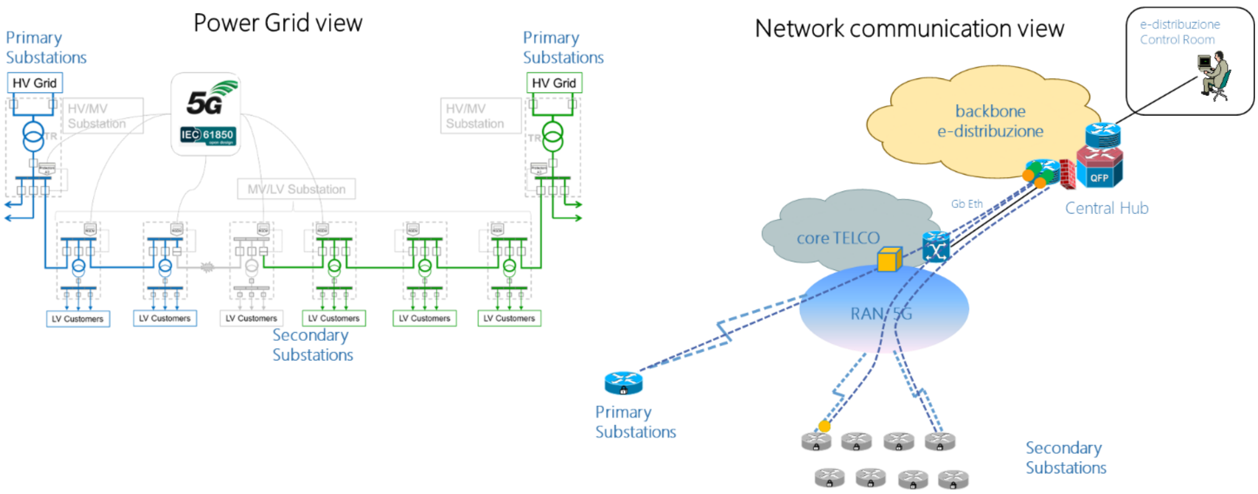


Figure 1 - Power grid layer and communication network

E-Distribuzione for the purpose of experimentation, has equipped the pilot's secondary substations with IEC61850-compliant sensors and disconnectors and a Cisco IR1101 router with which these sensors will be able to communicate with others installed on power grid.

In Figure 2 below the industrial router installed in use in each secondary substation of the Smart5Grid project is represented.

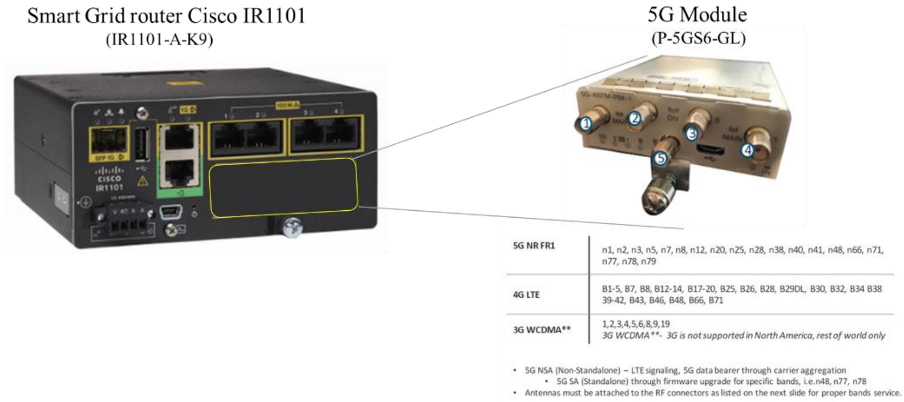


Figure 2 - Representation of the router Cisco

2.1.2. 5G Network

Table 2 illustrates the activities involved:

UC#1 - Activity ID & Description	Ownership
5.1.1 Radio planning	WI3
5.1.2 Tracking area definition	WI3
5.1.3 Installation and configuration of the S/P-GW (user-plane functionalities) and firewall at the edge facility owned by WI3	ATH
5.1.4 Installation and pre-configuration of the MEC server (physical server and virtualized environment) at the edge facility owned by WI3	ATH
5.1.5 Installation of a RADIUS server for SIM authentication	ATH
5.1.6 Connection between APN Smart5Grid and VPLS e-distribuzione	WI3
5.1.7 MEC server reachability by VPN for maintenance purposes	WI3
5.1.8 NAC reachability by MEC server for Network App orchestration	WI3
5.1.9 MQTT server reachability by MAC server to publish collected data	WI3
5.1.10 Core Network setup (APN – SIM authentication) and RADIUS Configuration	WI3, ATH
5.1.11 5G infrastructure Validation framework for specific UC	WI3/ENEL/NBC/STAM

Table 2 - UC#1: Activity ID & Description

For the UC#1, the first activity to build the field platform to support the demonstration and validation procedures for the Network Apps (later in the document referred as "platform") was to match the location of the target ENEL power substations with the WI3 5G radio covering: it resulted that the substations of interest are covered with 5G NR Frequency Division Duplex (FDD), Dynamic Spectrum Sharing (DSS) technology. To define the substations Registration Area the tracking area was also singled out. Considering that the W3 5G Non Standalone (NSA) network used is the commercial one, dedicated Access Point Names (APNs) was defined to isolate the Proof of Concept (PoC) environment, also to comply with WI3 security constraints.

Specific International Mobile Subscriber Identities (IMSIs) are dedicated to the devices deployed in the Enel substations and authenticated by WI3 Home Subscriber Server (HSS). A Remote Authentication Dial-In

User Service (RADIUS) server provided and configured by Athonet (ATH) was introduced to authenticate the SIM on a username and password mechanism to comply with ENEL securities constraints. RADIUS is a client-server protocol used for intercommunication between central and remote access servers, with the purpose of authenticating users and allowing or denying access to a target service or system. In this way, it was ensured ensured that only the authorized UC's SIMs deployed at the ENEL power substations are granted end-to-end network connectivity.

The steering of the dedicated APNs towards the ATHONET edge computing servers is performed by the WI3 Mobility Management Entity (MME) with the selection of the Serving/Packet data network -Gateway (S/P-GW) in the MEC, through the MME feature "SGW Selection Based on IMSI Number Series and Geographical Area for the MME".

WI3 HSS and MME were configured accordingly.

Secure Accesses to MEC Servers based on a WI3 Virtual Private Network (VPN) were configured to perform configuration and maintenance activities of the S/P-GW and the APP respectively for ATH and STAM TECH.

A Multiprotocol Label Switching (MPLS) connectivity was put in place by WI3 between the MEC Servers the Enel central HUB to implement the end-to-end (E2E) visibility between the Enel substations and the central HUB.

Finally, two dedicated connectivity were implemented to assure the reachability between the NBC's NAC (Network App Controller) needed to manage the Network App Orchestration and the STAM TECH MQTT (Message Queuing Telemetry Transport) server to publish collected data.

For complete architectural details please refer to D3.2 [3].

2.2. Use case 2: Spanish pilot

The scope of UC#2 is to introduce an automated process that enables the monitorization of workers and their tools when they are performing maintenance activities in a primary power substation. This use case is developed in the EcoGarraf primary substation, located near the Garraf Natural Park in Barcelona, Spain. The substation has an outdoor park where the voltage is 66kV as is shown in Figure 3

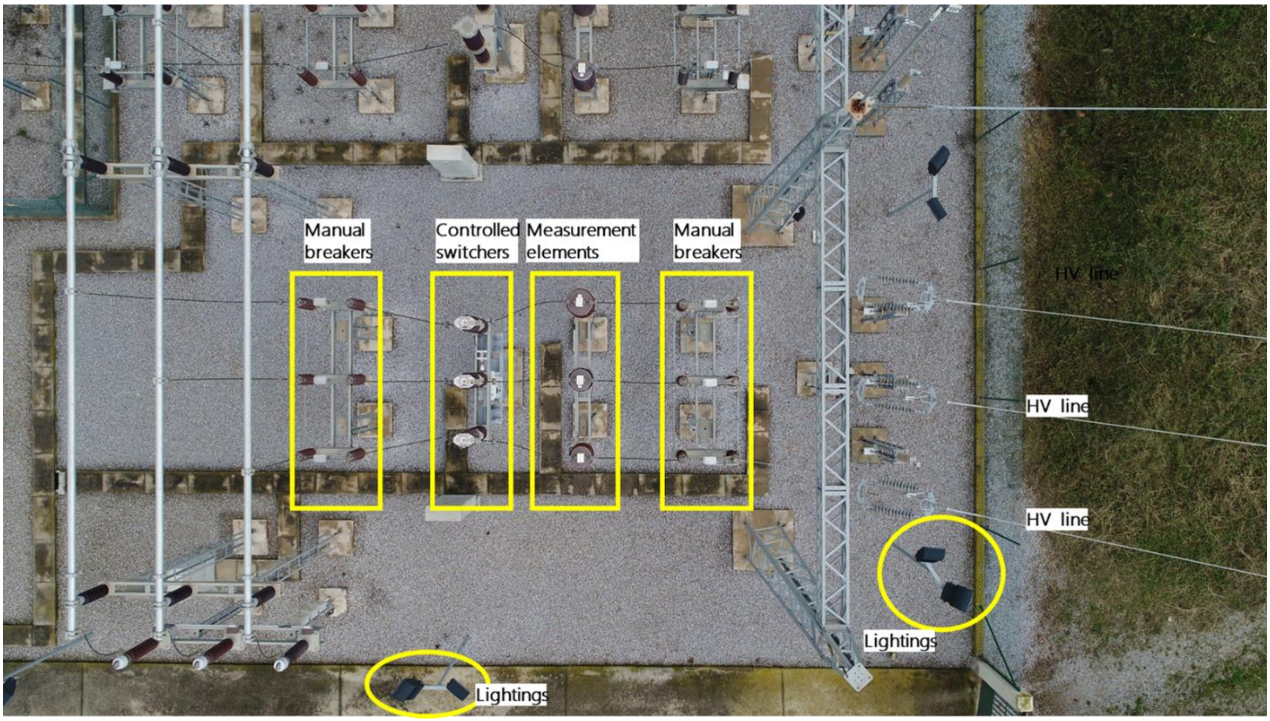


Figure 3 – Plan view of the substation and named electrical components.

In the substation the Smart5Grid field platform was deployed, consisting of a network of reading devices (e.g., Ultra- Wideband (UWB) sensors) and 3D cameras with AI functionalities that constitute the Real Time Location System (RTLS); the latter is connected to the Network App of the Use Case through the 5G network.

By using the 5G New Radio (NR) network, the transmission of information will be fast and reliable. This is because of having the edge computer hosting the Network App right next to the 5G radio access network. This enables minimal end-to-end delay between the cameras and sensors, and the equipment processing the information.

2.2.1. Real Time Location System (RTLS)

The RTLS consists of six 3D cameras and ten anchors/sensors using UWB.

The 3D cameras are Intel® RealSense series D455 [1]that capture the environment continuously once they are activated. The artificial intelligence is placed in other six microprocessor Khada[2] that are located near the cameras and are able to identify the person and their tools. The output of the six cameras is a recognition of the person and their tools and their position with respect to the camera, it also includes the accuracy of the detection and the time. This information is aggregated in the switch inside the main cabinet and sent through one Customer Premises Equipment (CPE) to the servers where the Network App is deployed.

[1] https://www.intelrealsense.com/depth-camera-d455/
[2] https://www.khadas.com/vim

On the other hand, the UWB sensors antennas were installed in several poles of the substation, building a rectangle. The anchors/sensors consist of UWB real-time positioning base stations. The worker's exact location is determined from the UWB signal exchange between the anchors and personal tags (which represent the current location of the worker inside the secure area) using the Time Difference of Arrival (TDOA) principle. Data from anchors/sensors (wrist tags position) are collected via another switch and sent to an industrial personal computer (PC), where they are pre-synchronized and sent through the same CPE to be evaluated in the Network App.

The data coming from the sensors and the cameras is processed inside the Network Application to evaluate whether a transgression has occurred or not. In order to do that, the position of the person is calculated and compared to the coordinates of the predefined safety zones. In the case that a transgression occurred, the information to warning the workers is sent back from the server to the industrial PC by the API. That information activates the alarm beacon installed at the substation and the vibration of the bracelets that the workers wear.

There is a switch in an independent box that aggregates the signals coming from the anchors. This aggregated signal is sent to the industrial PC placed in a different box, named before as main cabinet. There are another six small cabinets in total deployed in the substation that contains the microprocessor and the converters needed to power the system. These small boxes are connected to the main cabinet that contains two switches, to aggregate information from the different cameras plus the industrial PC. This main cabinet is connected to the CPE to send the aggregated information. Besides, there is a Long-Term Evolution (LTE) modem inside this cabinet that enables the owner of the solution to continuously monitor the devices.

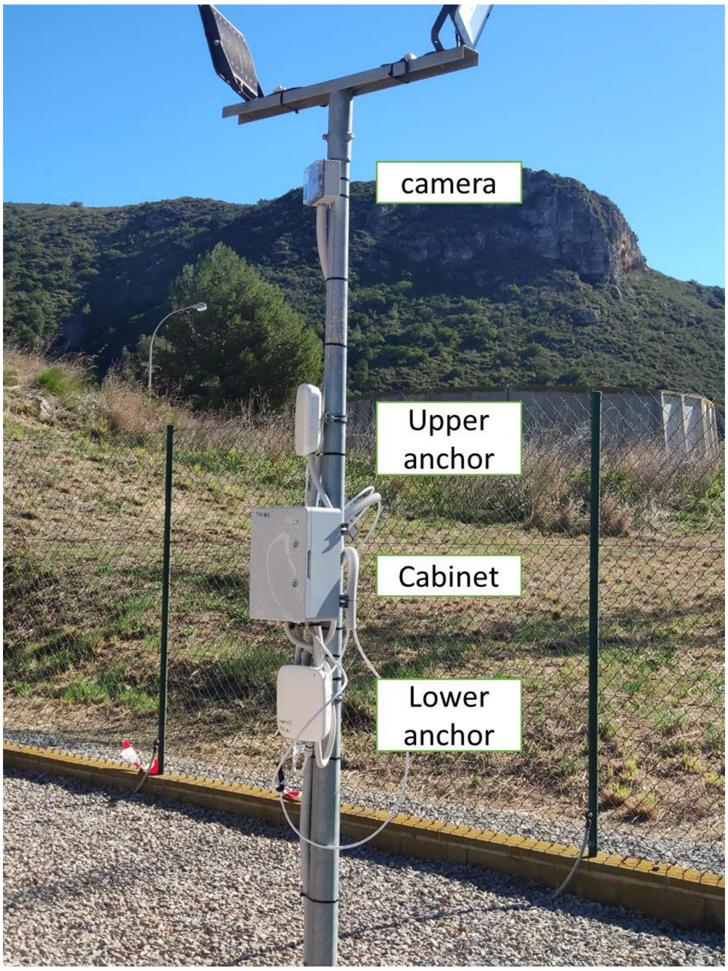


Figure 4 – Anchors positions

2.2.2. 5G network

The user equipment, including cameras and sensors, transmits the collected information via the CPE using the n77 band frequency provided by the Spanish Ministry. The antenna and Remote Radio Unit (RRU) located in the technical booth are connected to the virtual Radio Access Network (vRAN) server. The vRAN server is in turn connected to both the core server and the app server, where a Kubernetes cluster is deployed. The Network Application is deployed within this Kubernetes cluster, managed by Neutroon[3], responsible for 5G network management.

