H2020 5Growth Project
Grant No. 856709

D4.1: Service and Core KPI Specification

Abstract

The main objective of this deliverable is to provide a formal definition of the KPIs identified by the 5Growth project, with the purpose of evaluating the four different vertical pilots of the project on Industry 4.0, Transportation, and Energy. To achieve so, this work defines the Core 5G KPIs as the technical KPIs that can be directly measured on the use cases' infrastructure. On the other hand, Service KPIs are defined as the KPIs that allow validating an industrial 5G scenario from the vertical point of view. In most cases, Service KPIs are not directly measurable, and this is the reason why this deliverable also defines a formal mapping between Core 5G KPIs and Service KPIs. Furthermore, Core 5G KPIs, Service KPIs and their correspondent mapping are applied to the different 5Growth use cases to define the parameters that need to be evaluated in order to ensure they fulfill the expected requirements. Finally, the impact of COVID-19 on the planned KPI evaluation is analysed.

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List of Acronyms

AGV – Automated Guided Vehicle

API – Application Programming Interface

AR – Augmented Reality

CKPI – Core 5G KPI

CMM – Coordinate-Measuring Machine

CP – Control Plane

CPE – Customer Premises Equipment

CUPS – Control and User Plane Separation

DSS – Decision Support System

E2E – End-to-End

eMBB – enhanced Mobile Broadband

FR – Functional Requirements

I4.0 – Industry 4.0

IIoT – Industrial Internet of Things

KPI – Key Performance Indicator

LV – Low-Voltage

LX – Level Crossing

mMTC – massive Machine Type Communications

MTTR – Mean Time To Repair

NS – Network Service

RAN – Radio Access Network

SKPI – Service KPI

SLA – Service Level Agreement

SO – Service Orchestrator

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

UC – Use Case

UE – User Equipment

UP – User Plane

URLLC – Ultra-Reliable Low Latency Communication vEPC – virtual Evolved Packet Core

VIM – Virtualized Infrastructure Management

VM – Virtual Machine

VNF – Virtual Network Function

VPN – Virtual Private Network

VS – Vertical Slicer

ZDM – Zero Defect Manufacturing

Executive Summary and Key Contributions

The main objective of this deliverable is to provide a formal definition of the KPIs identified by the 5Growth project, with the purpose of evaluating the four different vertical pilots of the project on Industry 4.0, Transportation, and Energy.

The KPIs defined are divided into two categories: Core 5G KPIs and Service KPIs. The former KPIs are defined as the technical KPIs that can be directly measured on the use cases' infrastructure and network. On the other hand, the latter KPIs are defined as the key performance indicators that allow validating a business and industrial scenario from the vertical point of view.

The Service KPIs are identified taking into consideration the business and functional requirements of the verticals gathered in D1.1 [1], with the objective of validating the correct operation of the 5G use cases deployed using the 5Growth platform. However, due to their high-level definition, they are not directly measurable over the use cases infrastructure. This is the reason why this work achieves to define a mapping between Core 5G KPIs and Service KPIs, in such a way that by measuring specific combinations of Core 5G KPIs, certain Service KPIs can be correlated.

Finally, the Service KPIs identified, along with their corresponding mapping to Core 5G KPIs, are applied to each of the pilot use cases, with the goal of defining the KPIs that need to be fulfilled in order to demonstrate that the performance delivered by the implementation of the different use cases satisfy the expected requirements defined in D1.1 [1].

In summary, the main contributions of this deliverable can be listed as:

- Identification of 11 Core 5G KPIs, based on existing 5GPPP KPIs and KPIs defined by the TMV-WG, 5G-EVE and 5G-VINNI.
- Definition of 11 general 5Growth Service KPIs.
- Mapping between Core 5G KPIs and Service KPIs.
- Application of the Service KPIs and their mapping with Core 5G KPIs to the 5Growth pilots, obtaining:
    - 12 specific Service KPIs applied to the INNOVALIA Pilot on Industry 4.0.
    - 6 specific Service KPIs applied to the COMAU Pilot on Industry 4.0.
    - 5 specific Service KPIs applied to the EFACEC_S Pilot on Transportation.
    - 9 specific Service KPIs applied to the EFACEC_E Pilot on Energy.
- Mapping between the identified Service KPIs and the vertical functional requirements listed in D1.1 [1] for each use case.

The KPIs identified above will be used as one of the fundamental inputs for task T4.2, mainly focused on the methodology and tools for assessing these Service and Core 5G KPIs. Furthermore, they will be used in the pilot validation trials of T4.3, T4.4, T4.5 and T4.6.

Regarding KPI assessment and evaluation, this work provides a roadmap that indicates when the different KPIs defined will be measured. More specifically, it identifies for each vertical pilot which KPIs will be reported first in *D4.2 First validation and verification report in ICT-17 premises* (milestone

11, month 18 of the project) and which ones will be assessed in *D4.4 Validation results in the light of 5Growth layer* (milestone 18, month 27 of the project), taking into account the delays caused by the COVID-19 impact.

1. Introduction

This document is the result of the work developed under task T4.1 to identify Service KPIs and the related Core 5G KPIs, with the purpose of evaluating the different vertical pilots of the 5Growth project on Industry 4.0, Transportation, and Energy. In this work, **Service KPIs** are defined as the qualitative indicators that allow validating a business and industrial scenario from the vertical point of view. On the other hand, **Core 5G KPIs** are defined as the technical KPIs that can be directly measured on the use cases' infrastructure and network. In most cases, Service KPIs are not directly measurable, and this is the reason why this deliverable also defines a **mapping** between Core 5G KPIs and Service KPIs. In this way, combining different Core 5G KPIs (completely transparent for the verticals), specific Service KPIs can be obtained, which allow verticals to determine whether the use cases deployed using the 5G technology and the 5Growth platform fulfill the expected performance and functional requirements.

One of the goals of 5Growth is to provide an automated and sharable 5G End-to-End solution that will allow the vertical industries to achieve their respective key performance targets. For this reason, it must be ensured, by leveraging the KPIs identified, that the 5G platform used by the verticals is compliant with the vertical requirements and their expectations. Evaluating the performance of these pilot validation trials will allow verifying whether the vertical applications can be considered 5G-ready or not.

In order to identify and define Service KPIs that adjust as much as possible to the vertical expectations, this work relies on the business, functional and technical requirements identified in WP1 and gathered in D1.1[1]. Therefore, the evaluation of the Service KPIs here identified will directly validate whether the vertical requirements are satisfied.

In relation to other tasks of the project, the KPI definition provided in this document will be used as one of the fundamental inputs for task T4.2, mainly focused on the methodology and tools for assessing these Service and Core 5G KPIs. Furthermore, the lists of selected KPIs per use case, along with the methodology and tools defined in T4.2 to measure these KPIs, will be used in the pilot validation trials of T4.3, T4.4, T4.5 and T4.6, whose objective is to validate the correct operation of the different use cases defined under the 5Growth scope.

Going a step further and not only restricted to the 5Growth project scope, the 5Growth Service KPIs have been defined in a general manner, with the purpose of being applicable to other business and industrial 5G scenarios, which may be evaluated and validated leveraging the Service KPIs defined under this work. In a similar manner, the 5Growth Service KPIs may be extrapolated to define realistic Service SLA parameters that are more suitable to the vertical perspective.

The document is structured as follows.

Section 2 provides a list of identified Core 5G KPIs. As mentioned, these KPIs are technical KPIs that are directly measurable in the use cases' infrastructure and network. They are based on existing 5GPPP KPIs, the KPIs defined by the 5G-PPP Test, Measurement and KPI Validation Working Group (TMV-WG) and the KPIs that can be evaluated by the ICT-17 platforms 5G-EVE and 5G-VINNI.

Section 3 provides the definition of a set of general 5Growth Service KPIs, which are the KPIs that evaluate 5G business scenarios from the verticals point of view. These KPIs can be extrapolated to different 5G industrial scenarios and leveraged to define vertical SLAs.

Section 4 describes how the evaluation of Service KPIs can be performed by measuring a specific combination of Core 5G KPIs, providing the mapping between the Core 5G KPIs defined in Section 2 and the general 5Growth Service KPIs identified in Section 3.

Section 5 contains the sets of specific Service KPIs selected to evaluate each of the use cases of the different 5Growth pilots. That is, the general Service KPIs defined in Section 3 are applied to each of the use cases, explaining how they validate their correct operation and guaranteed performance. Furthermore, the mapping between the selected Service KPIs and the correspondent Core 5G KPIs is described, as well as where to measure each of the Core 5G KPIs within the use case architecture. Additionally, in order to demonstrate that the Service KPIs evaluate accurately the vertical functional requirements collected in D1.1 [1], a table containing the mapping between Service KPIs and vertical functional requirements is provided for each of the use cases.

Finally, an analysis of the impact of the COVID-19 on the planned roadmaps for the KPI assessment is provided in Appendix A – COVID-19 Impact Analysis on Plans and RoadmapsMore in detail, this analysis identifies for each vertical pilot the KPIs that will be included in the first KPI assessment report of the project (*D4.2 First validation and verification report in ICT-17 premises*, milestone 11, month 18) and those that will be included in the second (*D4.4 Validation results in the light of 5Growth layer,* milestone 18, month 27), taking into consideration the availability of the ICT-17 and 5Growth platforms.

2. Core 5G KPIs specification

The 5G-PPP Test, Measurement and KPI Validation Working Group (TMV-WG) defined in the White paper [2] presented at EuCNC 2019 some initial KPIs. This work is the outcome of the collaboration of many 5G-PPP Phase 1 and Phase 2 projects within the TMV-WG. Details of the specified KPIs are reported in Appendix B – Technical KPIs defined by 5G-PPP TMV-WG, 5G-EVE.

Moreover, the two ICT-17 projects whose infrastructures will be exploited by 5Growth, namely 5G-EVE and 5G-VINNI, identified KPIs to be collected in their experimental platforms. The KPIs considered by 5G-EVE and 5G-VINNI are reported for easy consultation in Appendix A.

Based on the aforementioned KPIs, 5Growth identified a set of Core 5G KPIs. Core 5G KPIs are performance parameters related to the network and system components of the communications infrastructure that constitutes the industrial pilots. The core KPIs are the KPIs that contribute to the service KPIs and that are mainly measured at the network level.

TABLE 1: CORE 5G KPI SPECIFICATION

CKPI Id	CKPI Name	CKPI Description	Units
CKPI-1	End-to-end Latency	Aggregation of one-way time delays measured between specific components of the logical architecture of the use case.	ms
CKPI-2	Packet Loss	The number of packets that fail to reach their destination, measured in specific interfaces of the use case logical architecture.	%
CKPI-3	Guaranteed Data Rate	The data rate is the number of bits per unit of time sent over a specific interface of the use case logical architecture. The guaranteed data rate is the minimum expected data ratefor the overall use case to function correctly.	Mbits/s
CKPI-4	Coverage	Radio access coverage area on the pilot premises.	m^2
CKPI-5	Availability	Percentage of time during which a specific component of the use case (application, server, network function, etc.) is responding to the requests received with the expected QoS requirements. That is, it is the ratio between the up-time of a specific component over the total time the component has been deployed.	%
CKPI-6	Slice Creation/adaption Time	Time elapsed since the creation/reconfiguration of a slice is triggered until the slice is fully operational.	ms
CKPI-7	Connection Density	The number of users/devices that can be connected simultaneously to the use case network infrastructure without degrading the performance of the users/devices that are already connected.	$1/m^2$

CKPI-8	Data Volume	The total quantity of information transferred over a given interface during specific use case operations, measured in bits.	Gbits
CKPI-9	Jitter	Variation of the end-to-end latency forthe communications between specific components of the use case. This core KPI is useful to correlate QoE KPIs for the different video visualizations performed in the use cases.	ms
CKPI-10	Received Radio Signal Quality	The quality of the received signal, as an abstract value compounding multiple low-level signal properties (e.g., power, SNR, synchronization).	%
CKPI-11	Buffer occupancy	The amount of user-data pending transmission (i.e., submitted by applications and waiting in transmission buffers).	bytes

Finally, within 5G-PPP TMV-WG, Phase II and Phase III projects are currently working together towards a common approach of mapping 5G core/network KPIs to vertical/service KPIs.

3. 5Growth Service KPIs identification

To build an infrastructure capable of meeting 5G requirements, it is necessary to describe a set of service KPIs (SPKIs) that gather the services' needs. Upon such a description, 5Growth can measure whether a 5G service deployment is satisfying the expected behavior or not. In this section, we provide a list of SKPIs that do not only describe the KPIs of those services tackled in 5Growth, but the KPIs encountered by any service using the 5G technology. Table 2 gives a detailed description of those SKPIs identified by 5Growth.

