H2020 5Growth Project
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D3.6: Execution report of in-house use cases for Pilots

Abstract

The goal of this deliverable is to report the final status of the pilots in November 2021 (M30) during which the pilot's final validation campaigns were carried out.

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Disclaimer

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List of Acronyms

AD – Administrative Domain

AGV – Automated Guided Vehicle

AIC – Automotive Intelligence Center

API – Application Programming Interface

AR – Augmented Reality

CKPI – Core 5G KPI

CMM – Coordinate-Measuring Machine

CP – Control Plane

CPE – Customer Premises Equipment

CS – Communication Service

CSMF – Communication Service Management Function

CU – Central Unit

CUPS – Control and User Plane Separation

DSS – Decision Support System

DU – Distributed Unit

E2E – End-to-End

eMBB – enhanced Mobile Broadband

FR – Functional Requirements

GUI – Graphical User Interface

HW – Hardware

I4.0 – Industry 4.0

IIoT – Industrial Internet of Things

IWL – Interworking Layer

KPI – Key Performance Indicator

LV – Low-Voltage

LX – Level Crossing

MNO - Mobile Network Operator

mMTC – massive Machine Type Communications

MTD – Moving Target Defense

MTTR – Mean Time To Repair

NF – Network Function

NS – Network Service

NSI – Network slice Instantiation

NST - Network Slice Template

RAN – Radio Access Network

RU – Radio Unit

SKPI – Service KPI

SDA – Semantic Data Aggregator

SLA – Service Level Agreement

SO – Service Orchestrator

SST - Slice/Service Type

SW – Software

TMV-WG – Test, Measurement and KPI Validation Working Group

UC – Use Case

UE – User Equipment

UP – User Plane

URLLC – Ultra-Reliable Low Latency Communication

vEPC – virtual Evolved Packet Core

VIM – Virtualized Infrastructure Management

VM – Virtual Machine

VNF – Virtual Network Function

VPN – Virtual Private Network

VS – Vertical Slicer

VSI – Vertical Slice Instantiation

WIM – Wide Area Network Infrastructure Management

ZDM – Zero Defect Manufacturing

Executive Summary

The 5Growth service platform developed in WP2 was integrated and deployed on top of ICT-17 platforms (WP3) and demonstrated through field trials, featuring 9 use cases across the 5Growth 4 pilots. Taking advantage of four real-world pilots focused on three specific industry sectors: Industry 4.0 (COMAU and INNOVALIA), Transport (EFACEC_S) and Energy (EFACEC_E), 5Growth carries out the technological (WP4) and business (WP1) validation of 5G technologies from a vertical point of view.

This deliverable D3.6 reports on the final status of the pilots in November 2021 (M30) and provides a mature definition of the technical solution for each vertical pilot under the scope of 5Growth, as well as the integration options between of the 5Growth platform and the selected ICT-17 platforms (5G-EVE and 5G-VINNI), that support the business validation of the pilots use cases.

Each vertical pilot defines a set of use cases to be demonstrated. This enabled the validation of 5G core technologies and the 5Growth service platform to meet the functional and technical requirements of the selected 5G-enabled vertical applications. An in-depth definition of the technical solution for each vertical pilot is included in this deliverable. This deliverable is divided into four main sections, one for each pilot: Section 2, for the INNOVALIA pilot; Section 3, for the COMAU pilot; Section 4, for the EFACEC_E pilot; and Section 5, for the EFACEC_S pilot. Each section reports, for the respective pilot:

- **5G infrastructure** - Description of key technical features (radio access and core, transport, 5Growth platform), physical location and connectivity, supported by schemes and images.
- **Integration of innovations and role** - Description of the innovations (WP2) that have been integrated into the pilots with details of the integration and identification of the benefits that they bring to the vertical. Validation of the innovations in the context of the use cases and results is reported in D4.4.
- **Vertical Integration capabilities** - Mature definition of the technical solution of each vertical pilot in the context of 5Growth and the integration capabilities of the 5Growth platform and the selected ICT-17 platforms (5G-EVE and 5G-VINNI). The monitoring network, capabilities of each pilot and the integration with the 5Growth Monitoring system are also described.
- **Integration of Use Cases** - A detailed description of the use cases, to enable a full understanding of the technical and operational aspects of each case, is supported by relevant schemes and images.

1. Introduction

The main objective of WP3 is to conduct field trials at vertical sites reusing ICT-17 platform infrastructures (5G EVE and 5G-VINNI) to the greatest extend possible with several activities, namely [1]:

- Gap analysis of 5Growth implementation over ICT-17 platforms.
- Integration of the novel 5Growth components developed in WP2 into the 5G baseline architecture.
- Deployment of the 5Growth system at all trial sites, including software and hardware components for all planned use cases such as 5G service-based core, NR.
- Integration and execution of vertical use cases in ICT-17 platforms.
- Field trial of 5Growth pilots over 5G platform deployed by 5G EVE/5G-VINNI, to demonstrate vertical use cases.

The previous deliverable D3.5 ("Final version of software implementation") documents the final release of the integration of 5Growth with the software components of ICT-17 platforms. The deliverable provides an overview of the software components and a detailed description of the changes made since the first snapshot of the software version described in D3.3. Therefore, D3.5 describes the main features made available to the vertical pilots resulting from the integration of 5Growth with the ICT-17 platforms that were available during the final use cases validation campaign.

In turn, this deliverable D3.6 reports the final status of pilots in November 2021 (M30), which also supports the final validation campaigns of the pilots. D3.6 addresses several subjects and aims to provide a final and integrated overview of the project's use cases and the integration between 5Growth and the ICT-17 platforms. Specifically, the deliverable aims to address the following considerations:

- Recalls and updates the main elements of the infrastructure and systems used in the vertical use cases, for which initial details were provided in D3.4.
- Describes the Innovations (WP2) selected for integration into the use cases, how they were carried out and the benefits they bring to the verticals.
- Describes how the integration of 5Growth with the ICT-17 platforms has been achieved and the features provided to the verticals.
- Presents the monitoring capabilities of the pilots and the technical solutions to integrate this local monitoring with the 5Growth monitoring system.
- Describes the vertical use cases in terms of deployment environment, architecture, technical features of the equipment and other relevant information to enable a full understanding of the technical and end-to-end operational aspects of each use case.

2. INNOVALIA Vertical Pilot

The INNOVALIA vertical pilot has the scope to integrate 5G networks and virtualized network services, exploiting the capabilities of edge and cloud computing for Industry 4.0 use cases, related to the remote and automated execution of quality inspection tests of manufactured pieces in a factory environment. The pilot includes two use cases, the *Connected Worker Remote Operation of Quality Equipment* and the *Connected Worker Augmented Zero Defect Manufacturing Decision Support System*. In the following sections, we detail the final deployment of such use cases on a distributed 5G and computing infrastructure implemented between 5TONIC lab in Madrid (Spain) and the Automotive Intelligence Center (AIC) in Amorebieta (Spain). The latter is the location selected by INNOVALIA as their vertical premises, so it can also be referred to in the text and the figures as INNOVALIA premises/site.

2.1. Infrastructure

2.1.1. 5G Infrastructure

Concerning the implementation of the infrastructure involving the INNOVALIA premises, this section describes the definitive equipment that has been installed. Figure 1 shows how the different components are distributed along INNOVALIA and 5TONIC sites.

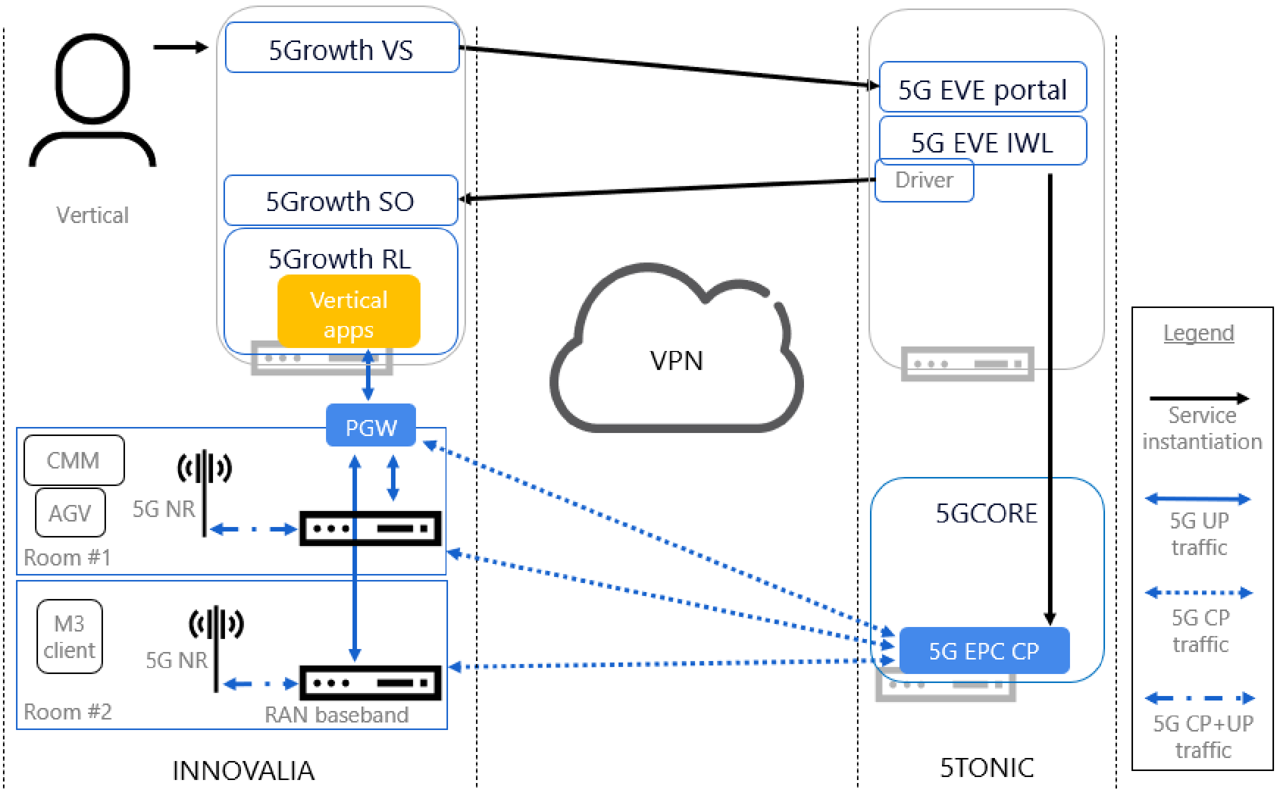

FIGURE 1: INNOVALIA PILOT – INFRASTRUCTURE DISTRIBUTION DIAGRAM

The 5Growth SW stack has been deployed on servers located at INNOVALIA premises. To deploy the services requested by the vertical, the 5Growth SW components intercommunicate with 5G EVE components running at 5TONIC site via VPN, leveraging on orchestration capabilities therein. The procedures used by these components to intercommunicate are further explained in Section 2.1.2.1. As a result of this process, the vertical applications get deployed at INNOVALIA site, and therefore the use cases can be executed.

Regarding the 5G infrastructure, the architecture used is the 5G NSA, because there were no terminals available at the time of this project that could support both the 5G SA option and the millimetre wave (mmW) band. The RAN and the Packet Gateway (PGW) are installed at INNOVALIA premises, while the rest of the 5G NSA Core is installed at 5TONIC. In this way, there is 5G coverage at INNOVALIA premises providing connectivity to the user end devices. The 5G RAN equipment splits the user plane traffic and the control traffic. The use cases' traffic is directed towards the vertical applications, so it remains geographically close to the end user devices, keeping the latency very low. On the contrary, the control and management planes of the 5G equipment can be done from a 5G Core located far away, as it does not require as low latency as the user plane.

Two areas of coverage are provided: one of them covers the Smart Factory, where the end user devices such as the Coordinate-Measuring Machine (CMM) and the Automated Guided Vehicle (AGV) work, and the other one covers the control room, where the M3 client runs.

As seen in Figure 2, there is a panel antenna in the factory working in the 26 GHz frequency band, also known as mmW band. Moreover, there are DOTs (Ericsson's antennas for indoor coverage) operating in the 3.5 GHz frequency band. The clock reference for time and phase synchronization is provided by a GPS antenna installed on the roof of the building. The router redistributes the synchronization signal to all the other equipment in addition to providing regular data routing tasks.

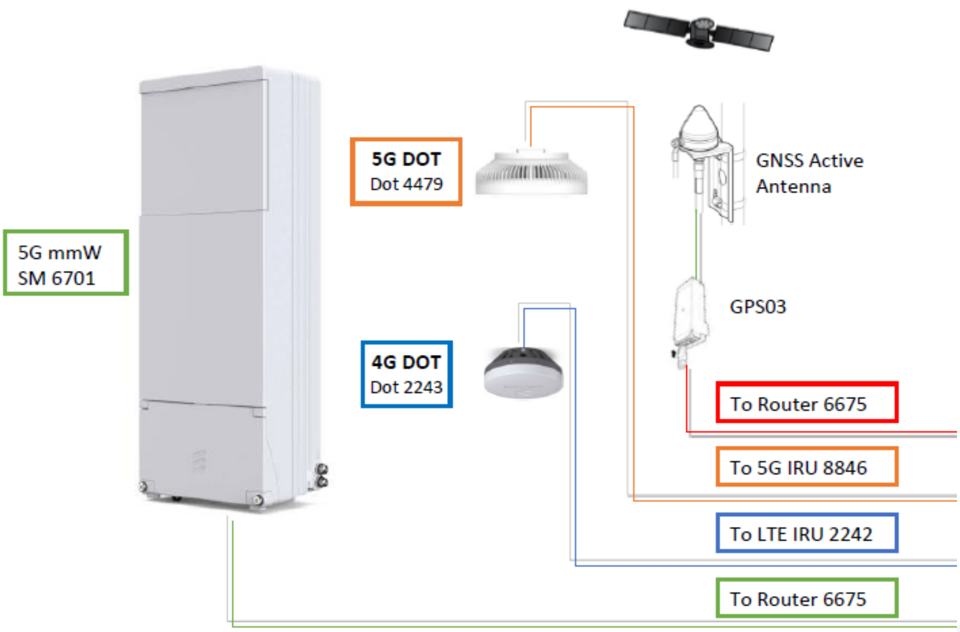

FIGURE 2: INNOVALIA PILOT – 5G RAN AT FACTORY

The equipment introduced above is connected to a flight rack in the same room, which contains the following Ericsson products: a Router 6675, a 5G Baseband 6648, a LTE Baseband 6630, a 5G Indoor Radio Unit (IRU) 8846, a LTE IRU 2242, a Packet Gateway and a Power Source Unit. Figure 3 shows the flight rack at its spot in INNOVALIA premises:

FIGURE 3: INNOVALIA PILOT – FLIGHT RACK AT FACTORY

The antennas are placed on the upper part of the columns of the Smart Factory, as shown in following Figure 4:

FIGURE 4: INNOVALIA PILOT – DOTS AND MMW ANTENNAS AT FACTORY

For the mmW band, the available bandwidth is 100 MHz and the equipment is configured to work with a TDD pattern of 7:3, a modulation of 256 QAM and 4x4 MIMO. For the mid-band, the only difference is that there is an available bandwidth of 50 MHz.

As seen in Figure 5, in the control room the coverage is provided by DOTs working in the mid frequency band. The DOTs are connected to their respective IRUs and Basebands, that are placed in the same room. These Basebands are connected via fiber to the router located at the factory.

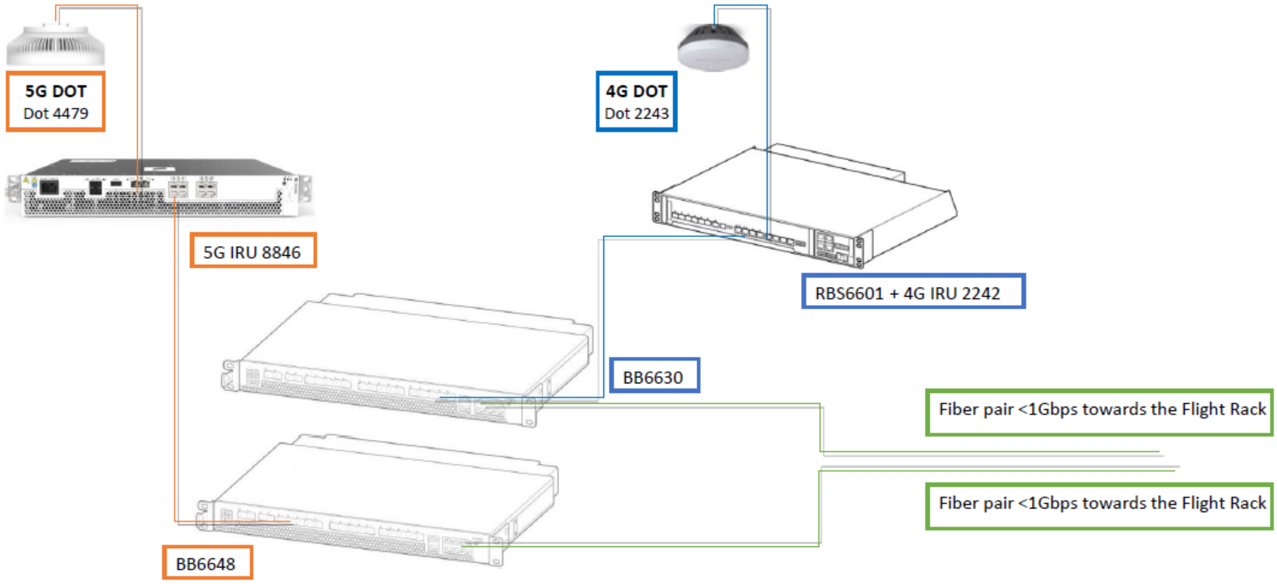

FIGURE 5: INNOVALIA PILOT – 5G RAN AT CONTROL ROOM

Figure 6 below shows the actual installation of this equipment:

FIGURE 6: INNOVALIA PILOT – INSTALLATION AT CONTROL ROOM

The networking configuration used for this implementation is the following, as shown in Figure 7.

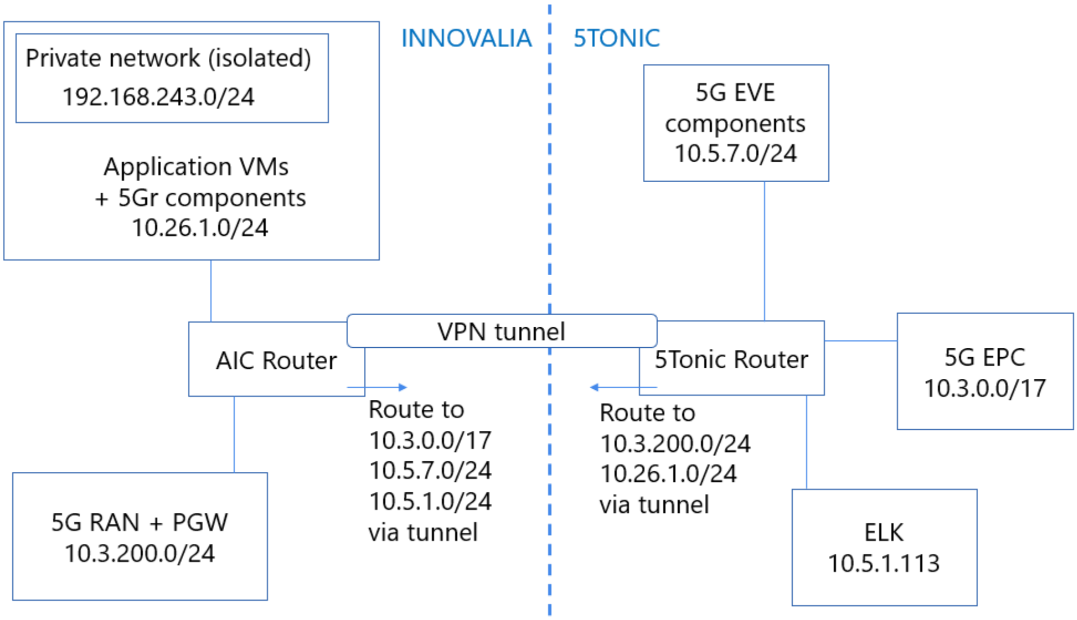

FIGURE 7: INNOVALIA PILOT – NETWORKING CONFIGURATION

The network configuration requires the existence of reserved subnets that are not in use by any other components in either of the sites.

At INNOVALIA side, the 10.26.1.0/24 subnet have been assigned to the application VMs and 5Growth components, and the 10.3.200.0/24 have been reserved for the 5G network equipment. There is also a need for a private network to host Openstack, but this is an isolated network that does not need connectivity to external networks.

At 5TONIC side, the 5G EVE components operate within the 10.5.7.0/24 subnet, the 5G EPC and some other nodes operate within 10.3.0.0/17, and the ELK[1] node that collects logs coming from the vertical VNFs is running on 10.5.1.113.

The routing tables have been configured to provide connectivity among all networks, using a VPN tunnel for communication between sites.

2.1.2. Innovations integration and role

After a suitability analysis, both from a technical and business perspective, two of the innovations proposed and developed in WP2 have been integrated in the pilot. These innovations are: (i) the I6 innovation on End-to-End Orchestration/Federation and Inter-Domain and (ii) the I8 innovation on Performance Isolation as part of the set of developed smart orchestration and resource control algorithms.

[1] Acronym for the popular open source tools Elasticsearch, Logstash and Kibana, used for aggregating logs from different sources, allowing the analysis of those logs, the visualization of data, troubleshooting, and more.

2.1.2.1. Innovation I6 - "End-to-End Orchestration: Federation and Inter-Domain"

The 5Gr-VS and the 5Gr-SO have been enhanced to enable the inter operation with the 5G-EVE platform. The specific details of such integration and its implementation are described in Section 3.3. of D3.2 [9] and Sections 2.1 and 2.2 of D3.3 [10], respectively. The 5Gr-VS sends a request to the 5G EVE portal through its Communication Service Management Function (CSMF) to trigger the instantiation of the vertical service. The multi-domain orchestrator of the 5G-EVE platform requests the provisioning of the different network services to the different test sites, in this case the 5Growth instance in the AIC center, which is then connected to the 5G infrastructure. In this case, the appropriate domain is the 5Growth domain located at the AIC facilities. A driver on the 5G EVE interworking Layer (IWL) commands the network service deployment at the 5Gr-SO. The integrated inter-working between platforms achieves vertical service deployments that meets the slice creation time, user-plane latency and capacity requirements of the various use cases in this pilot. Figure 8 shows the final integrated 5Growth – 5GEVE deployment.

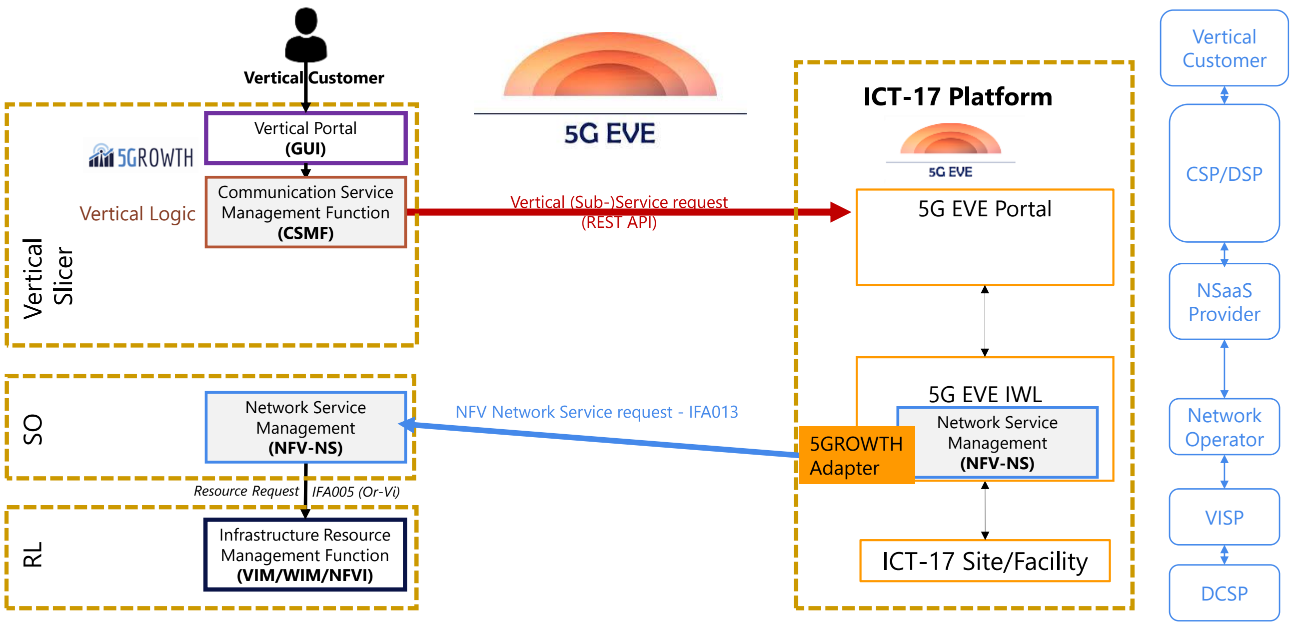

FIGURE 8: INNOVALIA PILOT – 5GROWTH-5GEVE PLATFORM INTEGRATION

2.1.2.2. Innovation I8 - "Performance isolation approach on network slicing to retain bandwidth and delay guarantee"

The innovation I8 Performance isolation presented in Section 3.2.1.2.2 of D2.3 [3] is implemented on the INNOVALIA use case and enables the separate allocation of network resources between slices with the goal of prioritizing a critical slice (i.e., the scanner traffic) over a non-critical slice (i.e., the video camera traffic). In this way, the system can provide acceptable performance and meet the expected QoS even under high network load.

The innovation consists of building an SDN-based network that uses various technologies to implement traffic measurement and traffic prioritization features. The network is composed of programmable network devices that can be orchestrated by resource orchestrator to implement network slices. For the integration of the innovation in the INNOVALIA use case, a P4 programmable switch is introduced in the network setup and an ONOS SDN controller is used to dynamically manage and control the device. The latter provides two applications for configuring the slices in the P4 switch: the Virtual Private LAN Service (VPLS) application and the QoSlicing application. The former is used to isolate connections in multipoint-to-multipoint communications (i.e., network slice creation for connectivity isolation) and is already included in the current ONOS distribution, while the latter adds the capability of performance isolation between the created slices by allocating particular networking resource to each slice. To enable performance isolation, the P4 switch is equipped with a data-plane program that implements the novel concept of virtual queues. Virtual queues is designed to model the latency of the packets as if they were arriving at the real queue which is served by a link with lower capacity than the actual capacity. This sojourn latency is referred to as "virtual delay" to distinguish it from the real delay spent through the P4 pipeline. For more information about the implementation, see D2.3 [3].

To implement the innovation in the INNOVALIA setup at 5TONIC, a legacy network switch was replaced with a MiniPC hosting a software P4 switch, aka Bmv2[2]. The new device was placed between the 5G Customer Premises Equipment (CPE) 2 and the industrial end devices (i.e., scanner and camera), and is responsible for defining two slices: one for the camera's video traffic and the other for the scanner's traffic. A detailed representation of the setup can be found in Figure 9.