These devices have been installed in the substation technical booth inside a rack as it can be seen in Figure 5 below:

[3] https://www.neutroon.com/

Figure 5 - Left: rack containing 5G servers installed in the primary substation. Right: 5G antenna

Table 3 below summarizes the associated tasks completed:

UC#2 - Activity ID & Description	Ownership
1. Technical analysis of the solution	NOSIA/SIDROCO/i2CAT/EDE
2. Nosia Software development	NOSIA
2.1. Software development UWB sensors	
2.2. Software development of cameras detection	
3. 5G devices purchase and configuration	i2CAT
LABORATORY TEST	
4. Phase 1: Basic tests (connectivity, compatibility, etc)	
4.1. Basic 5G Network Test	i2CAT
4.2. Anchors/sensors + single camera indoor (at no’ia's)	NOSIA
4.3. Single camera outdoor (Ecogarraf)	NOSIA/EDE
4.4. Anchors/sensors + camera indoor (NOSIA lab)	NOSIA
5. Phase 2: Integration	
5.1. Network App test (i2CAT lab)	SIDROCO /i2CAT
5.2. Basic Sensor/Camera traffic towards the Network App (i2CAT lab)	SIDROCO /i2CAT/NOSIA

UC#2 - Activity ID & Description	Ownership
5.3. Netwok App Synchronization Component with traces from Nosia's lab	SIDROCO
DEMO SITE ECOGARRAF	
6. Ask ministry for band frequency	i2CAT
7. Installation Demo Site	NOSIA/I2CAT/EDE
8. Configuration in field	NOSIA/i2CAT
8.1. Configuration of sensors and cameras	NOSIA/i2CAT
8.2. Configuration of 5G network	i2CAT
9. Field Tests	NOSIA/SIDROCO/i2CAT/EDE
10. Reporting	NOSIA/SIDROCO/i2CAT/EDE

Table 3 - UC#2 - Activity ID & Description

3. KPI & Testing Plan and Strategy

In section 3, the planned validation activities of the field platforms for Use Cases#1 & #2, are thoroughly presented. Subsection 3.1 presents a complete list of all the Field Platform Validation Metrics which could potentially apply to the Use Cases, marked as FPVM-xx. A brief description is also provided for each Metric and an indication on which of the Use Cases it applies to. Subsection 3.2 provides a detailed testing Plan and Strategy for the Metrics of Use Case #1 & 2 and the methodology used to measure the KPIs.

3.1. List of Field Platform Validation Metrics (FPVMs)

Table 4 presents a subset of the KPI's thresholds defined in *D2.1 ("Elaboration of UCs and System Requirements Analysis")* [1].

It was found that Device density and Location accuracy are not meaningful in UC#1: the number of substations is far from being a constraint for a 5GC Network and location accuracy is not meaningful being the substations fixed infrastructures.

N°	Use case Requirements	Units	Use Case #1 Automatic Power Distribution Grid Fault Detection 5G Use case category/Slice Type		
			URLLC	eMBB	mMTC
1	Communication service Availability	%	99.99	-	-
2	Communication service Reliability	%	99.99	-	-
3	End-to-end latency	msec	<40ms	-	-
4	Packet Loss	%	<0.01	-	-
5	Jitter	msec	<5	-	-

Table 4 - Summary of network requirements for the UC#1

In Table 5 are reported a subset of the KPI's thresholds defined in D2.1 [1].

With respect to the original choice of KPIs, additional considerations have been made.

End-to-end (E2E) latency refers to the one-way duration, encompassing the measurement of the time required for data to traverse from the sender to the receiver.

Data rate is not considered meaningful anymore because no big amount of data is downloaded in this use case therefore this KPI is discarded. Moreover, in order to measure the Data rate usually a file is transferred between two end points (MEC=Server, Client= Sensor in substations) Regarding the Device Density, in UC#1 there are 14 substations dislocated in around 20 km2. Being the 5G network capable of managing 1 million of devices per square kilometre (km2) once again this parameter is not meaningful in this use case therefore is discarded.

N°	Use case Requirements	Units	Use Case #2		
			Remote Inspection of Automatically Delimited Working Areas at Distribution Level		
			5G Use case category/Slice Type		
			URLLC	eMBB	mMTC
1	Communication service Availability	%	99.99%	99.99%	-
2	Communication service Reliability	%	99.99%	> 90%	-
3	End-to-end latency	msec	< 100	< 200	-
4	RAN latency	msec	< 50	< 50	-
5	Data rate	Gbps	< 0.01	< 0.15	-
6	Device Density	Dev/km^2	< 30	< 20	-
7	Location Accuracy	m	0.5	< 2	-
8	Security	Y/N	Y	Y	-
9	Network slicing	Y/N	Y	Y	-
10	Type of connection		UWB, 5G NR	5G NR	
11	Type of device		CPEs, UWB-tags	CPEs	

Table 5 - Summary of network requirements for the UC#2

For use UC#2 the network requirements are shown in the Table 5. E2E latency is referred to one way communication originating in the sensors or cameras, up to the Network Application, and the other way around.

Note that the location accuracy listed in this table is referring to the location accuracy provided by the application deployed in the network and not by the network per se. Also, it is important to highlight that in addition to the 5G network, an UWB network is deployed for the location services using UWB anchors and tags. For the readers convenience, we keep the values in the table, though they do not directly relate to 5G performance indicators, but still mark the target accuracy that the use case aims for.

Reviewing the device density, we determine that while the listed numbers could be realistic in a real physical and operational deployment as part of larger installations, the actual number of 5G-enabled devices for the pilot is much lower. In order to compensate for the low number of real physical devices deployed in the substation of UC#2 – in total up to 3, with 2 being connected permanently – channel saturation tests are performed to see how the network operates under a theoretical load that reaches the limits. Results are shown in Section 4.

The above KPIs defined for UC#1 and UC#2 have been synthesized in Table 6, indicating the Field Platform Validation Metrics (FPVM) common for UC#1 and UC#2.

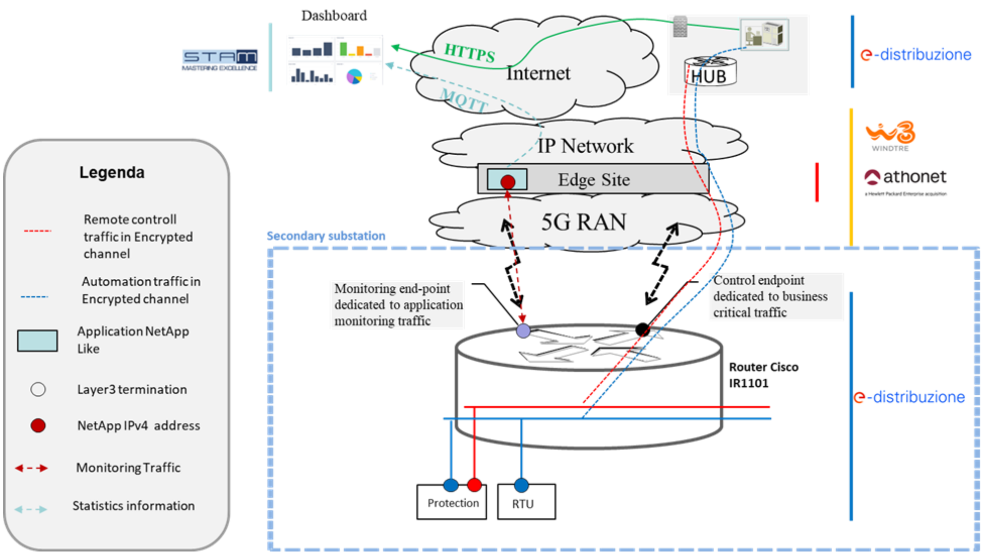
Metric code	Metric Name	Description	Unit	Measured at Use Cases #3, #4
FPVM-01	Latency/Delay	Total time required for the end user to receive an application response message after a request message is sent by the end-user, or a triggered action.	sec	UC#1, UC#2
FPVM-02	Delay Jitter	The variation of the end-to-end application latency for the communications between specific components of the use case measured at the end user.	sec	UC#1, UC#2
FPVM-03	Packet Loss	lost packets of data not reaching their destination after being transmitted across a network	#	UC#1, UC#2
FPVM-04	Availability	The amount of time the end-to-end application is properly delivered according to the specified performance metrics, over the amount of time the that is expected to deliver the end-to-end Network App service.	%	UC#1, UC#2
FPVM-05	Reliability	Reliability is defined as the percentage value of the amount of sent network layer packets successfully delivered to a given node within the time constraint required by the targeted service, divided by the total number of sent network layer packets. The reliability rate is evaluated only when the network is available.	%	UC#1, UC#2

Table 6 – Field Platform Validation Metrics (FPVM)

3.2. Description of the Testing Plan and Strategy for Use Case #1 & #2

List of validation cases:

- Platform performance validation
- Generic Network App onboarding and deployment validation
- UC#1
- UC#2

Use Case #1	
Description	The network test consists of measuring and validating the network required KPIs in term of latency, jitter, packet loss, throughput and network availability and reliability for each of the Use Cases 1 and 2. Purpose: The expected results should validate the optimal performance of the network in order to support the identified network requirements.
Network Deployment for the Italian Pilot Use Case #1	 Figure 6 - UC#1 Architecture Figure 6 highlights the software collection tools that will be used and installed in different network parts to collect data and provide network KPI measurements. More specifically, the installation will allow measurements of: 1)Latency 2)Jitter 3)Number of loss packet 4)Availability 5)Reliability
Testing Procedure	Step 1: The monitoring data collection tools is hosted on the MEC Server inside WI3's network side are set-up to obtain the measurements Step 2: Packets will be transferred through the network from MEC SERVER to the User Equipment side through ICMP protocol Step 3: Based on the answer received from the User Equipment Latency, Jitter and number of loss packet will be calculated Step 4: Packets will be transferred through the network from RAN side to the edge/cloud server via MQTT. Step 5: Data are visualized in the developed dashboard
Tested parameters and metrics	Metric code: FPVM-01 (Latency from the Substations to Network App in the MEC) Explanation: Latency is the time delay between input and output in a system, caused by factors like network congestion, processing time, or distance. Related Steps: Steps 1,2,3, 4 and 5 3

Use Case #1	
	KPI value (exp.):The Evaluated Latency Percentiles, are P90 and P99. They are used to measure the distribution of latencies within a system. In this case, we have set a threshold of 25 ms for all latency KPIs, including P90 and P99. P90 represents the latency that is faster than 90% of all operations, while P99 represents the latency that is faster than 99% of all operations. In other words, 90% of operations should be completed within the P90 threshold, and 99% of operations should be completed within the P99 threshold. If both P90 and P99 are under the 25 ms threshold, it indicates that the majority of operations are completing within an acceptable time frame. However, it's important to note that the remaining 10% and 1% of operations may still experience longer latencies, which could impact the overall user experience. Therefore, it's important to continue monitoring these metrics and analyzing any outliers to identify potential issues and improve the system's overall performance. Metric code: FPVM-02 (Jitter) Explanation: Jitter refers to the variation in latency or delay of a signal. It is the inconsistency or fluctuation in the time delay between input and output in a system, caused by factors such as network congestion, signal interference, or processing delays. Related Steps: Steps 1,2,3,4 and the time that a packet needs to be received from the RAN side and until it reaches the edge/cloud server will be measured KPI value (exp.):Jitter is a measure of the variation in latency over time. In other words, it measures how consistent the latency is over a given period. When monitoring jitter, a threshold is often set to ensure that the variation in latency remains within an acceptable range. We are monitoring the jitter of a network, and we have set a threshold of 5 ms for jitter, it means that the variation in latency should not exceed 5 ms. If the jitter exceeds this threshold, it may indicate issues with network congestion or other performance issues. Remarks: Measurement of packets sent as well as packets received. Measure of actual packet delivery. Metric code: FPVM-03 Packet Loss Explanation: Packet loss refers to the failure of one or more transmitted packets to arrive at their destination. It is the number of packets that are lost in transit or dropped by a network due to congestion, errors, or other issues. This can result in delays or

Use Case #1	
	disruptions in the transmission of data, and may require retransmission of lost packets. Related Steps: Steps 1,2,3,4 and 5 KPI value (exp.):Packet loss is a measure of the percentage of data packets that are lost or dropped during transmission. It can be caused by a variety of factors, including network congestion, faulty hardware, or software errors. We are monitoring packet loss in the network, and we have set a threshold of under 0.1%, it means that we aim to keep the packet loss rate below this threshold. If the packet loss rate exceeds this threshold, it may indicate issues with the network, and measures can be taken to address the issue before it impacts the user experience. Maintaining packet loss under 0.1% is important for ensuring the system's stability and reliability. If packets are lost during transmission, it can result in data corruption or retransmissions, which can impact the overall performance of the system. By setting a threshold of under 0.1% for packet loss, we aim to keep the packet loss rate at an acceptable level to ensure the system remains stable and reliable. Monitoring packet loss and keeping it under the threshold can help prevent potential issues and ensure the system meets its performance objectives. Metric code: FPVM-04 (Availability) Explanation: Availability refers to the ability of a system to remain operational and accessible to users, without interruption or downtime. It is a measure of reliability and uptime, indicating the percentage of time that a system or service is available and functioning as expected. High availability is important for critical systems and services that must remain operational at all times, such as data centers, financial systems, and emergency response services. Factors that can affect availability include hardware and software failures, network outages, and human error. Related Steps: Steps 1,2,3,4 and 5 KPI value (exp.): Remarks: Measure the packet error rate at the IP/Application layer. Metric code: FPVM-05 (Reliability) Explanation: 5G Network functionality: Reliability is the success probability of packet transmission within a required maximum time Related Steps: Steps 1,2 and 3 KPI value (exp.): Reliability in network analysis refers to the ability of a network to function effectively and consistently, providing reliable connectivity, communication, and data transfer between network devices and systems. It involves assessing and ensuring

Use Case #1		
		the availability, stability, and resilience of the network infrastructure and its components.
	Remarks:	Measure the packet error rate at the IP/Application layer.