TABLE 2: 5GROWTH SERVICE KPI IDENTIFICATION AND DEFINITION

SKPI Id	SKPI Name	SKPI Description
5GR-SKPI-1	Service Setup Time	Time elapsed since the vertical requests a specific service until the service is completely operational. This time comprises the provisioning and configuration of the resources needed for the use case.
5GR-SKPI-2	Synchronization between Communication Components	Synchronization between components evaluates the ordered and timely execution of operations requested among components. Out-of-order operation requests must be near zero in real-time communications among the involved components.
5GR-SKPI-3	Device Mobility	Capacity of the mobile devices of a given use case to move within the area of applicability of the service without degrading its performance, independently of the devices speed.
5GR-SKPI-4	High-resolution Real-time Video Quality	Specific use cases are supported by a real-time video streaming service whose high quality resolution is critical for the correct operation of the vertical service. This SKPI evaluates the QoE of the users consuming the video feed that supports a given use case. E.g., in a I4.0 context, the high-resolution video service is needed to perform accurate measurements of industrial pieces remotely and in real-time.
5GR-SKPI-5	Radius of Operation	Geographical area of the service applicability. That is, this SKPI determines wether the service implementation is able to deliver a correct operation within a city, a country, a continent or worldwide. All the requirements of a specific use case are fulfilled for any device connecting in the area of applicability specified by the deployed service.
5GR-SKPI-6	Integrated Multitype Communications	Integration of multiple types of communication and protocols (e.g., video, voice, control, etc.) with different performance requirements. This SKPI evaluates that their interoperability does not degrade the overall

		service performance and meets the same requirements as met when operating independently.
5GR-SKPI-7	Extensive Network Coverage in Vertical Premises	Capability of the elements and actors of a use case located at different places of the vertical premises to access the 5G network from anywhere without altering the performance of the service. This SKPI evaluates whether the 5G network access is provided in the complete vertical premises guaranteeing the minimum expected performance of each specific service.
5GR-SKPI-8	Service Operation Time	The service operation time is the minimum time needed to perform one iteration of the complete service workflow. E.g., in an industry 4.0 context, the time that it takes to scan an industrial piece, process the information and display the results to a QA operator.
5GR-SKPI-9	Service Operation Capacity	Number of iterations of the service workflow that are being performed simultaneously at a specific instant of time.
5GR-SKPI-10	Service Availability	Percentage of time during which the overall vertical service is working correctly and meeting the expected vertical requirements.
5GR-SKPI-11	Service Reaction Time	Time required by the service to react to changes or external events. This time comprises any possible run-time reconfigurations of the service.

3.1. 5Growth SKPI goals

The goal of 5Growth is to demonstrate with the Pilots that it is possible to build real experiments capable of meeting the SKPIs of Table 2. Such compliance will suppose a significant impact on the Pilots of this project. Section 5 shows which KPIs are present in each of the pilots, and how they relate to their applications.

5Growth goals do not deal with unrealistic SPKIs, Table 3 provides a quick glimpse of which SPKIs are actually used in other 5GPPP projects. Showcasing that 5Growth can meet them, implies that existing research can take benefit of the project work for validation purposes.

TABLE 3 5GROWTH SKPIS USED IN 5GPPP PROJECTS

	5GR-SKPI										
	1	2	3	4	5	6	7	8	9	10	11
5G VE	√	√	√	√	√	√	√	√	√	√	√
5GENESIS	√	√	√	√	√	√	√		√	√	√
5G VINNI	√	√				√		√	√	√	√
5G!DRONES	√	√	√	√	√	√	√		√	√	√
5G HEART	√	√	√		√	√	√		√	√	√
5G SMART	√		√		√		√	√			
5G SOLUTIONS	√		√	√	√	√	√	√			√
5G TOURS	√			√		√					
5G VICTORY	√		√	√	√	√	√	√		√	√

The definition of these SKPIs does not only map to the ongoing work of 5GPPP research projects but serves as a reference to evaluate the performance of first-phase deployments of 5G business use cases. For instance, Table 3 might serve as requirements for verticals once they ask to instantiate their services.

For example, the "*mobile broadband and media everywhere*" use case presented in [3] requires that there is mobile broadband in crowded areas like concerts. To realize whether the infrastructure owner is providing an appropriate service to a vertical, such as a Broadcaster, compliance 5Growth SKPIs {1,4,5,9,10} would imply that the vertical clients will experience the expected QoS. Consequently, SLAs will be met as long as the satisfaction of the SKPIs is ensured.

4. Core 5G and Service KPI relationship

As said before, SKPIs determine those business and operational-oriented metrics and figures of merit to be fulfilled certifying that the vertical services, once deployed, are perfectly operative (i.e., they work as expected to satisfy the demanded vertical requirements and agreed SLAs). In a nutshell, the SKPIs are considered as the guarantees that the underlying management entities promise to the verticals.

The set of SKPIs for each service deployed is a set of measurable, tangible, and quantifiable parameters being exclusively relevant and/or meaningful for that specific service. Thereby, the set of SKPIs for a given service may be orthogonal (not relevant) to other vertical services even if both co-exist and are rolled out over a common (compute and network) infrastructure. The vertical demands specify such SKPIs that are processed by the 5Growth VS. The latter then derives a pool of CKPIs bound to the specific compute and networking resources to be allocated for accommodating the vertical service. Indeed, recall that CKPIs provide measurable performance parameters associated with the network and compute infrastructure supporting the functions, applications, connectivity, etc. required by the vertical service.

Therefore, an unambiguous relationship is made between an SKPI for a vertical service and its determined set of CKPIs. Those CKPIs can be measured, retrieved, and assessed over different locations (e.g., edge DC, terminal, etc.), data and control interfaces, functions, systems, and devices related to the deployed vertical service. To do this, the 5Growth platform (i.e., VS, SO and RL) takes over of assessing the defined CKPIs for each specific SKPI. As an example, let us assume that a vertical service demands an SKPI requiring correct synchronization between two remote endpoints (e.g., worker and machine). Upon deploying the service (i.e., allocating the resources within the infrastructure), specific monitoring agents will be used to export selected metrics/monitored info. Such info will be used to derive a CKPI that allows assessing that the incurred latency contributions from each element/segment constituting the end-to-end communication between the teleworker and the remote machine is satisfied.

In the above example, it is important to outline that the vertical service remains completely agnostic to the set of required CKPIs to assess the targeted SKPI. For the vertical services forming the targeted pilots to be conducted in 5Growth, a list of SKPIs has been identified (see Section 3). These SKPIs are decomposed using the CKPIs described in Section 2). Table 4 aims at providing the required CKPI metric of every SKPI Observe that each SKPI presents its own set of CKPIs. For instance, 5GR-SKPI-10 (i.e., Service Availability) is one-to-one related to 5GR-CKPI-5 (i.e., Availability). On the other hand, 5GR-SKPI-7 (i.e., Extensive Network Coverage in Vertical Premises) needs to be assessed through 6 CKPIs as reflected in Table 4.

TABLE 4: MAPPING BETWEEN 5GROWTH SERVICE KPIS AND CORE 5G KPIS

5GR-SKPIs	Core 5G KPIs										
	CKPI-1	CKPI-2	CKPI-3	CKPI-4	CKPI-5	CKPI-6	CKPI-7	CKPI-8	CKPI-9	CKPI-10	CKPI-11
5GR-SKPI-1					X	X					
5GR-SKPI-2	X	X									
5GR-SKPI-3				X	X					X	X
5GR-SKPI-4		X	X					X	X		
5GR-SKPI-5	X				X						
5GR-SKPI-6		X	X		X						
5GR-SKPI-7	X	X	X	X	X		X				
5GR-SKPI-8		X	X								
5GR-SKPI-9	X		X		X						
5GR-SKPI-10					X						
5GR-SKPI-11	X										

5. Considered KPIs per Pilot

The following subsections are dedicated to the 5Growth pilots. First, an overview of each use case is given, detailing their components and logical architecture. Second, a set of 5Growth Service KPIs from Section 3 is selected to evaluate each of the different use cases. That is, the 5GR-SKPIs are applied specifically in order to explain how they validate their correct operation and expected performance. Then, the specific Service KPIs are decomposed in several Core 5G KPIs using the mapping provided in Section 4, with the purpose of detailing how the specific Service KPIs can be evaluated by measuring the correspondent 5G Core KPIs in specific components and interfaces of the use case logical architecture. And finally, a table containing the mapping between functional requirements specified in D1.1 [1] and the specific Service KPIs identified in this deliverable is provided, highlighting how the application of Service KPIs to the different use cases evaluate the fulfilment of the vertical requirements.

5.1. Industry 4.0 Pilot – INNOVALIA

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

The first INNOVALIA use case involves the remote operation of an industrial machine, called Coordinate-Measuring Machine (CMM). More specifically, as depicted in Figure 1 [4], an expert from INNOVALIA located at the headquarter controls the movement of the CMM in a remote location using a virtual joystick, while receiving visual information through low-latency video stream. Together with the CMM, an edge device that runs its software controller that translates the movement commands and the video equipment to record, compress and stream the images are deployed in the remote location.

Therefore, an end-to-end 5G connection is needed between the remote worker and the INNOVALIA premises, in order to guarantee the communication requirements of the different elements that compose the use case.

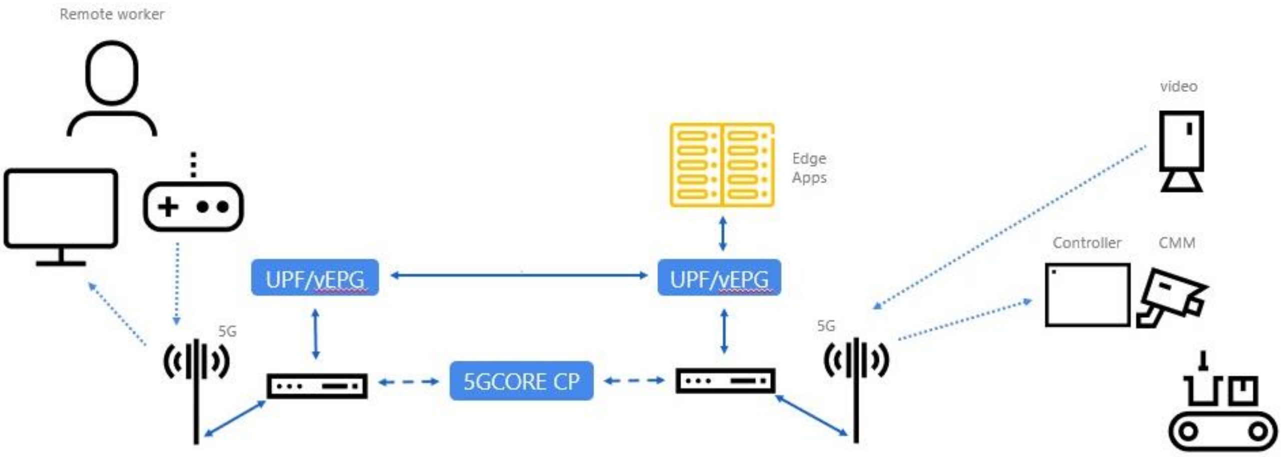

FIGURE 1: INNOVALIA UC1 LOGICAL ARCHITECTURE [4]

More in detail, Figure 2 shows the logical architecture of the use case **data plane.** It specifies the different data plane components, their connections/interfaces, and the 5G network slices through which they communicate.

Some elements of the architecture can be highlighted. First, two non-permanent slices (they are instantiated on-demand by the teleworker only while the remote operation takes place and terminated on the contrary) are used. Namely, one eMBB slice for the video streaming service and one URLLC slice for the control of the CMM movements. Second, the M3Box is the edge device that runs the software components that receive the movements produced by the virtual joystick and translate them into commands compatible with the CMM controllers, which subsequently execute the actual movements of the CMM.

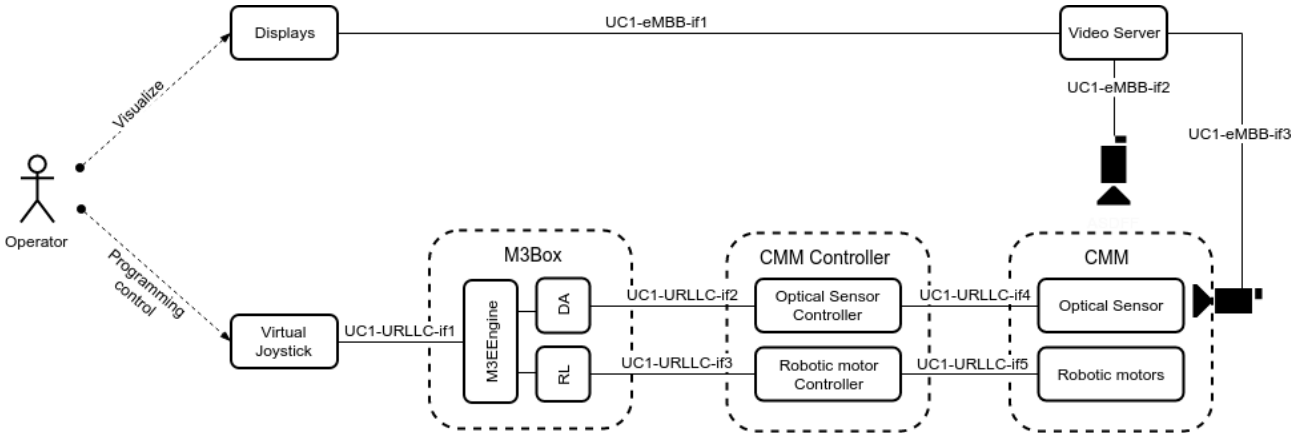

FIGURE 2: INNOVALIA UC1 DATA PLANE LOGICAL ARCHITECTURE

The following Service KPI subsections will refer to these architectures with the purpose of relating the different Service-to-Core 5G KPI mappings with the specific interfaces and elements of the use case.

5.1.1.1. P1UC1-SKPI-1: Teleworker-CMM Synchronization

This specific service KPI is applied from the general 5Growth Service KPI *5GR-SKPI-2 Synchronization between Communication Components*.

For the correct operation of the use case, whenever the teleworker executes a given movement of the CMM through the virtual joystick, he must immediately visualize the movement performed on the display. From the vertical perspective, this teleworker-CMM real-time synchronization is critical to validate use case. On the contrary, an excessive delay between the movements' execution and their visualization may disrupt the operation of the teleworker, even causing the crash of the optical sensors with the industrial piece being measured.

As stated in Section 4, the *5GR-SKPI-2* is mapped to the technical KPIs *CKPI-1 End-to-end Latency* and *CKPI-2 Packet Loss*.

