H2020 5Growth Project
Grant No. 856709

D3.2: Specification of ICT17 in-house deployment

Abstract

This deliverable provides a technical solution for experimentation and business validation of the vertical use cases in the scope of 5Growth project. As such, using the initial analysis reported in deliverable D3.1 as a starting point, this report progresses on the definition of the technical solution associated with each selected vertical pilot as well as on the integration options of 5Growth with the selected ICT-17 platforms.

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Disclaimer

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Contents

List of Figures

List of Tables

List of Acronyms

5G-NR – 5G New Radio

5Gr-RL – 5Growth Resource Layer

5Gr-SO – 5Growth Service Orchestrator

5Gr-VS – 5Growth Vertical Slicer

AGV – Automated Guided Vehicle

AMI – Advanced Metering Infrastructure

API – Application Programming Interface

AR – Augmented Reality

BB – Baseband

CB – Context Blueprint

CMM – Coordinate-Measuring Machine

CP – Control Plane

CPE – Customer Premises Equipment

CSMF – Communication Service Management Function

CUPS – Control and User Plane Separation

DSS – Decision Support System

E2E – End-to-End

eCPRI – enhanced Common Public Radio Interface

eMBB – enhanced Mobile Broadband

ExpB – Experiment Blueprint

ExpD – Experiment Descriptor

GPS – Global Positioning System

GUI – Graphical User Interface

HSS – Home Subscriber Server

I4.0 – Industry 4.0

IIoT – Industrial Internet of Things

IRU – Indoor Radio Units

KPI – Key Performance Indicator

LTE – Long Term Evolution

LV – Low-Voltage

LVS3 – Low Voltage Sensor

LX – Level Crossing

MANO – Mobile Network Management and Orchestration

mMTC – massive Machine Type Communications

MTTR – Mean Time To Repair

NDI – Network Device Interface

NFVI – Network Functions Virtualization Infrastructure

NFVO – Network Functions Virtualization Orchestrator

NG-PON2 – Next-Generation Passive Optical Network 2

NPN – Non-Public Network

NS – Network Service

NSA – Non-standalone

NSD – Network Service Descriptor

NSMF – Network Service Management Function

NTP – Network Time Protocol

OMS – Outage Management System

OTT – Over-The-Top

OWD – One Way Delay

PTZ – Pain-Tilt-Zoom

RAN – Radio Access Network

SDI – Serial Digital Interface

SLA – Service Level Agreement

SO – Service Orchestrator

TCB – Test Case Blueprint

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 Service

VSB – Vertical Service Blueprint

VSD – Vertical Service Descriptor

WIM – WAN Infrastructure Manager

ZDM – Zero Defect Manufacturing

Executive Summary and Key Contributions

5Growth targets the technological and business validation of 5G technologies from a vertical's point of view through real life pilots, centered around four specific industry sectors involved, namely: Industry 4.0 (i.e., COMAU and INNOVALIA), transport (i.e., EFACEC_S) and energy (i.e., EFACEC_E).

This deliverable provides a mature definition of the technical solution of each vertical pilot under the scope of 5Growth, as well as the integration options of 5Growth platform with the selected ICT-17 platforms (namely, 5G-EVE and 5G-VINNI), that, ultimately, will allow the business validation of the selected use cases.

Each vertical pilot defines a set of use cases to be demonstrated, which will allow the validation of 5G core technologies and 5Growth service platform to satisfy the functional and technical requirements of the selected 5G-enabled vertical applications. An in-depth definition of the technical solution of each vertical pilot is provided in this deliverable, which main key contributions are summarized as follows:

1) For COMAU vertical pilot:
    a) Plan and deployment setup for the provisioning of 5G connectivity at the COMAU vertical premise.
    b) Definition the three targeted use cases: (*i*) Digital Twin Apps; (*ii*) Telemetry/Monitoring Apps; and (*iii*) Digital Tutorial and Remote Support.
        i. Use case modelling, spanning across COMAU and TIM sites.
        ii. Identification of the required hardware and software components and their deployment location.
        iii. Identification of deployment and implementation options (e.g., for the Digital Twin Apps, robots can be controlled either using a computer with Hololens or using a mobile device).
        iv. Definition of a set of experiments that will allow the validation of the different components that are part of the use cases, regarding their functional behaviour and their technical KPIs.
        v. Planning the development roadmap, from the design up to the validation stages.
2) For EFACEC_E vertical pilot:
    a) Plan and deployment setup for the provisioning of 5G connectivity at the University of Aveiro.
    b) Definition the two targeted use cases: (*i*) Advanced Monitoring and Maintenance Support for Secondary Substation MV/LV distribution substation; and (*ii*) Advanced Critical Signal and Data Exchange across wide smart metering and measurement infrastructures.

i. Use case modelling, spanning across University of Aveiro and ALB sites.

ii. Identification of the different experimentation and validation campaigns: initially on a lab environment and, later, at University of Aveiro premises.

iii. Identification of the required hardware and software components and their deployment location, on each of the identified campaigns.

iv. Identification of deployment and implementation options, namely in terms of connectivity support on each one of the campaigns.

v. Definition of a set of experiments that will allow the validation of the different components that are part of the use cases, regarding their functional behaviour.

vi. Planning the development roadmap, from the design up to the validation stages.

3) For EFACEC_S vertical pilot:

   a) Plan and deployment setup for the provisioning of 5G connectivity at the Aveiro Harbor.

   b) Definition the two targeted use cases: (*i*) Safety Critical Communications; and (*ii*) Non-Safety Critical Communications.

      i. Use case modelling, spanning across Aveiro Harbor and ALB sites.

      ii. Identification of the different experimentation and validation campaigns: initially on a lab environment and, later, at Aveiro Harbor premises.

      iii. Identification of the required hardware and software components and their deployment location, on each of the identified campaigns.

      iv. Identification of deployment and implementation options, namely in terms of connectivity support on each one of the campaigns.

      v. Definition of a set of experiments that will allow the validation of the different components that are part of the use cases, regarding their functional behaviour and their technical KPIs.

      vi. Planning the development roadmap, from the design up to the validation stages.

4) For INNOVALIA vertical pilot:

   a) Plan and deployment setup for the provisioning of 5G connectivity at the INNOVALIA premises.

   b) Definition the two targeted use cases: (*i*) Connected Worker Remote Operation of Quality Equipment; and (*ii*) Connected Worker - Augmented ZDM Decision Support System.

i. Use case modelling, spanning across INNOVALIA and 5TONIC (5G-EVE) sites.

ii. Identification of the different experimentation and validation campaigns: initially on 5TONIC lab only and, later, at INNOVALIA premises.

iii. Identification of the required hardware and software components and their deployment location, on each of the identified campaigns.

iv. Identification of deployment and implementation options, regarding the development of supporting applications.

v. Definition of a set of experiments that will allow the validation of the different components that are part of the use cases, regarding their functional behaviour and their technical KPIs.

vi. Planning the development roadmap, from the design up to the validation stages.

The different use cases will be implemented over an infrastructure that comprises resources from the vertical premises and the 5G End-to-End platforms developed by ICT-17 platforms (i.e., 5G-EVE and 5G-VINNI). With this approach in mind, the 5Growth integration options with both 5G-EVE and 5G-VINNI are further analyzed:

- Two options are available for the integration of 5Growth with 5G-EVE. In the first option, the 5Gr-VS interacts with both the 5Gr-SO and 5G-EVE platform, requesting the deployment and instantiation of part of the vertical service under each site facilities. In the second option, the 5Gr-VS also interacts only with the 5G-EVE platform, requesting the deployment and instantiation of the whole vertical service. Then, it is 5G-EVE platform that instructs what network services are deployed and instantiated under the 5Growth site facility (by interacting with the 5Gr-SO) and under 5G-EVE site facility.
- The integration of 5Growth with 5G-VINNI (namely, the Aveiro experimental facility site) will follow a single integration option. In this option, the 5Gr-VS interacts with the NSMF at 5G-VINNI. This integration at the 5G-VINNI will be done with the SONATA platform that is available at the 5G-VINNI Aveiro experimental facility site.

Due to the exceptional situation due to the COVID-19 pandemic, this document also includes an analysis of its the impact on the plans and the roadmaps for the execution of the vertical pilots, along with the proposed contingency plans for mitigating such impact. It considers that normal working activities are going to be restricted for four months, including access to the labs and to the site facilities. As such, the assumed facts and the probable threats are identified, and the roadmaps are revisited to assess their impact on the execution of the vertical pilots. Keeping the original ending project dates, two options are assessed: (*i*) keep milestones' planned dates, through scope contention of M18's milestone and progressive catch-up afterwards; and (*ii*) delay M18's milestone, in order to keep the original planned activities unaffected.

All the findings reported in this deliverable are going to be further explored and detailed during the execution of the project in the scope of T3.2 (Platform implementation and deployment in ICT-17 and vertical premises) and T3.3-T3.6 (Integration with vertical systems and execution of each vertical pilot).

1. Introduction

5Growth project aims at integrating the 5Growth service platform with the selected ICT-17 platforms (namely 5G-EVE and 5G-VINNI), along with its deployment into complementary trial sites on the premises of verticals, in order to provide an extensive validation and trialing of 5G-enabled vertical applications. Such applications target specific industry sectors, namely Industry 4.0 (i.e., COMAU and INNOVALIA), transport (i.e., EFACEC_S) and energy (i.e., EFACEC_E), and are expected to be deployed in a TRL6/TRL7-comparable environment as close as possible to a real 5G commercial environment. In particular:

- COMAU will carry out its experimentation and validation activities on Industry 4.0 use cases at its own factory premises in the area of Turin, Italy.
- EFACEC_E will carry out its experimentation and validation campaigns on Energy use cases at University of Aveiro, Portugal; including an early validation in a lab environment on the premises of EFACEC.
- EFACEC_S will carry out its experimentation and validation campaigns on Transportation use cases at Aveiro harbour, Portugal; including an early validation in a lab environment.
- INNOVALIA will carry out its experimentation and validation activities on Industry 4.0 use cases both at 5TONIC site in Leganés, Spain, and at their R&D premises in Bilbao, Spain.

However, before any deployment and experimentation is put in place, it is required to plan and to develop the technological and architectural solutions considered for each vertical pilot use case as well as the proposed enhancements for each of the relevant locations. In addition, as each vertical pilot is going to leverage a selected ICT-17 platform, it is required to study how these platforms are going to integrate with the 5Growth service platform.

The remaining of this deliverable is structured as follows:

Section 2 provides a mature in-depth description of the technical solution for each vertical pilot, including (*i*) details about the 5G infrastructure deployment in the vertical premises; (*ii*) overview and modelling of each selected use case with the identification of the required hardware and software components; and (*iii*) the definition of a set of experiments that will allow an initial validation of different components of the use case. In addition, this section provides the plans and roadmaps for the deployment, experimentation and validation of each vertical pilot use case, along with an analysis of the impact of COVID-19 on its execution.

Section 3 extends the initial study performed in deliverable D3.1 [1] regarding the integration of 5Growth with the selected ICT-17 platforms. As such, this section details the selected mechanisms to manage the interactions between 5Growth and 5G-VINNI/5G-EVE, highlighting some initial workflows.

Finally, Section 4 summarizes the main findings in this deliverable while setting the prospects and pointers for future work.

2. Technical solution for the 5Growth Verticals Use Cases

This section presents the technical solutions of the selected use cases of each vertical pilot. For each vertical pilot, the 5G infrastructure deployment in the vertical premises is detailed along with its planned roadmap. Then, for each of the selected use cases, the use case modelling and the required hardware and software are presented, along with a description of initial experiments that will allow the validation of specific components as well as the plans and roadmaps for the implementation of the use case. Finally, an analysis of the COVID-19 impact on the plans and roadmaps is presented, highlighting the planned contingency actions.

2.1. COMAU Vertical Pilot

Figure 1 illustrates the logical architecture of the COMAU Vertical Pilot highlighting the main components placed on the COMAU and TIM premises in the area of Turin, Italy. This architecture supports all the three use cases planned in the COMAU's Industry 4.0 pilot, later indicated as COMAU-UC1 (Digital Twin Apps), COMAU-UC2 (Telemetry/Monitoring Apps), COMAU-UC3 (Remote Support and Digital Tutorial). More details about how this general architecture is unfolded in the three use cases is reported in Section 2.1.2, Section 2.1.3 and Section 2.1.4 where, in specific tables, are reported details of the various hardware and software components.

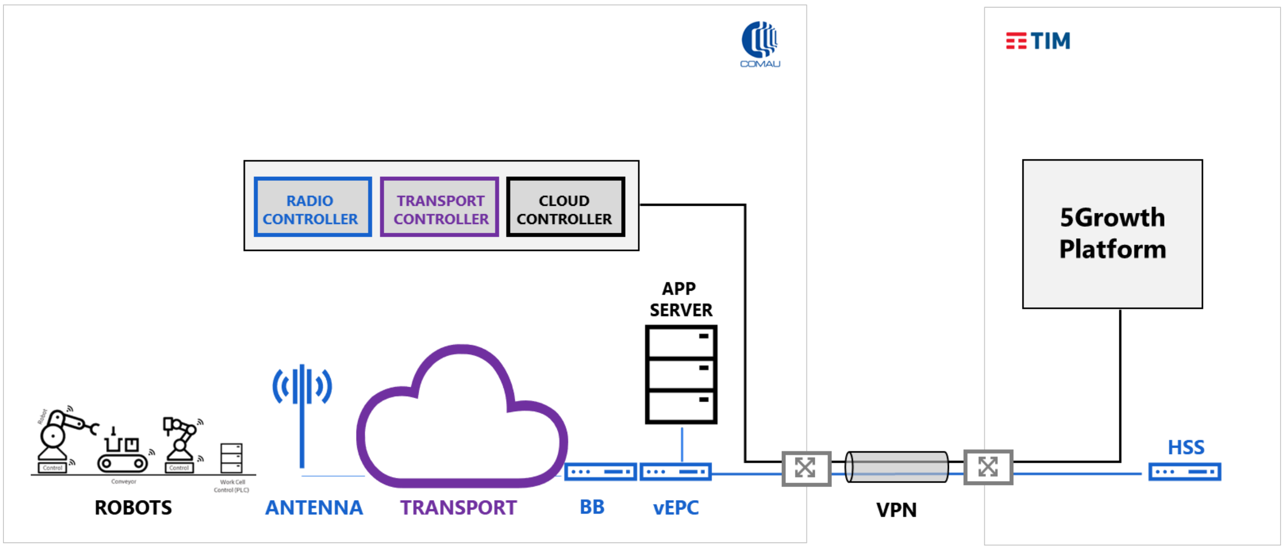


FIGURE 1: COMAU PILOT LOGICAL ARCHITECTURE

2.1.1. Infrastructure deployment in vertical premises

2.1.1.1. Roadmap

Figure 2 illustrates the main steps and their time plan for the deployment of the pilot components at the COMAU and TIM sites in the area of Turin, Italy. This plan refers to the three use cases included in the pilot. The chart shown in the figure starts at M4 when the in-field activities started. This plan intends to gradually setup the radio component, the underlying transport network and the 5Growth platform in which all the involved resources are coordinated.

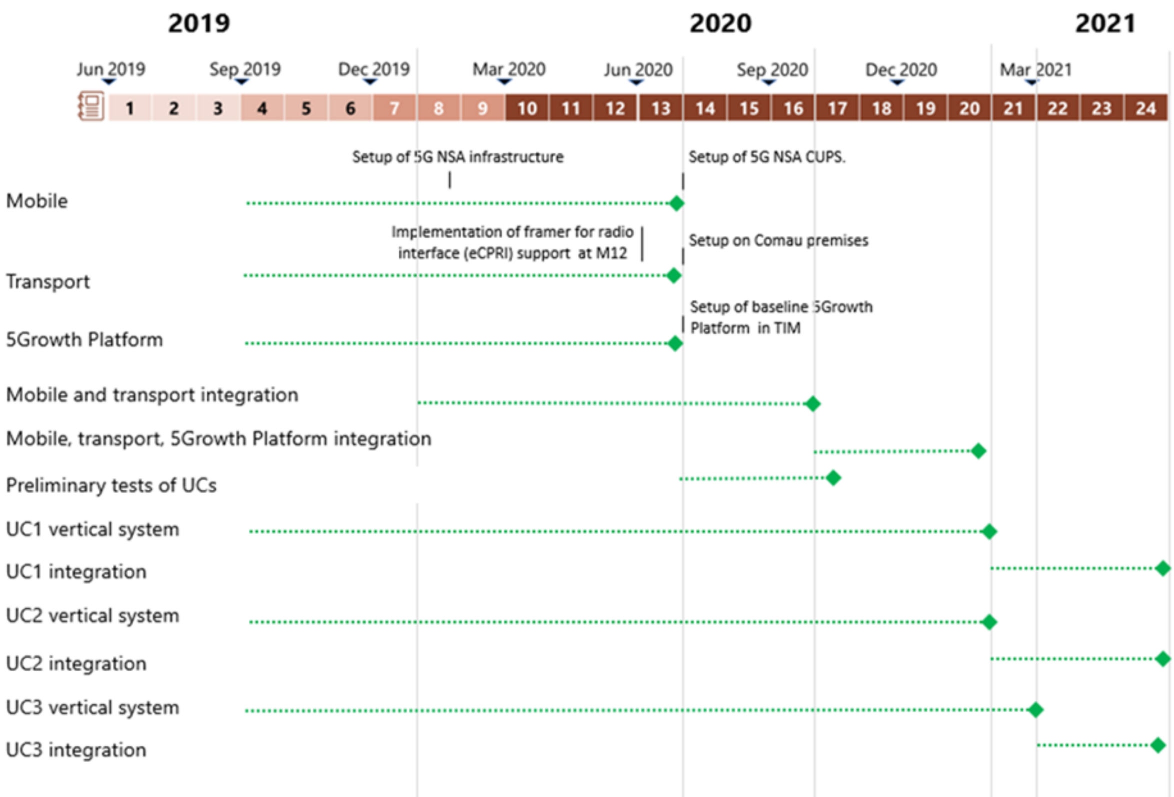


FIGURE 2: COMAU PILOT DEPLOYMENT PLAN

The 5G NSA network was installed and tested in the COMAU premises by end of M8, as illustrated in Figure 2. The next important step is preparing the operator's core network (i.e. TIM) to support the new 5G radio. By introducing Control and User Plane Separation (CUPS) in vEPC, operators can achieve maximum flexibility and completely independent capacity scaling for Control and User planes. In the CUPS setup, the user plane remains in COMAU premises while the control plane is migrated to TIM premises (it evolves the architecture depicted in Figure 1 where the HSS only is hosted on TIM premises). Such configuration is better suited to the needs of a real commercial network deployment since the mobile operator can serve more verticals with the same vEPC.

The transport layer, which currently comprises a fiber link subtended between the base station and the antenna, will evolve to support the transmission of eCPRI traffic, complying with the relevant latency constraints. In this direction, a specific framing will be introduced to wrap the eCPRI protocol over optical channels.

Finally, the 5Growth platform will be integrated with the pilot. Hosted in TIM site, the platform will include an orchestrator with the role to automate the instantiation and configuration of network services by coordinating the resource allocation of radio, transport, and cloud.

The integration of radio and transport is planned to be completed by M16. Afterwards, starting from M17, the 5Growth platform is planned to be integrated with the solution within M20.

COMAU-UC1 and COMAU-UC2 of the COMAU pilot will be completed and operative by M20 whereas the COMAU-UC3 will be completed and operative by M21 as per detailed deployment plans described in the following sections.

2.1.1.2. Plan and deployment setup

The 5G NSA radio infrastructure has been deployed on COMAU premises. Preliminary connectivity tests have been successfully tested using both OPPO 5G Smartphones and 5G pocket routers. These devices allowed the operation of two robots related to the UC2 Telemetry/Monitoring app.

Details of the functional elements and of their interconnection are provided in Figure 3.

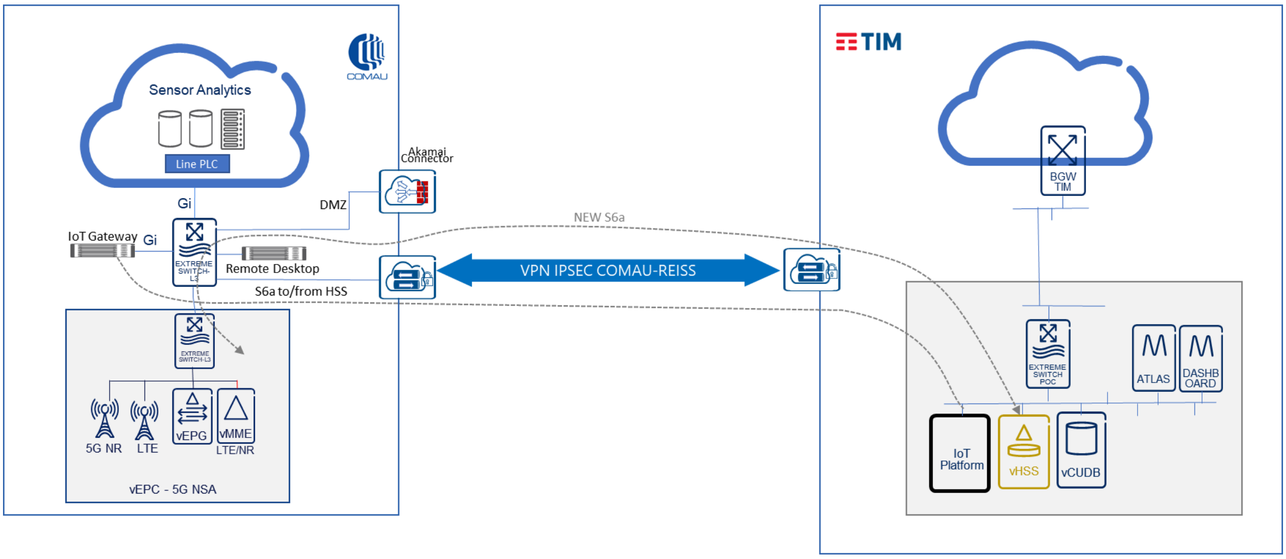


FIGURE 3: COMAU PILOT DETAIL OF RADIO DEPLOYMENT

In the current setup depicted in Figure 1, the transport segment comprises a fiber point-to-point link connecting the baseband (BB) unit with the antenna side. Such simple transport arrangement will evolve into the transport infrastructure depicted in Figure 4, which will constitute a more realistic representation of a fiber-based network serving industrial radio needs.

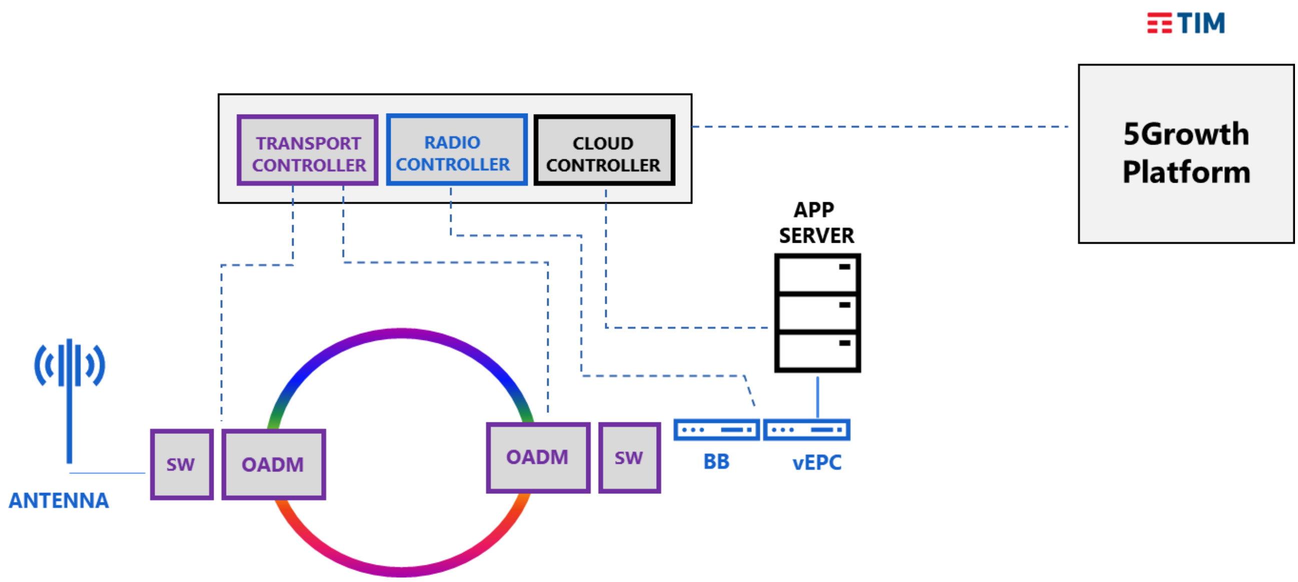


FIGURE 4: COMAU PILOT DETAIL OF THE TRANPORT INFRASTRUCTURE ON THE COMAU PREMISES

The implementation of such a transport infrastructure on COMAU premises is planned by M13, including one additional week for tests. A preliminary activity, planned within M12, will consist on the implementation of a framer, to wrap the eCPRI radio interface protocol over optical channels.

The final tests across the three use cases, operating on the radio-transport integrated infrastructure (still without integration with the 5Growth platform), are planned within M16. Later, the integration with the 5Growth platform will be done and tested.

2.1.2. Use Case 1: Digital Twin Apps

2.1.2.1. Use Case Modelling

The Digital Twin is essentially a virtual representation of something that exists in the real world, such as physical assets, processes, people, places, systems and devices connected in real-time thanks to a continuous data stream.

To demonstrate 5G´s low latency performance and its feasibility in URLLC scenarios, this use case has the objective to create a digital twin of an actual robot to achieve two goals:

1. Enabling real-time reporting on the robot status, with no delays about robot status and its performance without the need to be geographically close to it; and
2. Enabling remote control using an interface to receive commands from external applications or virtual machines.

As such, this use case has as major objective to demonstrate the 5G low latency feature (i.e. URLLC profile).

As shown in Figure 5, the use case architecture includes a robot and a computer, both attached to the 5G network via respective user equipment units (5G CPEs), and a computer producing instructions to the robot. HoloLens goggles are connected to the computer via Wi-Fi as it is the only connection supported by this device.

In a first implementation step, COMAU has used a robot model e.DO [2], which is a modular small "educational" robot having the same multi-axis movements capabilities of a commercial "industrial" robot. In a second step, COMAU will replace e.DO with a Racer model [3] (the one depicted in the figures), which is a robot projected for quick applications in restricted spaces, including handling, assembly and pick-and-place operations.

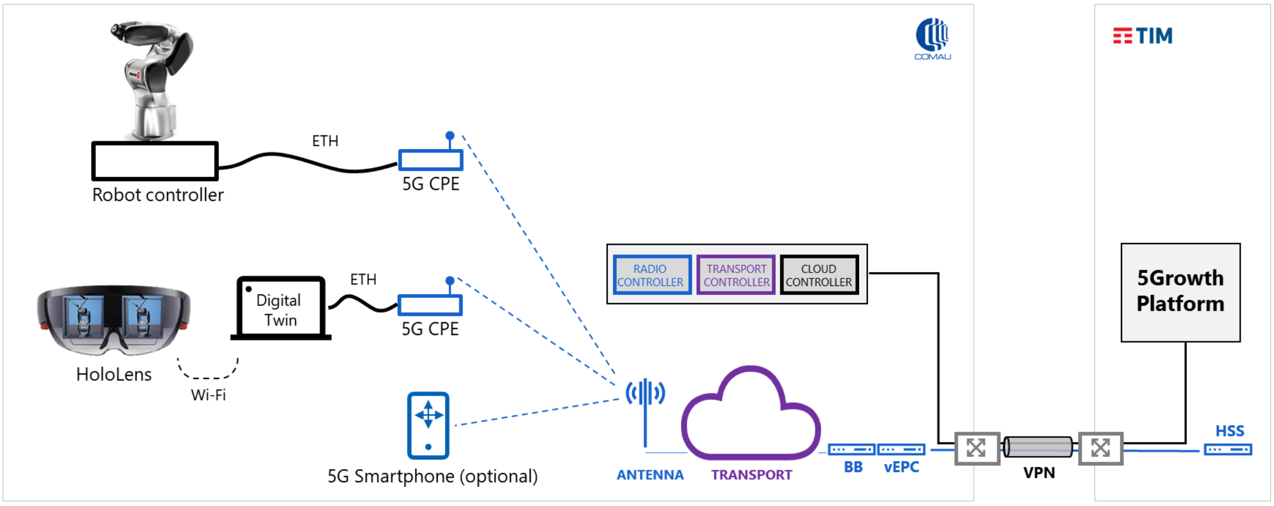


FIGURE 5: COMAU-UC1 OVERVIEW

This use case consists in a robot remotely controlled by a computer. To this end, the workflow consists on periodically sending the robot coordinates of the position the robot has to assume; gather positioning data from the robot controller in real-time (which estimates the actual position of the robot via the encoders installed on the axes motor); and replicate the behavior via a virtual version on the augmented reality device (i.e. in the HoloLens).

It is important to transmit positioning data of the robot remotely in order to change the current paradigm in which robots are programmed offline, each with its own program language.

In order to further investigate this aspect, a remote controller of the robot has been instrumented into a 5G smartphone. With this remote controller, which also has low-latency requirements, an operator has the ability to instruct and drive the robot using a sort of "joystick" as an alternative to the batch of instructions sent by the computer.

2.1.2.2. Hardware / Software components

TABLE 1: COMAU-UC1 HARDWARE COMPONENTS

Component	Description	Location
Anthropomorphic Robot	COMAU robot (e.DO and Racer models), remotely controlled and replicated in the digital twin system	COMAU site

Component	Description	Location
Augmented Reality Device (HoloLens)	Device where the virtual twin of the actual robot is shown via AR with real time position emulation.	COMAU site
Computer including a display	Computer where robot instructions are elaborated (and sent to the robot) and where the AR software is processed. AR Device is connected with this computer via Wi-Fi.	COMAU site
5G Smartphone (optional)	Smartphone, connected through 5G, where an application allows to control the robot from a remote location	COMAU site
Antenna System	Ericsson antenna system for 5G	COMAU site
Baseband (BB) System	Ericsson Baseband System	COMAU site
vEPC	Ericsson Virtual Evolved Packet Core providing core radio functionalities. vEPC functions are entirely deployed on COMAU premises in first phase while just the HSS functionality is hosted in TIM. Later, the 5G architecture will evolve into a CUPS configuration with the user plane located in COMAU and the control plane located in TIM.	COMAU site. TIM site in the CUPS evolution.
Server for controllers	Server where RAN controller, VIM, and WIM runs (related to the 5Growth platform hosted in TIM)	COMAU site
Transport	Wired connection between the antenna system, BB, vEPC, Switches	COMAU and TIM sites
HSS	Home Subscriber Server	TIM site
5Growth platform server	Server where the 5Growth components run (5Gr-VS, 5Gr-SO, 5Gr-RL) as reported in D2.1 [4]	TIM site

TABLE 2: COMAU-UC1 SOFTWARE COMPONENTS

Component	Description	Location
Augmented Reality Application	Software related to the realization of the digital twin of the actual robot	COMAU site
Control software of the robot	Software controlling the robot, running on the same computer where the digital twin application runs	COMAU site
Application in the 5G Smartphone (optional)	Application running on the smartphone to drive the robot from remote	COMAU site
5Growth software platform	5Growth software components (5Gr-VS, 5Gr-SO, 5Gr-RL) as reported in D2.1 [4]	TIM site

2.1.2.3. Deployment and implementation setup

As mentioned previously, this use case envisions the control of the robot either using a computer (which will be referred to as "Option A") or, alternatively, using a mobile device (which will be referred to as "Option B").

In Option A, two 5G CPEs are used to connect the robot and the computer (with HoloLens) to the overall architecture. CPEs are linked with the robot and the computer with Ethernet cables.

In Option B, the computer and the respective 5G CPE are replaced with a 5G-enabled smartphone. Meaning, that a single 5G CPE is used to connect the robot with the overall architecture, while the smartphone connects directly to overall architecture using its 5G capabilities. The remote-control component needs to be developed and deployed not only in an actual computer or virtual machine (VM), but also in the 5G smartphone to implement the Option B.

Regarding the software, Unity has been used as library to show the virtual twin of the robot synchronized in with the actual position streaming on the HoloLens. In turn, the computer and the smartphone use a similar interface, implemented in the robot controller, for gathering real-time positioning data and for transmitting movement commands.

2.1.2.4. Initial experiment description

Currently, in Option A, the application that uses COMAU open-source e.DO robot has been already developed and tested with two alternative 5G CPEs. In Option B, industrial robots work on a real-time operating system, which means strict latency requirements down to 1 ms. This will lead to more challenging experiments.

Before defining technical KPIs regarding 5G network performance, the following functional experiments can provide a practical means to verify the expected functional behaviour:

1. Perfect synchronisation between the physical robot and the virtual one projected on the HoloLens glasses.
2. No delay in remote controlling the actual robot both from the computer and the smartphone.

Those experiments are already verified with the current solution (with the e.DO robot).

Quantitative measurements will be performed to validate the technical KPIs shown in Table 3. Full KPIs verification, including service KPIs, is the responsibility of WP4.

TABLE 3: COMAU-UC1 KPIS

KPI	Units	Expected values
E2E One Way Delay (OWD)	ms	< 15 (all end devices at same location)
Availability/Reliability	%	99.999/80
Packet Loss	%	< 0.1
Jitter	us	100

All the above-mentioned software integrations need to be tested with the 5G network, where the transport layer consists currently in just a fiber cable, including its further implementations in terms of transport layer, CUPS, VNFs, slicing and orchestration.

Once the integration phase ends, the KPIs will be further tested to validate any possible discrepancy against the expected performances on the final complete setup.

2.1.2.5. Plan and roadmap

Figure 6 shows the development roadmap for this use case.

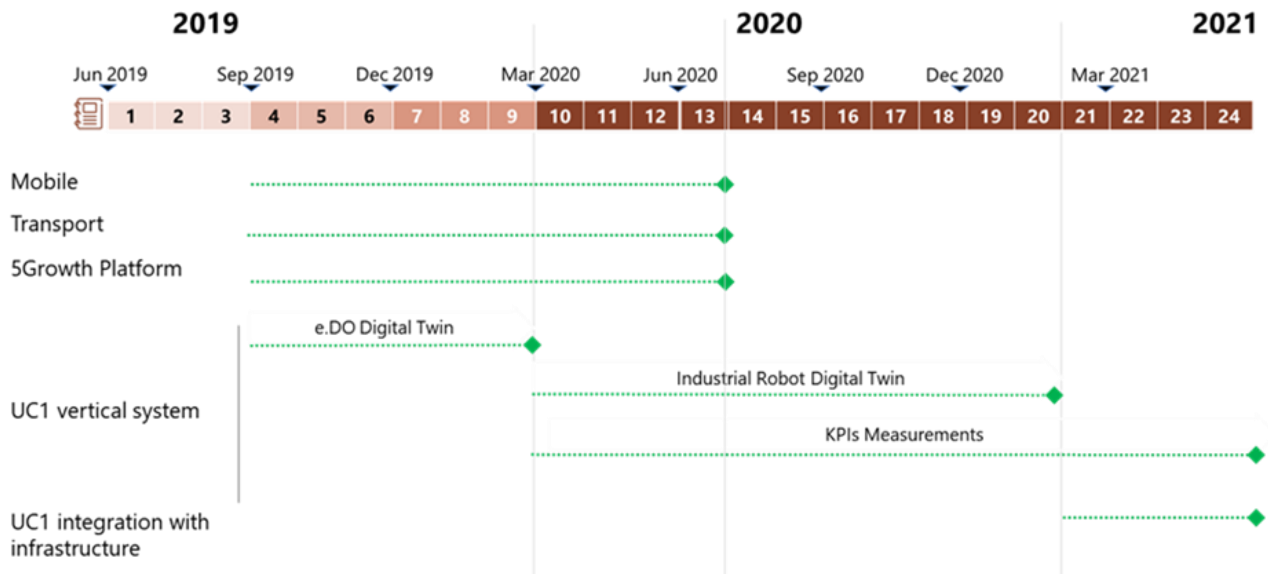


FIGURE 6: COMAU-UC1 DEPLOYMENT PLAN

The initial deployment phase for the COMAU-UC1 vertical system has already started. This included the means to collect real-time data from the robot controller, and the implementation of the interface for remote control (running on the console depicted in Figure 5). This initial phase is based on the e.DO robot and it is indicated with "e.DO Digital Twin" in the above timeline. Starting from M10, the implementation will see the replacement of this robot with an industrial robot, which is indicated as "Industrial Robot Digital Twin" in the timeline. Later, approximately from M16 on, the activity will focus on the design and development of the application that will use such features, and on the implementation of the AR digital twin using the libraries of the augmented reality device. The complete implementation of the COMAU-UC1 is expected to be finished at the end of M20, including tests and bug fixes. In parallel with the development of the applications, KPIs measurement are expected to be continuously performed.

2.1.3. Use Case 2: Telemetry/Monitoring Apps

2.1.3.1. Use Case Modelling

In this use case, an extensive sensor deployment is in place to monitor and prevent failures of machinery and equipment through massive data collection (i.e. vibration, pressure, temperature and so on). 5G facilitates the installation of a wide range of different wireless sensors easy to be attached to machinery without the rigidity of cable, which is also more sensible to attrition.

COMAU has already developed its own IIoT (Industrial Internet of Things) platform, which gathers data directly from machineries as well as from sensor data. With respect to the state of art of this platform, this use case aims at reinforcing the fault predictive capabilities with more data collected via 5G.

As shown in Figure 7, the architecture involves some industrial robots and a gateway on the COMAU premises. Photocells are used as sensors to detect the presence of an object to be manipulated and a sensor is used to detect the dimension of such object. COMAU IIoT solution, which gathers data directly from machinery as well as sensor data, is hosted in the TIM site. The two sites are connected via a VPN channel.

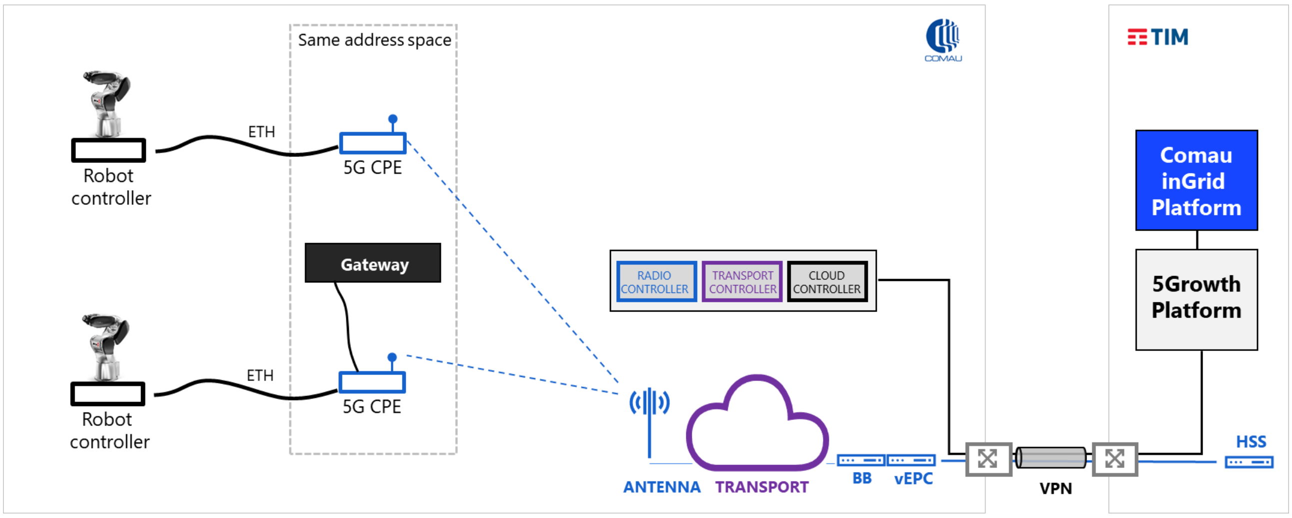


FIGURE 7: COMAU-UC2 OVERVIEW

Detailing the architecture of the testbed, two different user equipment elements are used, CPEs, in order to test two different types of communications. Indeed, the piece of software which gathers the information and sends it to the platform in TIM is the gateway. The first robot is connected to a 5G CPE. The second robot and the gateway are connected to a second 5G CPE. IP addresses are the ones assigned by the vEPC. All the robots are in the same address space managed by the gateway so, from a logical point of view, all the robots are connected to the gateway (via the 5G network).

Information gathered from all the robots is sent via 5G, through the Gateway, to the COMAU IIoT platform, hosted in TIM site, through the VPN channel.

2.1.3.2. Hardware / Software components

TABLE 4: COMAU-UC2 HARDWARE COMPONENTS

Component	Description	Location
Industrial Robots	Production line including robots and other systems. The final number of robots in the use case is three.	COMAU site
Photocells	Photocells to recognize piece presence	COMAU site
Sensor	Sensor to gather physical dimensions	COMAU site
Gateway	PC to gather data from industrial equipment	COMAU site
Antenna System	Ericsson antenna system for 5G	COMAU site
Baseband (BB) System	Ericsson Baseband System	COMAU site
vEPC	Ericsson Virtual Evolved Packet Core providing core radio functionalities. vEPC functions are entirely deployed on COMAU premises in first phase. Later the 5G architecture will be evolved in a CUPS configuration with the user plane part in COMAU and control plane part is in TIM.	COMAU site. TIM site in the CUPS evolution.
Server for controllers	Server where RAN controller, VIM, and WIM runs (related to the 5Growth platform hosted in TIM)	COMAU site
Transport	Wired connection between the antenna system, BB, vEPC, Switches	COMAU and TIM sites
HSS	Home Subscriber Server	TIM site
Server	Server where the COMAU IIoT Platform runs	TIM site
5Growth platform server	Server where the 5Growth components run (5Gr-VS, 5Gr-SO, 5Gr-RL) as reported in D2.1 [4]	TIM site

TABLE 5: COMAU-UC2 SOFTWARE COMPONENTS

Component	Description	Location
COMAU IIoT Platform	COMAU IIoT platform (inGrid) which gathers data directly from machinery as well as sensor data	TIM site
5Growth software platform	5Growth software components run (5Gr-VS, 5Gr-SO, 5Gr-RL) as reported in D2.1 [4]	TIM site

2.1.3.3. Deployment and implementation setup

In order to have a use case as realistic as possible, COMAU has designed and it is developing a small production line with the actual components, both software and hardware, used in real shop floors (manufacturing plants).

The target architecture includes three robots, the PLC (cell control) and several sensors. As part of IIoT hardware, in COMAU premises there is just the gateway. About the IIoT software, the collection of the data is almost finalised, future developments regard 1) a better visualisation layer, and 2) the further implementation of more effective predictive analytics procedures.

2.1.3.4. Initial experiment description

The first experiments, already developed and tested, were about the two different ways of communication between machinery and the gateway. The IIoT platform has already been installed at TIM premises. In order to check the correct functional behaviour of this application, the reference experiments are:

1. To check, at gateway level, the data flow coming from all the connected pieces of machinery and robots.
2. To check, from the IIoT platform deployed in TIM, the correct operation of all the industrial equipment as well as the gateway in use.

Table 6 sums up the technical KPIs related to this use case. Full KPIs verification, including service KPIs, is in charge of WP4.

TABLE 6: COMAU-UC2 KPIS

KPI	Units	Expected values
E2E One Way Delay (OWD)	ms	< 30 (all end devices at same location)
Availability/Reliability	%	99.999/80
Packet Loss	%	< 0.1

Further integrations will consist on developing a new user interface and gathering data from the PLC and other sensors. Additional effort is directed to the development of predictive maintenance algorithms, starting from collected data.

All the above-mentioned software integrations and KPIs must be tested on the actual 5G network, where the transport layer is just a fibre cable, with its further implementations in terms of, transport layer, CUPS, VNFs, slicing and orchestration.

2.1.3.5. Plan and roadmap

Figure 8 sums up the roadmap related to this use case.

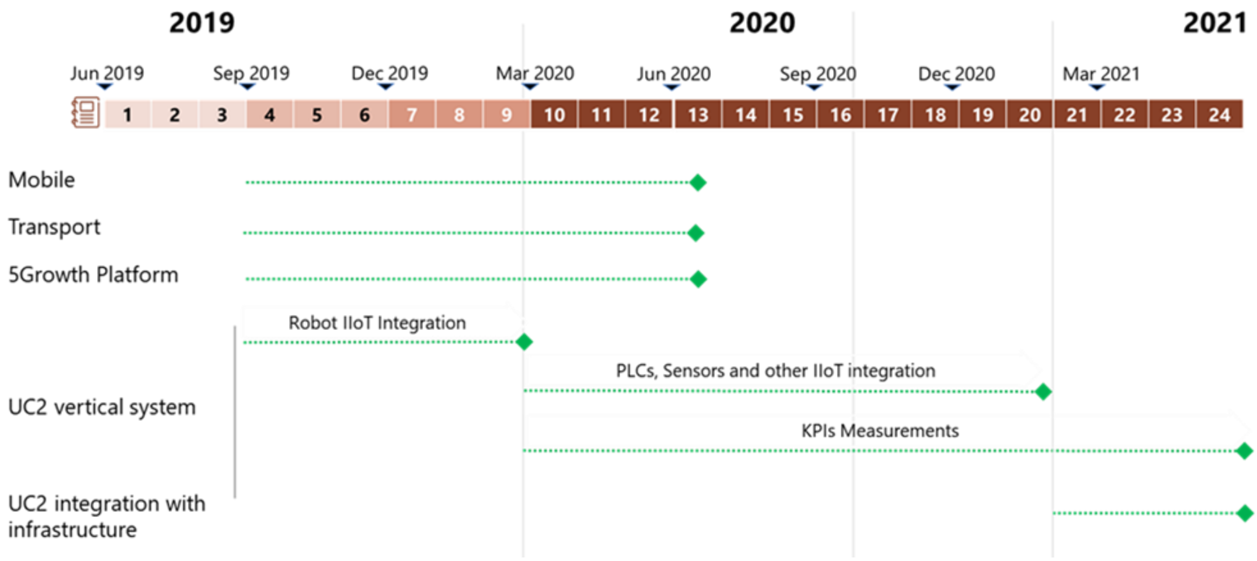


FIGURE 8: COMAU-UC2 DEPLOYMENT PLAN

As said above, the target architecture includes three robots, the PLC for the robotic cell control and several sensors. The deployment plan indicates the integration of robots to be completed within M9 and the integration of all other components, including PLCs and sensors, within M20.

The initial deployment stage for COMAU-UC2 is about line deployment and programming combining all the different components involved. Completion of this activity is expected for the end of M20, including the new prediction algorithms for both maintenance and scheduled activities. By the end of M24, the objective is to integrate the overall vertical system with the infrastructure.