Table 7 - Measure and validation of the network KPIs in Use Case #1

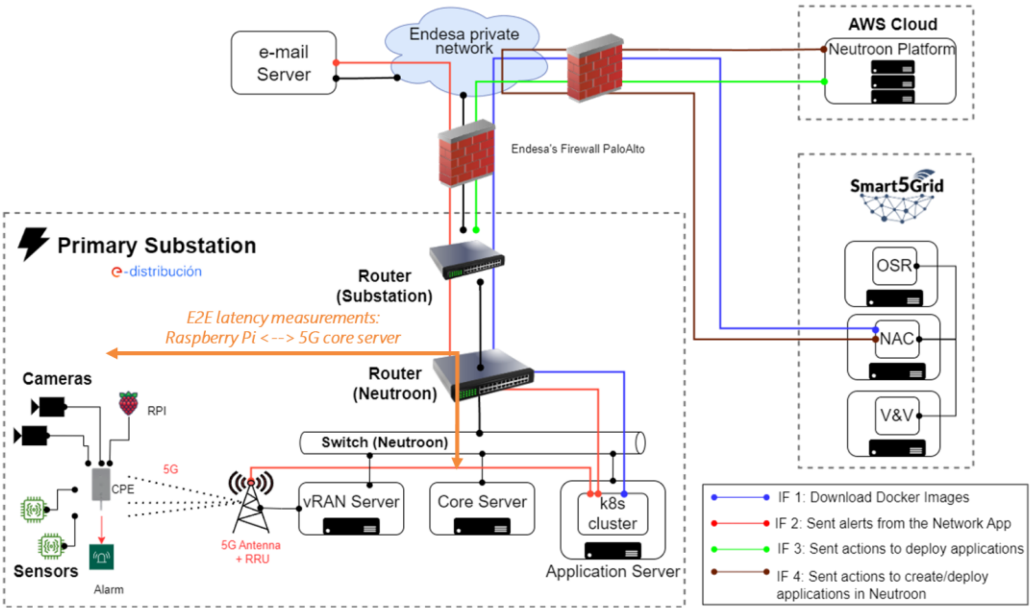
<table>
<tr><th colspan="2">Use Case #2</th></tr>
<tr><td>Description</td><td>The network test consists of measuring and validating the network required KPIs in term of latency, jitter, packet loss, throughput and network availability and reliability for each of the Use Cases 1 and 2.
Purpose: The expected results should validate the optimal performance of the network in order to support the identified network requirements.</td></tr>
<tr><td></td><td>


Figure 7 - UC#2 Architecture

Figure 7 shows the elements of the 5G network deployment in the ECOGARRAF substation.
Software tools to collect KPIs and measure the performance of the network will be used in the adequate network segments. Based on the KPIs that have been defined in D2.1, all measurements are to be performed from user equipment connected to the 5G network (via CPE). More specifically, the installation will allow the following measurements:
A laptop will be connected through Ethernet port to a CPE, thus gaining access to the 5G network and connectivity to the application server where the Network Applications are deployed.</td></tr>
</table>

Use Case #2	
	The laptop will use two tools: iperf[4] and ping[5] (based on the exchange of ICMP packets), the two tools that allow to measure the network performance with regards to the latency and throughput KPIs.
Testing Procedure	Step 1: To measure the end-to-end metrics, the laptop needs to be connected to the 5G network, just like the other UEs in the 5G network. In this sense, the laptop is connected over Ethernet to a dedicated CPE that connects to the 5G network. Step 2: To be able to do the end-to-end measurements, an iperf instance needs to be running on the Network Application, i.e., in addition to the functionality the Network application implements, an iperf server needs to be running in one of the pods that form the network application. Step 3: An iperf client needs to be instantiated on the laptop connected to the 5G network. Step 4: Using iperf and ping as tools, the end-to-end connectivity of the network can be tested. Step 5: The 5G network and network application are left running over the course of 1 week.
Tested parameters and metrics	Metric code: FPVM-01 (Latency) Explanation: The end-to-end latency is of high relevance for UC#2, it determines how long it takes for a packet sent by a UE to be received by the network application. Since in this UC the information sent by the UEs contains information about whether a worker is in danger, it is very important to have a very small latency so that an alarm might be raised as quick as possible. Related Steps: Steps 1 and 4: the time that a packet needs to be sent by the laptop and received by the edge application server will be measured. Since the ping tool used for this experiment, the round-trip time is measured. It can be assumed that the latency is half of this value. KPI value (exp.): less than 50 ms Remarks: The tests are repeated 3 times over a duration of 4 minutes. Metric code: FPVM-02 (Jitter) Explanation: It is typical for radio connections to fluctuate in their performance given that radio links can be affected by interference, weather-related attenuation or temporary (moving obstacles). In this sense, it is useful to understand how much the latency varies during execution to understand if the radio is stable or not. Related Steps: Steps 1 and 4: Refers to the jitter observed in FPVM-01. KPI value (exp.): No specific KPI was indicated in the initial use case description as per D2.1 [1], but the jitter should ideally be less than half the latency. Remarks: The tests are repeated 3 times over a duration of 4 minutes.

[4] https://iperf.fr/
[5] https://manpages.ubuntu.com/manpages/xenial/man8/ping.8.html

Use Case #2	
	Metric code: FPVM-03 (Data rate) Explanation: While the traffic generated in UC#2 by the devices connected to the network is rather low (below 10 Mbps), we still consider the achievable data rate to be a relevant indicator for the 5G network. The data rate is measured for two transport protocols covering the majority of applications and for the uplink and downlink. Iperf is used for these tests. Related Steps: Steps 1 to 4 KPI value (exp.): The data rate should be at 15 Mbps in both directions or more. Remarks: The tests are repeated 3 times over a duration of a minute. Metric code: FPVM-04 (Availability) Explanation: For a security-related application, it is mandatory for the 5G network and the application deployed to be always operational. In technical terms, this corresponds to the availability. To measure it, the system is simply left operational (includes 5G network and the network application) and after a determined period, here 1 week, it can be checked whether the application was running all the time and the network was up and running permanently. Related Steps: Step5 KPI value (exp.): 99,9% Remarks: Metric code: FPVM-05 (Reliability) Explanation: 5G Network functionality: Reliability is the success probability of packet transmission within a required maximum time. To determine this value, a long-term ping is launched throughout the duration of 1 week. With default settings, this corresponds to the transmission of over 600000 packets that will allow to determine whether packets have been lost or not. A minor rate of packet losses can be expected, given the outdoor environment might Related Steps: Steps 1, 4 and 5 KPI value (exp.): 99% Remarks:

Table 8 - Measure and validation of the network KPIs in Use Case #1

4. Initial results of the test

The tests were divided into 2 phases:

- Test in STAM LAB 4.1

- Test on Near-Real Environment 4.2

In the first phase, tests were aimed at the operation of the implemented microservices.

Thus, connectivity tests were performed with routers, network overload tests to visualize effects on P90 and P99 latency and jitter.

Once the stability of the implemented microservices was established, field tests were conducted.

The field tests in the first instance included connectivity tests and latency and jitter calculations as for the laboratory tests. Like reported in the deliverable D2.1, the KPI in the real environment are the following.

N°	Use case Requirements	Units	Use Case #1		
			Automatic Power Distribution Grid Fault Detection		
			5G Use case category/Slice Type		
			URLLC	eMBB	mMTC
1	Communication service Availability	%	99.99	-	-
2	Communication service Reliability	%	99.99	-	-
3	End-to-end latency	msec	<40ms	-	-
4	Packet Loss	%	<0.01	-	-
5	Jitter	msec	<2	-	-

Table 9 - Summary of network requirements for the UC#1

4.1. UC#1 - Test on STAM LAB

In the STAM labs, the setting tests of the developed microservice were carried out, leaving out the number values of the KPIs, as it was important to establish the communication, the correct calculation of the KPIs of interest, the publication of the results on a dynamic dashboard, the generation of the alarms when the set threshold was exceeded.

4.2. UC#1 - Test on Near-Real Environment

Following the setup phase of the implemented service, a field test phase was carried out. The user equipment (CISCO IR1101) involved in this testing phase are 3:

10.2.1.27 based in Roma

10.2.1.29 based in Milano

10.2.1.30 based in Milano

Additional 16 routers (CISCO IR1101) were initialized, of which 2 are for testing and the remaining 14 are located in Sardinia subdivided as follows at the primary cabins of:

- Eucaliptu with 3 user equipment
- Golfo Aranci with 3 user equipment
- Putzolu with 4 user equipment
- Piciaredda with 4 user equipment
- Milan with 1 user equipment (for testing purposes)
- Rome with 1 user equipment (for testing purposes)

The User equipment is distributed as reported in Figure 8 (3 additional backup sims for laboratory/testing purposes, were available, which lead to the total of 19 sims of the figure below)

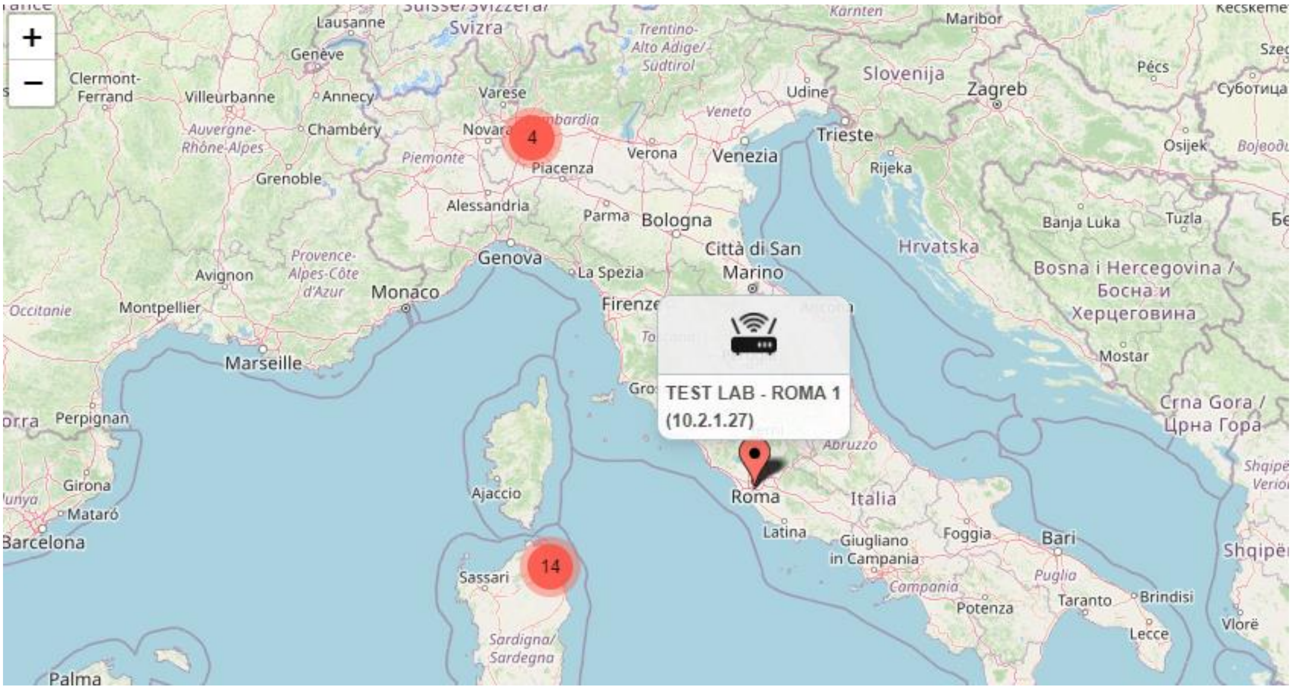


Figure 8 - User equipment UC#1 map

Although the real case is not fully complied with during this field test, in fact the UEs are located at the Milan and Rome sites, while the MEC Server on which the traffic analysis service is run is at the Sardinian site in Cagliari in contrast to the real case where the MEC will be significantly physically closer. The KPIs selected for use case 1, as reported in D2.1 are as follows:

- Number of packet loss less than 0.1%.
- P90 latency less than 40ms
- P99 latency less than 40ms
- Jitter less than 2ms

4.3. UC#2 data collection

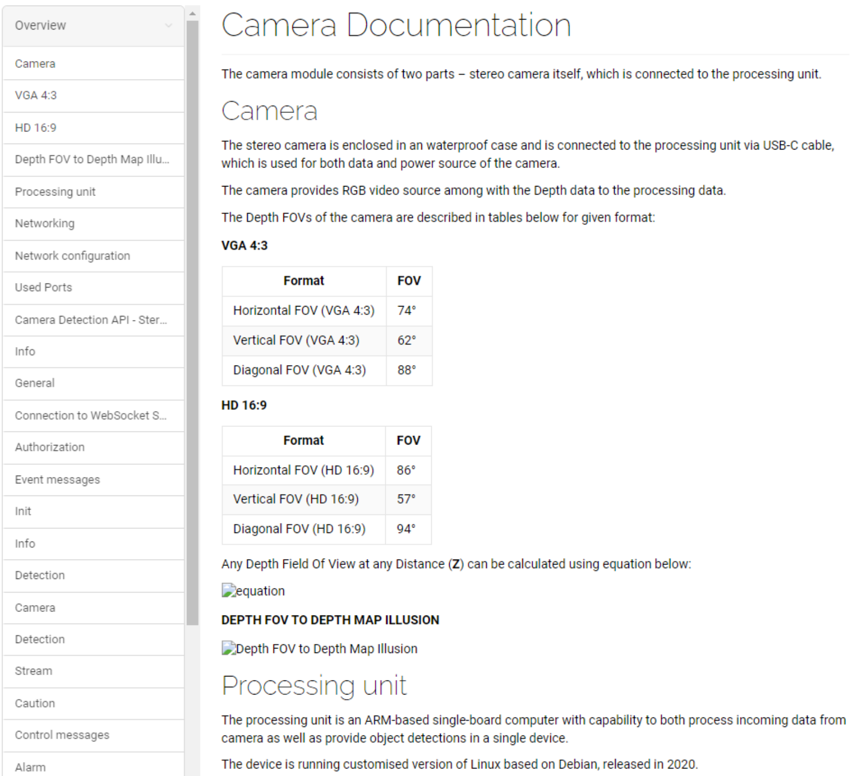
RTLS (cameras and sensors) are continuously monitoring the environment and processing data locally. In next deliverable network app dashboard will be shown where the configuration of the safety zones and the start of the work is defined. This section shows the field devices that are involved in the use case.