[2] https://github.com/p4lang/behavioral-model

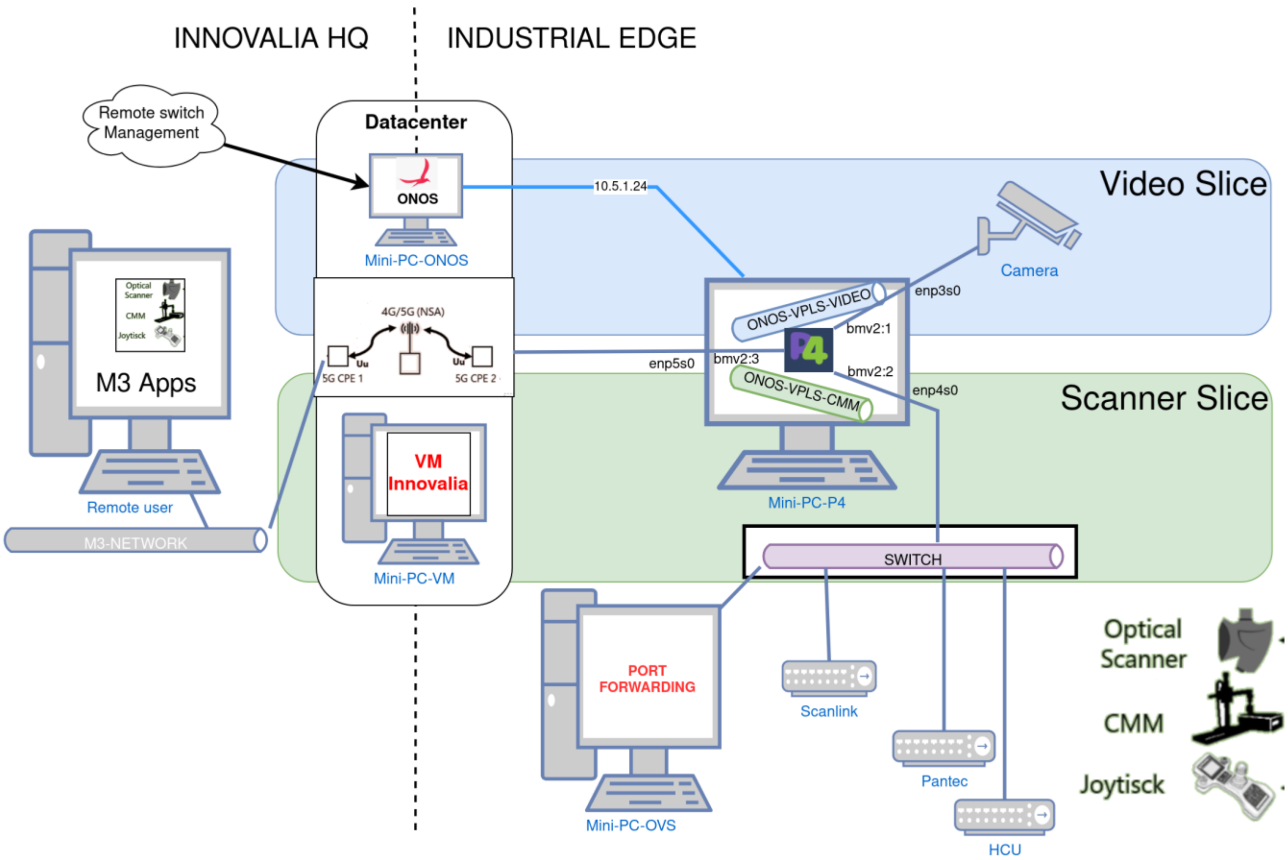

FIGURE 9: INNOVALIA PILOT – APPLYING INNOVATION TO UC1

As shown in the figure, the goal is to create two network slices: one for the Optical Scanner traffic (Scanner slice) and one for the video camera traffic (Video Slice). The ONOS SDN controller creates two VPLSs in the switch and isolates the traffic of the two slices as it passes through the Bmv2 software switch. The QoS parameters can then be setup for both slices to achieve the desired performance. In the INNOVALIA use-case, the goal is to give higher priority to the network traffic of Optical Scanner since this is the device that has the highest requirements for an acceptable user experience. On the other hand, the network traffic of the video slice is throttled but not completely blocked so that the video stream provides a sufficient quality. The innovation take effect after queues are built up. The Bmv2 software switch allows the control of its physical queue, with the ability to adjust packet rate and packet depth constraints. This allows us to create a network "bottleneck" and validate the innovation under critical network conditions.

Before the P4 software switch was installed in the INNOVALIA setup at 5TONIC, a thorough feasibility and performance evaluation campaign was conducted with the MiniPC. The technical specifications of the device are as follows:

- CPU: Intel(R) Core(TM) i7-3610QE CPU @ 2.30GHz
- Memory: 8 GB
- Network interfaces: 6 Gigabit Ethernet ports
- Operating system: Ubuntu Linux 18.04.6 Linux Operating System

The Bmv2 software was installed on the device, with careful selection of compile arguments for performance optimization[3]. To assess whether the available hardware could process and forward network packets at an acceptable throughput, a stress test was performed. The performance of the bmv2 software switch is measured by using the Python traffic control libraries and Mininet network emulation software. As a result of the performance measurement scripts, the median throughput value is 826 Mbps. This is acceptable for the requirements of the pilot application.

Before implementing the performance isolation feature in the actual physical interfaces of the INNOVALIA scenario, a virtual environment was developed in the MiniPC in order to pre-test all parameters and validate the correct operation of the innovation.

For this purpose, the scenario shown in Figure 10 is deployed.

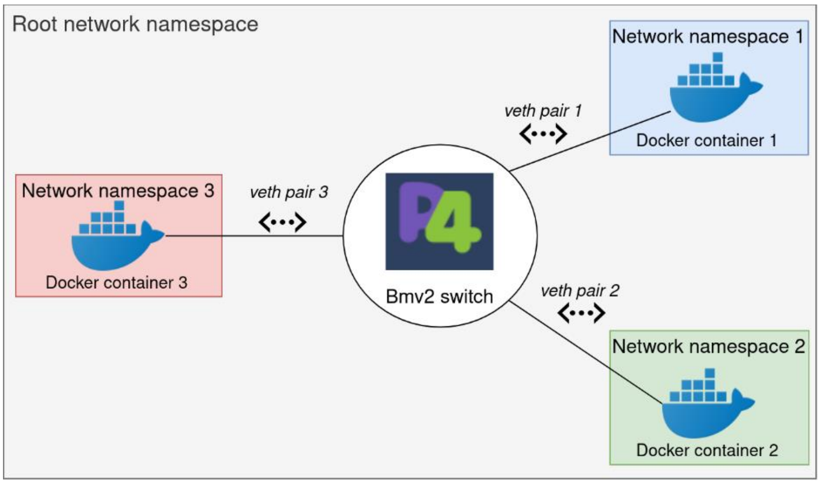

FIGURE 10: INNOVALIA PILOT – VIRTUAL ENVIRONMENT FOR INNOVATION PROOF OF CONCEPT

Each Docker container emulates one of the hosts in the scenario of Figure 10: container 1 emulates the video camera host, container 2 emulates collectively the devices of the scanner slice, and finally container 3 emulates the M3 machine host. To connect the containers to the Bmv2 software switch, Virtual Ethernet pairs are created to link the network namespace of each container to the corresponding interface of the switch.

With this setup, the containers were configured to simulate the traffic of real hosts. The Bmv2 switch was connected to the ONOS SDN controller and equipped with the software required to run the VPLS and QoSlicing applications. Several tests were performed to find the right combination of parameters for the particular traffic characteristics of the INNOVALIA use-case. The first important result obtained with the tests in the virtual scenario is the validation of the correct operation of the innovation on the new hardware. The tests have also shown that the slice priority parameter, a specific feature offered by the QoS application, is the one that affects performance the most. Setting a higher priority for the scanner slice, provides a good user experience for the M3 application. The

[3] https://github.com/p4lang/behavioral-model/blob/main/docs/performance.md

video slice receives less network resources, which degrades the video quality but keeps it at an acceptable level.

To achieve the correct operation of the virtual scenario, several issues were resolved. First, the checksum offloading features of all the network interfaces had to be disabled, as they interfere with the packet processing of the Bmv2 switch. On the other hand, several attempts were made to connect Docker containers to the Bmv2 interfaces using the macvlan[4] network driver. The latter allows connecting containers directly to the physical interfaces of the host, which is closer to the real networking scenario in Figure 9, but despite several attempts, there was no network connectivity between the Docker containers and the Bmv2 switch interfaces. Finally, the use of isolated namespaces was preferred.

The integration of the MiniPC hosting the Bmv2 switch into the INNOVALIA use-case setup at 5TONIC was achieved without any disruptive changes to the existing setup, apart from re-cabling devices from a legacy switch to the Bmv2 switch. The pilot setup consists of a single Layer 2 collision domain with all hosts at the industrial edge side on the same Layer 3 network. In addition, remote connectivity between the end-user and the core network requires the use of port forwarding settings. These design constraints have been carefully taken into consideration and the substation of the legacy network switch with the Bmv2 switch resulted in no impact on the existing pilot scenario's infrastructure.

The Bmv2 software switch has been reconfigured to use the physical Ethernet interfaces of the host. It is important to note that both the results of the stress test and the virtual scenario test results are obtained by measuring virtual host to virtual host traffic, i.e., containers shown in Figure 10, over the Bmv2 switch without any packets actually leaving the host's root network namespace. There are important differences when physical interfaces are involved. We can discuss these differences at several layers. At the lowest level, the Ethernet network interface cards in the host have been set as the ports for the Bmv2 switch. To implement slice performance isolation, the switch must alter the default queuing behavior of the network interfaces. Unlike internal host emulation for traffic metering, end-to-end traffic control must cope with the aforementioned connection of the physical interfaces with software switch ports. This has several implications for offloading on the one hand, and more importantly buffering on the other. Offloading of network card features is a common mechanism often implemented by default, related to TCP windowing and checksum computation. In several end-to-end tests, before actually tuning the QoS profiles to the pilot, an optimal setting was found by disabling the generic reception offload function related to buffering in the physical to logical connection.

Finally, the full functionality of the new setup shown in Figure 9 was validated. The test plan for the traffic profiling, parameter tuning, and the validation of the innovation is presented in Section 3.1.4.2 of D4.4 [8].

[4] https://docs.docker.com/network/macvlan/

2.1.3. Vertical Integration capabilities

2.1.3.1. Log Management Tool integration with the Semantic Data Aggregator

The Log management tool described in Section 2.2.1 of D4.3 [11] has been integrated with the Semantic Data Aggregator (SDA). Figure 11 shows this integration.

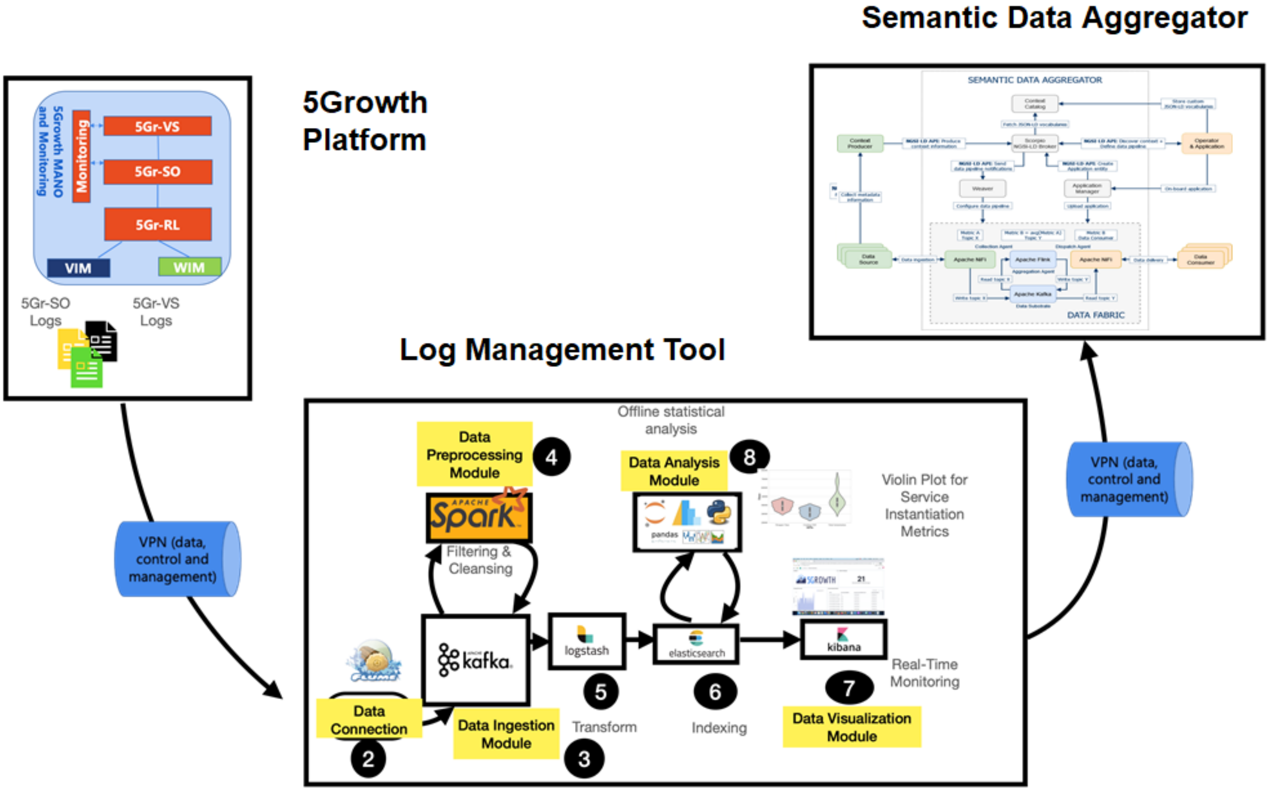

FIGURE 11: INNOVALIA PILOT – LOG MANAGEMENT TOOL INTEGRATION WITH SDA

The architecture of the Log Management Tool provides a data pipeline that can extract time-related metrics in both batch and real-time modes, for various lifecycle management operations taking place on the 5Gr-VS and the 5Gr-SO. More specifically, in the case of the 5Gr-VS, the Log Management tool is able to parse vertical service instantiation and termination operations and in the case of the 5Gr-SO, the Log Management Tool is able to parse instantiation, scaling and termination operations.

For this purpose, the Log Management Tool is fed with the log files created by the operations of the 5Gr-VS and the 5Gr-SO. After processing the corresponding time metrics for the different operations, they are published in an Apache Kafka topic that feeds the SDA, as explained in Section 2.1.1 of D4.3 [11]. Then, the SDA transforms the data models generated by the Log Management tool into the data models expected by the possible connected data consumers and applies visualization tools (e.g., Prometheus Server and Grafana).

2.1.3.2. Monitoring – Integration with 5G EVE monitoring

The measurements in the INNOVALIA pilot are obtained with the 5Probe presented in Section 2.3.5 of D4.2 [12]. Figure 12 shows the infrastructure setup on INNOVALIA premises, highlighting the monitoring components and interactions.

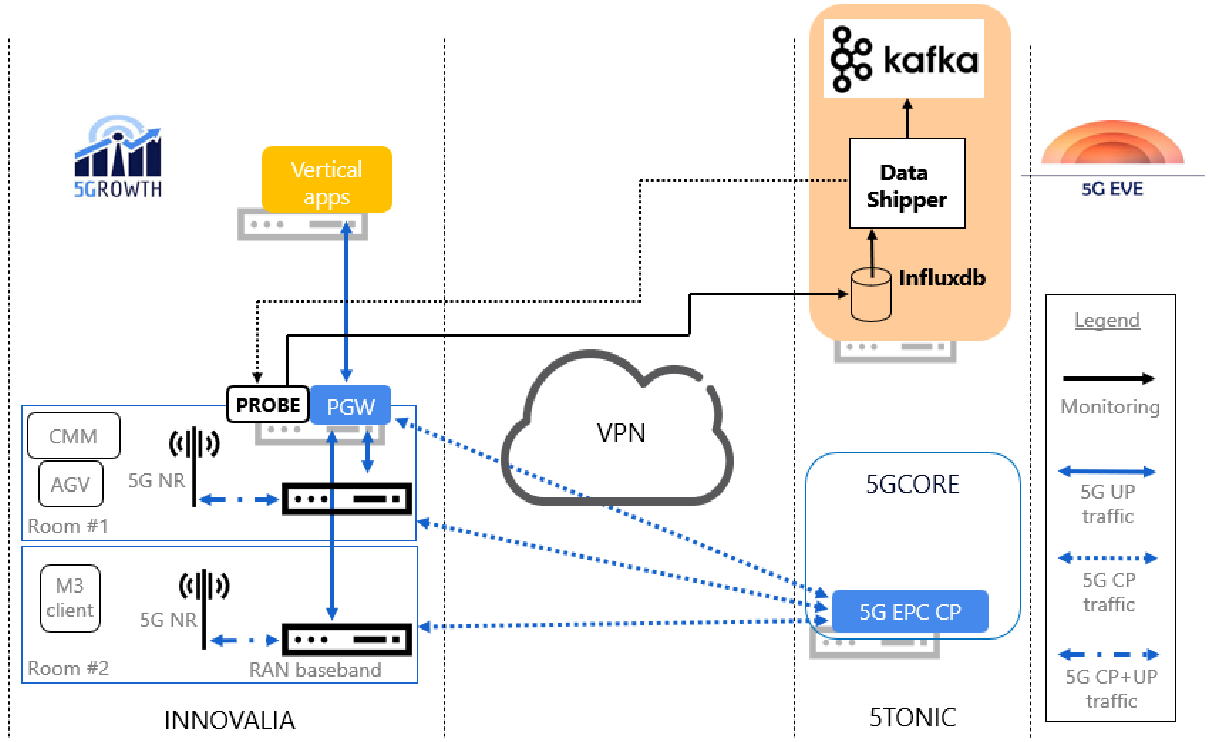

FIGURE 12: INNOVALIA PILOT – INTEGRATION WITH 5G EVE MONITORING PLATFORM

On the 5TONIC premises the 5G EVE monitoring components are deployed. A Kafka broker is in charge of collecting and persisting monitoring data. The 5Probe is registered in the 5G EVE platform as a Data Shipper, capable of providing infrastructure monitoring data. More specifically, the 5Probe can provide network measurements for user-plane data rate (both downlink and uplink) and average round-trip time latency. The actual probe is deployed on INNOVALIA premises, in the PGW gateway, in order to capture and inspect all the user-plane traffic between the VNFs and the vertical applications.

The dashed arrow going from the Data Shipper to the probe indicates that the probe can be managed from the 5G EVE monitoring platform. Indeed, the probe can be dynamically activated and deactivated remotely. The solid arrow going from the probe to the InfluxDB component shows the monitoring data produced by the probe and sent to the monitoring system. The Data Shipper takes care of retrieving the data, converting it to the proper 5G EVE format, and finally push it to the Kafka broker for centralized collection.

The integration of the 5G EVE monitoring platform in the new pilot setup required minimal intervention. In fact, the registration of a new Data Shipper, with updated information about the new placement of the probe, was enough in order for the 5G EVE monitoring platform to provide correct management and data collection.

2.2. Use Case 1 integration: Connected Worker Remote Operation of Quality Equipment Infrastructure

This section describes how Use Case 1 is implemented.

The M3 client is on one end of the setup. The INNOVALIA application is running as a VM on the servers of the datacenter placed at INNOVALIA site. The components that are contained in the application are: (i) the Robot Link (RL), which controls the moves of the CMM, and (ii) the Data Assembler (DA), which gathers the information of the 3D position of the scanner arm. On the other end of the setup, there is the CMM. Additionally, an Open vSwitch (OVS) solution was implemented, as the CMM controllers were fixed to work within a private local network. Thus, the OVS transforms the incoming IP packets, so the CMM controller can respond to that traffic. The OVS transforms the outgoing traffic as well, to send the traffic towards the other end of the setup. The M3 commands traffic flow goes from the M3 client to the application VM, then to the OVS and finally reaches the CMM. The CMM positions and scan results are sent from the CMM, they travel through the OVS, they go to the VM and finally they get to the M3 client. The video streaming flow is simpler. It flows between the camera placed on one side and the display used on the other side.

This is all illustrated in following Figure 13:

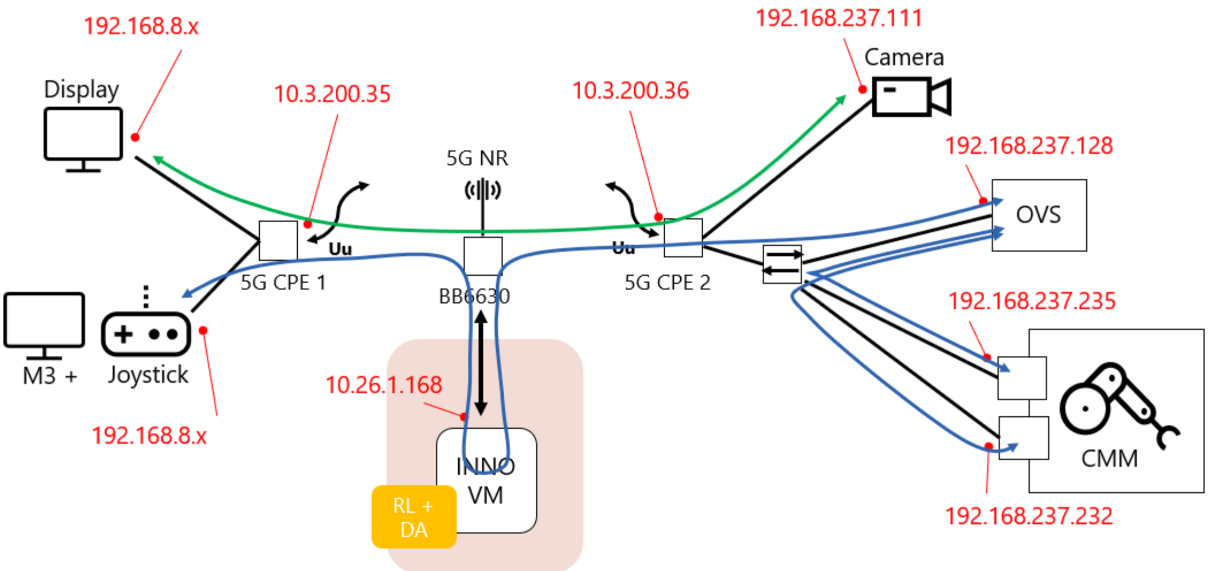

FIGURE 13: INNOVALIA PILOT – UC1 SETUP

The IPs are NATed in the CPEs to allow the traffic from the user end devices to go outside the local network. The public network for the CPEs is the 10.3.200.0/24. The datacenter domain uses the subnet 10.26.1.0/24.

2.3. Use Case 2 integration: Connected Worker - Augmented ZDM Decision Support System (DSS)

This section describes how the Use Case 2 is implemented.

This use case adds to the previous use case an Automated Guided Vehicle (AGV) device that moves in the area close to the CMM. The AGV has its own CPE, allowing full mobility of the device. The AGV controller (AGVc) application is running on the servers of the datacenter. The AGV sends information to the AGVc VM and the application controls the movement of the AGV.

Furthermore, there is communication between the AGVc and the RL. When the AGV takes the part to the desired position for scanning, the AGVc sends a command to report that fact to the INNOVALIA application. Then, the RL commands the CMM to start the scanning procedure. When the scanning procedure is completed, the RL communicates this to the AGVc, which orders the AGV to move again and take the part somewhere else.

Figure 14 illustrates the traffic flows of this use case:

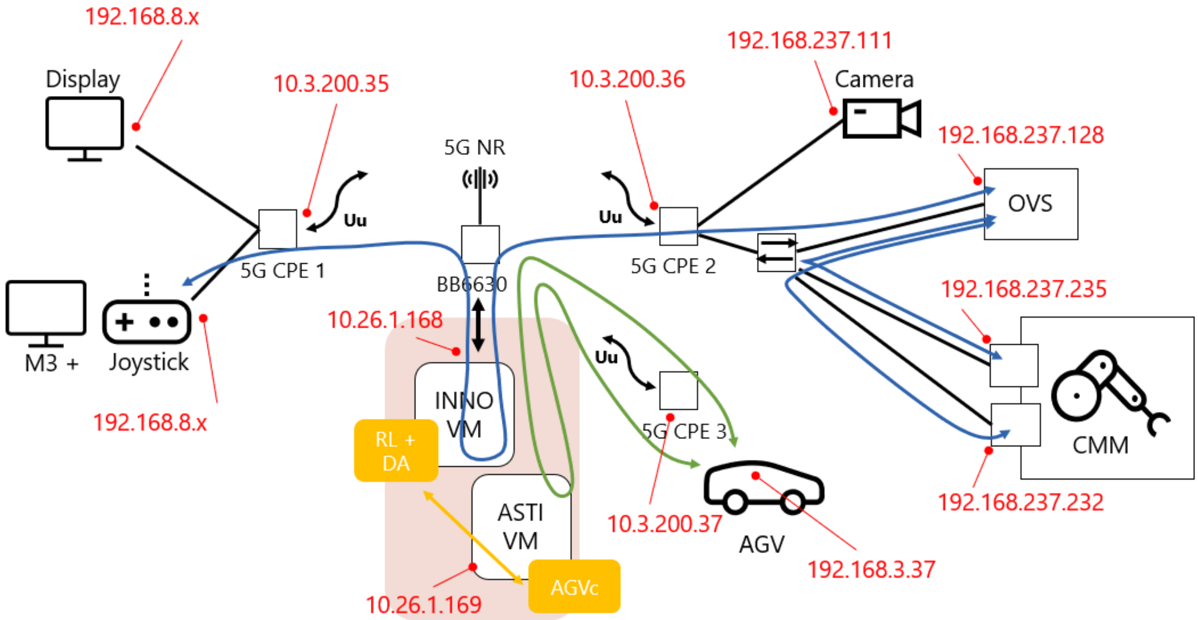

FIGURE 14: INNOVALIA PILOT – UC2 SETUP

3. COMAU Vertical Pilot

COMAU's vertical pilot is designed to demonstrate full support of a 5G network, combined with transport infrastructure and a cloud platform, for different use cases requiring different radio performance (i.e. 5G slicing technique). The COMAU site in Turin, Italy, hosts the vertical premises where the pilot has been primarily executed. Figure 15 shows a picture of the experimental site. The labels on the picture indicate the main components of the pilot on the shop floor. Figure 20 in Section 3.1.1 illustrates, in detail, the system components that make up the radio, transport, and application rack which can be seen on the right side of Figure 15. The sites of other partners (TIM, Ericsson, POLITO) also host essential components of the overall pilot architecture, as explained in the following sections.