By the end of the first phase, and in parallel with the development of the applications, KPIs measurements are expected to be continuously supported.

2.1.4. Use Case 3: Digital Tutorial and Remote Support

2.1.4.1. Use Case Modelling

This use case aims at providing technicians and maintenance staff with digital tutorials and remote support by means of high definition videos and live connections to remote technical offices. The main objective is to reduce the MTTR (Mean Time To Repair) using real-time streaming with a skilled technician in remote locations to support maintenance and repair operations in the production line of the factory. Another advantage is the possibility to access to tutorials and instructions for training purposes.

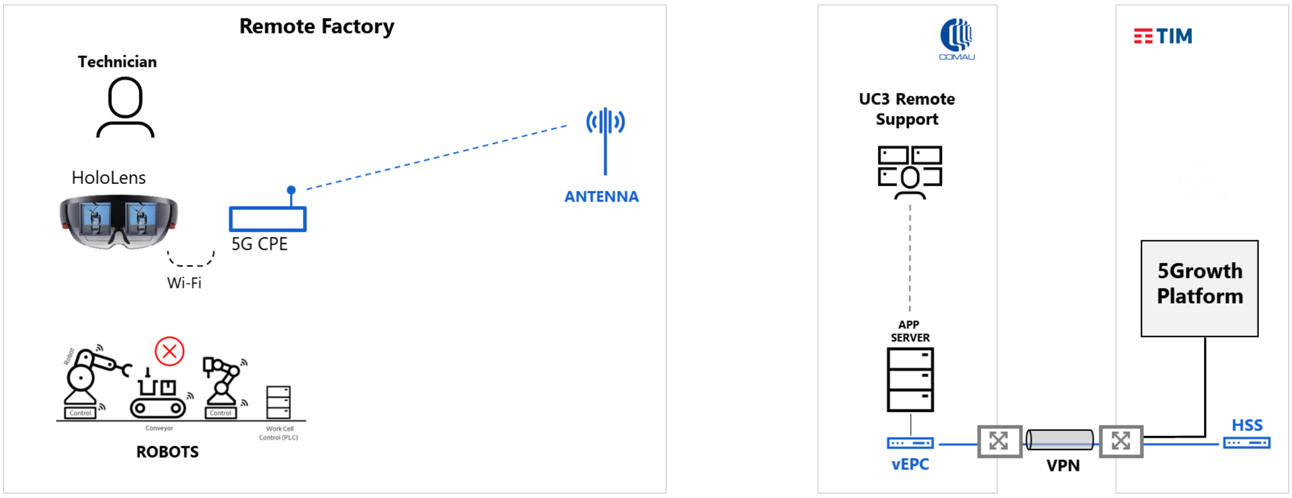


FIGURE 9: COMAU-UC3 OVERVIEW

The scenario, illustrated in Figure 9, involves a “remote factory”. Here some machinery is affected by a fault, but the local staff requires advanced support to rapidly fix the problem. Technicians in the remote factory can use the HoloLens device connected via Wi-Fi to a 5G CPE. On the other side of the connection, geographically separated from the factory, there is an expert with a remote maintenance application. Such expert has the “full picture” of the fault and can provide remote support to the in-field technician.

The application requested in this use case has to enable:

- A high definition video streaming.
- The possibility to set up a call between the technician and the expert.
- The possibility to send instructions and procedures to the technician (i.e. a digital tutorial), also leveraging on the AR capabilities of the HoloLens to superimpose graphical elements to the reality in front of the technician thus facilitating identifying the different components affected by the fault.

In the practical implementation of the use case, the “remote factory” could be located inside the same COMAU site or elsewhere (the exact location is still under discussion).

2.1.4.2. Hardware / Software components

TABLE 7: COMAU-UC3 HARDWARE COMPONENTS

Component	Description	Location
Anthropomorphic Robot	COMAU robot used to simulate failures and maintenance activities	COMAU site
Augmented Reality Device (HoloLens)	Device used both to visualize procedures and remote instructions as well as for the high-quality streaming.	COMAU site
Antenna System	Ericsson antenna system for 5G	COMAU site
Baseband (BB) System	Ericsson Baseband System	COMAU site

Component	Description	Location
vEPC	Ericsson Virtual Evolved Packet Core providing core radio functionalities. vEPC functions are entirely deployed on COMAU premises in first phase. Later the 5G architecture will be evolved in a CUPS configuration with the user plane part in COMAU and control plane part is in TIM.	COMAU site. TIM site in the CUPS evolution.
App Server	Server platform running COMAU applications devoted to providing remote support and digital tutorials as foreseen in the use case	COMAU site
Server for controllers	Server where RAN controller, VIM, and WIM runs (related to the 5Growth platform hosted in TIM)	COMAU site
Transport	Wired connection between the antenna system, BB, vEPC, Switches	COMAU and TIM sites
HSS	Home Subscriber Server	TIM site
5Growth platform server	Server where the 5Growth components run (5Gr-VS, 5Gr-SO, 5Gr-RL) as reported in D2.1 [4]	TIM site

TABLE 8: COMAU-UC3 SOFTWARE COMPONENTS

Component	Description	Location
Augmented Reality Application	Software related to realization of the digital twin of the actual robot	COMAU site
Remote Support Application	COMAU applications devoted to providing remote support and digital tutorials as foreseen in the use case	COMAU site
5Growth software platform	5Growth software components run (5Gr-VS, 5Gr-SO, 5Gr-RL) as reported in D2.1 [4]	TIM site

2.1.4.3. Deployment and implementation setup

The actual implementation of this use case has still to be started.

The hardware needed involve the HoloLens device, a 5G user equipment to connect it to the 5G network and an application to both receive video streaming and send maintenance suggestions and procedures.

This use case has, as its first deployment, an implementation on COMAU premises to test both the quality of the overall solution, the ergonomics of the AR device and the integration with our policies with the 5G network and the possibility to stream images coming from production fields (which may contain sensitive data). Further implementation and uses will be addressed in next steps.

2.1.4.4. Initial experiment description

The initial experiments for this use case implementation can be split in two phases. The first phase consists in setting up the video streaming using the 3D device integrating the possibility to voice interaction between the two people involved in the call. Once reached this objective with a satisfying quality and reliability, the development can go in the following phase which is about discovering some mechanisms to show virtual maintenance procedures on the glasses in order to actually show to the remote maintenance crew all the steps which are to be performed to complete the task.

In this scenario, the key functional experiments are:

1. High-quality video streaming from the remote factory to the COMAU premises.
2. No perceptible delay in video streaming and voice communication.
3. Clear, simply visible and precise AR instructions about the task to perform.
4. Potentially show in AR some notes written from the remote expert.

At the end of each development phase, the technical KPIs, listed in Table 9, will be tested and verified. Full KPIs verification, including service KPIs, is in charge of WP4.

TABLE 9: COMAU-UC3 KPIS

KPI	Units	Expected values
E2E One Way Delay (OWD)	ms	< 50 (all end devices at same location)
Availability/Reliability	%	99.999/80
Bandwidth (in total)	Mbps	> 500

The first planned experiment consists in using the mobile 5G network without a transport layer, nor virtualization or any WP2 innovations. All those components are going to be progressively integrated and tested within this use case.

The KPIs are going to be compared after the deployment of each new network component in order to verify any loss in performance.

2.1.4.5. Plan and roadmap

Figure 10 shows the roadmap regarding the development of this use case.

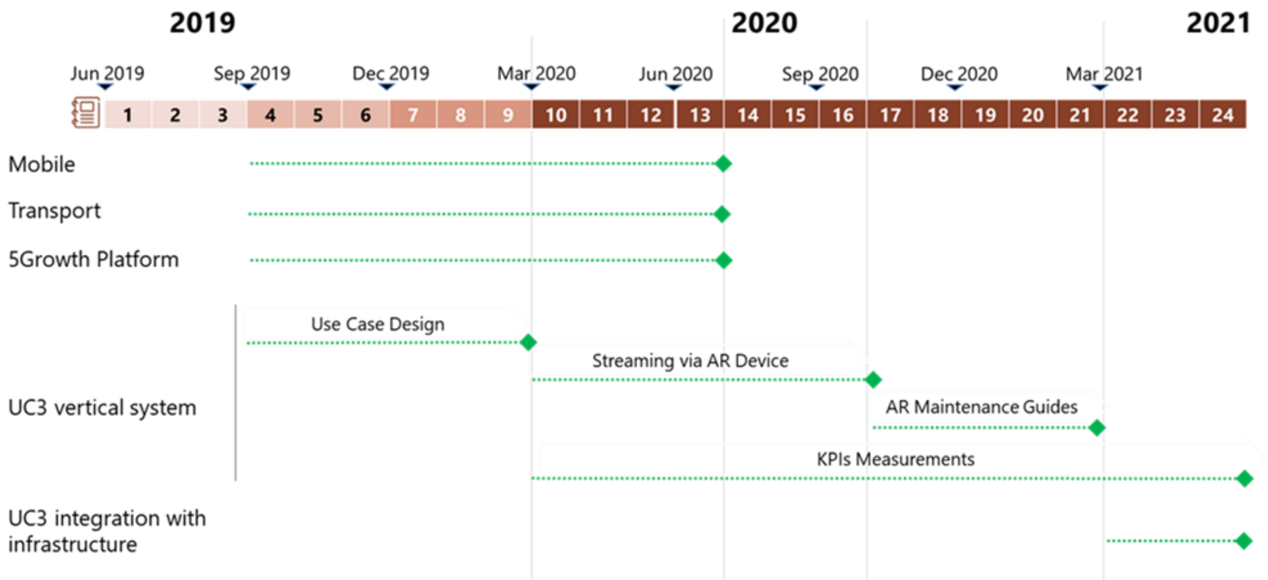


FIGURE 10: COMAU-UC3 DEPLOYMENT PLAN

This use case is at the design level. The first version, consisting on just the video streaming, will be developed for the end of M16 and completed with the integration of the AR maintenance guides (i.e. the digital tutorial) by the end of the M21. Integration with the infrastructure will end within M24.

In parallel with the development of the applications, KPIs measurement are expected to be continuously supported.

2.1.5. COVID-19 Impact Analysis on Plans and Roadmaps

As the COVID-19 situation develops, governments applied restrictions to the mobility of their citizens and enterprises are also applying restrictions to the mobility of their employees. These restrictions will impact the original plan of the pilot.

The project is considering a worst-case scenario of four months of unavailability for on-site activities in COMAU premises, TIM premises, in laboratories of vendors, SMEs and universities. It is assumed that only "off-site" activities (i.e. working from home without access to office premises and labs) can continue without impact.

The impact can be grouped into the assumed facts (those that will certainly happen) and the probable threats (those that could happen) during those four months.

1) **Assumed Facts:**
    a. HW Deployments:
        i. Not possible in this period
        ii. No feasible mitigation
    b. COMAU, TIM, TEI lab, NXW lab, Academics on-site activities:
        i. Not possible on site,
        ii. Only "working from home" activities
    c. Attendance to F2F meetings:
        i. Not possible in this period

ii. Switched to virtual meetings

d. Attendance to Events:

i. Not possible in this period

ii. Dissemination via digital video channels

2) **Probable Threats:**

a. Potential unavailability of involved staff in the project

b. Potential shortages and delays in the supply of 3rd party products

c. Delays in other WPs in 5Growth

Considering all the above, the project partners will shift their plans and will focus on activities that are less likely to be impacted by the restrictions, such as:

- System study to define solutions (innovations) and related extensions of building block of 5Growth platform to be implemented in the Pilot
- SW development of building block extensions
- SW development of applications
- SW upgrades
- Preparing documentation
- Getting ready for on-site tasks

With the aim of keeping the original ending project dates, two options are evaluated:

1) **Keep Milestones' planned dates**, through scope contention of M18's Milestone and progressive catch-up afterwards, in order to enable incremental testing of the pilot both before and after M18.
2) **Delay M18's Milestone 2 months**, in order to keep the original planned activities unaffected.

These two alternative options are considered in assessing the impact on the deployment of the infrastructure (mobile, transport, 5Growth platform). As for the three use cases in the pilot, the impact is in some cases mitigated by operating on emulated/simulated environments and by starting the integration of the vertical systems with the infrastructure when said vertical system is at a sufficient (even if not completed) maturity stage. For each use case, however, it is also reported a "light" version which brings to fulfil the original target dates by not deploying some minor features without affecting the capability to assess all the KPIs and not limiting the technical value and scope of the use cases thus preserving the same ambition level.

The estimated impact on the infrastructure is provided in Section 2.1.5.1 for Option 1 and in Section 2.1.5.2 for Option 2. The estimated impact the use cases is provided in Section 2.1.5.3 for COMAU-UC1, Section 2.1.5.4 for COMAU-UC2, Section 2.1.5.5 for COMAU-UC3 detailing both Option 1 and Option 2 in each section. M18 does not constitute a final deadline for the use cases deployment because they are developed in a continuous integration fashion.

2.1.5.1. Option 1 - Estimated Impact in the Infrastructure Roadmap

Figure 11 shows the estimated impact when the delay due to lockdown does not exceed the milestone at M18 (dashed line). The red arrows indicated the expected (maximum) delay for each of the activities.

FIGURE 11: COMAU 5G NETWORK INFRASTRUCTURE ROADMAP ESTIMATED IMPACT IN OPTION 1

The impacted activities are related to the set up on site (in COMAU and TIM sites) and the development of the HW part in lab. In any case, the setup of mobile infrastructure in COMAU for the 5G NSA installation has been already completed and tested, which allows testing all the use cases without any limitation on the performance evaluation. Possible delays could be expected for the availability of a larger number of 5G devices, for the complete replacement of current smartphones and packet routers that are used as temporary 5G dongles. Having a larger number of such devices would allow to have all the three use cases operating simultaneously in their final, planned, HW setup. The HW development related to the transport part is also impacted because it needs to be done in TEI lab. HW is already available. The 5Growth platform deployment, instead, can be carried out even without accessing to labs (i.e. working from home) being mainly related to software deployments so it could experience a minor delay. The study activity, to define the innovations and the extensions of the building block for the 5G Growth platform should similarly suffer minor delays.

As a result of the above, deployments of mobile, transport, 5Growth platform (blue arrows) can have a maximum delay of three months (red arrows), but they still remain within M18. Integration of mobile and transport would consequently experience three months delay (reaching M19). By limiting the (delayed) mobile-transport integration at M18 (the delay is indicated with a light red arrow), it is also possible that the test campaign on mobile-transport will be reduced. This could result in achieving limited performances in term of latency and synchronization for supporting eCPRI transport for 5G. In this case it is possible to (provisionally) replace the full transport network with the original point-to-point fiber link and to restore the full transport arrangement later.

Related to the subsequent integration with the 5Growth platform, it is possible to increment the test activity by relying upon «dummy hardware», starting from M16, in order to gather all the tests planned in WP4. For example, tests related to NFV and resources configuration. Thus, verification of KPIs in WP4 shall not be affected.

2.1.5.2. Option 2 - Estimated Impact in the Infrastructure Roadmap

Figure 12 shows the estimated impact accepting a delay of the milestone at M18 (dashed line).

FIGURE 12: COMAU 5G NETWORK INFRASTRUCTURE ROADMAP ESTIMATED IMPACT IN OPTION 2

As said in the previous section, the three components of the infrastructure (mobile, transport, 5Growth platform) could be delayed for a maximum of three months each. This however does not compromise the M18's milestone. While considering the mobile-transport integration, it is consequently delayed by three months from M16 to M19. This delay is propagated to the further integration with the 5Growth platform.

2.1.5.3. Estimated impact in Use Case 1 Plan and Roadmap

Figure 13 shows the estimated impact in the plan and roadmap of COMAU-UC1.

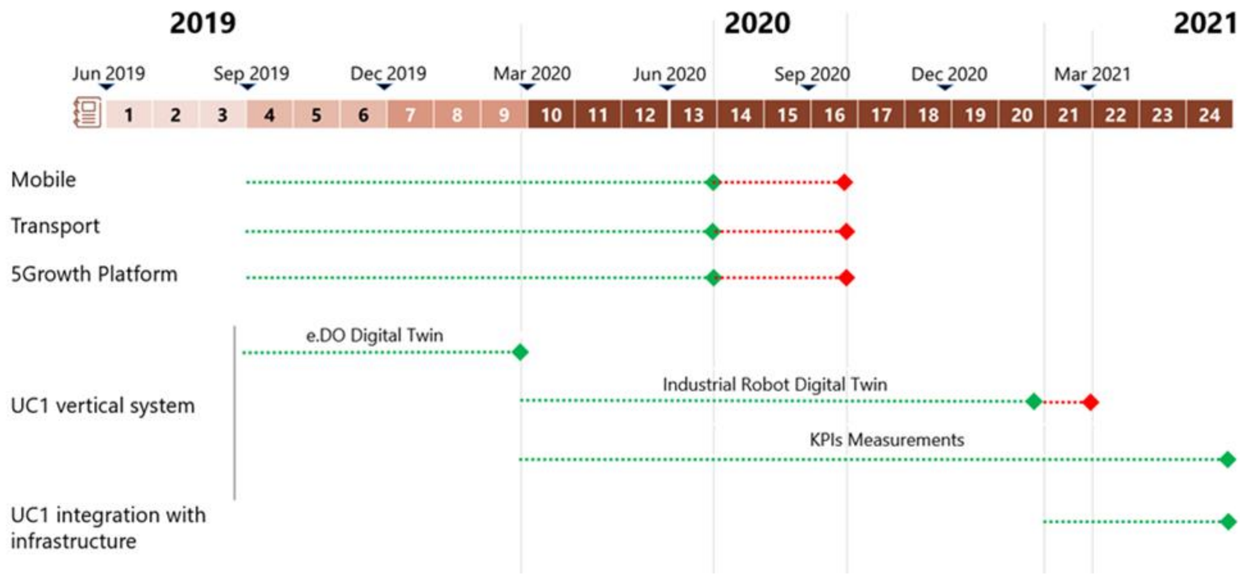


FIGURE 13: COMAU-UC1 PLAN AND ROADMAP ESTIMATED IMPACT

COMAU-UC1 is partially impacted because we are building up simulated environment to make possible homeworking. Nevertheless, the setup of the physical robots will be possible when work on site becomes permitted again. Even in the worst case scenario of 4 months delay, it should be possible to complete the use case application development by the end of the end of M21, instead of by the end of M20, with the integration of Industrial robots in the use case (i.e. Option 2). In case that such one-month delay should not be possible (i.e. Option 1), the use case can be demonstrated with the e.DO robots instead of the industrial robots.

However, even in the case of one-month delay in integrating the industrial robots (i.e. Option 2) the integration of COMAU-UC1 vertical system with the infrastructure can start, as planned, at the beginning of M21 so that the final date to have COMAU-UC1 up and running in the final configuration is confirmed for the end of M24 without a delay with the respect to the original completion date.

2.1.5.4. Estimated impact in Use Case 2 Plan and Roadmap

Figure 14 shows the estimated impact in the plan and roadmap of COMAU-UC2.

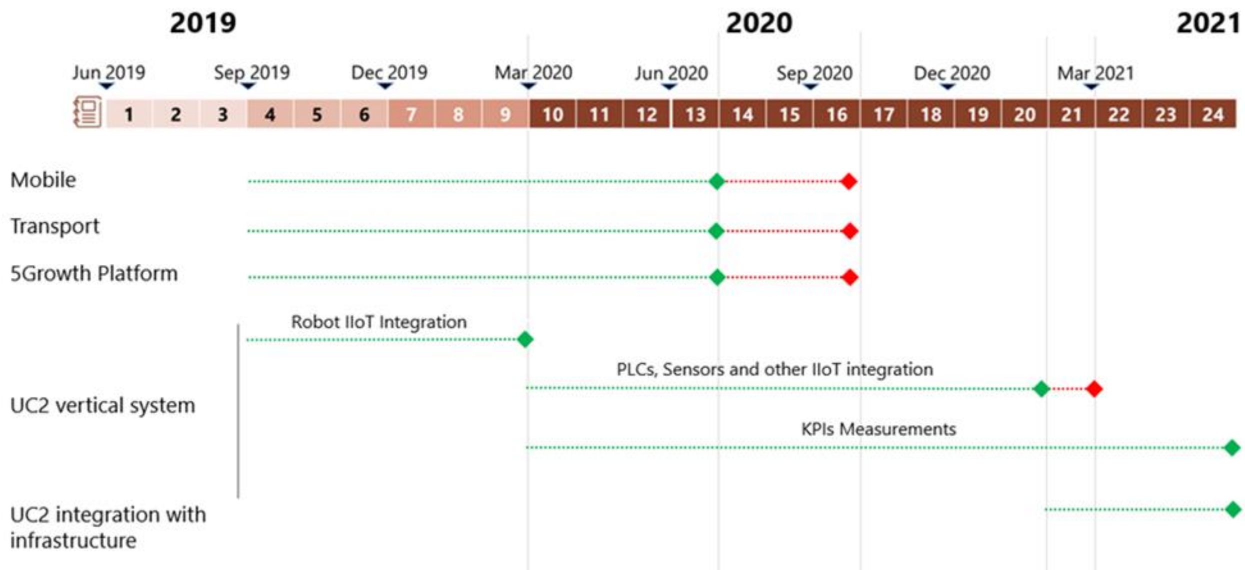


FIGURE 14: COMAU-UC2 PLAN AND ROADMAP ESTIMATED IMPACT

COMAU-UC2 is largely based on robotic HW deployment, hence the physical access to labs is required. Moreover, such use case requires to be connected to COMAU IoT platform installed in TIM premises. The estimation is to complete the use case by the end of the M21, instead of M20, with the full set of monitored devices like PLCs, motors (i.e. Option 2). In case that such one-month delay should not be possible (i.e. Option 1), the use case can be demonstrated with a reduced number of monitored devices.

However, even in the case of one-month delay in completing the use case with all the monitored devices (i.e. Option 2), the integration of COMAU-UC2 vertical system with the infrastructure can start, as planned, at the beginning of M21 so that the final date to have the COMAU-UC2 up and running in the final configuration is confirmed for the end of M24 without a delay with the respect to the original completion date.

2.1.5.5. Estimated impact in Use Case 3 Plan and Roadmap

Figure 15 shows the estimated impact in the plan and roadmap of COMAU-UC3.

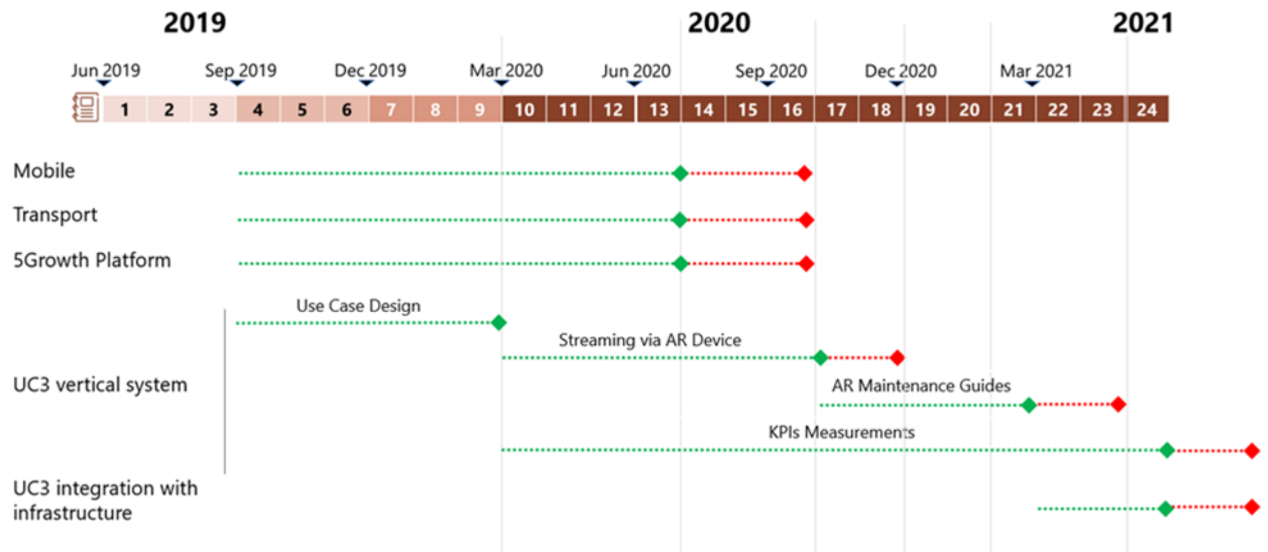


FIGURE 15: COMAU-UC3 PLAN AND ROADMAP ESTIMATED IMPACT

COMAU-UC3 is currently at the end of the design phase. This specific use case requires that most of the activities are deployed on site so it could suffer of two months delay ending at the end of M23 instead of M21.

However, even in the case of two-months delay (i.e. Option 2), the integration of COMAU-UC3 vertical system with the infrastructure can start, as planned, at the beginning of M22.

Planning of COMAU-UC3, including the mentioned two-months delay, has been reviewed to achieve a consistent release of the use case with all the functionalities required for testing and KPI evaluation (with WP4) within the original M24 target.

The additional two months will be used to refine the "digital tutorial" application inside the already completed AR experience in HoloLens without any implication on tests and KPI evaluation. In case that such delay is not possible (i.e. Option 1), this functionality can be not deployed.

2.2. EFACEC_E Vertical Pilot

The EFACEC_E vertical pilot explores the provisioning of 5G enablers for the energy sector, taking place in power equipment located at the University of Aveiro campus, in Portugal. It unfolds into two different use cases. The first one, detailed in Section 2.2.2, scopes the advanced monitoring and maintenance support to assist both the remote operator in the control centre, and the crews dispatched to the field to better assess the severity and the impact of the outage they are facing. The second one, detailed in Section 2.2.3, scopes the advanced monitoring and fault detection in the low voltage grid. Their detailed description is preceded by all the deployment details in Section 2.2.1. This deployment is addressed considering two phases. The first phase (Phase I) considers lab-based and early trial assessments, with a minimal set of system features in place. The second phase (Phase II) considers the final trial assessments considering the full-fledged system deployed.

2.2.1. Infrastructure deployment in vertical premises

2.2.1.1. Roadmap

Figure 16 depicts the 5G network infrastructure planning for the Aveiro site, which is common to both EFACEC_E and EFACEC_S pilots. This plan intends to gradually introduce new functionalities until September 2020, when it is expected that a 5G end-to-end network is available for the first time.

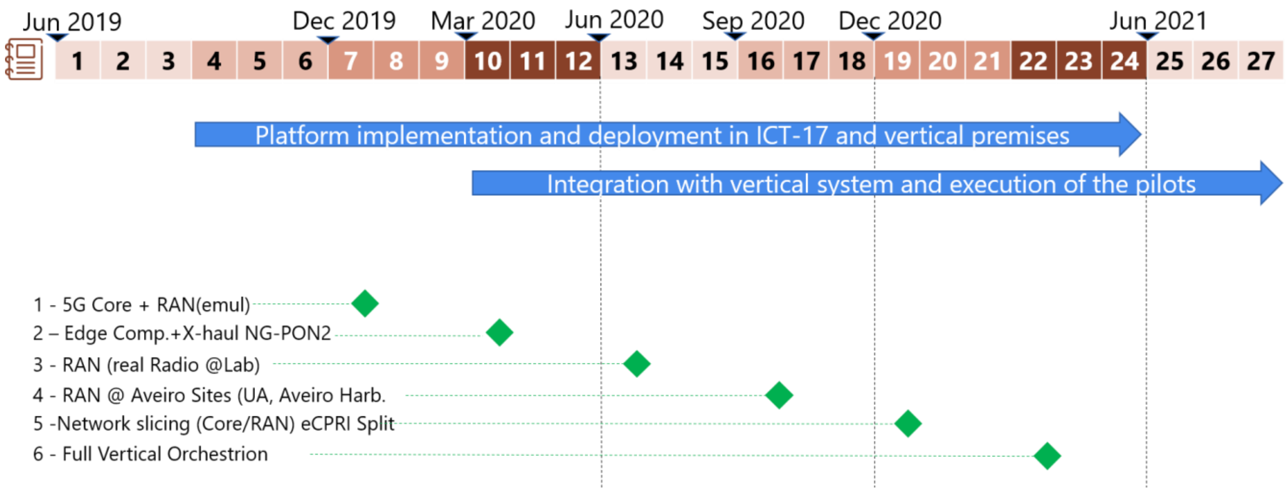


FIGURE 16: EFACEC_E 5G NETWORK INFRASTRUCTURE ROADMAP

The steps depicted on Figure 16 are explained below in more detail.

1) By December 2019 (M7), SONATA [5] [6] is used to perform the deployment of a 5G-Core (Open5GCore) and an emulated RAN+UE (coming with Open5GCore [7]) Network Services. The Core and RAN+UE services are on-boarded and deployed in different VIMs, and interconnected through a tunnel.
2) By March 2020 (M10), Edge Computing capabilities (Altice Labs) will be added in order to divert traffic that requires low latencies to applications running at the edge. In addition, NG-PON2 technology will be added, previously on the back-haul (later will be used for the mid-haul).
3) By June 2020 (M13), the emulated RAN component will be replaced by a real radio hardware in a Lab environment.
4) By September 2020 (M16), the real RAN solution deployed at the Lab will be extended to the pilot sites, the University of Aveiro (Energy) and the Aveiro Harbour (Transportation).
5) By December 2020 (M19), Network Slicing features will be added to the Lab (first) and pilot sites, accommodating the different requirements of the pilots and respective use cases.
6) By March 2021, not only the network, but also vertical components will be orchestrated to be deployed on the network, either they are placed in the site, edge or core.

2.2.1.2. Plan and deployment setup

Figure 17 depicts the existing deployment setup by December 2019, where a 5G-Core and an emulated RAN (+UE) can be deployed by SONATA, both on IT premises, using a manually configured tunnel. By March 2020, edge computing (in-house Altice Labs solution) and GPON technology is introduced, using a slicing modelling for all components and automating connectivity among them using a SONATA WIM (WAN Infrastructure Manager) (with SONATA acting as a Connection Service Management Function (CSMF), interconnected with the 5Growth's platform, acting as a Network Slice Management Function (NSMF) [8]).

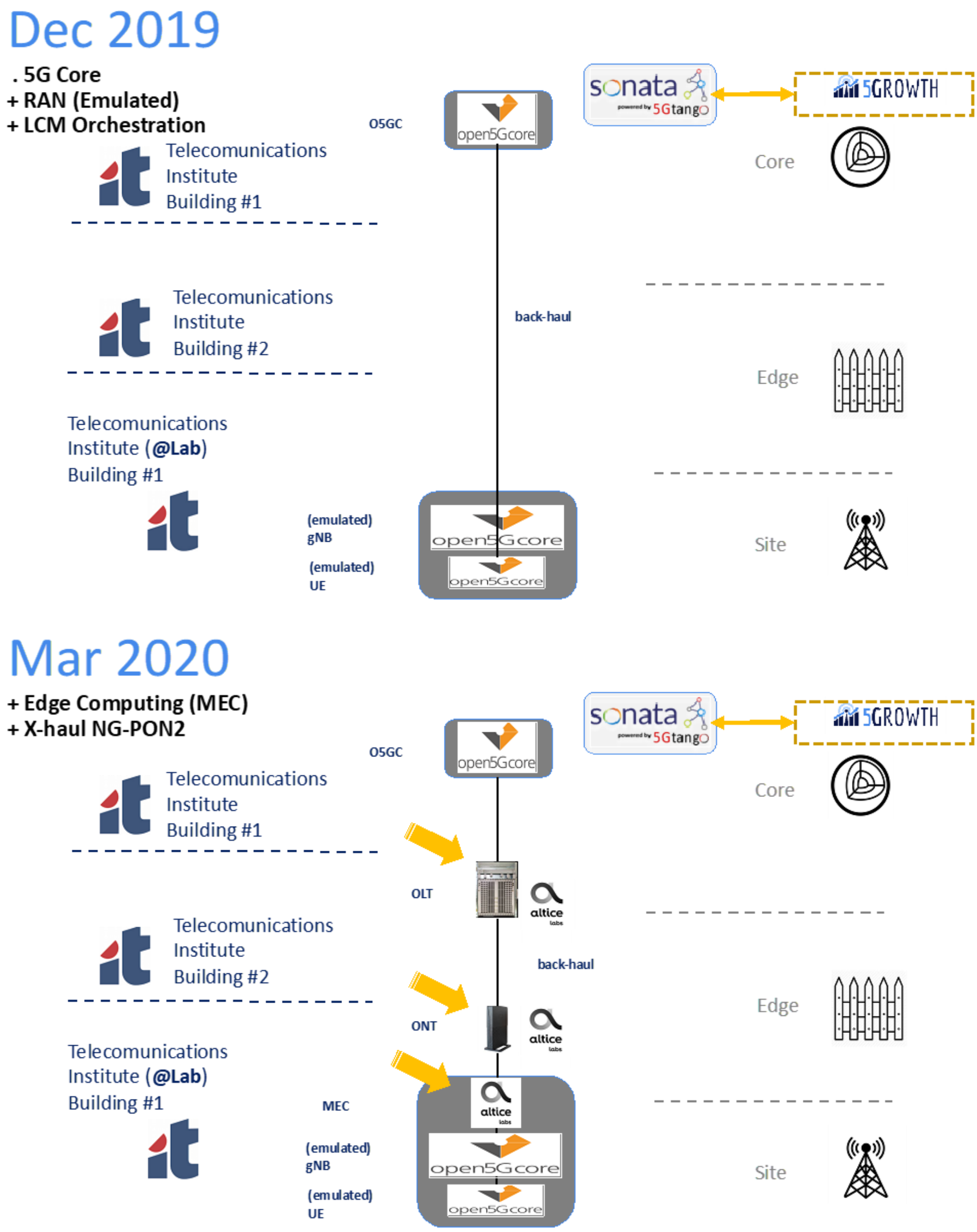


FIGURE 17: EFACEC_E 5G NETWORK DEPLOYMENT PLAN; DEC 2019, MAR 2020

Figure 18 depicts the deployment setup by June 2020, where real 5G-NR (monolithic version) is for the first time introduced (OpenAirInterface [9]). By September 2020, the real 5G-NR is extended to the pilot sites, the University of Aveiro (EFACEC_E pilot) and the Aveiro Harbour (EFACEC_S pilot).

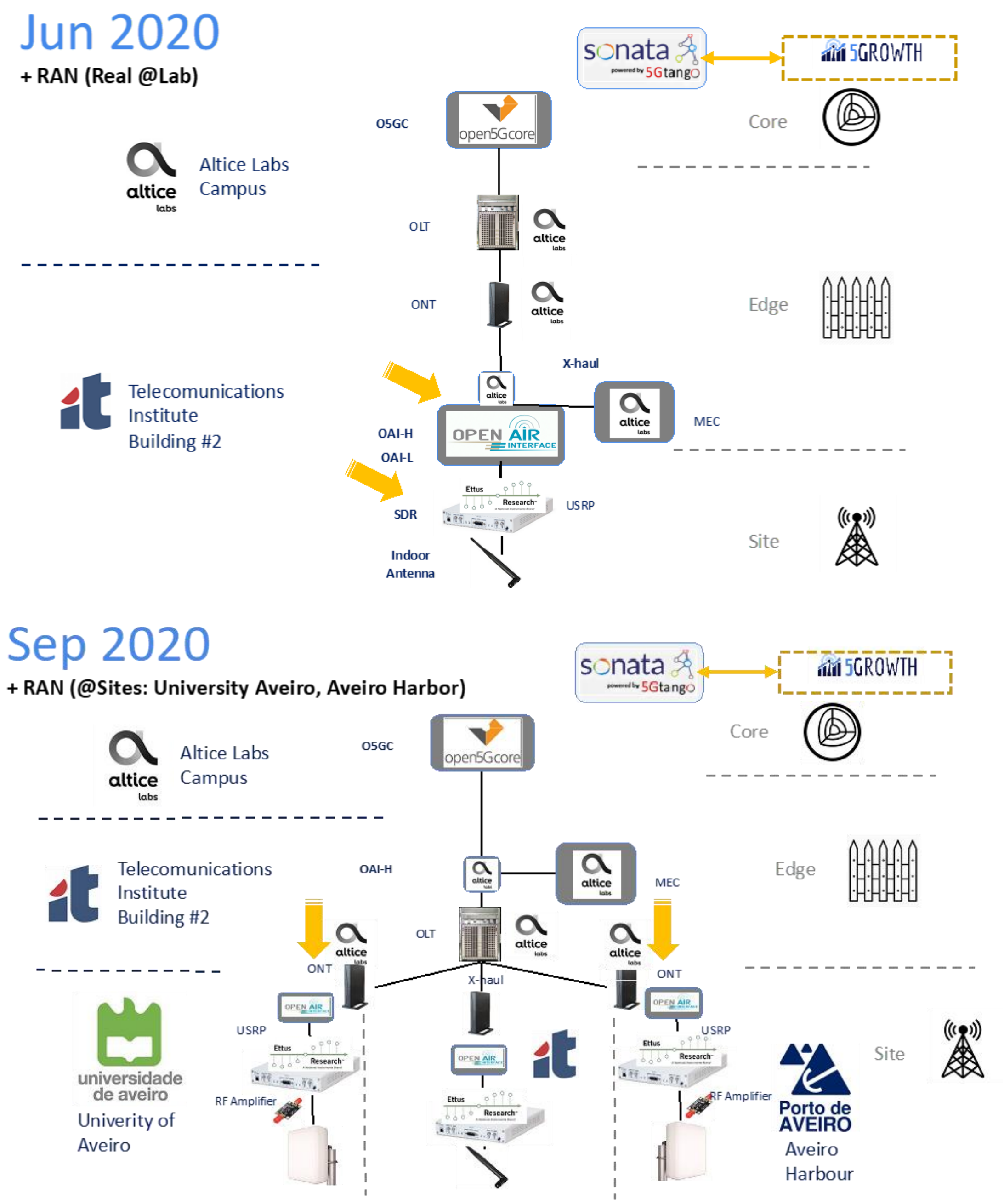


FIGURE 18: EFACEC_E 5G NETWORK DEPLOYMENT PLAN; JUN 2019, SEP 2020

Figure 19 depicts the deployment setup by December 2020, where Network Slicing capabilities are introduced and the monolithic gNB is split according to the eCPRI splitting models. By March 2021, the full pilot orchestration will be available, including the deployment of the pilot functions and services.

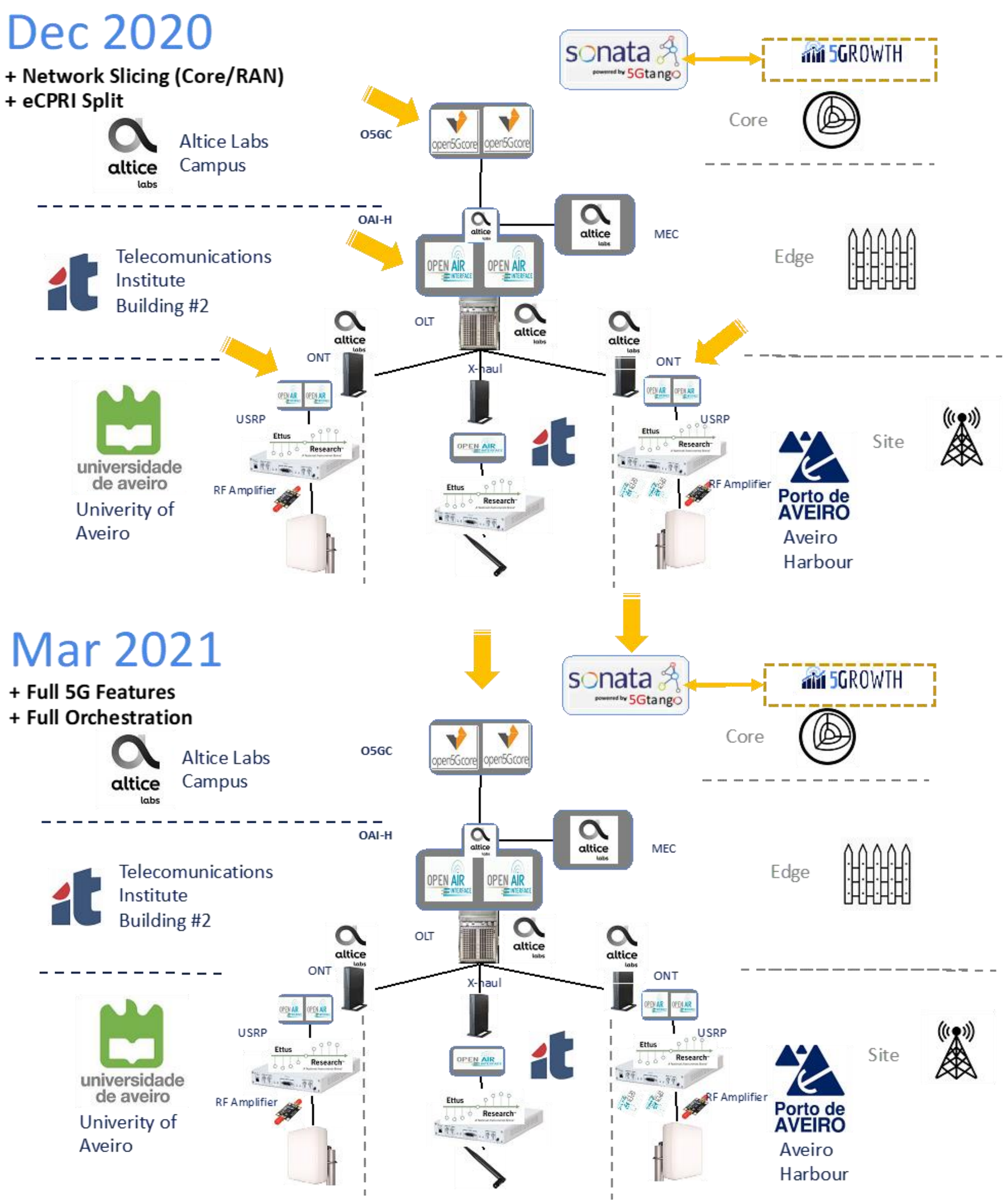


FIGURE 19: EFACEC_E 5G NETWORK DEPLOYMENT PLAN; DEC 2020, MAR 2021

Figure 20 illustrates the integration of the 5Growth Vertical Slicer with SONATA, which includes the adaptation layer, aimed at enabling Vertical Slicer's CSMF to manage network slice lifecycle through SONATA northbound API. Concretely, 5Growth will provide a graphical user interface allowing the Energy Service Provider to request Communication Services for the data exchanges necessary to the use cases of this pilot. At the Vertical Slicer, the request is processed, and sent as a Network Slice provisioning request (as standardised by the 3GPP) to be executed by the Network Operator. In case of the Aveiro deployments, the Network Service request will be handled by ICT-17's H2020 5G-VINNI deployment in Aveiro, which is managed through the SONATA platform. SONATA, will map this request into the necessary supported constructs, enabling the deployment of the necessary network resources.

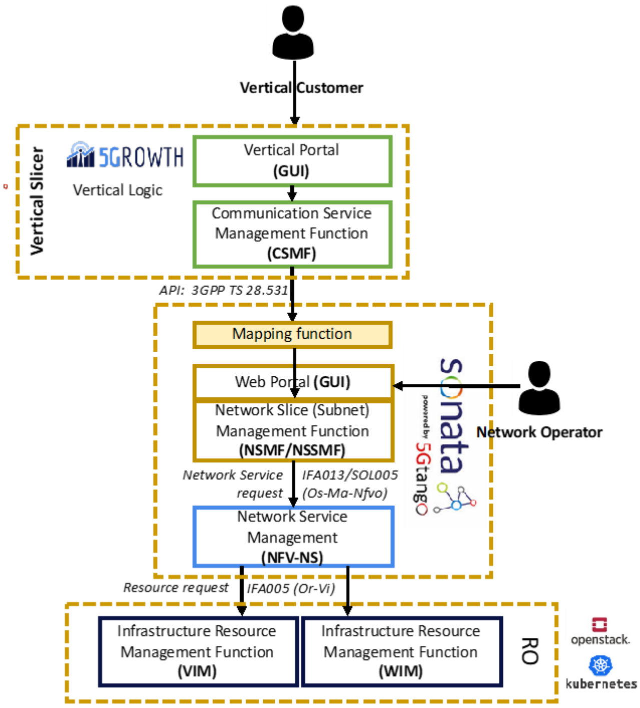


FIGURE 20: EFACEC_E PILOT VERTICAL SLICER / SONATA INTEGRATION

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

2.2.2.1. Use Case Modelling

This use case scopes the advanced monitoring and maintenance support to assist both the remote operator in the control centre, and the crews dispatched to the field to better assess the severity and the impact of the outage they are facing.

From the local surveillance systems available in the secondary substation, an HD video signal must be streamed both to the control centre and to the mobile devices of the maintenance crew, and monitoring assets (i.e. sensors and controller) shall communicate in nearly real-time to the control centre.

In the secondary substation, a set of low voltage sensors (LVS3 devices supervising low voltage feeders), the low voltage controller (GSmart device controlling perimeter intrusion and supervising the substation power transformer) and an HD IP video camera will be installed. In the IT cloud premises, a SCADA/ADMS system (ScateX# ADMS) will be installed to monitor and control the installation and to support the activity of both the operator and the maintenance crew.

Figure 21 depicts the modelling of this use case, generally illustrating that the vertical-based components (Control Centre and Secondary Substation) will be connected through a 5G network, which will contain the system and solutions developed within 5Growth, instead of using a plain LTE network as is done today. The communication protocols, concerning each interaction between components, are identified in the figure.