More specifically for this use case, the overall *teleworker-CMM-teleworker* delay that characterizes the synchronization of the remote operation can be split into the following one-way network latencies and component's processing times (see Figure 3):

Virtual Joystick + UC1-URLLC-if1 + M3Box + UC1-URLLC-if2/3 + CMM controller + UC1-URLLC-if4/5 + CMM + UC1-eMBB-if2/3 + Video Server + UC1-eMBB-if1 + Display.

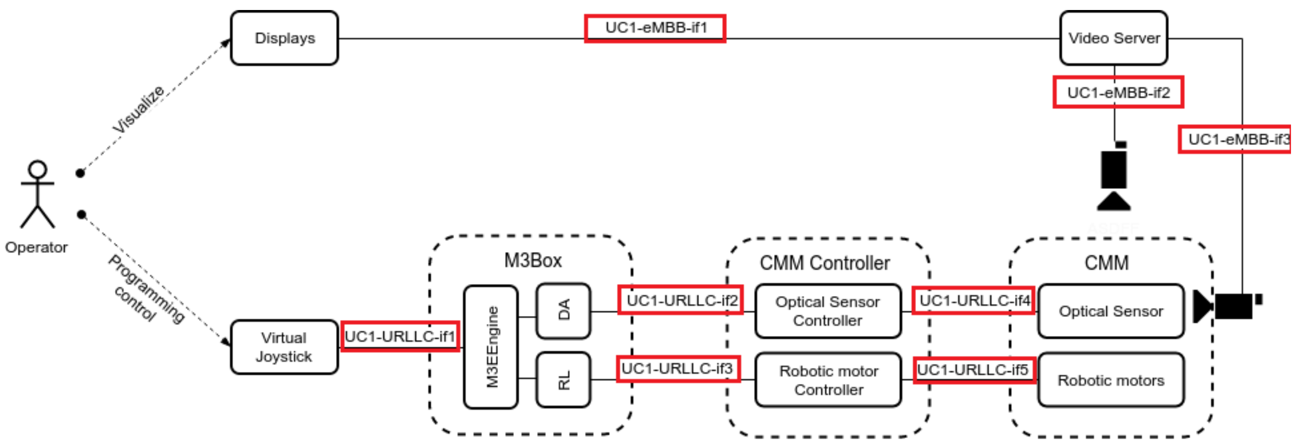

FIGURE 3: MEASUREMENT LOCATIONS OF THE END-TO-END LATENCY CORE 5G KPI FOR THE TELEWORKER-CMM SYNCHRONIZATION SERVICE KPI.

Additionally, the reliability of the URLLC interfaces handling the connection between the virtual joystick and the CMM has a notable importance, considering that an excessive packet loss rate may impact the smoothness of the CMM movements. Therefore, the *CKPI-2* must be measured in the following interfaces (see Figure 4):

UC1-URLLC-if1, UC1-URLLC-if2, UC1-URLLC-if3, UC1-URLLC-if4 and *UC1-URLLC-if5.*

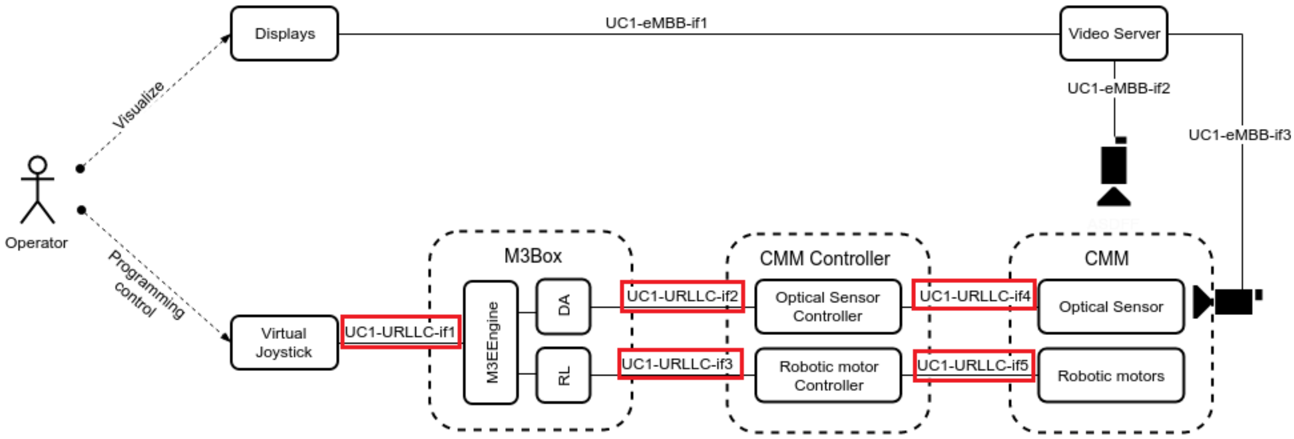

FIGURE 4: MEASUREMENT LOCATIONS OF THE RELIABILITY CORE 5G KPI FOR THE TELEWORKER-CMM SYNCHRONIZATION SERVICE KPI.

5.1.1.2. P1UC1-SKPI-2: High-resolution Real-time Video Quality

This Service KPI is directly applied to this use case from the *5GR-SKPI-4 High-resolution Real-time Video Quality*.

The teleworker must be provided with a **live video stream** that displays the industrial piece to be measured and the optical sensors of the CMM. Regarding its requirements, the video must have a resolution high enough to visualize exact shapes and limits in order to perform measurements with the needed accuracy and error tolerance. Moreover, the real-time video streaming service must be continuous, as sudden interruptions and stalling events may cause collisions between the sensitive sensors and the industrial piece.

According to Section 4, this specific service KPI is mapped to some of the technical KPIs identified in Section 2: *CKPI-2 Packet Loss, CKPI-3 Guaranteed Data Rate, CKPI-8 Data Volume* and *CKPI-9 Jitter*. These KPIs measure the Quality of Service (QoS) performance of the video streaming service of the use case, that is, based on the logical data plane architecture (Figure 2), they will be evaluated in the following components and interfaces (see Figure 5):

Display, UC1-eMBB-if1, Video Server, UC1-eMBB-if1 and UC1-eMBB-if3.

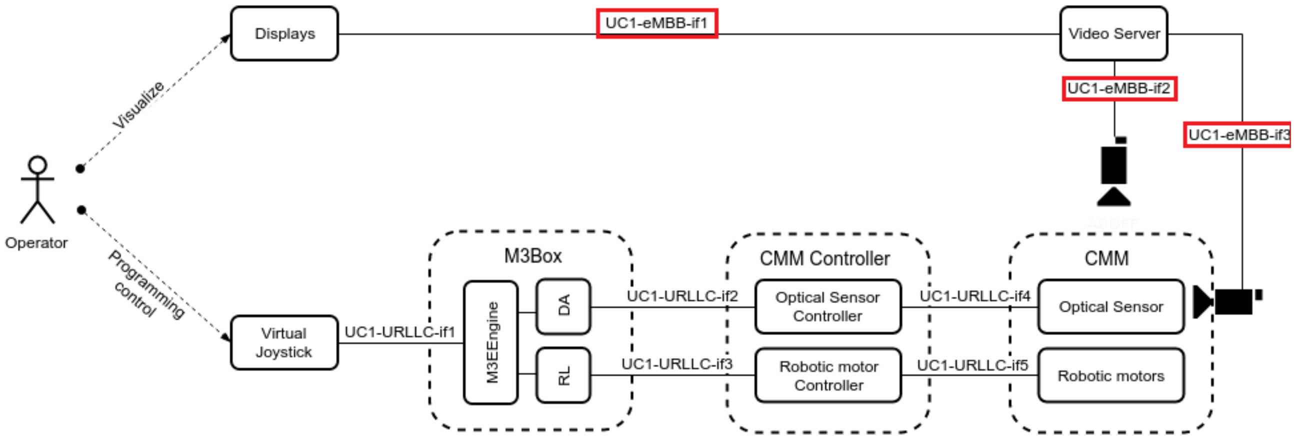

FIGURE 5: MEASUREMENT LOCATIONS OF THE QOS CORE 5G KPIS FOR THE HIGH-RESOLUTION REAL-TIME VIDEO QUALITY SERVICE KPI.

Once obtained, these technical KPIs will be extrapolated to evaluate the Quality of Experience (QoE) of the teleworker, to validate the video component of the use case from the vertical perspective.

5.1.1.3. P1UC1-SKPI-3: Service Setup Time

The *5GR-SKPI-1 Service Setup Time* can be directly applied to the first INNOVALIA use case. In this case, whenever the teleworker needs to control the CMM remotely, he is the actor that initiates the instantiation of the complete vertical service, in order to start the calibration of the CMM. The time elapsed since the request from the teleworker until the CMM is ready to be remotely controlled is essential to validate the use case and must not be longer than five minutes, according to the requirements from INNOVALIA. Excessive delays in this *Service Setup Time* may cause the dissatisfaction of INNOVALIA's clients, as in the manufacturing sector stalling events of even seconds can incur notable high costs.

This vertical KPI can be extrapolated from the following technical Core 5G KPIs: *CKPI-5 Availability* and *CKPI-6 Slice Creation Time*.

In relation with *CKPI-6 Slice Creation Time,* two non-permanent 5G network slices are dynamically created during the vertical service instantiation, one eMBB and one URLLC (see Figure 2). The CKPI-6 evaluates the time it takes to create these two slices. More specifically, the instantiation and configuration of the 5G virtual functions that enable the communication among the use case components, that is, the UPF/vEPG and the 5G Core control plane functions (see Figure 1).

Additionally, *CKPI-5 Availability* evaluates whether the virtual applications of the vertical use case are operational at a given point of time. In this case, as stated in Section 5.1.1, these applications are the displays, the virtual joystick, the video server, and the M3Box (see Figure 2).

By combining these two technical KPIs (that is, measuring the time taken by the 5Growth platform to establish connectivity between the vertical applications and identifying when the vertical applications are available) the *P1UC1-SKPI-3 Service Setup Time* can be extrapolated.

5.1.1.4. P1UC1-SKPI-4: Radius of Operation

This specific Service KPI is applied to the use case from the *5GR-SKPI-5 Radius of Operation*, and it refers to the maximum end-to-end distance of applicability of the vertical service. From the INNOVALIA requirements gathered in D1.1 [1], the correct operation of the service needs to be guaranteed in a radius that comprises distances from Bilbao to any factory within Europe, due to their headquarters are located in Bilbao and they have clients distributed at different locations within Europe.

From Section 4, it can be noted that this Service KPI is mapped to the technical KPIs *CKPI-1 End-to-end Latency* and *CKPI-5 Availability*.

Several mechanisms will be applied to validate the use case at different geographical locations, measuring the variations of the *CKPI-1 End-to-end Latency*, in order to evaluate whether the use case is operational (in close relation with *P1UC1-SKPI-1 Teleworker-CMM synchronization*) independently of the location.

Moreover, the evaluation of *CKPI-5 Availability* is needed to determine that the vertical applications are completely operational at the different locations where they are instantiated. The combination of both Core 5G KPIs, that is, the increase of the end-to-end latency until the vertical applications are not available anymore, will establish the limit of the area of the vertical service applicability.

5.1.1.5. P1UC1-SKPI-5: Integrated Multitype Communications

The general *5GR-SKPI-6 Integrated Multitype Communications* is directly applied to this use case. The vertical is consuming and producing two types of traffic at the same time, video (CMM movements) and data (CMM control commands). Even though they use two different 5G network slices, they both are transmitted through the same physical channels (see Figure 1). However, their separated performance (with very different requirements) must be guaranteed, ensuring their isolation and that they are not affected by other types of communication. Additionally, the integration of multitype communications must be transparent for the vertical, which must not notice any performance degradations of the overall vertical service caused by the network.

P1UC1-SKPI-5 Integrated Multitype Communications is decomposed into the following Core 5G KPIs: *CKPI-2 Packet loss, CKPI-3 Guaranteed data rate and CKPI-5 Availability.*

This composition is given because the availability of the virtual service applications must be guaranteed despite the complexity added to the 5G network to support the aggregation and differentiation of multitype traffic. In order to achieve this, the *CKPI-2 Packet loss* and *CKPI-3 Guaranteed data rate* must be measured for each type of traffic in those links where the traffic flows aggregated so that it can be validated that the CKPIs of one type of data (e.g. video) does not affect the CKPIs of the other (e.g. CMM commands). By looking at Figure 1, the traffic aggregation points would be the 5G radio antennas, and the links where the traffic is transmitted aggregated are the links between the antennas and the UPFs, and the network path between both UPFs.

5.1.1.6. P1UC1-SKPI-6: Extensive Network Coverage in the Factory Premises

Both the CMM and the Video Server must be provided with a reliable and constant 5G radio access connection while the CMM is being remotely operated. That is why it is important to apply the *5GR-SKPI-7 Extensive Network Coverage in Vertical Premises* to this use case. Depending on the manufacturing process of each INNOVALIA customer, the CMM may be portable to different locations inside the factory premises. In addition, providing a reliable wireless access connection may be made more complicated due to the specific wall materials and medium conditions of the industry environment.

With the purpose of evaluating this Service KPI, the following technical KPIs will be measured: *CKPI-1 End-to-end latency, CKPI-2 Packet loss, CKPI-3 Guaranteed data rate, CKPI-4 Coverage and CKPI-5 availability*. More specifically and regarding Figure 1 and Figure 2, these 5G Core KPIs must be evaluated in the radio link that connects the 5G antenna with the M3Box and the Video Server. On the other side of the connection, the same KPIs can be validated in the 5G access link provided to the teleworker, namely the display and the virtual joystick.