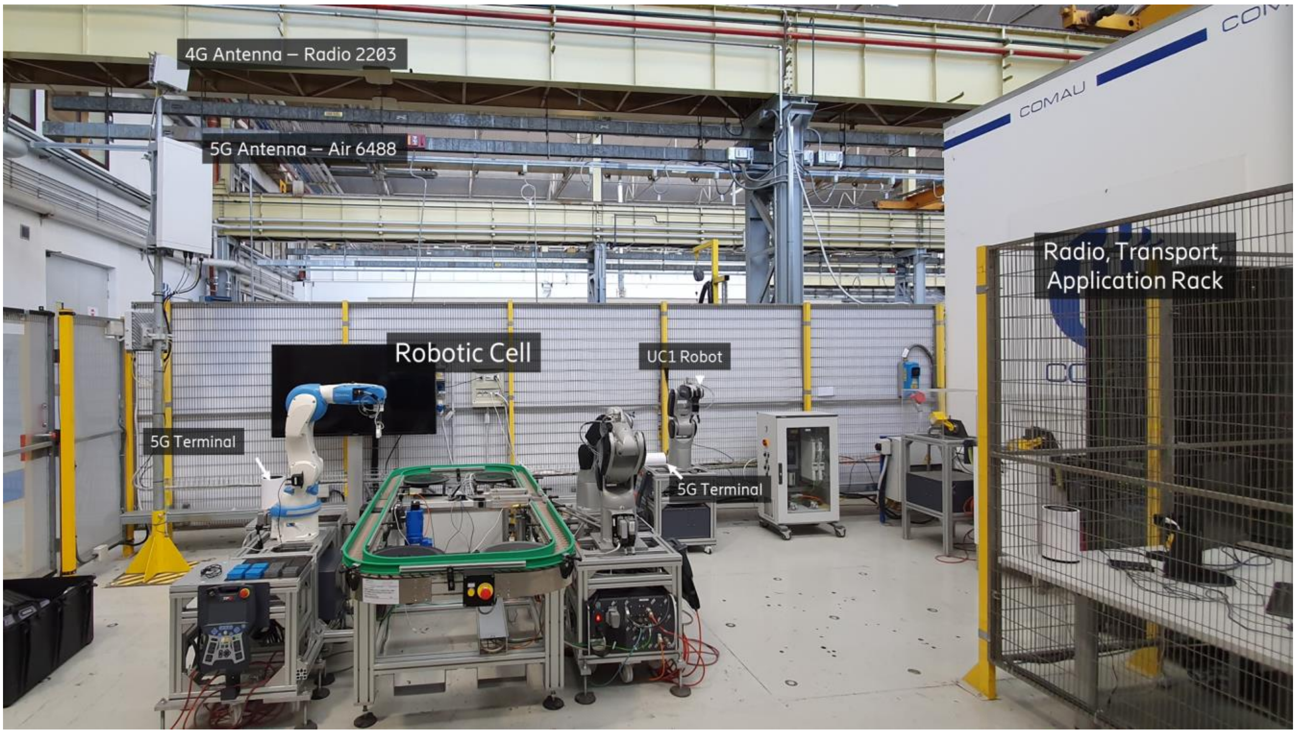

FIGURE 15: COMAU PILOT – PICTURE OF THE EXPERIMENTAL AREA HOSTED IN THE COMAU SITE

3.1.1. Infrastructure

Figure 16 illustrates the complete architecture of the COMAU pilot which spans several sites owned by COMAU, TIM, Ericsson (TEI), and POLITO.

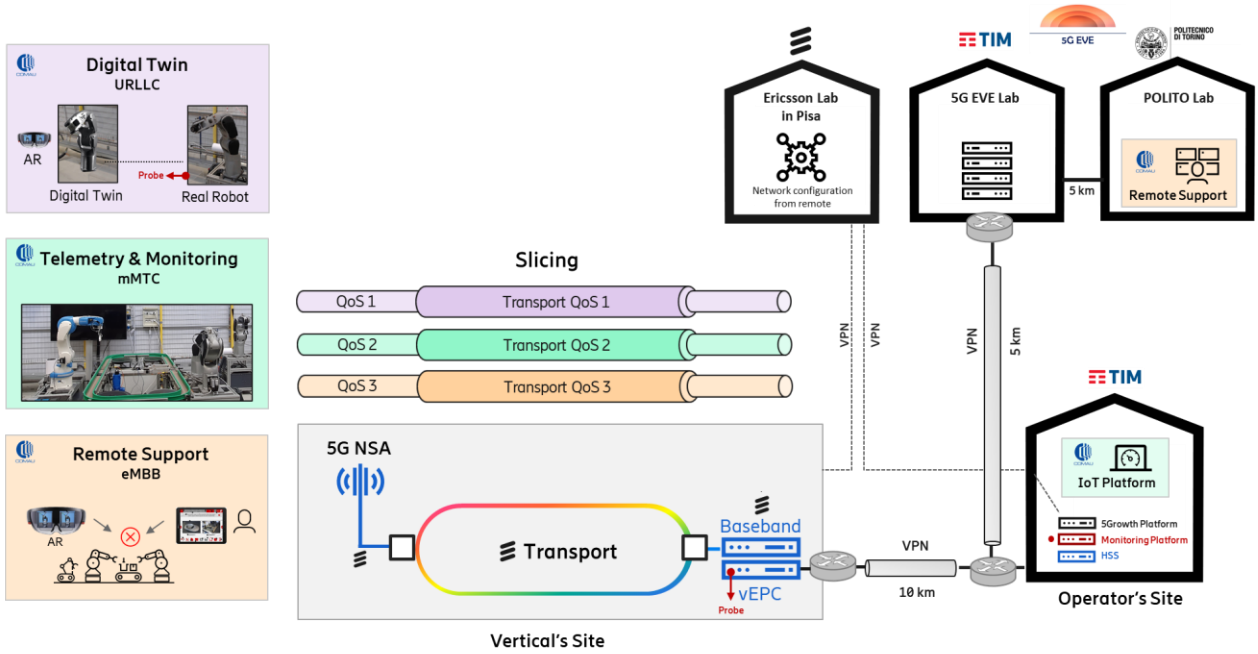

FIGURE 16: COMAU PILOT – HIGH-LEVEL ARCHITECTURE

The pilot consists of three use cases, each with specific requirements for the radio network and, indirectly, for the transport and cloud infrastructures. The complete description of the use cases can be found in D3.4, and an update on the execution is reported in Sections 3.2, 3.3, and 3.4.

Regarding the infrastructure, both the radio network (antenna, baseband, vEPC core system) and the transport infrastructure (optical nodes, fiber ring) are located on COMAU premises. The COMAU site is connected via a VPN to a first TIM site located in Via Reiss Romoli in Turin. This first TIM site also hosts the 5Growth platform, including the 5Gr-SO, the HSS, and the COMAU IIoT application *inGrid* that is used for the deployment of the second use case as reported in Section 3.3.

The third use case reported in Section 3.4, is based on the interworking of the 5G EVE platform with the COMAU pilot according to the schematic shown in Figure 16. More specifically, the first TIM site hosting the 5Growth platform is connected to a second TIM site, located in Via Borgaro in Turin 5 kms away from the first site. The second TIM site hosts the 5G EVE lab which is connected to the Politecnico di Torino (POLITO) site through the 5G EVE infrastructure. A server installed in POLITO hosts the COMAU application used to operate the "remote support" functionality in the third use case. With this setup it is possible to connect the experimental area in COMAU with the application running in POLITO, thanks to the interworking between 5G EVE and 5Growth.

Finally, the Ericsson (TEI) laboratory in Pisa is connected to COMAU and TIM sites via dedicated VPNs to allow remote configuration, tuning, and troubleshooting of all radio and transport infrastructure components. This remote connectivity was set up to minimize the number of on-site visits during the deployment of the pilot.

The pilot is complemented by a user-friendly Graphical User Interface (GUI) that allows users to activate and monitor the slices while gaining detailed insight into the various components of the 5Growth platform. The GUI can be considered as "front page" of the overall infrastructure.

The login page of the GUI grants access with two different authentication modes:

- The first mode is the **user mode**, which is dedicated to the vertical actor who can create an instance of the most appropriate slice for the specific use case, as shown in Figure 17. The user mode allows catalogue viewing, service selection, and instantiation.

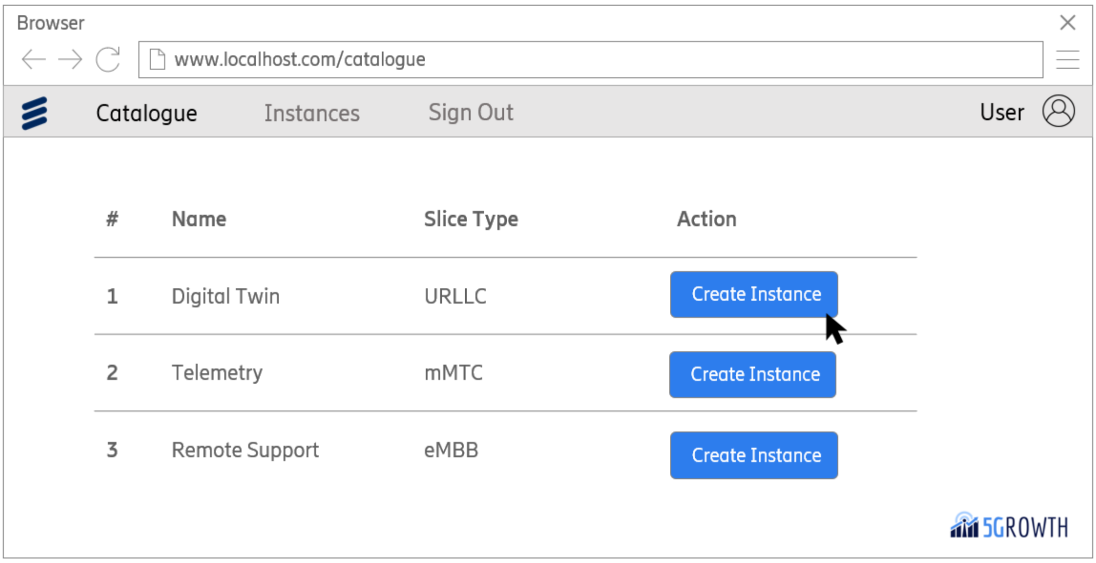

FIGURE 17: COMAU PILOT – GUI IN USER MODE

- The second mode is the **admin mode,** which is dedicated to the Mobile Network Operator (MNO) and has access to the detailed configuration and monitoring tools. Figure 18 illustrates an example of the on-boarding procedure screen in the GUI. The admin mode allows service onboarding, catalogue creation, and abstract view creation.

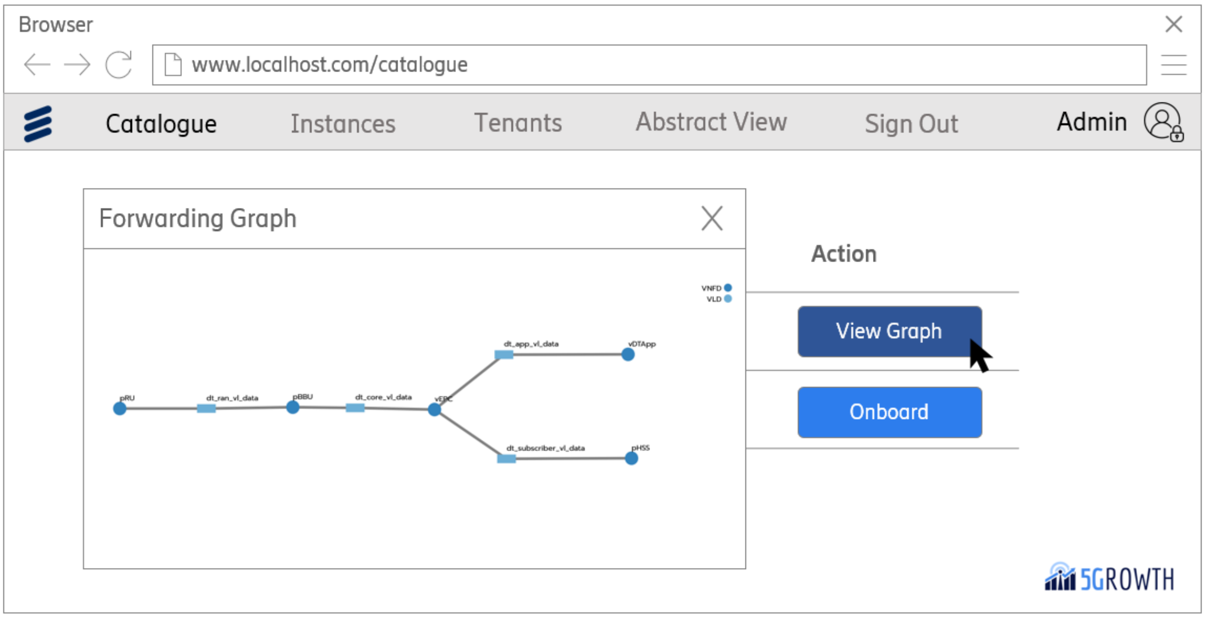

FIGURE 18: COMAU PILOT – GUI IN ADMIN MODE

3.1.2. 5G Infrastructure

The 5G network installed and operated on the vertical is deployed according the "Non-Stand Alone" (NSA) architecture. Here, the 5G Radio Access Network (RAN) and its New Radio (NR) interface are used in conjunction with a 4G (LTE) network and associated EPC. In the initial commercial deployment of 5G radio for verticals, the 5G NSA option makes the most sense for operators as it allows them to leverage their existing network investments in transport and mobile core rather than deploying an entirely new end-to-end 5G network.

Figure 19 provides more details on the 5G NSA (Non-Standalone) radio infrastructure based on Ericsson radio nodes and antennas. Dedicated 5G terminals and 5G pocket routers are used to connect the various components of the pilot (robots, controllers, AR glasses, sensors, etc) to the cellular network.

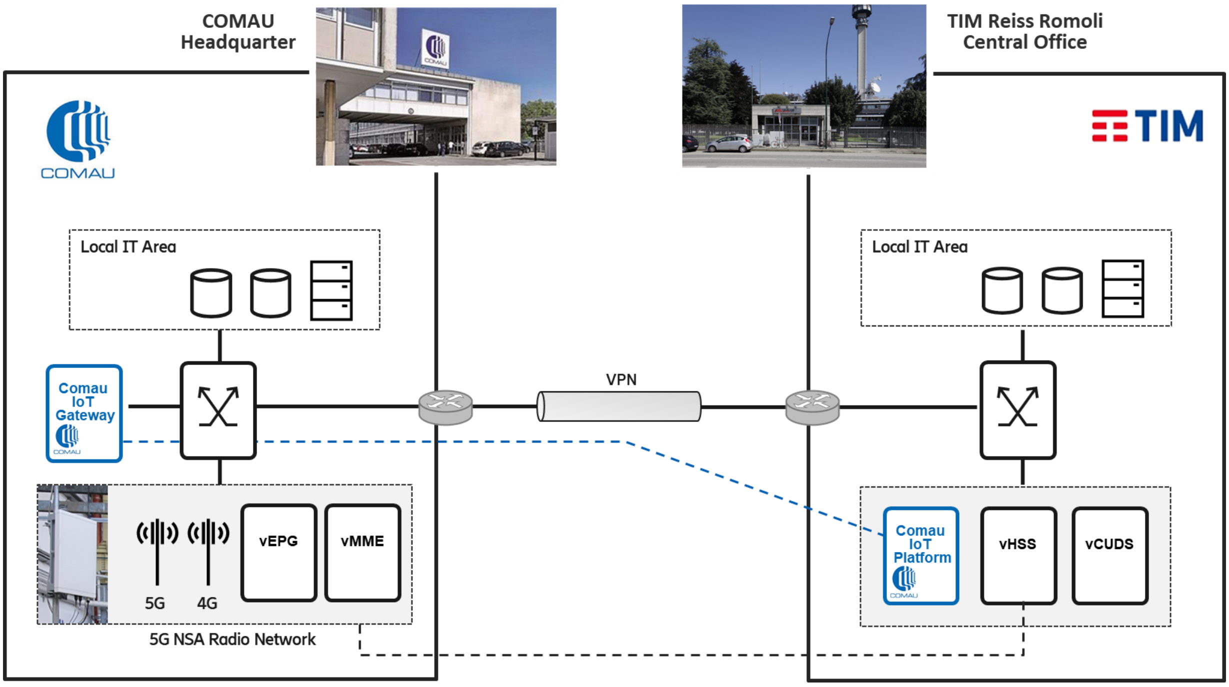

FIGURE 19: COMAU PILOT – HIGH-LEVEL ARCHITECTURE

Figure 20 shows a picture, enriched with labels, illustrating the rack located in the experimental area, which can also be seen on the right side of Figure 15.

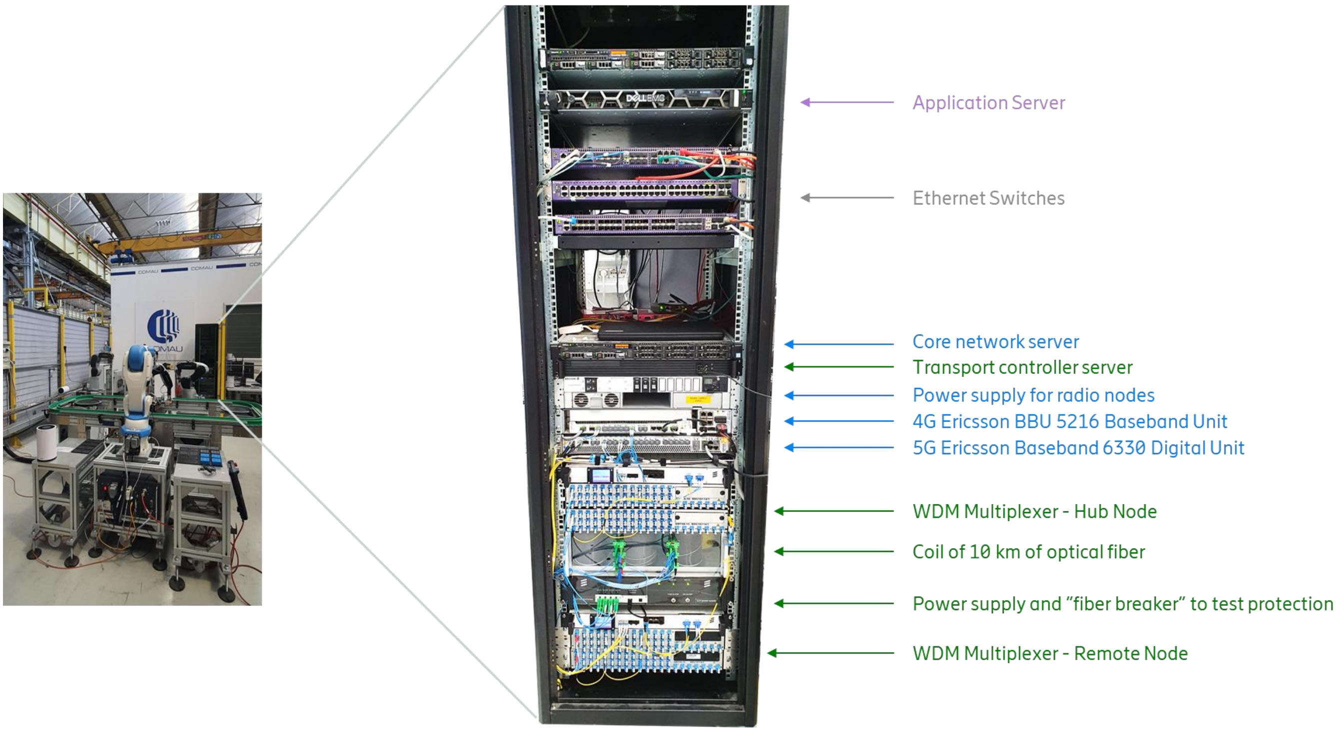

FIGURE 20: COMAU PILOT - DETAILS OF THE RACK

From top to the bottom, the rack includes:

- The application server on which the COMAU IoT gateway is installed
- The Ethernet switches connected to the VPN towards the TIM site

- The network server that hosts the vEPC radio core
- The transport infrastructure controller
- The power supply unit for the radio nodes
- The Ericsson's 4G baseband unit BBU 5216
- The Ericsson's 5G digital unit Baseband 6330
- The WDM multiplexer located on the "right side" of the ring in Figure 16 (i.e. on the hub side)
- The coil of 10 km optical fiber used as the optical fiber ring
- The power supply unit for the optical systems including the "fiber breaker" device to emulate a link failure in the optical ring
- The WDM multiplexer on the "left side" of the ring in Figure 16 (i.e. on the antenna side)

Blue labels are used for the radio systems, green for the transport systems, and purple for the application server.

3.1.3. Innovations integration and role

Among the innovations used in WP2, the following are relevant to the COMAU pilot:

- **Innovation 1 (I1):** "Support of Verticals. RAN segments in network slices". This innovation is used in all three use cases of the COMAU pilot to create the radio slice according to the ETSI and 3GPP specifications. Specifically, the radio slice parameters (like Slice/Service Type (SST), delay, jitter, bandwidth in uplink and downlink) are defined in a Network Slice Template (NST) according to GSMA NG.116 specifications [2] which is loaded in 5Gr-VS. This information is passed to the 5Gr-SO and 5Gr-RL during service instantiation and is used to allocate the necessary radio resources to meet the service requirements. In the COMAU pilot, a proprietary 5Gr-RL plugin was developed to interact with the commercial Ericsson radio systems. This plugin translates the IFA005 commands into radio commands which are compliant with the commercial Ericsson Management System and trigger the creation of the required slice in the infrastructure according to the 3GPP specification.
- **Innovation 2 (I2):** "Support of Verticals. Vertical Service Monitoring". This innovation is used in the first use case (UC1) to create and instantiate probes at the endpoint of the use case: one probe behind the CPE and the other in the Application server used for the use case. These probes collect measurements (jitter, delay, packet loss) that are then forwarded to the monitoring platform.
- **Innovation 3 (I3):** "Monitoring Orchestration". This innovation is used in the first use case (UC1). The monitoring platform is triggered by the 5Gr-SO, when a UC1 instance is created, to collect measurements from the probes (as specified above) and evaluate the QoS KPI. Innovation I3 will be used as released by WP2 and no customizations are done for the specific use in the COMAU pilot.
- **Innovation 6 (I6):** "End-to-End Orchestration. Federation and Inter-Domain". This innovation is used in UC3 as it enables integration with 5G-EVE. More specifically, the enabling features

are the split of a vertical service in vertical (sub)services and the enhanced vertical service lifecycle management with support for multi-domain communication service level scenarios.

3.1.4. Vertical Integration capabilities

As explained in D3.2, Section 3.3, integration between 5Growth and 5G-EVE platform is established at two different levels: (i) at the communication services level with the 5Gr-VS; (ii) at the network services level with the 5Gr-SO. In this sense, the 5Gr-VS uses the 5G-EVE platform to provision vertical (sub)services of the end-to-end service. The 5G-EVE platform processes the request and uses the 5Gr-SO for the provisioning and orchestrating of the network service to be deployed in the COMAU premises. For this purpose, the 5Growth COMAU site is registered as 5G-EVE site.

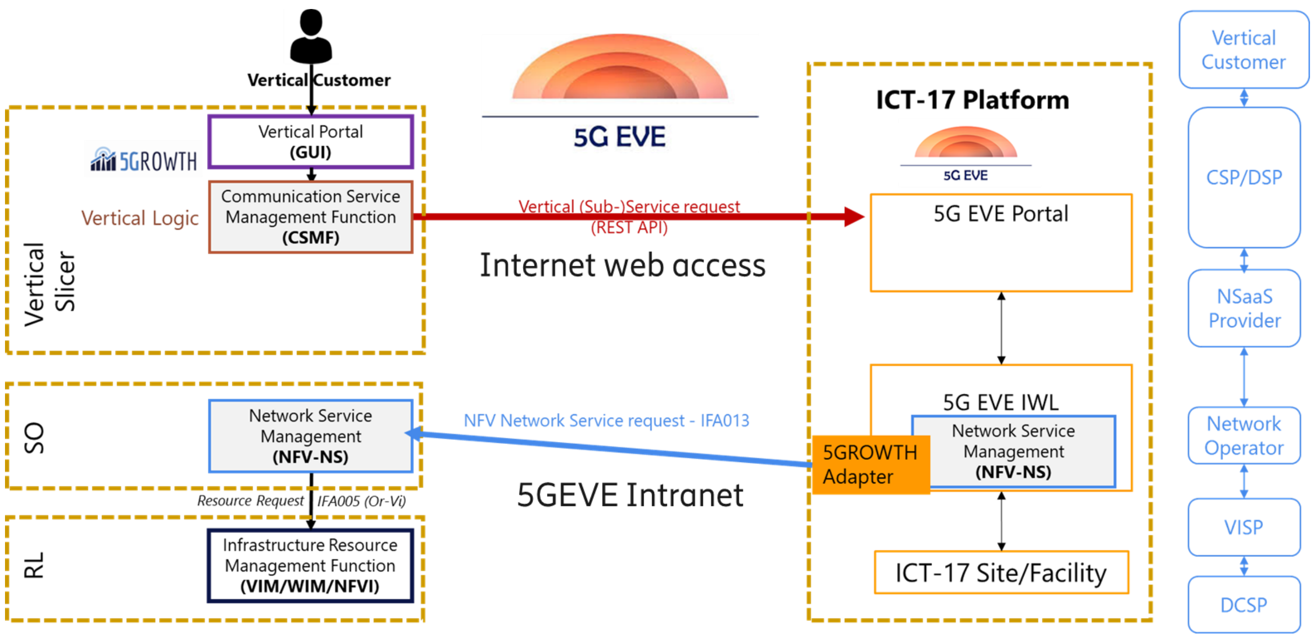

FIGURE 21: COMAU PILOT – 5GROWTH-5G EVE INTEGRATION

The service also leverages the infrastructure and orchestration capabilities provided by the 5G-EVE Italian test site.

3.2. Use Case 1 integration: Digital Twin Apps

Figure 22 illustrates the first use case (UC1), named “Digital Twin Apps”. It is entirely deployed in the COMAU premises. The robot in this use case is a 6-axes industrial robot, the COMAU Racer3, whose data is transmitted via a TCP/IP socket to the controller, which in turn sends it to the augmented reality (AR) HoloLens glasses. An additional high-performance TCP/IP socket was established from the computer (laptop icon in figure), responsible for remote control of the robot positions, and the robot controller.