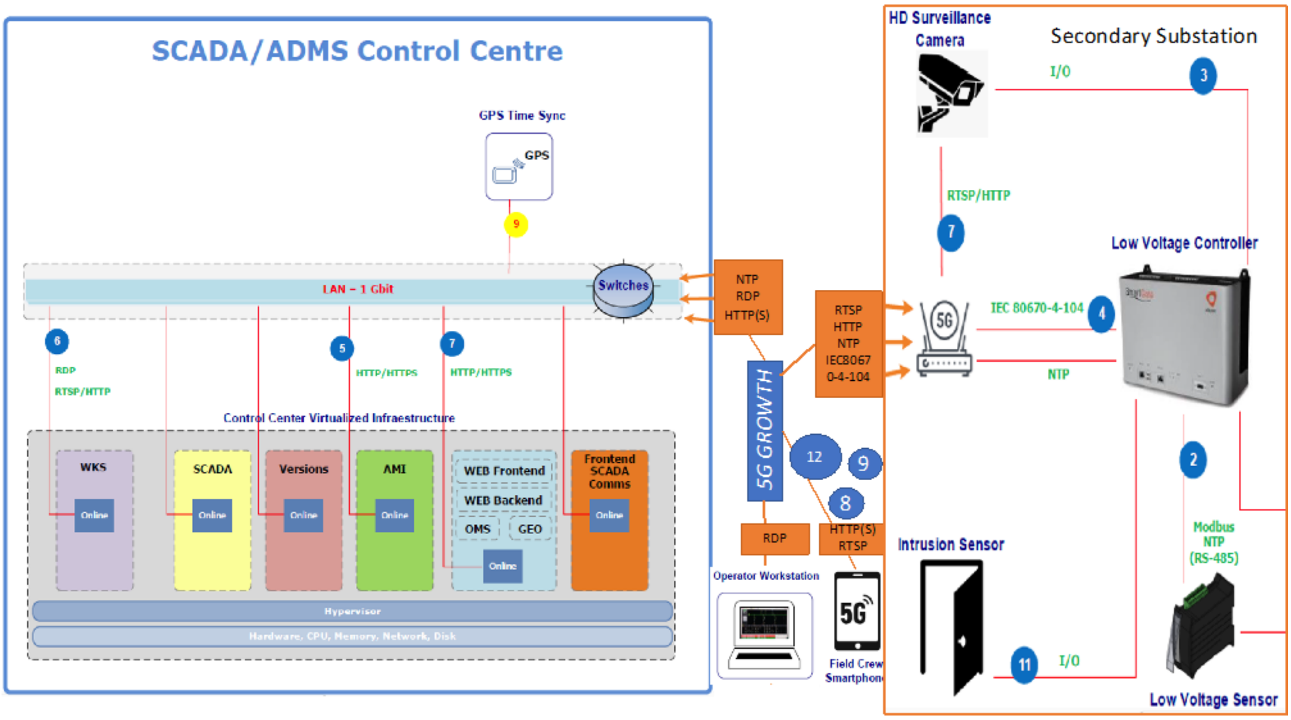


FIGURE 21: EFACEC_E-UC1 OVERVIEW

The use case sequence of events is shown in the figure above and is described as follows.

In the sequence of a fault in the low voltage feeder (typically the fuse blows), the low voltage sensor detects that fault (1) and reports it to the low voltage controller (2). After that, the low voltage controller sends an order to the video camera to start recording (3). And, at the same time, sends an alarm to the SCADA/ADMS System in the Control Centre (4). The SCADA/ADMS Frontend Processor receives the signal communication from the field and delivers it to the SCADA engine (5). The Control Centre operator detects the alarm in the alarm list interface (6) and, from the user interface, opens the HD camera window, starting the HD video streaming (7). The operator reports the fault to the maintenance team (8).

The maintenance team member, using a mobile device, receives the work order from the Control Centre (9) and opens the HD camera window (10), starting the HD video streaming (7). This way, the maintenance team can have immediately a first impression of the severity of the incident. When the maintenance team arrives to the installation, the intrusion system is activated (11), an alarm is sent to the control centre and the technical information of the installation is subsequently made available to the Control Centre operator (4 and 5). To efficiently perform the repair, the maintenance team will be provided with augmented reality devices, collecting technical information of the asset to be replaced (12).

2.2.2.2. Hardware / Software components

Phase 1

TABLE 10: EFACEC_E-UC1 HW COMPONENTS (PHASE I)

Component	Description	Location
Fuses (only @ Aveiro Campus)	Components used to protect the low voltage feeder against high currents. Already installed in the secondary substation	Aveiro Campus Secondary Substation
LV Sensors	Devices that will be installed in the secondary substation to monitor and detect faults in the low voltage feeders. EFACEC devices – LVS3	EFACEC Labs Aveiro Campus Secondary Substation
LV Controller	Device that will be installed in the secondary substation to monitor the transformer measures and to concentrate all the information from the substation and low voltage network. EFACEC device – GSmart	EFACEC Labs Aveiro Campus Secondary Substation
HD camera	IP video camera that will be installed in the secondary substation for surveillance	EFACEC Labs Aveiro Campus Secondary Substation
Intrusion Sensor (only @ Aveiro Campus)	Device that will be installed in the secondary substation to detects intrusions in the secondary substation	Aveiro Campus Secondary Substation
Smartphone	Smartphone used by the maintenance team (technical personnel responsible for the maintenance of the power grid and installations)	Aveiro Campus Area
LTE Router	4G CPE responsible for data exchange between the Secondary substation components (Low Voltage Controller and the HD Camera), and the Control Centre, using the 4G commercial service	EFACEC Labs Aveiro Campus Secondary Substation
5G Core	Mobile Network Core elements	Mobile Operator / Altice Labs (5G-VINNI)
RAN	The RAN portion of the operator's mobile network	Mobile Operator / Altice Labs (5G-VINNI)
Edge Computing	The edge MEC portion of the mobile operator, allowing for lower latency service provisioning whenever needed	Mobile Operator / Altice Labs (5G-VINNI)

TABLE 11: EFACEC_E-UC1 SW COMPONENTS (PHASE I)

Component	Description	Location
SCADA/ADMS System	SCADA ADMS system to support the operators to monitor and control the power grid and the installations	EFACEC Labs infrastructure IT Cloud premises
MANO	Mobile Network Management and Orchestration capability	Mobile Operator/Altice Labs (5G-VINNI)
VIM	Virtualized Infrastructure Management Capability	Mobile Operator/Altice Labs (5G-VINNI)

Note: The network components are identified and detailed in Section 2.3.2.2, in Figure 35.

Phase 2

TABLE 12: EFACEC_E-UC1 HW COMPONENTS (PHASE II)

Component	Description	Location
Fuses	Components used to protect the low voltage feeder against high currents. Already installed in the secondary substation	Aveiro Campus Secondary Substation
LV Sensors	Devices that will be installed in the secondary substation to monitor and detect faults in the low voltage feeders. EFACEC devices – LVS3	Aveiro Campus Secondary Substation
LV Controller	Device that will be installed in the secondary substation to monitor the transformer measures and to concentrate all the information from the substation and low voltage network. EFACEC device – GSmart	Aveiro Campus Secondary Substation
HD camera	IP video camera that will be installed in the secondary substation for surveillance	Aveiro Campus Secondary Substation
Intrusion Sensor	Device that will be installed in the secondary substation to detects intrusions in the secondary substation	Aveiro Campus Secondary Substation
Smartphone	Smartphone used by the maintenance team (technical personnel responsible for the maintenance of the power grid and installations)	Aveiro Campus Area
5G Router	5G CPE responsible for data exchange between the Secondary substation components (Low Voltage Controller and	Aveiro Campus Secondary Substation

Component	Description	Location
	the HD Camera), and the Control Centre, using the 5G service available	
5G Core	Mobile Network Core elements	Mobile Operator / Altice Labs (5G-VINNI)
RAN	The RAN portion of the operator's mobile network	Mobile Operator / Altice Labs (5G-VINNI)
Edge Computing	The edge MEC portion of the mobile operator, allowing for lower latency service provisioning whenever needed.	Mobile Operator / Altice Labs (5G-VINNI)

TABLE 13: EFACEC_E-UC1 SW COMPONENTS (PHASE II)

Component	Description	Location
SCADA/ADMS System	SCADA system to support the operators to monitor and control the power grid and the installations	IT Cloud premises
OMS (Outage Management System)	Subsystem, part of the SCADA/ADMS, responsible for processing inputs from the low voltage network, and to provide data to be presented to the network operators	EFACEC Labs infrastructure IT Cloud premises
AMI (Advanced Metering Infrastructure)	System responsible for managing the metering devices of the low voltage network. It is a system of its own, independent of the SCADA/ADMS. For convenience it is in this pilot hosted together with it	EFACEC Labs infrastructure IT Cloud premises
MANO	Mobile Network Management and Orchestration capability	Mobile Operator/Altice Labs (5G-VINNI)
VIM	Virtualized Infrastructure Management Capability	Mobile Operator/Altice Labs (5G-VINNI)

Note: The network components are identified and detailed in Section 2.3.2.2, in Figure 35.

2.2.2.3. Deployment and implementation setup

The use case will be deployed in two phases. In phase I, the use case will be deployed, to a limited extent, in a laboratory environment. For the 5G network components, this phase is planned to start in June 2020 (Figure 18Figure 30). The main goal in this phase is to verify that the 5G infrastructure, namely 5G core and NG-RAN, are capable of providing the functionality required by the use case and to identify (and overcome) possible issues that may affect the accomplishment of the pilot objectives. An initial assessment of relevant KPIs (e.g. service instantiation time, latency) will be performed. It should be noted that in this phase the Vertical Slicer is not expected to be integrated with the 5G-VINNI platform, therefore the vertical is not yet supposed directly interact with the platform. Prior to this, the initial experiment stage of the vertical components will be performed at EFACEC premises followed by site tests using as first approach LTE technology, to enable the functional validation of the components while 5G is becoming available, and at final stage 5G communications.

Phase II corresponds to the deployment of the use case on site. In this phase, the use case will be deployed in its full extent. Depending on specific requirements, e.g. power, distance, the RAN component may be different from the solution used in Phase I. At this point, the vertical slicer will be integrated with the remaining management & orchestration components, which will enable the vertical users to interact directly with the platform. With the availability of the 5G network, the vertical components can be coupled with 5G-enabled interfaces and use the 5G network for their communications.

Phase I

The deployment and implementation setup at Altice Labs concerning the 5G network will be shared with EFACEC_S vertical pilot and is presented in Section 2.3.2.3.

The initial experiment stage of the EFACEC_E-UC1 components will be performed at EFACEC premises followed by on-site tests using as first approach LTE technology and technology and a commercial 4G network.

Phase II

At the final stage, with the availability of the 5G network, the vertical components will be moved from EFACEC labs to the Aveiro campus (substation) and IT cloud premises (control centre), and can be coupled with 5G-enabled interfaces and use the 5G network for their communications.

2.2.2.4. Initial experiment description

The aim of this experiment is to validate the functional behaviour of the identified scenario. The validation of this scenario will assess each individual component, as well as the interactions between components.

Phase I

In this phase, a set of experiments shall be run, aiming to test the functional behaviour of each one of the use case components, and to validate the transactions between the components.

<u>Experiment#1</u> – Fault Monitoring in Workstation Alarm Interface

The aim of this experiment is to validate the functional behaviour of the identified scenario. Both individual component processing and interaction between components will be assessed. The configuration of the EFACEC_E-UC1 setup will also be validated.

- Simulated fault at the level of the LVS3 I/O module shall result in the exhibition of an alarm entry in the alarm list of the Command Centre workstation.

- Simulated measures at the level of the GSmart I/O module shall result in the exhibition of changing telemetered values in the substation one-line diagram.

Experiment#2 – Video Streaming Exhibition in Workstation

The aim of this experiment is to validate the functional behaviour of the identified scenario. Both individual component processing and interaction between components will be assessed. The configuration of the Surveillance Camera and the parametrization of the camera streaming feature in the SCADA/ADMS system will also be validated.

- With the camera ON, opening the camera window from the substation one-line diagram (a schematic representation of the substation internals) shall result in the exhibition, on request, of the live streaming fed from the surveillance camera.

Experiment#3 – Video Streaming Exhibition in Mobile Interface

The configuration of the work order for the maintenance team will also be validated.

- In the Command Centre workstation, issuing a work order to the maintenance team will result in the reception of that work order in the mobile interface of the maintenance team.
- Opening the work order in the mobile interface of the maintenance team, and selecting the link to the video streaming will result in the exhibition of the live streaming fed from the surveillance camera.

Experiment#4 – Augmented Reality in Mobile Interface

The configuration of the augmented reality feature in the mobile device will also be validated.

Phase II

The EFACEC_E-UC1 can be segmented in different experiments, driven by distinct goals and will be evaluated considering the service KPIs being defined in WP4).

Experiment#1 – Fault Monitoring in Workstation Alarm Interface

The objective of this experiment is to evaluate the latency and reliability requirements of the network and to determine the time between the fault detection by the Low Voltage Sensor (LVS3) and the alarm exhibition in the Workstation Alarm List Interface.

Experiment#2 – Video Streaming Exhibition in Workstation

The objective of this experiment is to evaluate the bandwidth requirements of the network and to determine the throughput and the quality of the visual experience in the exhibition of the video streaming in the Workstation.

Experiment#3 – Video Streaming Exhibition in Mobile Interface

The objective of this experiment is to evaluate the bandwidth requirements of the network and to determine the throughput and the quality of the visual experience in the exhibition of the video streaming in the mobile interface.

Experiment#4 – Augmented Reality in Mobile Interface

The objective of this experiment is to evaluate the latency and reliability requirements of the network and to evaluate the integrity of the AR service, representing the expected information timely on top of live video streaming.

2.2.2.5. Plan and roadmap

The plan and roadmap of the EFACEC_E-UC1 involve the following stages, which add to the network evolution roadmap presented in Figure 16. This is depicted in Figure 22 which shows the plan of EFACEC_E-UC1 deployment (both phase I and phase II) aligned with the 5G infrastructure availability.

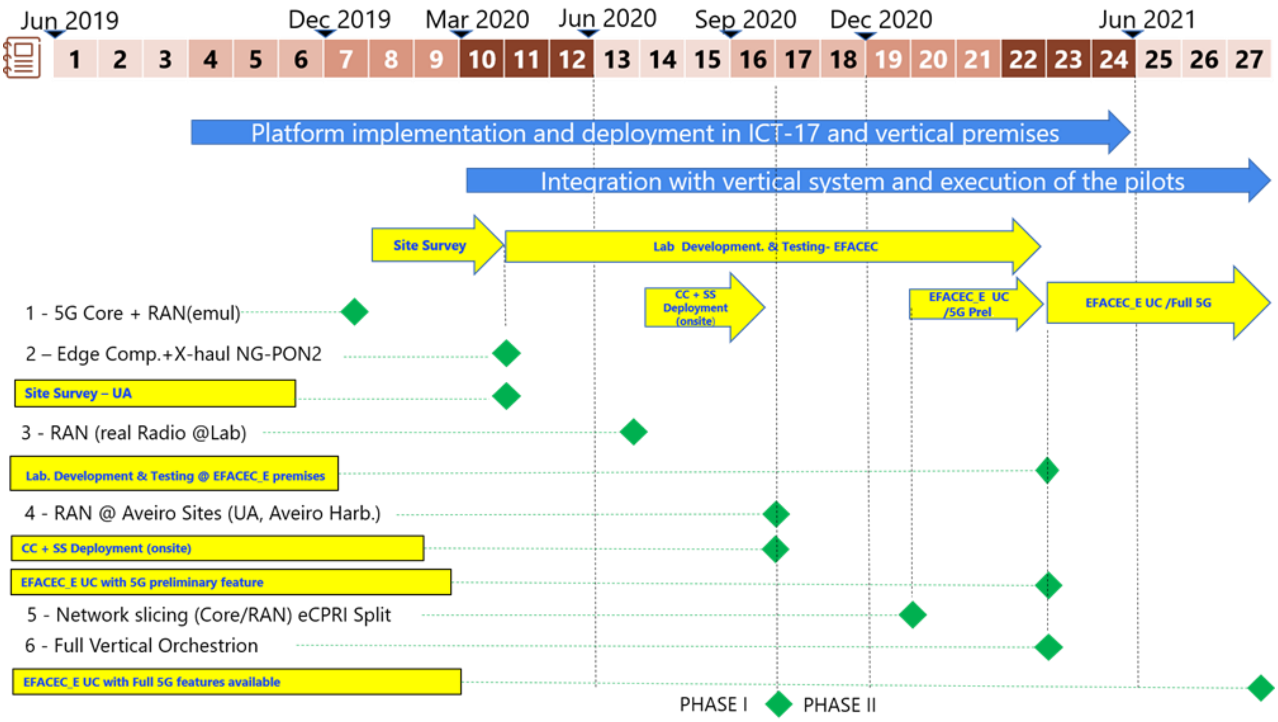


FIGURE 22: EFACEC_E-UC1 DEPLOYMENT PLAN

The following tasks are considered:

- Site Survey – The Site Survey will cover the two use cases at once. This period involves the final specification of the pilot in terms of bill of material, localization, power, connectivity and interfaces. The site survey will cover the area of EFACEC_E-UC1, namely the Secondary Substation inside Aveiro Campus, that will host the setup regarding this use case.
- Lab Development & Testing at EFACEC premises – All necessary software and hardware developments and configuration concerning the additional modules, interfaces, protocols and applications, will take place during this period at EFACEC premises. For the unitary tests an IP cable network and LTE network will be used. It is foreseen that this stage in a later period will run in parallel with the Energy Use Cases 5G Preliminary Testing Phase, scoping the final improvements in pilot setup and any need of bug fixing.

- Control Centre and Secondary Substation Automation Deployment (on-site) – This stage will be needed to deploy on site all the pilot components concerning the EFACEC_E-UC1. Some of the components deployed at this stage will also be used in the scope of the EFACEC_E-UC2, namely the Control Centre and the GSmart. Since at this stage the 5G network will be not fully available (Phase I), the integration tests will be performed with LTE technology.
- Energy Use Cases 5G Preliminary Testing Phase – At this stage, some 5G functionalities will be ready and the use cases will be tested and validated within these constrains.
- Energy Use Cases 5G Final Testing Phase – This stage requires that all functionalities will be available providing the full conditions to verify and validate the business, functional and technical requirements according to what have been specified previously.

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

2.2.3.1. Use Case Modelling

This use case scopes the advanced monitoring and fault detection in the low voltage grid. The last-gasp feature of smart devices in the low voltage grid is essential to detect and locate an electrical grid fault and to help the utility to determine which customers are affected.

The low voltage sensor (LVS3) is continuously monitoring the same bus that powers it. When a power outage occurs, the LVS3 will save the relevant information to memory and send a last-gasp message, before turning off. In order to avoid the need of auxiliary battery in the LVS3, the last gasp shall be processed on the communication interface, and a SNMP trap will be transmitted through the 5G modem.

Low latency communications are required immediately after the power outage is detected by the device, and it is essential to hold the communication channel active to send the last-gasp message before the device runs out of power (turning off).

Synchronization of the smart devices and data exchange requires even lower latency, which will improve the general quality of the acquired data (currents, voltages, powers, etc), benefiting advanced control applications dependent on correlation analysis and big data processing.

Figure 23 depicts the modelling of this use case. The general consideration portrayed in this figure is to illustrate the fact that the different components of the vertical, will be connected through a 5G network (enabled with the enhancements provided by 5Growth), instead of a plain LTE network as is presently the case for this vertical's products.

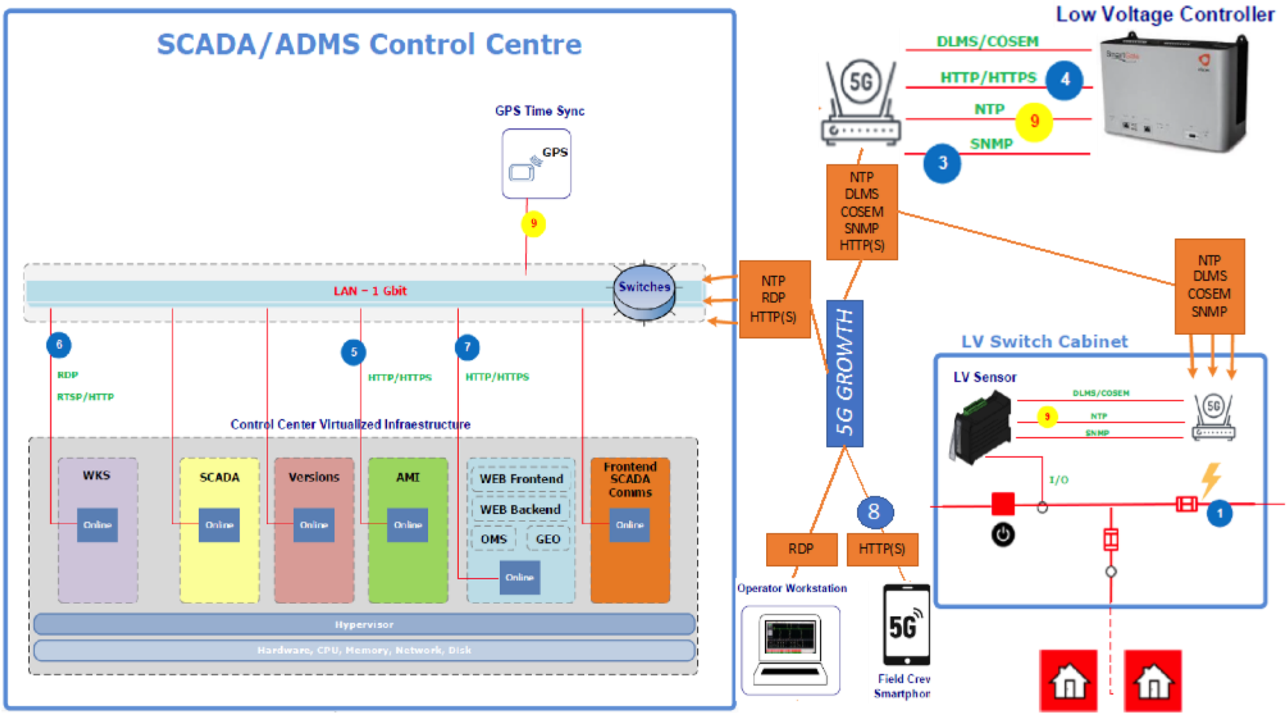


FIGURE 23: EFACEC_E-UC2 OVERVIEW

The use case sequence of events is shown in the figure above and is described as follows.

In the sequence of a fault in a switch cabinet along the low voltage grid, the low voltage sensor detects that fault (1) and reports it to the low voltage controller as a last gasp communication (2). After receiving the last gasp communication (3), the low voltage controller sends a *No Power* event to the Control Centre (4). When the AMI (Advanced Metering Infrastructure) receives a *No Power* event, it immediately transmits it to the SCADA/ADMS system (5). The Control Centre operator detects the *No Power* event in the OMS (Outage Management System) interface (6) and reports the fault to the maintenance team (7).

The maintenance team member, using a mobile device, receives the work order from the Control Centre (8) with the precise location of the fault. This way, the maintenance team can spare precious time arriving to the damaged installation.

In order to get high quality usable data from the low voltage sensors, the low voltage sensors must be provided with a high precision time synchronization (9) service. This will demand a very low latency service from the communication network.

2.2.3.2. Hardware / Software components

Phase 1

TABLE 14: EFACEC_E-UC2 HW COMPONENTS (PHASE I)

Component	Description	Location
LV Sensors	Devices that will be installed both in the distribution cabinet and in Aveiro	EFACEC Labs

Component	Description	Location
	University Lab, to monitor and detect faults in the low voltage circuits. EFACEC devices – LVS3	Aveiro Campus Distribution Cabinet UA Lab
LV Controller	Device that will be installed in the secondary substation to gather to concentrate all the information from the low voltage network, given by the LVS3 devices. EFACEC device – GSmart	EFACEC Labs Aveiro Campus Secondary Substation
Smartphone	Smartphone used by the maintenance team (technical personnel responsible for the maintenance of the power grid and installations).	Aveiro Campus Area
LTE Router	4G CPE responsible for data exchange between the Low Voltage Controller, inside the Secondary substation, and the Control Centre, using the 4G commercial service. Also responsible for data exchange between the Low Voltage Sensors in the distribution cabinet and in Aveiro University Lab, and the Low Voltage Controller, inside the Secondary substation, using the 4G commercial service	EFACEC Labs
5G Core	Mobile Network Core elements	Mobile Operator / Altice Labs (5G-VINNI)
RAN	The RAN portion of the operator's mobile network	Mobile Operator / Altice Labs (5G-VINNI)
Edge Computing	The edge MEC portion of the mobile operator, allowing for lower latency service provisioning whenever needed.	Mobile Operator / Altice Labs (5G-VINNI)

TABLE 15: EFACEC_E-UC2 SW COMPONENTS (PHASE I)

Component	Description	Location
SCADA/ADMS System	SCADA system to support the operators to monitor and control the power grid and the installations.	EFACEC Labs infrastructure IT Cloud premises
OMS (Outage Management System)	Subsystem, part of the SCADA/ADMS, responsible for processing inputs from the low voltage network, and to provide data to be presented to the network operators.	EFACEC Labs infrastructure IT Cloud premises
AMI (Advanced Metering Infrastructure)	System responsible for managing the metering devices of the low voltage	EFACEC Labs infrastructure

Component	Description	Location
	network. It is a system of its own, independent of the SCADA/ADMS. For convenience it is in this pilot hosted together with it.	IT Cloud premises
MANO	Mobile Network Management and Orchestration capability.	Mobile Operator/Altice Labs (5G-VINNI)
VIM	Virtualized Infrastructure Management Capability	Mobile Operator/Altice Labs (5G-VINNI)

Note: The network components are identified and detailed in Section 2.3.2.2, in Figure 35.

Phase 2

TABLE 16: EFACEC_E-UC2 HW COMPONENTS (PHASE II)

Component	Description	Location
Fuses (only @ Aveiro Campus)	Components used to protect the low voltage circuits against high currents. Already installed in the distribution cabinet	Aveiro Campus Distribution Cabinet
LV Sensors	Devices that will be installed both in the distribution cabinet and in Aveiro University Lab, to monitor and detect faults in the low voltage circuits. EFACEC devices – LVS3	EFACEC Labs Aveiro Campus Distribution Cabinet UA Lab
LV Controller	Device that will be installed in the secondary substation to gather to concentrate all the information from the low voltage network, given by the LVS3 devices. EFACEC device – GSmart	EFACEC Labs Aveiro Campus Secondary Substation
Smartphone	Smartphone used by the maintenance team (technical personnel responsible for the maintenance of the power grid and installations).	Aveiro Campus Area
SCADA/ADMS System	SCADA system to support the operators to monitor and control the power grid and the installations.	IT Cloud premises
5G Router	5G CPE responsible for data exchange between the Low Voltage Controller, inside the Secondary substation, and the Control Centre, using the 5G service available. Also responsible for data exchange between the Low Voltage Sensors in the	Aveiro Campus Secondary Substation Distribution Cabinet UA Lab

Component	Description	Location
	distribution cabinet and in Aveiro University Lab, and the Low Voltage Controller, inside the Secondary substation, using the 5G service available.	
5G Core	Mobile Network Core elements	Mobile Operator / Altice Labs (5G-VINNI)
RAN	The RAN portion of the operator's mobile network	Mobile Operator / Altice Labs (5G-VINNI)
Edge Computing	The edge MEC portion of the mobile operator, allowing for lower latency service provisioning whenever needed.	Mobile Operator / Altice Labs (5G-VINNI)

TABLE 17: EFACEC_E-UC2 SW COMPONENTS (PHASE II)

Component	Description	Location
SCADA/ADMS System	SCADA system to support the operators to monitor and control the power grid and the installations.	IT Cloud premises
OMS (Outage Management System)	Subsystem, part of the SCADA/ADMS, responsible for processing inputs from the low voltage network, and to provide data to be presented to the network operators.	EFACEC Labs infrastructure IT Cloud premises
AMI (Advanced Metering Infrastructure)	System responsible for managing the metering devices of the low voltage network. It is a system of its own, independent of the SCADA/ADMS. For convenience it is in this pilot hosted together with it.	EFACEC Labs infrastructure IT Cloud premises
5G Core	Mobile Network Core elements	Mobile Operator / Altice Labs (5G-VINNI)
RAN	The RAN portion of the operator's mobile network	Mobile Operator / Altice Labs (5G-VINNI)
Edge Computing	The edge MEC portion of the mobile operator, allowing for lower latency service provisioning whenever needed.	Mobile Operator / Altice Labs (5G-VINNI)
MANO	Mobile Network Management and Orchestration capability.	Mobile Operator/Altice Labs (5G-VINNI)
VIM	Virtualized Infrastructure Management Capability	Mobile Operator/Altice Labs (5G-VINNI)

Note: The network components are identified and detailed in Section 2.3.2.2, in Figure 35.

2.2.3.3. Deployment and implementation setup

The use case will be deployed in two phases: (i) in phase I, since 5G network and CPEs are not available yet, LTE CPEs and the 4G commercial network will be used, both in the EFACEC Lab and in Aveiro University Site, to enable the functional validation of the components while 5G is becoming available; and (ii) in phase II, 4G connectivity is going to be replaced with 5G connectivity

Phase I

The deployment and implementation setup at Altice Labs concerning the 5G network will be shared with EFACEC_S vertical pilot. The use case will be deployed in two phases. In phase I, the use case will be deployed, to a limited extent, in a laboratory environment. For the 5G network components, this phase is planned to start in June 2020 (Figure 18). The main goal in this phase is to verify that the 5G infrastructure, namely 5G core and NG-RAN, are capable of providing the functionality required by the use case and to identify (and overcome) possible issues that may affect the accomplishment of the pilot objectives. An initial assessment of relevant KPIs (e.g. service instantiation time, latency) will be performed. It should be noted that in this phase the Vertical Slicer is not expected to be integrated with the 5G-VINNI platform, therefore the vertical is not yet supposed directly interact with the platform. Prior to this, the initial experiment stage of the vertical components will be performed at EFACEC premises followed by site tests using as first approach LTE technology and at final stage 5G communications.

The initial experiment stage of the EFACEC-UC2 components will be performed at EFACEC premises followed by on-site tests using as first approach LTE technology and technology and a commercial 4G network.

Phase II

At the final stage, with the availability of the 5G network, the vertical components can be coupled with 5G-enabled interfaces and use the 5G network for their communications. Phase II corresponds to the deployment of the use case on site (Figure 18). In this phase, the use case will be deployed in its full extent. Depending on specific requirements, e.g. power, distance, the RAN component may be different from the solution used in Phase I. At this point, the vertical slicer will be integrated with the remaining management & orchestration components, which will enable the vertical users to interact directly with the platform. With the availability of the 5G network, the vertical components can be coupled with 5G-enabled interfaces and use the 5G network for their communications.

2.2.3.4. Initial experiment description

The aim of this experiment is to validate the functional behaviour of the identified scenario. Both individual component processing and interaction between components will be assessed. The Service KPIs defined in WP4 will be used to assess the performance of the elements within these experiments.

<u>Experiment#1</u> – Fault Detection – Last Gasp

The configuration of the EFACEC_E-UC2 setup will also be validated.

- Cutting the power to the LVS3 device shall result in the exhibition of a new outage in the SCADA/ADMS OMS interface, identifying the correct LVS3 as having *No Power*.

Experiment#2 – Low Voltage Sensors Synchronization

The configuration of both the GPS Time Server and the NTP services in the LVS3 and GSmart devices will also be validated.

- When turned on and connected to the network, all the low voltage sensors and controller shall show themselves synchronized with the time of the GPS Time Server

Phase II

The EFACEC_E-UC2 can be segmented in different experiments, driven by distinct goals (service KPIs).

Experiment#1 – Fault Detection – Last Gasp

The objective of this experiment is to evaluate the latency and reliability requirements of the network and to determine the time between the fault detection by the Low Voltage Sensor (LVS3) and the outage event exhibition in the Workstation OMS Interface.

As said before, in order to avoid the need of an auxiliary battery in the low voltage sensor, the last gasp event will be processed at the communication interface level and will be notified to the low voltage controller as a SNMP trap. Because we are talking about UDP communications, the reliability of the network service is critical in this experiment.

Experiment#2 – Low Voltage Sensors Synchronization

The objective of this experiment is to evaluate the latency of the network when providing the synchronization of the low voltage sensors.

In order to keep the devices all timely synchronized, the connectivity among them needs to be of low latency, and jitter should be as low as possible in order to enable a predictive latency, which is an important aspect on time synchronization

2.2.3.5. Plan and roadmap

The plan and roadmap of the EFACEC_E-UC2 involve the following stages, which add to the network evolution roadmap presented in Figure 16. This is depicted in Figure 24, which shows the plan of EFACEC_E-UC2 deployment, phase I and phase II, aligned with the 5G infrastructure availability.

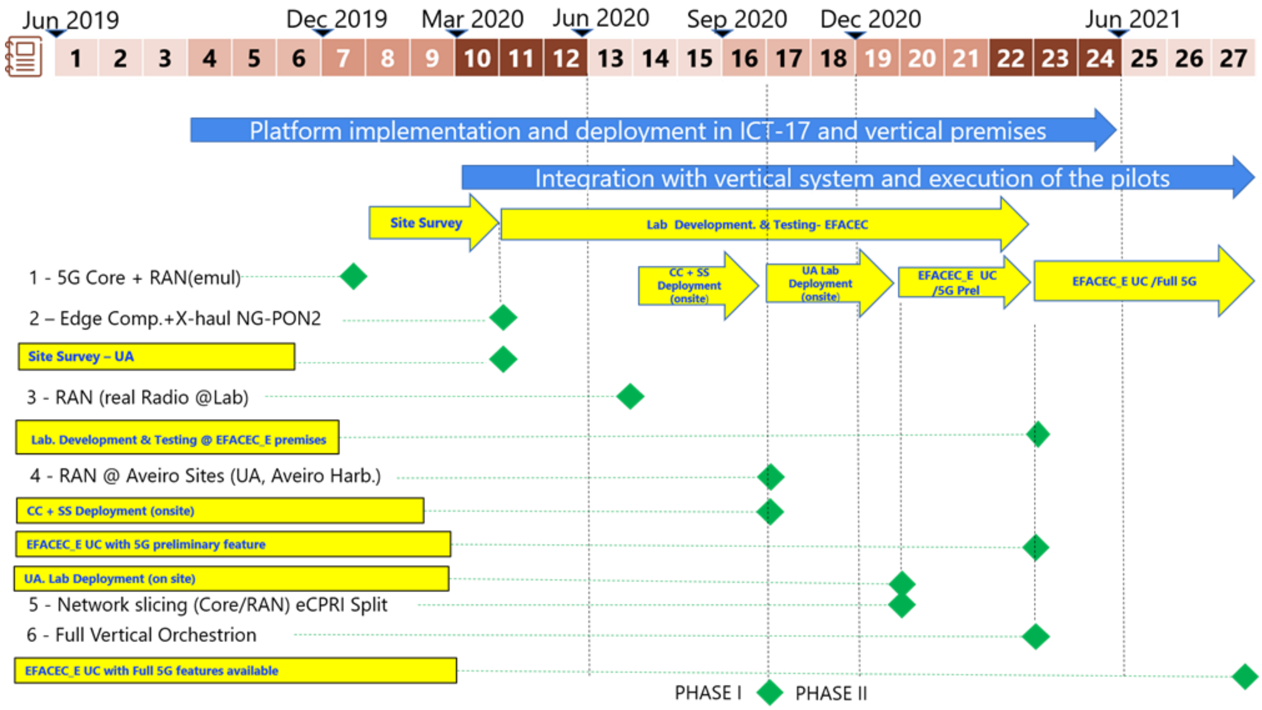


FIGURE 24: EFACEC_E-UC2 DEPLOYMENT PLAN

This comprises the following tasks:

- Site Survey – The Site Survey will cover the two use cases at once. This period involves the final specification of the pilot in terms of bill of material, localization, power, connectivity and interfaces. The site survey will cover the area of EFACEC_E-UC2, namely the building belonging to Aveiro University that will host the setup regarding this use case.
- Lab Development & Testing at EFACEC premises – All necessary software and hardware developments and configuration concerning the additional modules, interfaces, protocols and applications, will take place during this period at EFACEC premises. For the unitary tests an IP cable network and LTE network will be used.
- Control Centre and Secondary Substation Automation Deployment (on-site) – This stage is common to the one mentioned in the roadmap of phase I, since some of the components deployed at this stage will also be used in the scope of the EFACEC_E-UC1, namely, the Control Centre and the GSmart. Since at this stage the 5G network will be not fully available (Phase I), the integration tests will be performed with LTE technology.
- U. Aveiro Lab Deployment (on-site) - This stage will be needed to deploy on site all the pilot components specific to the EFACEC_E-UC2. These components will be installed in the locations determined in the site survey. At this stage the 5G network will be partially available so, whenever possible, the integration tests will be performed with 5G technology.
- Energy Use Cases 5G Preliminary Testing Phase – At this stage, some 5G functionalities will be ready and the use cases will be tested and validated within these constrains.
- Energy Use Cases 5G Final Testing Phase – This stage requires that all functionalities will be available providing the full conditions to verify and validate the business, functional and technical requirements according to what have been specified previously.

2.2.4. COVID-19 Impact Analysis on Plans and Roadmaps

As the COVID-19 situation develops, governments are applying restrictions to the mobility of their citizens and enterprises are also applying restrictions to the mobility of their employees. Those restrictions will impact the original plan of the pilot.

The project is considering a worst-case scenario of four months highly constrained activity at the University of Aveiro, and in the EFACEC and ALB laboratories.

The impact can be grouped into the assumed facts (those that will certainly happen) and the probable threats (those that could happen) during those four months.

1) **Assumed Facts:**
   a. HW Deployment & Upgrades:
      i. Not possible in this period
      ii. No feasible mitigation
   b. Supply of 3rd party products
      i. Not possible in this period
      ii. No feasible mitigation
   c. Aveiro University on-site activities:
      i. Not possible in this period, except for activities whose non-realization cause great prejudice to the University, pending acceptance of the institution responsible
      ii. No feasible mitigation
   d. Aveiro Harbour on-site activities:
      i. Not possible in this period
      ii. No feasible mitigation
   e. Attendance to F2F meetings:
      i. Not possible in this period
      ii. Switched to virtual meetings
   f. Attendance to Events:
      i. Not possible in this period
      ii. Dissemination via digital video channels
2) **Probable Threats:**
   a. Potential infection of involved staff in the project
   b. Potential degradation of remote access to current labs infrastructure
   c. Potential performance degradation of current labs infrastructure

With the aim of keeping the original ending project dates, two options are evaluated:

1) **Keep Milestones' planned dates**, through scope contention of M18's Milestone and progressive catch-up afterwards, in order to enable incremental testing of the pilot both before and after M18.
2) **Delay M18's Milestone 4 months**, in order to keep the original planned activities unaffected.

Considering all the above, the project partners will shift their plans and will focus on activities that are less likely to be impacted by the restrictions, such as:

a. SW applications development
b. Preparing documentation
c. Partial validation of (sub)components or concepts that are part of the whole solution
d. Getting ready for on-site tasks

2.2.4.1. Option 1: Estimated Impact in the 5G Network Infrastructure Roadmap

This option focuses on an estimation of what can be accomplished by M18 of the project, considering both the network deployments and the vertical deployments, expressing possibilities that aim allowing the validation of key aspects. This mainly encompasses the availability of a 5G link, and the concretization of the train track related components.

For M18, Open5GCore and a real 5G radio will be integrated and fully functional in a Lab environment and being able to cover the secondary substation position in the Aveiro University.

Network Slicing features should preferable also be available in the Lab.

2.2.4.2. Option 1: Estimated impact in EFACEC_E-UC1 Plan and Roadmap

This will allow the deployment of trial-versions of EFACEC components at the secondary substation, covering part of the EFACEC_E-UC1. This will also allow to validate the capability of the infrastructure in handling the configuration and requirements for connecting such components.

In that sense, for EFACEC_E-UC1, the following trial components will be deployed:

a. SCADA/ADMS Control Centre, hosted in ITAV cloud, with configuration covering part of the EFACEC_E-UC1;
b. Low Voltage Controller (GSmart) at the secondary substation, with configuration covering the EFACEC_E-UC1;
c. Low Voltage Sensor (LVS3) at the secondary substation, with configuration covering the EFACEC_E-UC1;
d. HD Surveillance Camera;
e. 5G network interface router/module;

With this Lab scenario, it will be possible to test over a 5G link the communication, latency and availability of the real time telemetry between the secondary substation and the Control Centre.

It will be also possible to test the availability and quality of the video streaming between the secondary substation and the Control Centre. The two fragments pointed above are a relevant part of EFACEC_E-UC1.

Regarding measurements, we foresee that the technical support needed to perform a part of the measurements in the control centre concerning the validation of the real-time telemetry KPIs will be available.

This plan is also dependent on the timely acquisition of compatible 5G-based interfaces for connecting to the deployed 5G network.

2.2.4.3. Option 1: Estimated impact in EFACEC_E-UC2 Plan and Roadmap

At this moment, EFACEC_E anticipate that it will not be possible to deploy a minimum setup concerning the EFACEC_E-UC2, that would allow to have the same approach depicted above for the EFACEC_E-UC1, covering specific parts of the integrated Use Case.

This plan is also dependent on the timely acquisition of compatible 5G-based interfaces for connecting to the deployed 5G network.

Overall, with the Option 1, considering the restrictions currently being imposed by COVID-19 to the participants of this pilot, we will be able to see partial deployment of the initially intended use case, and allow experiments, integration and monitoring to begin.

2.2.4.4. Option 2: Estimated Impact in the 5G Network Infrastructure Roadmap

Figure 25 shows the estimated impact:

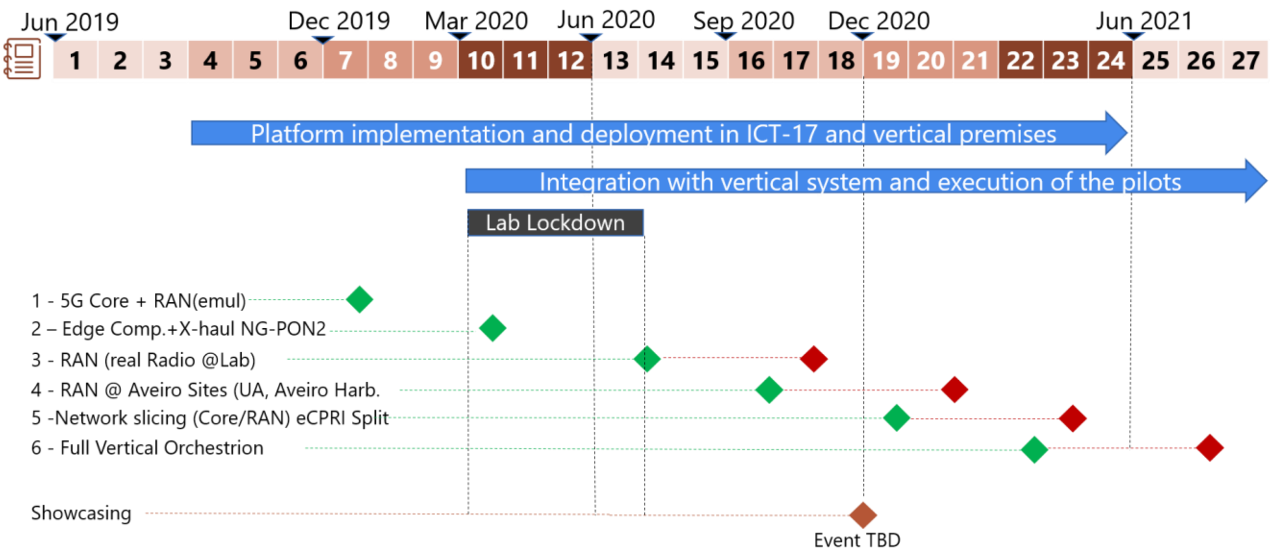


FIGURE 25: EFACEC_E 5G NETWORK INFRASTRUCTURE ROADMAP ESTIMATED IMPACT

Phase I was planned that by June 2020 (M13), the emulated RAN component will be replaced by a real radio hardware in a Lab environment. But if the access to Lab is still unavailable and the persons involved on the set up are confined to their own home by four months, this phase will be inevitably postponed four months. This delay will negatively impact the next phases that will be shifted four months (Figure 25):

- October 2020 (M17) the emulated RAN component will be replaced by a real radio hardware in a Lab environment (the OAI solution as planned, or another solution that may be available faster or with better deployment capabilities);
- January 2021 (M20), the real RAN solution deployed at the Lab will be extended to the pilot sites, the University of Aveiro (Energy) and the Aveiro Harbour (Transportation);
- April 2021 (M23), Network Slicing features will be added to the Lab (first) and pilot sites, accommodating the different requirements of the pilots and respective use cases;

- July 2021 (M26), not only the network, but also vertical components are orchestrated to be deployed on the network, either they are placed in the site, edge or core.

There are more constraints that could hinder or prevent the accomplishment of the present plan due the restraints to circulation of persons and manufacturing of no essential goods during so long time (4 months). There is a positive note, work that can be carried out remotely or software development only will suffer a minor impact assuming, we must be positive, that there is no personals impact.

2.2.4.5. Option 2: Estimated impact in EFACEC_E-UC1 Plan and Roadmap

Figure 26 shows the estimated impact in the plan and roadmap of EFACEC_E-UC1.

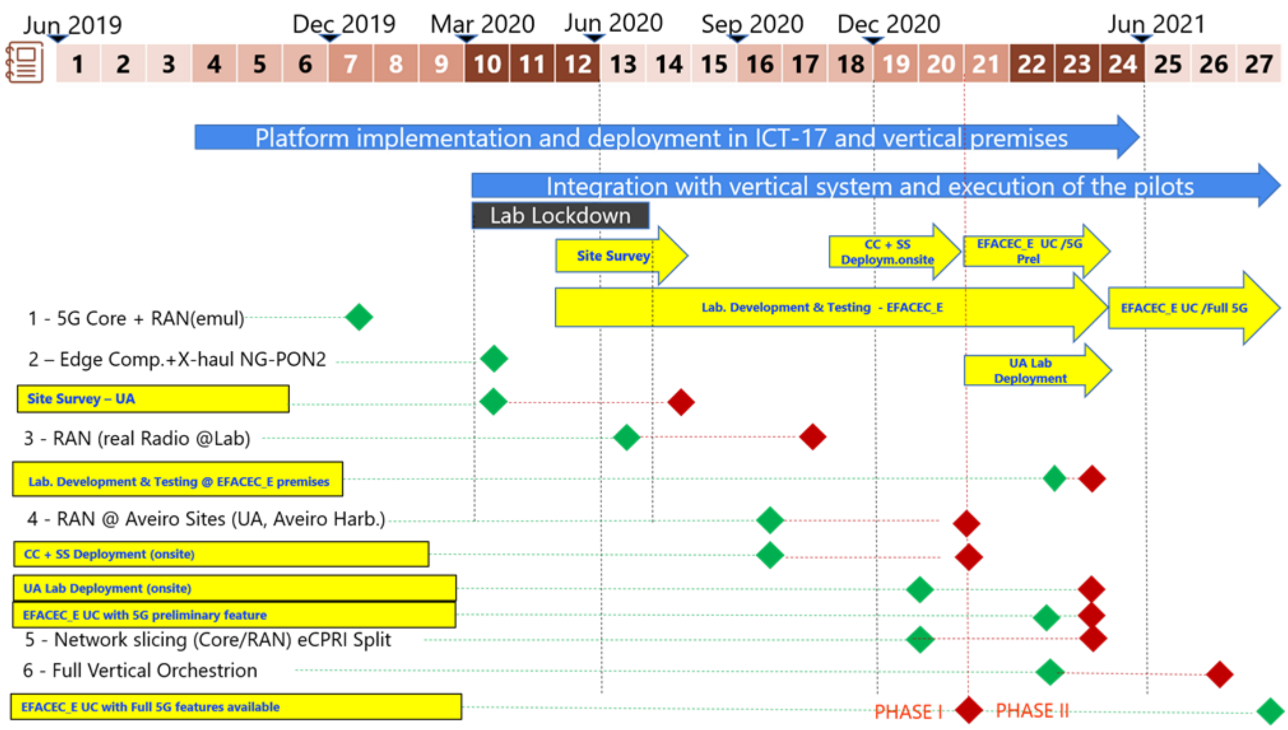


FIGURE 26: EFACEC_E-UC1 PLAN AND ROADMAP ESTIMATED IMPACT

The site survey on University of Aveiro, programmed to occur during the first quarter, will be directly impacted. It will be delayed four months in the considered scenario.