As presented in section 2.2. there are two main data collectors from the substation. On the one hand cameras that detect people and their tools. Intel® RealSense series D455 and their microprocessors Khadas detect the person and their tools and position them in the center of the image. This data is shown in Figure 9. In the first column it is shown that the camera is monitoring the environment. The second column shows the time in Unix time. Each camera has an identification so is shown in "camera" label. In the colored row it is shown a detection of a person and the confident of the detection. The exact position of the person detected is given by its x,y,z and width, height and depth from the center of the image. Also, it is given the rectangle that captures the person.


```
{"action": "detection", "timestamp": 1695213383814, "data": {"camera": {"name": "Camera 59a1feba4ede", "fps": 6, "width": 640, "height": 480, "rotation": {"x": 0, "y": 0, "z": 0}}, "detections": []}}
{"action": "detection", "timestamp": 1695213383852, "data": {"camera": {"name": "Camera 6da5dbdbbb41", "fps": 7, "width": 640, "height": 480, "rotation": {"x": 0, "y": 0, "z": 0}}, "detections": []}}
{"action": "detection", "timestamp": 1695213383851, "data": {"camera": {"name": "Camera 53a02a8ab053", "fps": 6, "width": 640, "height": 480, "rotation": {"x": 0, "y": 0, "z": 0}}, "detections": []}}
{"action": "detection", "timestamp": 1695213383844, "data": {"camera": {"name": "Camera 5f847b8924ba", "fps": 6, "width": 640, "height": 480, "rotation": {"x": 0, "y": 0, "z": 0}}, "detections": [{"label": "person", "confidence": 0.9793139696121216, "position": {"x": -4.630555629730225, "y": 1.0098788738250732, "z": 7.913000583648682}, "width": 1.00653076171875, "height": 2.0217172130942345, "depth": 0.9400000446476042, "rect": {"left": 80, "top": 239, "width": 46, "height": 106}}]}}
{"action": "detection", "timestamp": 1695213384005, "data": {"camera": {"name": "Camera 6da5dbdbbb41", "fps": 7, "width": 640, "height": 480, "rotation": {"x": 0, "y": 0, "z": 0}}, "detections": []}}
{"action": "detection", "timestamp": 1695213384005, "data": {"camera": {"name": "Camera 59a1feba4ede", "fps": 6, "width": 640, "height": 480, "rotation": {"x": 0, "y": 0, "z": 0}}, "detections": []}}
{"action": "detection", "timestamp": 1695213384042, "data": {"camera": {"name": "Camera 53a02a8ab053", "fps": 6, "width": 640, "height": 480, "rotation": {"x": 0, "y": 0, "z": 0}}, "detections": []}}
```


Figure 9 – Data collected from cameras and microprocessor Khadas

It was developed an API for describing the software implemented for both, cameras and sensors. The documentation on where to find more information about the API can be seen in figure 10.



Overview
Camera
VGA 4:3
HD 16:9
Depth FOV to Depth Map Illu...
Processing unit
Networking
Network configuration
Used Ports
Camera Detection API - Ster...
Info
General
Connection to WebSocket S...
Authorization
Event messages
Init
Info
Detection
Camera
Detection
Stream
Caution
Control messages
Alarm

Camera Documentation

The camera module consists of two parts – stereo camera itself, which is connected to the processing unit.

Camera

The stereo camera is enclosed in an waterproof case and is connected to the processing unit via USB-C cable, which is used for both data and power source of the camera.

The camera provides RGB video source among with the Depth data to the processing data.

The Depth FOVs of the camera are described in tables below for given format:

VGA 4:3

Format	FOV
Horizontal FOV (VGA 4:3)	74°
Vertical FOV (VGA 4:3)	62°
Diagonal FOV (VGA 4:3)	88°

HD 16:9

Format	FOV
Horizontal FOV (HD 16:9)	86°
Vertical FOV (HD 16:9)	57°
Diagonal FOV (HD 16:9)	94°

Any Depth Field Of View at any Distance (**Z**) can be calculated using equation below:

equation

DEPTH FOV TO DEPTH MAP ILLUSION

Depth FOV to Depth Map Illusion

Processing unit

The processing unit is an ARM-based single-board computer with capability to both process incoming data from camera as well as provide object detections in a single device.

The device is running customised version of Linux based on Debian, released in 2020.

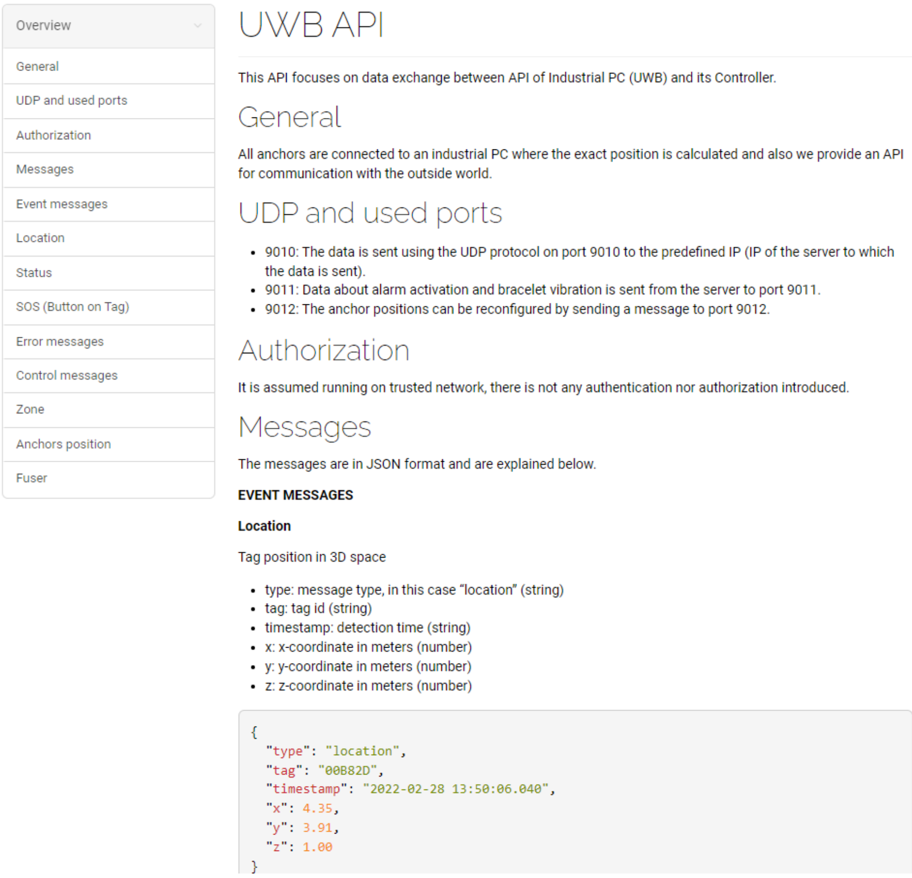
Figure 10 - camera's API documentation

On the other hand, the data coming from the bracelet of the workers. Each worker is wearing the UWB bracelet, which position is collected in the antennas deployed in the demo site. In this case there is a preprocessing step that sent the worker's position referred to a common reference point. The information sent to the Network App is as follows:

{"type":"location","tag":"00D003","timestamp":"2023-09-20 14:36:49.395","x":6.263741363371386,"y":1.6077628365465084,"z":1}

It is sent the ID of the tag, the time in the timestamp and the coordinates of the tag from a common reference for all the antennas.

As well as for the cameras, the UWB sensors have an API that describes the software implemented, showed in the next figure.


Overview
General
UDP and used ports
Authorization
Messages
Event messages
Location
Status
SOS (Button on Tag)
Error messages
Control messages
Zone
Anchors position
Fuser

UWB API

This API focuses on data exchange between API of Industrial PC (UWB) and its Controller.

General

All anchors are connected to an industrial PC where the exact position is calculated and also we provide an API for communication with the outside world.

UDP and used ports

- 9010: The data is sent using the UDP protocol on port 9010 to the predefined IP (IP of the server to which the data is sent).
- 9011: Data about alarm activation and bracelet vibration is sent from the server to port 9011.
- 9012: The anchor positions can be reconfigured by sending a message to port 9012.

Authorization

It is assumed running on trusted network, there is not any authentication nor authorization introduced.

Messages

The messages are in JSON format and are explained below.

EVENT MESSAGES

Location

Tag position in 3D space

- type: message type, in this case "location" (string)
- tag: tag id (string)
- timestamp: detection time (string)
- x: x-coordinate in meters (number)
- y: y-coordinate in meters (number)
- z: z-coordinate in meters (number)

```
{
  "type": "location",
  "tag": "00B82D",
  "timestamp": "2022-02-28 13:50:06.040",
  "x": 4.35,
  "y": 3.91,
  "z": 1.00
}
```

Figure 11 - camera's API

UBW sensor's API

This data mentioned is then processed in the Network App deployed in the edge, and it sends an alarm in case a worker or a tool is out of the safety area.

4.4. Analysis of field results

4.4.1. UC#1 results

On this section a detailed analysis of the three User equipment is explained in detail.

To carry out the analysis, a developed dashboard is used which is presented with a dual main interface: in the first one the disposition of the UEs on a map is displayed like reported in the Figure 12, in the second one in schematic form in Figure 13. In the boxes in schematic form in addition to the UE address, the average values of the last 24 hours of P90 latency, P99 latency, jitter and percentage of lost packets are also shown.