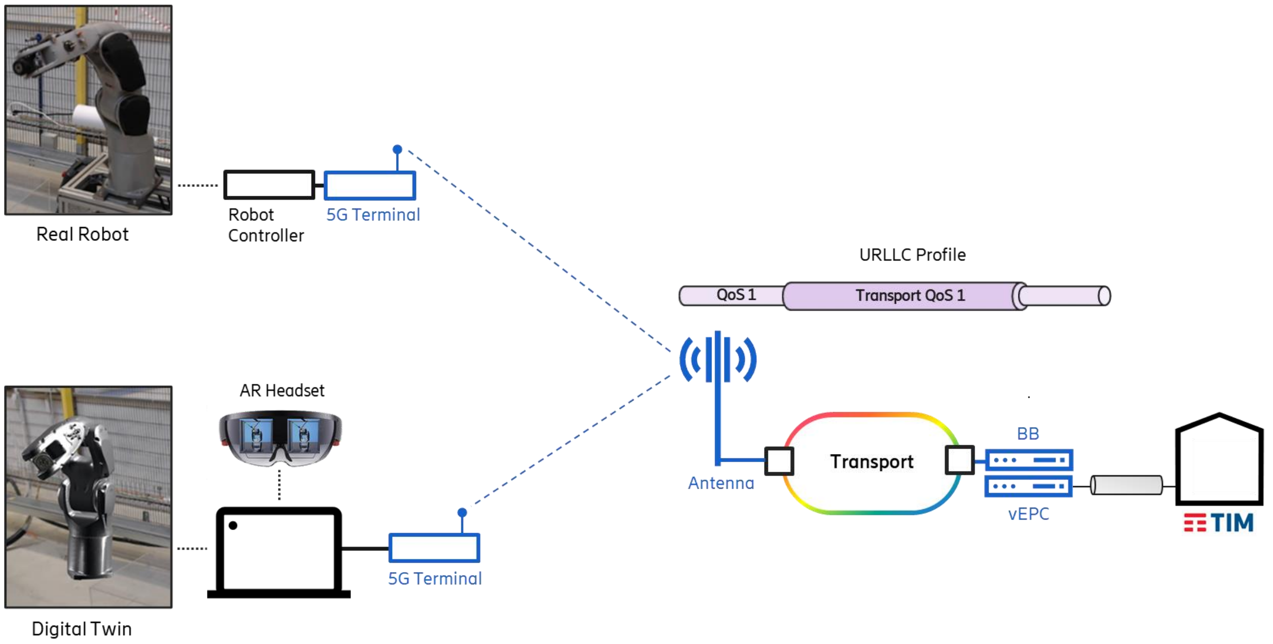

FIGURE 22: COMAU PILOT – UC1 DIGITAL TWIN APPS

The use case leverages the availability of a slice that provides a URLLC traffic profile. The latency values obtained after the infrastructure is fully integrated (see D4.4) allow the digital twin to operate according to the expected behaviour described in D3.4.

In terms of orchestration, the service supporting this use case is fully orchestrated by the 5Growth platform (i.e., 5Gr-VS, 5Gr-SO and 5Gr-RL, etc) deployed in the TIM premises (as shown in Figure 16).

As shown in Figure 16 and described in Section 3.1.3, UC1 uses innovations I2 and I3 to access certain monitored parameters with probes at the endpoints and for their collection by the monitoring platform.

3.3. Use Case 2 integration: Telemetry/Monitoring Apps

Figure 23 illustrates the second use case (UC2), named "Telemetry/Monitoring Apps". In this use case, the robotic systems are located on COMAU premises and an instance of the IoT platform *COMAU inGrid* is installed on a server in TIM's laboratory (Via Reiss Romoli, Turin). Thanks to the 5G-connected sensors, performance data are acquired from the machineries and sent to the InGrid platform where it is processed, analysed, and displayed through an interactive interface.

The robot cell is equipped with two COMAU Racer3 robots (grey/black in the picture) and with a COMAU Racer5 COBOT (grey/blue). The COBOT is a collaborative robot that can automatically switch from industrial robot speed to collaborative robot speed when a human operator enters its workspace. The three robots are complemented by a circular conveyor (green) to reproduce on a smaller scale, a realistic replica of a production line which typically works no-stop (24/7).

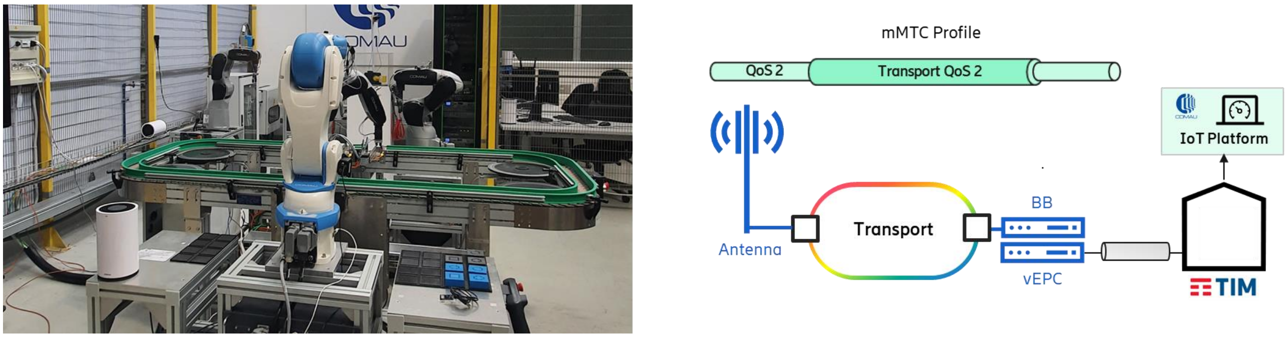

FIGURE 23: COMAU PILOT – UC2 TELEMETRY/MONITORING APPS

The 5G network provides a mMTC traffic profile that would allow the data collection from an extremely dense population of sensors in a real factory.

As in the previous use case, UC2 relies on the 5Growth platform at TIM for the full lifecycle management and orchestration of the service.

3.4. Use Case 3 integration: Digital Tutorial and Remote Support

Figure 24 illustrates the third use case (UC3), named "Digital Tutorial and Remote Support". In this use case, machines that represent the system in the factory on a smaller scale are installed at the COMAU site. Here, a technician on-site uses a tablet or AR devices (connected to a computer) to stream a real time video of the machineries, affected by a fault, to a remote expert located in the POLITO lab. This expert can use on a remote maintenance application to have the "full picture" of the fault and to assist the on-site technician in investigating and troubleshooting the problem. The use case also includes the ability to present a step-by-step digital tutorial to the technician to facilitate the problem-solving procedure.

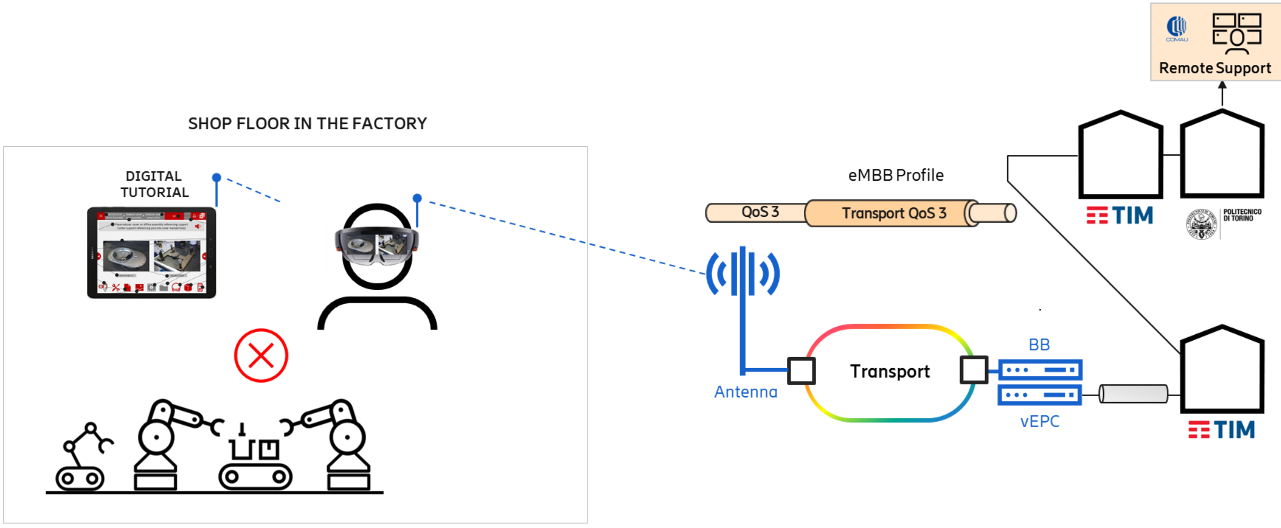

FIGURE 24: COMAU PILOT – UC3 TELEMETRY/MONITORING APPS

This use case exploits the 5Growth integration with the 5G-EVE experimentation platform, as explained in Section 3.1.4. The connectivity between the COMAU site and the POLITO lab is ensured, with the required eMBB profile according to the scheme shown in Figure 16 through dedicated VPNs connecting both TIM sites.

As in the previous use cases, UC3 relies on the 5Growth platform at TIM for full lifecycle management and orchestration of the service.

4. EFACEC_E Vertical Pilot

This pilot addresses the advanced monitoring and maintenance support of Low Voltage (LV) smart grid infrastructure, especially in the secondary substations, including monitoring HD video streaming from local cameras and augmented reality assistance for maintenance teams' mobile devices.

The main purpose is to validate advanced smart grid management solutions through use cases that promote the concurrent use of network resources that need to be shared by multiple applications with different service requirements within an LV-Smart Grid area, embedded in a wider smart city/campus.

4.1. Infrastructure

Figure 25 shows use case 1: "Advanced monitoring and maintenance support for secondary MV/LV distribution substation" and use case 2: "Advanced critical signal and data exchange across wide smart metering and measurement infrastructures", located at Aveiro University secondary substation and IT building 2 respectively. Details about the 5G infrastructure are provided in Section 4.1.1. Details about the use cases can be found in Sections 4.2 and 4.3.

FIGURE 25: EFACEC_E PILOT – UC1 AND UC2

The EFACEC_E use cases leverage the innovations designed and developed by 5Growth that are integrated into this pilot, to enhance the security and reliability of the provided services, as described in Section 4.1.2 Also the slicing integration of 5Growth with 5G-VINNI, described in Section 4.1.3.1 and the monitoring integration of 5Growth with 5G-VINNI, described in Section 4.1.3.2, bring enhanced network monitoring, QoS control, and flexibility to the network management as integrated components of the vertical pilot.

4.1.1. 5G Infrastructure

Figure 26 shows the infrastructure providing 5G services to the EFACEC_E vertical according to the use cases requirements. The same infrastructure, except for the RUs (Radio Unit), is shared with the EFACEC_S vertical, replicating the usage model of a public 5G network. For the final EFACEC_E validation campaign, a fully operational 5G Stand Alone network is available. It includes an Open 5G Core and 5G SA RAN ASOCs (CU, Central Unit + DU, Distributed Unit) deployed at IT Data Center, IT building 1. The 2 RUs are deployed in the substation of the Aveiro University (use case 1) and IT building 2 (use case 2) respectively.

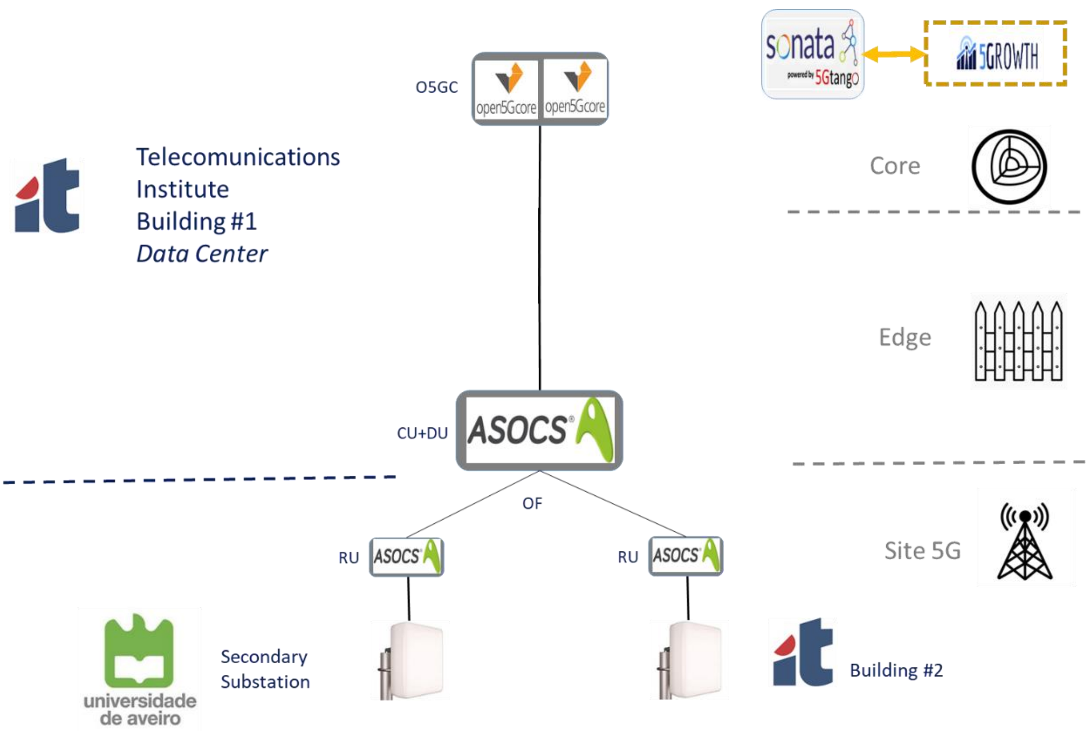

FIGURE 26: EFACEC_E PILOT – 5G INFRASCTRUTURE

The connection CU+DU, RU (secondary substation, use case 1), uses the private optical fibre infrastructure of the University of Aveiro. The connection CU+DU, RU (use case 2) uses the IT internal communications infrastructure.

The Radio Access Network component of the Aveiro 5G site is based on ASOCS CYRUS 2.0. ASOCS provides an open and fully virtualized software solution that delivers 5G to both LAN and WAN cellular network solutions and can run on a standard server or universal CPE. The RAN functionality is based on Open RAN architecture and it divided into several components, following the 3GPP 5G RAN architecture, namely CU, DU and RU, which can be deployed in various combinations. The O-RAN - FH 7.2 interface is used to connect to the radio. Table 1 shows the ASOCS RAN main radio technical specifications.

TABLE 1: EFACEC_E PILOT – ASOCS TECHNICAL SPECIFICATIONS

Maximum bandwidth	100 MHz
Frequency band	3700-3800 MHz
Output power per port	24 dBm
Demultiplexing	TDD
DL Modulation	QPSK, QAM-16/64/256
Modulation UL, DL	QPSK, QAM-16/64
MIMO	2*2 (4*4)

The Aveiro EFACEC pilots 5G Core is based on Fraunhofer Fokus Open5GCore Release 5. The integration of the CPE (Huawei 5G CPE Pro 2) and gNB (ASOCS CYRUS 2.0) with Open5GCore is illustrated in Figure 27.

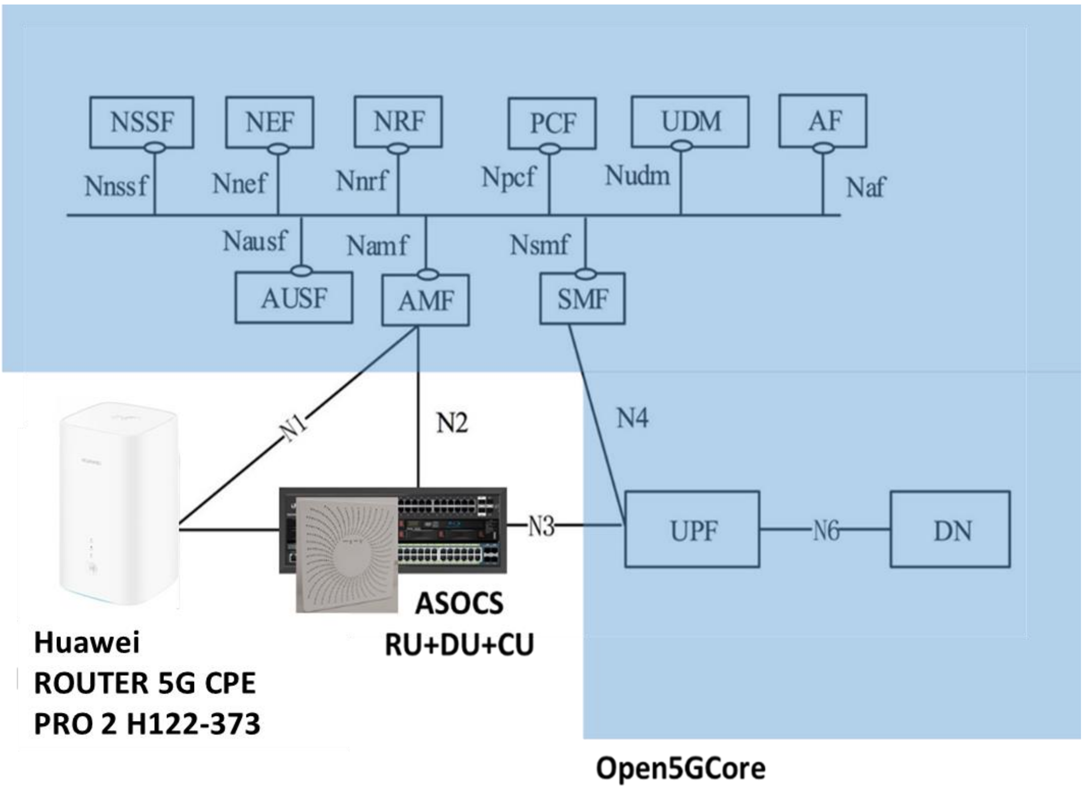

FIGURE 27: EFACEC_E PILOT – INTEGRATION CPE / GNB / 5G CORE

Figure 28 shows the physical appearance of the 5G Core and RAN systems.

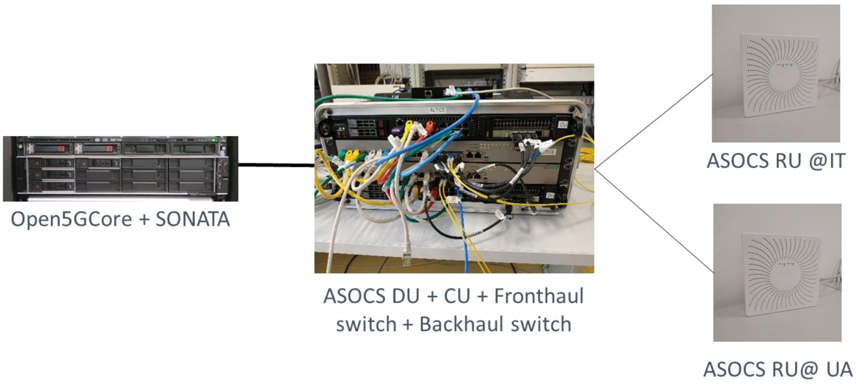

FIGURE 28: EFACEC_E PILOT – 5G INFRASTRUCTURE VIEW: O5GCORE, ASOCS CU+DU AND RUS

4.1.2. Innovations integration and role

The pilot will feature the integration of the "End-to-end Orchestration. Federation and Inter-domain (I6)" [3] and "Security and auditability (I11)" [3] innovations working together The objective of this joint integration is to allow verticals to be directly involved in inter-domain/inter-operator service deployment, when a service spans multiple domains/operators, without having to rely on a specific operator to take on the role of mediator. This capability allows the vertical, to negotiate directly with each operator for the individual billing through an alternative mechanism. In such a case, the considered service refers to the establishment of a secure channel using the MTD (Moving Target Defense) [4] security capability, which involves a tunnelled link, between two domains simulating two different operators.

In the deployment of these innovations, one endpoint of the tunnel is deployed in the domain of an OSM-based virtualized infrastructure and the other endpoint is deployed in the domain of an ICT-17 5G-VINNI virtualized infrastructure, managed using SONATA [5]. As a first step, the scenario under evaluation leverages the inter-domain capabilities built into the 5GR-VS and the 5Growth-enabled drivers in each virtualized infrastructure to instantiate the MTD mechanism and inter-connect it between the two domains. As a second step, the mechanism showcases its flexibility by dynamically requesting configuration changes to the tunnel, performing the inter-domain operations required for the needed updates. Since it is a cloud-based service that establishes a secure connection involving only the virtualized portion of the pilot's supportive cloud infrastructure, it does not directly impact the access connectivity aspects used by the devices or services connected over the 5G link. Therefore, it does not directly impact the KPIs of the pilot's use cases, and the integrated innovations can be independently assessed for validation.

Figure 29 shows the necessary adaptation done over ICT-17 VINNI's SONATA to support inter-domain innovation (I6). SONATA operates as a cloud-based network function virtualization infrastructure (VIM and WIM) that hosts the core network for the Aveiro pilot's 5G network. With the added adaptation, it is able to receive requests from 5Growth's Vertical Slicer, and perform the necessary lifecycle operations to serve deployment requests. In this case, it deploys a network function that forms one of the MTD-enabled tunnel endpoints of the secure communication service.

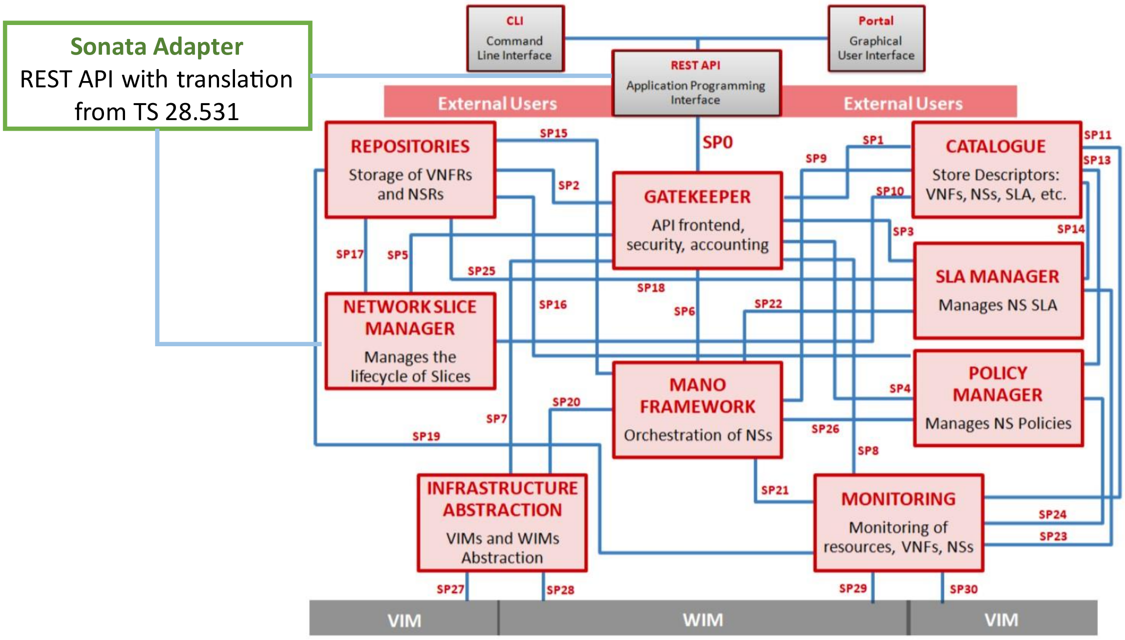

FIGURE 29: EFACEC_E PILOT – ICT-17 VINNI'S SONATA ADAPTIONS TO SUPPORT I6

The inter-domain procedure [6] is shown in Figure 30 and explained as follows. The instantiation of the desired CS (Communication Service) or Vertical Service is represented in Stage 1. This stage is further divided into steps to achieve the E2E network slice across domains. Depending on the number of NFs (Network Functions) used, this stage may include several operation steps and sub-steps associated with their instantiation/configuration (day-0 and day-1 operations).

The first step corresponds to the assignment of a unique identifier for each of the network slice subnets. The second step refers to delaying the instantiation of the network slice subnets via the 5GR-VS, until the OSM slice managers receive the request. The third step refers to the configuration of the VPN tunnel peers. The configuration of the MTD mechanism is also done at this time, if it is used. When this step is completed and everything goes as expected, the Vertical Service is ready to be used by the Vertical.

After the availability of the Vertical Service, the only operations available and supported at the time of writing to change the status of the Vertical Service and its associated E2E NSI (Network Slice Instantiation) are the update and termination of the Vertical Service. In both cases, this will result in termination of the service. This poses a problem for the Vertical as the service could be interrupted while the properties of the Vertical Service are being changed (e.g., changing the quality of service, following KPIs). Stage 2 focuses on the termination of the Vertical Service and the teardown of the E2E inter-domain network slice. In this context, step 4 specifies the requests at the 5GR-VS level for the termination of the network slice subnets. The request for termination of the E2E network slice subnets and the corresponding network resources at the various ADs (Administrative Domains) leads to the release of the NFVO resources at the VIMs. Thus, the network slice subnet is terminated which leads to the termination of the E2E slice when the last subnet is released. Finally, the termination of the E2E slice leads to the termination of the Vertical Service.

In the diagram, we show our current view for the Service Level Modification of the characteristics of the Network Slice resources deployed on the different AD. This procedure should follow the KPIs listed during CS onboarding. It is expected that a vertical solution provider can request to modify the characteristics of the offered service at a given time without having to tear down the entire service. Therefore, we propose a new flow of actions, marked with red arrows and executed in the 5GR-VS, so that a CSP can request to change a CS when needed. These actions are later forwarded to the slice managers and the respective NFVOs can change the correct NF, using day-2 primitives.

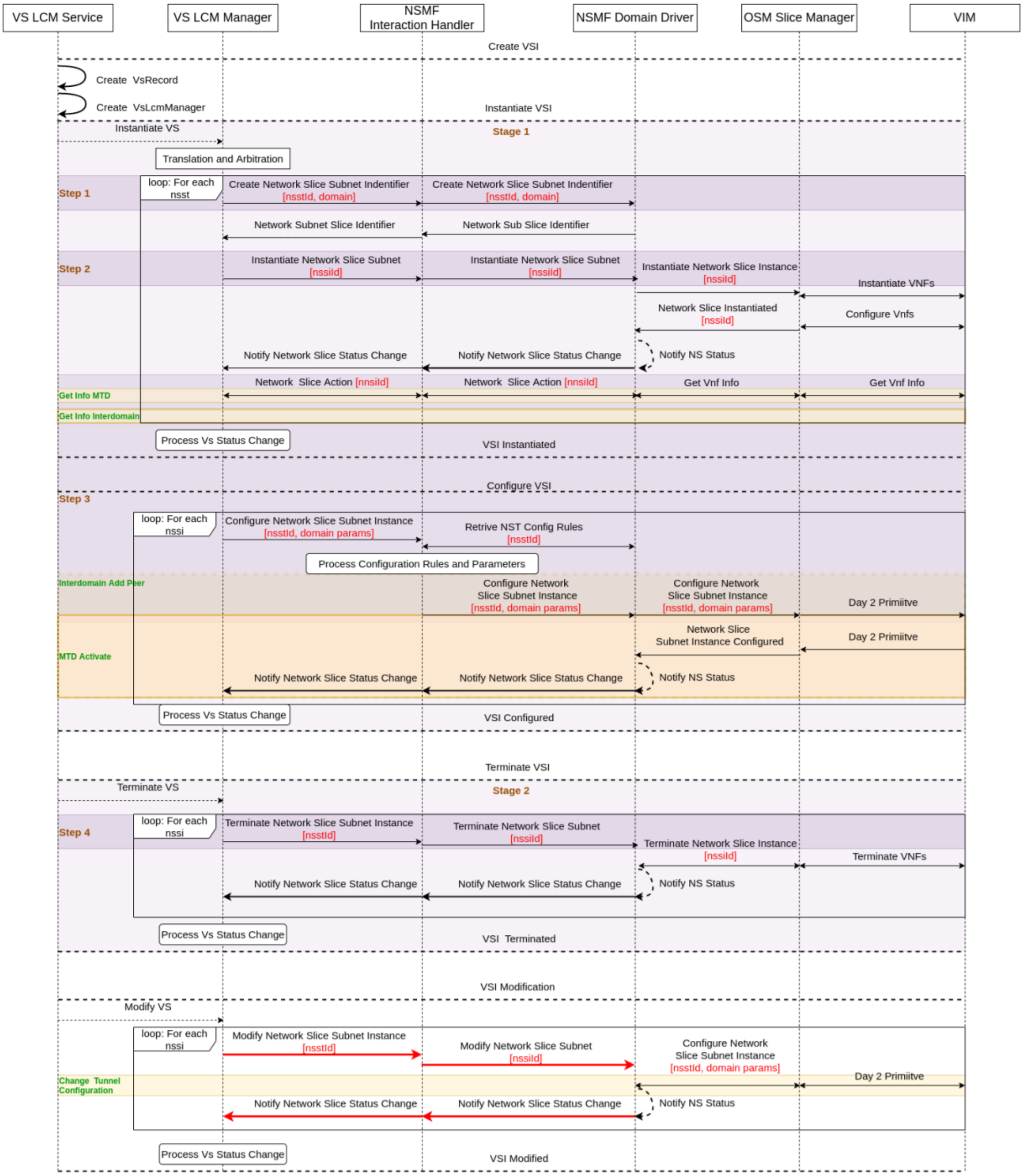

FIGURE 30: EFACEC_E PILOT – INTER-DOMAIN SIGNALING DIAGRAM

4.1.3. Vertical Integration capabilities

4.1.3.1. Orchestration - Integration of 5Growth with 5G-VINNI

The integration between 5Growth and 5G-VINNI was described in D3.3 Section 1.1.2. This integration comprises the adaptation of the 5Gr-VS requests to the SONATA Slice Manager. The flow between 5Gr-VS and 5G-VINNI's Network Function Virtualization Orchestrator (NFVO) follows the lines shown in Figure 31.