5.1.1.7. Mapping between Functional Requirements (FR) and Specific Service KPIs.

This section includes the direct relationship between the functional requirements gathered in D1.1 [1] and the specific Service KPIs applied to the use case. In this way, the reader can directly observe the Service KPIs that will be evaluated in order to validate the fulfilment of the correspondent pilot functional requirements.

TABLE 5: INNOVALIA UC1 MAPPING BETWEEN FUNCTIONAL REQUIREMENTS AND SPECIFIC SERVICE KPIS

UC Functional Requirements [1]		UC Service KPIs
FR-P1UC1-01	The factory manager is the one that initiates the process	**Qualitative verification**
FR-P1UC1-02	Security measures to avoid unauthorised access to the CMM	**Qualitative verification**
FR-P1UC1-03	Usable interface for the Metrology Expert (virtual joystick)	**P1UC1-SKPI-1** – Teleworker-CMM Synchronization
FR-P1UC1-04	Real time video streaming to see the movement of the CMM	**P1UC1-SKPI-2** – High-resolution Real-time Video Quality
FR-P1UC1-05	Enable 5G connectivity to the M3Box edge device	**P1UC1-SKPI-6** – Extensive Network Coverage in the Factory Premises
FR-P1UC1-06	Security of the data interchange (encryption)	**Qualitative verification**
FR-P1UC1-07	Radius of action – From Bilbao to Europe	**P1UC1-SKPI-4** – Radius of Operation
FR-P1UC1-08	The industrial environment must be equipped with 5G-enabled devices	**Qualitative verification**
FR-P1UC1-09	High availability of the remote connection including redundant	**5GR-SKPI-10** – Service Availability

	connection in order to guarantee the communication in case of failure	
FR-P1UC1-10	Solution shall include additional capabilities (e.g., specific features, probes) that will take care of the monitoring process	**Qualitative verification**
FR-P1UC1-11	Solution must support programmability and virtualization to enable flexible and dynamic reconfiguration	**Qualitiative verification**
FR-P1UC1-12	The solution must guarantee proper levels of isolation (in the form of network slice)	**P1UC1-SKPI-5** – Integrated Multitype Communications
FR-P1UC1-13	Simultaneous support of integrated communications (voice, data, etc)	**P1UC1-SKPI-5** – Integrated Multitype Communications

5.1.2. Use Case 2: Connected Worker: Augmented Zero Defect Manufacturing (ZDM) Decision Support System (DSS)

The second INNOVALIA use case aims at semi-automatizing the different stages during the quality control process. At first, the components used during the metrology process, i.e., the M3ExecutionEngine, RobotLink, and Data Assembler, will be deployed on an edge-cloud server.

On the one hand, this will enable to develop a Machine-2-Machine (M2M) communication protocol between an Automated Guided Vehicle (AGV), which carries the specific parts to the Coordinate Measuring Machine (CMM) for quality testing, and the CMM itself, so that the CMM can start loading the exact measuring program. This would save valuable time to the quality control workers, as they would not have to wait for the pieces to start loading the program. On the other hand, while the scan of a piece takes place, the measurement data is going to be transmitted from the CMM to a Multi-access Edge Computing (MEC) device which will enable the quality control manager to visualize the results of the scan in a portable device. That is, there will be cloud support for computational geometry processing and plotting the measured data. Figure 6 illustrates the complete process.

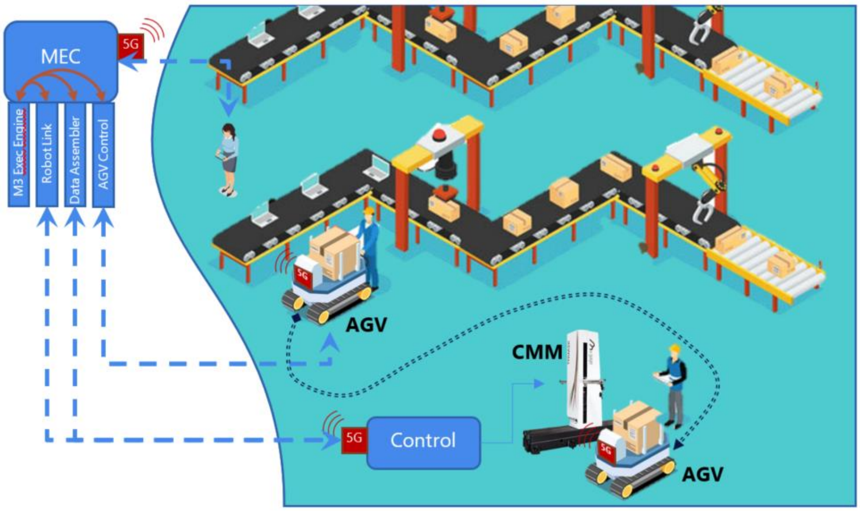

FIGURE 6: OVERVIEW OF INNOVALIA USE CASE 2

In summary, this Use Case aims to showcase new collaboration capabilities between systems enabled by a 5G edge infrastructure, by combining together an edge-cloud deployment of INNOVALIA software components M2M communications.

5.1.2.1. P1UC2-SKPI-1: Service Operation Time

This specific service KPI is applied from the general 5Growth Service KPI 5GR-SKPI-8 *Service Operation Time*.

This use case develops a M2M protocol between the AGV and the CMM. This will enable the CMM to start loading the program for measuring a specific part before the AGV has taken a specific part to the measuring site. Furthermore, once the inspection finishes the measurements processing and plotting and the AGV part transportation back to production runs also simultaneously. This service KPI measures the impact of using 5G on the time of the complete operation, depicted in Figure 7.

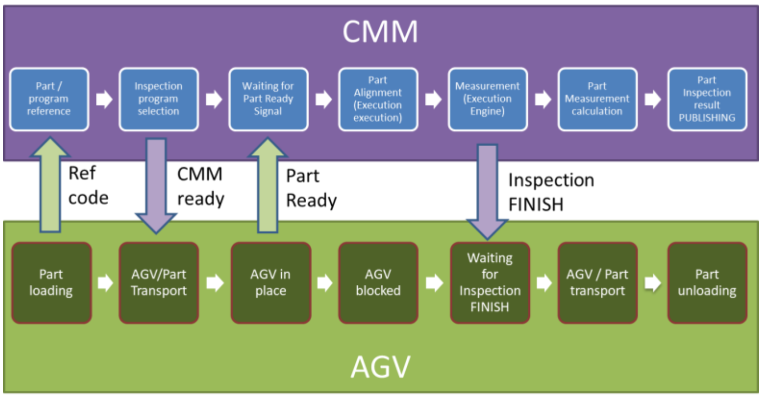

FIGURE 7: PROCESS FOLLOWED BY THE CMM AND AGV TO INSPECT AN INDUSTRIAL PART

This KPI is mapped to *CKPI-2 Packet Loss and CKPI-3 Guaranteed Data Rate*. We can measure the time for each of the stages of the AGV and CMM as adding up the individual times of each stage. Once we have the timestamps, we are going to evaluate which ones are simultaneously executed so that we can measure the total operation time. These timestamps can also be used to predict how many times a day we can carry out this operation and evaluate the time gains of using 5G in the whole process.

5.1.2.2. P1UC2-SKPI-2: Service Operation Capacity

This specific service KPI is applied from the general 5Growth Service KPI 5GR-SKPI-9 *Service Operation Capacity*.

The service operation capacity measures how many workflows can now be run simultaneously in the use case. As this use case enables some of the operations between the AGV and the CMM to run concurrently, it is key to measure what are the gains of these parallel operations. Moreover, it also enables to predict how many measures could be done during a certain amount of time. This KPI is mapped to *CKPI-1 End-to-end latency, CKPI-3 Guaranteed data rate* and *CKPI-5 Availability*. Beyond measuring the savings for each for the phases that are executed simultaneously on the overall execution time, these CKPIs also let us measure the capacity that is required to sustain one workflow, and eventually takes into account possible downtime on the total capacity in a given timeframe.

5.1.2.3. P1UC2-SKPI-3: Service Creation Time

This specific service KPI is applied from the general 5Growth Service KPI 5GR-SKPI-1 *Service Setup Time*.

This use case deploys the M3ExecutionEngine, RobotLink, and Data Assembler in an edge-cloud server to carry out the operations between the AGV and the CMM. This SKPI evaluates the impact of this by measuring the time needed to deploy and start the components before the service is considered operational. This KPI is mapped to *CKPI-5 Availability* and *CKPI-6 Slice Creation / Adaptation Time*. Therefore, we measure the boot time for each of the components. This KPI can be used to determine whether there is any problem when deploying the components for the first time in the edge-cloud server.

5.1.2.4. P1UC2-SKPI-4: AGV-Edge Control Synchronization

AGV-Edge control synchronization is fundamental to ensuring accurate AGV operations in the factory, avoiding potential crashes and unexpected maneuvers. Figure 8 shows the interactions between the AGV controller and the AGV. The AGV control software is located at the edge infrastructure and sends commands to the AGV instructing on the next movement. Simultaneously, the AGV reports location and context information back to the control software. As a result, end-to-end latency and packet loss are the main core 5G KPIs impacting P1UC2-SKPI-4. High end-to-end latency may compromise the AGV operations by delaying the maneuvers, while packet loss may generate crashes as the AGV may drive in the wrong direction. In other words, such core KPIs can impact service reliability as well as cause accidents and hazards, thus affecting the safety of the working environment.

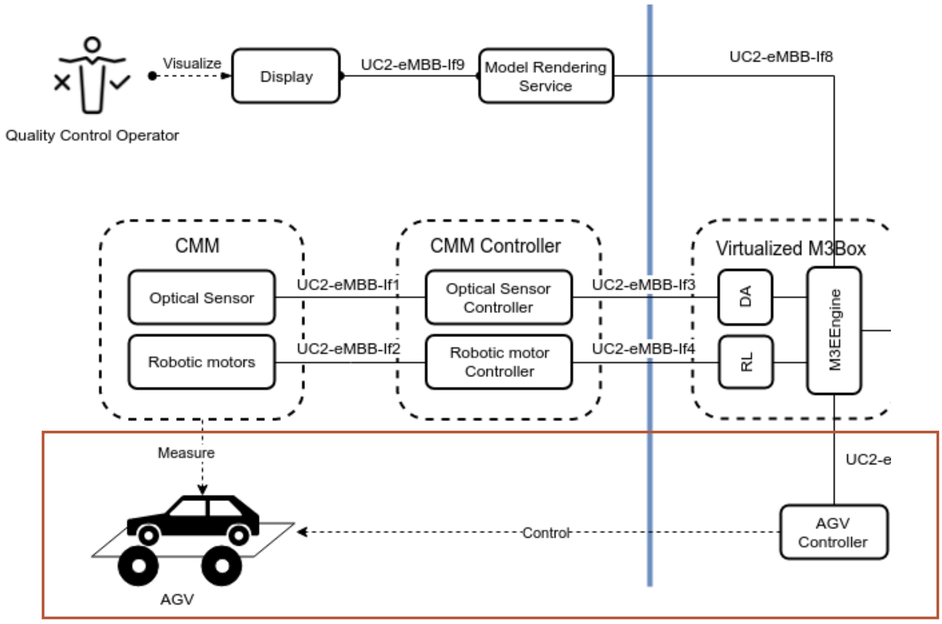

FIGURE 8: AGV-EDGE CONTROL SYNCHRONIZATION

5.1.2.5. P1UC2-SKPI-5: Network support for user mobility

To ensure correct and safe operations, AGVs and the quality control operator must stay connected at any time and in any conditions. Device mobility (5GR-SKPI-3) is a service KPI influenced by availability (CKPI-5), coverage (CKPI-4), radio signal quality (CKPI-10) and buffer occupancy (CKPI-11). CKPI-4, CKPI-10 and CKPI-11 are a set of metrics related to the mobile device features, including speed limits, reaction time to changes, handovers, etc. On the other hand, service availability must be guaranteed at any time and in any location of the factory floor while the end-devices are moving, without degrading the overall performance of the service and meeting the use case requirements.

5.1.2.6. P1UC2-SKPI-6: Concurrency of simultaneous users in a given area

The maximum number of served users is also a key metric in this use case. The SKPI "Concurrency of simultaneous users in a given area" intends to capture the impact of the number of users in a given area. Three core KPIs can impact this SKPI: the connection density, indicating the number of connections served per unit of area, the service availability, and the data volume, as the capability of meeting the service requirements of a number of users depends on the amount of data transferred. Nevertheless, we do not expect that all the potential users will be connected at the same time, and therefore we can consider a concurrency rate. In any case, users must perceive the same service availability regardless of the total data volume.

5.1.2.7. Mapping between Functional Requirements (FR) and Specific Service KPIs.

This section includes the direct relationship between the functional requirements gathered in D1.1 [1] and the specific Service KPIs applied to the use case. In this way, the reader can directly observe the Service KPIs that will be evaluated in order to validate the fulfilment of the correspondent pilot functional requirements.