Concerning the development phase in EFACEC lab, the EFACEC_E-UC1 setup depends, on one hand, on the purchasing of third-party components including the surveillance camera, the 5G Smartphone and the intrusion detector and, on the other hand, on the availability of LVS3 and Gsmart devices subjected to external manufacturing. It will be delayed four months in the considered scenario.

The whole integration of the EFACEC_E-UC1 setup during the development phase depends on physical presence on EFACEC Lab, which is also directly impacted. It will be delayed four months in the considered scenario.

These delays will impact the beginning of Secondary Substation deployment of the EFACEC_E-UC1 setup. It will be delayed four months in the considered scenario.

As can also be seen, in order to maintain the overall end date of the work, it is important that, unlike the original plan, the vertical deployment tasks (in yellow) do not wait for the finish of the network deployment tasks (in green), and actually start in a parallel with the final works of the network deployment tasks.

2.2.4.6. Option 2: Estimated impact in EFACEC_E-UC2 Plan and Roadmap

Figure 27 shows the estimated impact in the plan and roadmap of EFACEC_E-UC2.

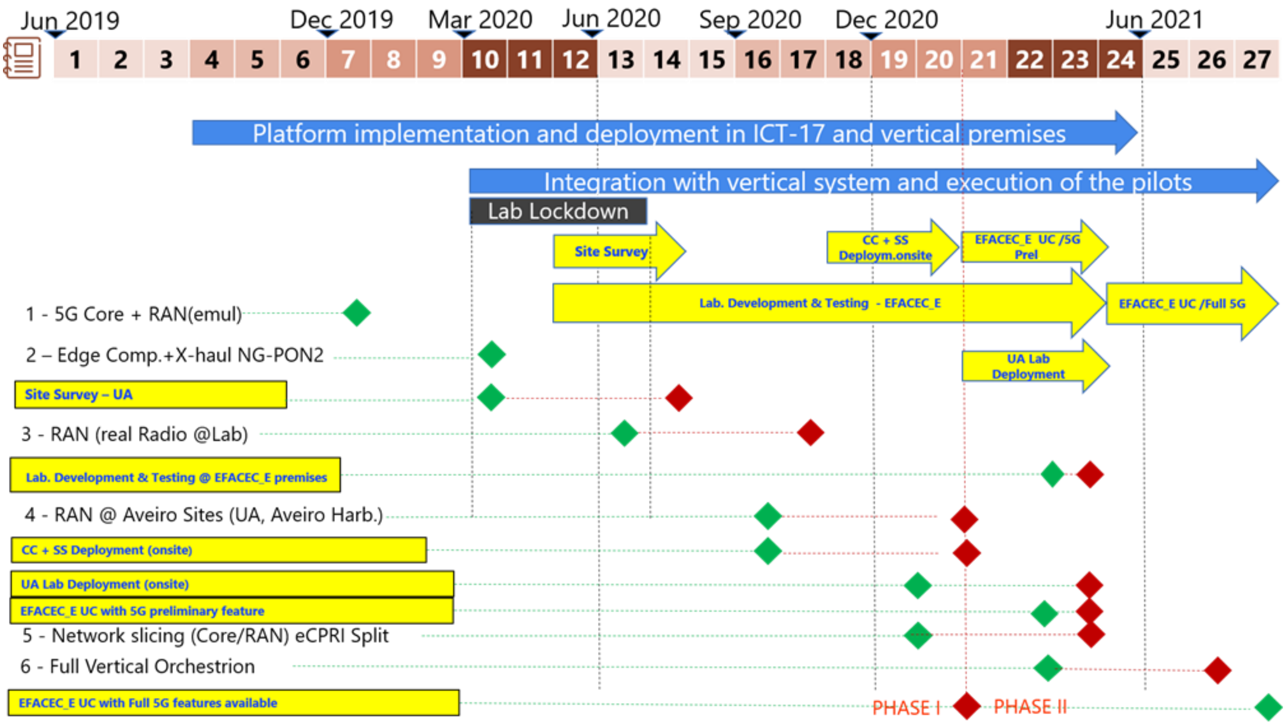


FIGURE 27: EFACEC_E-UC2 PLAN AND ROADMAP ESTIMATED IMPACT

The site survey on University of Aveiro, programmed to occur during the first trimester, will be directly impacted. It will be delayed four months in the considered scenario.

On the other hand, the hardware development activities on LVS3 device, needed for the EFACEC_E-UC2, depend on purchasing of third-party components, and on physical presence on EFACEC Lab, which are also directly impacted. It will be delayed four months in the considered scenario.

These delays will impact the beginning of University of Aveiro Lab deployment of the EFACEC_E-UC2 setup. It will be delayed four months in the considered scenario.

The necessary upgrades to Command Centre software and Secondary Substation hardware will be deployed during the same temporal slot predicted for the base deployment for the EFACEC_E-UC1.

As can also be seen, in order to maintain the overall end date of the work, it is important that, unlike the original plan, the vertical deployment tasks (in yellow) do not wait for the finish of the network deployment tasks (in green), and actually start in a parallel with the final works of the network deployment tasks.

2.3. EFACEC_S Vertical Pilot

The EFACEC_S vertical pilot explores the provisioning of 5G enablers for the transportation sector, taking place Aveiro Harbour. It unfolds into two different use cases. The first one involves a signalling safety critical scenario, detailed in Section 2.3.2, and considers the use of a 5G network to relay the detection of an incoming train, towards a Level Crossing controller. The second one, detailed in Section 2.3.3, reinforces the safety conditions and considers the video stream of live footage from the Level Crossing towards the incoming train and maintenance crews in the area. The deployment details are presented next, in Section 2.3.1. The deployment is considered following two different phased. The first one (Phase 1), considers a preliminary lab-based deployment with a skeleton system composed of the minimum necessary features for initial trials. The second one (Phase 2) considers on-site trials with the full-fledged system.

2.3.1. Infrastructure deployment in vertical premises

The roadmap and deployment setup for this pilot are exactly the same as for the EFACEC_E vertical pilot (as described in Section 2.2.1), since the 5G network infrastructure will be common. Nevertheless, for the completeness and self-contained description of this vertical pilot, we also provide here the relevant content.

2.3.1.1. Roadmap

Figure 28 depicts the 5G network infrastructure planning for the Aveiro site, which is common to both pilots, EFACEC_S and EFACEC_E pilots. This plan intends to gradually introduce new functionality until September 2020, when it is expected that a 5G end-to-end network is available for the first time.

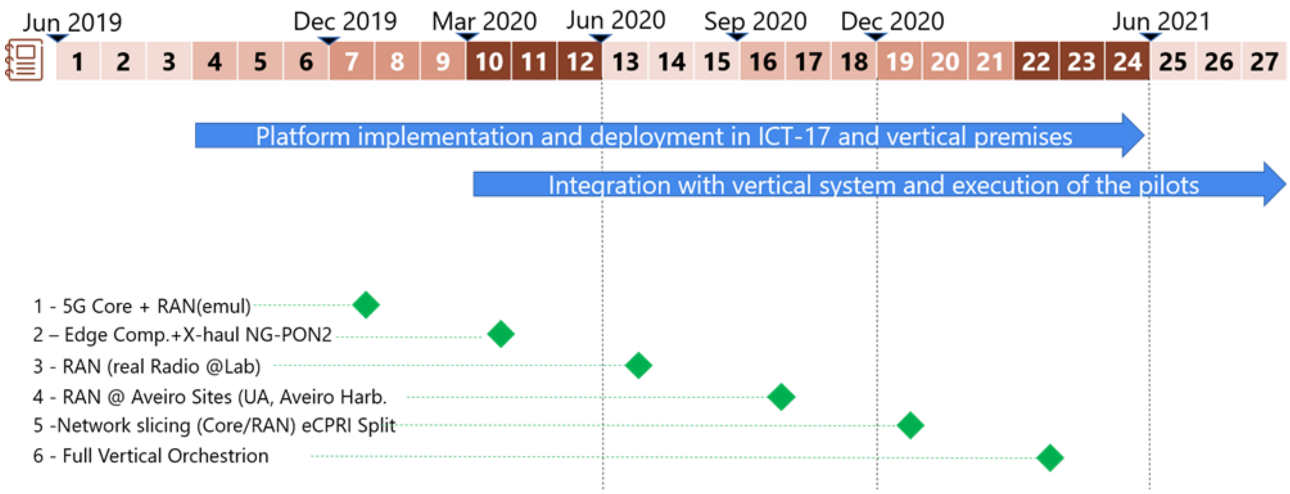


FIGURE 28: EFACEC_S 5G NETWORK INFRASTRUCTURE ROADMAP

The steps depicted on Figure 28 are explained below in more detail.

1) By December 2019 (M7), SONATA [5] [6] is used to perform the deployment of a 5G-Core (Open5GCore) and an emulated RAN+UE (coming with Open5GCore [7]) Network Services. The

Core and RAN+UE services are on-boarded and deployed in different VIMs, and interconnected through a tunnel.

2) By March 2020 (M10), Edge Computing capabilities (Altice Labs) will be added in order to divert traffic that requires low latencies to applications running at the edge. In addition, NG-PON2 technology will be added, previously on the back-haul (later will be used for the mid-haul).
3) By June 2020 (M13), the emulated RAN component will be replaced by a real radio hardware in a Lab environment.
4) By September 2020 (M16), the real RAN solution deployed at the Lab will be extended to the pilot sites, the University of Aveiro (Energy) and the Aveiro Harbour (Transportation).
5) By December 2020 (M19), Network Slicing features will be added to the Lab (first) and pilot sites, accommodating the different requirements of the pilots and respective use cases.
6) By March 2021, not only the network, but also vertical components will be orchestrated to be deployed on the network, either they are placed in the site, edge or core.

2.3.1.2. Plan and deployment setup

Figure 29 depicts the existing deployment setup by December 2019, where a 5G-Core and an emulated RAN (+UE) can be deployed by SONATA, both on IT premises, using a manually configured tunnel. By March 2020, edge computing (in-house Altice Labs solution) and GPON technology is introduced, using a slicing modelling for all components and automating connectivity among them using a SONATA WIM (WAN Infrastructure Manager) (with SONATA acting as a Connection Service Management Function (CSMF), interconnected with the 5Growth's platform, acting as a Network Slice Management Function (NSMF) [8]).

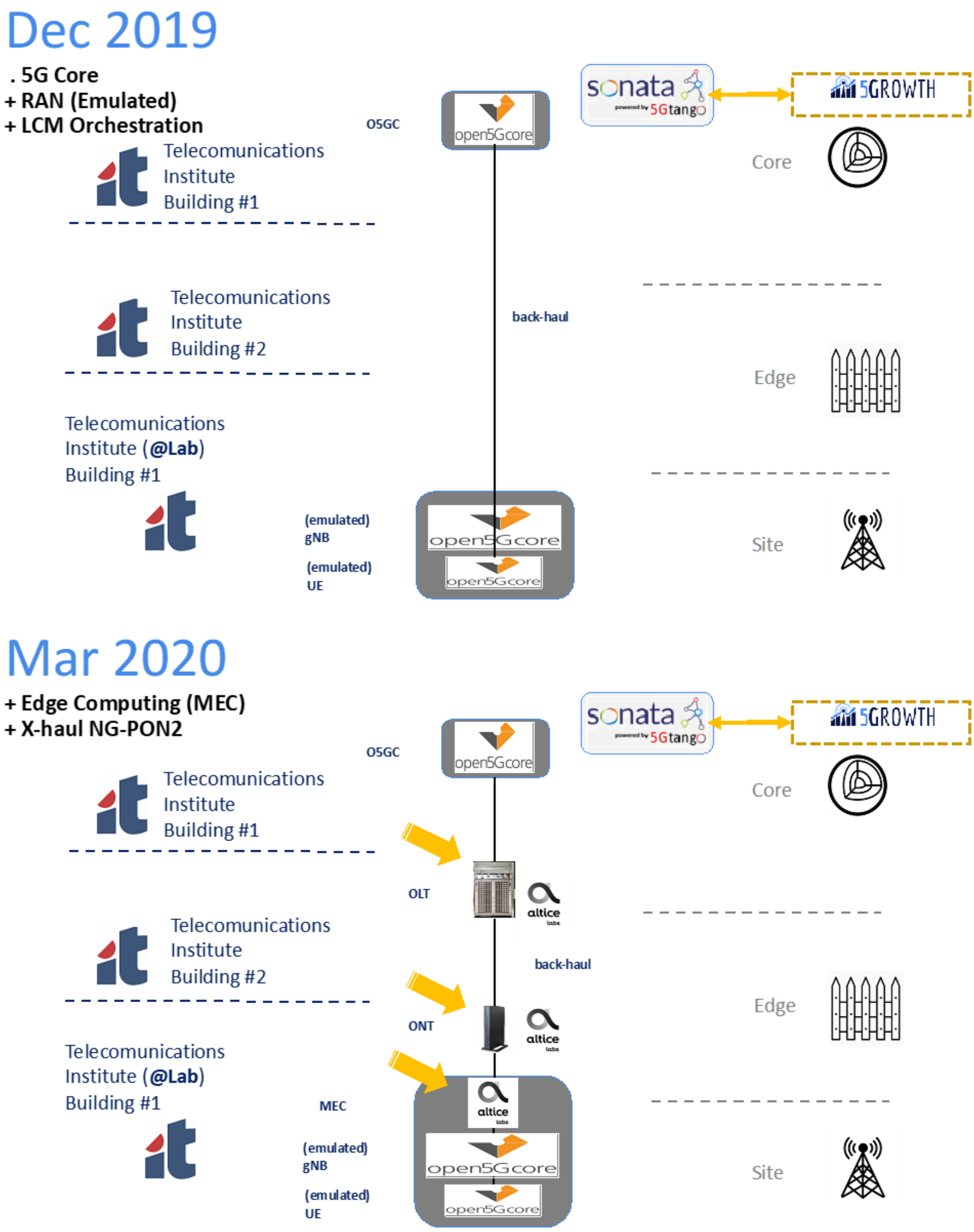


FIGURE 29: EFACEC_S 5G NETWORK DEPLOYMENT PLAN; DEC 2019, MAR 2020

Figure 30 depicts the deployment setup by June 2020, where real 5G-NR (monolithic version) is for the first time introduced (OpenAirInterface [9]). By September 2020, the real 5G-NR is extended to the pilot sites, the University of Aveiro (EFACEC_E pilot) and the Aveiro Harbour (EFACEC_S pilot).

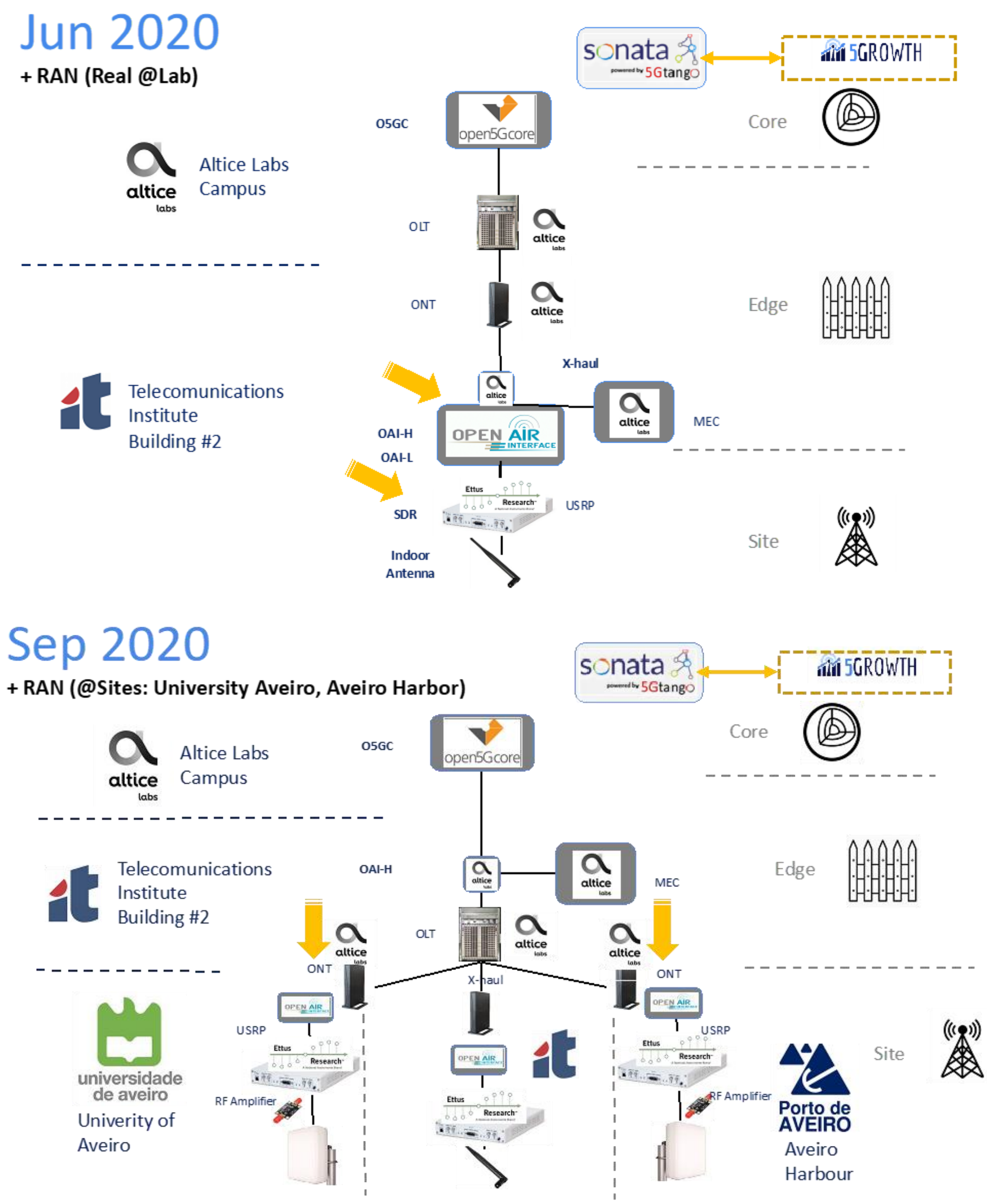


FIGURE 30: EFACEC_S 5G NETWORK DEPLOYMENT PLAN; JUN 2019, SEP 2020

Figure 31 depicts the deployment setup by December 2020, where Network Slicing capabilities are introduced and the monolithic gNB is split according to the eCPRI splitting models. By March 2021, the full pilot orchestration will be available, including the deployment of the pilot functions and services.

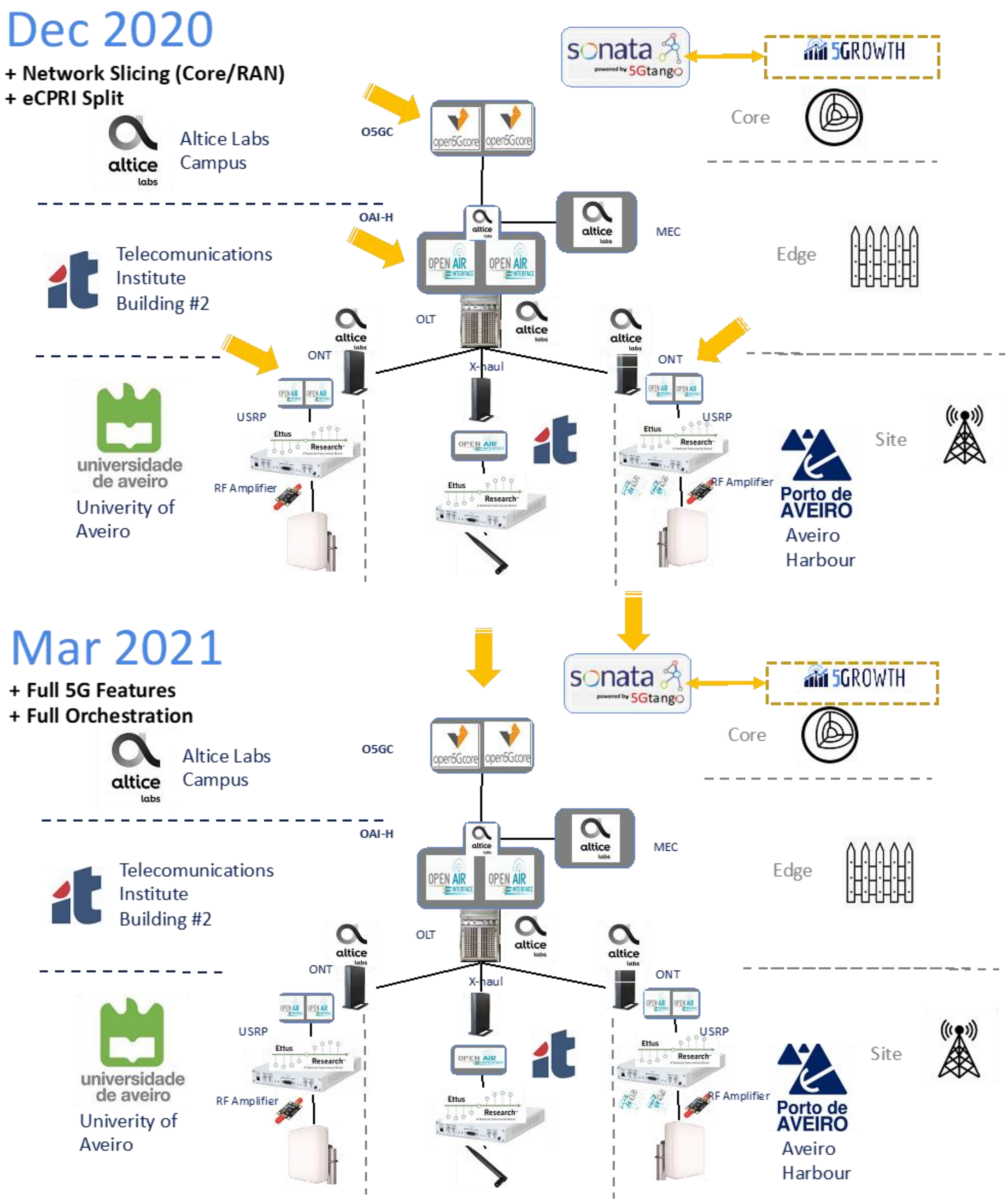


FIGURE 31: EFACEC_S 5G NETWORK DEPLOYMENT PLAN; DEC 2020, MAR 2021

Figure 32 illustrates the integration of the 5Growth Vertical Slicer with SONATA, which includes the adaptation layer, aimed at enabling Vertical Slicer's CSMF to manage network slice lifecycle through SONATA northbound API. Concretely, 5Growth will provide a graphical user interface allowing the Engineering Service Provider to request Communication Services for the data exchanges necessary to the use cases of this pilot. At the Vertical Slicer, the request is processed, and sent as a Network Slice provisioning request (as standardised by the 3GPP) to be executed by the Network Operator. In case of the Aveiro deployments, the Network Service request will be handled by ICT-17's H2020 5G-VINNI deployment in Aveiro, which is managed through the SONATA platform. SONATA, will map this request into the necessary supported constructs, enabling the deployment of the necessary network resources.

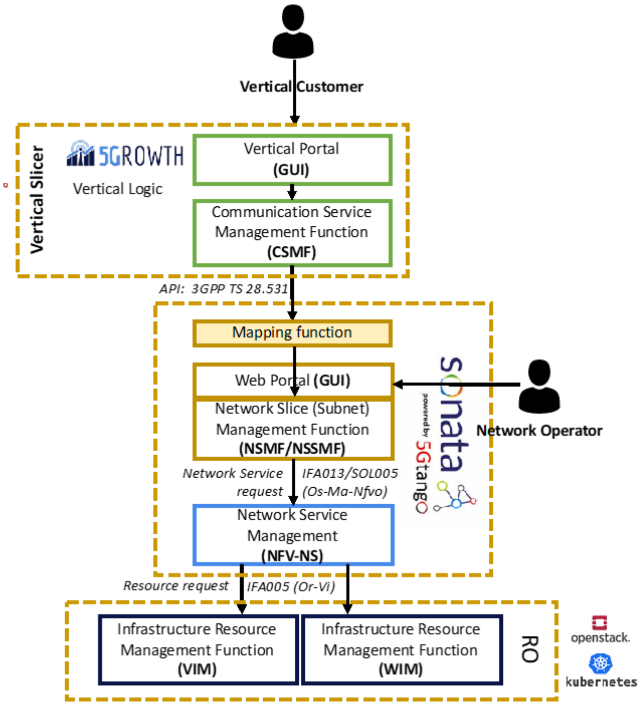


FIGURE 32: EFACEC_S PILOT VERTICAL SLICER / SONATA INTEGRATION

2.3.2. Use Case 1: Safety Critical Communications

2.3.2.1. Use Case Modelling

Figure 33 depicts the modelling of the use case, focusing on its components and interfaces.

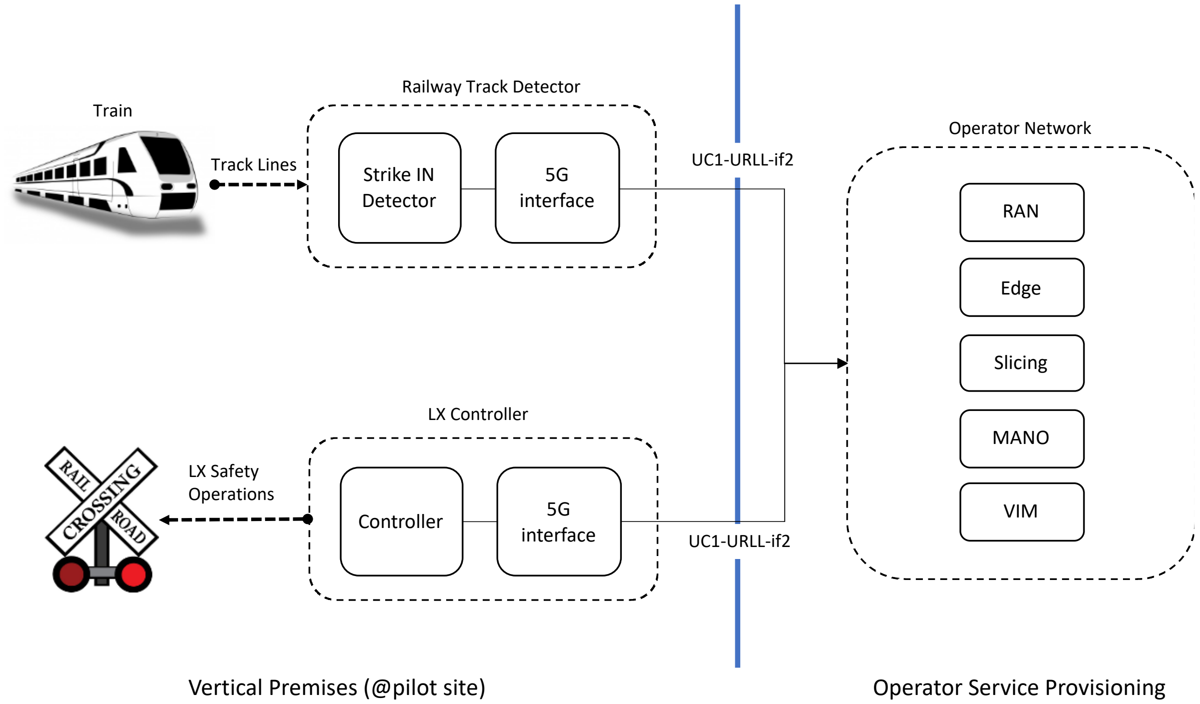


FIGURE 33: EFACEC_S-UC1 OVERVIEW

The use case 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 Detector and LX Controller to communicate, supported by all the RAN and Core operation service provisioning mechanisms.

Figure 34 shows the solution architecture of the EFACEC_S-UC1, allowing the communication between the train detecting sensors and the LX Controller.

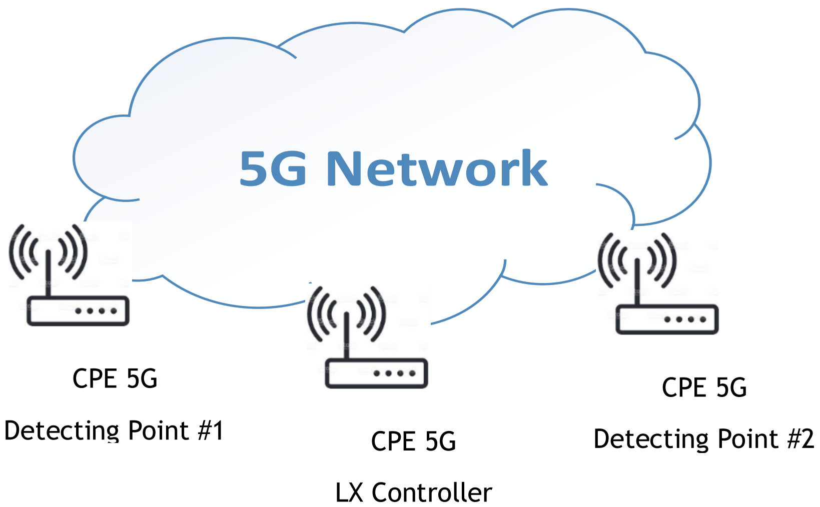


FIGURE 34: EFACEC_S-UC1 COMMUNICATION BETWEEN THE TRAIN DETECTING SENSORS AND THE LX CONTROLLER

The slice requirements are introduced by the vertical using the Vertical Slicer (5Gr-VS), depicted in Figure 32, which interacts with the Aveiro 5G-VINNI testbed through the SONATA orchestrator to instantiate the network service. SONATA will be in charge of 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.

2.3.2.2. Hardware / Software components

The components related with this use case are presented in the following table, showcasing the components for both Phase I and Phase II of the use case's validation.

TABLE 18: EFACEC_S-UC1 HW COMPONENTS

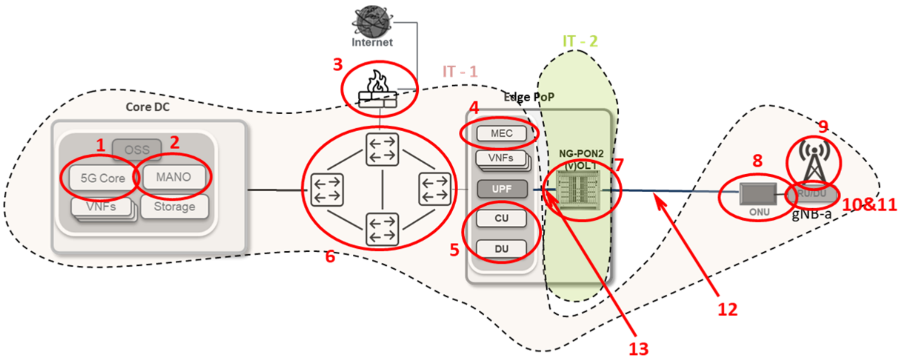
Component	Description	Location
Train	The machine responsible to transport people or freight	Aveiro Harbour
Strike in detectors/axle counter train detector system	Device (system) that can detect if a train is approaching the level crossing area	Level Crossing area-Aveiro Harbour
Train detectors/axle counter 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
Traffic lights	Device that is installed in the Level Crossing area and is responsible to process traffic information	Level Crossing area-Aveiro Harbour
Lx protection signals	Device used to inform the train driver that he can proceed (level crossing is free), or if he must stop the train (level crossing is occupied, or its operation status is unknown)	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
Half Barriers	The device that physically protects the Level Crossing against non-authorized entrances	Level Crossing area-Aveiro Harbour
5G Interface (CPE)	Mobile network interface able to connect to a 5G mobile network	Strike IN Detector/LX Controller at the Railway track
LTE router	Mobile network interface able to connect to a LTE mobile network	Strike IN Detector/LX Controller at the Railway track
Core 5G	5G Mobile network core elements	Mobile Operator/Altice

Component	Description	Location
		Labs/Aveiro Harbour (5G-VINNI)
RAN	The RAN portion of the operator's mobile network	Mobile Operator/Altice Labs (5G-VINNI)
Edge Computing	The edge MEC portion of the mobile operator, allowing for lower latency service provisioning whenever needed	Mobile Operator/Altice Labs (5G-VINNI)

TABLE 19: EFACEC_S-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)	Level Crossing area-Aveiro Harbour
5G Interface (cybersecurity application)	Mobile network interface able to connect to a 5G mobile network	Strike IN Detector/LX Controller at the Railway track
Core 5G	5G Mobile network core elements	Mobile Operator/Altice Labs/Aveiro Harbour
Edge Computing	The edge MEC portion of the mobile operator, allowing for lower latency service provisioning whenever needed	Mobile Operator/Altice Labs
MANO	Mobile Network Management and Orchestration capability	Mobile Operator/Altice Labs
VIM	Virtualized Infrastructure Management Capability	Mobile Operator/Altice Labs

The components presented in Figure 35 provide more details regarding the network components, and also represent the same components that will be used for both Phase I and Phase II of the use case's validation.



	Component	Hardware
1	Open5GCore	Server
2	SONATA NFV orchestrator	Server
3	Firewall / VPN termination	-
4	MEC functions	Server
5	CU/DU (OAI-H)	-
6	IP network	IT internal network
7	OLT	OLT2T2
8	ONT	NG-PON2 ONT-SFU
9	Antena	-
10	gNB	Server
11	RU/DU OAI-L	-
12	Fiber OLT/ONT connection	Dedicated fiber
13	Fiber OLT/PoP connection	Dedicated fiber

FIGURE 35: EFACEC_S VERTICAL PILOT NETWORK COMPONENTS

2.3.2.3. Deployment and implementation setup

The use case will be deployed in two phases. In phase I, the use case will be deployed, to a limited extent, in a laboratory environment. For the 5G network components, this phase is planned to start in June 2020 (Figure 30). The main goal in this phase is to verify that the 5G infrastructure, namely 5G core and NG-RAN, are capable of providing the functionality required by the use case and to identify (and overcome) possible issues that may affect the accomplishment of the pilot objectives. An initial assessment of relevant KPIs (e.g. service instantiation time, latency) will be performed. It should be noted that in this phase the Vertical Slicer is not expected to be integrated with the 5G-VINNI platform, therefore the vertical is not yet supposed directly interact with the platform. Prior to this, the initial experiment stage of the vertical components will be performed at EFACEC premises followed by site tests using as first approach LTE technology, to enable the functional validation of the components while 5G is becoming available, and at final stage 5G communications.

Phase II corresponds to the deployment of the use case on site. In this phase, the use case will be deployed in its full extent. Depending on specific requirements, e.g. power, distance, the RAN component may be different from the solution used in Phase I. At this point, the vertical slicer will be integrated with the remaining management & orchestration components, which will enable the vertical users to interact directly with the platform. With the availability of the 5G network, the vertical components can be coupled with 5G-enabled interfaces and use the 5G network for their communications.

2.3.2.4. Initial experiment description

At Aveiro Harbour pilot scenario, several experiments must be carried out, starting to verify the business and functional requirements, while the 5G is not available, and progressively verifying the technical requirements according the 5G network readiness. At the beginning, it is mandatory to check if all components are communicating properly and if the behaviour of the Level Crossing is the right one. This includes scenarios when communication is available and scenarios in the presence of failures in the communication (for instance, in case of communication failures, the level crossing must be set to its safe mode (protection mode)).

At a functional level, the initial experiment consists of the following:

- In the presence of an approaching train (strike in/train detector), specific messages (axle detection and axle count information) must be sent to the LX controller, to inform that a train is approaching the level crossing as well as to transmit the status of the equipment on the track. The LX controller then must start the set of actions to assure safe conditions to the train, cars and people. After detecting that the train has left the Level Crossing (passing), the peripheral devices must return to normal state. Therefore, the LX controller gets the sensors information to automatically define the position of the half-barriers, the traffic lights and the protection signal.

The most important requirements to verify at initial stage are the following:

TABLE 20: EFACEC_S-UC1 FUNCTIONAL REQUIREMENTS VALIDATION

FR-ID	Description
FR-P3UC1-01	Validate if the communications between the components (track lines equipment's and LX controller) are using standard protocols both for safety and security
FR-P3UC1-02	Validate if the Strike-In detector/axel counter train detector system is detecting trains approaching the Level Crossing
FR-P3UC1-03	Validate if the Train detector/ axel counter train detector system is detecting if the train is occupying the Level Crossing section and is detecting the absence of the train in the section
FR-P3UC1-04	Validate if the LX controller is receiving sensors and equipment information and is working properly (LX actions/railways signalling operation)
FR-P3UC1-08	Validate that the traffic lights are informing the car driver's properly
FR-P3UC1-09	Validate that the Protection LX Signals are working properly (to inform train drivers that the Level Crossing is free)

Experiments will be carried out in the two phases identified above.

Phase I

Experiment#1 – Network slice deployment time

The objective of this experiment is to check the capability to setup a network slice and determine the time between the service request and the service availability (as reported in Table 21). In phase 1, deployment is not yet triggered directly by the vertical.

TABLE 21: EFACEC_S-UC1 EXPERIMENT 1 KPIS (PHASE I)

KPI	Unit	Expected values
Service Deployment time	s	<120

Experiment#2 – Data plane performance KPIs

The objective of this experiment is to measure the data plane performance KPIs (summarized in Table 22). It should be noted that these measurements are performed in a laboratory environment, therefore should be taken as preliminary.

TABLE 22: EFACEC_S-UC1 EXPERIMENT 2 KPIS (PHASE I)

KPI	Units	Expected values
E2E One Way Delay (OWD)	ms	<10
Throughput	Mbps	70-100
Packet Loss	%	< 0.1
Jitter	us	100

Phase II

Experiment#1 – Network slice deployment time

As in Phase I, the goal is checking the capability to setup a network slice and the time interval between the service request and the service availability (as reported in Table 23), but now the process is expected to be fully automated and triggered by the vertical through the vertical slicer.

TABLE 23: EFACEC_S-UC1 EXPERIMENT 1 KPIS (PHASE II)

KPI	Unit	Expected values
Service Deployment time	s	<60

Experiment#2 – Data plane performance KPIs

The objective of this experiment is to measure the data plane performance KPIs (as shown in Table 24), in the real pilot environment, not in laboratory as in Phase I.

TABLE 24: EFACEC_S-UC1 EXPERIMENT 2 KPIS (PHASE II)

KPI	Units	Expected values
E2E One Way Delay (OWD)	ms	<10
Throughput	Mbps	70-100
Packet Loss	%	< 0.1
Jitter	us	100

After the completion of these phases the scenario will be ready to validate all functional and technical requirements, defined for the EFACEC_S-UC1, since the 5G network will be working properly.

2.3.2.5. Plan and roadmap

The plan and roadmap of the EFACEC_S-UC1 involve the following stages, which add to the network evolution roadmap presented in Figure 28. This is depicted in Figure 36, which shows the plan of EFACEC_S-UC1 deployment, aligned with the 5G infrastructure availability.

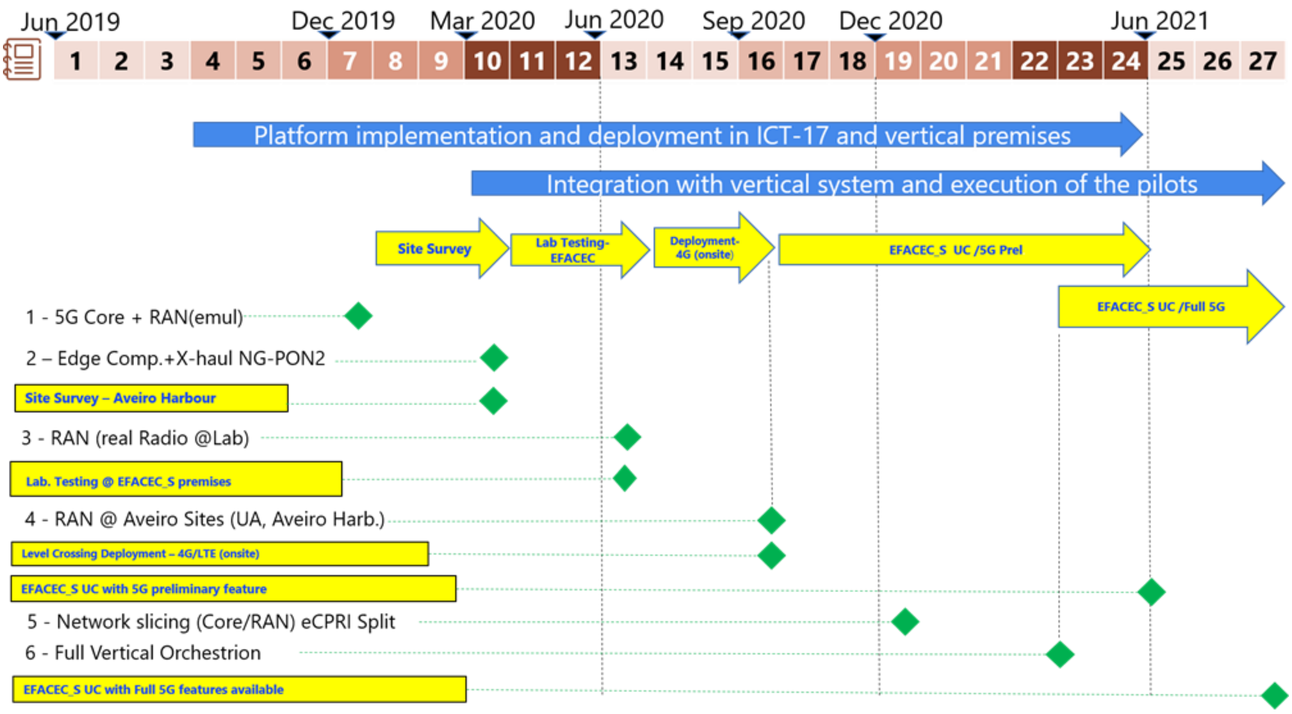


FIGURE 36: EFACEC_S-UC1 DEPLOYMENT PLAN

This comprises the following tasks:

- Site Survey –This phase involves the final specification of the pilot in terms of bill of material, localization, power, connectivity and interfaces.
- Lab testing at EFACEC premises – The pilot, involving the Level Crossing and all the additional modules, interfaces, protocols and applications develop in the scope of this project will initially be deployed at EFACEC premises. The main goal of this stage is to assure that all the components, devices and modules are properly assembled and communicating, in compliance with the functional requirements. In this stage the network is assumed to be LTE and the unitary tests will be performed with IP cable and LTE networks.
- Level Crossing deployment at Aveiro Harbour (on-site) – This stage will be needed to deploy all the pilot components on site. Since at this stage the 5G network will be not fully available, the integration tests will be performed with LTE technology and focusing on functional requirements.
- Use Case 5G preliminary testing phase – At this stage, some 5G functionalities will be ready and the use case will be tested and validated according with those constrains. Nevertheless, at this stage the preliminary integration with 5G-VINNI platform will be performed and E2E services will be tested.

- Use case 5G final testing phase – This stage requires that all functionalities will be available providing the full conditions to verify and validate the business, functional and technical requirements according what have been specified previously collecting thus evidences concerning requirements and service KPIs in the context of this UC.

2.3.3. Use Case 2: Non-safety Critical Communications

2.3.3.1. Use Case Modelling

Figure 37 depicts the logical architecture for the connected worker use case, including all the necessary components and labelled interfaces.

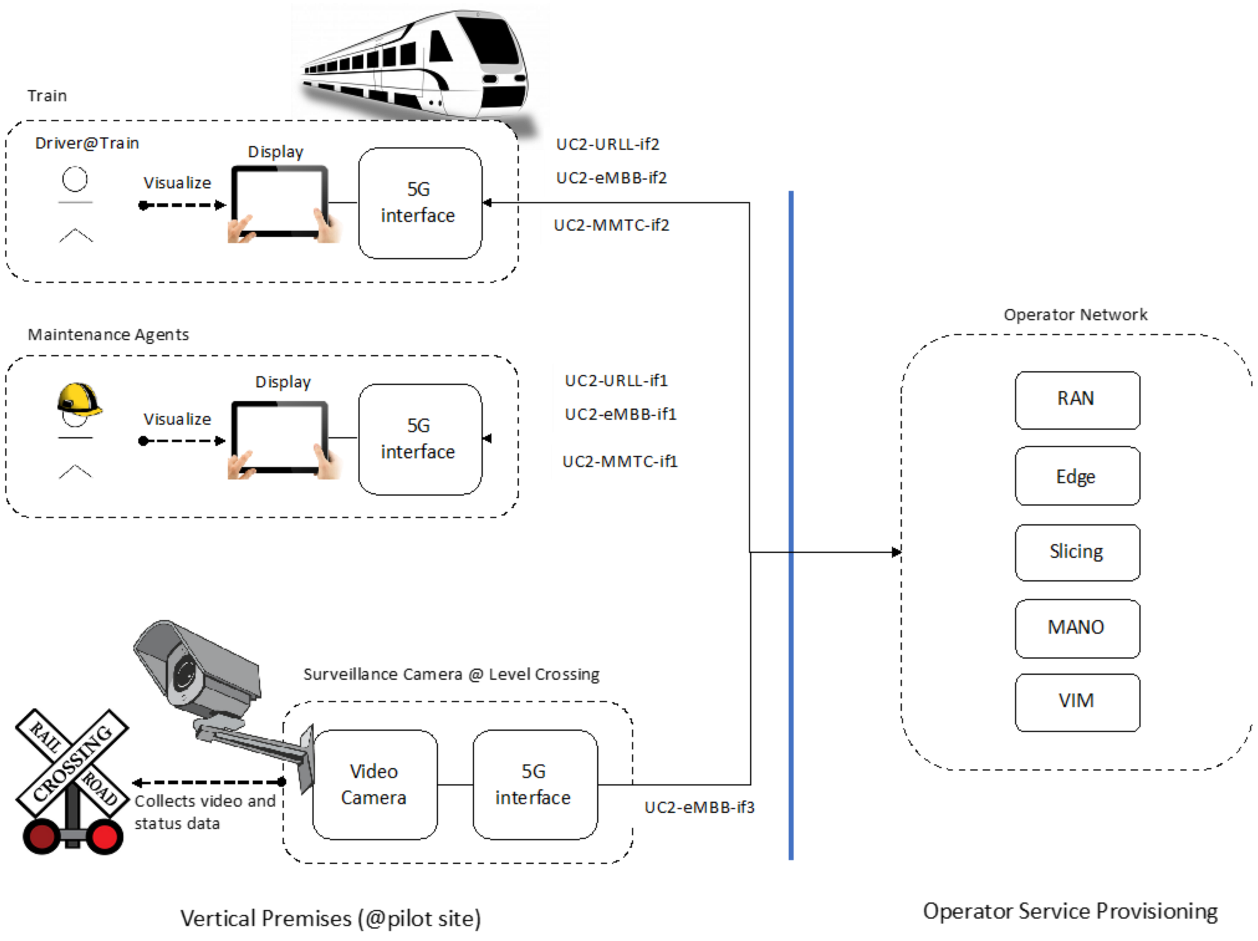


FIGURE 37: EFACEC_S-UC2 OVERVIEW

The use case considers a surveillance camera placed at a railroad crossing, able to broadcast its video feed towards an incoming train 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 38 shows the solution architecture of the EFACEC_S-UC2, allowing the real-time video transmission between the Level Crossing (Lx) site and the train driver/Maintenance staff and Level Crossing Supervision.