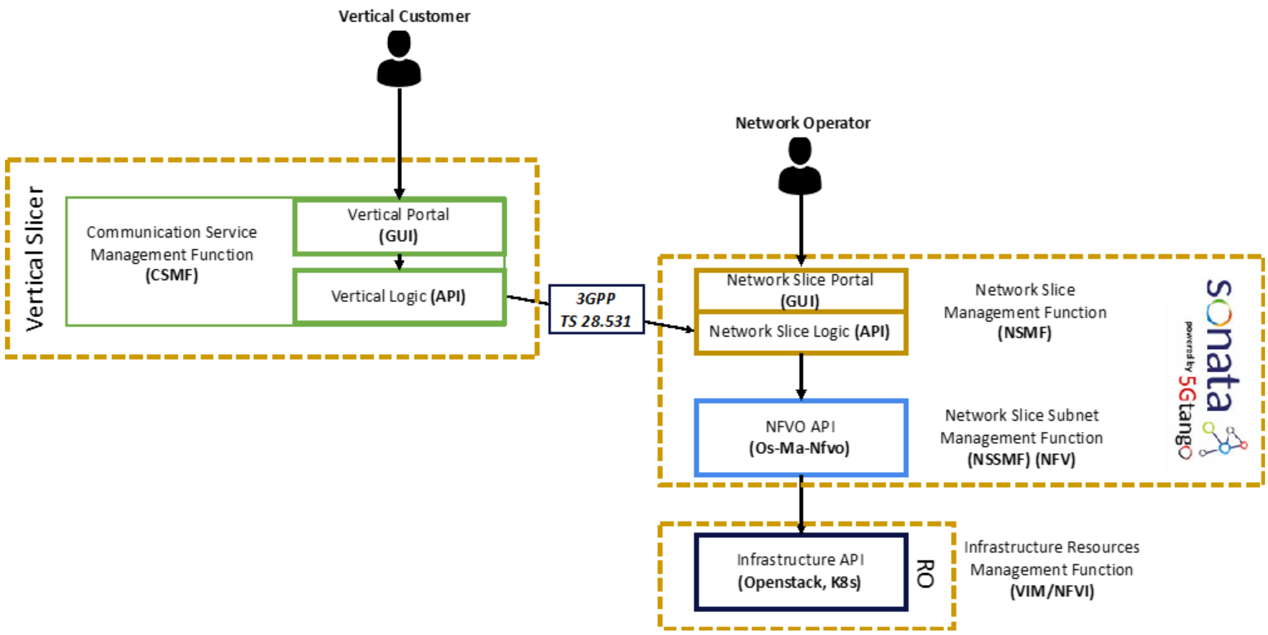

FIGURE 31: EFACEC_E PILOT – 5GROWTH INTEGRATION WITH 5G-VINNI

The software components required to enable the interaction between 5Growth and 5G-VINNI, described in D3.3 Sections 2.3 and 2.4, are the following:

- Sonata driver, in 5Growth platform
- SONATA adaptor, in the 5G-VINNI platform

The architecture of these two components is illustrated in Figure 32:

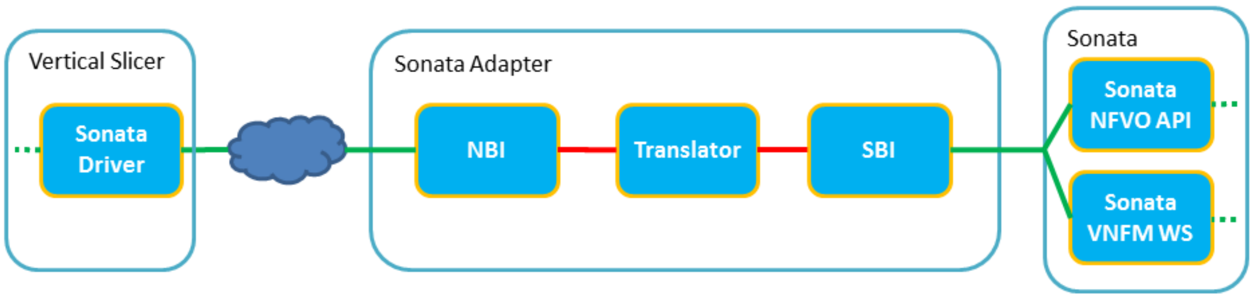

FIGURE 32: EFACEC_E PILOT – SONATA ADAPTER HIGH-LEVEL ARCHITECTURE

This integration has the following features:

- Handle messages in format TS 28.531 with Vertical Slicer;
- Handle messages with SONATA in the specific SONATA API format;
- Translate the messages format from/to TS 28.531 and SONATA API;
- Support the messages type:
  - Instantiate – operation to instantiate a new slice network service on SONATA;
  - Terminate – operation to terminate a specific slice network service on SONATA;
  - Query Slice Instantiations – operation to obtain selected data about the running slice network service on SONATA (in this operation now is possible to retrieve specific info from the Slice/Service/Function);
  - Configure Slice Instantiations – operation to configure a network service slice on SONATA.

4.1.3.2. Monitoring Integration of 5Growth with 5G-VINNI

The 5Growth Monitoring Platform was integrated with the 5G-VINNI Monitoring platform, using the SDA component between them. Figure 33 shows this integration.

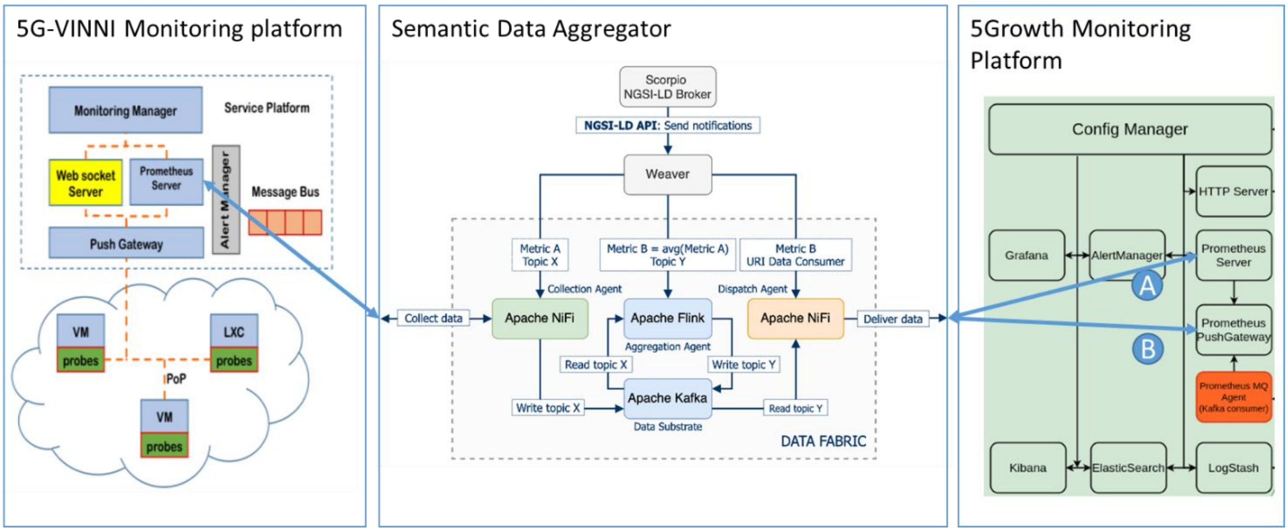

FIGURE 33: EFACEC_E PILOT – MONITORING INTEGRATION BETWEEN VINNI AND 5GROWTH

The 5G-VINNI Monitoring platform is part of the Sonata Framework and uses a Prometheus Server and a Prometheus Pushgateway. The probes can be located in the pilots UE, in the 5G core, or in servers, and send data metrics to Prometheus at regular intervals.

The SDA (Semantic Data Aggregator) component, described in D4.3 Section 2.1.1, collects the configured data metrics from the 5G-VINNI Monitoring platform and then has two options for delivering data to the 5Growth Monitoring Platform:

A. 5Gr-Mon's Prometheus scrapes metrics from an HTTP endpoint available within the SDA. This alternative requires the usual configuration of a new job in Prometheus.
B. The SDA sends new metrics to a specific Prometheus PushGateway instance. In this case, 5Gr-Mon's Prometheus must have a PushGateway instance properly configured.

The 5Growth Monitoring Platform can be considered as a data consumer of SDA, and displays the collected metrics in visual form using the Grafana sub-component.

This pilot uses the probes "End-to-end Unidirectional Link Latency Evaluator" described in D4.2 Section 2.3.1 to measure latency, jitter, and packet loss in the link; and the probes "Passive Network Interface Probe" described in D4.3 Section 2.2.2 to measure the average throughput in each interface.

Figure 34 shows the location of the probes.

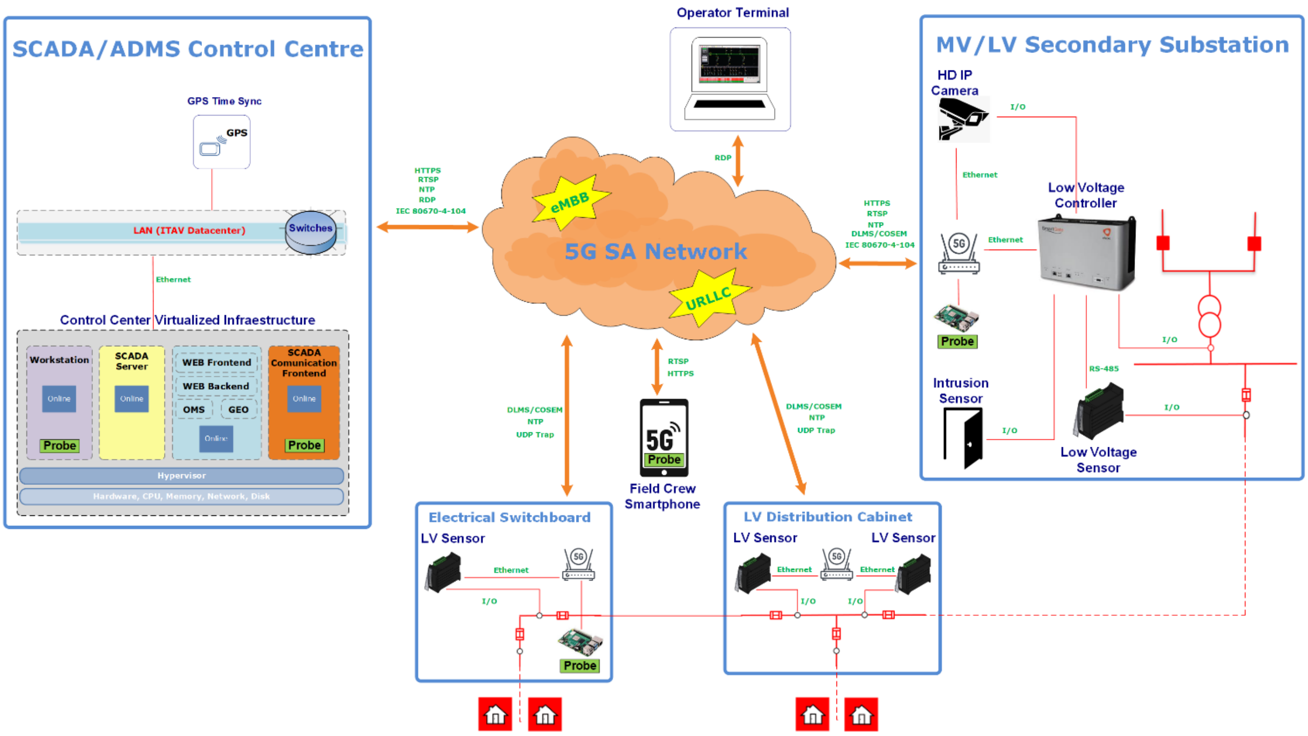

FIGURE 34: EFACEC_E PILOT – PROBES LOCATION FOR ENERGY USE CASES

4.1.3.3. Log Management Tool integration with the Semantic Data Aggregator

The available 5Growth platform, as described in Section 2.1.3.1, has been connected to the Log Management Tool and the SDA component to collect and analyse the operational logs of the Vertical Slicer. From these logs, the Log Management Tool can derive the time metrics associated with the vertical service instantiation and termination operations for the integrated environment depicted in Figure 31.

4.2. Use Case 1 integration: Advanced Monitoring and Maintenance Support for Secondary Substation MV/LV distribution substation

Figure 35 represents the first use case of Energy Pilot - EFACEC_E-UC1, focusing on its components and interfaces.

The EFACEC_E-UC1 is completely deployed in University of Aveiro premises as planned.

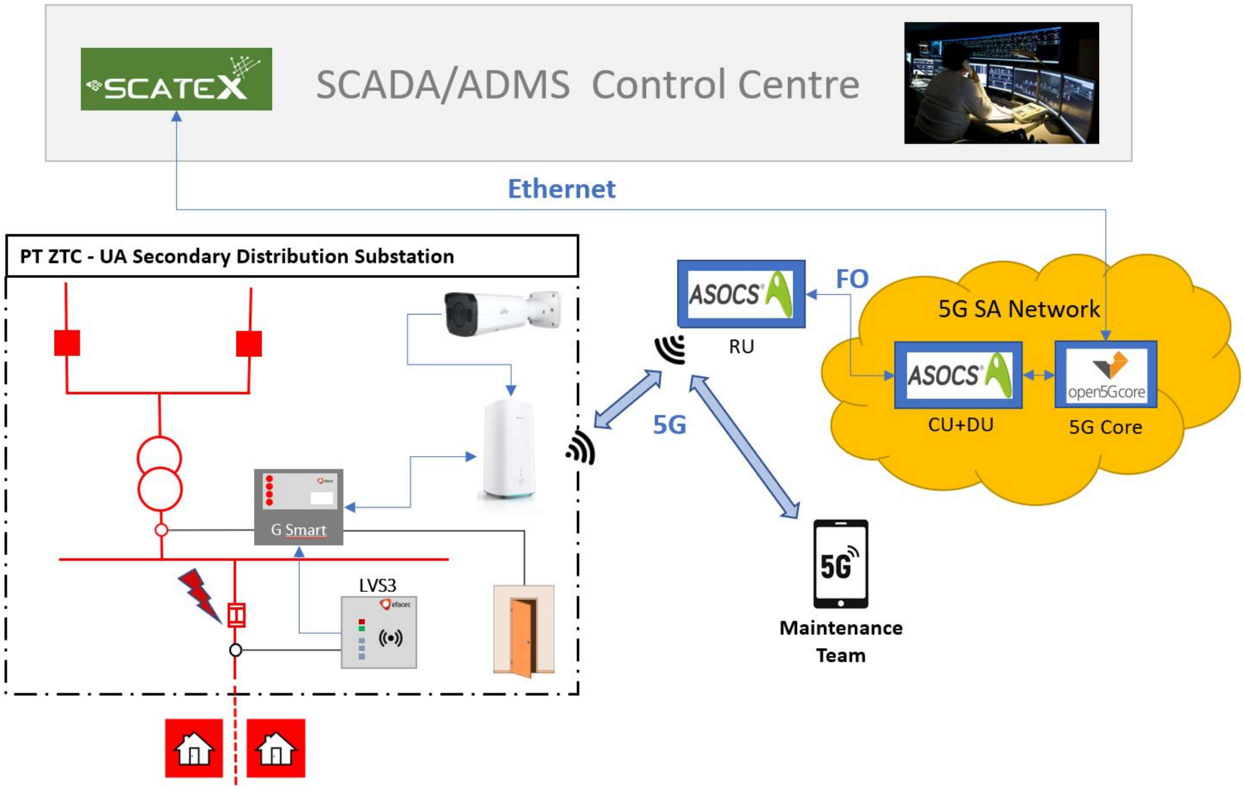

FIGURE 35: EFACEC_E PILOT – UC1 ADVANCED MONITORING AND MAINTENANCE SUPPORT FOR SECONDARY SUBSTATION MV/LV DISTRIBUTION SUBSTATION

In this use case, the communication between the UA ZTC secondary substation automation and the SCADA/ADMS Control Centre is provided by a 5G SA network.

The Efacec's Distribution Transformer Controller – G Smart – collects live telemetry from the electrical systems inside the secondary substation, and auxiliary signals, for instance, from intrusion detectors. The telemetry is then transmitted to the Control Centre via IEC 60870-5-104 SCADA protocol using 5G communication, as depicted in Figure 35.

Also, a HD video IP camera streams HD video from inside the secondary substation to the Control Centre and to a mobile device worn by the maintenance team.

The 5G-enabled mobile device receives the live telemetry of the secondary substation through a web access to the control centre SCADA/ADMS system. Using the incorporated camera, the mobile device is capable to identify the electrical assets inside the secondary substation and to give enhanced information to the maintenance team through an augmented reality application.

The slice requirements – eMBB profile - for both the 5G CPE inside the substation, and the 5G mobile device are introduced by the vertical using the Vertical Slicer (5Gr-VS) which interacts with the Aveiro 5G-VINNI testbed through the SONATA orchestrator to instantiate the network service. SONATA will oversee controlling the lifecycle of the network slices that support the use case. Once the connectivity and the service are in place, the use case can be executed as planned. When the process is over, the release of the network slice and respective infrastructure resources can be requested, through the Vertical Slicer again.

The following images illustrate the deployed setup concerning the EFACEC_E-UC1 use case.

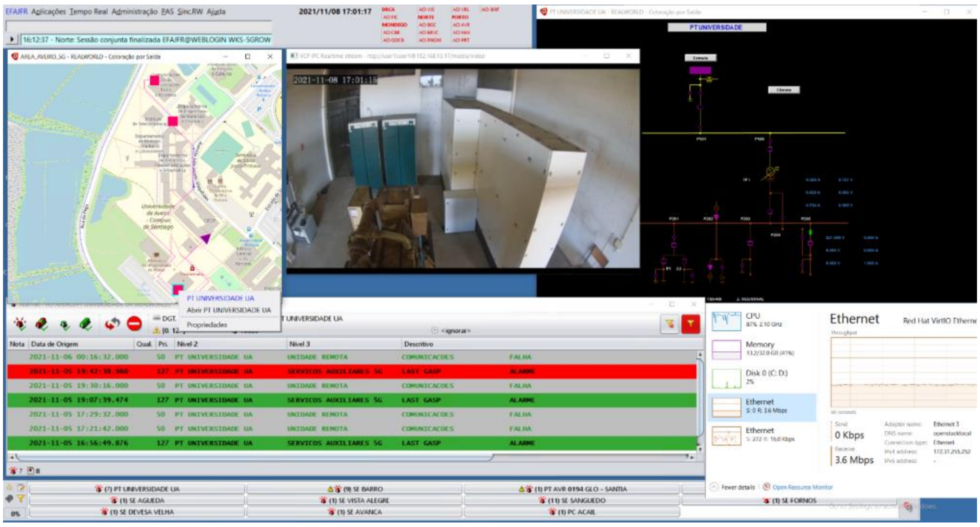

FIGURE 36: EFACEC_E PILOT – UC1 CONTROL CENTRE OPERATOR INTERFACE

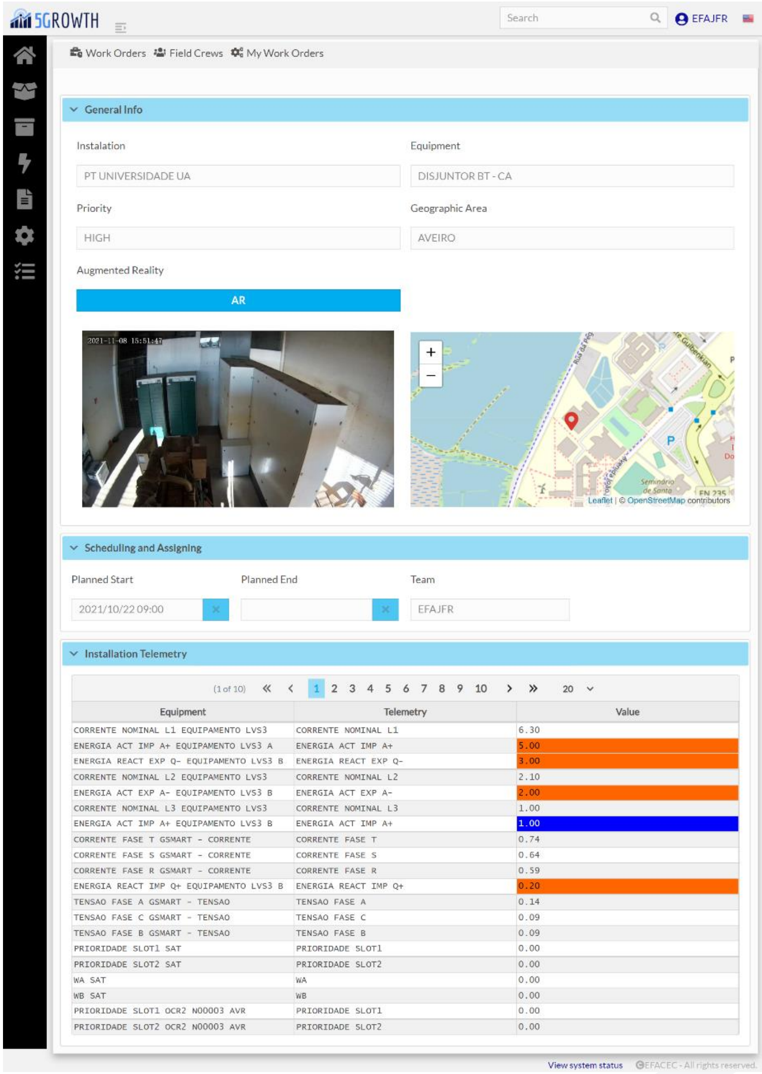

FIGURE 37: EFACEC_E PILOT – UC1 MAINTENANCE TEAM INTERFACE

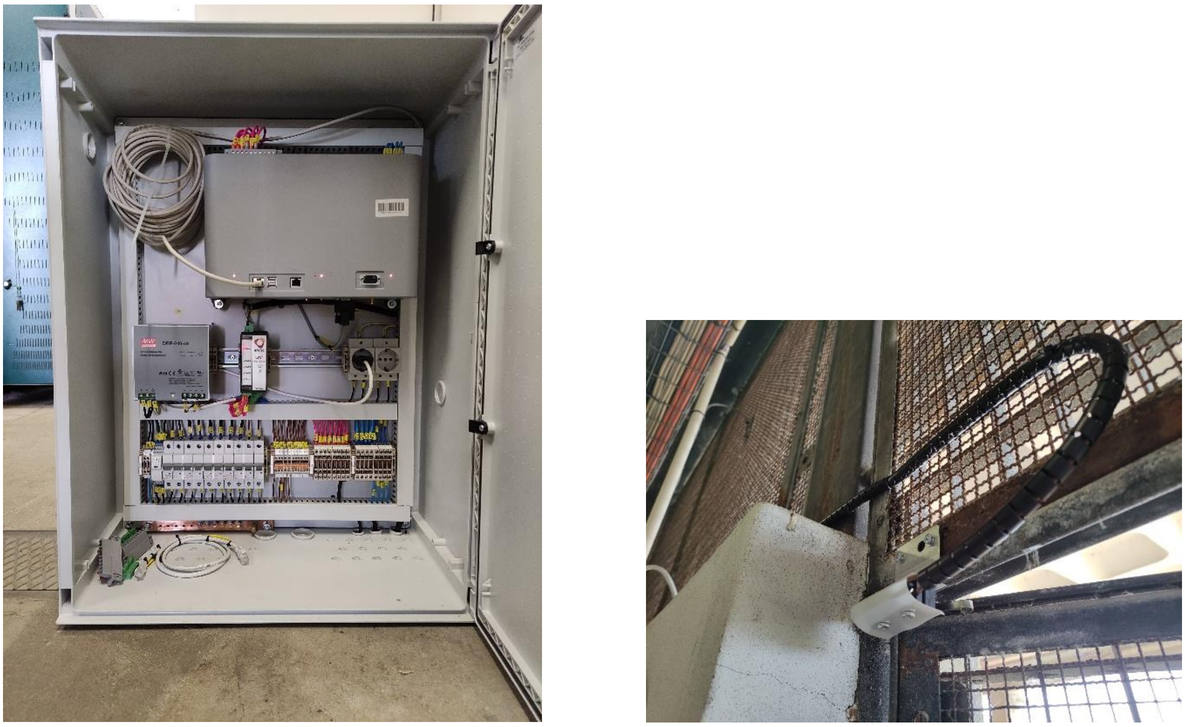

FIGURE 38: EFACEC_E PILOT – UC1 SECONDARY SUBSTATION AUTOMATION CABINET AND INTRUSION DETECTOR

FIGURE 39: EFACEC_E PILOT – UC1 SECONDARY SUBSTATION 5G CPE AND RU

4.3. Use Case 2 integration: Advanced Critical Signal and Data Exchange across wide smart metering and measurement infrastructures

Figure 40 represents the second use case of Energy Pilot - EFACEC_E-UC2, focusing on its components and interfaces.

The EFACEC_E-UC2 is completely deployed in University of Aveiro premises as planned.