TABLE 6: INNOVALIA UC2 MAPPING BETWEEN FUNCTIONAL REQUIREMENTS AND SPECIFIC SERVICE KPIS

UC Functional Requirements [1]		UC Service KPIs
FR-P1UC2-01	Externalization of the Edge Computing system	**P1UC2-SKPI-1** – Service Operation Time **P1UC2-SKPI-2** – Service Operation Capacity **P1UC2-SKPI-3** – Service Creation Time
FR-P1UC2-02	M3 software deployed in the manager device (laptop, tablet)	**P1UC2-SKPI-1** – Service Operation Time **P1UC2-SKPI-2** – Service Operation Capacity **P1UC2-SKPI-3** – Service Creation Time
FR-P1UC2-03	Deployment of Robotlink, DataAssembler and AGV control services on a Cloud Edge System	**P1UC2-SKPI-1** – Service Operation Time **P1UC2-SKPI-2** – Service Operation Capacity **P1UC2-SKPI-3** – Service Creation Time
FR-P1UC2-04	Enable 5G connectivity on the CMM controller	**Qualitative verification**
FR-P1UC2-05	CMM-AGV communication protocol working over 5G connection	**P1UC2-SKPI-5** – Network support for user mobility
FR-P1UC2-06	Enable 5G connectivity on the AGV	**P1UC2-SKPI-4** – AGV-Edge Control Synchronization **P1UC2-SKPI-5** – Network support for user mobility
FR-P1UC2-07	Enable 5G connectivity on the manager device	**P1UC2-SKPI-5** – Network support for user mobility
FR-P1UC2-08	Security: end-to-end encryption	**Qualitative verification**
FR-P1UC2-09	The industrial environment must be equipped with 5G-enabled solutions	**Qualitative verification**
FR-P1UC2-10	High availability of the remote connection including redundant connection in order to guarantee the communication in case of failure	**5GR-SKPI-10** – Service Availability
FR-P1UC2-11	Solution must include additional capabilities (e.g., specific features, probes) that will take care of the monitoring process	**Qualitiative verification**

FR-P1UC2-12	Solution must support programmability and virtualization to enable flexible and dynamic reconfiguration	**Qualitative verification**
FR-P1UC2-13	The solution must guarantee proper levels of isolation (in the form of network slice)	**5GR-SKPI-6** – Integrated Multitype Communications

5.2. Industry 4.0 Pilot – COMAU

5.2.1. Use Case 1: Digital Twin Apps

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

To demonstrate 5G low latency performance and its feasibility in URLLC, this use case has the objective to create a digital twin of an actual robot with both the aim to enable visibility and remote insights with no delays about robot status and its performance (without the need to be geographically close to it); and enabling remote controlling using an interface to receive a command from external applications or virtual machines thanks to high-level program languages.

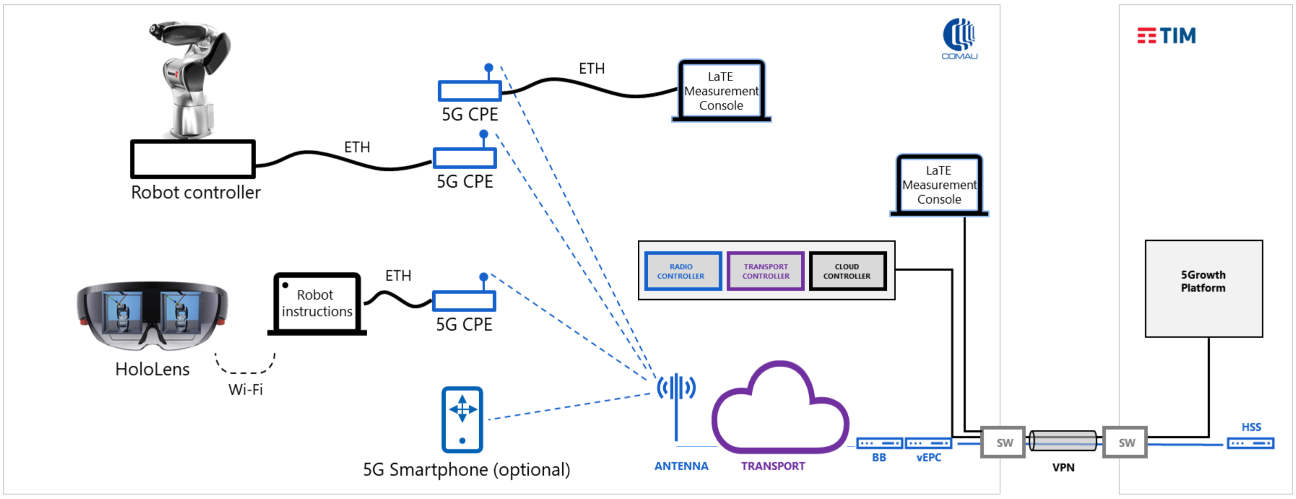

FIGURE 9: ARCHITECTURE OF COMAU UC1

The use case has as major objective the demonstration of 5G low latency features (i.e., URLLC profile).

As Figure 9 shows, the use case architecture includes an industrial robot, which reaches the 5G network thanks to a user equipment (5G CPE), and a PC, similarly connected, where robot instructions are generated and sent from. HoloLens glasses are connected to the PC via Wi-Fi as it is the only connection supported by this device.

The use case workflow consists in remotely control the robot using the PC, which means send to it time by time the position it has to assume, gathering real-time position data from the robot controller (which takes the actual position of the robot thanks to encoders installed on axes motor), and replicate the behavior via a virtual version on the augmented reality device (i.e. the HoloLens).

Remotely send robot positions from IT devices (PCs or even VMs) is important in industry scenario since it aims at changing the current paradigm which requires to offline program every single robot, each with its program language.

In order to further investigate this aspect, characterized by low latency requirements, a remote controlling of the robot has been developed as well using a 5G smartphone. With this handy device, it is possible to instruct and drive the robot using a sort of "joystick" as an alternative to the instructions sent by the PC.

The following subsections describe the specific Service KPI for this UC (i.e. P2UC1-SKPI-x), mentioning from what 5GR-SKPI the Service KPIs applied, how it validates the service implemented by the UC, the decomposition of the Service KPI into Core 5G KPIs and where to measure each Core 5G KPI within the UC infrastructure/logical architecture.

5.2.1.1. P2UC1-SKPI-1: Digital Twin – Delay Guarantees

This specific service KPI is applied from the general 5Growth Service KPI *5GR-SKPI-11 Service Reaction Time*. It represents the time between the instant a problem occurs and the moment in which the plant manager decides how to mitigate it. The delay must be minimal, up to being not perceptible. The plant manager must be able to see immediately the results of his/her decisions. For this reason, there should be no delay in the representation of the virtual twin. As stated in Section 4*, 5GR-SKPI-11* is mapped onto the core KPI CKPI-1 *End-to-end Latency*.

Measurements of this SKPI basically amount to the quantification of the End-to-end latency. As shown in Figure 9, measurement consoles will be deployed at the CPE and at the backend of the vEPC, allowing the quantification of latency through the injection of test traffic.

5.2.1.2. P2UC1-SKPI-2: Support of Industrial Protocols over 5G networks

This specific service KPI is applied from the general 5Growth Service KPI *5GR-SKPI-11 Service Reaction Time*. Plant components use dedicated industrial communication protocols that currently work over cable. These protocols are used to interconnect sensors, stations and PLCs. Industrial protocols, such as Profinet or Ethernet/IP, are strongly based on time synchronization of data exchange cycles. They can be tunneled over a 5G link if requirements about latency, data rate, packet loss and reliability are met. In this sense, the 5G network should behave as a wired network as much as possible. Similarly to SKPI-1, *5GR-SKPI-11* is mapped onto the core KPI CKPI-1 *End-to-end Latency*.

Measurements of this SKPI basically amount to the quantification of the end-to-end latency, so the same observations as in P2UC1-SKPI1 can be applied.

5.2.1.3. P2UC1-SKPI-3: Extensive on-Plant Coverage

This specific service KPI is primarily applied from the general 5Growth Service KPI 5GR-SKPI-7 *Extensive Network Coverage in Vertical Premises*. A steady connection must be ensured to all connected stations in the plant. To do so, the network must be broadly available throughout the plant and proper QoS must be ensured to all devices. A minimum link quality, with no packet loss, measured from peers connected to the 5G network, is required to guarantee the service. Since a multitude of sensors will be connected in a limited area, the network must offer a minimum connected device density and support integrated multitype communications, as provisioned in the general 5Growth Service KPI 5GR-SKPI-6 *Integrated Multitype Communications*. As shown in Figure 9, measurement consoles will be deployed at the CPE and at the backend of the vEPC. The CPE will then be moved over all the area of the plant, providing a mapping of performance in the different regions.

5GR-SKPI-7 is then mapped onto the core KPIs CKPI-1…5 as well as CKPI-7, while 5GR-SKPI-6 is mapped onto CKPI-2, -3 and -5.

5.2.1.4. Mapping between Functional Requirements (FR) and specific Service KPIs.

This section includes the direct relationship between the functional requirements gathered in D1.1 [1] and the specific Service KPIs applied to the use case. In this way, the reader can directly observe the Service KPIs that will be evaluated in order to validate the fulfilment of the correspondent pilot functional requirements.

TABLE 7: COMAU UC1 MAPPING BETWEEN FUNCTIONAL REQUIREMENTS AND SPECIFIC SERVICE KPIS

UC Functional Requirements [1]		UC Service KPIs
FR-P2UC1-01	Wi-Fi coverage up to 400m² for office and double for open factory	**Qualitative verification**
FR-P2UC1-02	Cellular indoor coverage of up to 800 m² for office and double in open factory	**P2UC1-SKPI-3** – Extensive on plant coverage
FR-P2UC1-03	Implement industrial protocols based on cable via wireless connection	**P2UC1-SKPI-1** – Delays guaranteed **P2UC1-SKPI-2** – Support of industrial protocols over 5G
FR-P2UC1-04	Guarantee updated information with no delays	**P2UC1-SKPI-1** – Delays guaranteed
FR-P2UC1-05	Use the COMAU internal tool to collect and analyse data in order to predict future problems in production lines	**Qualitative verification**

5.2.2. Use Case 2: Telemetry/Monitoring Apps

In this use case an extensive sensor deployment is in place to monitor and prevent failures of machineries 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 attach on machineries without the rigidity of cable which is also more sensible to attrition.

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

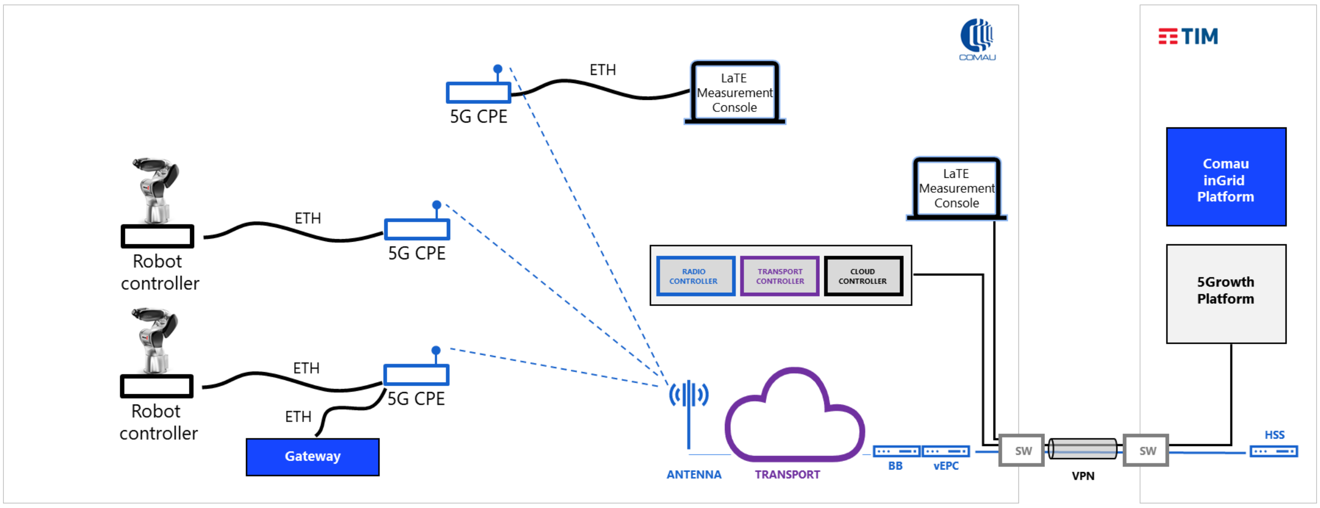

FIGURE 10: ARCHITECTURE OF COMAU UC2

As shown in Figure 10, the architecture involves some industrial robots and a gateway on the COMAU premises. COMAU IIoT platform is hosted in the TIM site. The two sites are connected via a VPN channel.

Detailing the architecture of the testbed, we have used two different user equipment, actually CPEs, in order to test two different communications. Indeed, the piece of software which gathers the information and sends them to the platform in TIM is the gateway; a local connection (behind the same router) to the industrial machinery connects a first robot (in the bottom part of the figure) to the gateway. The other robot (in the upper part of the figure) is connected through a dedicated 5G CPE. This second robot, however, is in the same address space of the first one and so, logically, it is connected to the same gateway (i.e. same network).

Having gathered information from all the robots via those two different communications, everything is sent via 5G to the COMAU IIoT platform, hosted in TIM site, through the VPN channel.

The following subsections describe the specific Service KPI for this UC (i.e. P2UC2-SKPI-x), mentioning from what 5GR-SKPI the Service KPIs applied, how it validates the service implemented by the UC, the decomposition of the Service KPI into Core 5G KPIs and where to measure each Core 5G KPI within the UC infrastructure/logical architecture.

5.2.2.1. P2UC2-SKPI-1: Extensive Network Coverage for High-density Sensors

This specific service KPI is primarily applied from the general 5Growth Service KPI 5GR-SKPI-7 *Extensive Network Coverage in Vertical Premises*. Equipment monitoring for fault detection and predictive maintenance requires a network able to support all the sensors that are simultaneously reporting data from each station of the production line. As shown in Figure 10, and similarly to what is foreseen for P2UC1-SKPI3, measurement consoles will be deployed at the CPE and at the backend of the vEPC. The CPE will then be moved over all the area of the plant, providing a mapping of performance in the different regions.

5GR-SKPI-7 is then mapped onto the core KPIs CKPI-1…5 as well as CKPI-7.