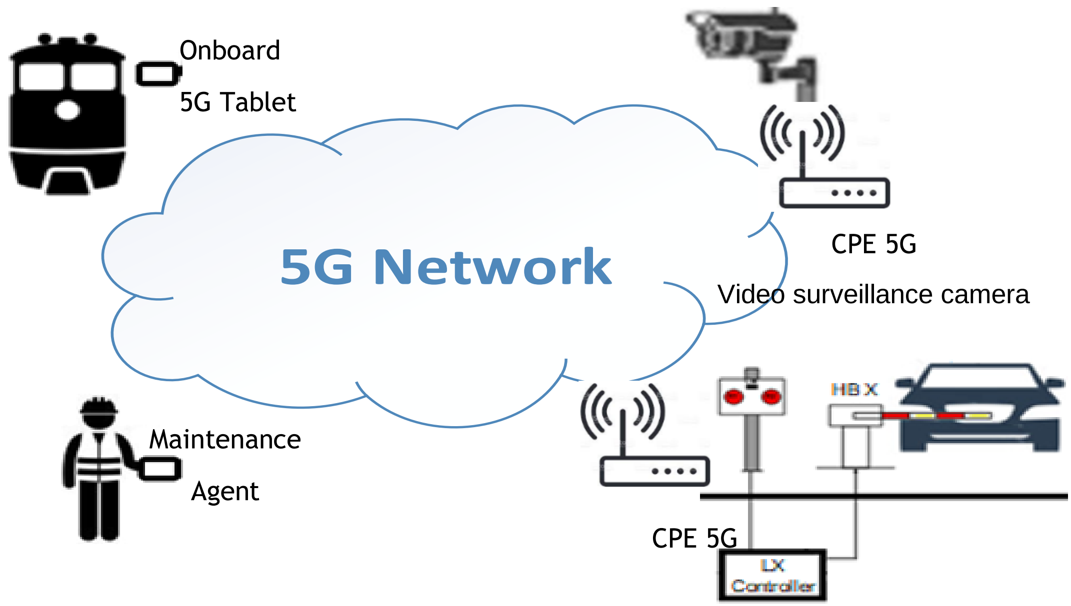


FIGURE 38: EFACEC_S-UC2 REAL-TIME VIDEO TRANSMISSION BETWEEN THE LEVEL CROSSING SITE AND THE TRAIN DRIVER/MAINTENANCE STAFF + LEVEL CROSSING SUPERVISION

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.

2.3.3.2. Hardware / Software components

The components related with this use case are presented in the following table, showcasing the components for both Phase I and Phase II of the use case's validation.

TABLE 25: EFACEC_S-UC2 HW COMPONENTS

Component	Description	Location / HW/SW
Train	The machine responsible to transport people or freight	Aveiro Harbour
Tablet/Mobile Devices	Devices to be 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
HD Video Camera	Device (video camera) that will be installed in the level crossing area and allows	Level Crossing area-Aveiro Harbour

Component	Description	Location / HW/SW
	surveillance and image transmission to the train and to a command center	
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
GPS position system	Device to be installed in the train in order to report its geographical positioning	Train-Aveiro Harbour
5G Interface (CPE)	Mobile network interface able to connect to a 5G mobile network	Train, Maintenance Crew Terminal, Surveillance Camera
LTE router	Mobile network interface able to connect to a LTE mobile network	Train, Maintenance Crew Terminal, Surveillance Camera
Video Camera	HD video camera able to send video stream over a network link	Level Crossing-Aveiro Harbour
Core 5G	Mobile network core elements	Mobile Operator/Altice Labs/Aveiro Harbour (5G-VINNI)
RAN	The RAN portion of the operator's mobile network	Mobile Operator/Altice Labs (5G-VINNI)
Edge Computing	The edge MEC portion of the mobile operator, allowing for lower latency service provisioning whenever needed.	Mobile Operator/Altice Labs (5G-VINNI)

TABLE 26: EFACEC_S-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)	Level Crossing area-Aveiro Harbour
5G Interface (cybersecurity application)	Mobile network interface able to connect to a 5G mobile network	Train, Maintenance Crew Terminal, Surveillance Camera
Core 5G	Mobile network core elements	Mobile Operator/Altice Labs/Aveiro Harbour (5G-VINNI)

Component	Description	Location
Edge Computing	The edge MEC portion of the mobile operator, allowing for lower latency service provisioning whenever needed	Mobile Operator/Altice Labs (5G-VINNI)
MANO	Mobile Network Management and Orchestration capability	Mobile Operator/Altice Labs (5G-VINNI)
VIM	Virtualized Infrastructure Management Capability	Mobile Operator/Altice Labs (5G-VINNI)

The same detailed view on the network components identified in Figure 35, are also considered in this use case.

2.3.3.3. Deployment and implementation setup

The approach described in Section 2.3.2.3 in relation to EFACEC_S-UC1 is followed in this case as well.

2.3.3.4. Initial experiment description

At functional level, the initial experiment consists in the following description:

- In the presence of an approaching train (GPS positioning), the train driver will receive real-time HD video from the next level crossing video camera that is installed in the next level crossing area. After detecting that the train has left the Level Crossing (passing), the video transmission will be interrupted, in order to not disturb the driver normal activity. The real-time video images will be also transmitted to maintenance agents' tablets and to a command centre. The LX controller status and alarms will be transmitted (5G communication) to the maintenance agents' tablets.

Experiments will be carried out in the two phases identified and detailed in the previous use case in Section 2.3.2.4.

For this use case the experimentation strategy will be the same already considered to the EFACEC_S-UC1, validating at the first level the functional requirements and at final stage, with 5G network available, the technical requirements.

Before the 5G Network is available for the integration, the following experiments and validation test must be performed:

FR-ID	Description
FR-P3UC2-02	Validate the GPS System
FR-P3UC2-03/08	Validate the LX events and alarms reception both at Command Centre (CC) and Tablet Device (maintenance staff)
FR-P3UC1-01/05/08/09	Validate LX video images transmission to CC and Tablets (Train and Maintenance Staff)

2.3.3.5. Plan and roadmap

This use case's plan and roadmap will follow the same strategy of the previous use case expressed in Section 2.3.2.5.

2.3.4. COVID-19 Impact Analysis on Plans and Roadmaps

As the COVID-19 situation develops, governments are applying restrictions to the mobility of their citizens and enterprises are also applying restrictions to the mobility of their employees. Those restrictions will impact the original plan of the pilot.

The project is considering a worst-case scenario of four months highly constrained activity at the University of Aveiro, Aveiro Harbour, and in the EFACEC and ALB laboratories.

The impact can be grouped into the assumed facts (those that will certainly happen) and the probable threats (those that could happen) during those four months.

1) **Assumed Facts:**
    a. HW Deployment & Upgrades:
        i. Not possible in this period
        ii. No feasible mitigation
    b. Supply of 3rd party products
        i. Not possible in this period
        ii. No feasible mitigation
    c. Aveiro University on-site activities:
        i. Not possible in this period, except for activities whose non-realization cause great prejudice to the University, pending acceptance of the institution responsible
        ii. No feasible mitigation
    d. Aveiro Harbour on-site activities:
        i. Not possible in this period
        ii. No feasible mitigation
    e. Attendance to F2F meetings:
        i. Not possible in this period
        ii. Switched to virtual meetings
    f. Attendance to Events:
        i. Not possible in this period
        ii. Dissemination via digital video channels
2) **Probable Threats:**
    a. Potential infection of involved staff in the project
    b. Potential degradation of remote access to current labs infrastructure
    c. Potential performance degradation of current labs infrastructure

No specific impacts are expected from ICT-17 5G-VINNI (in addition to those already identified above), as the deployment and operation of the infrastructure is under the responsibility of Altice Labs in both projects and the respective activities are executed in a coordinated way. Furthermore, the possible utilisation of (parts of) the 5G-VINNI infrastructure by other projects or activities will not affect the 5Growth pilots in any circumstance.

With the aim of keeping the original ending project dates, two options are evaluated:

1) **Keep Milestones' planned dates**, through scope contention of M18's Milestone and progressive catch-up afterwards, in order to enable incremental testing of the pilot both before and after M18.
2) **Delay M18's Milestone 4 months**, in order to keep the original planned activities unaffected.

Considering all the above, the project partners will shift their plans and will focus on activities that are less likely to be impacted by the restrictions, such as:

a. SW applications development
b. Preparing documentation
c. Partial validation of (sub)components or concepts that are part of the whole solution
d. Getting ready for on-site tasks

The two options are discussed in the next two sections, with each option affecting both use cases of the pilot, and solutions provided for each one.

2.3.4.1. Option 1: Estimated Impact in the 5G Network Infrastructure Roadmap

This option focuses on an estimation of what can be accomplished by M18 of the project, considering both the network deployments and the vertical deployments, expressing possibilities that aim allowing the validation of key aspects. This mainly encompasses the availability of a 5G link, and the concretization of the train track related components.

For M18, Open5GCore and a real 5G radio will be integrated and fully functional in a Lab environment, preferably along with Network Slicing features also available in the Lab. This will allow the deployment of trial-versions of EFACEC components at the same lab, which are able to assume the same behavioural role of their field counterpart components. This will also allow to validate the capability of the infrastructure in handling the configuration and requirements for connecting such components.

In that sense, for EFACEC_S-UC1, the following trial components will be deployed:

a. Train presence detection sensor;
b. Train detection rack;
c. Processing board for implementing safety and security functions (i.e., Raspberry Pi 4)
d. 5G network interface router/module;
e. EFACEC simulation tool (Level Crossing).

With this Lab scenario, it will be possible to test over a 5G link the communication, latency and availability of the Train/Level Crossing Detector interface, which is the core vertical element belonging to EFACEC_S-UC1. Regarding measurements, we will use the EFACEC simulation tool and open source network tools (e.g., iperf) to measure network latency. Figure 39 depicts an idealization of the proposed setup.

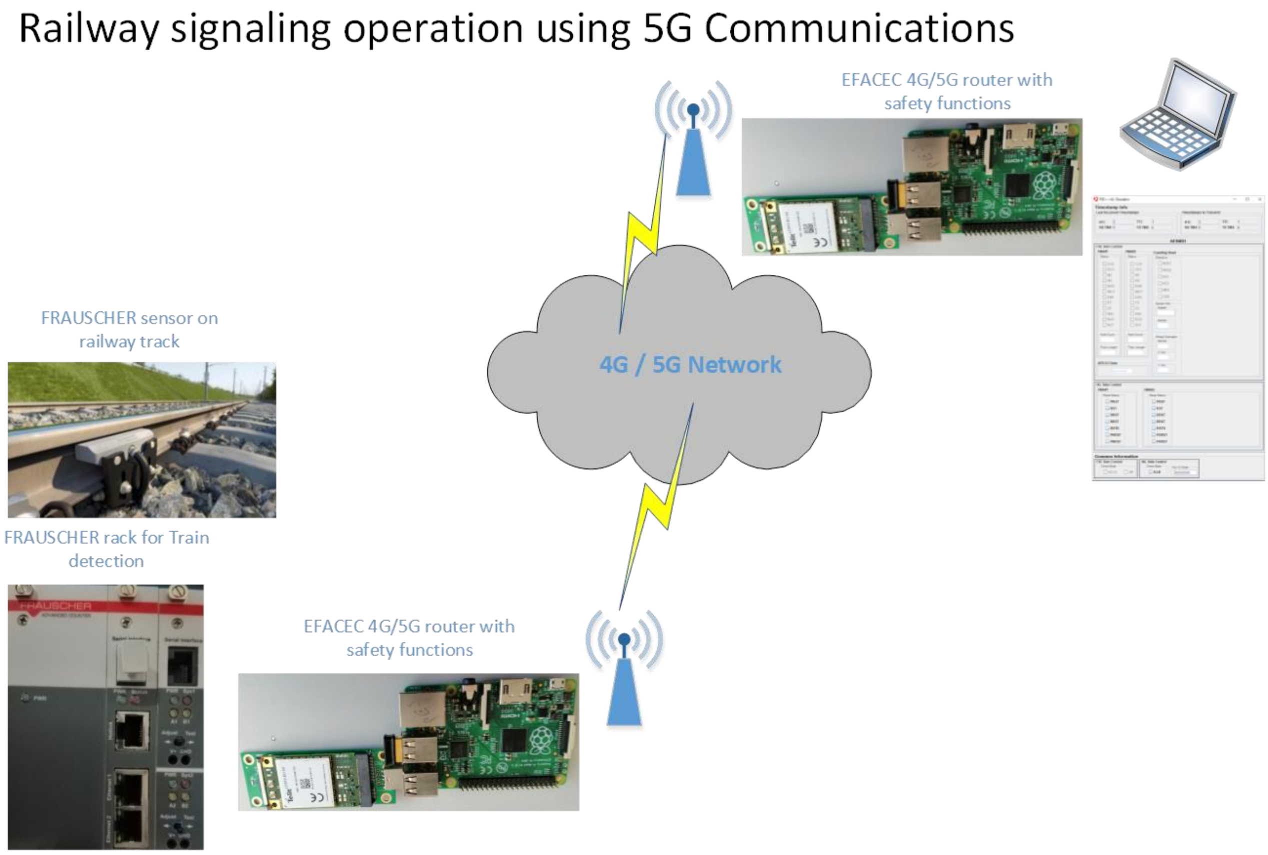


FIGURE 39: EFACEC_S-UC1 LAB TRIAL SETUP FOR OPTION 1

For EFACEC_S-UC2, the same infrastructure will allow the deployment of a test setup for the video streaming, aiming to emulate the conditions experienced for sending such video from the Level Crossing to an incoming train. The first base possibility for this considers the usage of video streaming and receiver equipment embedded at the laboratory. However, in order to assess the capabilities of a moving receiver, a scenario where an automobile acting as a train (equipped with a 5G router, along with a GPS antenna and a tablet), and within range of the 5G coverage of the Lab, will also be considered. For the emulation of the video streaming camera that would be located at the Level Crossing, a PN video System (equipped with a 5G router, and Bosch video camera) coupled with a processing board (or, as another possibility, a Virtual Machine), for the necessary algorithms to control and send the video recording. Figure 40.

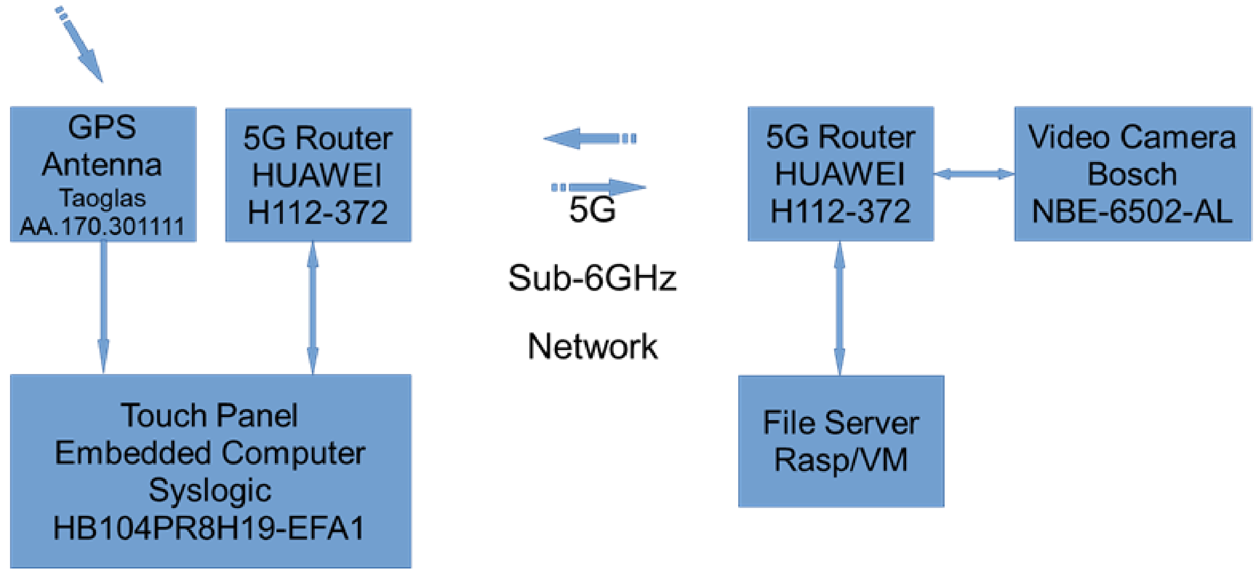


FIGURE 40: EFACEC_S-UC2 LAB TRIAL SETUP FOR OPTION 1

This plan is also dependent on the timely acquisition of compatible 5G-based interfaces for connecting to the deployed 5G network.

Overall, with this option, considering the restrictions currently being imposed by COVID-19 to the participants of this pilot, we will be able to see partial deployment in a Lab of the initially intended use cases, and allow experiments, integration and monitoring to begin.

2.3.4.2. Option 2: Estimated Impact in the 5G Network Infrastructure Roadmap

Figure 43 shows the estimated impact:

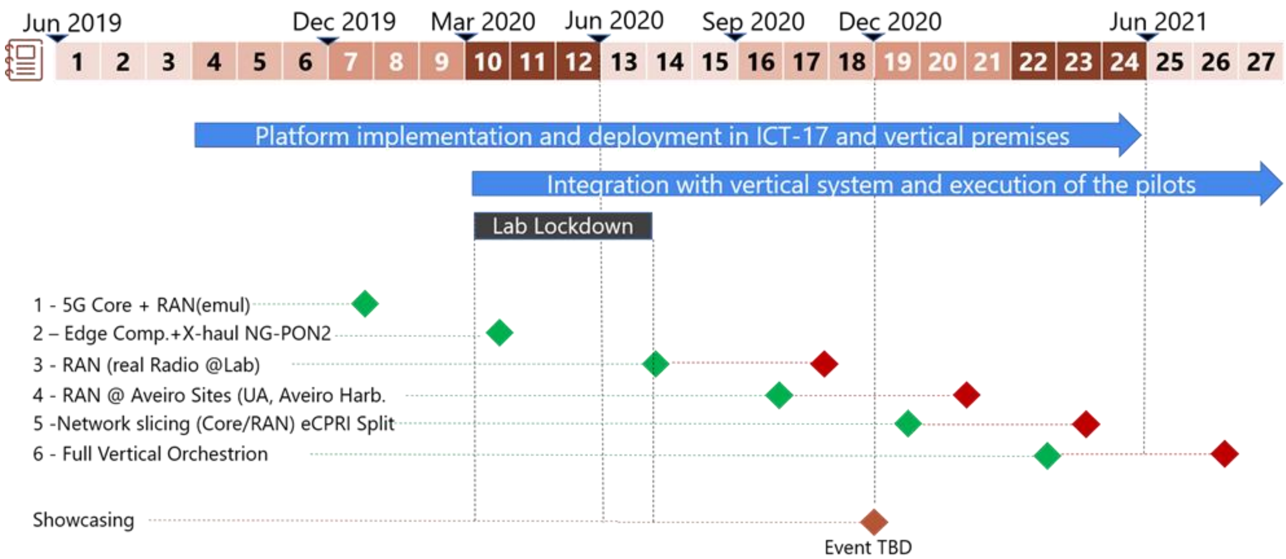


FIGURE 41: EFACEC_S 5G NETWORK INFRASTRUCTURE ROADMAP ESTIMATED IMPACT

Phase I was planned that by June 2020 (M13), the emulated RAN component will be replaced by a real radio hardware in a Lab environment. But if the access to Lab is still unavailable and the persons involved on the set up are confined to their own home by four months, this phase will be inevitably postponed four months. This delay will impact negatively the next phases that will be shifted four months (Figure 25):

- October 2020 (M17), the emulated RAN component will be replaced by a real radio hardware in a Lab environment (the OAI planned, or another solution if OAI is not ready until a deadline);
- January 2021 (M20), the real RAN solution deployed at the Lab will be extended to the pilot sites, the University of Aveiro (Energy) and the Aveiro Harbour (Transportation):
- April 2021 (M23), Network Slicing features will be added to the Lab (first) and pilot sites, accommodating the different requirements of the pilots and respective use cases;
- July 2021 (M26), not only the network, but also vertical components are orchestrated to be deployed on the network, either they are placed in the site, edge or core.

There are more constraints that could hinder or prevent the accomplishment of the present plan due the restraints to circulation of persons and manufacturing's of no essential goods during so long time (4 months). There is a positive note, work that can be carried out remotely or software development only will suffer a minor impact assuming, we must be positive, that there is no personals impact.

2.3.4.3. Estimated impact in EFACEC_S-UC1/UC2 Plan and Roadmap

Figure 42 shows the estimated impact in the plan and roadmap of both use cases.

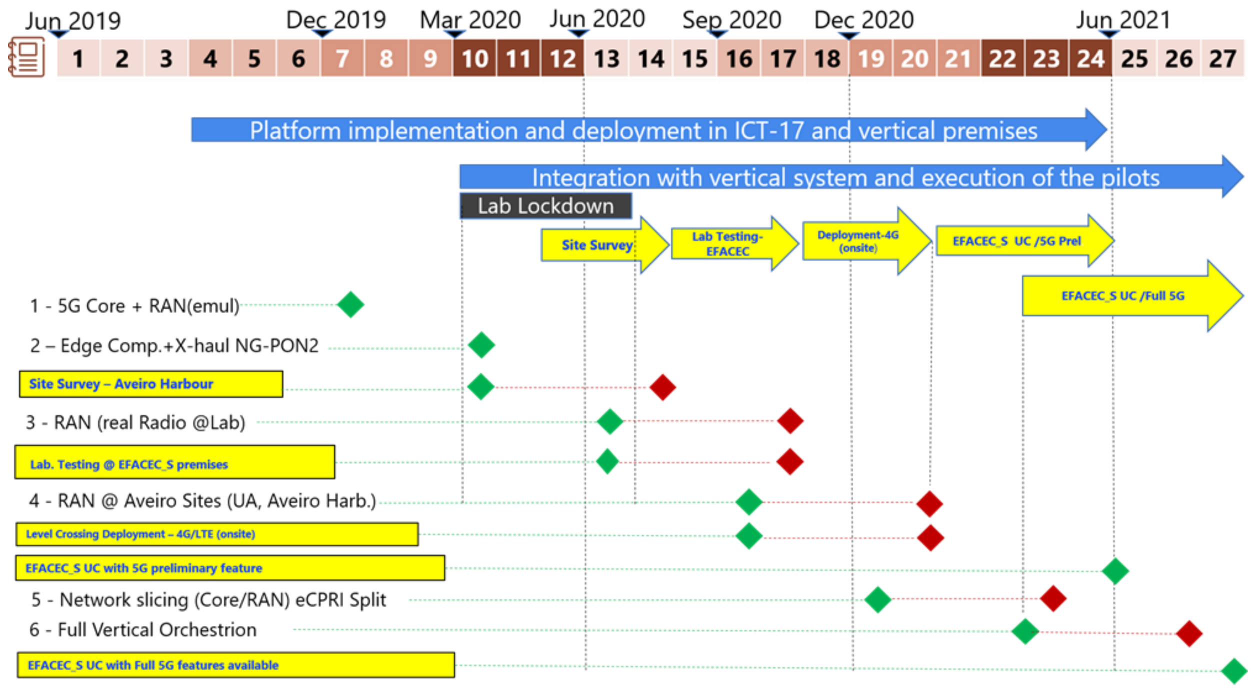


FIGURE 42: EFACEC_S-UC1/UC2 PLAN AND ROADMAP ESTIMATED IMPACT

The site survey on Aveiro Harbour, programmed to occur during the first trimester, was not performed yet and will be directly impacted. It will be delayed four months in the considered scenario.

Concerning the development phase in EFACEC lab, the Use Cases setup depends, on the purchasing of the components regarding the 5G Level Crossing scenario (EFACEC_S-UC1 and EFACEC_S-UC2) and also the production and testing of this environment at EFACEC premises. Note that, for the moment, only remote work is allowed at EFACEC_S. Thus, it is estimated a delay of four months in the considered scenario.

Therefore, the whole integration of the Use Cases, depends on physical presence on EFACEC Lab, which is also directly impacted. It will be delayed four months in the considered scenario.

Therefore, this constrains have impact in the estimated date to start de deployment on site which also be affected. The 5G Use Case preliminary testing phase and also Full 5G testing phase also be impacted according the new 5G network estimated dates. This roadmap indicates that will be an overlap concerning the Transportation UCs (Full vertical Orchestration and Full UC 5G functionalities), but the realistic approach should be extend this milestone at least two months in order to validate the complete use case requirements after the 5G full orchestration is completely available.

2.4. INNOVALIA Vertical Pilot

The INNOVALIA pilot explores the use of 5G related technologies in the Industry 4.0 sector. 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, which will be detailed in the document.

As a general reference for all the subsections of this pilot, it must be noted that the plan is structured in two phases. In phase I, the implementation, deployment and integration of all the components will take place at 5TONIC lab. In phase II, leveraging the results of the previous phase, some of the components will be deployed at INNOVALIA premises and final testing will be performed. References will be made in the upcoming subsections to these phases.

2.4.1. Infrastructure deployment in vertical premises

2.4.1.1. Roadmap

The Figure 43 depicts when each of the required infrastructure components for the INNOVALIA pilot will be available.

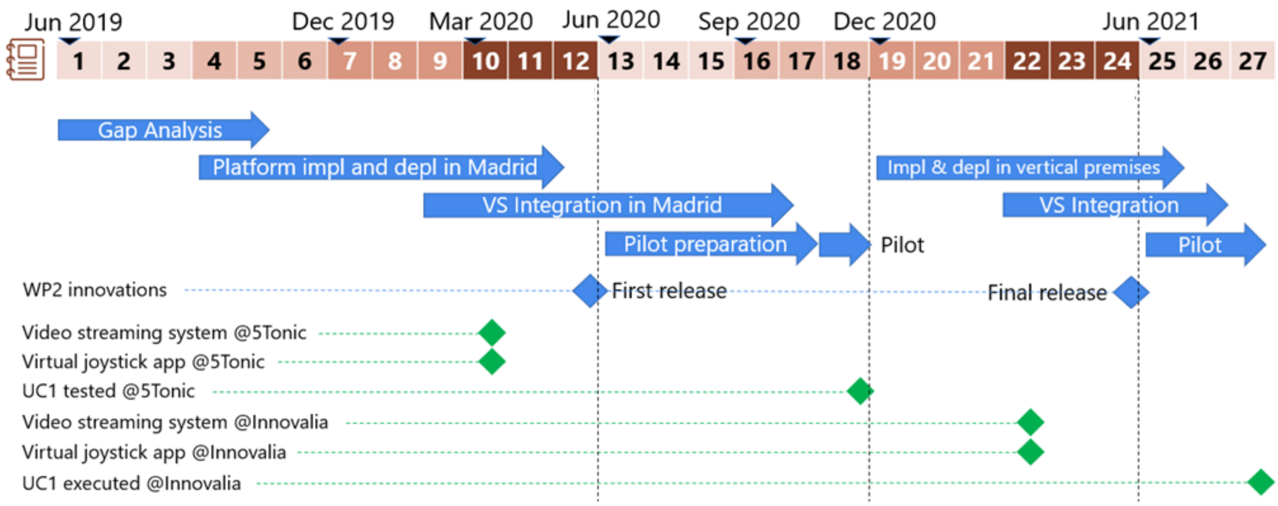


FIGURE 43: INNOVALIA 5G NETWORK INFRASTRUCTURE ROADMAP

These steps are explained in more detail as follows:

1) By the end of March 2020 (M10), the INNOVALIA 3-D scanner and service application will be installed, and the 5Growth baseline SW platform will be deployed at 5TONIC lab.
2) By the end of June 2020 (M13), the 5G RAN and CORE with Stand Alone option will be available at 5TONIC lab. Stand Alone means that it does not need to rely on 4G infrastructure.
3) By the end of September 2020 (M16), the 5Growth components installed at 5TONIC lab will be integrated with 5G-EVE
4) By the end of November 2020 (M18), the available functionalities for the pilot will be tested at 5TONIC lab.
5) By the end of March 2021 (M22), the infrastructure except 5G RAN will be deployed at INNOVALIA premises.
6) By the end of May 2021 (M24), the 5Growth final SW platforms will be deployed, including the final innovations developed.
7) By the end of May 2021 (M24), the 5G RAN will be installed at INNOVALIA premises. The 5G CORE used is the one available at 5TONIC lab.

2.4.1.2. Plan and deployment setup

In this section, the deployment setup of each of the phases is described.

Phase I

For the first phase, all the infrastructure will be deployed at 5TONIC lab.

General purpose servers will be available at the lab for holding the 5Growth platform SW.

RAN and CORE equipment will be installed. One of the keys of the setup is that the control plane (CP) and user plane (UP) are split. This is an enabler to have the RAN controlled by the operator and shared by different customers.

Moreover, the 5G-EVE Framework is included for supporting the deployment and validation of the proposed use cases. The impact of network KPIs over the use cases will be validated, with particular attention to the reliability and latency KPIs. For that, a set of 5G-EVE experiments will be defined and executed, with variable levels of latency and reliability parameters and using the 5G-EVE data collection framework for verifying the impact.

Figure 44 shows the expected setup. The vertical interacts with the Vertical Slicer (5Gr-VS) GUI of the 5Growth SW platform. The 5Growth and 5G-EVE platforms are interconnected, leveraging the features of both platforms. The platforms interact with the CORE and RAN components to establish the connectivity requested by the vertical. Also, the platforms instantiate the service apps on the available servers.

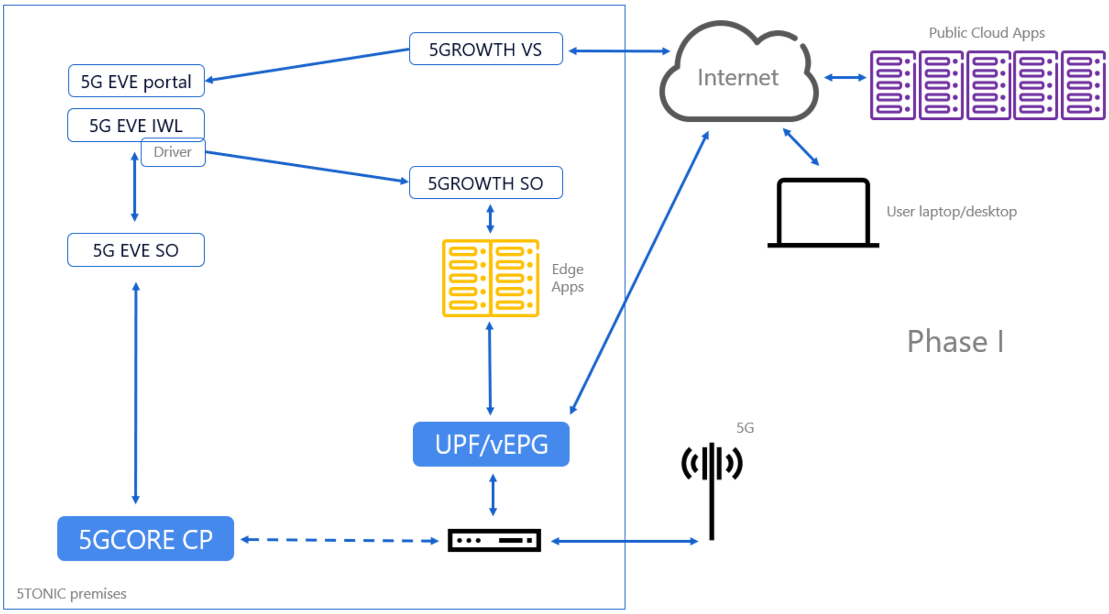


FIGURE 44: INNOVALIA PHASE I SETUP (5TONIC LAB)

The following figure (Figure 45) shows the required network equipment common to all use cases. The equipment needed to provide 4G and 5G network coverage and to manage the spectrum are the radio units, which can be placed close to the antenna or integrated with the antenna, and the basebands units that hold the control logic for the radio access, which are installed in a rack. The radio signal needs a timing reference which will be provided by a GPS receiver. Also, in the rack, multi-purpose servers will be installed to hold the core network (5G vEPC or 5GC), the SW platform for resource orchestration, and the service applications. A router will interconnect all equipment within the rack and to provide external connectivity if needed.

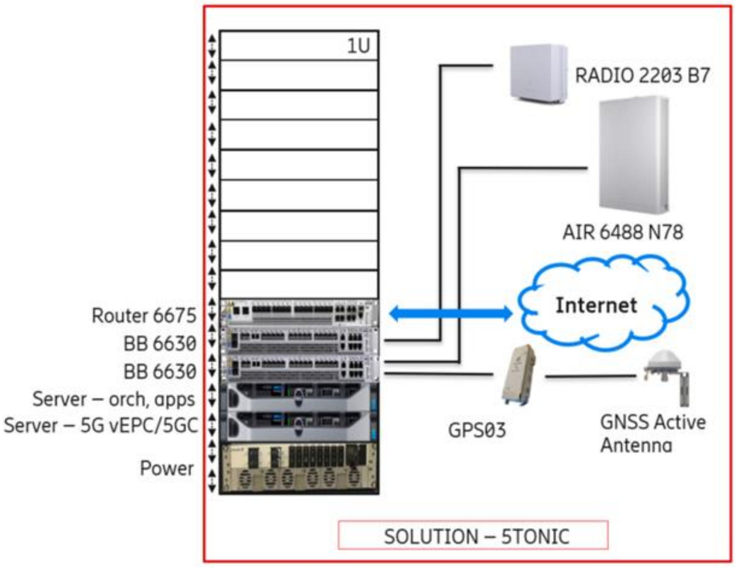


FIGURE 45: INNOVALIA PHASE I SETUP (5TONIC LAB) NETWORK EQUIPMENT

In this first phase, a portable Coordinate-Measuring Machine (CMM) will be installed and used in the 5TONIC Lab. Figure 46 shows a picture of the portable CMM which is composed of the CMM, a reduced-size controller, a joystick which is connected directly to the controller, and a PC which is the one running M3, the software solution that runs the quality tests.

For the experiments, the PC will be replaced by the M3Box, which is an edge device that runs the M3 services that move the robot and controls the sensors, and will be connected to a 5G router. Through the 5G network, the PC will be able to connect remotely to the M3Box, stablishing a wireless link that will allow the user to command the CMM from the remote computer.

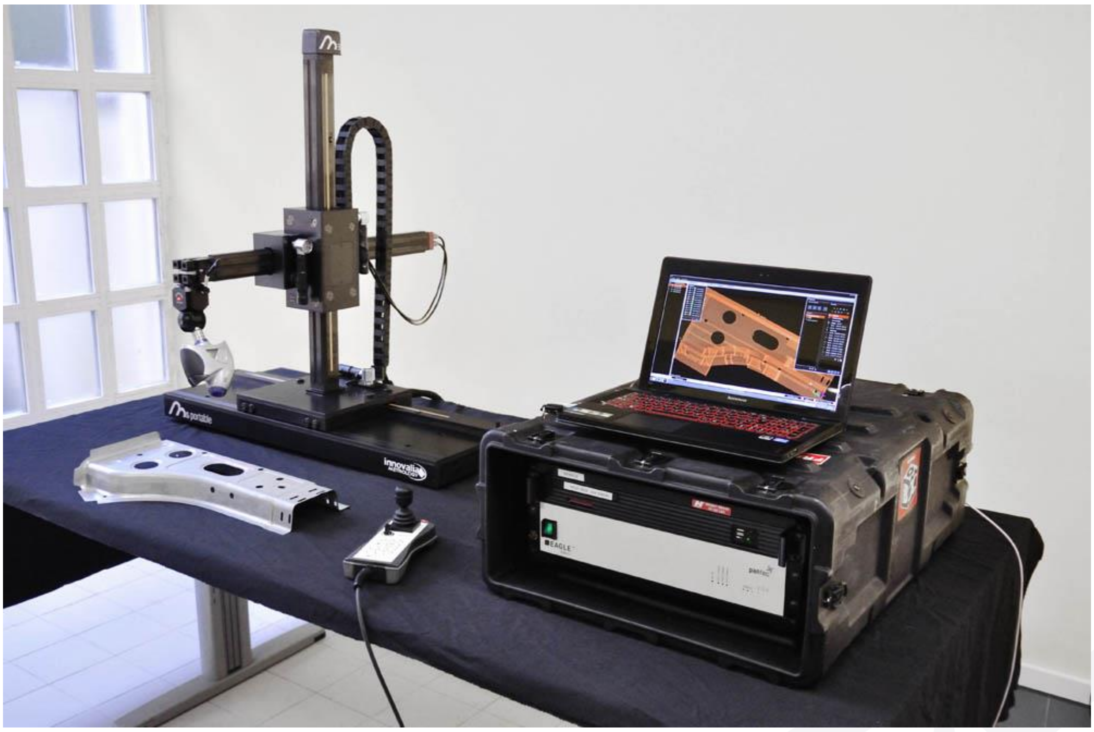


FIGURE 46: PORTABLE CMM

Phase II

For the second phase, some of the infrastructure will be deployed at INNOVALIA premises.

The idea is to reuse as much as possible the setup of the phase I, so for that purpose, the Core of the Network and the 5G-EVE platform will remain in 5TONIC. The service apps, the 5Growth software components and the RAN equipment will be placed at INNOVALIA premises, and will connect to the components in 5TONIC through the public network. This is a deployment with shared radio access network and control plane (see Figure 47).

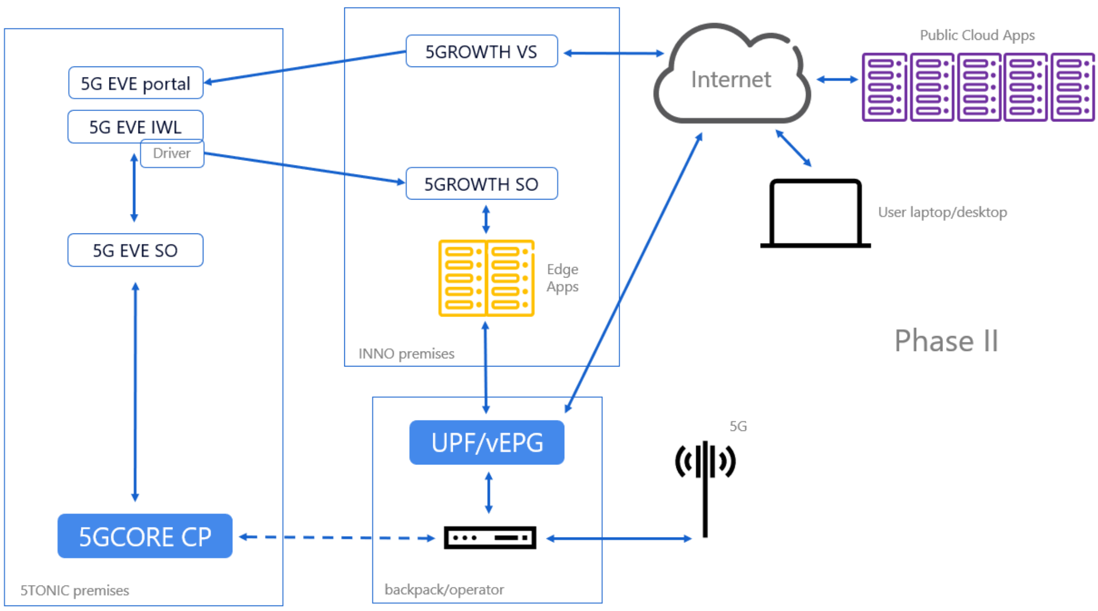


FIGURE 47: INNOVALIA PHASE II SETUP (INNOVALIA PREMISES)

The required network equipment at INNOVALIA premises, common to all use cases, are depicted in Figure 48. The equipment selected to provide 4G and 5G network coverage for INNOVALIA indoor environment are the Radio Dot antennas, which are connected to Indoor Radio Units (IRU) placed in a rack. This interconnection is done through a patch panel also placed in the rack. The IRUs are then connected to the basebands units that provide the control logic for the radio access. The radio signal needs a timing reference which will be provided by a GPS receiver. In the rack at INNOVALIA premises, a multi-purpose server is needed to host the 5Growth SW platform for resource orchestration, and the service applications. A router shall interconnect all equipment within the rack and shall provide external connectivity if needed. Note that the 5G-EVE platform and the 5G core network (5G vEPC or 5GC) will not be installed at INNOVALIA premises.

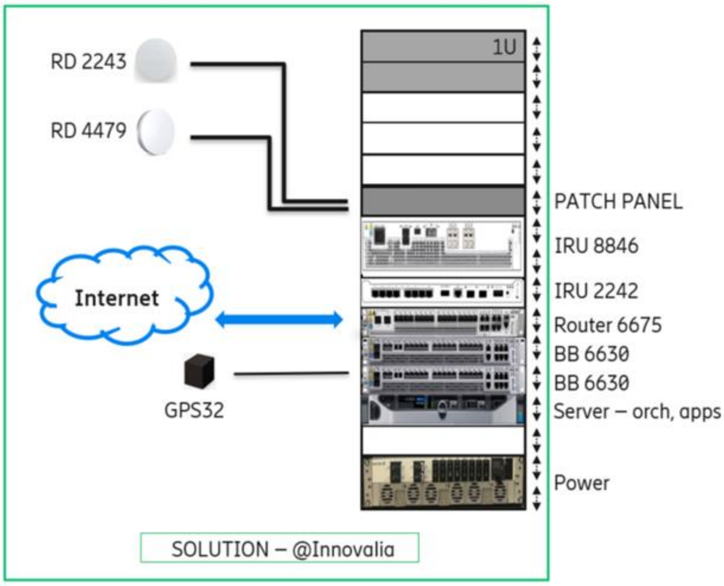


FIGURE 48: INNOVALIA PHASE II SETUP (INNOVALIA PREMISES) NETWORK EQUIPMENT

At INNOVALIA premises there are 2 rooms that will need 5G radio coverage. The map in Figure 49 shows the location of the rooms within the building.

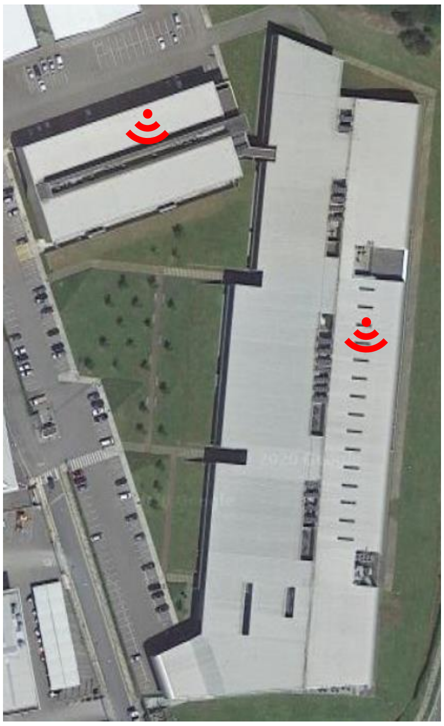


FIGURE 49: INNOVALIA PREMISES INDOOR ANTENNAS

The CMM that will most probably be used in this second phase is not the portable one, but it is still not decided which model will be deployed, as there are other players (like the ASF managers) involved in the decision. However, the services and the components involved will be exactly the same, no matter which specific model will be used, as they use the same controllers.

2.4.2. Use Case 1: Connected Worker Remote Operation of Quality Equipment

2.4.2.1. Use Case Modelling

The Coordinate Measuring Machine (CMM) must be calibrated by an expert before it can measure a manufactured piece. This use case leverages remote connectivity to the CMM so that the operator can program the machine using a virtual joystick, while at the same time a live video of the CMM is displayed giving feedback to the operator. The connectivity requirements are met with two non-permanent end-to-end slices (both running at the same time, the same life-cycle management will be applied on both slices). For the video streaming, an eMBB slice is required, and for the control of the machine, an URLLC slice is required. The connectivity will be established just for the period that the calibration process last. For the URLLC slice the critical parameter is the reliability. Additionally, the latency will play an important role between the synchronization of the video stream and the virtual joystick.

The slice requirements are introduced by the vertical using the Vertical Slicer (5Gr-VS). The 5Gr-VS interacts with the 5G-EVE framework for the Network Service instantiation and for the use of the metric collection platform. The 5Growth Service Orchestrator (5Gr-SO) instantiates the service apps. Once the connectivity and the service are ready, the remote worker will be able to operate the machine. When the process is over, the connection can be released.