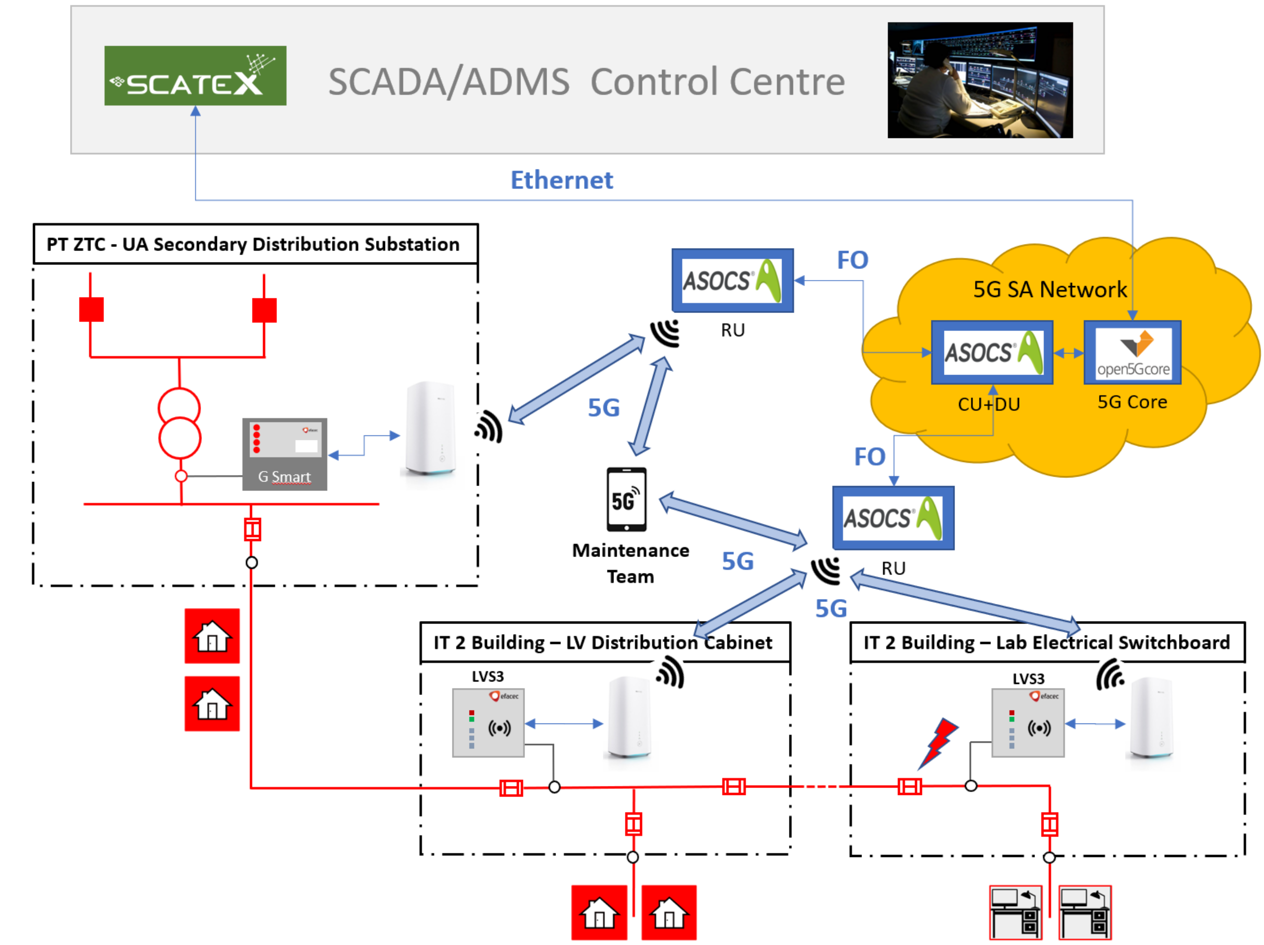

FIGURE 40: EFACEC_E PILOT – UC2 ADVANCED CRITICAL SIGNAL AND DATA EXCHANGE ACROSS WIDE SMART METERING AND MEASUREMENT INFRASTRUCTURES

In this use case, the focus is the communication between the low voltage sensors placed across the low voltage electrical network and the Distribution Transformer Controller inside the feeding secondary substation. This communication is provided by a 5G Standalone network.

The Efacec's Low Voltage Three-phase Sensor – LVS3 – collects live telemetry from the LV electrical installations, such as the distribution cabinet and the building switchboard. The telemetry is then transmitted to the Substation Controller via DLMS/COSEM protocol using 5G communication, and then to the Control Centre via IEC 60870-5-104 SCADA protocol also using 5G communication, as depicted in Figure 40.

The 5G-enabled mobile device receives the live telemetry of the low voltage network through a web access to the control centre SCADA/ADMS system. Using the incorporated camera, the mobile device is capable to identify the electrical installations across the LV network and give enhanced information to the maintenance team through an augmented reality application.

The slice requirements – URLLC profile - for both the 5G CPEs connected the each LVS3, and the 5G mobile device are introduced by the vertical using the 5Gr-VS which interacts with the Aveiro 5G-VINNI testbed through the SONATA orchestrator to instantiate the network service. SONATA will oversee controlling the lifecycle of the network slices that support the use case. Once the connectivity and the service are in place, the use case can be executed as planned. When the process is over, the release of the network slice and respective infrastructure resources can be requested, through the Vertical Slicer again.

The following images illustrate the deployed setup concerning the EFACEC_E-UC2 use case.

FIGURE 41: EFACEC_E PILOT – UC2 IT2 BUILDING MAIN SWITCHING BOARD WITH LVS3 AND 5G CPE

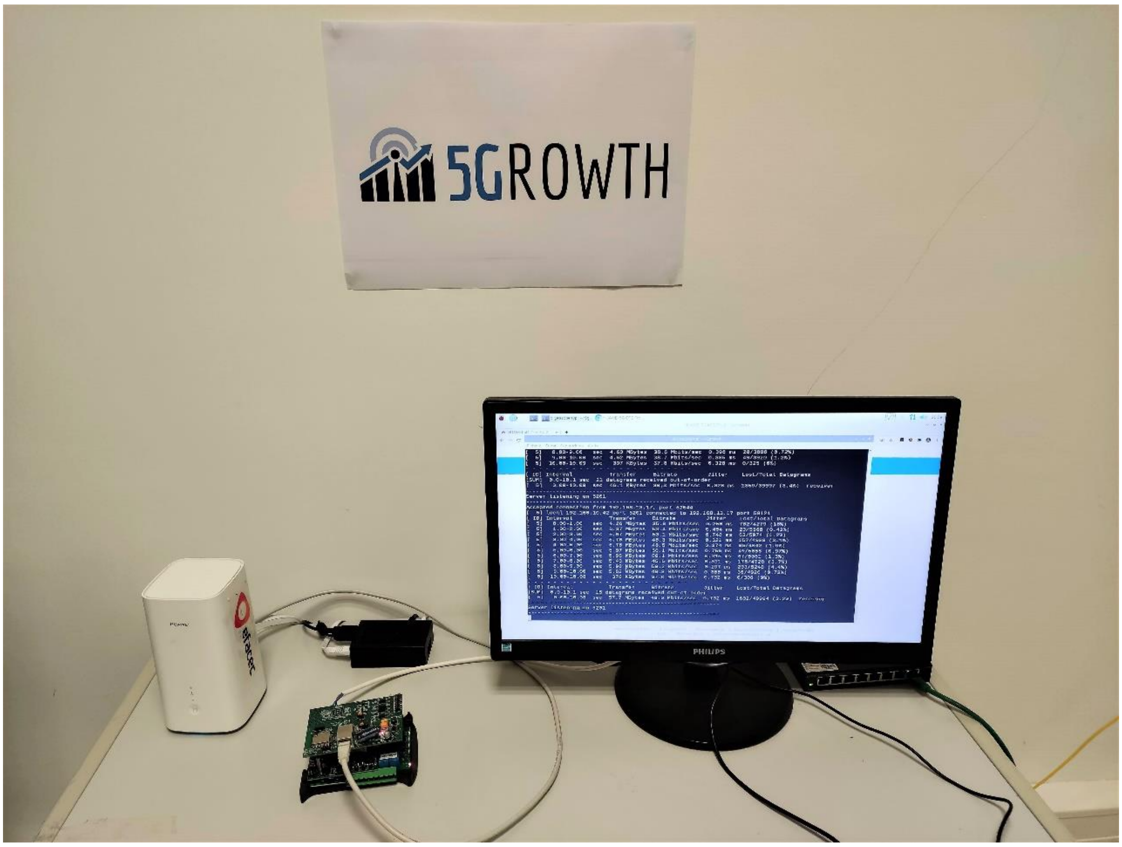

FIGURE 42: EFACEC_E PILOT – UC2 IT2 BUILDING LAB WITH LSV3 AND 5G CPE

5. EFACEC_S Vertical Pilot

The purpose of this pilot is to demonstrate a high-performance, yet highly flexible communication architecture provided by 5G to address railway signalling operations in relation to level crossing environment and secure communications. In the field trial, 5G communications was deployed to support railway signalling operations, in particular to meet the communications requirements at railway level crossing namely: (*i*) for safety critical communications from approaching train detectors (strike in detectors) to the level crossing controllers, and (*ii*) for transmission of level crossing real-time video images from level crossing to mobile devices on approaching trains and to maintenance agents tablet devices.

5.1. Infrastructure

The figure below shows the location of the 5G site (water tower tank), wheel sensor 1 (train detector for approaching freight trains that is leaving the harbour), wheel sensor 2 (train detector for approaching freight trains reaching the harbour) and the level crossing, at the Aveiro commercial harbour integrating the EFACEC_S use case 1: *Safety Critical Communications* and use case 2: *Non-Safety Critical Communications*. Details of the 5G infrastructure can be found in Section 5.1.1. Details of the use case and its deployment at vertical site can be found in Sections 5.2 and 5.3.

FIGURE 43: EFACEC_S PILOT – AVEIRO HARBOUR, 5G SITE, SENSOR 1 (RAILWAY TRACK), SENSOR 2 (RAILWAY TRACK, LEVEL CROSSING AND LEVEL CROSSING CONTROLLER LOCATION

The EFACEC_S use cases leverage the innovations designed and developed in WP2 which have been integrated into this pilot (WP3) to increase the security and reliability of the provided services, Section 5.1.2. Also, the orchestration integration of 5Growth with 5G-VINNI, described in Section 5.1.3.1, and the monitoring Integration of 5Growth with 5G-VINNI, described in Section 5.1.3.2, bring enhanced network monitoring, QoS control and flexibility to the network management as integrated components of the vertical pilot.

5.1.1. 5G Infrastructure

For the last EFACEC_S validation campaign, starting in the beginning of July 2021, a fully functional 5G SA network is available. Encompassing an Open 5G Core and 5G SA RAN ASOCs (CU+DU, RU) deployed in IT Labs. The Open 5G Core is installed at IT Aveiro building 1, ASOCS (CU+DU) at IT Aveiro building 2 and the RU was deployed on the top of a water tower at Aveiro harbour, 7 km away from IT building 2.

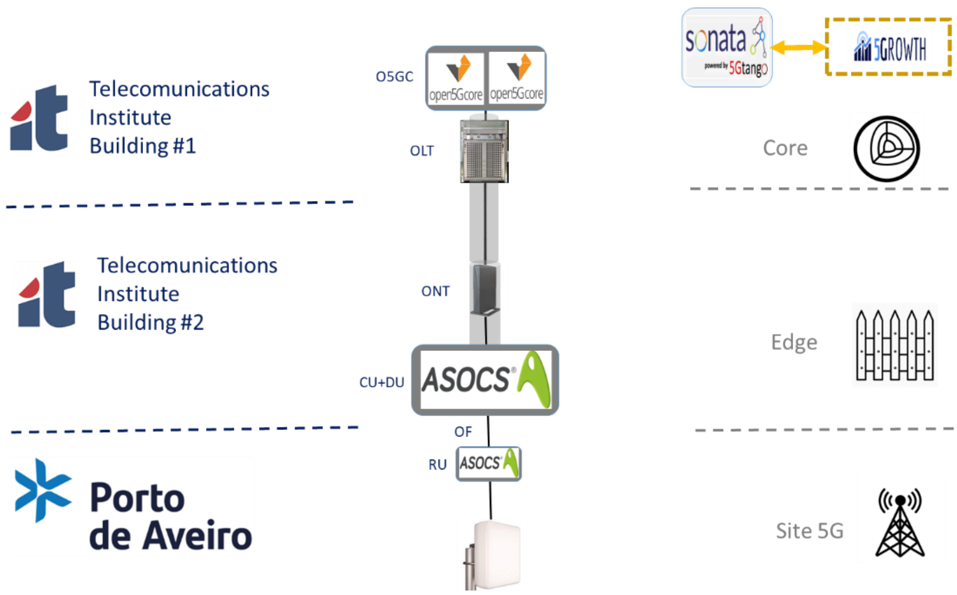

FIGURE 44: EFACEC_S PILOT - 5G NETWORK AT AVEIRO HARBOUR

The connection O5GCore, CU+RU uses the University of Aveiro private optical fiber infrastructure and the CU+DU, RU are connected by dedicated optical fiber from the public network.

The RAN component of the Aveiro 5G site is based on ASOCS CYRUS 2.0. ASOCS provides an open and fully virtualized software solution that delivers 5G for both LAN and WAN cellular network solutions and can run on a standard server or a universal CPE. The RAN functionality is based on the Open RAN architecture and it is split into multiple components, following the 3GPP 5G RAN architecture, namely CU (Central Unit), DU (Distributed Unit) and RU (Radio Unit), which can be deployed in multiple combinations. The O-RAN - FH 7.2 interface is used to connect to radio. Table 2 shows the ASOCS RAN main radio technical specifications.

TABLE 2: EFACEC_E PILOT – ASOCS TECHNICAL SPECIFICATIONS

Maximum bandwidth	100 MHz
Frequency band	3700-3800 MHz
Output power per port	24 dBm
Demultiplexing	TDD
DL Modulation	QPSK, QAM-16/64/256
Modulation UL, DL	QPSK, QAM-16/64
MIMO	2*2 (4*4)

The Aveiro Efacec pilots 5G Core is based on Fraunhofer Fokus Open5GCore Release 5. The integration of the CPE (in example a Huawei 5G CPE) and gNB (ASOCS CYRUS 2.0) with Open5GCore is illustrated in Figure 45

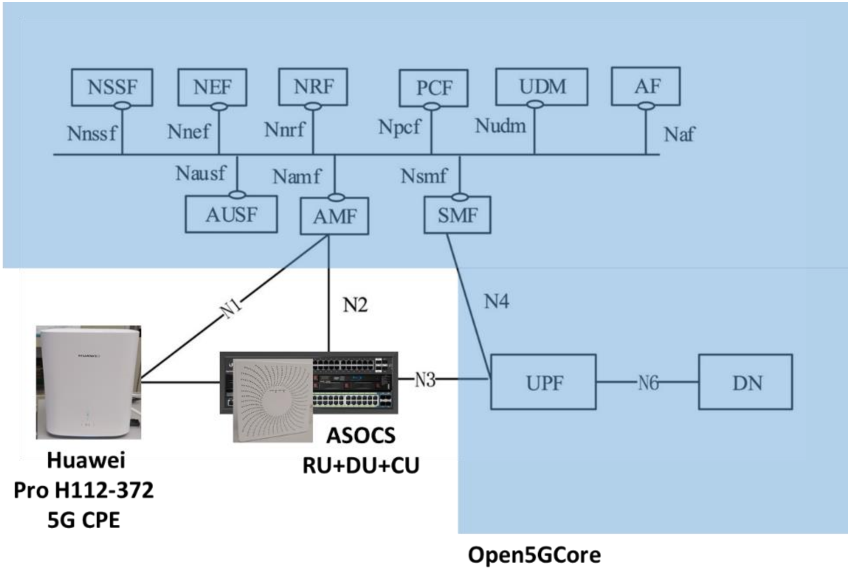

FIGURE 45: EFACEC_S PILOT – INTEGRATION CPE/GNB/5G CORE

Figure 46 shows the physical appearance of the 5G Core and RAN

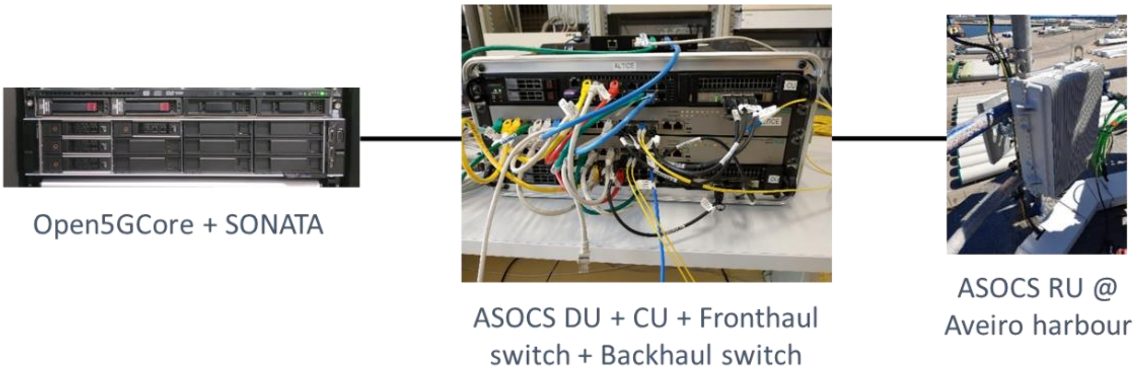

FIGURE 46: EFACEC_S PILOT – 5G INFRASTRUCTURE VIEW: O5GCORE AND ASOCS CU+DU

The 5G RAN of the EFACEC_S pilot is based on ASOCS 5G evaluation kit that is a not a final commercial product. Regarding this, several interoperability issues and performance constraints were identified. With the cooperation and commitment of ALB, ASOCS and EFACEC_S all the main limitation were overcame. In this sense 5Growth:

- contributed to a new product
- evaluated an innovative 5G architecture (O-RAN)
- gives visibility to a no mainstream 5G architecture
- promotes a new player: ASOCS

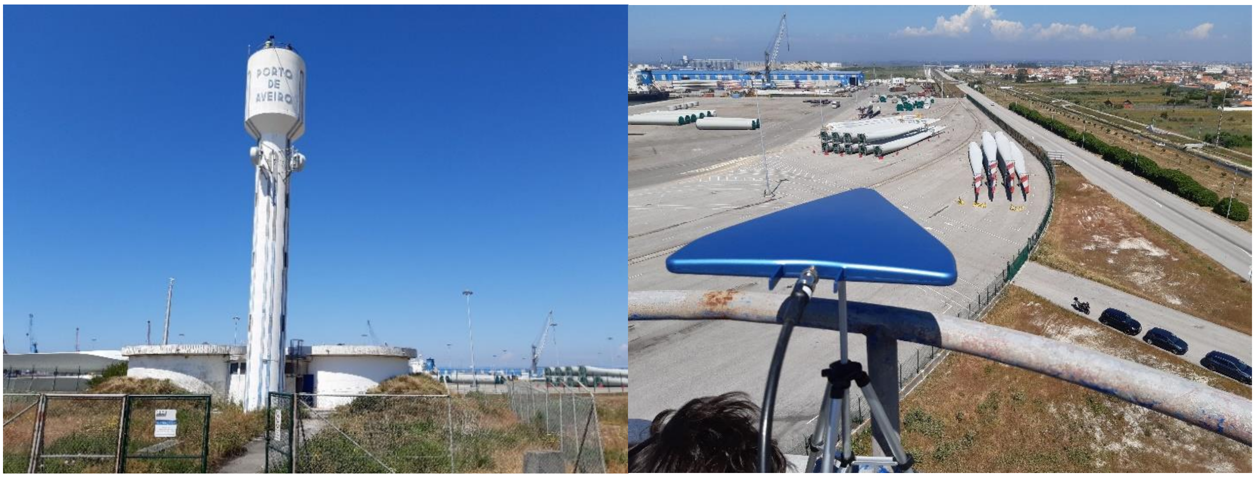

FIGURE 47: EFACEC_S PILOT – 5G SITE AT AVEIRO HARBOUR

The RU and external antennas deployed on the top of a water tower at Aveiro harbour provide radio line of sight to the train level crossing, train detecting sensors and train (Figure 47). Therefore, this solution provides coverage to the railway track that supports freight trains that are arriving or leaving the harbour.

5.1.2. Innovations integration and role

The pilot will feature the integration of the Inter-domain (I6) [3] and security (I11) [3][22] innovations, working jointly with one another. The objective of this joint integration usage is to allow verticals to be directly involved in inter-domain/inter-operator service deployment, when a service involves multiple domains/operators, without requiring a specific operator to play the role of mediator. This is the same behaviour as the EFACEC_E pilot, with the details described in section 4.1.2.

5.1.3. Vertical Integration capabilities

5.1.3.1. Orchestration - Integration of 5Growth with 5G-VINNI

The integration of 5Growth with 5G-VINNI was described in D3.3 Section 1.1.2. This integration involves the adaptation of the 5Gr-VS requests to the SONATA Slice Manager. The flow between 5Gr-VS and the 5G-VINNI's Network Function Virtualization Orchestrator (NFVO) follows the lines shown in Figure 48.

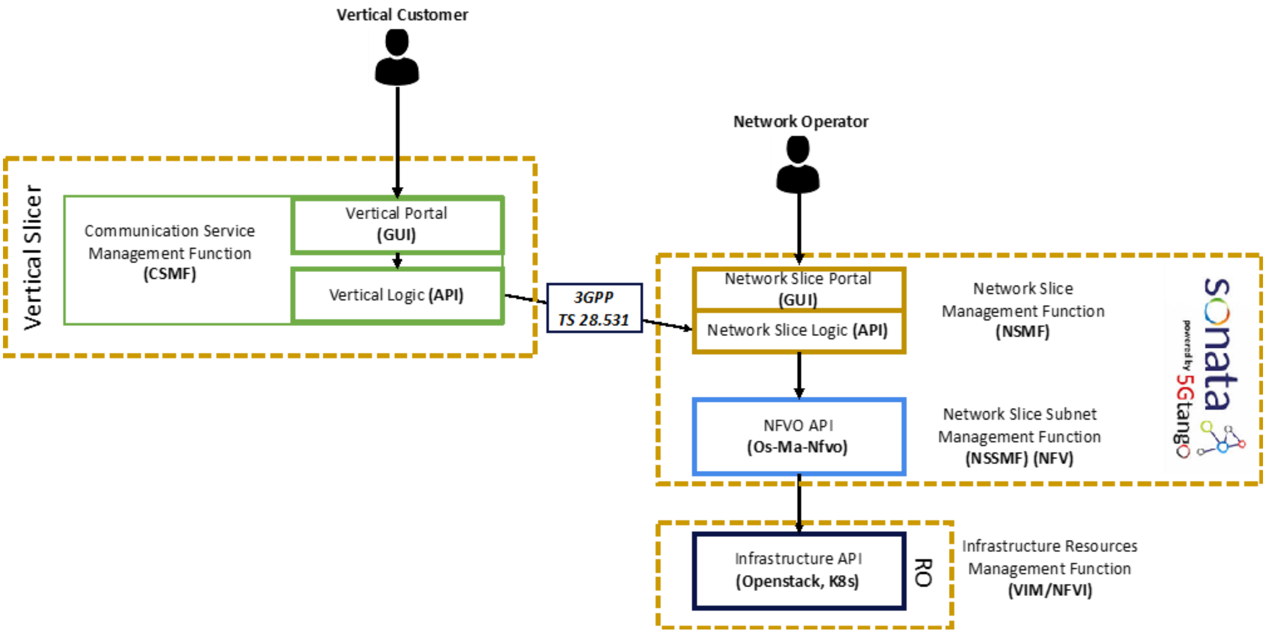

FIGURE 48: EFACEC_S PILOT – 5GROWTH INTEGRATION WITH 5G-VINNI

The software components required to enable the interaction between 5Growth and 5G-VINNI, described in D3.3 Sections 2.3 and 2.4, are the following:

- Sonata driver, in 5Growth platform
- SONATA adaptor, in the 5G-VINNI platform

The architecture of these two components can be seen in the next figure:

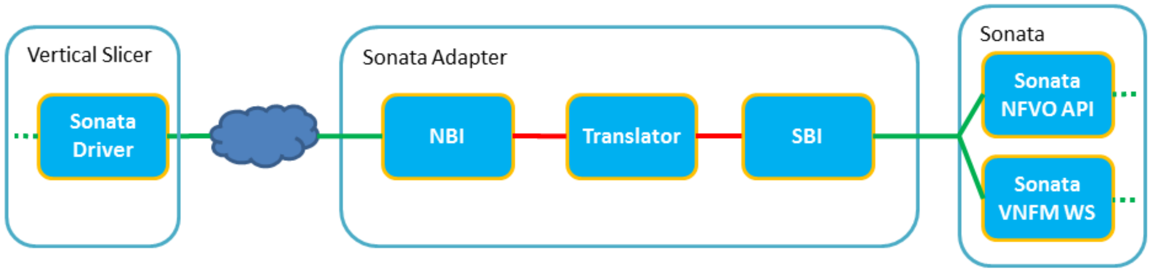

FIGURE 49: EFACEC_S PILOT – SONATA ADAPTER HIGH-LEVEL ARCHITECTURE

This integration has the following features:

- Handle messages in format TS 28.531 with Vertical Slicer;
- Handle messages with SONATA in the specific SONATA API format;
- Translate the messages format from/to TS 28.531 and SONATA API;
- Support the messages type:
    - Instantiate – operation to instantiate a new slice network service on SONATA;
    - Terminate – operation to terminate a specific slice network service on SONATA;
    - Query Slice Instantiations – operation to obtain selected data about the running slice network service on SONATA (in this operation now is possible to retrieve specific info from the Slice/Service/Function);

- Configure Slice Instantiations – operation to configure a network service slice on SONATA.

5.1.3.2. Monitoring-Integration of 5Growth with 5G-VINNI

The 5Growth Monitoring Platform was integrated with the 5G-VINNI Monitoring platform, using the SDA component between them. The next figure shows this integration.