5.2.2.2. Mapping between Functional Requirements (FR) and Specific Service KPIs.

This section includes the direct relationship between the functional requirements gathered in D1.1 [1] and the specific Service KPIs applied to the use case. In this way, the reader can directly observe the functional requirements that are validated when the selected Service KPIs are evaluated.

TABLE 8: COMAU UC2 MAPPING BETWEEN FUNCTIONAL REQUIREMENTS AND SPECIFIC SERVICE KPIS

UC Functional Requirements [1]		UC Service KPIs
FR-P2UC2-01	Wi-Fi coverage up to 400m^2 for office and double for open factory	**Qualitative verification**
FR-P2UC2-02	Cellular indoor coverage of up to 800 m^2 for office and double in open factory	**P2UC2-SKPI-1** – Extensive coverage for high density networks
FR-P2UC2-03	Guarantee updated information with no delays	**P2UC2-SKPI-1** – Extensive coverage for high density networks
FR-P2UC2-04	Enable 5G connectivity on as much machineries as possible	**P2UC2-SKPI-1** – Extensive coverage for high density networks
FR-P2UC2-05	Implement industrial protocols over wireless channel	**Qualitative verification**
FR-P2UC2-06	Use the COMAU internal tool to collect and analyse data in order to predict future problems in machineries	**Qualitative verification**
FR-P2UC2-07	High availability and low latency of connection in order to avoid machine stops	**Qualitative verification**

5.2.3. Use Case 3: Digital Tutorial and Remote Support

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 video 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 on-demand tutorials and instructions for training purposes.

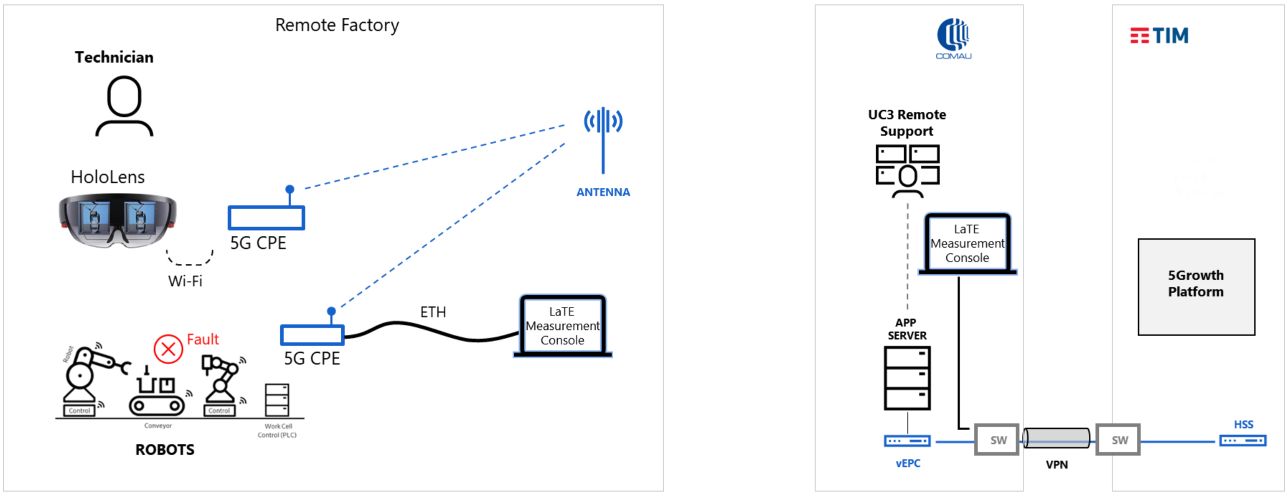

FIGURE 11: ARCHITECTURE OF COMAU UC3

This scenario, depicted in Figure 11, illustrates a remote factory operation. Here some machinery is affected by a fault, but the local staff needs 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 onfield technician.

The application requested in this use case must enable:

- A high definition video streaming.
- The possibility to set up a video call between the technician and the expert.
- The possibility to assist the technician with detailed instructions and procedures (i.e., a digital tutorial) enhanced by exploiting the AR capabilities of the HoloLens device. By adopting the AR technology, it would be feasible to superimpose graphical elements to the reality so as to assist the technician with the identification of the various components affected by the fault.

The following subsections describe the specific Service KPI for this UC (i.e., P2UC3-SKPI-x), detailing from what 5GR-SKPI the Service KPIs is applied, how it validates the service implemented by the UC, the decomposition of the Service KPI into Core 5G KPIs and where to measure each Core 5G KPI within the UC infrastructure/logical architecture.

5.2.3.1. P2UC3-SKPI-1: High-resolution Real-time Video Quality

This specific service KPI is mapped onto the general 5Growth Service KPI 5GR-SKPI-4 *High-resolution Real-time Video Quality*. Applications in support of remote assembly and maintenance operators run on consumer devices such as tablets or smartphones and are based on high-quality video feed. Similarly, tutorials and assembly instruction videos are expected to require HD quality. In addition, for the correct operation of the use case, the priority is to immediately assist the technicians in case of an emergency. From the vertical perspective, the real-time HD video quality is critical, however, in order to assure a smooth factory operation in case of disruption there should be several factors that need to be taken into consideration. A real-time HD video streaming requires high bandwidth and low packet loss. Moreover, in order for the vertical to enable a real-time satisfactory interaction, there must be a requirement for low latency and jitter. As shown in Figure 11, measurement consoles will be deployed at the CPE and at the backend of the vEPC, allowing the quantification of latency and throughput through the injection of test and background traffic.

As stated in Section 4, the *5GR-SKPI-4* is mapped onto the technical KPIs *CKPI-2 Packet Loss, CKPI-3 Guaranteed Data Rate, CKPI-8 Data Volume and CKPI-9 Jitter*.

More specifically for this use case, in order for the vertical to establish a reliable QoE-aware connection between the remote technical experts and the local technicians with no service interruptions, a low packet loss rate should be guaranteed, considering that otherwise it may impact the smoothness of the remote support.

Finally, due to the real-time nature of the Use Case scenario for remote operation, jitter should substantially decrease.

Once obtained, these technical KPIs will be used to evaluate the QoE of the service offered to the onfield technicians from the vertical perspective.

5.2.3.2. P2UC3-SKPI-2: Network Support for Device Mobility

This specific service KPI is mapped onto the general 5Growth Service KPI 5GR-SKPI-3 *Device Mobility* as well as onto KPI 5GR-SKPI-7 *Extensive Network Coverage in Vertical Premises*. In order to ensure the reliability of the use case operations, the provided remote support service should be available all over the factory area in order to enable remote maintenance activities. Maintenance operators' devices should stay connected to the network all over the facility, even when they move across the plant. Service should be available all over the plant to allow remote maintenance activities close to every station of the facility. Based on the above-mentioned requirements, device mobility should be taken into account so as to ensure service availability. Measurement consoles will be deployed at the CPE and at the backend of the vEPC. The CPE will then be moved across all the area of the plant, tracking the performance as the CPE is being moved.

As stated in Section 4, 5GR-SKPI-3 is mapped onto the core KPIs CKPI-4 *Coverage*, CKPI-5 *Availability*, CKPI-10 *Radio Signal Quality* and CKPI-11 *Buffer Occupancy,* while 5GR-SKPI-7 is mapped onto the core KPIs CKPI-1…5 as well as CKPI-7 *Connection Density*.

5.2.3.3. Mapping between Functional Requirements (FR) and specific Service KPIs.

This section includes the direct relationship between the functional requirements gathered in D1.1 [1] and the specific Service KPIs applied to the use case. In this way, the reader can directly observe the Service KPIs that will be evaluated in order to validate the fulfilment of the correspondent pilot functional requirements.

TABLE 9: COMAU UC3 MAPPING BETWEEN FUNCTIONAL REQUIREMENTS AND SPECIFIC SERVICE KPIS

UC Functional Requirements [1]		UC Service KPIs
FR-P2UC3-01	Wi-Fi coverage up to 400m² for office and double for open factory	**Qualitative verification**
FR-P2UC3-02	Cellular indoor coverage of up to 800 m² for office and double in open factory	**P2UC3-SKPI-2** – Network Support for Device Mobility
FR-P2UC3-03	High quality stream video with low delay	**P2UC3-SKPI-1** – Realtime High Definition Video Quality
FR-P2UC3-04	Provide the possibility to interact using the same tool	**Qualitative verification**
FR-P2UC1-05	Have a storage where save procedures and 3D models of machineries	**Qualitative verification**

5.3. Transportation Pilot – EFACEC Engenharia e Sistemas

5.3.1. Use Case 1: Safety Critical Communications

The main goal of this Use Case involves the use of 5G communications to support railway signaling operations; in particular, to meet railway level crossing communication requirements (M2M), namely regarding safety-critical communications from approaching train detectors (Strike In detectors) to the level crossing controllers.

Figure 12 depicts the use case overview, illustrating the relevant interface requiring URLL slice capabilities.

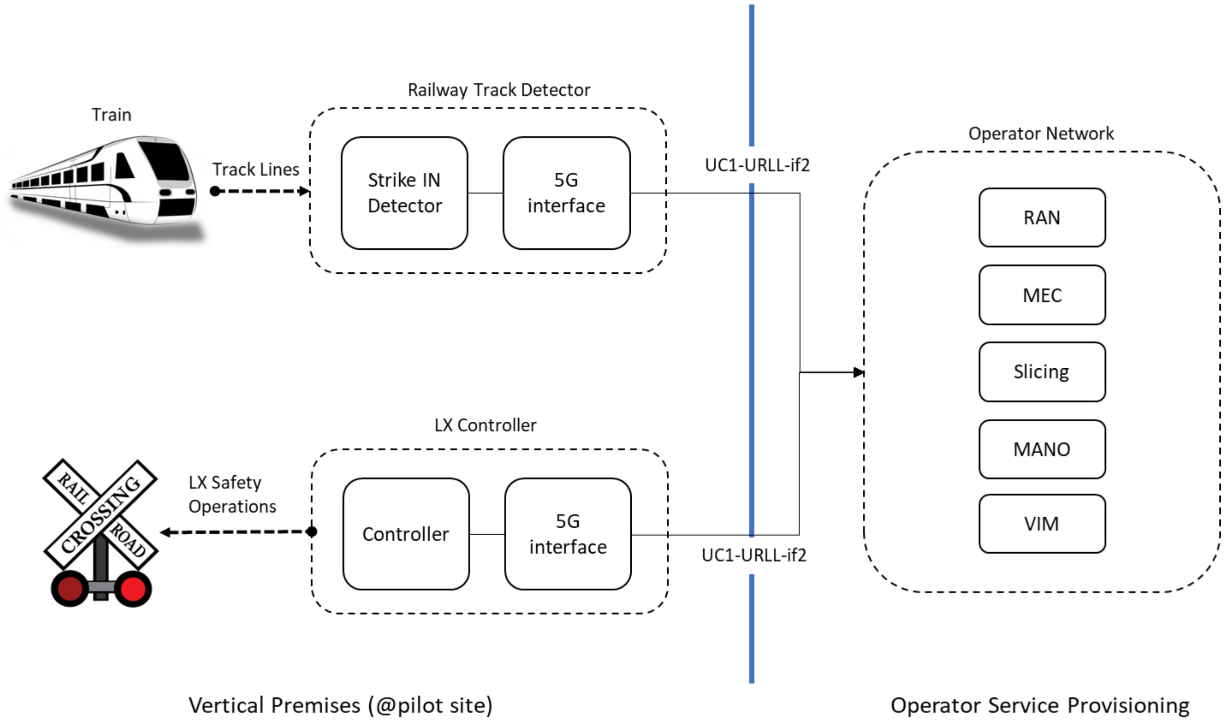

FIGURE 12: EFACEC_S UC1 OVERVIEW

5.3.1.1. P3UC1-SKPI-1: Communication Latency between LX Detectors and LX Controller.

Communication between these critical components must be established with low latency according to the railway standards[1], in order to assure the proper behavior of the Level Crossing; otherwise, The Level Crossing, including the half-barriers will enter into protection mode, blocking the road traffic. The network needs to ensure a **minimum** end-to-end latency in order to reduce the communication time between railway protection devices.

As such, this use case SKPI applies to the general **5Growth 5GR-SKPI-2** "Sync between communication components", which maps to the core CKPI-1 "e2e latency" and CKPI-2 "packet loss".

Regarding the "CKPI-1 – e2e latency" packets (data messages) between the rail sensor (strike in detector) and the railway crossing controller need to be exchanged with very low latency (< 10 ms) in order to detect that a train is approaching the Level Crossing and to start the safety signaling operation. If the data messages do not reach the destination with low latency a failure will occur and once again the system will operate in protection mode. The e2e latency can be measured at the level crossing controller.

For the "CKPI-2: packet loss", the communication between the strike in detector and the level crossing controller involves two different kinds of packets (data messages): i) events that occur when a new

[1] *CENELEC SIL4 and EN 50159 – for transmission systems)*

train is approaching the level crossing and ii) other protocolary messages such as keep-alive messages to guarantee a stable communication between the devices. Packet loss must be measured at the level of the crossing controller. In order to be compliant with Railway CENELEC standards and thus assuring a Certified Level crossing, this Core KPI must be guaranteed. If the availability or a failure that occurs doesn't recovery automatically in the proper time will represent a failure in the Level Crossing, starting this way to an operation in a protection mode (road traffic will be blocked). This situation has a huge impact in operation, can motivate penalties and requires the presence of maintenance people to manually recover from this operation mode.