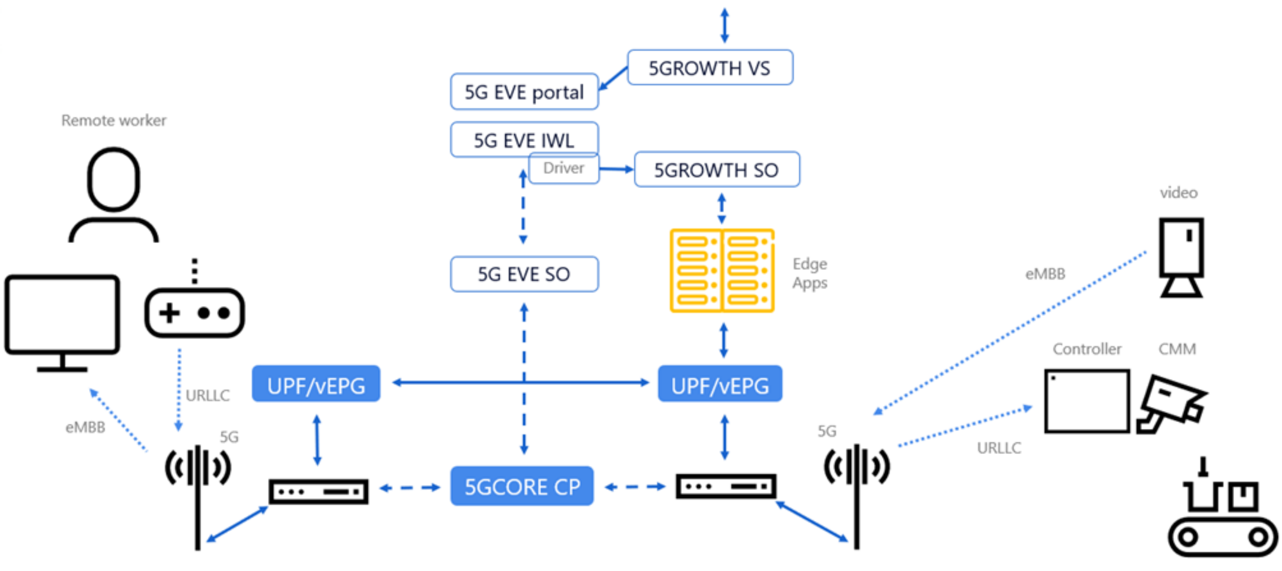


FIGURE 50: INNOVALIA-UC1 OVERVIEW

2.4.2.2. Hardware / Software components

Phase I

TABLE 27: INNOVALIA-UC1 HARDWARE COMPONENTS (PHASE I)

Component	Description	Location
CMM	Robot that contains the scanner to measure the pieces. It will be operated remotely	5TONIC
CMM-Controller	Hardware that controls the movement of the CMM	5TONIC
M3BOX	Edge Computing device that holds the CMM services	5TONIC
Virtual Joystick HW	PC/Tablet running M3 software & Virtual Joystick	5TONIC
Video Cameras	Capture images of the CMM position and movements	5TONIC
Video Server	Translate RAW video to bytes-based video	5TONIC
Visual Display	Show the video images to the remote worker	5TONIC
Multi-purpose servers	Hold the SW components of the 5G CORE and the service apps	5TONIC
RAN baseband	Control the RAN functionalities and communicate with the CORE	5TONIC
Antennas	Provide 5G radio coverage to the devices	5TONIC
Router	Provide interconnectivity among RAN baseband and multi-purpose servers	5TONIC

TABLE 28: INNOVALIA-UC1 SOFTWARE COMPONENTS (PHASE I)

Component	Description	Location
M3	Software suite to design, deploy and run the measurement program	5TONIC
Virtual joystick	Send action commands to the robot	5TONIC
RobotLink	Software service that moves the robot	5TONIC
DataAssembler	Software service that manages the sensor data	5TONIC
M3ExecEngine	Software service that manages the measuring process, sending the orders to RobotLink & DataAssembler	5TONIC
5Growth platform	Allow verticals to request their slice requirements. Dynamically orchestrate VNFs and apps.	5TONIC
5G-EVE platform	Instantiate Network Services and provide a metric collection platform	5TONIC
5G CORE CP	Functions of the CORE related to the Control Plane of the network. Control how devices connect to the network and ensure required connectivity	5TONIC
UPF	Function of the CORE related to the User Plane. Handle the service application traffic	5TONIC

Phase II

TABLE 29: INNOVALIA-UC1 HARDWARE COMPONENTS (PHASE II)

Component	Description	Location
CMM	Robot that contains the scanner to measure the pieces. It will be operated remotely	INNOVALIA
CMM-Controller	Hardware that controls the movement of the CMM	INNOVALIA
Virtual Joystick	PC/Tablet running M3 software & Virtual Joystick	INNOVALIA
Video Cameras	Capture images of the CMM position and movements	INNOVALIA
Video Server	Translate RAW video to bytes-based video	INNOVALIA
Visual Display	Show the video images to the remote worker	INNOVALIA
Multi-purpose servers	Hold the SW components of the 5G CORE and the service apps	INNOVALIA
RAN baseband	Control the RAN functionalities and communicate with the CORE	INNOVALIA
Antennas	Provide 5G radio coverage to the devices	INNOVALIA
Router	Provide interconnectivity among RAN baseband and multi-purpose servers	INNOVALIA

TABLE 30: INNOVALIA-UC1: SOFTWARE COMPONENTS (PHASE II)

Component	Description	Location
M3	Software suite to design, deploy and run the measurement program	INNOVALIA
Virtual joystick	Send action commands to the robot	INNOVALIA
RobotLink	Software service that moves the robot	INNOVALIA
DataAssembler	Software service that manages the sensor data	INNOVALIA
M3ExecEngine	Software service that manages the measuring process, sending the orders to RobotLink & DataAssembler	INNOVALIA
5Growth platform	Allow verticals to request their slice requirements. Dynamically orchestrate VNFs and apps	INNOVALIA
5G-EVE platform	Instantiate Network Services and provide a metric collection platform	5TONIC
5G CORE CP	Functions of the CORE related to the Control Plane of the network. Control how devices connect to the network and ensure required connectivity	5TONIC
UPF	Function of the CORE related to the User Plane. Handle the service application traffic	INNOVALIA

2.4.2.3. Deployment and implementation setup

Phase I

The video system is provided by InterDigital. It consists of an Over-The-Top (OTT) service provided through low-latency 5G wireless connectivity provisioned by the 5TONIC facility. The video system uses Network Device Interface (NDI) protocol for device discovery and low latency video. As shown in Figure 51, the video system implementation can be broken down into the following blocks:

- **Pain-Tilt-Zoom (PTZ) camera:** a PTZ camera offers orientation and up to 30x optical zoom adjustment and can be remotely controlled via the NDI protocol. Such protocol provides low-latency video delivery and can handle a throughput ranging from 70 to 100 Mbps. Alternatively, a Serial Digital Interface (SDI) combined with an HDMI converter can be employed, although the data rate may increase to 3 Gbps, thus requiring a 10 GbE fiber connection to support the video stream.
- **User PTZ control:** the PTZ camera control is provided by the NDI controller software and allows the remote operator to operate the camera, e.g., zooming in and out or turning the camera. The camera control can be enabled through a traditional keyboard or a joypad.
- **NDI encoder/decoder:** the NDI protocol requires either a software-based encoding-decoding module with specific SDK or hardware encoding-decoding platform. The NDI input is then converted to HDMI by the decoder.
- **HDMI switch:** the HDMI switch is employed to switch the displayed image from multiple sources (up to 4) for the user display. The switch also transmits the selected HDMI image from USB, which can be captured by a laptop or by an embedded processing board for further analysis.

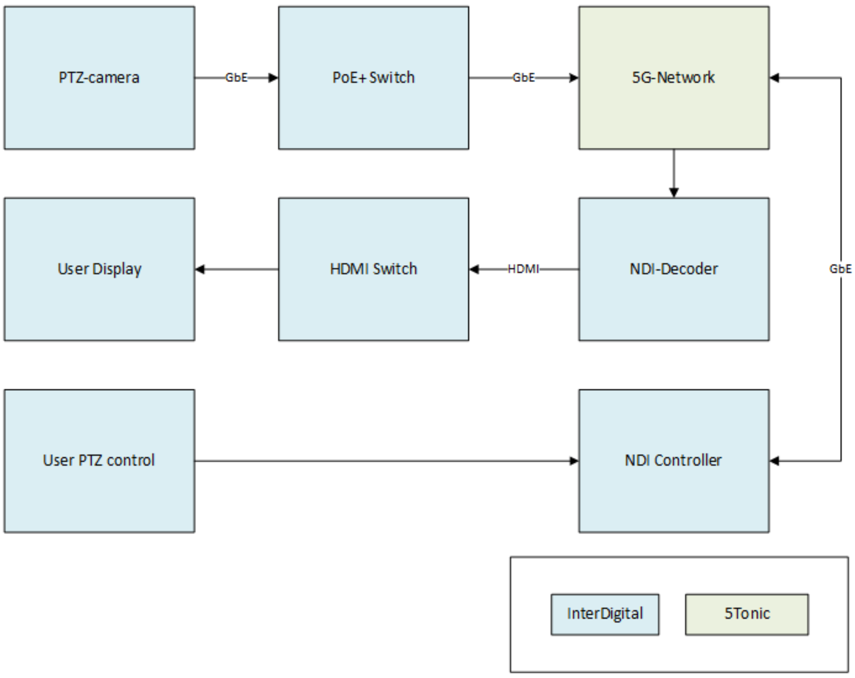


FIGURE 51: INNOVALIA-UC1 VIDEO SYSTEM IMPLEMENTATION

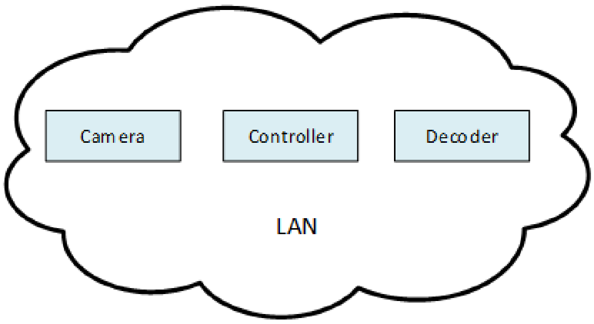


FIGURE 52: INNOVALIA-UC1 NDI CAMERA, CONTROLLER AND DECODER ASSUME THE SAME NETWORK

In the following we also list the main requirements that must be met in order to provide an optimal video streaming delivery service:

- **Connectivity**
  - The NDI protocol used for video is designed to be operated over Gigabit Ethernet network and CAT5e cable type. The INNOVALIA 5Growth pilot is using NDI over 5G network across two wireless links. The recommended round trip latency between NDI end points is 14ms for optimal video switching performance. However, the 5Growth INNOVALIA pilot sites are far away from each other so the latency is expected to be more than 14ms. One of the aspects to test in this pilot is how a system that is designed to be run over GbE Network operates over E2E 5G network and over long distances.
- **Managed switching**
  - The following setting are recommended by NDI specification:
    - DISABLE Jumbo Frames
    - ENABLE Flow Control as Asymmetrical or simply as On (required for TCP data transfer using versions prior to NDI 3.5)
    - ENABLE IGMP Snooping if using multicast (mDNS is automatically blocked by many switches when snooping is enabled)
    - CONFIGURE IGMP Querier and Query Interval for each switch in multi-switch networks when using multicast connectivity
- **Firewalling**
  - mDNS/Bonjour must be accessible for automatic discovery of NDI
  - Manual discovery requires access to port 5960 for the NDI messaging server, and subsequent ports starting at 5961 for NDI video streams

Figure 53 illustrates the designed E2E remote operator application with 5G-Network (User Plane) in between the two sites.

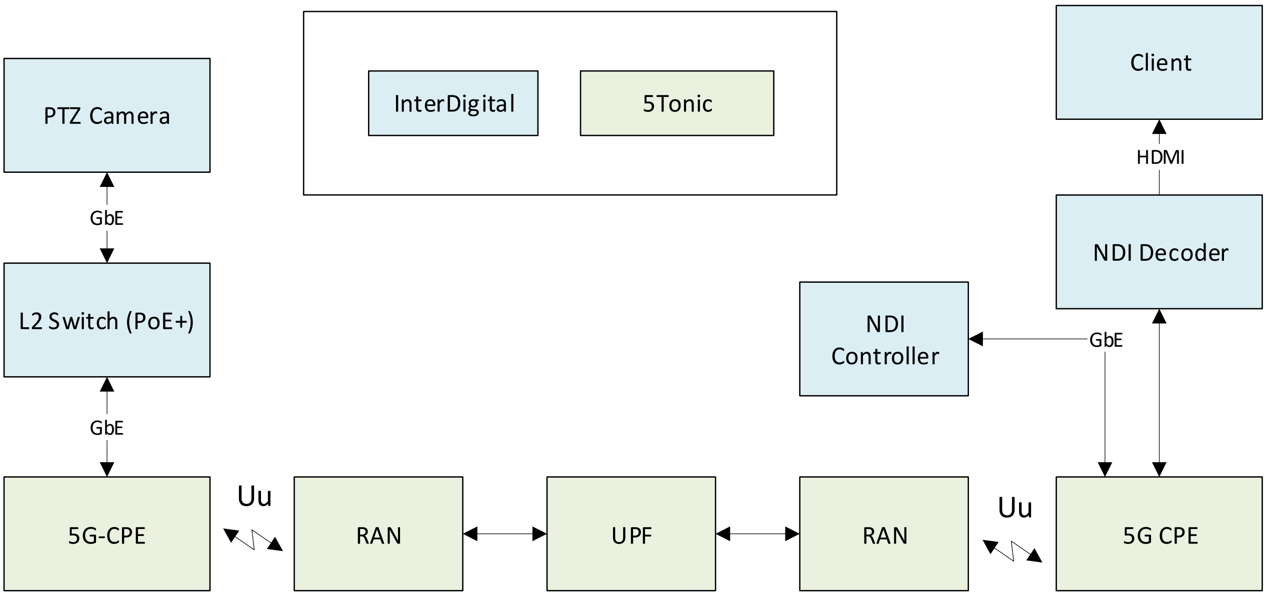


FIGURE 53: INNOVALIA-UC1 DEPLOYMENT WITH TWO 5G-AIR INTERFACES AND CPES

The communications for the control of the machine, on the other hand, will require a low latency connection to interconnect the M3box Edge device and the Virtual Joystick. The blocks diagram for the CMM control application is described in Figure 54, and is composed of the following blocks:

- **Coordinate Measuring Machine:** This is the device to be remotely controlled. It has two important blocks:
  - **Optical sensor:** This hardware component senses the distances based on reflection. It sends a ray of light with a certain angle and measures the time it takes to receive the reflected ray.
  - **Robot Motors:** They allow the movement of the sensor to be able to measure different areas.
- **Controllers:** These components control the hardware described above. There is one hardware device for each component of the CMM (one for the optical sensor and another for the motors). The connection between the controllers and the hardware components is composed of multiple wired cables with proprietary protocols.
  - **Optical Sensor controller:** This component controls the optical sensor (turning it on or off, and setting the resolution), and captures the data (converting the raw information to understandable information).
  - **Robot Motor Controller:** This component translates the software orders into voltages and currents to move the arm of the robot to a specific position.
- **M3BOX:** This is an edge device that hosts the main SW components to control the CMM. It hosts 3 services. It is physically connected to both controllers through Gigabit Ethernet connections, using TCP as communication protocol.
  - **DataAssembler:** This software component is the one that communicates with the optical sensor controller. Besides the control and the data collection, this component executes some cleansing protocols, to reduce the size of the information removing redundant or useless information.

- **RobotLink:** This component is responsible for the communication with the robot controller. It is independent of DataAssembler as it can be used for other kind of robots. It sends the movements that the controller has to execute, and also keeps track constantly of the position of the arm.
- **M3ExecutionEngine:** This component is the one that stores and execute the measuring program, communicating with the other two components through logical connections.

- **PC/TABLET:** This device, that can be either a computer, a tablet or even a mobile device, hosts the software that allows the control of the CMM.
  - **M3Software:** This is the main software suite to control the CMM and to create and run measuring programs.
  - **Remote joystick:** This software allows to control the movement of the robot and the functioning of the sensors directly, on a similar way that a physical joystick does.

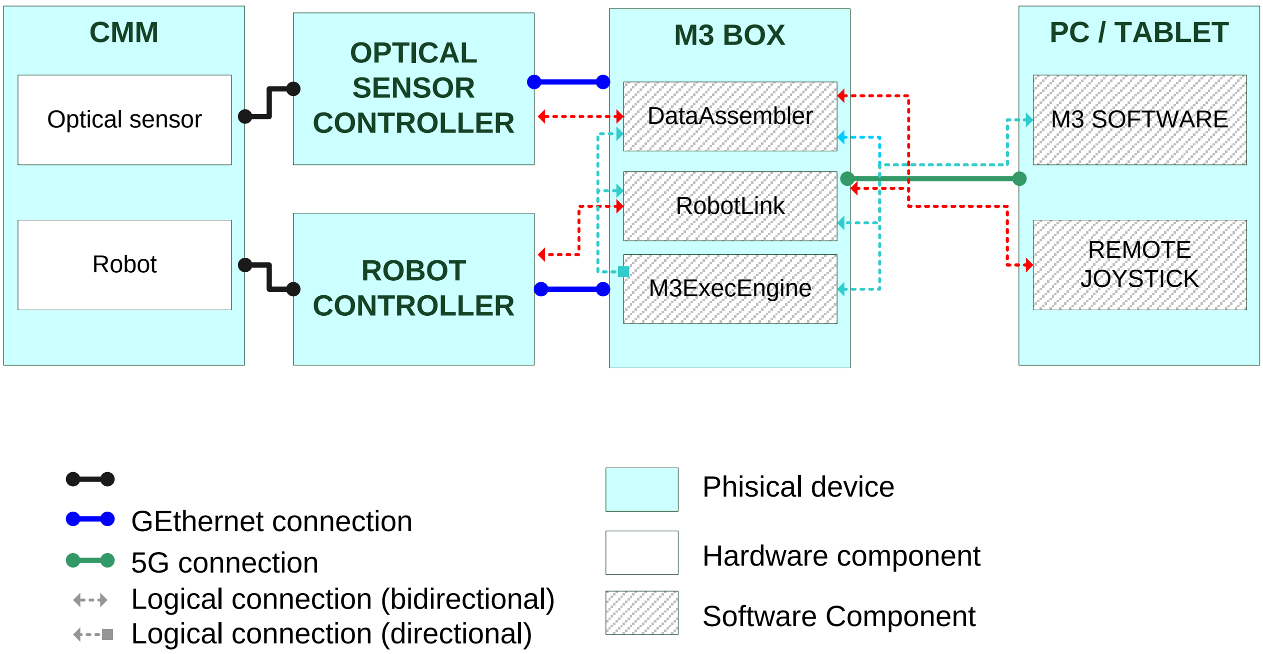


FIGURE 54: INNOVALIA-UC1 CMM CONTROL APP IMPLEMENTATION

Phase II

The deployment of all the components is expected to be smooth and swift, thanks to the experience and lessons learnt from phase I. The latest available release of SW components will be implemented and later they will be upgraded if new versions are released. Note that at this phase some of the components are deployed at vertical premises, as described throughout the document.

2.4.2.4. Initial experiment description

Phase I

Experiment #1: Video streaming service

Test the end-to-end video streaming service connected through the 5G network at 5TONIC lab.

The video streaming service that is going to be used in the use case can be tested as shown in Figure 55. The end devices used will be the video cameras on one end and the display on the other end. They will be connected to the 5G network and the network performance requirements are those of an eMBB slice.

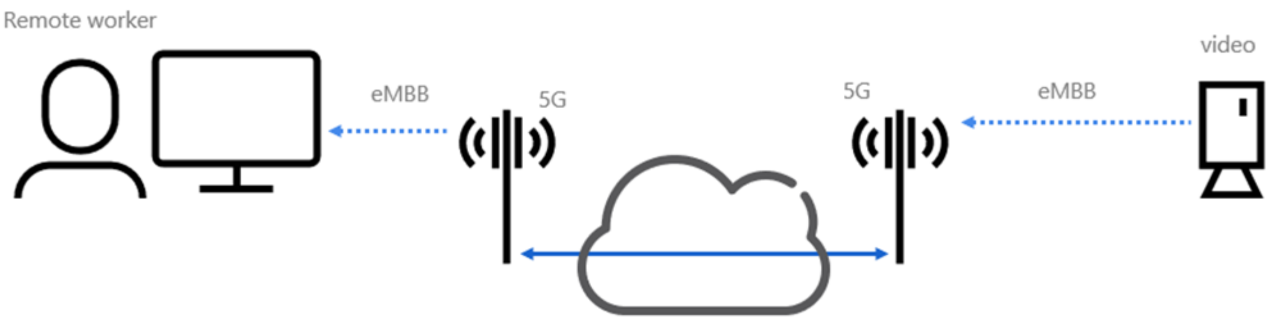


FIGURE 55: INNOVALIA-UC1 EXPERIMENT 1

For the feasibility of the use case, there are several service properties that must be monitored.

First, it is needed that the video quality perceived by the remote worker is acceptable. The display will be the visual input for the remote worker, thus the image must be neat to allow the worker to identify shapes and forms. At the lab, different video source qualities will be tested in order to identify the minimum quality requirements.

Second, the delay of the image seen in the display compared to the actual object must be very low, because an excessive delay between the moving object and the display visualization could prevent a successful remote operation, hindering the calibration process or even causing the damage of the optical sensors.

Additionally, every service depends on a good reliability of the end-to-end connectivity. Not only the service would be interrupted if the connectivity is interrupted, but also the service could be degraded if many packets are being lost.

At the lab where the tests will be performed, there is no significant distance between end devices, but in the real-life scenario, it is likely that the distances can be longer. For this matter, using Traffic Control shaping features, extra delays can be added to simulate longer physical end-to-end distance and compare the performance.

All being said, the relevant KPIs to be measured would be the latency, the data rate, the packet loss, the jitter and the Quality of Experience of the video service (shown in Table 31).

TABLE 31: INNOVALIA-UC1 EXPERIMENT 1 KPIS

KPI	Units	Expected values
End-to-end Latency	ms	<100 (all end devices at same location)[1]
Guaranteed Data Rate	Mbps	70-100
Packet Loss	%	< 0.1
Jitter	us	100
High-resolution Real-time Video Quality	scale 1-5	4

Experiment #2: Virtual joystick operation

Test the virtual joystick connected through the 5G network at 5TONIC lab. Verify that the CMM responds successfully to the received commands. Check that the remote operation of the CMM is safe.

The virtual joystick operation can be tested as shown in Figure 56. The end devices used will be the CMM machine on one end and the virtual joystick on the other end. They will be connected through a 5G network. An URLLC static slice will be established for the data transmission.

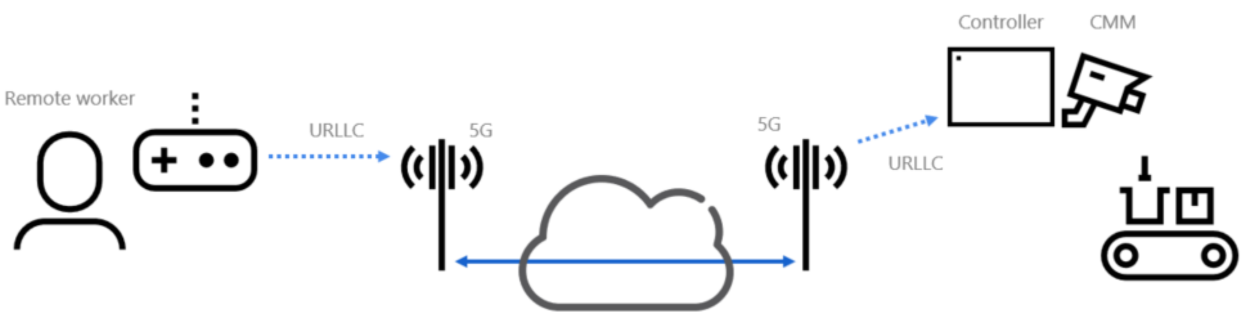


FIGURE 56: INNOVALIA-UC1 EXPERIMENT 2

The application must fulfil several requirements to be considered suitable for the use case.

To start with, the delay between the time the remote worker issues commands with an action and the time the action is actually performed by the CMM must be very low. This is absolutely essential for a smooth operation of the CMM. The worker must feel that the CMM is reacting instantaneously to their orders. Failing to do so, would cause the degradation of the calibration process or even could cause the optical sensor to collide with other objects, getting damaged.

To follow, the reliability of the end-to-end connectivity is also very important. The connectivity interruptions must be very rare and the packet loss must be very low to ensure the smoothness of

[1] Video processing will be the main cause of latency

the CMM movements. Using Traffic Control shaping features, different packet data loss rates can be defined, and the impact on the CMM operation can be measured. Even the maximum packet data loss that grants a smooth CMM operation could be obtained.

At the lab where the tests will be performed, there is no significant distance between end devices, but in the real-life scenario, it is likely that the distances can be longer. For this matter, using Traffic Control shaping features, extra delays can be added to simulate longer physical end-to-end distance and compare the performance.

For this experiment, the relevant KPIs would be the ones related with the latency, the availability, the packet loss rate and the jitter (as reported in Table 32).

TABLE 32: INNOVALIA-UC1 EXPERIMENT 2 KPIS

KPI	Units	Expected values
End-to-end Latency	ms	5 (all end devices at same location)
Service Availability	%	99.99
Packet Loss	%	< 0.1
Jitter	us	100

Experiment #3: Slice management

Test the management of the slices through the 5Gr-VS (Figure 57).

The SW components that allow the creation of slices and orchestrating the resources are shown in the figure. Interacting with the 5Gr-VS component, slices can be established when needed according to traffic requirements and they can be released when no longer needed.

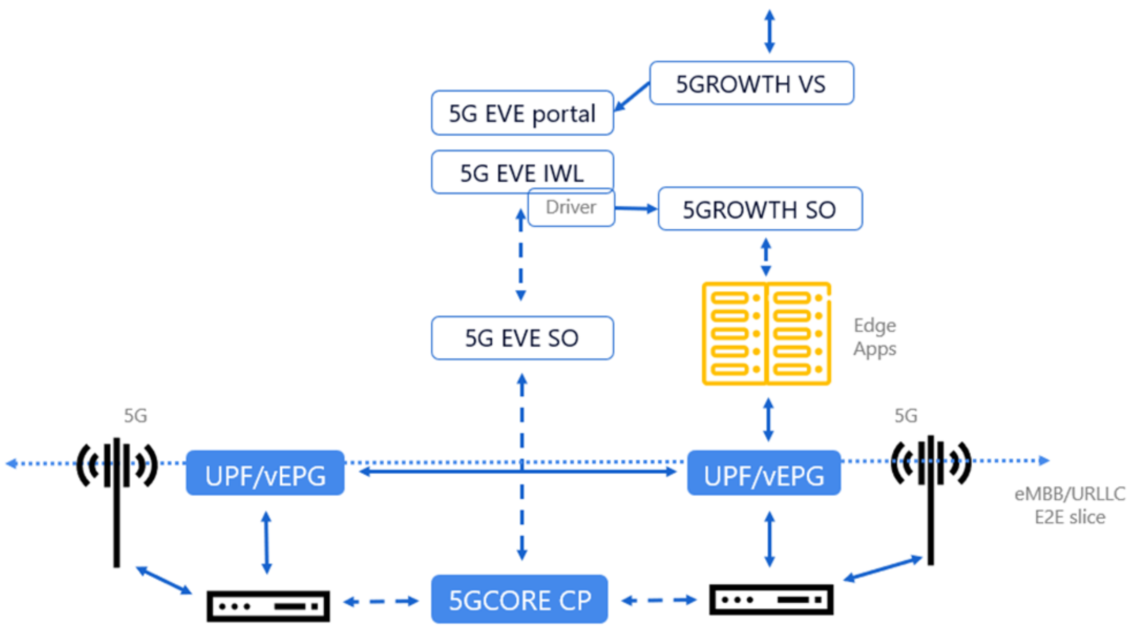


FIGURE 57: INNOVALIA-UC1 EXPERIMENT 3

Ideally, in the real-life scenarios, the vertical will create a slice when they need connectivity to a machine in a remote factory. This process has to be easy and quick. They will not be aware of the complexity of the actions triggered when the request is done. They just expect to get connectivity to the machine as a result of their request. At the lab, the total time related to slice creation and removal operations will be measured (as shown in Table 33). The resulting value can be offered to the verticals in the future as a Service Level Agreement (SLA).

TABLE 33: INNOVALIA-UC1 EXPERIMENT 3 KPIS

KPI	Units	Expected values
Slice creation time	min	<5
Slice removal time	min	<5

<u>Full use case experiment</u>

Ultimately, putting together the environments above, the full use case will be validated. At this stage, the feasibility of the remote operation must be validated and extra (artificial) delays will be simulated in order to determine at which end-to-end distance it will no longer be possible to handle the CMM in real time.

Phase II

At the second phase, the full use case will be directly tested from the onset. At this stage, additionally to what was tested so far, the new and enhanced functionalities of the WP2 innovations will be tested. There is also the difference at this phase that some of the components will be deployed at INNOVALIA premises and they have to connect to components at 5TONIC lab, so the availability of this connectivity will be verified.

2.4.2.5. Plan and roadmap

FIGURE 58: INNOVALIA-UC1 PLAN AND ROADMAP

As shown in the Figure 58, the highlights of the plan for this use case are:

1) The video streaming system will be implemented in 5TONIC by the end of March 2020 (M10).
2) The CMM and the INNOVALIA virtual joystick application will be implemented in 5TONIC by the end of March 2020 (M10).
3) The video streaming system will be implemented at INNOVALIA premises by the end of March 2021 (M22).
4) The CMM and the INNOVALIA virtual joystick application will be available for project use at INNOVALIA premises by the end of March 2021 (M22).

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

2.4.3.1. Use Case Modelling

In this use case, when a manufactured piece comes out of the production line, the piece code will be identified. For the identification of the piece, the communication only requires low bandwidth and it is not very demanding on latency, so the requirements would be similar to those of a mMTC slice.

The piece is placed in an Automated Guided Vehicle (AGV) that takes it to the scan area. While the piece is being carried to the scan area, the application will download the measuring program for that particular piece to the CMM. For this data transmission, the most relevant feature will be the data throughput, so it could be considered an eMBB slice.

When the piece arrives to the scan area, the scanner will be ready to measure the piece. The AGV sends a message for the measuring process to start. The results of the measurement are sent to the quality control system, where it can be visualized in real-time and stored for further use. When the process is over, the CMM informs the system and the AGV will take the piece to its final destination. The connectivity needs are permanent in this case. The control for the AGVs has URLLC slice requirements. The transmission of the measurement results will need an eMBB slice.

The slice requirements are introduced by the vertical using the 5Growth's Vertical Slicer. The 5Gr-VS interacts with the 5G-EVE framework for the Network Service instantiation and for the use of the metric collection platform. The Service Orchestrator (5Gr-SO) instantiates the service apps. For more accurate detail on how 5Growth and 5G-EVE platforms interact, please refer to Section 3.3 in this document. Once the connectivity and the service apps are ready, the service will work as described.

The use case is depicted in Figure 59:

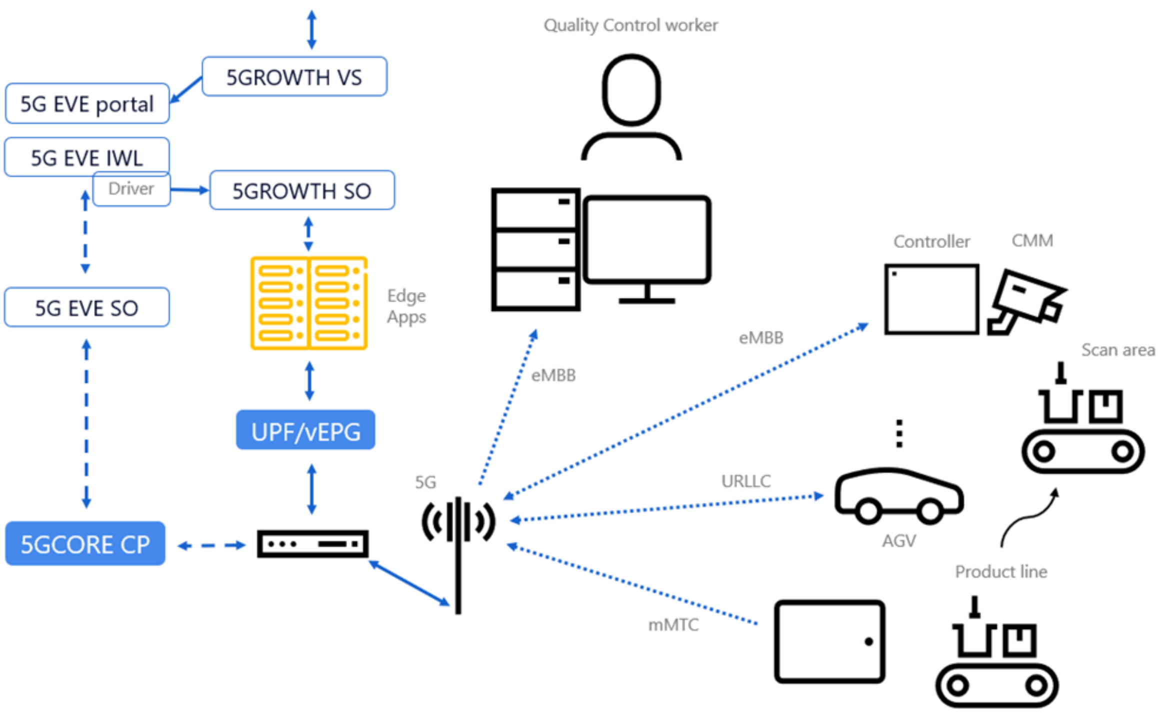


FIGURE 59: INNOVALIA-UC2 OVERVIEW

2.4.3.2. Hardware / Software components

Phase I

TABLE 34: INNOVALIA-UC2 HARDWARE COMPONENTS (PHASE I)

Component	Description	Location
CMM	Robot that contains the scanner to measure the pieces	5TONIC
CMM-Controller	Hardware that controls the movement of the CMM	5TONIC
AGV	Move the piece from the product line to the scan area	5TONIC
Storage device	Store the digital twin	5TONIC
Visual Display	Show the measurement results to the Quality Control worker	5TONIC
Multi-purpose servers	Hold the SW components of the 5G CORE and the service apps	5TONIC
RAN baseband	Control the RAN functionalities and communicate with the CORE	5TONIC
Antennas	Provide 5G radio coverage to the devices	5TONIC
Router	Provide interconnectivity among RAN baseband and multi-purpose servers	5TONIC

TABLE 35: INNOVALIA-UC2 SOFTWARE COMPONENTS (PHASE I)

Component	Description	Location
M3	Software suite to design, deploy and run the measurement program	5TONIC
RobotLink	Software service that moves the robot	5TONIC
DataAssembler	Software service that manages the sensor data	5TONIC
M3ExecEngine	Software service that manages the measuring process, sending the orders to RobotLink & DataAssembler	5TONIC
AGV controller	Control the AGV	
5Growth platform	Allow verticals to request their slice requirements. Dynamically orchestrate VNFs and apps	5TONIC
5G-EVE platform	Instantiate Network Services and provide a metric collection platform	5TONIC
5G CORE CP	Functions of the CORE related to the Control Plane of the network. Control how devices connect to the network and ensure required connectivity	5TONIC
UPF	Function of the CORE related to the User Plane. Handle the service traffic	5TONIC

Phase II

TABLE 36: INNOVALIA-UC2 HARDWARE COMPONENTS (PHASE II)

Component	Description	Location
CMM	Robot that contains the scanner to measure the pieces. It will be operated remotely	INNOVALIA
CMM-Controller	Hardware that controls the movement of the CMM	INNOVALIA
AGV	Move the piece from the product line to the scan area	INNOVALIA
Storage device	Store the digital twin	INNOVALIA
Visual Display	Show the measurement results to the Quality Control worker	INNOVALIA
Multi-purpose servers	Hold the SW components of the 5G CORE and the service apps	INNOVALIA
RAN baseband	Control the RAN functionalities and communicate with the CORE	INNOVALIA
Antennas	Provide 5G radio coverage to the devices	INNOVALIA
Router	Provide interconnectivity among RAN baseband and multi-purpose servers	INNOVALIA

TABLE 37: INNOVALIA-UC2 SOFTWARE COMPONENTS (PHASE II)

Component	Description	Location
M3	Software suite to design, deploy and run the measurement program	INNOVALIA

Component	Description	Location
RobotLink	Software service that moves the robot	INNOVALIA
DataAssembler	Software service that manages the sensor data	INNOVALIA
M3ExecEngine	Software service that manages the measuring process, sending the orders to RobotLink & DataAssembler	INNOVALIA
AGV controller	Control the AGV	
5Growth platform	Allow verticals to request their slice requirements. Dynamically orchestrate VNFs and apps.	INNOVALIA
5G-EVE platform	Instantiate Network Services and provide a metric collection platform	5TONIC
5G CORE CP	Functions of the CORE related to the Control Plane of the network. Control how devices connect to the network and ensure required connectivity	5TONIC
UPF	Function of the CORE related to the User Plane. Handle the service traffic	INNOVALIA

2.4.3.3. Deployment and implementation setup

Phase I

The services that nowadays are running on the M3BOX, which move the CMM or manage the sensor's information, will be deployed in the cloud-edge, as well as the software service which controls the AGV, as the block diagram in Figure 60 shows.

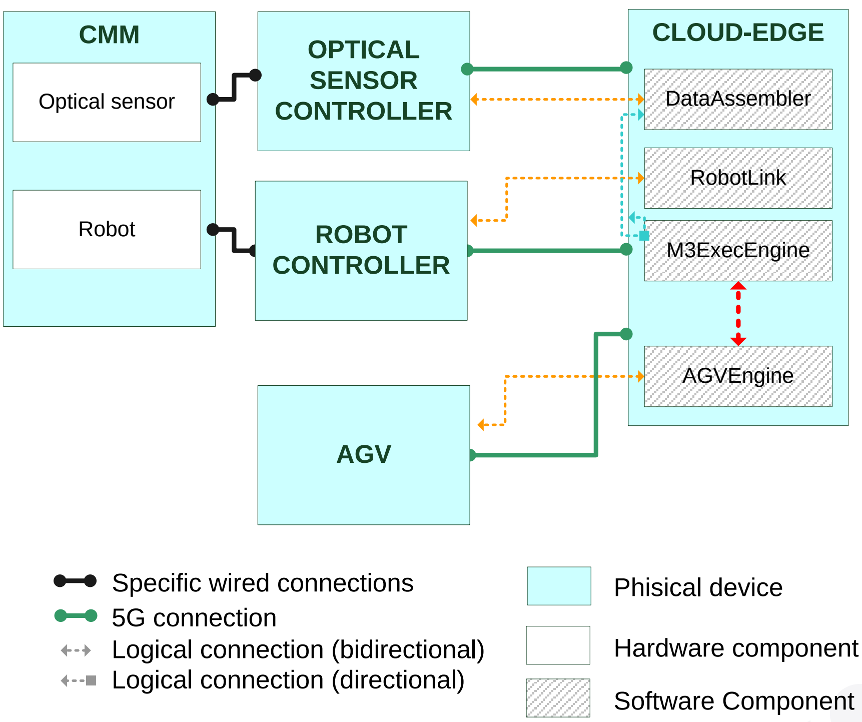


FIGURE 60: INNOVALIA-UC2: M2M COLLABORATION APP IMPLEMENTATION

Besides, an additional service has to be developed and deployed in the cloud-edge, to enable the communication between the CMM and the AGV, in order to allow the factory operator that places a specific part on the AGV to introduce the part number into the system so that the CMM can be prepared to measure that specific part while the AGV takes it to the measuring station. Figure 61 describes the flow of the process and the information transmitted between the different modules. It is still undecided if the communication between the two components will be performed by an independent module (M2MEngine) or will be integrated in the M3ExecutionEngine, but the flow will remain very similar.

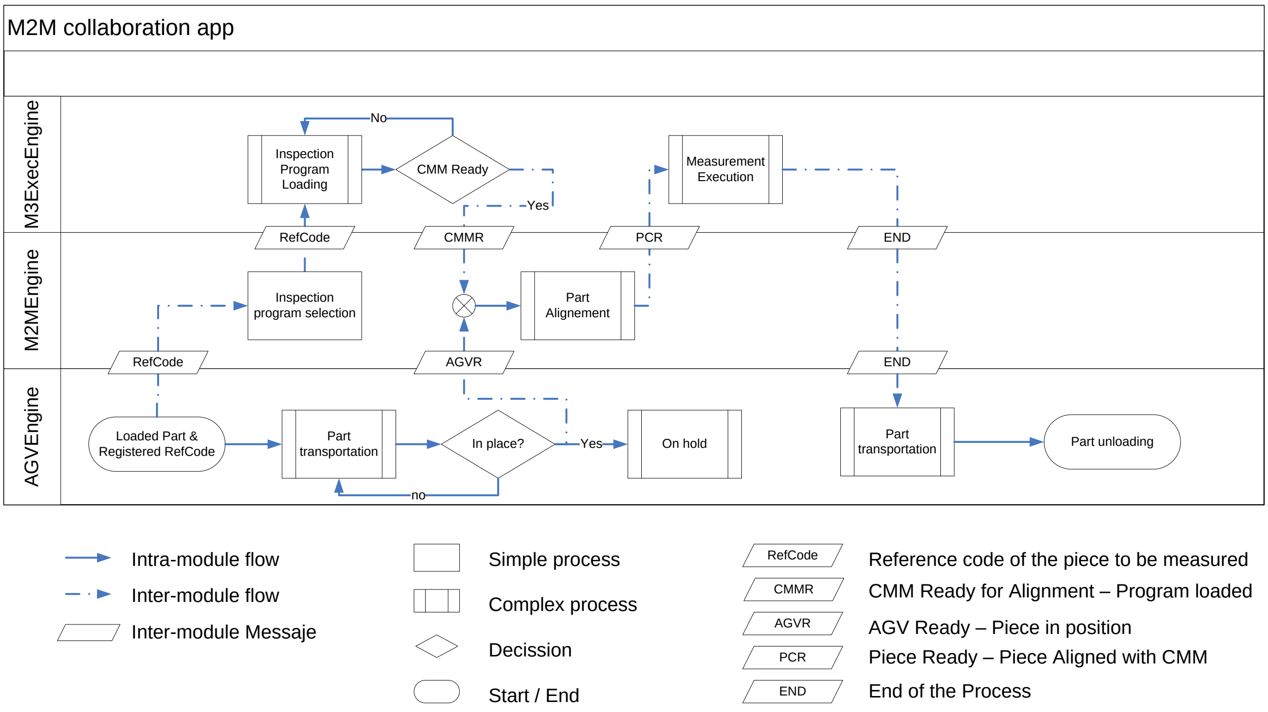


FIGURE 61: INNOVALIA-UC2: M2M COLLABORATION APP PROCESS

Phase II

The deployment of all the components will be quick, thanks to the lessons learnt of phase I. The latest available release of SW components will be implemented and later they will be upgraded if new versions are released. Note that at this phase some of the components are deployed at vertical premises, as described throughout the document.

2.4.3.4. Initial experiment description

Phase I

<u>Experiment #1:</u> Piece identification

Test the application that sends the piece code to the CMM for the measuring program to be downloaded to the CMM.

The piece identification application can be tested as shown in Figure 62. The end devices used will be the CMM machine and a code reader to identify the piece. They will be connected through the

5G network. The performance requirements for the code reader are very low, it will be enough to have an mMTC type slice. The CMM needs a high-speed connection, such as the provided by an eMBB slice, to be able to download the measuring program.

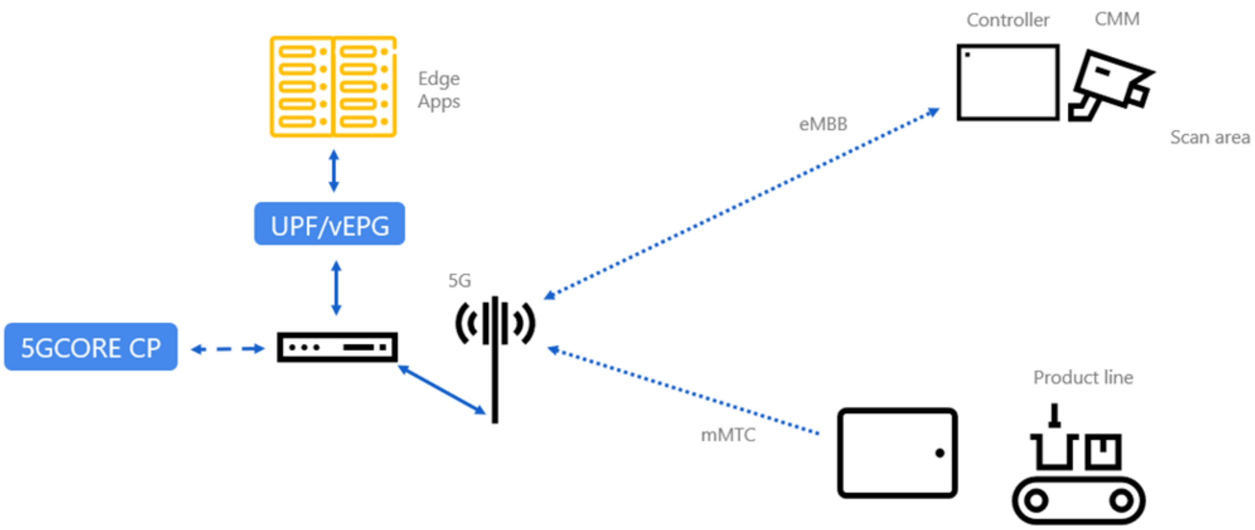


FIGURE 62: INNOVALIA-UC2 EXPERIMENT 1

The most relevant KPI in this experiment (as presented in Table 38) is the total time it takes for the CMM to be ready to measure the piece since the code is read at the production line. Ideally, this time should be lower than the time it takes to carry the piece from the production line to the scan area. As this time must remain short, the speed of the connection should be high. When the download is complete and the CMM is ready to start scanning the piece, the CMM should send a message to the system to report it.

In conclusion, the KPIs to measure would be the total time of operation and the data rate.

TABLE 38: INNOVALIA-UC2 EXPERIMENT 1 KPIS

KPI	Units	Expected values
Service Operation Time	s	120
Guaranteed Data Rate	Mbps	100

Experiment #2: Measurement results handling

Test the transmission of the measurement results to the visualization and storage device.

The experiment setup would be the one shown in Figure 63. The end devices would be the CMM on one hand and the visualization and storage device on the other. The connections, as big amounts of data are transmitted, must provide eMBB type slice capabilities.

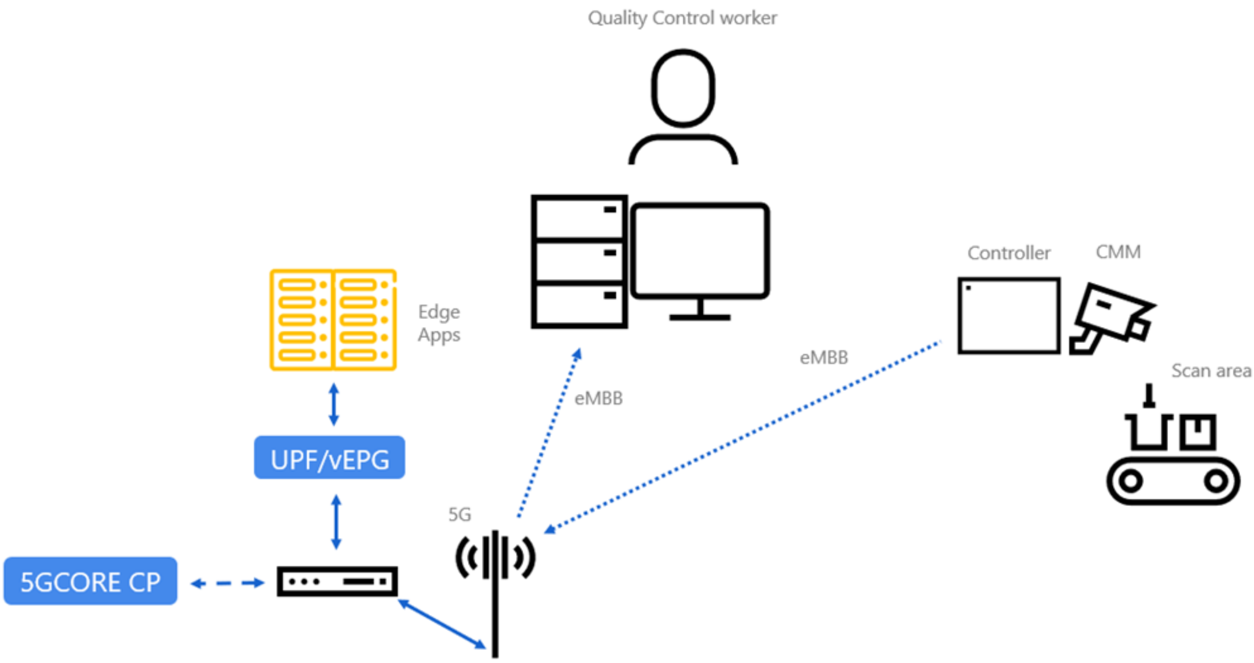


FIGURE 63: INNOVALIA-UC2 EXPERIMENT 2

The experiment consists in the CMM measuring the piece and sending the results to the visualization and storage device. The results are sent in real-time towards the device. They can be visualized in real-time and they are also stored for future analysis.