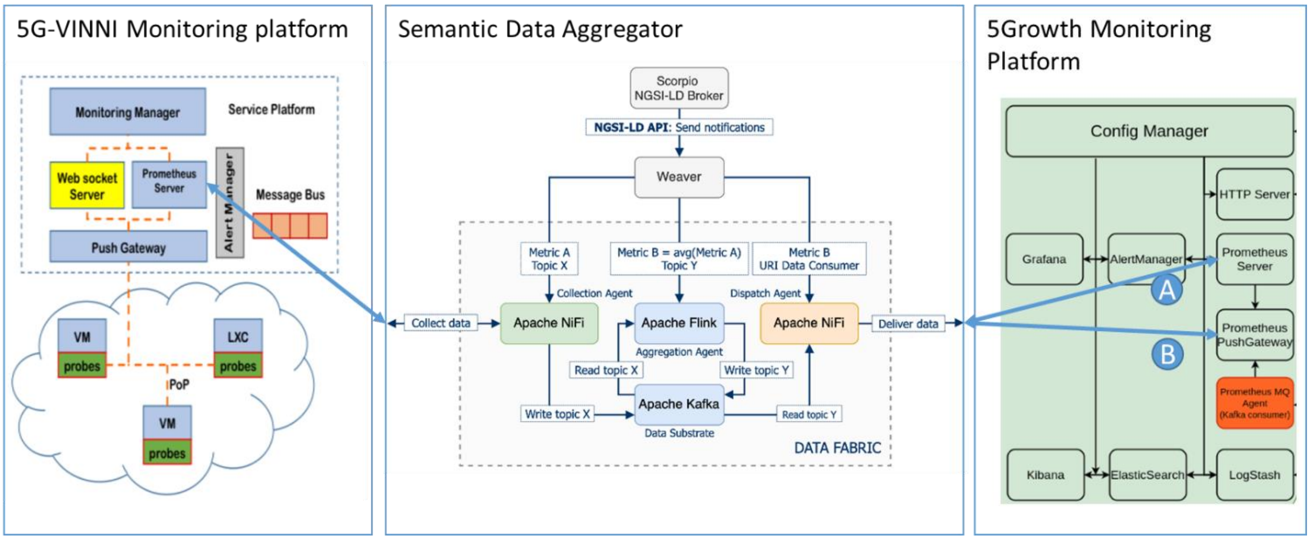

FIGURE 50: EFACEC_S PILOT – MONITORING INTEGRATION BETWEEN VINNI AND 5GROWTH

The 5G-VINNI Monitoring platform is part of Sonata Framework and uses a Prometheus Server and a Prometheus PushGateway. The probes can be located in the pilots UE, in the 5G core, or in servers, and periodically send data metrics to the Prometheus.

The SDA (Semantic Data Aggregator) component, described in D4.3 Section 2.1.1 collects the configured data metrics from 5G-VINNI Monitoring platform and then has two options for delivering data to the 5Growth Monitoring Platform:

A. 5Gr-Mon's Prometheus scrapes metrics from an HTTP endpoint available within the SDA. This alternative requires the usual configuration of a new job in Prometheus.
B. The SDA sends new metrics to a specified Prometheus PushGateway instance. In this case, 5Gr-Mon's Prometheus must have a PushGateway instance properly configured.

The 5Growth Monitoring Platform can be considered as a data consumer of SDA, and displays the collected metrics in visual form with Grafana sub-component.

This pilot uses the probes "End-to-end Unidirectional Link Latency Evaluator" described in D4.2 Section 2.3.1 to measure latency, jitter and packet loss in the link; and the probes "Passive Network Interface Probe" described in D4.3 Section 2.2.2 to measure the average throughput in each interface.

The next figure, shows the location of the probes for Use Case 1:

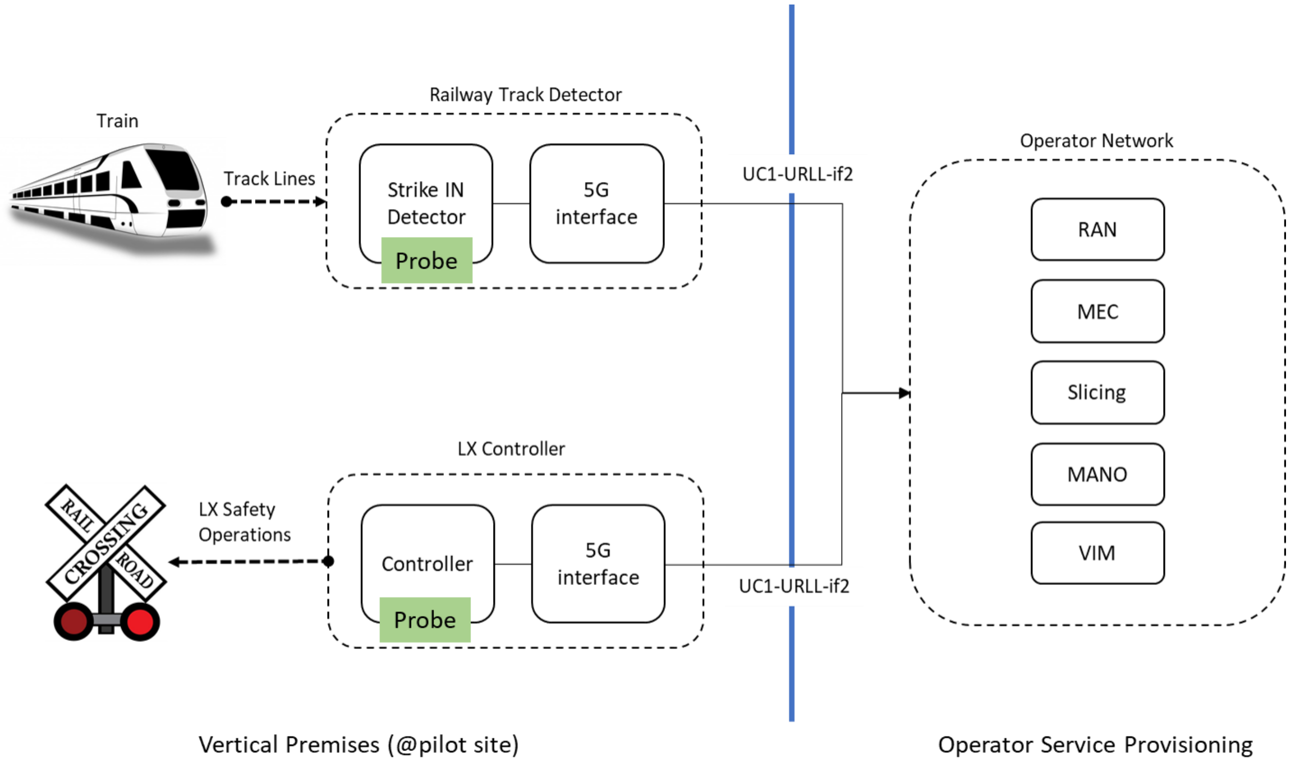

FIGURE 51: EFACEC_S PILOT – PROBES LOCATION FOR UC1

5.1.3.3. Log Management Tool integration with the Semantic Data Aggregator

The available 5Growth platform, as described in Section 2.1.3.1, has been connected to the Log Management Tool and the SDA component to collect and analyze the operational logs of the Vertical Slicer. From these logs, the Log Management Tool can derive the time metrics associated with the vertical service instantiation and termination operations for the integrated environment depicted in Figure 48.

5.2. Use Case 1 integration: Safety Critical Communications

Figure 52 illustrates the EFACEC_S-UC1, i.e., Fix permanent 5G communications between the train approaching detectors and level crossing (LX) controller.

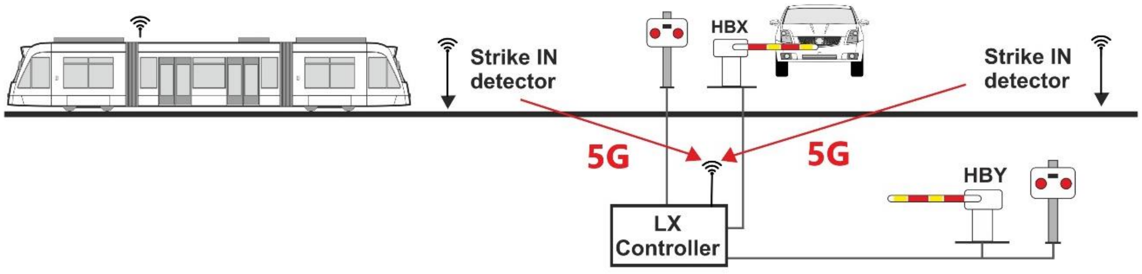

FIGURE 52: EFACEC_S PILOT – UC1 OVERVIEW I

Figure 53 depicts the modelling of EFACEC_S-UC1, focusing on its components and interfaces.

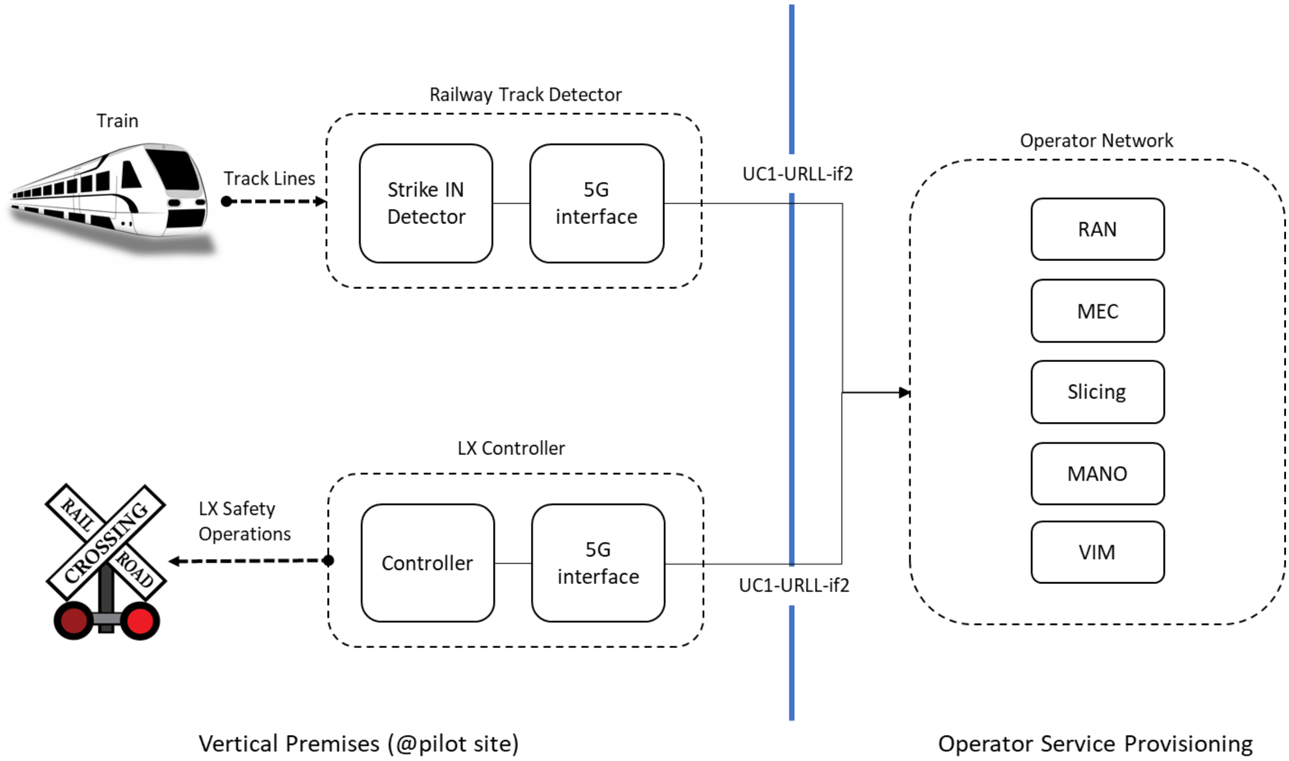

FIGURE 53: EFACEC_S PILOT – UC1 OVERVIEW II

EFACEC_S-UC1 considers a 5G-enabled Railway Track Detector with the ability to detect trains passing through a specific point in the railway, and to signal such event (using 5G communication) towards a Level Crossing (LX) Controller, which is in charge of controlling a railroad crossing. A mobile operator network provides the necessary link for the Railway Track Detectors and LX Controller to communicate, supported by all the RAN and Core operation service provisioning mechanisms.

Figure 54 shows the solution architecture of the EFACEC_S-UC1, allowing the communication between the train detecting sensors and the LX Controller.

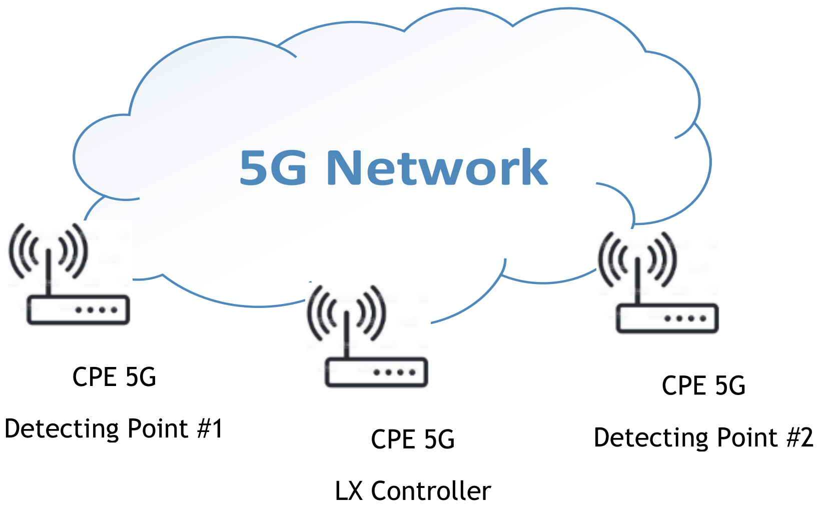

FIGURE 54: EFACEC_S PILOT – UC1 COMMUNICATION BETWEEN THE TRAIN DETECTING SENSORS AND THE LX CONTROLLER

The slice requirements are introduced by the vertical using the Vertical Slicer (5Gr-VS) which interacts with the Aveiro 5G-VINNI testbed through the SONATA orchestrator to instantiate the network service. SONATA will oversee controlling the lifecycle of the network slices that support the use case. Once the connectivity and the service are in place, the use case can be executed as planned. When the process is over, the release of the network slice and respective infrastructure resources can be requested, through the Vertical Slicer again.

Figure 55 represents the logic diagram of the EFACEC_S-UC1 showing all the layers to support the 5G communication between the Train detectors and the level crossing controller.

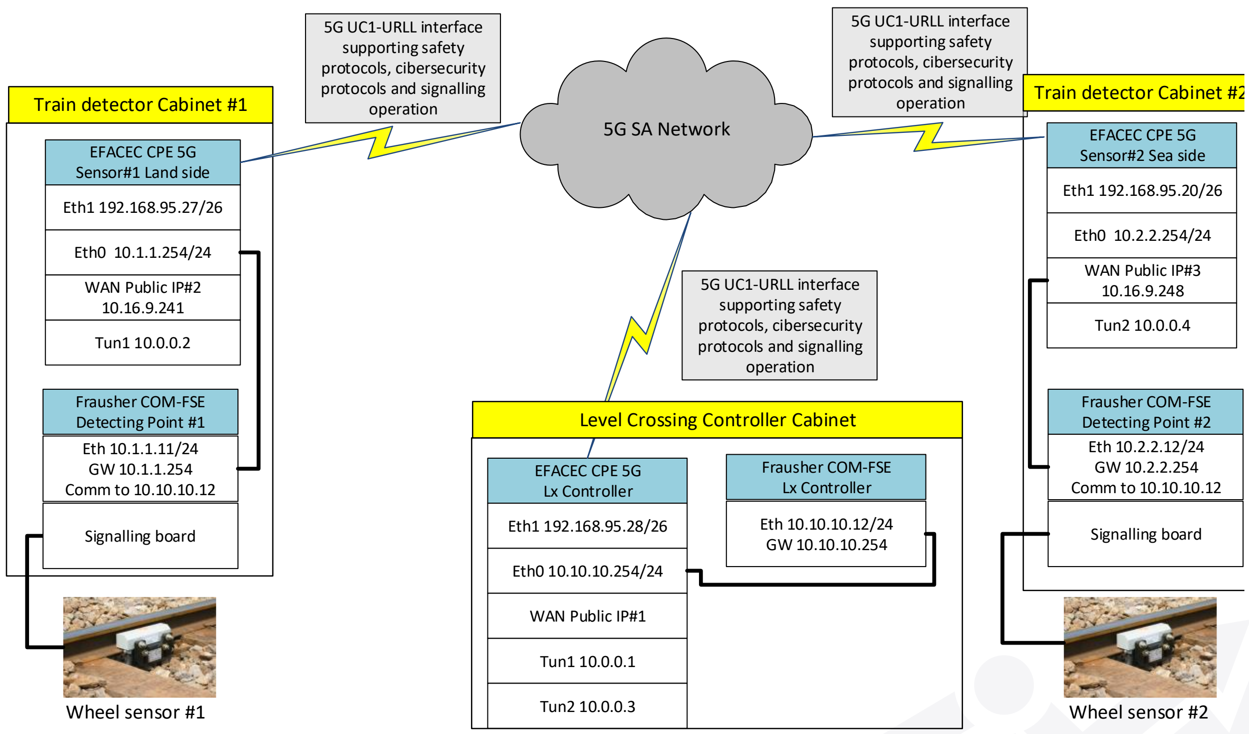

FIGURE 55: EFACEC_S PILOT – UC1 COMMUNICATION BETWEEN THE TRAIN DETECTING SENSORS AND THE LX CONTROLLER

5.2.1. Status

After the deployment and validation performed at lab environment level new tasks were carried out to deploy the real scenario at Pilot vertical site (Aveiro Harbour). This milestone was achieved and since the beginning of July the uses cases were being verified and validated and measurements were being collected.

The planned HW/SW components were reported in D3.2 (i.e., see Table 3 and Table 4 therein). Some modifications have been required with respect to the original tables. Thus, the updated tables for EFACEC_S-UC1 are reported below, adding details and pictures of the real environment.

TABLE 3: EFACEC_S PILOT – UC1 HW COMPONENTS

Component	Description	Location
Train	The machine responsible to transport people or freight	Aveiro Harbour (Figure 56)
Strike in detectors/axle counter train detector system	Device (system) that can detect if a train is approaching the level crossing area. There are two systems, one for upstream (trains arriving the harbour) and other for downstream (trains leaving the harbour). These detectors communicate the presence of a train locally (by cable) and by 5G technology to the Lx controller. This system is powered by a solar energy system, assuring that no cable ducts is needed between the sensors and the level crossing controller.	Level Crossing area- Aveiro Harbour (Figure 57), [13], [18], [19]. Taking as reference point the 5G antenna, the first Train sensor is located at 547 meters and the second train sensor is located at 840 meters
Train detectors/axle counter train detector system	Device (system) to detect if the train is occupying the Level Crossing section or to detect the absence of the train in that section	Level Crossing area- Aveiro Harbour (Figure 58)
Traffic lights	Device that is installed in the Level Crossing area and is responsible to process traffic information	Level Crossing area- Aveiro Harbour [16], (Figure 60)
LX controller	Shelter of devices that receive sensors and equipment information, process this information and assures the LX actions (railways signaling operation)	Level Crossing area- Aveiro Harbour. Taking as reference point the Lx controller is located at 650 meters (Figure 59), [17]
Half Barriers	The device that physically protects the Level Crossing against non-authorized entrances. Taking in consideration the safety standards, the low speed of the train in this area and the distance (few meters) between	Level Crossing area- Aveiro Harbour

Component	Description	Location
	the sensor and the lx Controller, in this scenario, no half-barriers is needed. The safety conditions are provided by traffic lights and bells.	
Level Crossing Bells	Sound system controlled at LX Controller indicated the presence of an approaching train. This interface and system were not considering in the preliminary design but it reinforce the safety conditions of the level crossing	Level Crossing area on both sides of the road (Figure 61)
5G Interface (CPE)	Mobile network interface able to connect to a 5G mobile network	Strike IN Detectors/LX Controller at the Railway track (Figure 62)
LTE router	Mobile network interface able to connect to a LTE mobile network. Used just for functional validation of the Level Crossing safety protection.	Strike IN Detector/LX Controller at the Railway track
Core 5G	5G Mobile network core elements	IT -Building #1
RAN	The RAN portion of the operator's mobile network	CU + DU IT- Building #2; RU -Aveiro Harbour

FIGURE 56: EFACEC_S PILOT – UC1 TRAIN (AVEIRO HARBOUR)

FIGURE 57: EFACEC_S PILOT – UC1 TRAIN DETECTOR/AXLE COUNTER

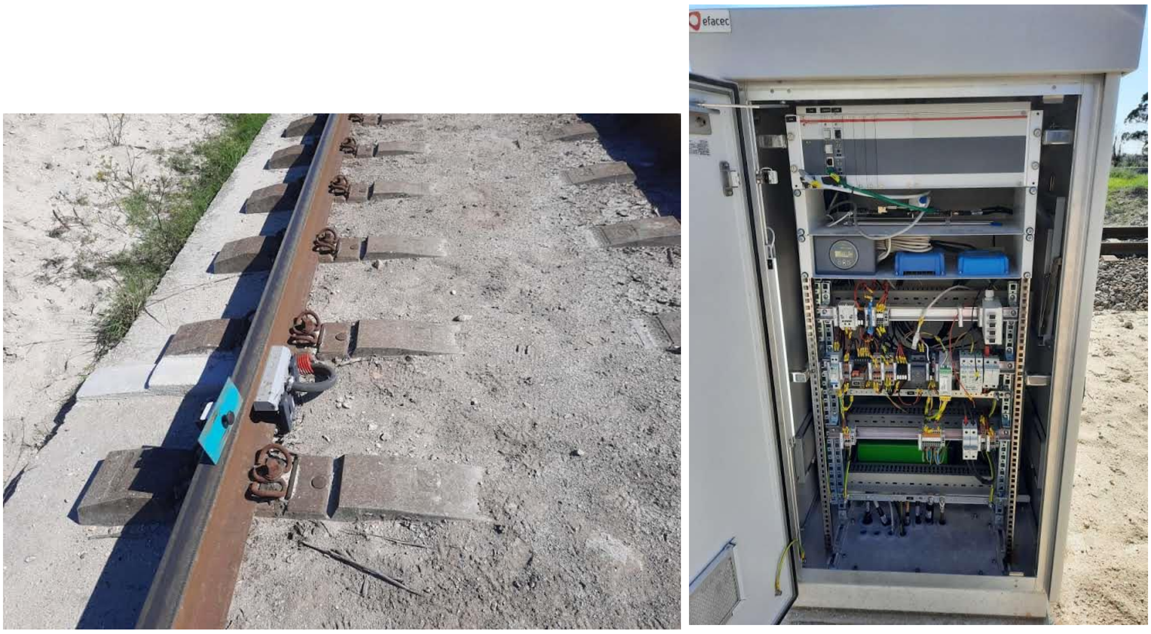

FIGURE 58: EFACEC_S PILOT – UC1 TRAIN DETECTOR/AXLE COUNTER SYSTEM

FIGURE 59: EFACEC_S PILOT – UC1 LX CONTROLLER

FIGURE 60: EFACEC_S PILOT – UC1 LEVEL CROSSING TRAFFIC LIGHTS

FIGURE 61: EFACEC_S PILOT – UC1 LEVEL CROSSING BELLS

FIGURE 62: EFACEC_S PILOT – UC1 5G CPE'S AND 5G ANTENNA LOCATED IN THE TRAIN DETECTOR SHELLTERS

TABLE 4: EFACEC_S PILOT – UC1 SW COMPONENTS

Component	Description	Location
LX controller (Safety SW application)	Shelter of devices that receive sensors and equipment information, process this information and assures the LX actions (railways signaling operation). It also supports the signaling safety applications, the communications and the safety protocols	Level Crossing area- Aveiro Harbour

Component	Description	Location
5G Interface (cybersecurity application)	Mobile network interface able to connect to a 5G mobile network supporting the cybersecurity mechanisms to assure a dedicated and secure tunnel between devices. This interface is running in the EFACEC 5G CPE's. This application also integrates the Software probes allowing the monitoring information to be sent to Prometheus	Strike IN Detector/LX Controller at the Railway track
Core 5G	5G Mobile network core elements	IT -Building #1
MANO	Mobile Network Management and Orchestration capability	(IT -Building #1)
VIM	Virtualized Infrastructure Management Capability	(IT -Building #1)

5.3. Use Case 2 integration: Non-safety Critical Communications

Figure 63 illustrates EFACEC_S-UC2, i.e. HD video image mobile transmission from LX surveillance camera to Approaching Trains and Maintenance Agents tablets.

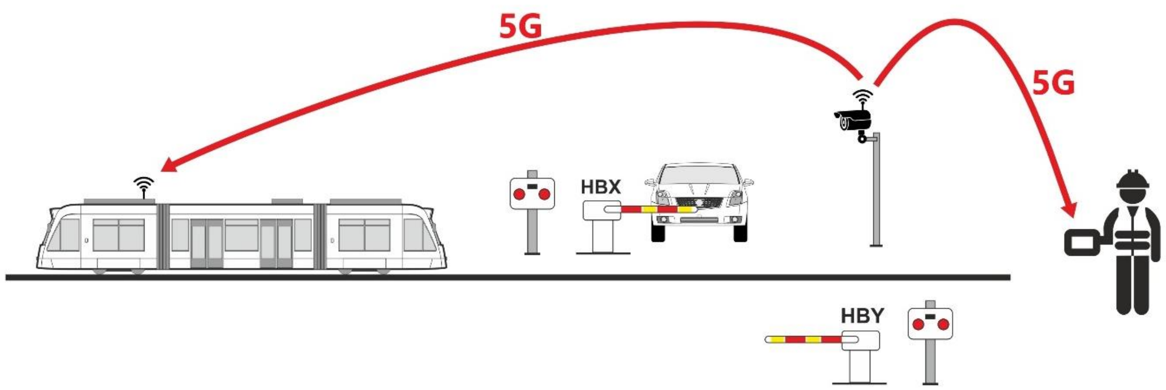

FIGURE 63: EFACEC_S PILOT – UC2

Figure 64 depicts the logical architecture for the connected worker EFACEC_S-UC2, including all the necessary components and labelled interfaces.