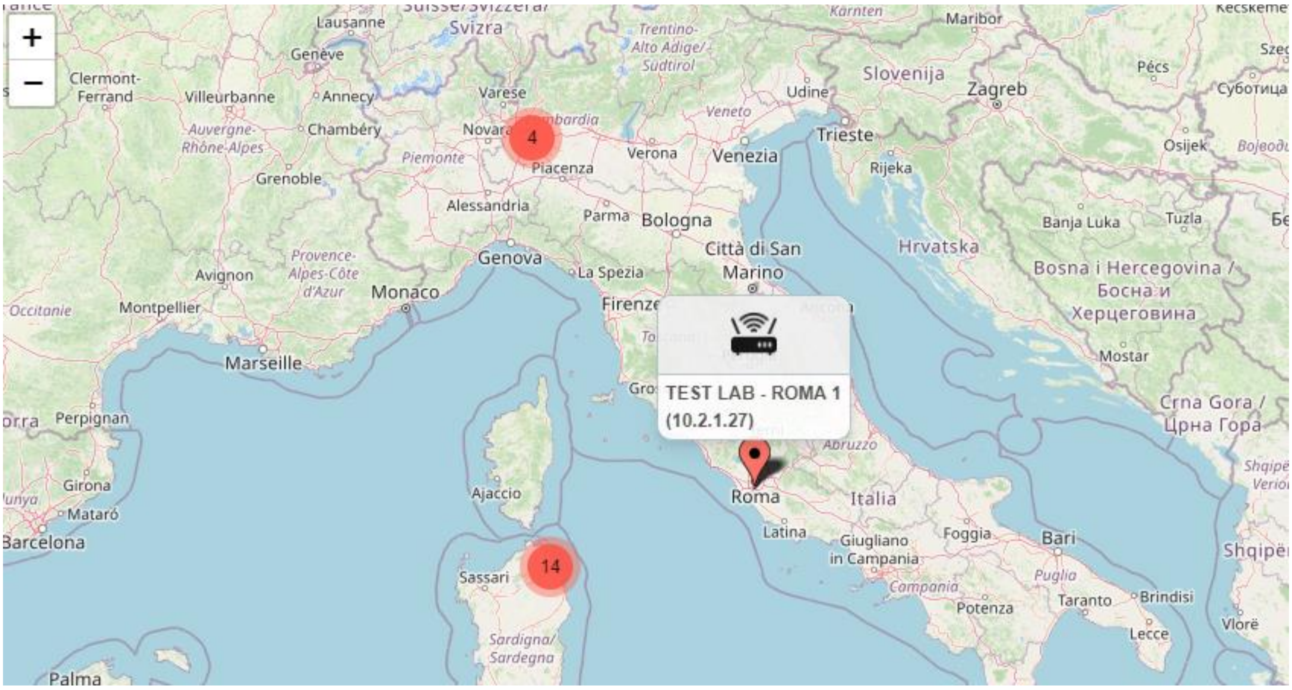


Figure 12 - User equipment UC#1 map

Figure 13 - User equipment UC#1 schematic interface

Figure 14 - Geographical distribution of Lab user equipment in Milan

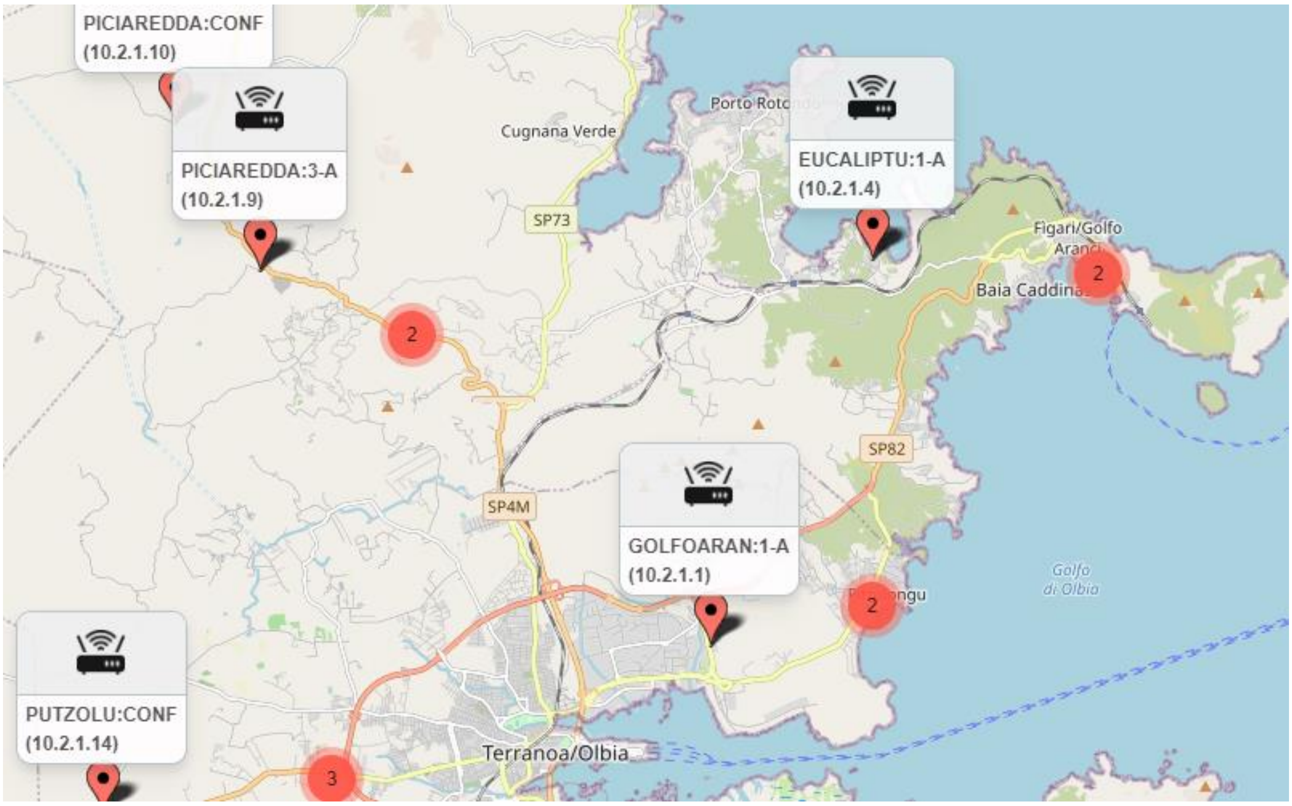


Figure 15 - Geographical distribution of user equipment in Olbia area

Clicking on the UE of interest allows to access a screen composed at the top by the list of detected alarms, the historical reference data like reported in the Figure 16.

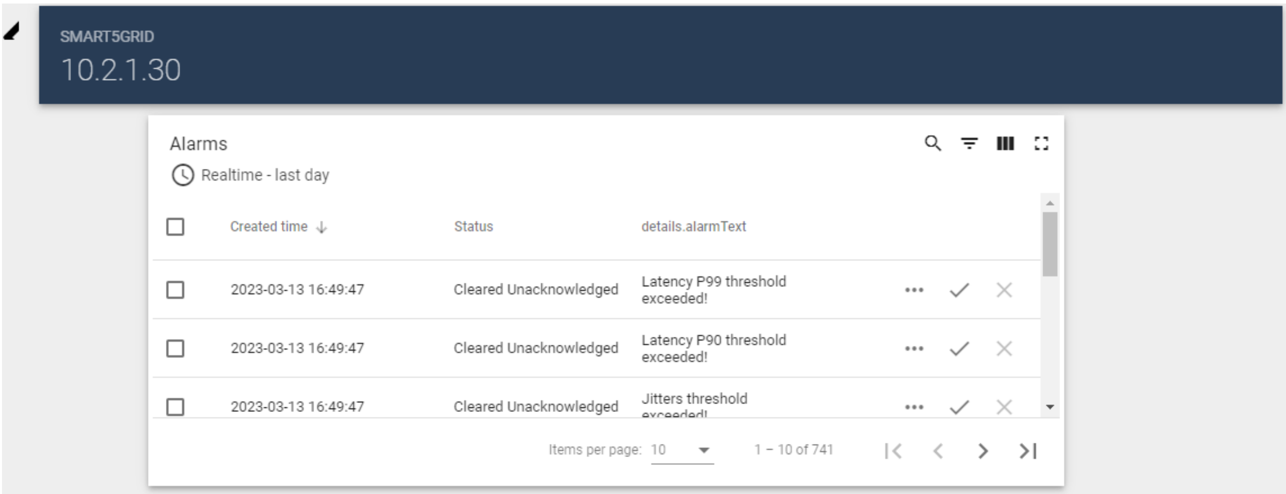


Figure 16 - Top of detailed user equipment interface

4.4.1.1. IP 10.2.1.27 UE Equipment Analysis

Figure 17 – Packet loss UE 10.2.1.27

FPVM-03 (Packet Loss): an average number of packet loss of 0% is observed. This value is in line with the selected threshold

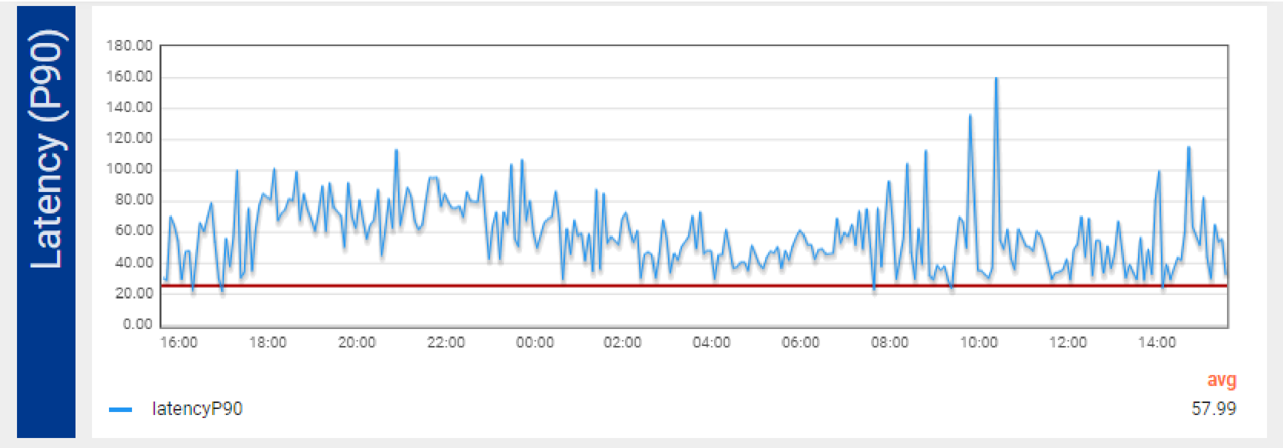


Figure 18 – Latency P90 UE 10.2.1.27

FPVM-01 (Latency P90): We observe an average latency of 57.99 ms. This is higher than the expected 25ms. The highest value measured in these series of repetitions is 159.91 ms, which is also still higher the desired latency.

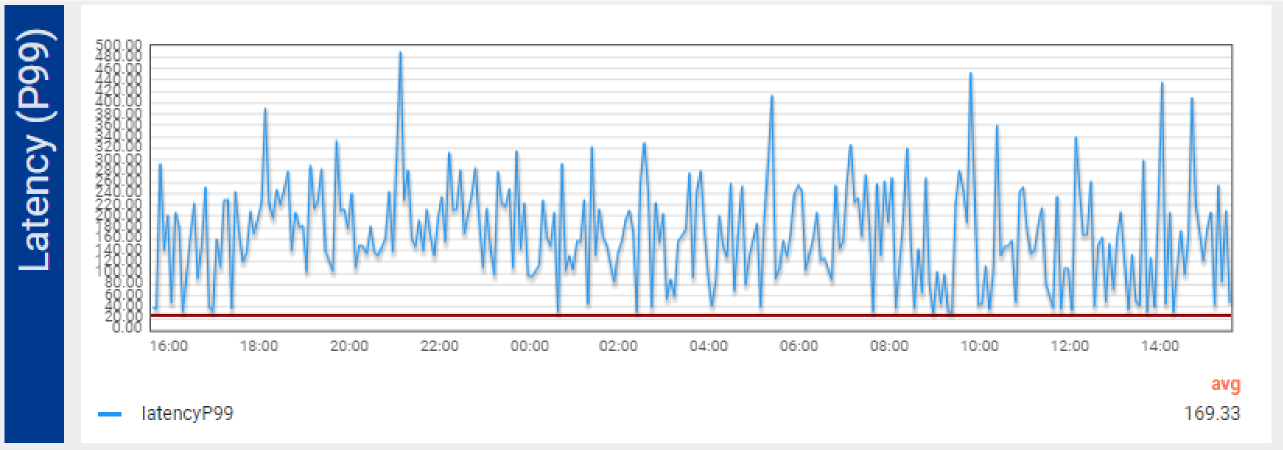


Figure 19 – Latency P99 UE 10.2.1.27

FPVM-01 (Latency P99): We observe an average latency P99 of **169.33 ms**. This is higher than the expected 25ms. The highest value measured in these series of repetitions is 489.91 ms, which is also still higher the desired latency.

Figure 20 – Jitter UE 10.2.1.27

FPVM-02 (Jitter): We observe a standard deviation throughout the repetition of the experiments of 18.86 ms, which indicates a very unstable connection.

The following three figures are not considered in the same time interval of the previous test and report the results in terms of availability, with focus on Unreachability in the last 24 hours and punctual. In terms of reliability.

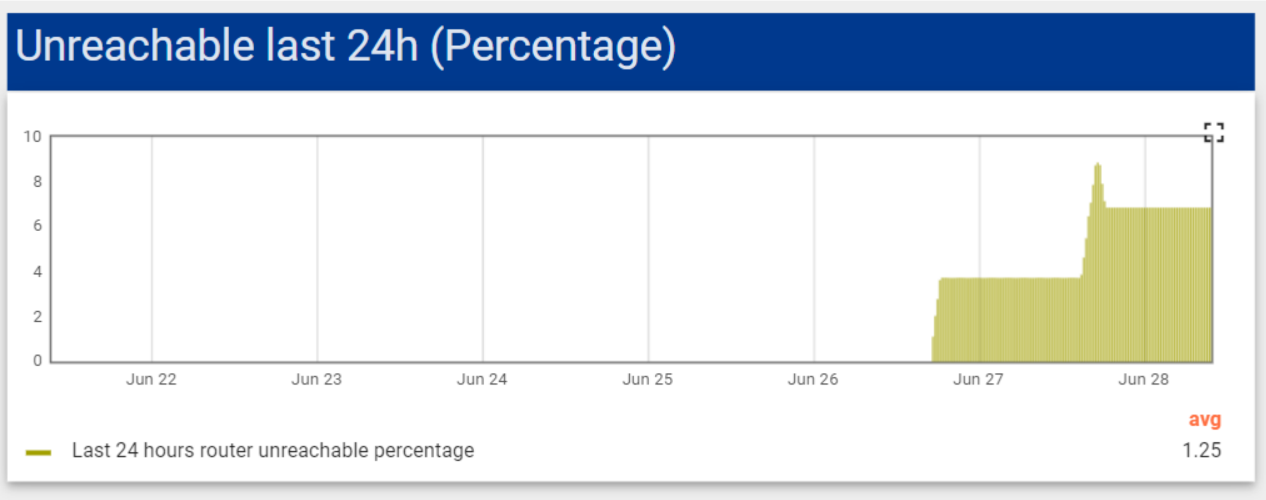


Figure 21 – Unreachable last 24 h UE 10.2.1.27

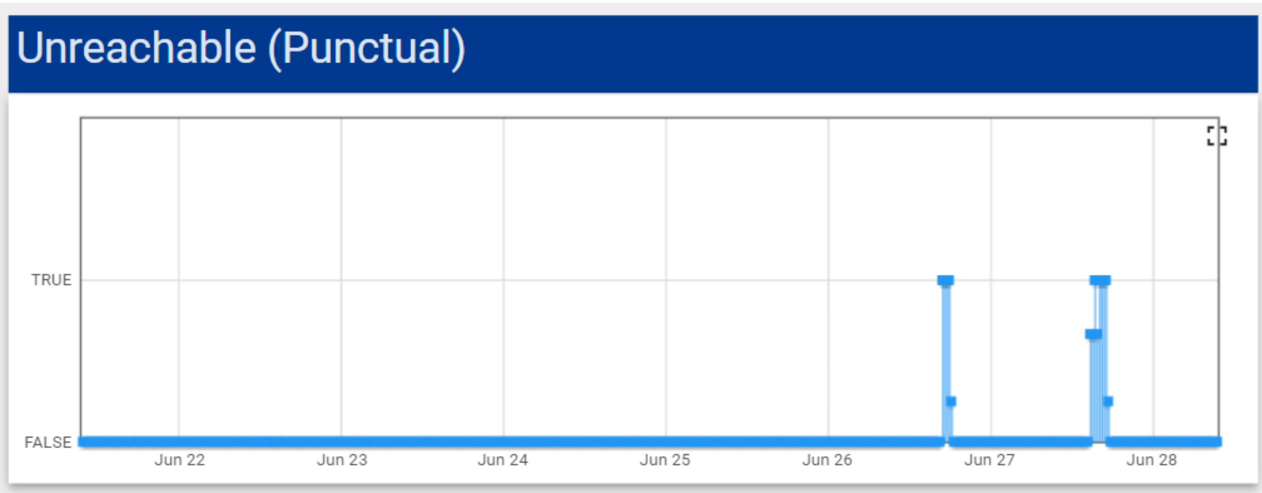


Figure 22 – Unreachable UE 10.2.1.27

FPVM-04 (Availability): The image provides visual evidence of a notable occurrence that took place during the timeframe spanning from June 27th to 28th. It reveals a discernible period when the User Equipment experienced unreachability, indicating a disruption in its communication capabilities. The depicted figure not only serves as a visual representation of this unreachability but also highlights the specific moment when it occurred, capturing a significant event in the timeline.