Thus, the main KPIs (as presented in Table 39) to be monitored here are data rate and latency.

TABLE 39: INNOVALIA-UC2 EXPERIMENT 2 KPIS

KPI	Units	Expected values
Guaranteed Data Rate	Mbps	100
End-to-end Latency	ms	5

Experiment #3: AGV operation

Test the AGV successful operation.

The setup for the experiment would be the one shown in Figure 64. The end device is uniquely the AGV, which needs to be connected to the 5G network to send and receive commands. The AGV controller software is placed at the edge servers shown in the figure. The slice type needed would be an URLLC.

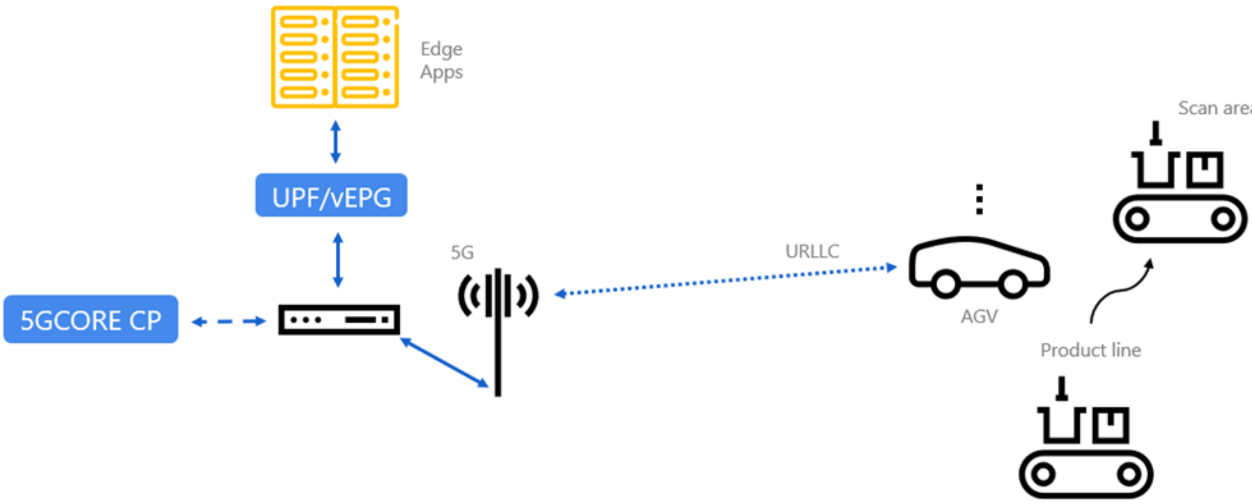


FIGURE 64: INNOVALIA-UC2 EXPERIMENT 3

In this experiment, first we will monitor the ability of the AGV controller to effectively guide the vehicle. For the AGV to adapt to changing conditions, it needs to get instructions from the controller with very little delay.

Second, we need to test the ability to send and receive commands from an external system (in this case INNOVALIA's system) to coordinate the operation of both systems. When a piece is placed in an AGV, the vehicle will get a command to move to the scan area. Also, when the AGV reaches the scan area, the vehicle must send a message informing that the piece is in place to be measured. The time that this process takes can be monitored.

So, the KPIs to be monitored (as presented in Table 40) are the latency and the total time of operation.

TABLE 40: INNOVALIA-UC2 EXPERIMENT 3 KPIS

KPI	Units	Expected values
End-to-end Latency	ms	5
Service Operation Time	s	120 (depends on the distance though)

<u>Experiment #4:</u> Slice management

Test the management of the slices through the 5Gr-VS.

The SW components that allow the creation of slices and orchestrating the resources are shown in Figure 65. When different kind of slices are established, there are mechanisms to maintain the desired level of service for each kind.

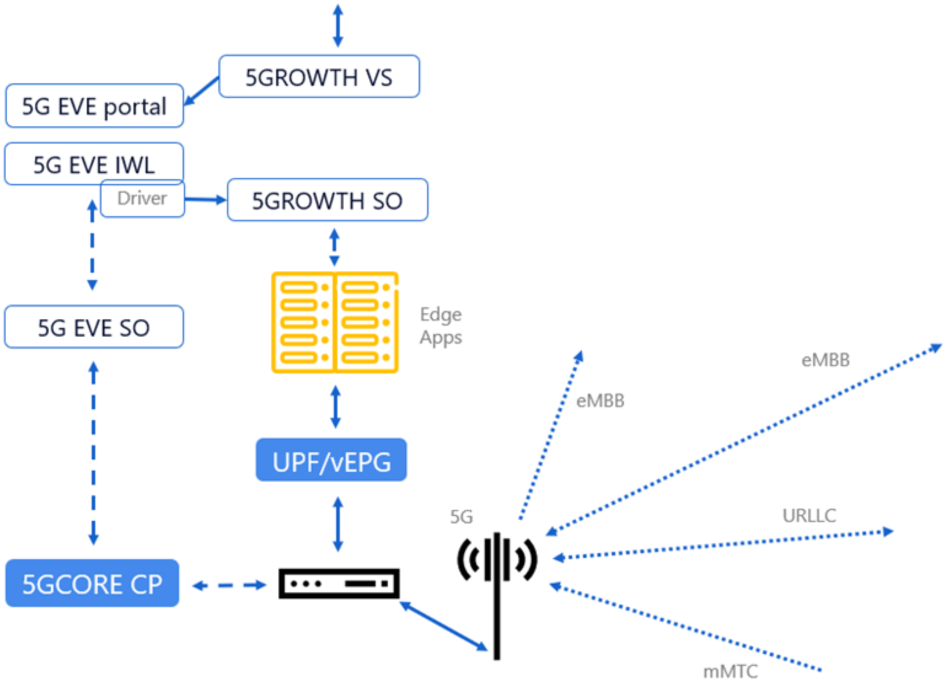


FIGURE 65: INNOVALIA-UC2 EXPERIMENT 4

For this experiment, there will be several slices working with different network performance requirements. It can be verified that using the 5Gr-VS, different slices can be established over the same network. At the lab, the total time that takes since the user requests a slice until the connectivity is established will be measured.

The KPIs to be monitored are presented in Table 41.

TABLE 41: INNOVALIA-UC2 EXPERIMENT 4 KPIS

KPI	Units	Expected values
Slice creation time	min	<5
Slice removal time	min	<5

Full use case experiment

Ultimately, putting all the previous tests together, the full use case will be verified. First, the piece code is identified and sent to the application control system. Then, the corresponding measuring program can be downloaded. In the meanwhile, the piece must be placed in the AGV and the vehicle must be commanded to move to the scan area. When the AGV reaches the area, it will send a message. The CMM will then know that the measuring process can start. The results will be sent to the storage device and will be available for further visualization.

Phase II

During the second phase, the full use case will be directly tested. At this stage, additionally to what was tested so far, the new and enhanced functionalities of the WP2 innovations will be tested. There is also the difference at this phase that some of the components will be deployed at INNOVALIA premises and they have to connect to components at 5TONIC lab, so the availability of this connectivity will be verified.

2.4.3.5. Plan and roadmap

FIGURE 66: INNOVALIA-UC2 PLAN AND ROADMAP

As shown in the Figure 66, the highlights of the plan for this use case are:

1) The application to send the piece codes to the CMM will be available at 5TONIC by the end of June 2020 (M13).
2) The M3 with virtualized functionalities will be ready at 5TONIC by the end of September 2020 (M16).
3) The applications needed will be available for project use at INNOVALIA premises by the end of March 2021 (M22).

2.4.4. COVID-19 Impact Analysis on Plans and Roadmaps

As the COVID-19 situation develops, governments are applying restrictions to the mobility of their citizens and enterprises are also applying restrictions to the mobility of their employees. Those restrictions will impact the original plan of the pilot.

The project is considering a worst-case scenario of four months of unavailability for 5TONIC on-site activities. It is assumed that the restrictions applied will be relaxed gradually and the last restriction to lift will be the possibility for the partners to meet at 5TONIC lab.

The impact can be grouped into the assumed facts (those that will certainly happen) and the probable threats (those that could happen) during those four months.

1) **Assumed Facts:**
   a. HW Deployment:
      i. Not possible in this period
      ii. No feasible mitigation

   b. 5TONIC on-site activities:
      i. Not possible in this period
      ii. No feasible mitigation
   c. Attendance to F2F meetings:
      i. Not possible in this period
      ii. Switched to virtual meetings
   d. Attendance to Events:
      i. Not possible in this period
      ii. Dissemination via digital video channels

2) **Probable Threats:**
   a. Potential infection of involved staff in the project
   b. Potential degradation of remote access to current labs infrastructure
   c. Potential performance degradation of current labs infrastructure
   d. Potential shortages and delays in the supply of 3rd party products
   e. Potential delays in other related projects such as 5G-EVE or other WPs in 5Growth
   f. Potential scarce availability of 5G-EVE when crisis ends, as many projects will need to use 5G-EVE platform at the same time

Considering all the above, the project partners will shift their plans and will focus on activities that are less likely to be impacted by the restrictions, such as:

   a. SW applications development
   b. SW upgrades
   c. Preparing documentation
   d. Getting ready for on-site tasks

To be able to keep the original ending project dates, two options are evaluated:

1) **Keep Milestones' planned dates**, through scope contention of M18's Milestone and progressive catch-up afterwards, in order to enable incremental testing of the pilot both before and after M18.
2) **Delay M18's Milestone 2 months**, in order to keep the original planned activities unaffected.

2.4.4.1. Option 1: Estimated impact in the Infrastructure Roadmap

Figure 67 shows the estimated impact:

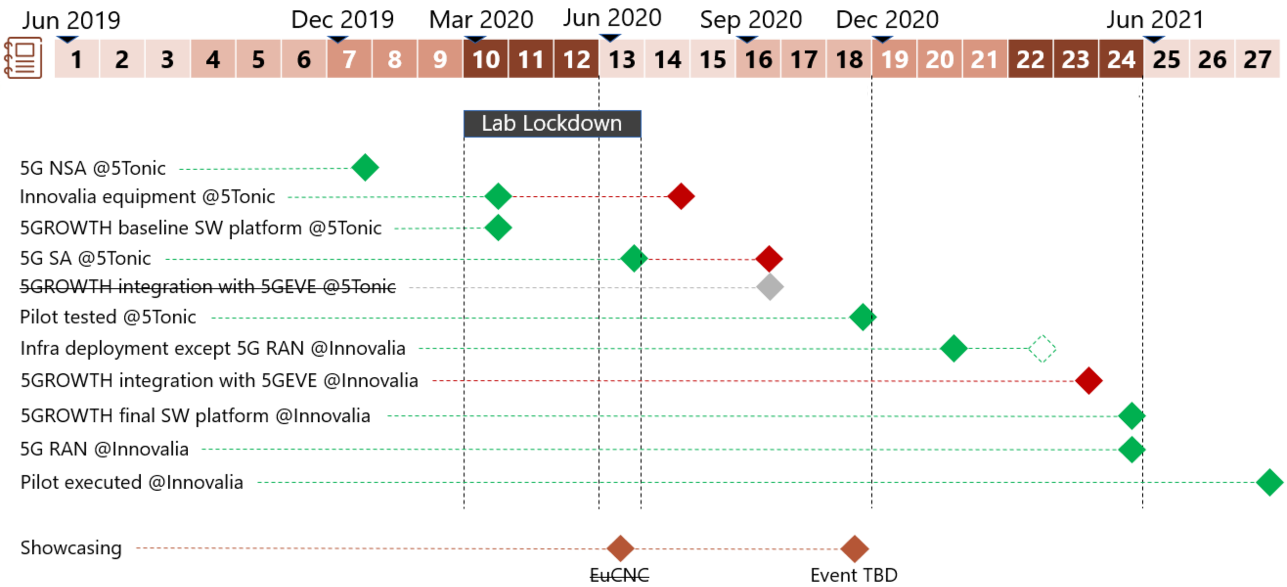


FIGURE 67: INNOVALIA 5G NETWORK INFRASTRUCTURE ROADMAP ESTIMATED IMPACT (OPTION 1)

One of the impacted achievements is the one about INNOVALIA equipment. The original plan was to have their equipment at 5TONIC by the end of March 2020 and start testing the applications there using the available 5G network. Instead, we must follow an alternative approach. As the restrictions to work locally are more likely to be lifted earlier, INNOVALIA can progress with the SW application development and it can start basic testing in its premises when possible, targeting to have a more mature SW release when all restrictions are lifted. For performing those tests, INNOVALIA shall acquire 4G CPEs, in order to use the commercial 4G network for their basic testing activities during the lockdown. The commercial 4G network's performance is of course not enough to meet the full use case requirements, but it is good enough to test end to end connectivity and help early basic testing and debugging of the application.

Another impacted expectation is the one referring to having 5G equipment with Stand Alone option. It requires to have a SW release upgrade in the RAN equipment and to have both HW and SW deployments for the Core equipment. The original plan was to have it ready by the end of June 2020. With the restrictions, the date might be delayed three months. Many of the tasks to be done depend on the possibility to access 5TONIC lab facilities. Regarding the RAN equipment, as the HW is already installed in 5TONIC, the SW upgrade must be done on-site. This task needs to be well prepared in advance to have a successful execution. Regarding the Core equipment, the SW can be deployed in the HW equipment at Ericsson premises, and later, when 5TONIC lab is again accessible, the HW can be moved to 5TONIC and final configurations can be done.

A third impacted expectation is having 5Growth integrated with 5G-EVE at 5TONIC. Such ambition is relaxed in order to let all partners dedicate their efforts to having an operational pilot as soon as possible, thus enabling to obtaining some results by M18 and not impacting WP4. The integration of 5Growth with 5G-EVE may well be accomplished later, directly with the 5Growth platform deployed at INNOVALIA premises. It will be ready by the end of April 2021.

Regarding showcasing, the EuCNC event (demos are cancelled) is no longer targeted. While restrictions are in place, alternatively, virtual dissemination ways are being planned. By the end of the year, an event will be identified where results can be shown.

2.4.4.2. Option 1: Estimated impact in INNOVALIA-UC1 Plan and Roadmap

Figure 68 shows the estimated impact in the plan and roadmap of INNOVALIA-UC1.

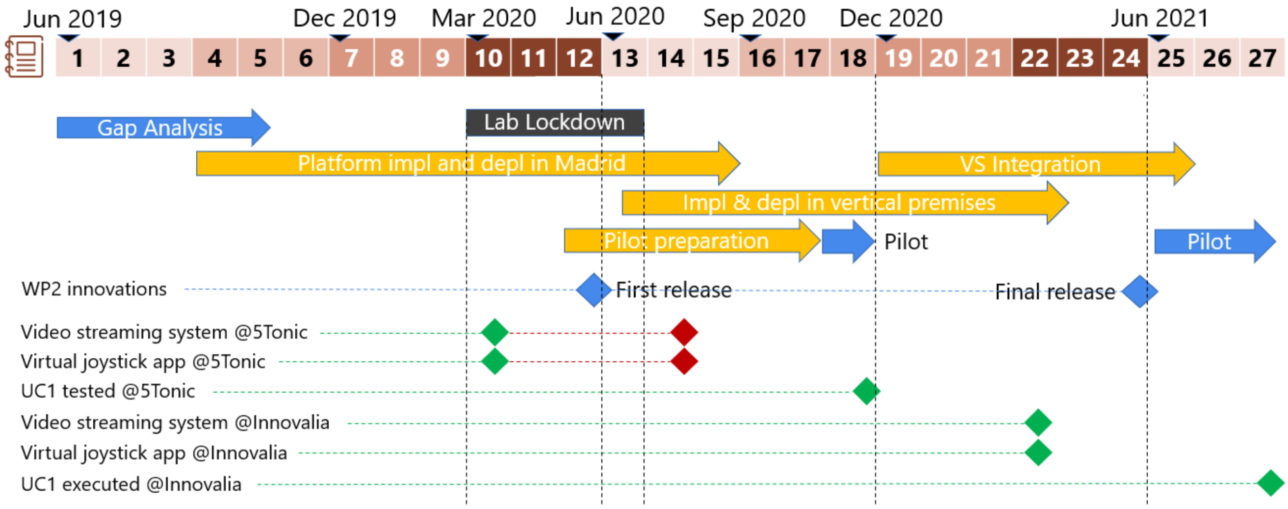


FIGURE 68: INNOVALIA-UC1 PLAN AND ROADMAP ESTIMATED IMPACT (OPTION 1)

The end of the activities related to the platform implementation and deployment in Madrid will be delayed. The activities for the 5Growth integration in Madrid are removed. Instead, the activities of implementation and deployment in vertical premises are started earlier, including the use of 4G CPEs at vertical premises. Consequently, the VS integration in vertical premises can be started earlier than in the original plan. As the integration is done directly in vertical premises, extra time is needed. With this plan, both pilot execution dates are kept.

The goal of having the video streaming system implemented in 5TONIC by the end of March 2020 will also be impacted. It will be delayed four months in the considered scenario. The video system has already been tested successfully using Ethernet cable, but the deployment in 5TONIC aimed to assess its performance while using 5G connectivity. To anticipate some work when it can be finally implemented in 5TONIC, the end to end connectivity of the video system can be tested over the 4G commercial network on the premises of InterDigital. To achieve that, it will be required to buy 4G CPEs to use the commercial 4G network for the testing purposes.

The goal of having the virtual joystick application available at 5TONIC for testing by the end of March 2020 has also been impacted. It will be delayed four months in the considered scenario. This is an application developed by INNOVALIA. It can progress in the development and basic testing in its premises. It will need 4G CPEs to test basic connectivity through the 4G network on their premises. This way the SW will be more mature when deployed in 5TONIC.

2.4.4.3. Option 1: Estimated impact in INNOVALIA-UC2 Plan and Roadmap

Figure 69 shows the estimated impact in the plan and roadmap of INNOVALIA-UC2.

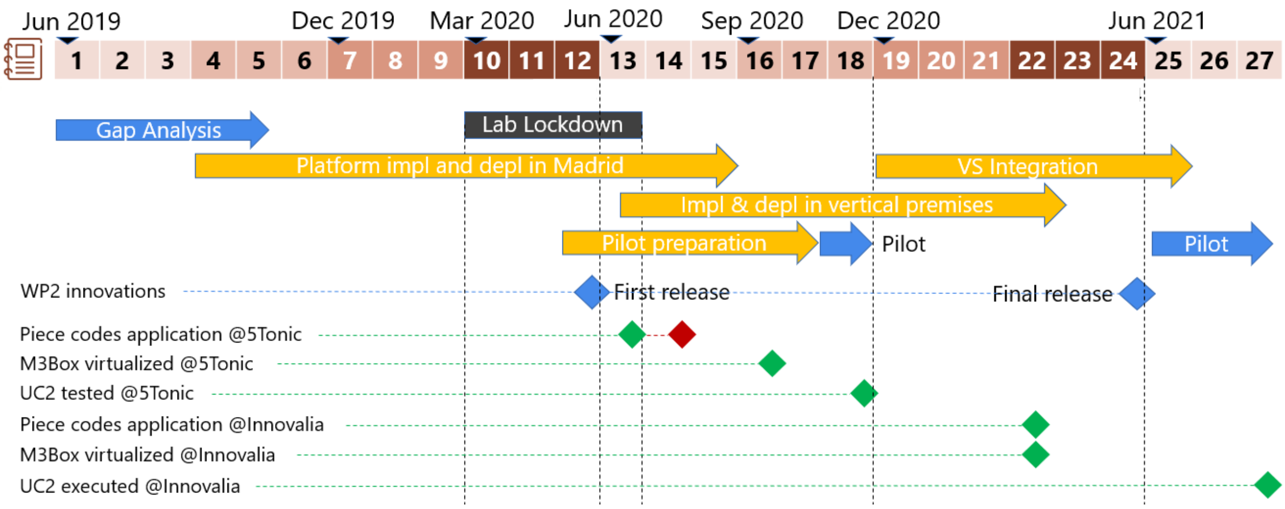


FIGURE 69: INNOVALIA-UC2 PLAN AND ROADMAP ESTIMATED IMPACT (OPTION 1)

See Section 2.4.4.2 for comments on the timeplan.

For this use case, there was a commitment to have the piece codes identification application at 5TONIC by the end of June 2020. With the restriction to work in 5TONIC lab, this milestone will be delayed one month. The SW application can hopefully be developed on time, but the deployment in 5TONIC will be delayed one month from the original plan.

2.4.4.4. Option 2: Estimated impact in the Infrastructure Roadmap

Figure shows the estimated impact:

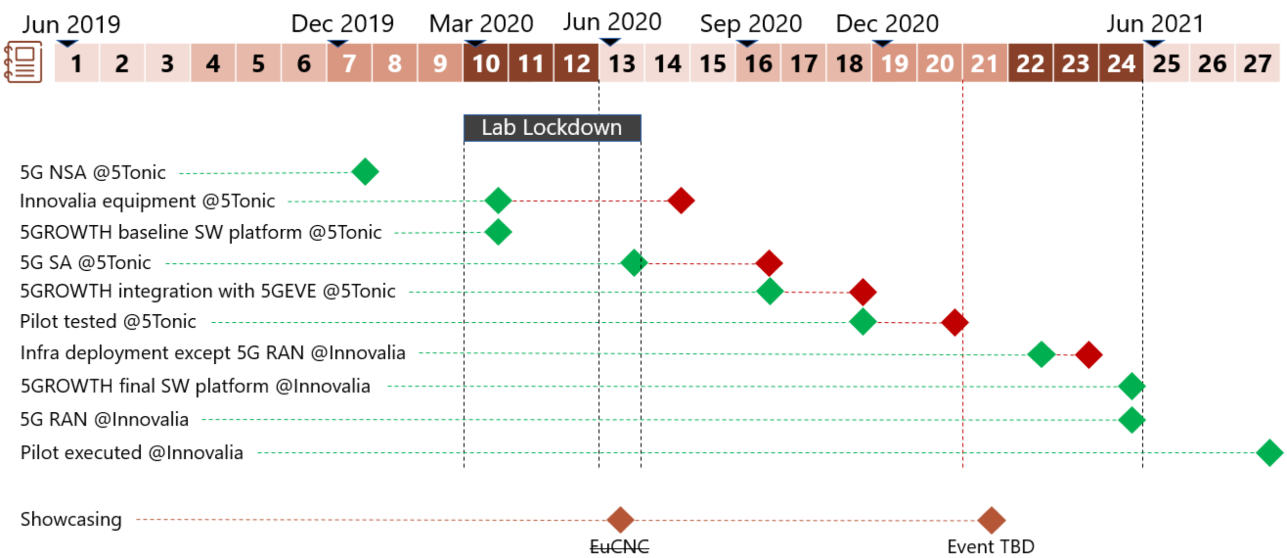


FIGURE 70: INNOVALIA 5G NETWORK INFRASTRUCTURE ROADMAP ESTIMATED IMPACT (OPTION 2)

The first two expected achievements would be equally impacted as in option 1. Please see Section 2.4.4.1 for the details.

The achievement of 5Growth integration with 5G-EVE would be delayed until the end of November 2020. The delay is caused by the lack of resources until October 2020 to tackle the needed activities.

The availability of pilot results would be delayed to January 2021. There is a need of two full months for experimenting, tuning and testing.

The following achievement, the infrastructure deployment except 5G RAN, would also be delayed by one month. It should be ready by the end of April 2021. The start of the activities will be delayed, and the duration of the activities must be compressed to keep catching up with the original plan.

With this plan, showcasing of results would not be possible until mid Q1 2021, at the earliest.

2.4.4.5. Option 2: Estimated impact in INNOVALIA-UC1 Plan and Roadmap

Figure shows the estimated impact:

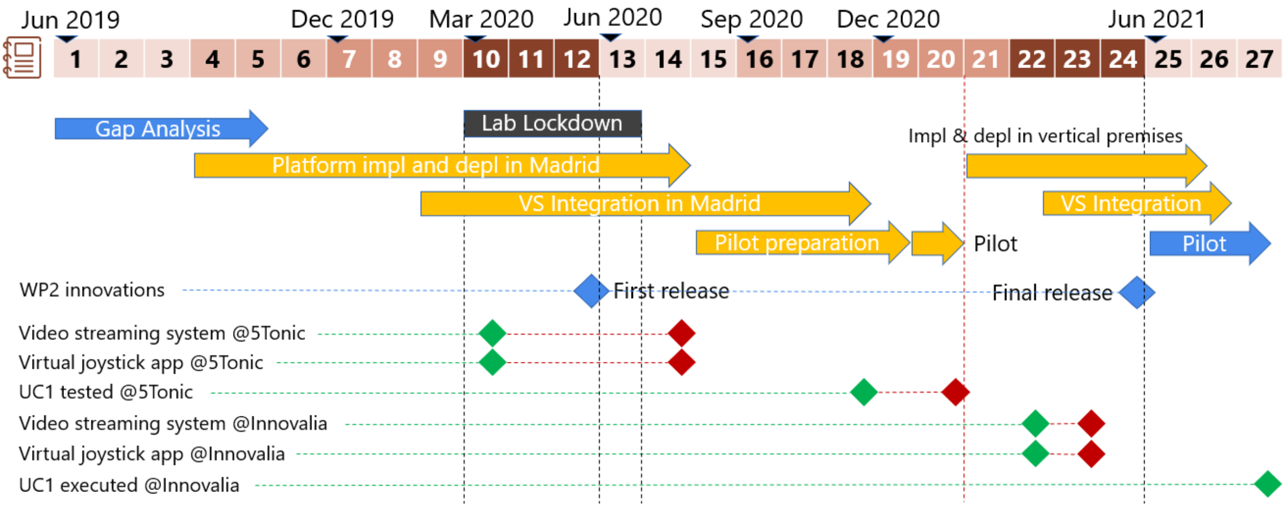


FIGURE 71: INNOVALIA-UC1 PLAN AND ROADMAP ESTIMATED IMPACT (OPTION 2)

With this plan, the end of all the activities in Madrid would be delayed. The activities would require extra effort from the partners to be able to perform the pilot in Madrid with a delay of 2 months, to have results by M20. The start of the activities in vertical premises would also be delayed 2 months, meaning less time for partners to perform the work to catch up with the planned dates for the pilot in vertical premises.

The first two achievements would be impacted as described in Section 2.4.4.2.

The testing of the INNOVALIA-UC1 would be achieved by M20.

The achievements of having the video streaming system and the virtual joystick application available at INNOVALIA must be delayed one month. They could be ready by April 2020.

2.4.4.6. Option 2: Estimated impact in INNOVALIA-UC2 Plan and Roadmap

Figure shows the estimated impact:

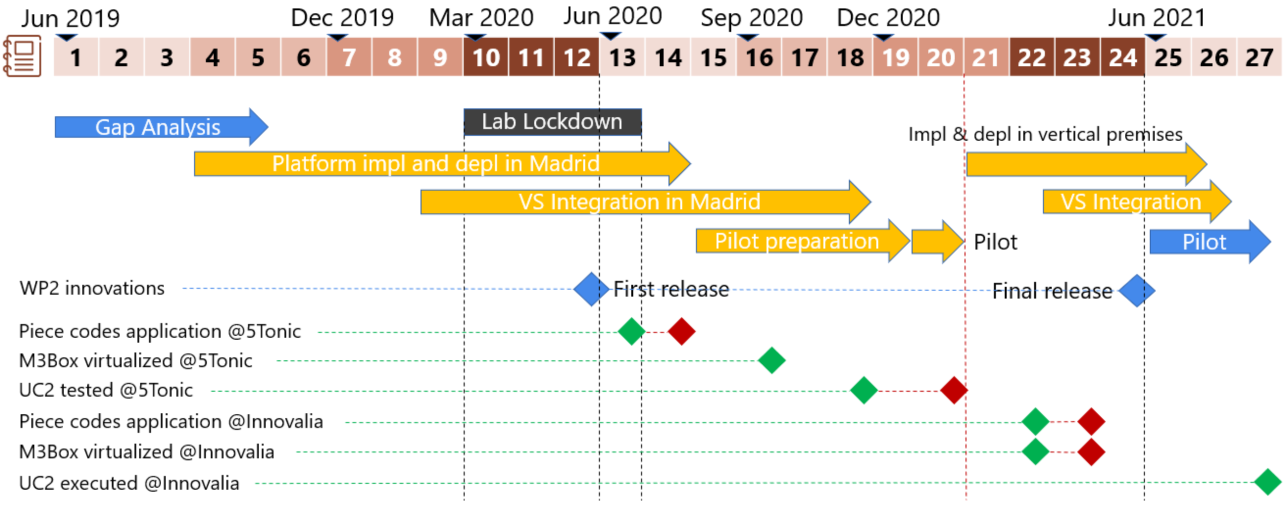


FIGURE 72: INNOVALIA-UC2 PLAN AND ROADMAP ESTIMATED IMPACT (OPTION 2)

The time-plan comments are the same as in previous Section 2.4.4.5.

The piece codes application availability at 5TONIC would be delayed one month, to the end of July 2020.

The testing of the INNOVALIA-UC2 would be achieved by M20.

The piece codes application and the virtualized M3Box would be ready to INNOVALIA by the end of April 2021 (M23), with a one-month delay over the original plan.

3. 5Growth Integration with ICT-17 platforms

This section departs from the preliminary study and analysis of the possible integration options, reported in the deliverable D3.1 [1], and it provides the progress on the analysis of the integration of 5Growth with the two ICT-17 platforms (i.e., 5G-EVE and 5G-VINNI), highlighting the selected integration schemes and the initial interaction workflows.

3.1. Pilot Deployment Scenario

As shown in Figure 73, an industrial vertical requests the deployment of its vertical services towards the service platform available in the vertical premises (NPN). This service platform decides on the decomposition of the vertical service, requesting the public network operators (as the role of the service and infrastructure providers) to partly or entirely deploy the vertical service End-to-End (E2E) by building a customized network slices tailored for the vertical service requirements. In the context of the project, 5Growth is the service platform available in the vertical premises, while 5G-EVE and 5G-VINNI are the service platforms available in the public networks. In this sense, the operators also need to take care of the connections to the vertical sites and how to connect them to their networks as well as to the ICT-17 platforms.

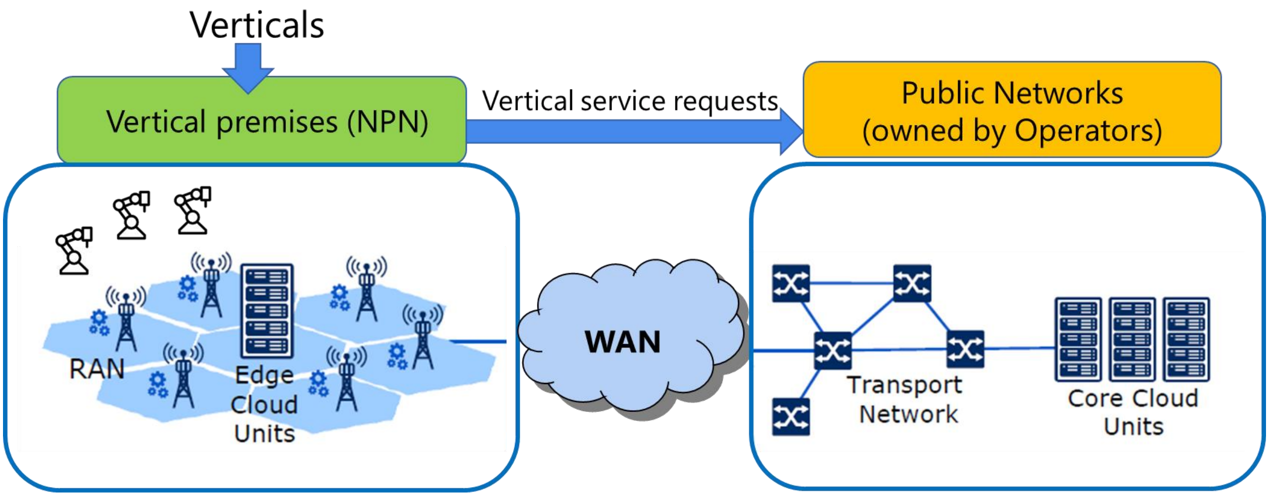


FIGURE 73: VERTICAL SERVICE REQUEST SCENARIO

Each vertical pilot can be classified into one possible 5G Non-Public Network (NPN) deployment scenario introduced by 5G-ACIA [10]:

- COMAU use cases will follow an NPN deployed as Isolated Network.
- Both EFACEC_E and EFACEC_S use cases will follow an NPN deployed in Public Network.
- INNOVALIA use cases will follow an NPN deployed with Shared RAN and Control Plane.

3.2. Approaches for Multi-domain in 5Growth

At a conceptual level, 5Growth considers multi-domain interactions at three different levels: (i) CSMF-to-CSMF; (ii) CSMF-to-NSMF; and (iii) SO-to-SO. These three multi-domain interactions aim to handle different types of services, namely communication services, network slices, and NFV network services, respectively. These interactions are depicted in Figure 74.

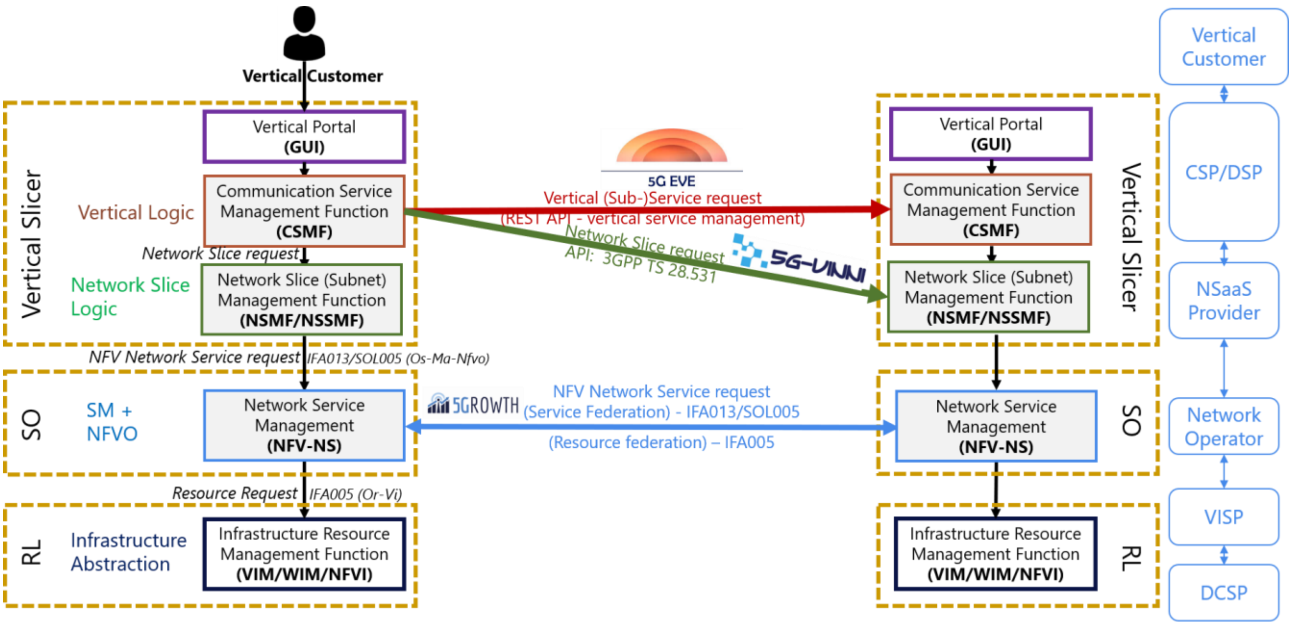


FIGURE 74: APPROACHES FOR MULTI-DOMAIN IN 5GROWTH

The first option, handled between Vertical Slicers (the building block embedding the CSMF functionality defined by 3GPP), considers the multi-domain at the CSMF level at the Vertical Slicer layer. In this interaction, the CSMF of the consumer domain is the only building block with an E2E view of the vertical service. As such, based on the vertical request, it decides on how to split the communication service into subservices and which subservices must be requested to the CSMF of the respective peer domains. Moreover, advertisement of vertical service blueprints comprising the communication service offerings of the peer domain as well as resource layer information for stitching the vertical sub-services are required to be handled at the CSMF.

The second option, handled between Vertical Slicers (the building block embedding the CSMF and NSMF functionalities defined by 3GPP), considers a single-domain CSMF interacting with one or more NSMFs at the Vertical Slicer layer. As in the previous interaction, the CSMF of the consumer domain is the only building block with an E2E view of the vertical service. As such, it decides which part of the E2E slice is deployed in the peer domains, by requesting its deployment to the NSMF of the peer domains.

The third option, handled between peering Service Orchestrators, considers the multi-domain at NFV network service level at the Service Orchestrator layer. This is already supported by 5Growth for federation between two peers supporting 5Growth service platform.

3.3. 5Growth Integration with 5G-EVE

The integration of 5Growth with 5G-EVE can be achieved following two different options, as depicted Figure 75 and Figure 76. In Option 1, the CSMF at 5Gr-VS interacts with the 5G-EVE Portal through a programmable REST API to request the deployment and instantiation of part of the vertical service towards a 5G-EVE platform site facility (i.e., vertical (sub-)service request). The deployment and instantiation of the remaining of the vertical service is requested by the 5Gr-VS to the 5Gr-SO. In Option 2, the CSMF at 5Gr-VS also interacts with the 5G-EVE Portal through the same REST API, requesting the deployment and instantiation of the whole vertical service by the 5G-EVE platform (i.e., vertical service request). In this option, the 5G-EVE platform (more specifically, at the 5G-EVE IWL level) instructs what network services are deployed and instantiated in the vertical premises' resources, by interacting with the 5Gr-SO in the vertical premises.

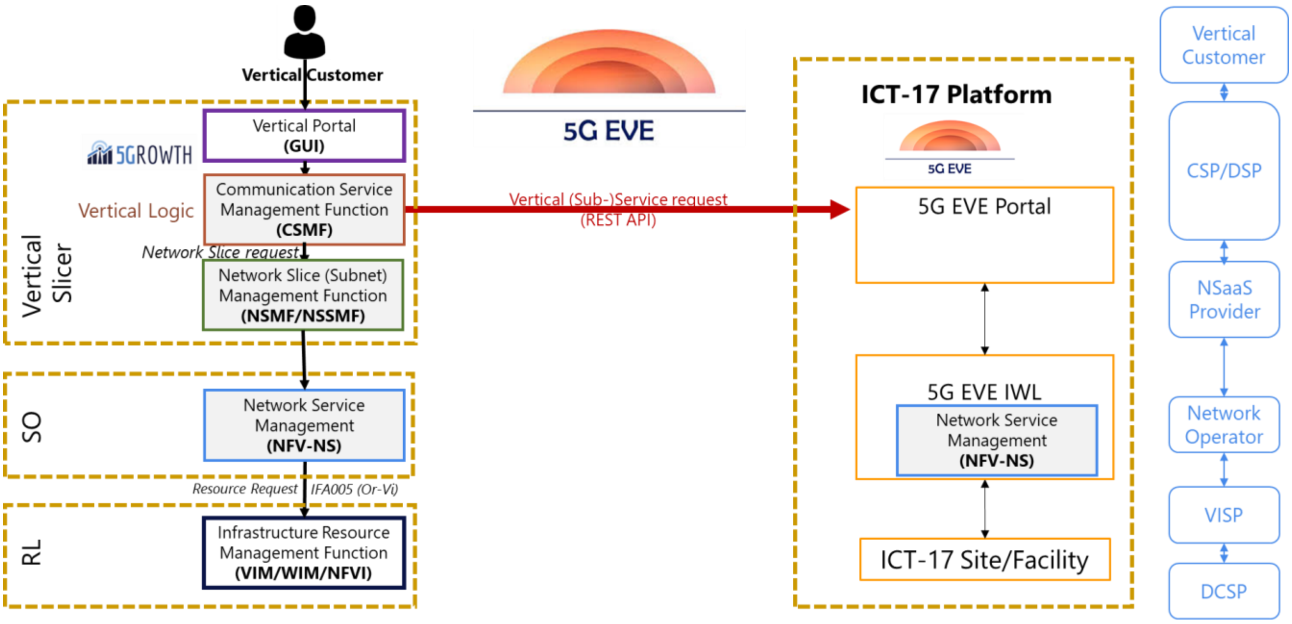


FIGURE 75: 5GROWTH INTEGRATION WITH 5G-EVE (OPTION 1)

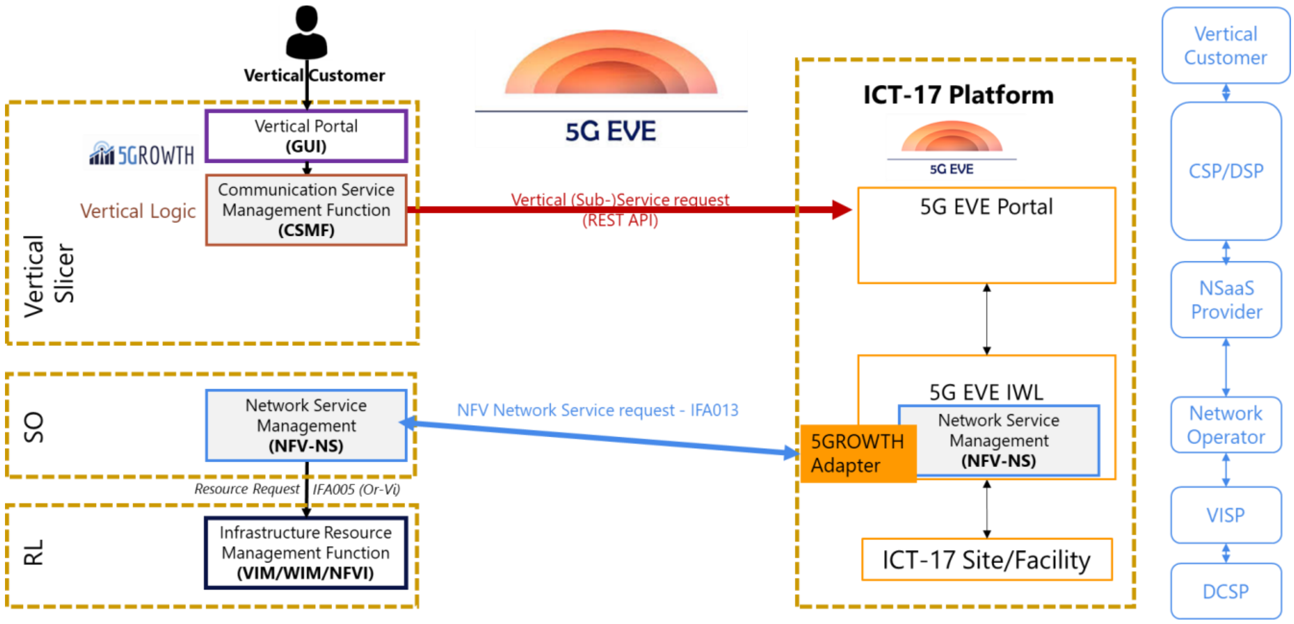


FIGURE 76: 5GROWTH INTEGRATION WITH 5G-EVE (OPTION 2)

The 5G-EVE Portal API enables a programmable interaction between 5Growth and 5G-EVE at the portal level. Such API is expected to be available in July 2020. The documentation of a preliminary, internal release of the 5G-EVE Portal API is available in 5G-EVE D4.2 [11] (in Section 1.2). The 5G-EVE Portal API will support experiment lifecycle management operations (e.g., instantiation, termination, polling status, etc.), whilst all the experiment design operations will be available only through the 5G-EVE Portal GUI. This means that a preliminary offline step will be needed through the 5G-EVE Portal GUI to create blueprints and descriptors for the experiments associated to the vertical (sub-)service in 5G-EVE platform. The interaction between the 5G-EVE IWL and the 5Growth Service Orchestrator will be mediated through a 5Growth Adapter, to be installed at the 5G-EVE IWL side, which will translate the unified messages and information models for the lifecycle management and descriptor catalogue of NFV-NS from the format adopted in 5G-EVE (based on ETSI NFV SOL 005 standard [12]) and the format adopted at the North Bound Interface of the 5Growth Service Orchestrator (based on ETSI NFV IFA standards). The support for this adapter on the 5G-EVE side will be available starting from July 2020. The documentation of a preliminary, internal release of the 5G-EVE adaptation layer and its interfaces is available in 5G-EVE D3.3 [13].

In addition, it is assumed that a pre-provisioning of connectivity between 5Growth and 5G-EVE sites is already in place through a secure VPN.

Option 1

In a first step (Figure 77), the vertical needs to manually decompose the vertical service identifying what is going to be deployed in the vertical premises (through the 5Growth service platform) and what is going to be deployed in 5G-EVE site facility. Afterwards, the vertical interacts manually with the GUI offered by the 5G-EVE Portal in order to create the vertical (sub-)service, including the onboard of the different blueprints, descriptors and VNFs as well as the scheduling of the experiment. When the experiment is created in 5G-EVE Portal, the vertical can request the deployment of the vertical service to the 5Growth service platform. Although this request contains the whole vertical service descriptor, it already identifies which (sub-)services are going to be deployed in 5G-EVE.