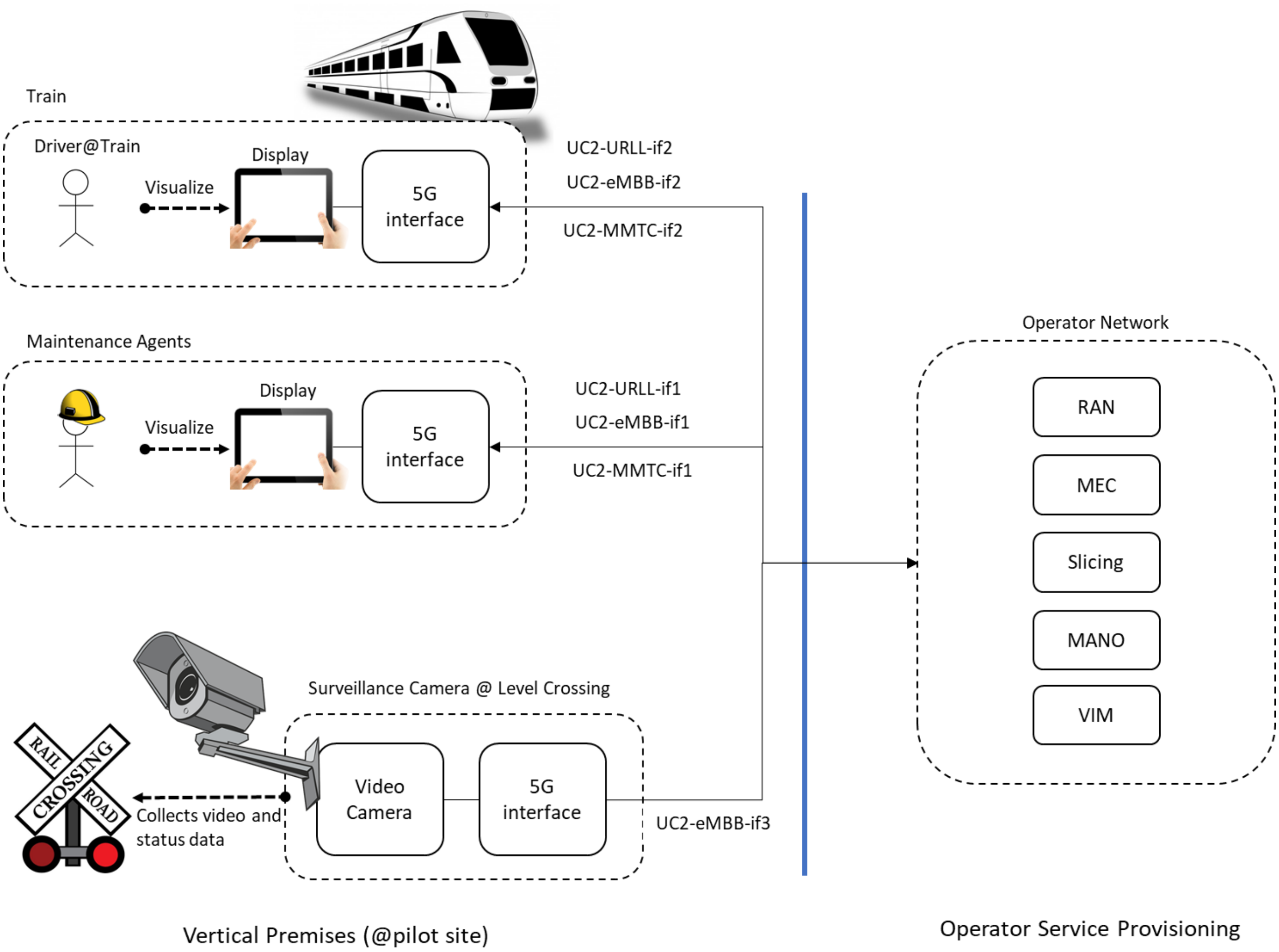

FIGURE 64: EFACEC_S PILOT – UC2 OVERVIEW

EFACEC_S-UC2 considers a surveillance camera placed at a railroad crossing, able to broadcast its video feed towards an incoming train (arriving or leaving the Aveiro harbour) and a local maintenance crew, via a 5G network. A mobile operator network provides the necessary link between all three actors, supported by all the RAN and Core operation service provisioning mechanisms.

Figure 65 shows the solution architecture of the EFACEC_S-UC2, allowing the real-time video transmission between the LX site and the train driver/Maintenance staff and Level Crossing Supervision.

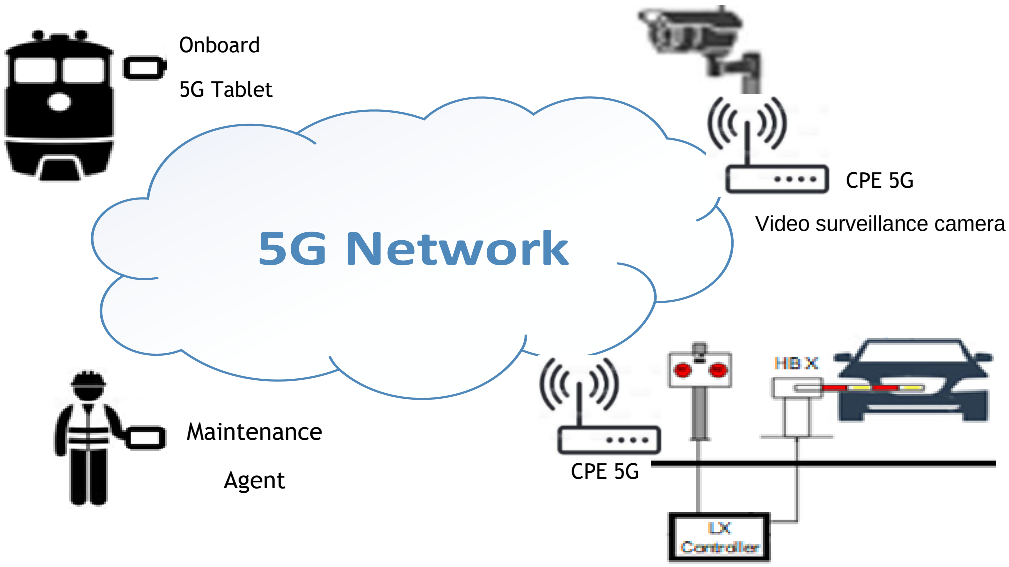

FIGURE 65: EFACEC_S PILOT – UC2 REAL-TIME VIDEO TRANSMISSION BETWEEN THE LEVEL CROSSING SITE AND THE TRAIN DRIVER/MAINTENANCE STAFF + LEVEL CROSSING SUPERVISION

As in EFACEC_S-UC1, the 5Gr-VS is used to express the necessary slice requirements for the video feed, which are then used by the SONATA orchestrator at the Aveiro 5G-VINNI testbed to establish the connectivity and service.

Figure 65 represents the logic diagram of the EFACEC_S-UC2 showing all the layers to support de 5G communication between the video camera and the driver onboard console

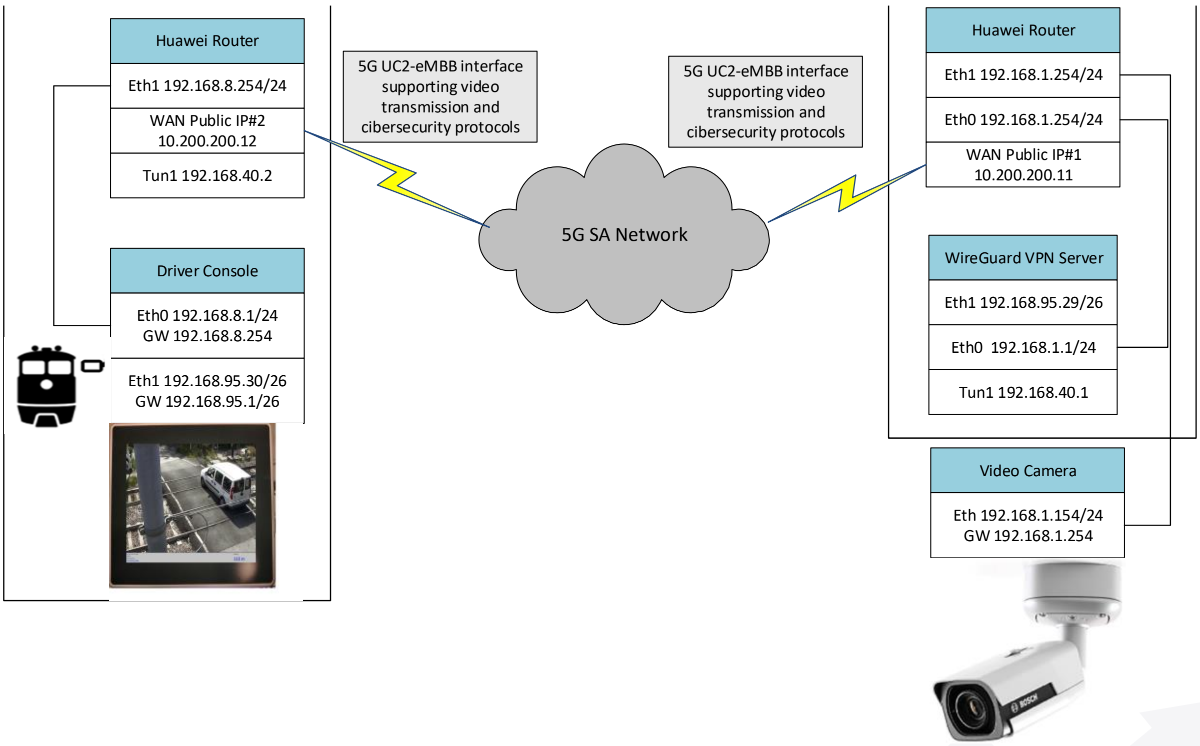

FIGURE 66: EFACEC_S PILOT – UC2 REAL-TIME VIDEO TRANSMISSION BETWEEN THE LEVEL CROSSING SITE AND THE TRAIN DRIVER

5.3.1. Status

After the deployment and validation performed at lab environment level new tasks were carried out to deploy the real scenario at Pilot vertical site (Aveiro Harbour). This milestone was achieved and since the beginning of July the uses cases were being verified and validated and measurements were being collected.

The planned HW/SW components were reported in D3.4 (i.e. see Table 5 and Table 6 therein). Some modifications have been required with respect to the original tables. For that reason, the updated details for EFACEC_S-UC2 are reported in the following tables, adding details and pictures of the real environment.

TABLE 5: EFACEC_S PILOT – UC2 HW COMPONENTS

Component	Description	Location / HW/SW
Train	The machine responsible to transport people or freight	Aveiro Harbour (Figure 56, Figure 67)
Tablet/Mobile Devices	Devices installed in the train and to be used by maintenance agent to monitor the level crossing area (video) and to assure the proper installation operation	Train/Aveiro Harbour (Figure 68)
HD Video Camera	Device (video camera) that is installed in the level crossing area and allows surveillance and image transmission to the train and to a command center	Level Crossing area-Aveiro Harbour (Figure 69)
Command Centre	Technical and Operation rooms to support the monitor and control of the Level Crossing	Level Crossing area-Aveiro Harbour
LX controller	Shelter of devices that receive sensors and equipment information, process this information and assures the LX actions (railways signaling operation).	Level Crossing area-Aveiro Harbour (Figure 70)
GPS position system	Device installed in the train in order to report its geographical positioning. The application and the GPS computations runs in the video console device	Train-Aveiro Harbour (Figure 71)
5G Interface (CPE)	Mobile network interface able to connect to a 5G mobile network	Train, Maintenance Crew Terminal, Surveillance Camera (Figure 72)
LTE router	Mobile network interface able to connect to a LTE mobile network. Used just for functional validation of the Level Crossing safety application.	Train, Maintenance Crew Terminal, Surveillance Camera
Core 5G	Mobile network core elements	IT- Building #1
RAN	The RAN portion of the operator's mobile network	CU + DU IT- Building #2; RU -Aveiro Harbour

FIGURE 67: EFACEC_S PILOT – UC2 TRAIN (AVEIRO HARBOUR)

FIGURE 68: EFACEC_S PILOT – UC2 TABLET/VIDEO CONSOLE

FIGURE 69: EFACEC_S PILOT – UC2 HD VIDEO CAMERA (LEVEL CROSSING AREA)

FIGURE 70: EFACEC_S PILOT – UC2 LX CONTROLLER

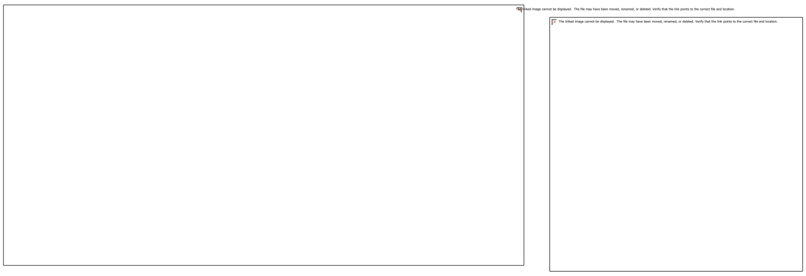

FIGURE 71: EFACEC_S PILOT – UC2 GPS SYSTEM FOR TRAIN LOCATION

FIGURE 72: EFACEC_S PILOT – UC2 5G CPE'S (HUAWEI SOLUTION), 5G ANTENNA AND THE CABINET IN THE VERTICAL SITE

TABLE 6: EFACEC_S PILOT – UC2 SW COMPONENTS

Component	Description	Location
Command Centre:	Software applications to support the monitor and control of the Level Crossing	Level Crossing area- Aveiro Harbour
LX controller (SW application)	Shelter of devices that receive sensors and equipment information, process this information and assures the LX actions (railways signaling operation). It also supports the signaling safety applications, the communications and the safety protocols	Level Crossing area- Aveiro Harbour
5G Interface (cybersecurity application)	Mobile network interface able to connect to a 5G mobile network supporting the cybersecurity mechanisms to assure a dedicated and secure tunnel.	Train, Maintenance Crew Terminal, Surveillance Camera
EFACEC GUI for video console devices	Application running in the video onboard device, allowing the processing of the train positioning, providing performance information, running algorithms to stablish	

Component	Description	Location
	video communications according a pre-configuration railway track position and also integrates the cybersecurity application. This application also integrates the Software probes allowing the monitoring information to be sent to Prometheus	
Core 5G	Mobile network core elements	IT- Building #1
MANO	Mobile Network Management and Orchestration capability	IT – building #1
VIM	Virtualized Infrastructure Management Capability	IT building #1

6. Conclusions

This deliverable was organized into four main sections, one for each pilot: Section 2 for the INNOVALIA pilot, Section 3 for the COMAU pilot, Section 4 for the EFACEC_E pilot, and Section 5 for the EFACEC_S pilot. In each section, key information about the pilot projects is provided in terms of 5G infrastructure, innovations integration and their role, vertical integration capabilities and use cases integration.

D3.6 addressed several subjects and aims to provide a final and integrated overview of the project's use cases and of the integration between 5Growth and the ICT-17 platforms. D3.6 along D3.5 ("Final Version of Software Implementation") which contains the documentation of the final release of integration of the 5Growth with the software components of the ICT-17 platforms, makes available detailed information concerning the deployed software, infrastructure and the features of the system.

D3.6 reports the final status of the pilots as of November 2021 (M30) within which the pilots final validation campaigns were conducted. Despite of the negative impacts of COVID-19 (restricted travel, lack of supplies, limited access to the deployment site), the pilot deployments, tests and validation campaigns were carried out and the WP3 objectives were achieved:

- Integration of the novel 5Growth components developed in WP2 into the 5G baseline architecture.
- Deployment of the 5Growth system at all trial sites, including software and hardware components for all planned use cases such as the 5G service-based core, NR.
- Integration and execution of vertical use cases in ICT-17 platforms.
- Field trial of 5Growth pilots over the 5G platform deployed by 5G EVE/5G-VINNI, to demonstrate vertical use cases.

7. References

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[13] D-N00001052019-EFS-LX-0009 – 5Growth EFACEC_S Electrical Schematics

[14] D-N00001052019-ELD-LX-0016 – 5Growth EFACEC_S Cable Plan

[15] D-N00001052019-ELD-LX-0012 - 5Growth EFACEC_S Cable Routing and Equipment Placement Diagram

[16] EGTSSF000-LC-DW-0699 - 5Growth EFACEC_S Road Signal – Foundation:

[17] EGTSEN000-SG-DW-1285 - 5Growth EFACEC_S Level Crossing Cabinet - Foundation and Layout

[18] EGTSEN000-LC-DW-1323 - 5Growth EFACEC_S Solar Panel – Foundation

[19] D-N00001052019-EDC-LX-0015 - 5Growth EFACEC_S Strike in Cabinet - Foundation and Layout

[20] D-N00001052019-EDB-LX-0002 - 5Growth EFACEC_S General Description

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8. Annex. INNOVALIA coverage study and pre-installation work

To perform a successful installation on field, preparatory pre-installation work must be done. First, a preliminary coverage study was done. See in Figure 73 the Reference Signal Received Power (RSRP), where it is foreseen that the aisles of the room would be properly covered, while there are a few areas where the signal strength could drop a little bit due to the obstacles in the way.

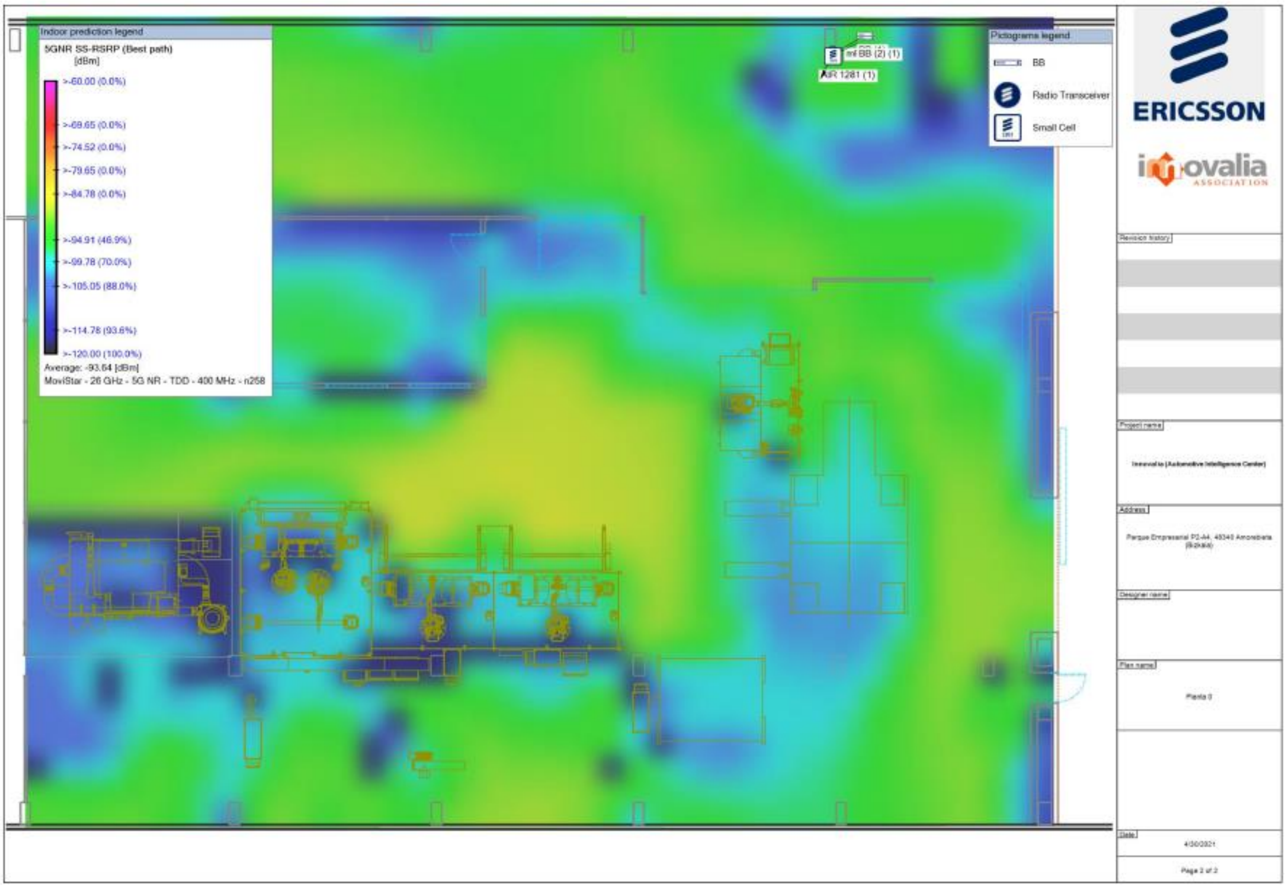

FIGURE 73: INNOVALIA COVERAGE STUDY

Later, a visit to the site was done to decide where and how to place the antennas, verify how to make the cabling and check the materials that would be needed. This work is illustrated in the two following pictures. Figure 74 shows the installation layout on the factory, while Figure 75 shows the installation layout on Innovalia's control room.

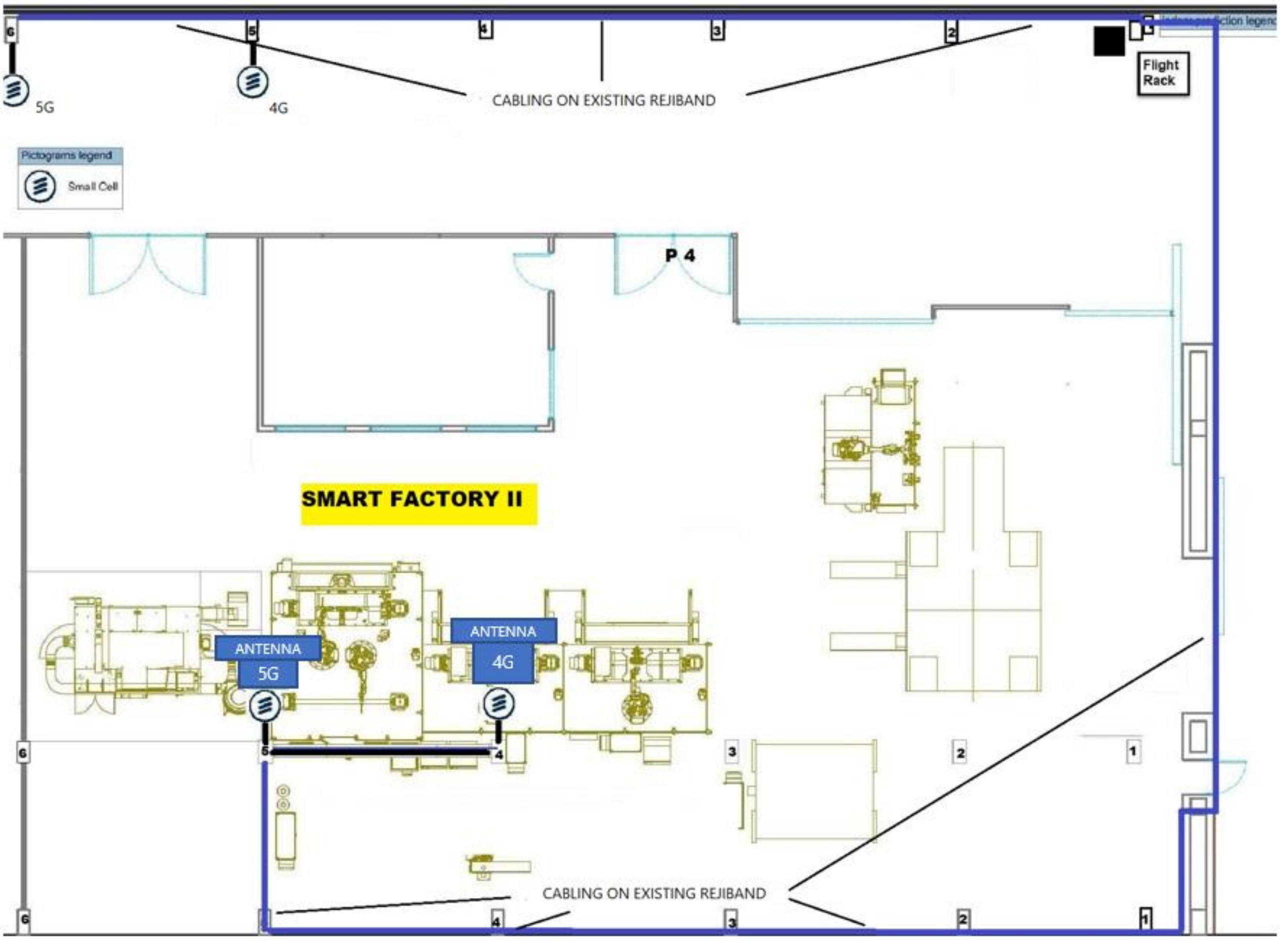

FIGURE 74: INNOVALIA FACTORY LAYOUT

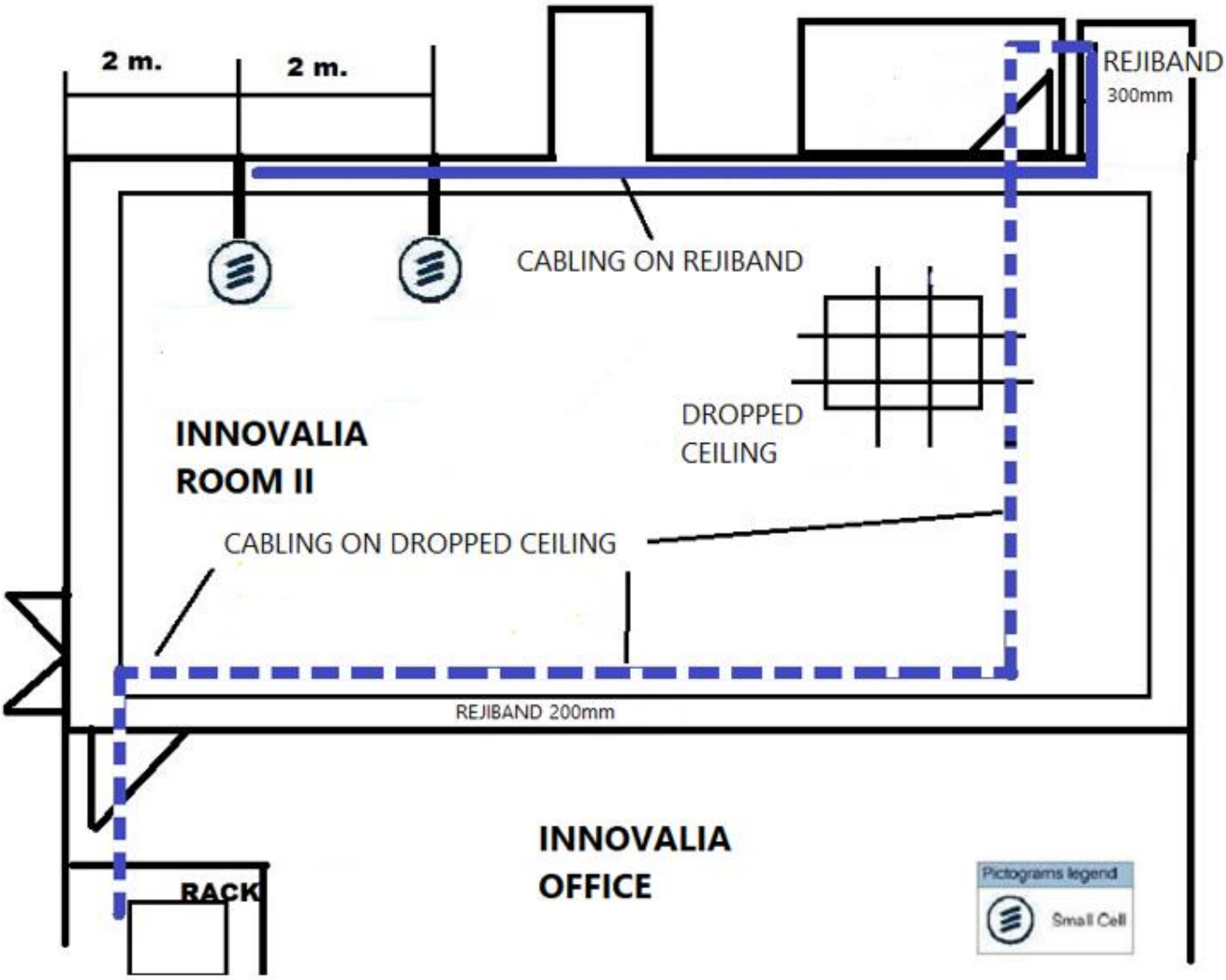

FIGURE 75: INNOVALIA CONTROL ROOM LAYOUT