The result discussed before it is also confirmed in terms of reliability

FPVM-05 (Reliability): The featured Figure 23 provides a compelling visual representation, highlighting a specific period that coincides precisely with the occurrence of unreachability. This synchronization between the identified timeframe and the moment of system failure serves as a clear indication of the system's inherent unreliability. The image effectively emphasizes the crucial connection between the observed period and the ensuing unreachability, underscoring the system's inability to consistently maintain proper functionality.

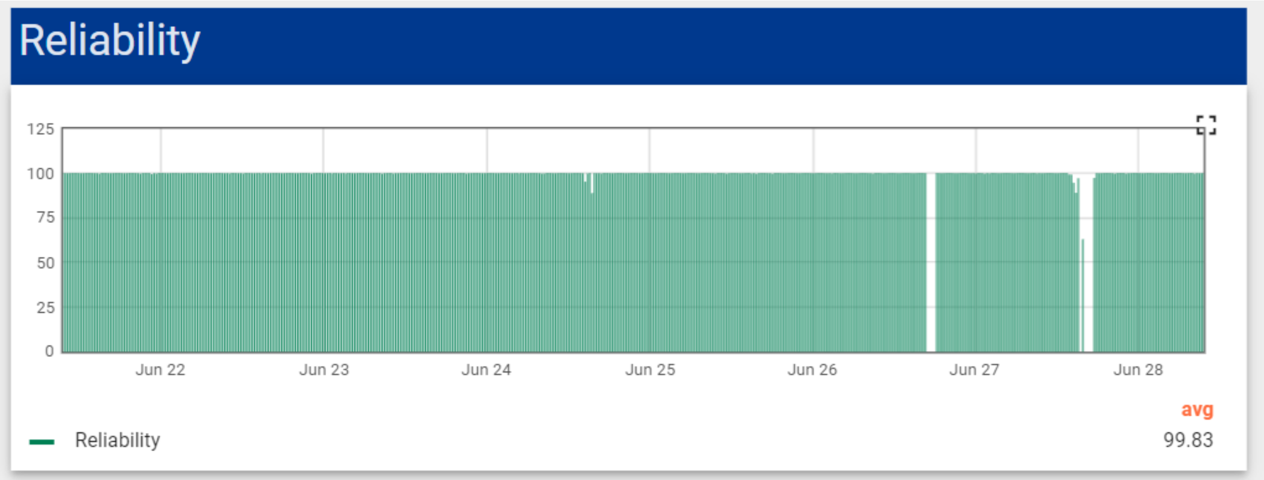


Figure 23 – Reliability UE 10.2.1.27

4.4.1.2. IP 10.2.1.29 UE Equipment Analisys

The User equipment 10.2.1.29 is situated in Milano and has a SIM that supports LTE connection.

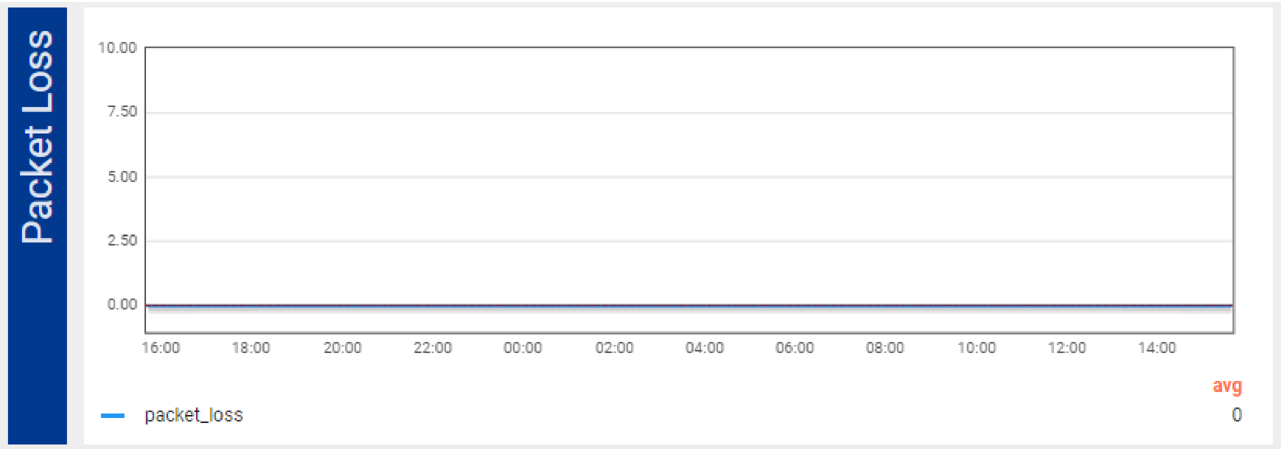


Figure 24 - Packet loss UE 10.2.1.29

FPVM-03 (Packet Loss): We observe an average number of packet loss of 0, this value is in line with the selected threshold.

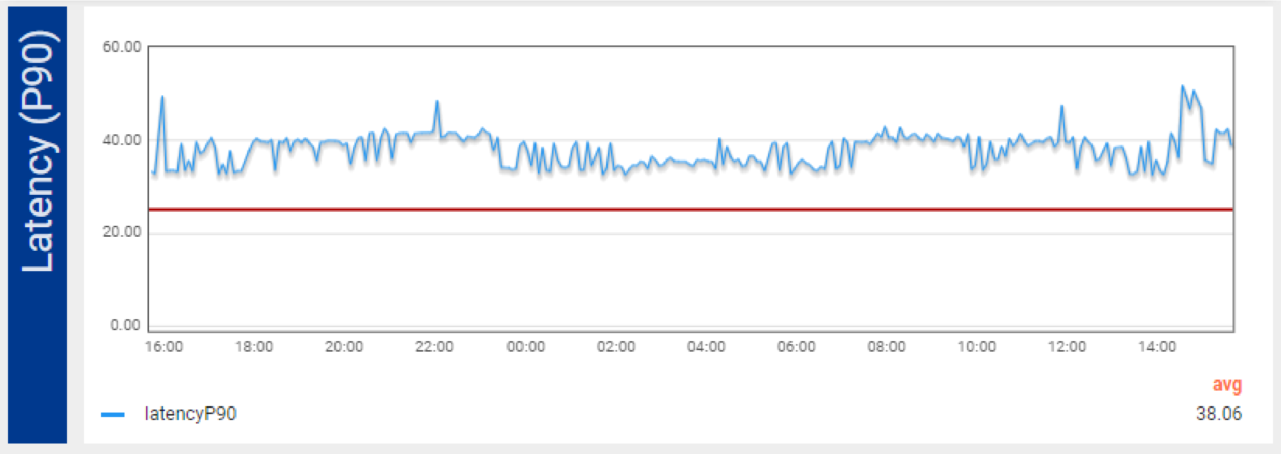


Figure 25 - Latency P90 UE 10.2.1.29

FPVM-01 (Latency P90): We observe an average latency of 38.06 ms. This is higher than the expected 25ms. The highest value measured in these series of repetitions is 52.91 ms, which is also still higher the desired latency.

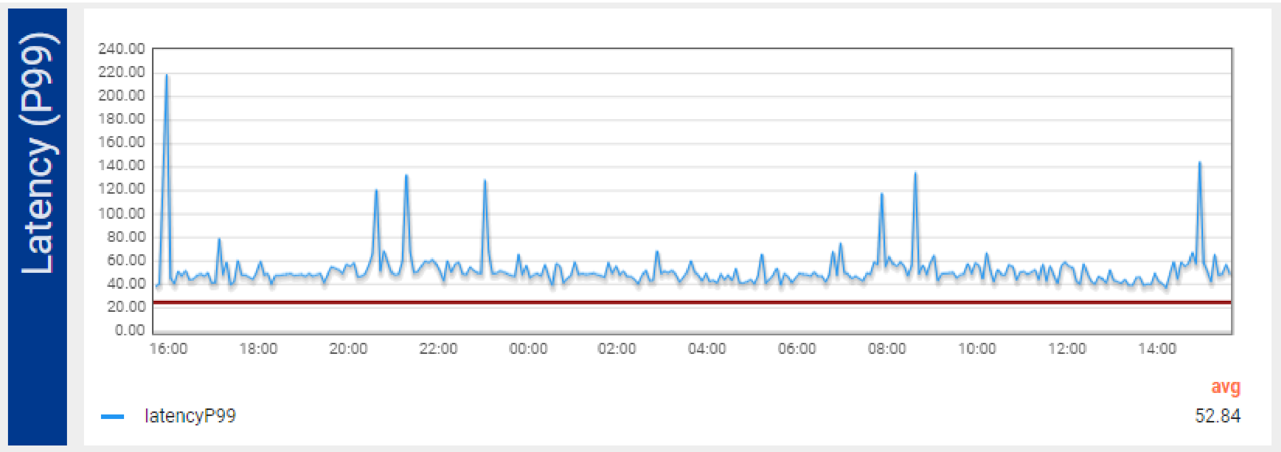


Figure 26 - Latency P99 UE 10.2.1.29

FPVM-01 (Latency P99): We observe an average latency P99 of 52.84 ms. This is higher than the expected 25ms. The highest value measured in these series of repetitions is 220.91 ms, which is also still higher the desired latency.

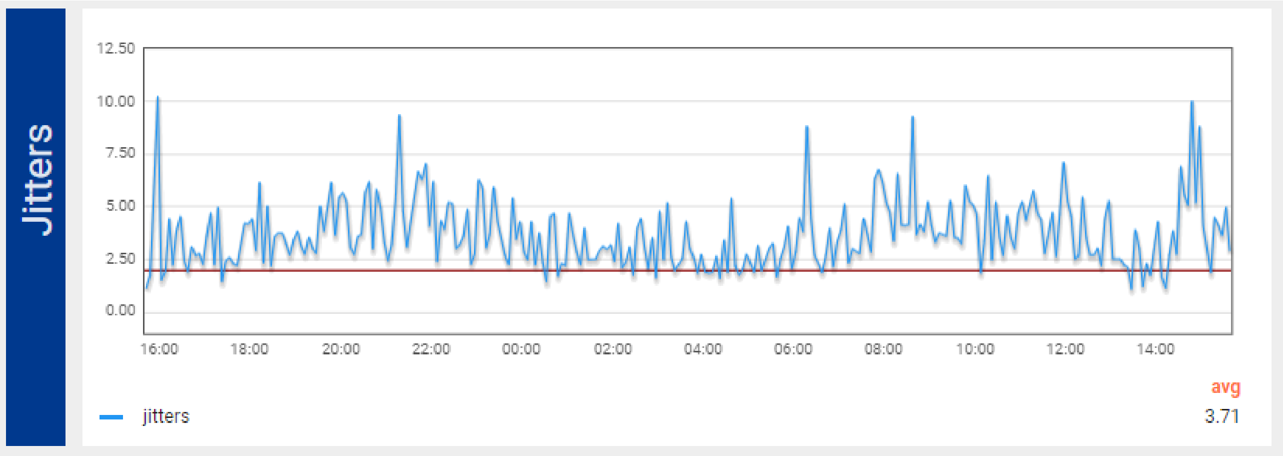


Figure 27 - Jitter UE 10.2.1.29

FPVM-02 (Jitter): We observe a standard deviation throughout the repetition of the experiments of 3.71ms, which indicates a very unstable connection.

The following three figures are not considered in the same time interval of the previous test and report the results in terms of availability, with focus on Unreachability in the last 24 hours, punctual Unreachability and reliability.

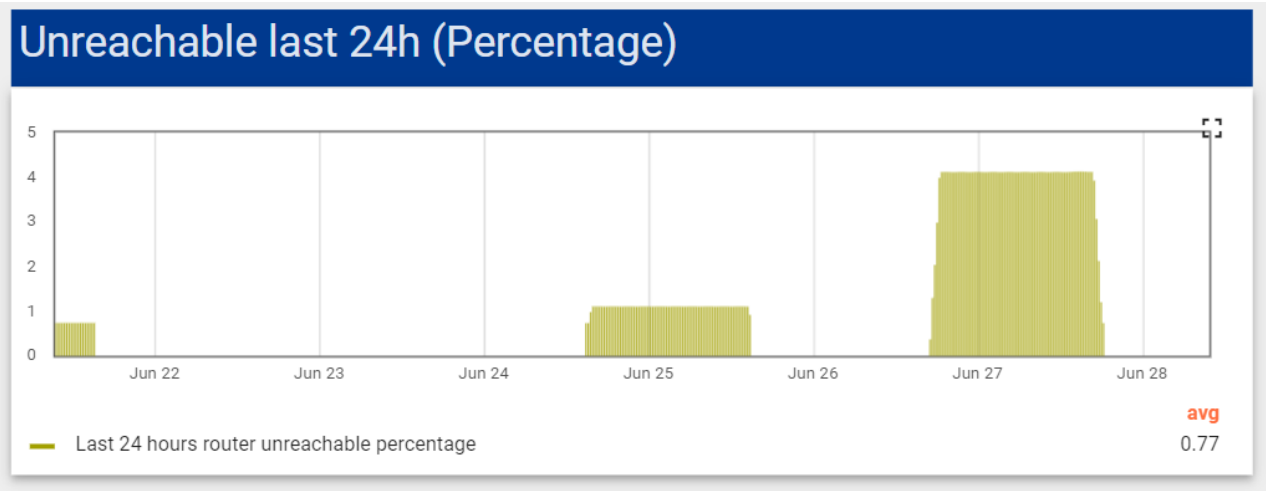


Figure 28 Unreachable last 24 h UE 10.2.1.29

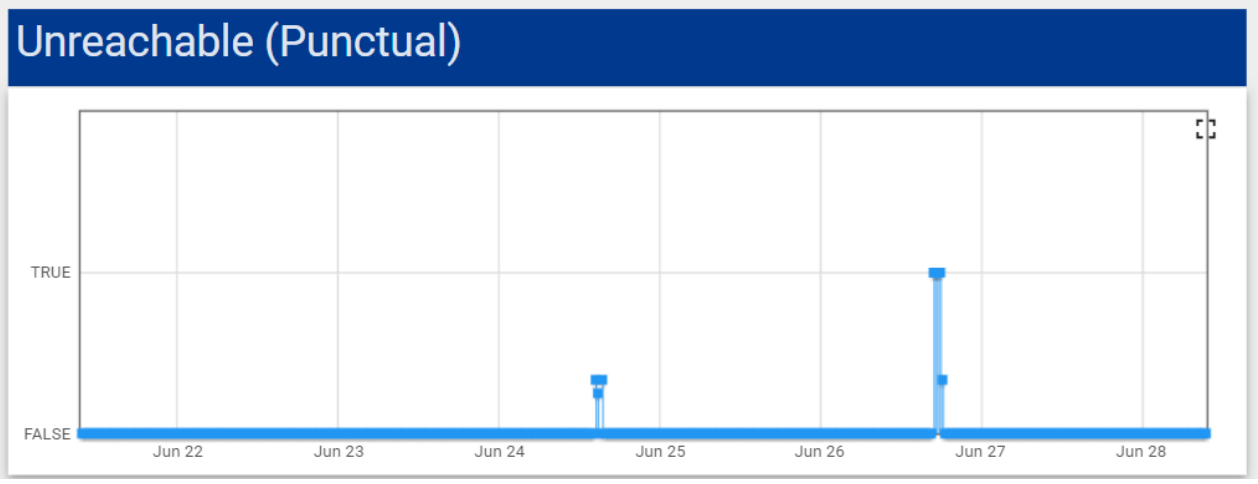


Figure 29 - Unreachable UE 10.2.1.29

FPVM-04 (Availability): The image provides visual evidence of a notable occurrence that took in during the timeframe during the 25th and the 27th of June. It reveals a discernible period when the User Equipment experienced unreachability, indicating a disruption in its communication capabilities. The depicted figure not only serves as a visual representation of this unreachability but also highlights the specific moment when it occurred, capturing a significant event in the timeline.