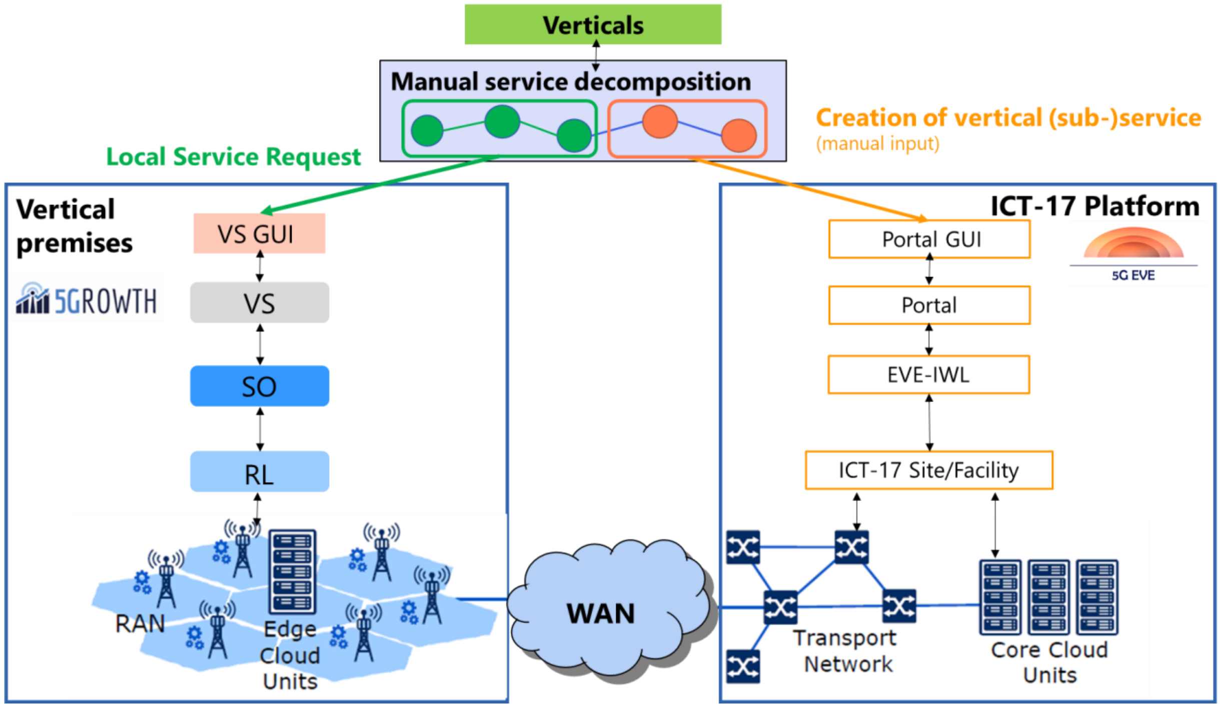


FIGURE 77: MANUAL DECOMPOSITION AND CREATION OF VERTICAL (SUB-)SERVICE

In a second step (Figure 78), 5Growth polls the status of the vertical (sub-)service deployed in the 5G-EVE site facility, triggering the instantiation of the whole vertical service, both in the vertical site and 5G-EVE site facility.

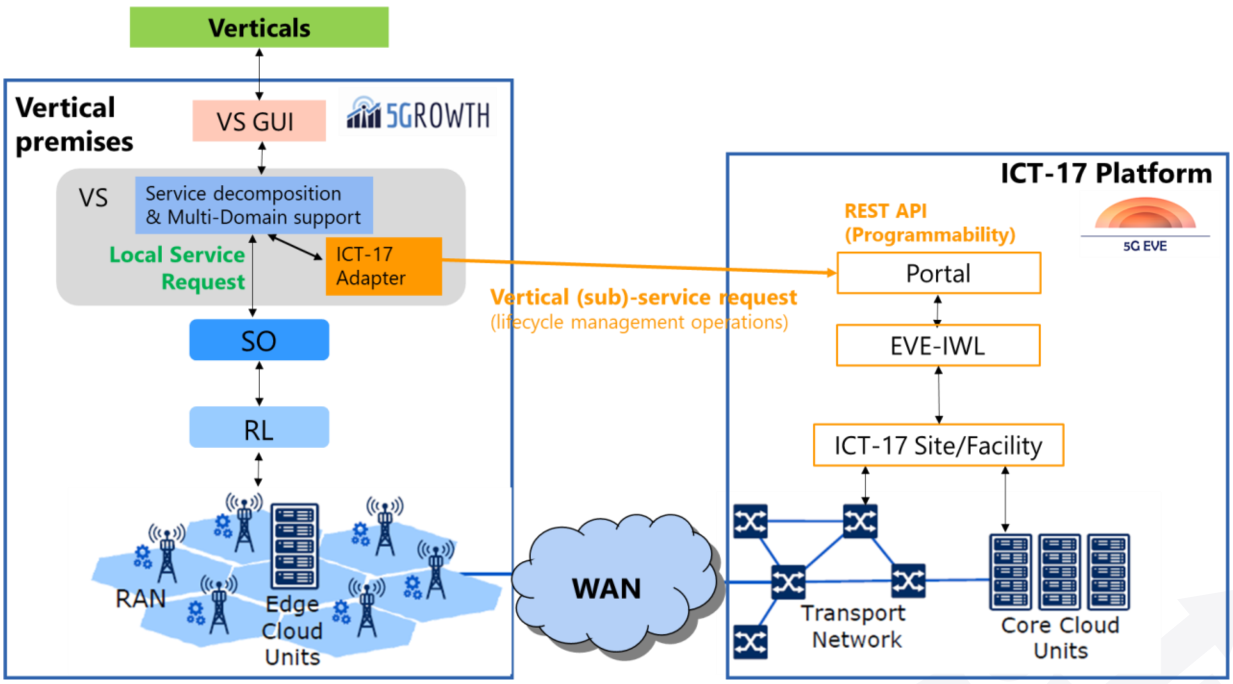


FIGURE 78: VERTICAL SERVICE LIFECYCLE MANAGEMENT

As a final note, 5Gr-VS has no view with respect to the resource available at 5G-EVE, delegating the deployment of vertical (sub-)services to 5G-EVE. These (sub-)services are completely under the control of 5G-EVE platform, but from 5Growth platform it will be possible to query these (sub-)services and to trigger lifecycle management operations.

In this integration option, the 5G-EVE and 5Growth platforms will directly manage the monitoring on their own domains, so limited to the part of the network service fully under their own control. This means, external logic will be needed to extract and aggregate per-domain monitoring metrics into end-to-end service monitoring information, based on the correlation of information provided by each platform.

Option 2

This integration option, considered as the default approach defined in 5G-EVE to interact with platforms from ICT-19 projects, relies on the interworking capabilities of the 5G-EVE platform for handling multi-site services and experiments. Following this concept, the coordination of the provisioning of the end-to-end service is entirely delegated from the 5Gr-VS to the 5G-EVE platform, which in turn will be responsible to interact with the orchestrators available at each site (i.e. the selected 5G-EVE site facility and the 5Growth target facilities) to deploy the associated sub-service.

As for option 1, the first step is to define the vertical service and its subcomponents and onboard the related blueprints on the 5G-EVE platform, using the 5G-EVE Portal GUI. The difference in this case is that the entire vertical service will be onboarded through the 5G-EVE portal, since both the sub-services are managed through the 5G-EVE platform, independently on the site where they need to be deployed. The vertical service onboarded on the 5Gr-VS and requested to 5G-EVE will thus be associated to two “nested” NSDs that constitute the end-to-end “composite” NSD corresponding to the whole vertical service. These three NSDs will be also onboarded by the 5G-EVE platform, so that the 5G-EVE IWL will orchestrate the composite NSD, through the deployment of the nested ones on each of the target site facility.

All the vertical service lifecycle management actions (i.e. instantiate and terminate) triggered at the 5Gr-VS will be translated and forwarded to the 5G-EVE Portal API. Within the 5G-EVE platform, the internal workflows will rely on a 5Growth Adapter (developed by 5Growth), as depicted in Figure 76, to deploy and manage the nested network service to be instantiated on the 5Growth vertical facilities. The adapter will use the interfaces exposed by the 5Gr-SO to trigger the 5Growth internal workflows for the network service lifecycle management.

In terms of monitoring, the 5G-EVE platform will be responsible of providing the collection and visualization functionalities for the monitoring data of the entire vertical service, provided that the VNFs developed by 5Growth support the required extensions to publish monitoring data into the 5G-EVE monitoring platform. 5G-EVE platform supports the visualization of monitoring data through the 5G-EVE portal GUI and provides internal functionalities for performance validation and evaluation based on KPIs. Further mechanisms to enable the integration of external monitoring data consumers for third party data analytics are not in the current scope of 5G-EVE.

3.3.1. Workflows

The 5G-EVE platform follows an Experiment-as-a-Service model which is exposed towards the verticals and experimenters through the 5G-EVE Portal. The Experiment-as-a-Service model enables to validate vertical services in different 5G environments and operational conditions through the execution of tailored experiments. The 5G-EVE Portal acts as the unified entry point to all the 5G-EVE platform functionalities supporting the Experiment-as-a-Service across the different phases: experiment design and definition, experiment preparation and experiment execution. In the following sections we explain the implications of the experiment phases in the 5Growth vertical service high-level workflows, in order to support interaction between 5G-EVE Portal and 5Gr-VS at the CSMF level.

3.3.1.1. Vertical service definition workflow

The first phase of a 5G-EVE experiment is the experiment design and definition, where the VNF providers and Verticals submit all the material required to run the experiment. This includes the VNF Packages needed, the NSDs and the following high-level descriptors envisioned by 5G-EVE for the experiment definition (described in [14]):

- **Vertical Service Blueprint (VSB):** 5G-EVE and 5Growth use a similar descriptor to describe the vertical service (inherited from 5G-TRANSFORMER). The most notorious difference is that 5G-EVE extended the VSB in order to include the application metrics that the vertical service is able to monitor. Such application metrics are collected by the 5G-EVE monitoring platform and used to calculate the experiment KPIs.
- **Context Blueprint (CB):** Following a similar approach to the VSB, 5G-EVE models the context of an experiment using a Context Blueprint. This high-level descriptor will be translated to a specific network service deployment containing the contextual VNFs (such as traffic generators, etc). It is important to highlight that the CB allows to specify application and infrastructure related metrics.
- **Test Case Blueprint (TCB):** TCBs allow to define scripts followed during the experiment execution.
- **Experiment Blueprint (ExpB) and Experiment Descriptor (ExpD):** The ExpB contains the final experiment definition using references to the three previous descriptors, and special parameters to further detail the infrastructure metrics which can be collected from the NFVI supporting the experiment. It also contains the definition of the KPIs which will be calculated during the experiment execution. The ExpD allows to customize the experiment using specific values for the experiment parameters, following the same approach used for the Vertical Service Descriptors (VSDs) from 5G-TRANSFORMER.

The API for CSMF interaction supported by 5G-EVE, as shown in Figure 77, enables a specific set of Vertical (sub)-services lifecycle management actions, which in this case are mapped to experiments lifecycle actions: schedule, deploy, execute and terminate. The experiment definition, on the other hand, must be performed manually via the 5G-EVE Portal GUI and is included in the 5Growth vertical service definition workflow as described in Figure 79.

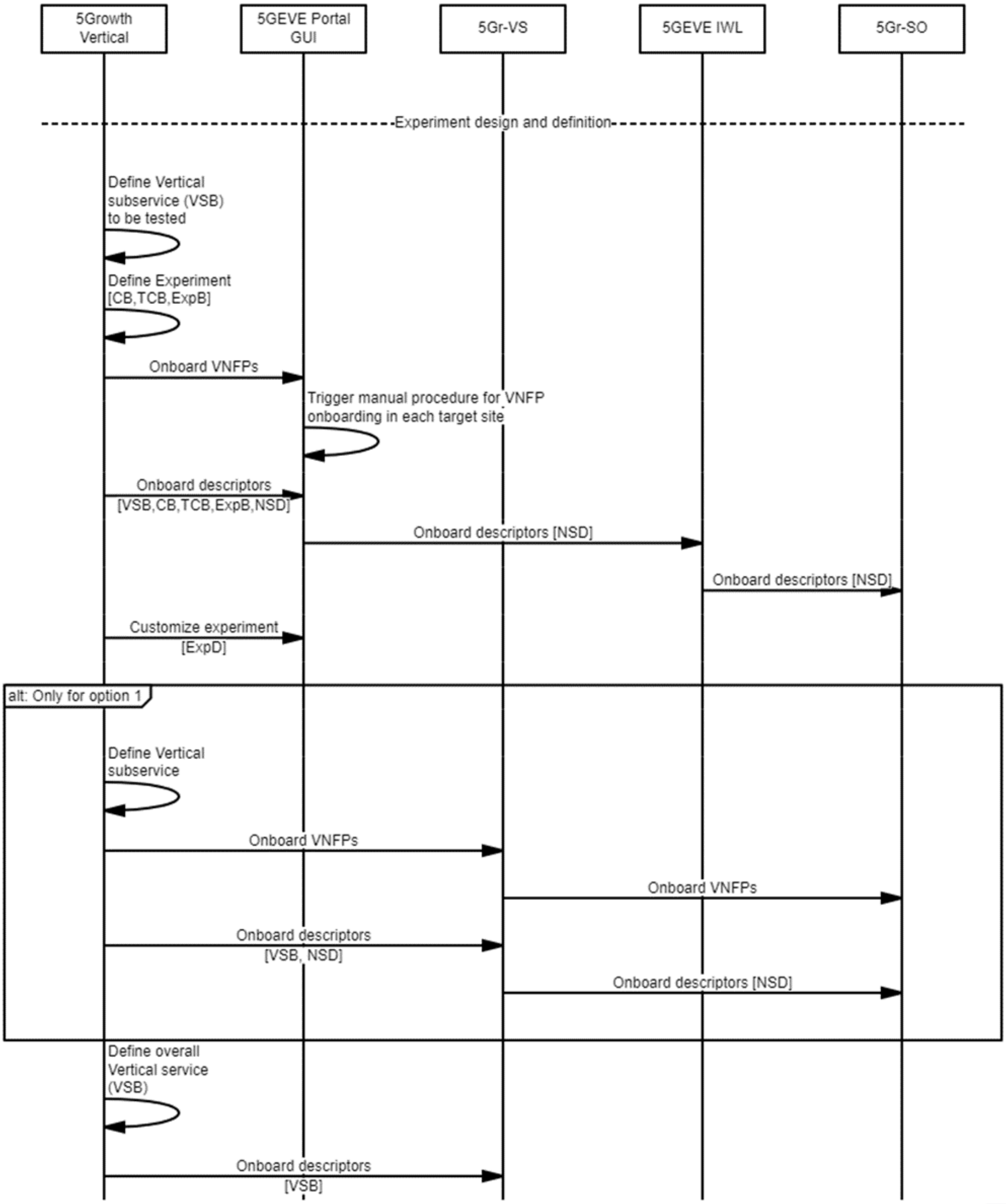


FIGURE 79: VERTICAL SERVICE DEFINITION HIGH-LEVEL WORKFLOW

As can be seen in the figure, both integration options include as a first step the 5G-EVE Experiment design and definition phase, where the 5Growth vertical defines and submits all the material required to run experiment that will be mapped as a vertical subservice, and a final step where the overall vertical service definition is onboarded on the 5Gr-VS. The integration option 1, includes an additional sub-workflow where the vertical can onboard the definition and the VNF packages of the subservice which will be completely under the control the 5Growth platform.

The on-boarding of VNF packages and NSDs triggered through the 5Gr-VS follows the 5Growth approach, where the 5Gr-VS interacts directly with the 5Gr-SO to on-board both the entities. On the other hand, the on-boarding performed through the 5G-EVE Portal GUI is coordinated by the 5G-EVE platform and follows different approaches for VNF packages and NSDs. In particular, 5G-EVE assumes that VNF packages must be manually on-boarded on each target site by the site administrator. This is motivated by the different policies and validation procedures that must be applied in the different administrative environments. These are not unified and usually require offline processes, e.g. to verify the licenses of the software included in the VM images and to assess the compatibility and the performance of the VMs in the facility infrastructure. The on-boarding of the VNF package will thus result in a ticket sent to the site administrator that will manually proceed with the on-boarding on each site. For the 5Growth segment, the 5Growth administrator will need to interact with the 5Gr-SO and with the related VIMs for what regards the VM images. On the other hand, the on-boarding of the NSD in the target site is fully automated and it is handled by the IWL that will interact with the 5Gr-SO through the 5Growth adapter.

3.3.1.2. Vertical service instantiation workflow

Once the Vertical Service definition workflow has been completed, a vertical can request the instantiation using the 5Gr-VS as shown in Figure 80. The internal functionality of the CSMF of the 5Gr-VS will determine, based on the VSB subservice decomposition, the number and the kind of subservices that must be instantiated. In option 1, the result of this decomposition will indicate that two VS subservices A and B will need to be instantiated, the former in the 5G-EVE platform and the latter in the 5Growth platform. In option 2, the decomposition result will indicate a single subservice A to be entirely deployed in the 5G-EVE platform. This means that, from the 5Gr-VS perspective, in option 2 the entire vertical service will be fully delegated to 5G-EVE, while in option 1 the 5Gr-VS will maintain the knowledge of the target platforms for the different parts of the service.

In both options, however, the management for the VS subservice A must be delegated to the 5G-EVE platform. This is done through an instantiation request send from the 5Gr-VS to the 5G-EVE platform, through its Portal APIs. The translation between the 5Growth information model and the 5G-EVE Portal API request will be done through a dedicated driver at the 5Gr-VS. This initial procedure is shown in Figure 80.

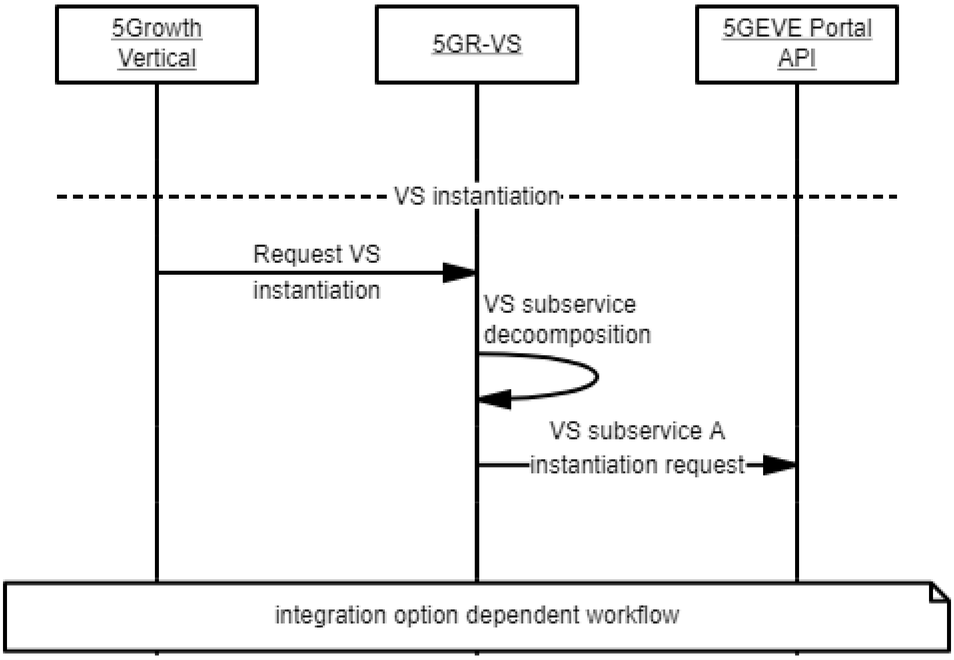


FIGURE 80: VERTICAL SERVICE COMMON INSTANTIATION WORKFLOW

The instantiation workflow described so far is common to the two 5G-EVE integration options considered. The rest of the workflow however is different depending on the integration option selected. In option 1, as shown in Figure 81, the Vertical subservice A will be fully managed and executed by the 5G-EVE platform and facilities, and will be therefore transparent to the 5Growth platform. However, as mentioned before, the result of the VS decomposition includes an additional subservice B that needs to be instantiated in the 5Growth platform. The 5Gr-VS, after having verified the successful instantiation of VS subservice A in the 5G-EVE platform (through queries on the subservice status), will start the instantiation of VS subservice B. This will follow the 5Gr-VS internal translation and arbitration procedures and will eventually proceed with the 5Gr-SO and 5Gr-RL instantiation workflows.

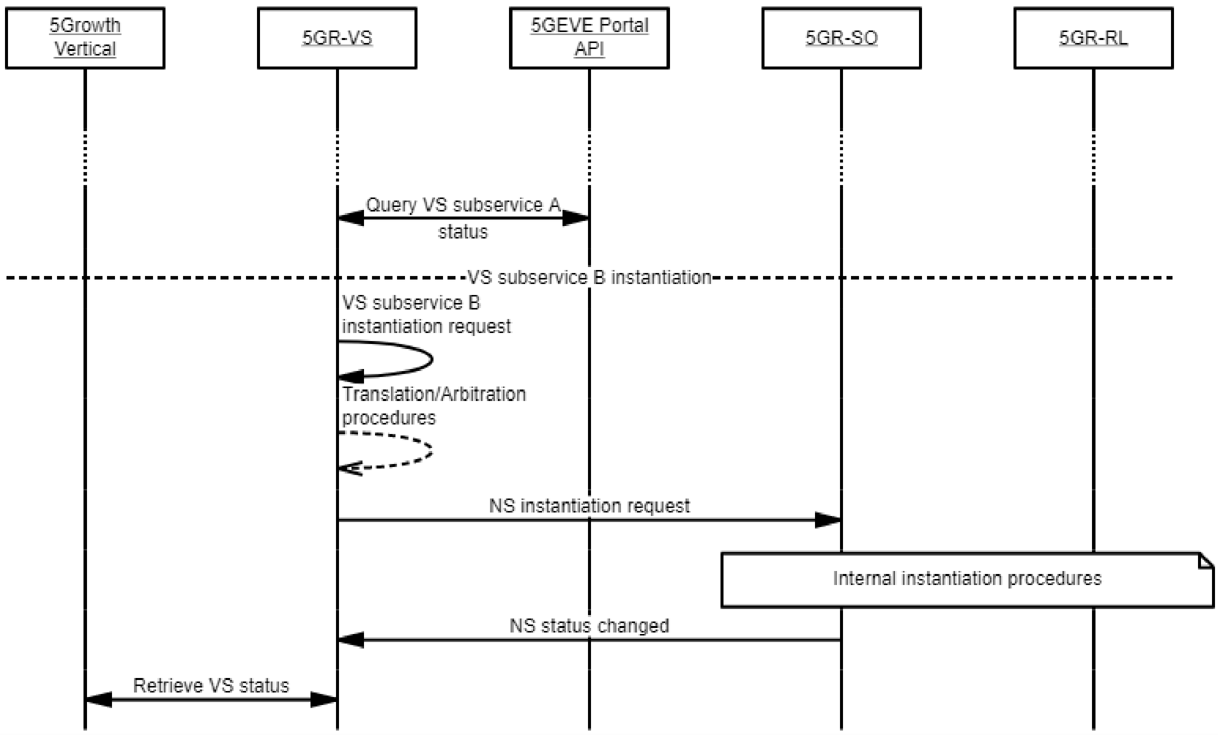


FIGURE 81: VERTICAL SUBSERVICE INSTANTIATION FOR OPTION 1

As shown in Figure 82, in option 2, the vertical service is fully delegated to the 5G-EVE platform where one 5Growth site has been configured as part of the 5G-EVE available NFVI to be used as part of the experiment. It is responsibility of the 5G-EVE platform to manage the instantiation of the vertical service, and therefore to use the 5Growth adapter to correctly instantiate the correspondent network service on the 5Growth facility, interacting with the 5Gr-SO.

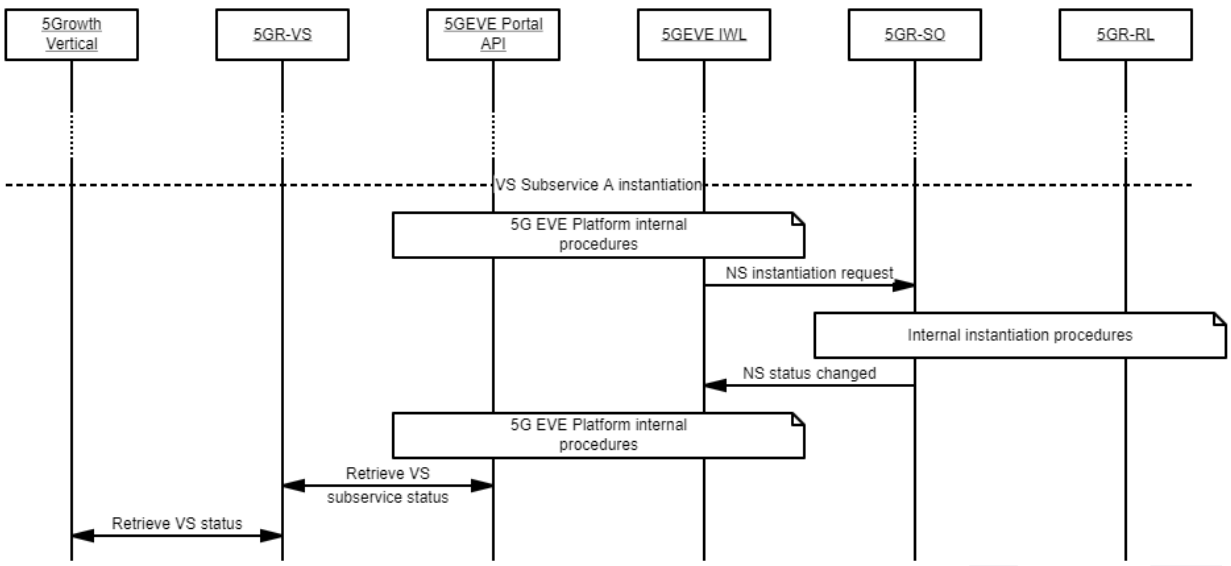


FIGURE 82: VERTICAL SUBSERVICE INSTANTIATION FOR OPTION 2

3.3.1.3. Vertical service termination workflow

The termination workflow follows essentially the same logic than the instantiation workflow described previously. There is a common workflow, as shown in Figure 83, where the Vertical requests the vertical service termination, and the 5Gr-VS uses the information regarding particular vertical service instance to determine the vertical subservices to be terminated. Particularly for the vertical subservice running on the 5G-EVE platform, the termination request is translated and forwarded to the 5G-EVE Portal API.

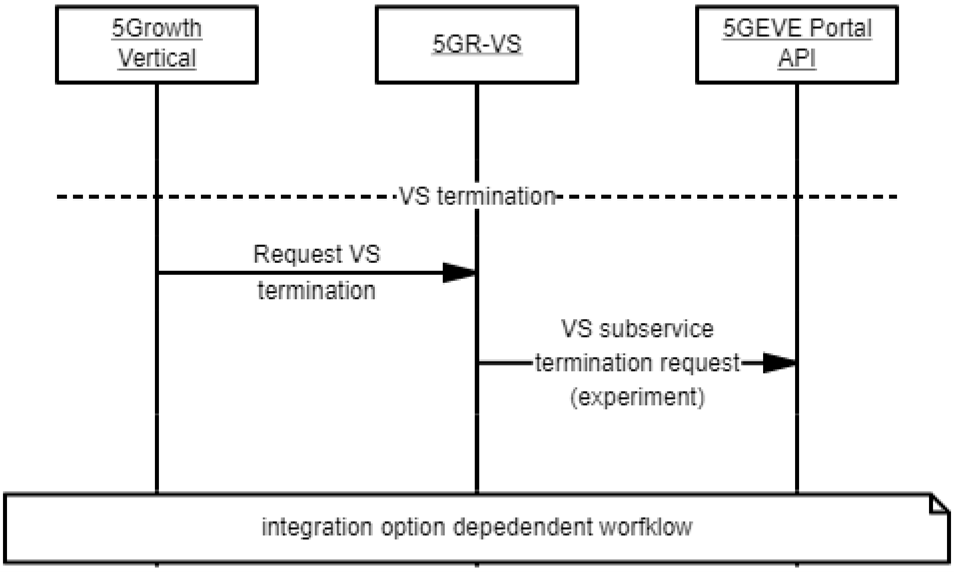


FIGURE 83: VERTICAL SERVICE COMMON TERMINATION WORKFLOW

In Figure 84 and Figure 85, we show how the termination workflow evolves depending on the integration option selected. Similar to the instantiation workflow, for option 1, the 5Gr-VS remains agnostic of the internal procedures in the 5G-EVE platform for the delegated vertical subservice A and determines the result of the termination action polling the status of subservice A with queries. After this, it starts the termination procedure for subservice B on the 5Growth side, following the usual VS termination workflow for the subservice B interacting with the 5Gr-SO. In option 2, the 5G-EVE platform will use the 5Growth adapter in order to forward the appropriate termination request to the 5Gr-SO.

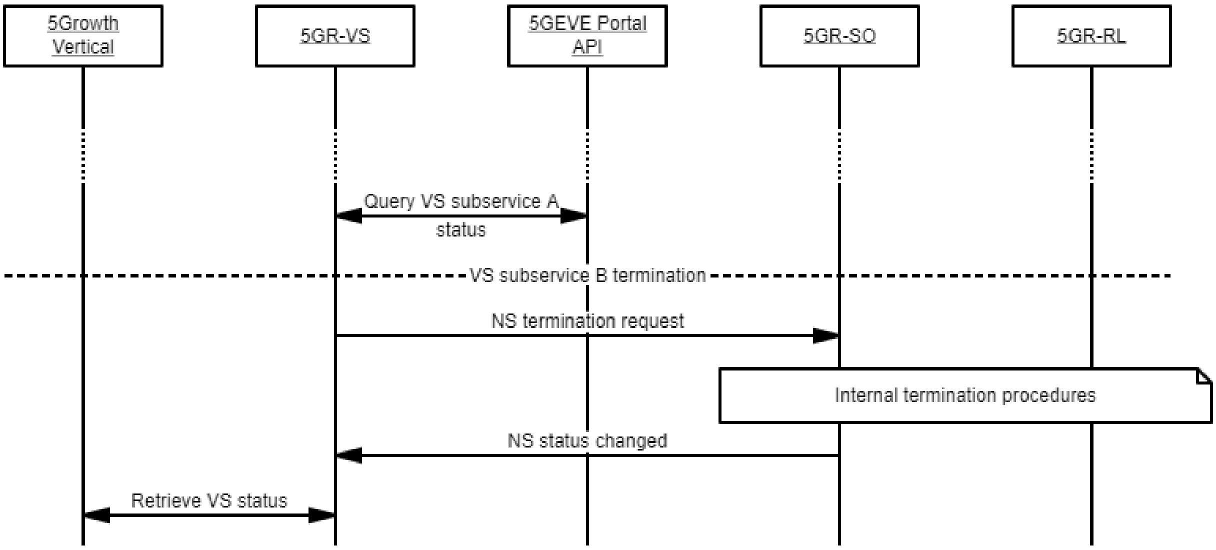


FIGURE 84: VERTICAL SUBSERVICE TERMINATION FOR OPTION 1

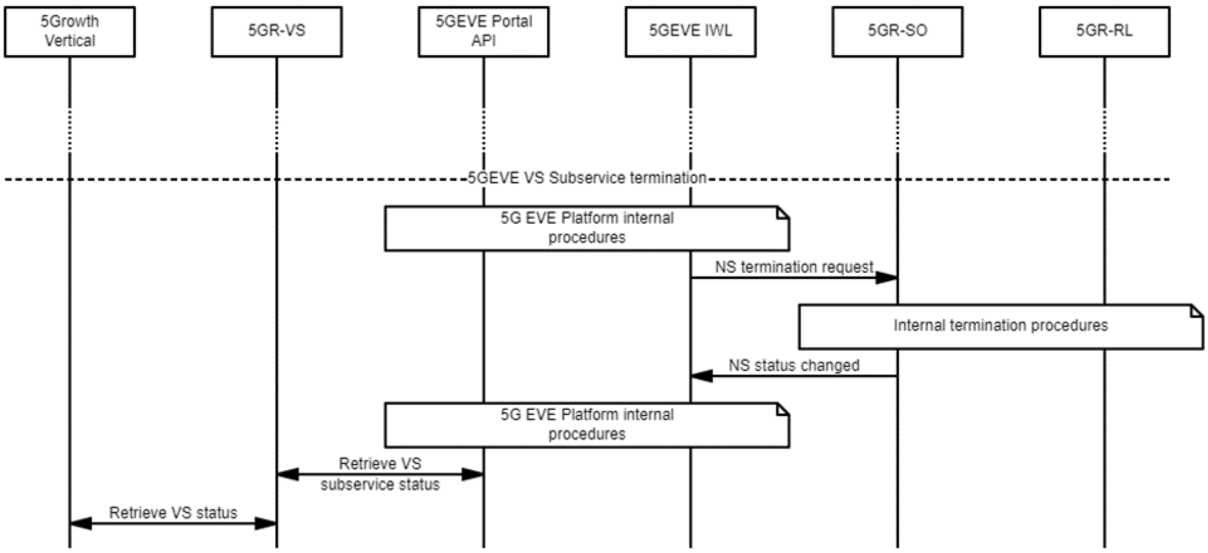


FIGURE 85: VERTICAL SUBSERVICE TERMINATION FOR OPTION 2

3.4. 5Growth Integration with 5G-VINNI

For integration of 5Growth with 5G-VINNI, the CSMF at 5Gr-VS interacts with the NSMF at 5G-VINNI. In particular, the integration between 5Growth and 5G-VINNI will be done with the SONATA platform [5], a result of the 5GTANGO project, that is available at the 5G-VINNI Aveiro site. This integration will comprise the adaptation of the 5Gr-VS requests to the SONATA Slice Manager, which has been designed and implemented prior to the 3GPP technical specification 28.531 [8].

The integration between 5Gr-VS and 5G-VINNI's NFVO will follow the lines shown in Figure 86.

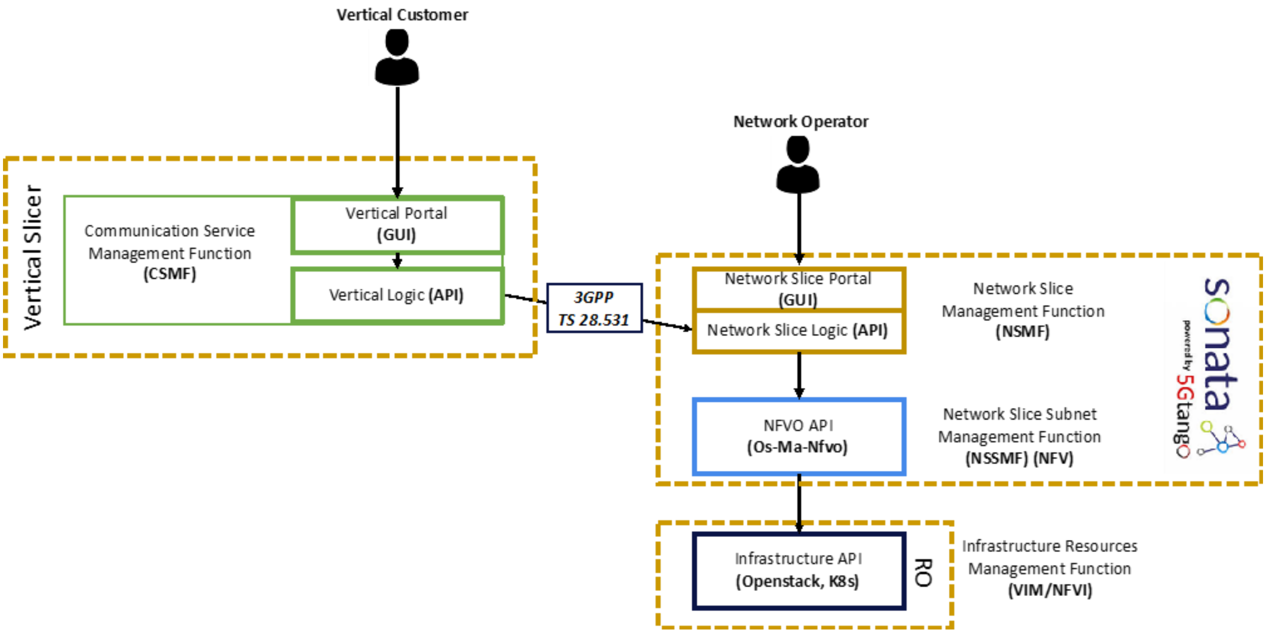


FIGURE 86: INTEGRATING THE 5GROWTH VERTICAL SLICER WITH THE 5G-VINNI NFVO, SONATA

ITAV will leverage a refactor of the VS into two network slice related management components, namely the CSMF and the NSMF and the following the recommendations of TS 28.801, and using a MANO-based provisioning approach standardised by the 3GPP in its technical specification 28.531 [8], to convey 5GROWTH structures towards SONATA.

3.4.1. Workflows

This sub-section describes the workflows that will be implemented in the integration between 5Growth and 5G-VINNI.

3.4.1.1. High-level workflow

As a pre-condition to the slice creation/instantiation steps, Figure 87 shows a generic workflow to create and on-board of Network Services Descriptors (NSDs) and Virtual Network Functions Descriptors (VNFDs). SONATA v5.1 supports both functions implemented either with VMs and/or with (docker) containers. When the required NSDs/VNFDs are available in the SONATA NFVO catalogue, the CSMF can then build a slice with them.

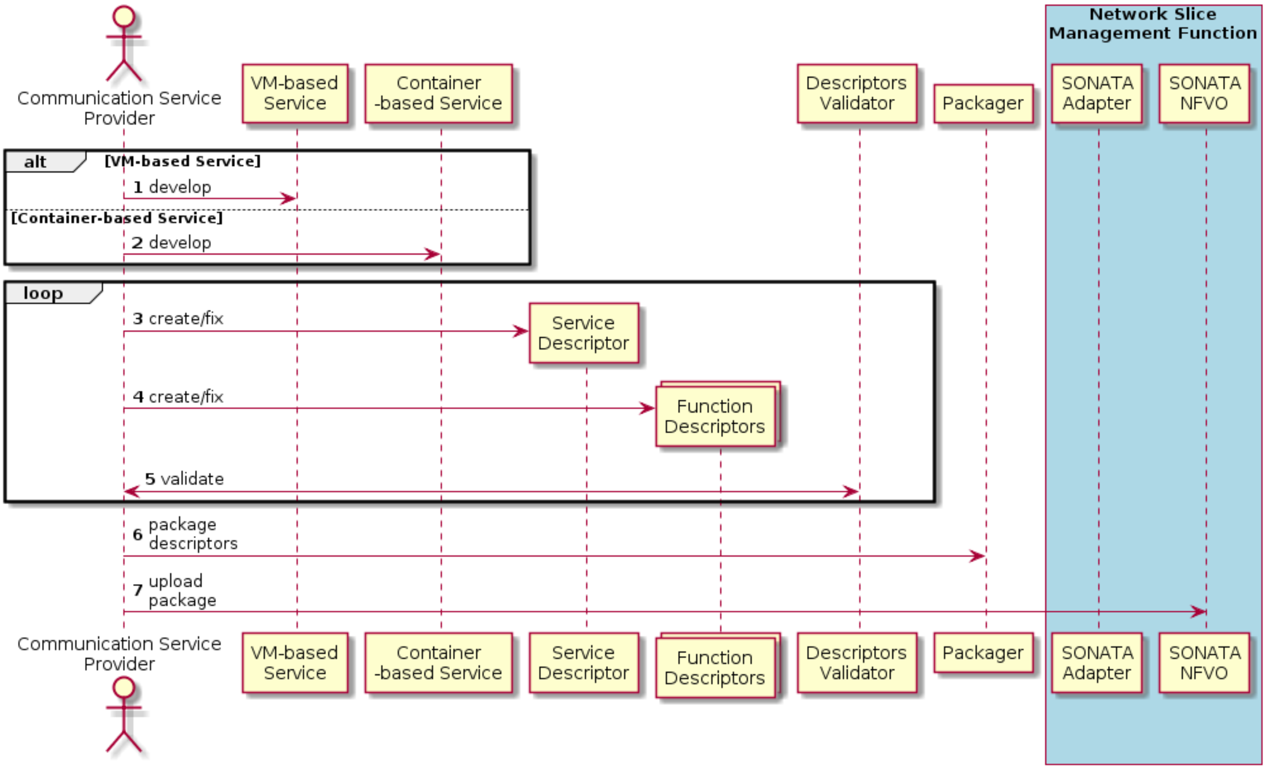


FIGURE 87: SONATA CATALOGUE POPULATION WITH THE SERVICES AND FUNCTIONS

Having the needed NSs available at the SONATA NFVO catalogue, the Communication Service Management Function (CSMF) can create the slice and instantiate it, as shown in the flow in Figure 88.

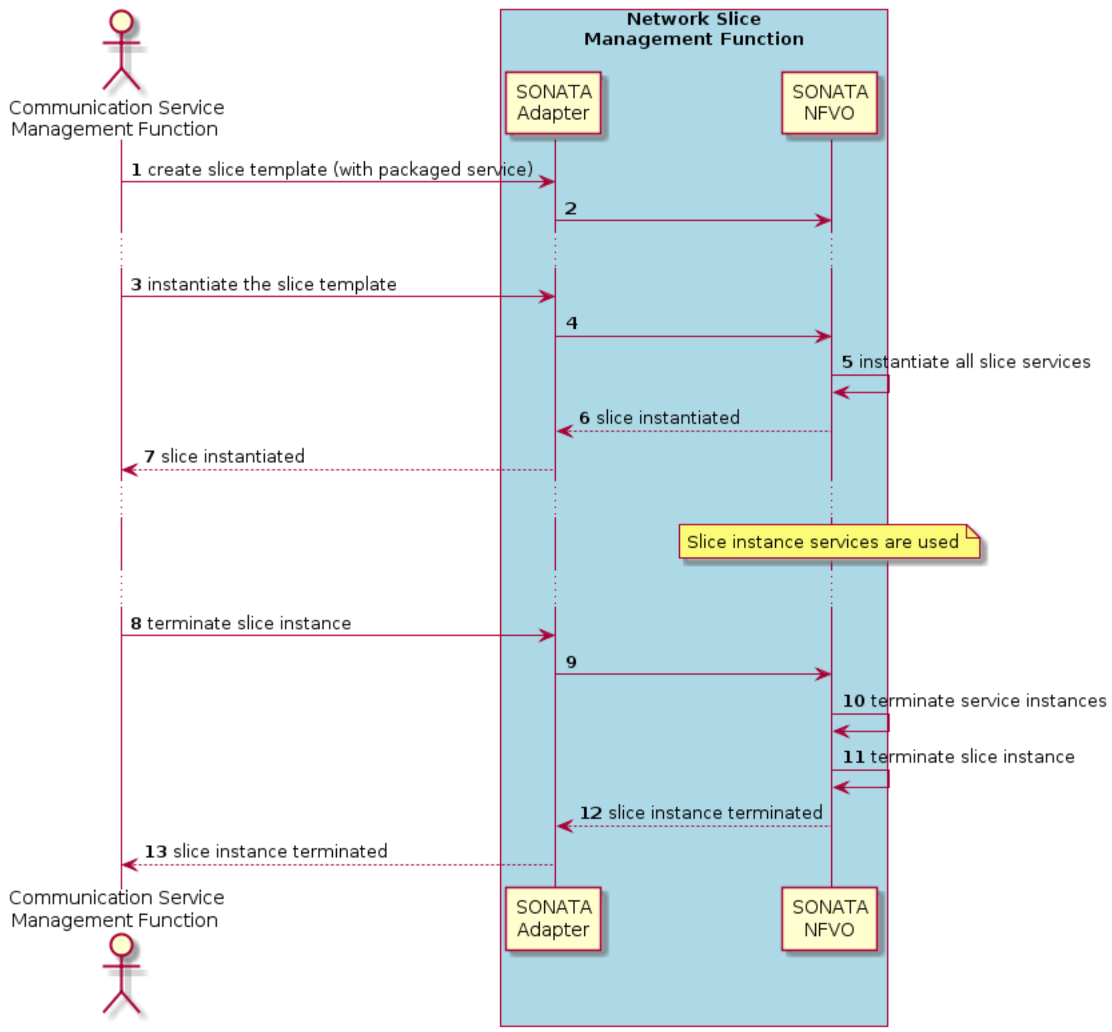


FIGURE 88: HIGH-LEVEL WORKFLOWS USED IN INTEGRATING 5G-VINNI

In this picture, the actor playing the CSMF creates the slice template (step 1) with services that are available in the SONATA NFVO catalogue, including a description of how the NFVO will and interconnects them.

Both of these generic workflows are described and analysed as follows:

- **Service creation:** In Figure 87 we can see a first set of two steps (steps 1 and 2) which describe the implementation of the network service itself by a generic Communications Service Provider actor. Please note that these VNF implementations might have to change, e.g., when we deploy and test and we find a bug that needs to be fixed, or we need improvements to increase performance.
- **Service description:** Then we represent a loop (steps 3 to 5) in which descriptors of the service and its functions are written and validated, using the Service Programmability Development Kit (SDK) tools. After this step,
- **Service on-boarding:** In SONATA every service descriptor must be on-boarded after being packaged along with the descriptors of the VNFs, by using another tool of the SDK, the

packager. This is step 6. After having a valid package, it has to be on-boarded the SONATA NFVO platform, done in step 7.

- **Slice creation:** When the service(s) we want to be part of the slice we want to create are all on-boarded, the CSMF can create the slice template, with the interconnected services. This is represented in step 1 of Figure 88. Please note that these slice creation requests might have to go through a SONATA Adapter (step 2).
- **Slice instantiation:** Once created, the CSMF may request the slice instantiation with the necessary parameters (step 3), a request that again must go through the SONATA Adapter (step 4). When all NSs that are part of the slice are instantiated and interconnected (step 5), the result is communicated to the CSMF (steps 6 and 7), which can then make the slice instance available for usage. Not represented in the above picture is the possibility of several slice instances being able to share the same NS instance.
- **Slice termination:** When the slice instance is not needed anymore, the CSMF can request its termination (step 8), again through the SONATA Adapter (step 9). All NS instances that are part of the slice are terminated (step 10, except for the NS instances that are shared between multiple slice instances, of course), as well as the slice instance itself (step 11). The result is communicated back to the CSMF (steps 12 and 13).

4. Conclusions

This deliverable provides the specification of selected 5G-enabled applications that are going to be target of extensive experimentation, trialing and validation within the 5Growth project. These 5G-enabled applications, to be demonstrated through 9 use cases across 4 pilots (comprising I4.0, transportation and energy industry sectors), aim at being deployed in a TRL6/TRL7-comparable environment as close as possible to a real 5G commercial environment. As such, COMAU and INNOVALIA factory premises are going to be the target for the deployment of the I4.0 use cases, while University of Aveiro and Aveiro harbour are going to be the target for the deployment of the energy and transportation use cases, respectively.

An in-depth and mature definition of the technical solution of each vertical pilot and corresponding use cases is provided. This includes the details regarding the deployment of the 5G infrastructure in the vertical premises as well as the progress related with the use case modelling, identification of the hardware and software components and the set of experiments for initial validation of different components of the use case. In addition, this deliverable provides the plans and roadmaps for the deployment, experimentation and validation of each vertical pilot use case, along with an analysis of the impact of COVID-19 on its execution.

As 5Growth aims at leveraging the use of the 5G-EVE and 5G-VINNI platforms for the trialing and validation of the selected vertical pilot use cases, in this deliverable are analyzed and detailed the selected integration options of 5Growth with the ICT-17 platforms. To complement this analysis, initial interaction workflows were presented.

The findings and plans presented in this deliverable are provided as key inputs for paving the way to future developments regarding the execution of the vertical pilots use cases in the premises of the vertical partners while leveraging the integration and the resources available in the ICT-17 platforms.

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