5.3.1.2. P3UC1-SKPI-2: Communication Availability between LX Detectors and LX Controller.

Communication between these critical components must be established with availability according to the railway standards[1], in order to assure the proper behavior of the Level Crossing; otherwise, The Level Crossing, including the half-barriers will enter into protection mode, blocking the road traffic. The network needs to ensure **high levels** of availability and resilience, in order to ensure that the communication between railway protection devices is always up and running.

As such, this use case SKPI applies to the general 5Growth **5GR-SKPI-10** "Service availability", which maps to the core CKPI-5 "Availability". As indicated in section 5.3.1.2, in order to be compliant with Railway CENELEC standards and thus assuring a Certified Level crossing, this Core KPI must be guaranteed. If the availability or a failure that occurs doesn't recovery automatically in the proper time (<500ms) will represent a failure in the Level Crossing, starting this way to an operation in a protection mode (road traffic will be blocked). This situation has a huge impact in operation, can motivate penalties and requires the presence of maintenance people to manually recover from this operation mode. The availability of this critical communication can be measured at level crossing controller

5.3.1.3. Mapping between Functional Requirements (FR) and Specific Service KPIs.

This section includes the direct relationship between the functional requirements gathered in D1.1 [1] and the specific Service KPIs applied to the use case. In this way, the reader can directly observe the Service KPIs that will be evaluated in order to validate the fulfilment of the correspondent pilot functional requirements.

TABLE 10: EFACEC_S UC1 MAPPING BETWEEN FUNCTIONAL REQUIREMENTS AND SPECIFIC SERVICE KPIS

UC Functional Requirements [1]		UC Service KPIs
FR-P3UC1-01	The communications between the components (track lines equipment's and LX controller) must use standard protocols both for safety and security	**Qualitative verification**
FR-P3UC1-02	A Strike-In detector/axel counter train detector system will be needed to detect trains approaching the Level Crossing	**Qualitative verification**

FR-P3UC1-03	A Train detector/ axel counter train detector system will be needed to detect if the train is occupying the Level Crossing section or to the detect the absence of the train in the section	**P3UC1-SKPI-1** – Communication Latency **P3UC1-SKPI-2** – Communication Availability
FR-P3UC1-04	A LX controller will be needed to receive sensors and equipment information and to assure the LX actions (railways signalling operation)	**P3UC1-SKPI-1** – Communication Latency **P3UC1-SKPI-2** – Communication Availability
FR-P3UC1-05	The communication between the Strike-in detectors and the LX controller must be supported over IP	**Qualitative verification**
FR-P3UC1-06	In a presence of communication failures, the LX must be set to its safe mode (protection mode)	**Qualitative verification**
FR-P3UC1-07	The communication between the axel counters and the LX controller must be 5G	**P3UC1-SKPI-1** – Communication Latency **P3UC1-SKPI-2** – Communication Availability
FR-P3UC1-08	Traffic lights will be needed to inform car driver's	**Qualitative verification**
FR-P3UC1-09	Protection Lx Signals will be needed to inform train drivers that the Level Crossing is free	**Qualitative verification**
FR-P3UC1-10	5G CPE devices will be needed to assure the 5G connectivity of Lx devices to 5G network	**P3UC1-SKPI-1** – Communication Latency **P3UC1-SKPI-2** – Communication Availability
FR-P3UC1-11	5G CPE devices must support Ethernet interfaces	**Qualitiative verification**
FR-P3UC1-12	The same Level of safety and security must be assured by the 5G network	**P3UC1-SKPI-1** – Communication Latency **P3UC1-SKPI-2** – Communication Availability
FR-P3UC1-13	The site pilot must be covered by a 5G network	**5GR-SKPI-7** – Extensive Network Coverage in Vertical Premises

5.3.2. Use Case 2: Non-Safety Critical Communications

This use case is broken down into two different scenarios. involving (*i*) HD video image transmission from level crossing surveillance camera to the approaching trains' on-board tablets and/or maintenance agents' handheld tablets and (*ii*) Level crossing controller status and alarm events transmission to maintenance agents' tablets.

The main objective of the first scenario is to transmit, supported by 5G communications, HD video images to the approaching train, allowing the driver to get images of the level crossing area, thus preventing accidents caused by cars trapped between the level crossing gates. In the scope of this UC, it is also desired to transmit the same video images to maintenance agents/Command Centre, providing this way, mechanisms to reinforce the level crossing safety.

Regarding the second scenario, the main objective is to allow maintenance agents to monitor (status and alarm event transmission) and manage, remotely, the level crossing controller, through a tablet device (5G communications).

Figure 13 depicts the use case overview, illustrating the relevant interface requiring URLL and eMBB slice capabilities.

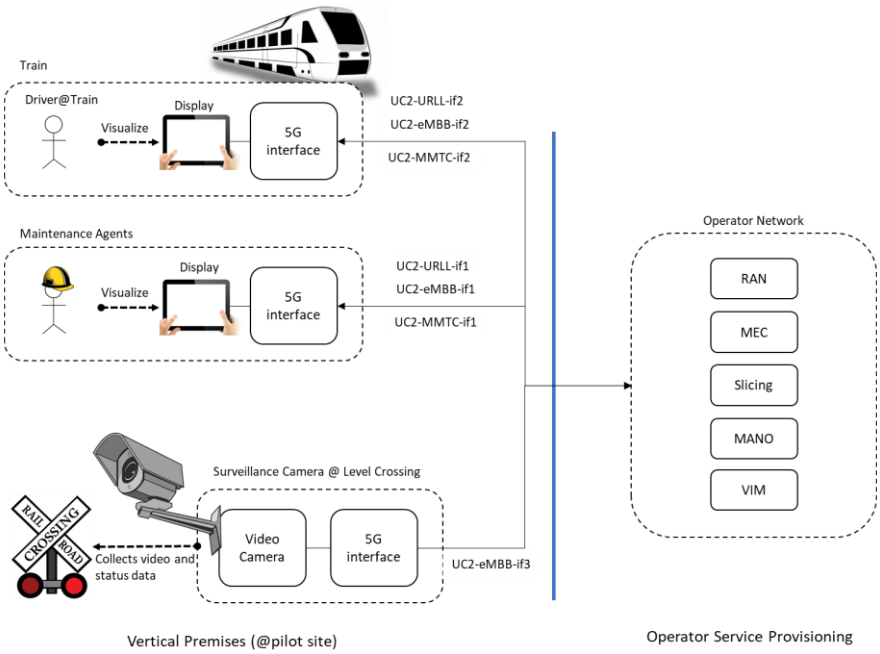

FIGURE 13: EFACEC_S UC2 OVERVIEW

5.3.2.1. P3UC2-SKPI1: High-definition Surveillance Video.

The control center and mobile devices (Train and maintenance agents) need to be able to visualize the HD surveillance video with good quality and low latency; that means MOS of at least 4[2] and in

[2] *Mean Opinion Score (MOS) is a well-known measure of video quality (5-Excellent, 4-Good, 3-Fair, 2-Poor, 1-Bad).*

accordance with Video Surveillance Systems[3]. The network needs to ensure the appropriate resources to transmit HD video with a good level of quality and without delay. That means a sustained bandwidth, low end-to-end latency and jitter.

As such, this use case SKPI applies to the general 5Growth **5GR-SKPI-4** "High-Resolution Real-Time Video Quality", which maps to the core CKPI-2 "Packet Loss", CKPI-3 "Guaranteed Data Rate", CKPI-8 "Data Volume" and CKPI-9 "Jitter".

Regarding CKPI-2 "Packet Loss", the link needs low packet loss in order to avoid any loss of quality to the video or its freeze. This UC does not apply to safety critical communications but is used to reinforce the safety conditions of the level crossing. However, to have real-time video images to help train drivers or maintenance agent to make decisions, no packet loss in the transmission must be assured. This KPI can be measured at tablet devices (train).

Regarding CKPI-3 "Guaranteed Data Rate", the link needs to guarantee enough data rate to support the video stream. A guaranteed data rate of 160 Mbps is needed to accommodate high video resolution and M-JPEG compression assuring that 2 trains in the same level crossing can receive, simultaneously the LX images. This KPI can be measured at tablet devices (train).

Regarding CKPI-8 "Data Volume", this KPI is not considered due to its low relevance regarding real-time video. The link needs to have enough capacity to hold the transmission of the video at the highest quality possible.

Regarding CKPI-9 "Jitter", interarrival delays need to be avoided in order not to impact the quality of the video. According to the best practices for real-time video systems applicable to railway scenarios, the latency should be less than 100 ms, in order to have optimal performance. This latency as a direct relationship with the train speed and the 5G network performance. Latency between 100 and 200 ms causes impact in images visualization and latency higher than 500 ms are unacceptable and any image shall be removable from the displays. This jitter can be measured at tablet devices (train) and at the command center.

5.3.2.2. P3UC2-SKPI2: Real-time Sensors Monitoring Latency.

Real-time status and alarm information need to reach the control center and maintenance team devices (Tablet) in useful time (less than 100ms). The network needs to ensure that the monitoring is performed with a **minimum** end-to-end latency so that the information can be collected with the appropriate accuracy.

As such, this use case SKPI applies to the general 5Growth **5GR-SKPI-2** "Sync between communication components", which maps to the core CKPI-1 "e2e latency" and CKPI-2 "packet loss".

[3] *IEC62676 Video Surveillance Systems for use in security application in terms of security, integrity, availability and latency*

Regarding the "CKPI-1 – e2e latency" packets (data messages) between the Lx Controller sensors and the maintenance teams need to be exchanged with low latency (< 100 ms) in order to allow the team to work without perceivable delay regarding the sensed information. If the data messages do not reach the destination with enough low latency, the quality of the maintenance team can be impacted. The latency can be measured at Tablet Devices.

For the "CKPI-2: packet loss", the communication between the sensors and the maintenance crew involves two different kinds of packets (data messages): i) events that occur when a new train is approaching the level crossing and ii) other protocolary messages such as keep-alive messages to guarantee a stable communication between the devices. The latency can be measured at Tablet Devices (maintenance teams).

5.3.2.3. P3UC2-SKPI3: Real-time Sensors Monitoring and Visualization Data Connection Availability.

The network needs to ensure that the monitoring services are continuously provided with a high level of reliability and availability in order to manage the status and alarms in a proper way, allowing them to make decisions in near-real-time. As such, this use case SKPI applies to the general 5Growth 5GR-SKPI-10 "Service availability", which maps to the core CKPI-5 "Availability".

Regarding the "CKPI-5 – Availability", the KPI can be measured at Tablet Devices (maintenance teams).

5.3.2.4. Mapping between Functional Requirements (FR) and Specific Service KPIs.

This section includes the direct relationship between the functional requirements gathered in D1.1 [1] and the specific Service KPIs applied to the use case. In this way, the reader can directly observe the Service KPIs that will be evaluated in order to validate the fulfilment of the correspondent pilot functional requirements.

TABLE 11: EFACEC_S UC2 MAPPING BETWEEN FUNCTIONAL REQUIREMENTS AND SPECIFIC SERVICE KPIS

UC Functional Requirements [1]		UC Service KPIs
FR-P3UC2-01	At least a HD camera must be installed in the LX area	**Qualitative verification**
FR-P3UC2-02	Geolocation coordinates must be received by GPS	**Qualitative verification**
FR-P3UC2-03	Tablet devices must support 5G communications	**P3UC2-SKPI-1** – High-definition surveillance video **P3UC2-SKPI-3** – Real-time sensors monitoring and visualization data connection availability
FR-P3UC2-04	5G communication must available to exchange information between the system components	**P3UC2-SKPI-1** – High-definition surveillance video **P3UC2-SKPI-2** – Real-time sensors monitoring latency

		P3UC2-SKPI-3 – Real-time sensors monitoring and visualization data connection availability
FR-P3UC2-05	Video Images must be visualized in Tablet Devices	**P3UC2-SKPI-1** – High-definition surveillance video
FR-P3UC2-06	Video Camera must support IP protocols and interfaces	**P3UC2-SKPI-1** – High-definition surveillance video
FR-P3UC2-07	5G CPE devices will be needed to assure the 5G connectivity of system devices to 5G network	**Qualitative verification**
FR-P3UC2-08	A command centre will be needed to aggregate information (video images and to broadcast alarms)	**Qualitative verification**
FR-P3UC2-09	An app for mobile devices (Tablet) must be supplied mainly for supervision purposes and to visualize video images regarding Level Crossing areas	**P3UC2-SKPI-1** – High-definition surveillance video
FR-P3UC2-10	The site pilot must be covered by a 5G network	**5GR-SKPI-7** – Extensive Network Coverage in Vertical Premises

5.4. Energy Pilot – EFACEC Energia

5.4.1. Use Case 1: Advanced Monitoring and Maintenance Support for Secondary Substation MV/LV Distribution Substation

The main goal of this Use Case is to implement an efficient control system in a secondary substation of the University of Aveiro, supporting both the real-time network operation in the Control Centre and the maintenance activities executed by field teams.

Upon receiving a work order from the Control Center, the field team will be capable to immediately watch the live video feed from the secondary substation and, when arriving at the site, will be assisted with the necessary maintenance actions by an augmented reality functionality.

With these tools, it is possible to aid and optimize the repair and replacement of damaged equipment, upon a fault detection in a secondary substation.

5.4.1.1. P4UC1-SKPI-1: Monitoring Sensors Information Collection and Visualization End-to-end Latency.

An alarm triggered in a secondary substation with the relevant sensor information needs to reach the control center and the maintenance team in less than 100ms. The 5G network needs to ensure

minimum end-to-end latency, allowing the telemetric information to reach the control center and the mobile crew with no perceived delay associated.

As such, this use case SKPI applies to the general 5Growth **5GR-SKPI-2** "Sync between communication components", which maps to the core CKPI-1 "e2e latency" and CKPI-2 "packet loss.