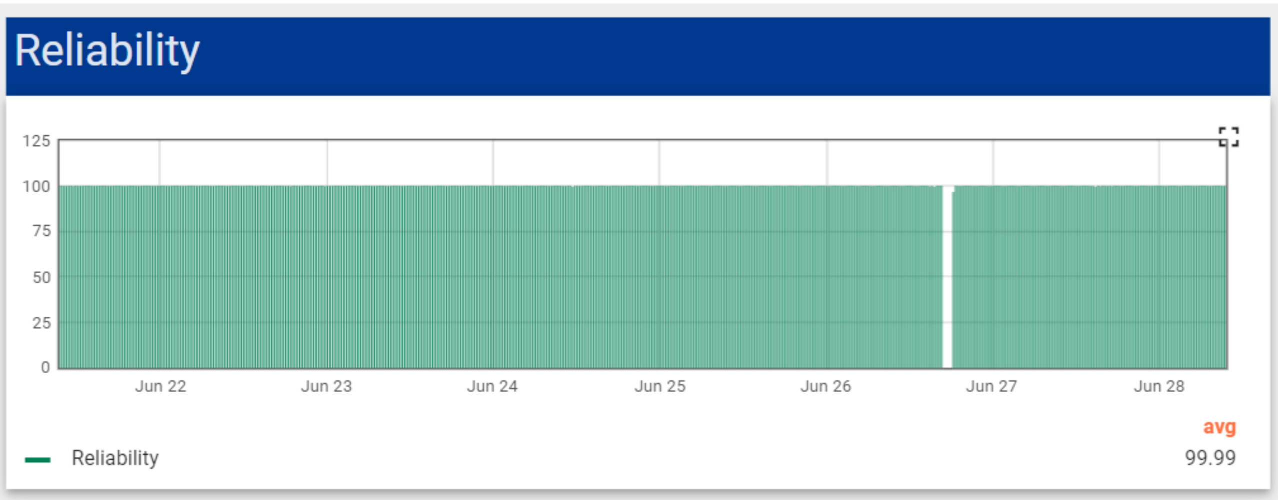


Figure 30 – Reliability UE 10.2.1.29

FPVM-05 (Reliability): The featured image provides a compelling visual representation, highlighting a specific period that coincides precisely with the occurrence of unreachability. This synchronization between the identified timeframe and the moment of system failure serves as a clear indication of the system's inherent unreliability. The image effectively emphasizes the crucial connection between the observed period and the ensuing unreachability, underscoring the system's inability to consistently maintain proper functionality.

4.4.1.3. IP10.2.1.30 User Equipment Analysis

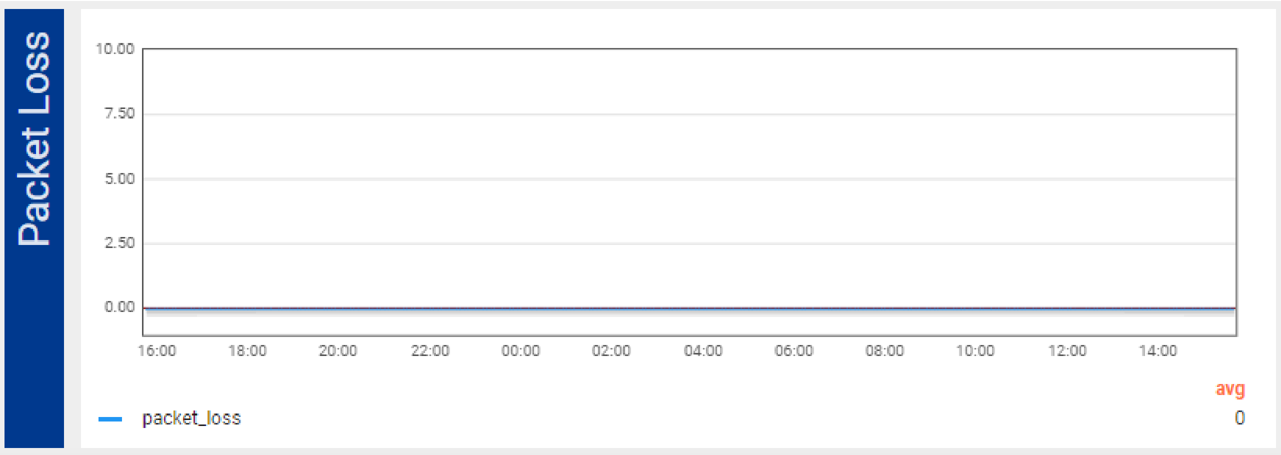


Figure 31 - Packet loss UE 10.2.1.30

FPVM-03 (Packet Loss): We observe an average number of packet loss of 0, this value is in line with the selected threshold.

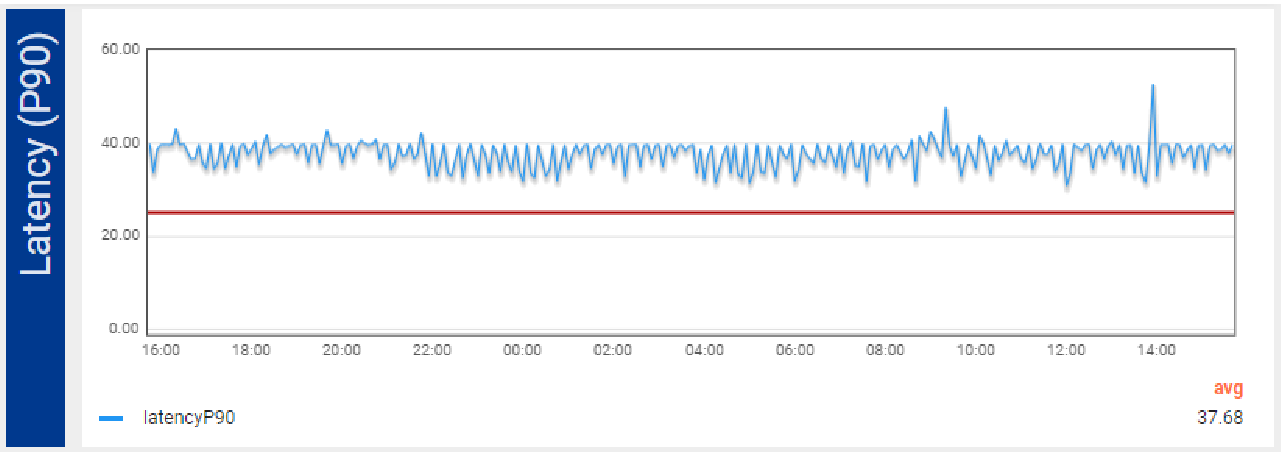


Figure 32 - Latency P90 UE 10.2.1.30

FPVM-01 (Latency P90): We observe an average latency of 37.68 ms. This is higher than the expected 25ms. The highest value measured in these series of repetitions is 51.3ms, which is also still higher the desired latency.

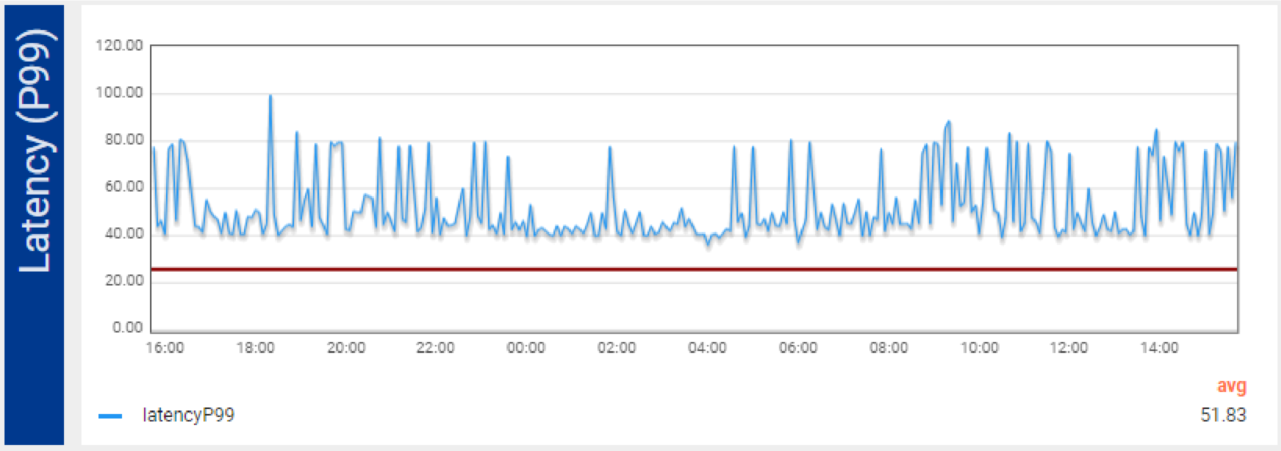


Figure 33 - Latency P99 UE 10.2.1.30

FPVM-01 (Latency P99): We observe an average latency P99 of **51.83 ms**. This is higher than the expected 25ms. The highest value measured in these series of repetitions is 99.3 ms, which is also still higher the desired latency.

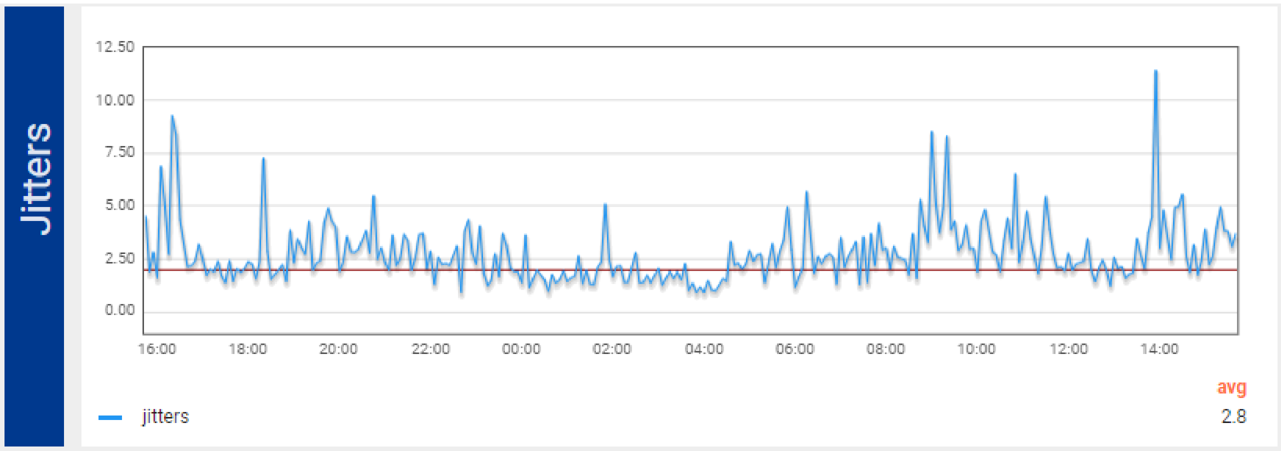


Figure 34 - Jitter UE 10.2.1.30

FPVM-02 (Jitter): We observe a standard deviation throughout the repetition of the experiments of 2.8 ms, which indicates a quite stable connection.

The following three figures are not considered in the same time interval of the previous test and report the results in terms of availability, with focus on Unreachability in the last 24 hours, punctual Unreachability and reliability.

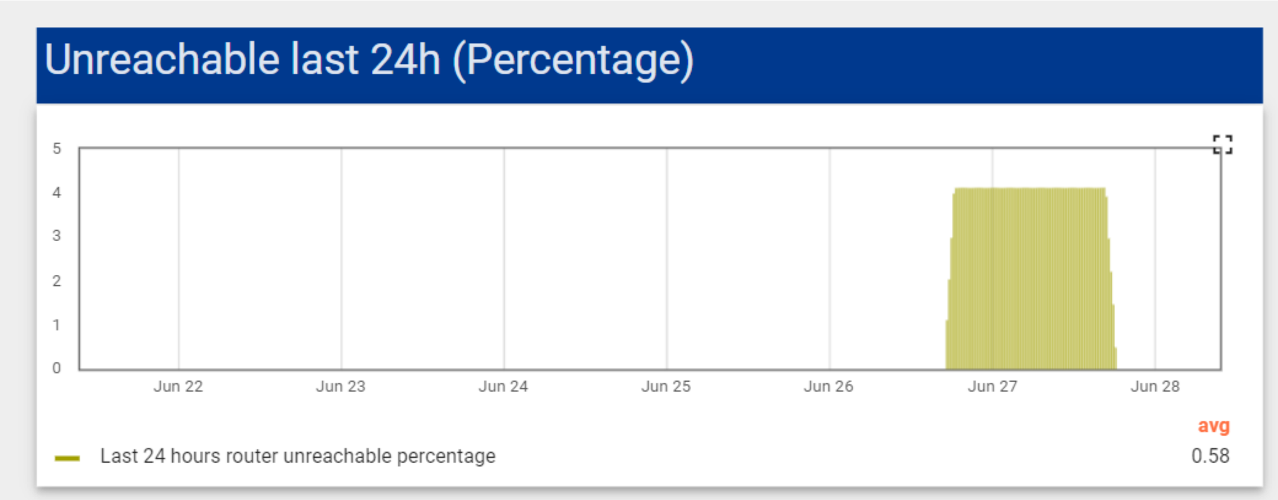


Figure 35 - Unreachable last 24 h UE 10.2.1.30

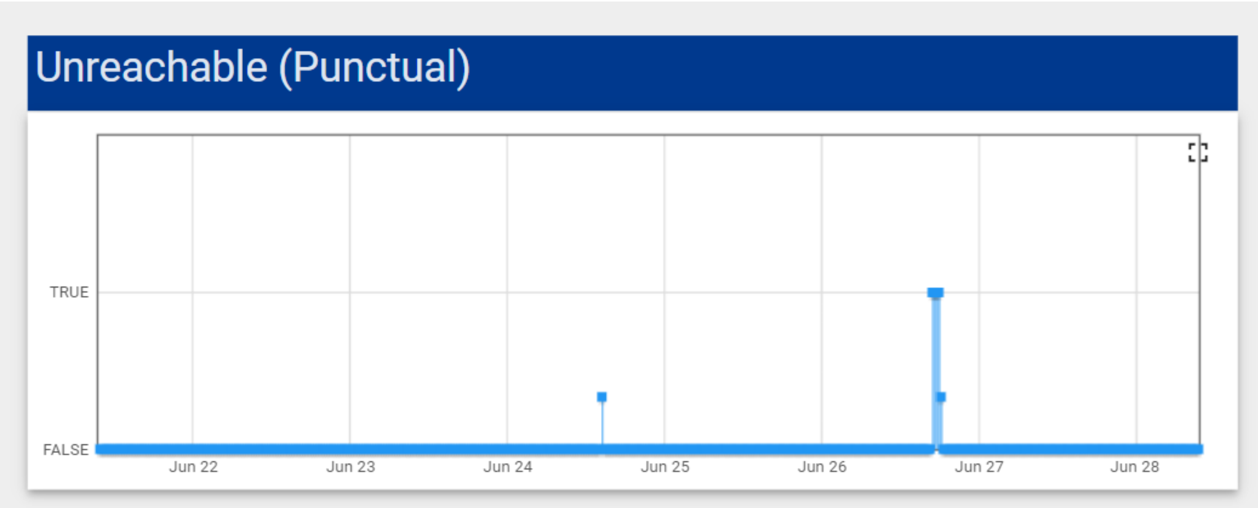


Figure 36 - Unreachable UE 10.2.1.30

FPVM-04 (Availability): The image provides visual evidence of a notable occurrence that took place during the timeframe during the 25th and the 27th of June. It reveals a discernible period when the User Equipment experienced unreachability, indicating a disruption in its communication capabilities. The depicted figure not only serves as a visual representation of this unreachability but also highlights the specific moment when it occurred, capturing a significant event in the timeline.

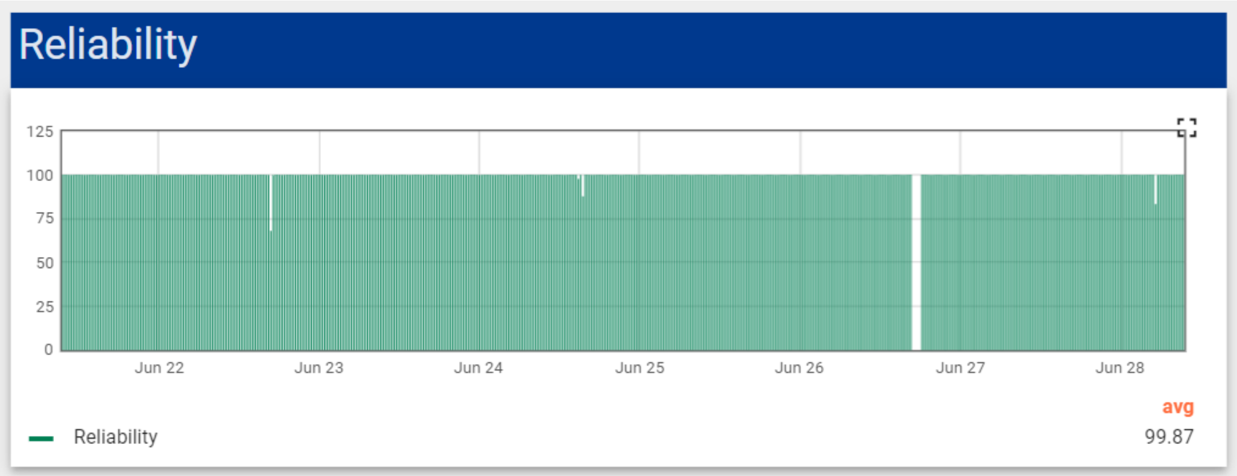


Figure 37 - Reliability UE 10.2.1.29

FPVM-05 (Reliability): The featured image provides a compelling visual representation, highlighting a specific period that coincides precisely with the occurrence of unreachability. This synchronization between the identified timeframe and the moment of system failure serves as a clear indication of the system's inherent unreliability. The image effectively emphasizes the crucial connection between the observed period and the ensuing unreachability, underscoring the system's inability to consistently maintain proper functionality. Furthermore, it is worth noting that the image reveals the presence of negative peaks even during periods when the user equipment remains reachable. This occurrence can be attributed to the intermittent unreachability of the UE during the time interval when reachability testing was conducted. Such intermittent unreachability adversely impacts the overall reliability of the system, as clearly demonstrated in the provided image.

4.4.2. UC#2 results

The tests done for UC#2 can be split into two phases: I) the lab phase prior to the on-site deployment at the substation ii) the field-deployment phase, in which the 5G network and the network application run in the substation.

This report considers both phases of tests and validations, using the lab environment in a first step and the substation environment in the second step.

4.4.3. First phase: i2CAT lab

In UC#2, while the lab environment can be further broken down into the i2CAT lab environment and the NOSIA lab environment, the validations listed in Section 3 are performed only in the i2CAT lab in this first phase. The setup limits to using a single 5G CPE that is connected to the 5G network, where the UC#2 network application is running. Instead of the laptop, in this phase a Raspberry Pi 4 (Model B) is used as device to run the iperf and ping tools.

Further, we also confirm that all the devices (UEs) that will be mounted in the substation can be connected simultaneously to the 5G network, as such satisfying the requirement of supported device density for UC#2. The private 5G network potentially support more devices, if the infrastructure should be extended later on.

In the following, we present the results obtained for the tests performed in the lab:

FPVM-01 (Latency): We observe an average latency of **13.8 ms** throughout the 3 repetitions of the test. This is clearly below the expected 50 ms. The highest value measured in these series of repetitions is 22.85 ms, which is also still clearly below the desired latency.

FPVM-02 (Jitter): We observe a standard deviation throughout the repetition of the experiments of **3.02 ms**, which indicates a very stable connection, with only minor variations.

FPVM-03 (Data Rate): We differentiate between uplink (UL) and downlink (DL) data rates, as well as between the TCP and UDP protocols. The following table summarize the average values measured throughout all repetitions.

	Uplink	Downlink
UDP	14.5 Mbps	*
TCP	24.6 Mbps	202 Mbps

Table 10 - Data Rate measured for Uplink/Downlink vs UDP/TCP

The results show that the requirements are met for the TCP traffic case. However, we identify some issues that are related to the use of the iperf tool that we discuss in the following. In the case of UDP traffic we identify two issues: In these measurements only 14.5 Mbps are measured. Also, due to how the 5G network works, no DL traffic can be measured (UDP connection towards UEs is not supported by default).

We study the behaviour of iperf and realize that the results are not reliable enough. As such, we consider other options, but only find useful tools for TCP communications, like for example speed tests against an Internet server. Considering that eve with with iperf, which seems to underperform clearly compared to an Internet speed test on top of the same 5G network, we can achieve via TCP the required data rates, we consider the results sufficient. Other tests that are carried apart in other occasions reveal data rates of up to 40 Mbps for UDP (performed with the same 5G network but using a different source and destination: a laptop and the 5G Core, respectively.). Again, it can be blamed on the way iperf measures the data rates.

Given the low data rates necessary for the use case (compressed logs sent by cameras and lightweight alert messages for the UWB sensors, with an overall data rate of less than 0.5 Mbps), we determine that the 5G network capacity would allow for the deployment of tens of CPEs that could carry the load in larger installations with many other cameras and UWB anchors.

FPVM-04 (Availability): We leave the system up and running over the course of 1 week and do not detect any downtime. The tests are extended further, and even after 3 weeks of uptime, the system does not suffer from any downtime. In this sense the required **99.9% of availability are achieved**.

FPVM-05 (Reliability): Throughout the testing period of 1 day, the system shows to obtain a 100% delivery rate, which means that the required degree of reliability can be achieved. It should be noted though that this value is measured indoors in a stable testing environment. Tests are to be repeated in the substation.

4.4.3.1. Phase 2: Substation

After the setup testing in the lab to validate all the key functionalities of the 5G network, the infrastructure is moved to the substation and tested in the deployment there. The differences in this setup compared to the first phase are:

- The setup is now an outdoor one, where the 5G network is using a directive antenna radiating towards the CPEs deployed in the substation.
- The CPEs are deployed amidst the substation infrastructure, enabling 5G connectivity between the sensors/cameras deployed outdoors and the Network App running at the edge.

Due to a change of the planned connectivity among the sensors and cameras, the need for hosting 2 separate CPEs is eliminated: the switches that aggregate the sensors and cameras are connected to each other, so that connecting 2 CPEs to these switches creates a redundancy and networking issues. As such, the decision is made to turn off one of the CPEs and to just keep one CPE to connect both groups of devices (sensors + cameras) with the 5G network.

For measuring the KPIs of the 5G network, tests supervised by i2CAT technical personnel are conducted, following the same methodology established in the previous section dedicated to the lab tests.

FPVM-01 (Latency): We observe an average latency of **14.5 ms** throughout the 3 repetitions of the test. This is again clearly below the expected 50 ms. The highest value measured in these series of repetitions is 22.5ms, which is also still clearly below the desired latency.

FPVM-02 (Jitter): We observe a standard deviation throughout the repetition of the experiments of **5.98 ms**, which indicates still very small variations, however a bit larger than in the lab environment. This can be caused by the more irregular and less controlled environment in which the 5G network is deployed (outdoor substation with metal and electrical equipment next to the equipment).

FPVM-03 (Data Rate): Again, we differentiate between UL and DL data rates, as well as between the TCP and UDP protocols. The following table summarize the average values measured throughout all repetitions.

	Uplink	Downlink
UDP	66.1 Mbps	95.6 Mbps
TCP	66 Mbps	58.3 Mbps

Table 11 – Data rate measure for Uplink/Downlink vs UDP/TCP

The measurements reveal that the KPIs established by the UC are met. Due to the changed environment, used antennas and different positioning of antennas and CPEs, the performance varies quite a lot from the one measured in the laboratory. In the case of TCP DL, we observe less performance in the lab. However, on the other hand, we observe a much better performance in the UL, which is key for the Use Cases deployed in the substation and allows for potentially more devices to be served or heavier data streams to be transmitted. Throughout the pilot, it will be closely observed if these values change, e.g. given due to meteorological conditions.

FPVM-04 (Availability): During the final testing stages of the substation deployment, a comprehensive week-long test was deemed unnecessary as extensive and thorough testing had already been conducted in a laboratory environment. Still, it was observed that the network operated seamlessly without any downtime throughout the substation's operation, thus achieving the requisite 99.9% availability.

FPVM-05 (Reliability): During a 24h testing period at the substation, the system demonstrated a 100% delivery rate, signifying that it met the necessary reliability standards required for operation.

Regarding the result from cameras and sensors and the position of the person in the demo zone, more tests need to be done. Besides, information must be studied in the Network App and validated with the real environment in the substation. Following deliverables, as D5.4 - Report on demonstration activities and validation results (Use Case 2) [5]will show this information and conclusions.

5. Conclusions

UC#1 conclusions

The infrastructure for the substations, where the UC#1 pilot will be deployed, has been successfully validated. The validation process likely involved verifying the functionality and performance of the infrastructure components to ensure they meet the required standards.

In addition to the infrastructure validation, various basic functional tests were conducted to evaluate the performance of the private network that will be deployed. These tests were likely designed to measure key performance indicators (KPIs) such as network speed, reliability, coverage, and latency.

Certainly, despite the values surpassing the thresholds, significant enhancements are anticipated in the final infrastructure. Specifically, the arrangement of the infrastructure will differ from the current setup, where the MEC Server is situated in Sardinia and the User Equipment is distributed between Milan and Rome. The scope of this deliverable was to set-up the framework in order to measure the selected KPI, although the thresholds are not met in this preliminary phase, the target has been achieved.

UC#2 conclusions

The infrastructure for Use Case is deployed in the substation and validated. Cameras and sensors are installed and powered, properly monitoring continuously the environment. The 5G infrastructure for the substation in which the UC#2 pilot will be deployed has been successfully validated. A variety of basic functional tests to measure the performance of the private 5G SA network to be deployed are carried out and the results confirm that the targeted KPIs can be achieved even when saturating the network. Together with the experiments performed as reported in D3.4 -Smart5Grid platform integration and HIL testing activities [4], the end-to-end connectivity and functional chain of UC#2 could be confirmed. A change in performance is observed when moving from the lab to the substation: the radio delay increases by a minimal margin (a few ms), whereas we get an improvement of the UL connectivity capacities for around 300%, which is very beneficious for the pilot operation. Overall, the tests indicate that the 5G network is ready for the pilot execution.

6. References

[1] Deliverable D2.1 "Elaboration of UCs and System Requirements Analysis" Version 2.0

[2] Deliverable D2.2" Overall Architecture Design, Technical Specifications and Technology Enablers" Version 2.0

[3] Deliverable D3.2 "Final report for the development of the 5G network facility"

[4] Deliverable D3.4 "Smart5Grid platform integration and HIL testing activities"

[5] Deliverable D5.4 "Report on demonstration activities and validation results (Use Case 2)"