Regarding the "CKPI-1 – e2e latency", the different measurement devices, control center and maintenance crew devices need to receive and send their information with low latency.

In what concerns to the visualization in the Control center (operator workstation), the KPI can be measured at the Control Centre, by inspection and comparison of the data source time and data processed time of each telemetered event.

In what concerns to the visualization in the mobile interface (tablet device, handheld by the maintenance team), the KPI can be measured at the Tablet Device, by inspection and comparison of the data source time, data processed time (server) and data processed time (tablet) of each telemetered event.

For the "CKPI-2: packet loss", the different measurement devices, control center and maintenance crew devices need to receive and send their information.

5.4.1.2. P4UC1-SKPI-2: Monitoring Sensors Information Collection and Visualization Availability.

An alarm triggered in a secondary substation with the relevant sensor information needs to reach the control center and the maintenance team with high availability to ensure timely failure detection. The network needs to provide **maximum** reliability to ensure that monitoring information is transmitted continuously and with no **packet loss**, to prevent retransmissions and information not timely reached.

As such, this use case SKPI applies to the general 5Growth **5GR-SKPI-10** "Service availability", which maps to the core CKPI-5 "Availability" as well as the **5GR-SKPI-2** "Synchronization between Communication Components", which maps to the core CKPI-2 "Packet Loss" (it also maps to the CKPI-1 "Latency" but it is not considered relevant for P4UC1-SKPI-2).

Regarding "CKPI-5: Availability", the service needs to be available for continuously sending the monitoring data and video surveillance.

The KPI can be measured at the Control Centre, by inspection of the logs of the "keep-alive" function in the SCADA Frontend module.

Regarding "CKPI-2: Packet Loss", the different measurement devices, control center and maintenance crew devices need to receive and send their information.

The KPI can be measured both at the Control Centre and at the tablet device.

5.4.1.3. P4UC1-SKPI-3: High-definition Surveillance Video.

The control center and the maintenance crews need to be able to visualize the HD surveillance video with good quality and low latency. The network must sustain an ensured required bandwidth for the video service, in order to allow the delivery of HD video with no glitches and enable remote crew assistance to work effectively.

As such, this use case SKPI applies to the general 5Growth **5GR-SKPI-4** – "High-Resolution Real-Time Video Quality", which maps to the core CKPI-2 "Packet Loss", CKPI-3 "Guaranteed Data Rate", CKPI-8 "Data Volume" and CKPI-9 "Jitter".

Regarding the CKPI-2 "Packet Loss", the link needs low packet loss in order to avoid any loss of quality to the video or its freeze._Regarding the CKPI-3 "Guaranteed Data Rate", the link needs to guarantee enough data rate to support the video stream. Regarding the CKPI-8 "Data Volume", the link needs to have enough capacity to hold the transmission of the video at the highest quality possible.

Regarding the CKPI-9 "Jitter", the interarrival delays need to be avoided in order not to impact the quality of the video.

In what concerns to the visualization in the Control center (operator workstation), the KPI can be measured at the operator workstation. In what concerns to the visualization in the mobile interface (tablet device, handheld by the maintenance team), the KPI can be measured at the Tablet Device.

5.4.1.4. P4UC1-SKPI-4: Augmented Reality Information Real-time End-to-end Latency.

The augmented reality (AR) application will need to use real-time video from the mobile device (ex. Smartphone) and real-time information from the installation through the control center. If the information does not come on time, the AR service will lose integrity, representing wrong or not timely information on top of live video streaming. The network needs to ensure **minimum** end-to-end latency, allowing the telemetric information to reach the control center and the mobile crew with no perceived delay associated, enabling a correct representation of data over the video.

Therefore, this UC1 SKPI shares the same considerations as presented in P4UC1-SKPI-1 "Monitoring sensors information collection and visualization must have an end-to-end latency below 100ms (<100ms)." in section 5.4.1.1. Concretely, it also applies to the general 5Growth **5GR-SKPI-2** "Sync between communication components", which maps to the core CKPI-1 "e2e latency" and CKPI-2 "packet loss.

The KPI can be measured at the Tablet Device, by inspection and comparison of the data source time, data processed time (server) and data processed time (tablet) of each telemetered event.

5.4.1.5. P4UC1-SKPI-5: Augmented Reality information Real-time Availability.

The augmented reality (AR) application will stream real-time video from the mobile device (ex. Smartphone) and must have high availability and low packet loss to ensure that data is timely collected and represented on top of live video streaming. The network needs to ensure **high availability**, ensuring a continuous service for data delivery. It also needs low **packet loss,** preventing information re-transmission, which will cause undesirable effects on the AR service.

Therefore, this UC1 SKPI shares the same considerations as presented in P4UC1-SKPI-2 "Monitoring sensors information collection and visualization must be available more than 99.9% of the time (>99.9%)." in section 5.4.1.2. Concretely, it also applies to the general 5Growth **5GR-SKPI-10** "Service availability", which maps to the core CKPI-5 "Availability" as well as the **5GR-SKPI-2** "Synchronization between Communication Components", which maps to the core CKPI-2 "Packet Loss" (it also maps to the CKPI-1 "Latency" but it is not considered relevant for P4UC1-SKPI-2). The KPI can be measured at the tablet device.

5.4.1.6. Mapping between Functional Requirements (FR) and Specific Service KPIs.

This section includes the direct relationship between the functional requirements gathered in D1.1 [1] and the specific Service KPIs applied to the use case. In this way, the reader can directly observe the Service KPIs that will be evaluated in order to validate the fulfilment of the correspondent pilot functional requirements.

TABLE 12: EFACEC_E UC1 MAPPING BETWEEN FUNCTIONAL REQUIREMENTS AND SPECIFIC SERVICE KPIS

UC Functional Requirements [1]		UC Service KPIs
FR-P4UC1-01	The communications between the components (Low voltage sensor, LV controller, and HD video camera) must use standard protocols	**Qualitative verification**
FR-P4UC1-02	The communication between the LV sensor and LV controller must be RS 485 using Modbus protocol	**Qualitative verification**
FR-P4UC1-03	The connection between the HD video camera and LV Controller must be Ethernet or wireless	**Qualitative verification**
FR-P4UC1-04	The LV controller and HD video camera must be connected to a router with 5G communication	**Qualitative verification**
FR-P4UC1-05	A digital input in the LV controller must be available to receive the intrusion alarm	**Qualitative verification**
FR-P4UC1-06	The connection between the secondary substation (LV controller and HD video camera) and the control centre must be 5G	**P4UC1-SKPI-1** – Monitoring sensors information collection and visualization end-to-end latency **P4UC1-SKPI-2** – Monitoring sensors information collection and visualization availability **P4UC1-SKPI-3** – High Definition surveillance video

FR-P4UC1-07	5G communication must be used between the smartphone and control centre	**P4UC1-SKPI-4** – Augmented reality information real-time end-to-end latency **P4UC1-SKPI-5** – Augmented reality information real-time availabillity
FR-P4UC1-08	The fault detection functionality must be implemented in the low voltage sensor	**Qualitative verification**
FR-P4UC1-09	The fault must be transmitted to the control centre whenever is detected	**P4UC1-SKPI-1** – Monitoring sensors information collection and visualization end-to-end latency
FR-P4UC1-10	Transmission of HD video from the secondary substation to the control centre must be implemented	**P4UC1-SKPI-3** – High Definition surveillance video
FR-P4UC1-11	A SCADA system must be implemented for monitoring and control of the low voltage network	**Qualitiative verification**
FR-P4UC1-12	The intrusion sensor must be available	**P4UC1-SKPI-2** – Monitoring sensors information collection and visualization availability
FR-P4UC1-13	The intrusion alarm must be transmitted to the control centre whenever is activated	**P4UC1-SKPI-1** – Monitoring sensors information collection and visualization end-to-end latency
FR-P4UC1-14	The control centre must have the capacity to send information to the maintenance crew whenever is needed	**P4UC1-SKPI-2** – Monitoring sensors information collection and visualization availability **P4UC1-SKPI-5** – Augmented reality information real-time availabillity
FR-P4UC1-15	The maintenance crew must have a smartphone with capacity to receive messages from the control centre	**Qualitiative verification**
FR-P4UC1-16	The control centre must have the capacity to send a command to the secondary substation to start the transmission of the HD video	**Qualitiative verification**
FR-P4UC1-17	An augmented reality application must be available to be installed in the smartphone for maintenance support	**P4UC1-SKPI-5** – Augmented reality information real-time availabillity
FR-P4UC1-18	The LV sensor must be connected to the LV network using Rogowski coils for currents and direct connection for the voltages	**Qualitiative verification**
FR-P4UC1-19	The LV controller must be connected to the LV network using current	**Qualitiative verification**

	transformers for currents and direct connection for the voltages	
FR-P4UC1-20	An intrusion sensor must be installed in the substation door	**Qualitiative verification**
FR-P4UC1-21	The control centre must be installed in the cloud with connectivity to the 5G network	**Qualitiative verification**

5.4.2. Use Case 2: Advanced Critical Signal and Data Exchange Across Wide Smart Metering and Measurement Infrastructures

The goal of this Use Case is to develop a new supervision architecture for the low voltage network, in order to reduce downtime/outage duration and the number of customers affected by the outage.

Relying on an enhanced level of automation in the secondary substations and low voltage distribution network, and also on the LV device connectivity through the 5G network, it will be possible to detect and locate an electric grid fault occurring in the low voltage distribution network in real-time, which will be immediately notified to the control center operator. The Control Centre operator will then be able to send precise information to the maintenance team identifying the electric grid fault location, which will lead to a significant reduction on the time taken to restore the power to the affected costumers.

5.4.2.1. P4UC2-SKPI1: Last-gasp Information End-to-end latency.

In a power outage situation, last-gasp capable devices must be able to send their latest information in memory to the control center, via 5G network, before the devices cannot send it anymore (because of a power outage). The network needs to send the last-gasp capable devices information as soon as it is generated with very low **latency**, to ensure that the device still has power.

As such, this use case SKPI applies to the general 5Growth **5GR-SKPI-2** "Sync between communication components", which maps to the core CKPI-1 "e2e latency" and CKPI-2 "packet loss.

Regarding the "CKPI-1 – e2e latency", the last gasp information needs to be sent out as soon as it is generated.

The KPI can be measured in the GSmart device, by inspection and comparison of the data source time and data reception time (GSmart) of each last gasp.

For the "CKPI-2: packet loss", the last gasp information needs to be sent with no packet loss.

The KPI can be measured in the GSmart device, by inspection and comparison of the received last gasps with the set of triggered and timestamped power outages at the source. This measurement has the particularity that, since transmission is done using UDP, there can be potential unrecoverable packet loss.

5.4.2.2. P4UC2-SKPI2: Last-gasp Information Connectivity Availability.

In a power outage situation, the last-gasp capable devices must be able to send their latest information in memory to the control center, via 5G network, ensuring that the network is available and has no packet loss. The network needs to send the last-gasp capable devices information in a continuous manner requiring that the network service is highly **available**, and without **packet loss,** as there will be no chance for retransmission.

As such, this use case SKPI applies to the general 5Growth **5GR-SKPI-10** "Service availability", which maps to the core CKPI-5 "Availability" as well as the **5GR-SKPI-2** "Synchronization between Communication Components", which maps to the core CKPI-2 "Packet Loss" (it also maps to the CKPI-1 "Latency" but it is already considered in P4UC2-SKPI1).

Regarding "CKPI-5: Availability", the system needs to be available whenever there is a need to send last gasp information.

The KPI can be measured in the GSmart device, by inspection of the logs of the "keep-alive" function over the connected low voltage sensors.

Regarding "CKPI-2: Packet Loss", the KPI can be measured in the GSmart device.

5.4.2.3. P4UC2-SKPI3: Secondary Substation End-to-end Latency.

While analyzing the power outage event, the control center crew can issue further queries to the monitoring system, requesting more information. In this case, the latency requirement can be least stringent when compared to the live power outage. As the reconstruction of the power outage event requires very precise analysis, the analysis crew needs to be able to collect information quickly. The information needs to be sent with very low delay when it is requested.

Therefore, this UC1 SKPI shares the same considerations as presented in P4UC2-SKPI-1 "Last-gasp information must reach the control center in less than 20ms (<20ms)" in section 5.4.2.1. Concretely, it also applies to the general 5Growth **5GR-SKPI-2** "Sync between communication components", which maps to the core CKPI-1 "e2e latency" and CKPI-2 "packet loss. This SKPI, however, can be revisited in the future regarding its usefulness, as it ends up being covered by the remaining SKPI's in UC1.

5.4.2.4. P4UC2-SKPI4: Secondary Substation Availability.

While analyzing the power outage event, the control center crew can issue further queries to the monitoring system, requesting more information. For that purpose, the network needs to be continuously available. As the reconstruction of the power outage event requires very precise analysis, the analysis crew needs to be able to collect information, requiring that the network service is always **available** to fulfill the communication need, and without **packet loss**.

Therefore, this UC SKPI shares the same considerations as presented in P4UC2-SKPI-2 "Last-gasp information connectivity with the control center must be available more than 99.9% of the time

(>99.9%)" in section 5.4.2.2. Concretely, it also applies to the general 5Growth **5GR-SKPI-10** "Service availability", which maps to the core CKPI-5 "Availability" as well as the **5GR-SKPI-2** "Synchronization between Communication Components", which maps to the core CKPI-2 "Packet Loss" (it also maps to the CKPI-1 "Latency" but it is not considered relevant for P4UC1-SKPI-2). This SKPI, however, can be revisited in the future regarding its usefulness, as it ends up being covered by the remaining SKPI's in UC1.

5.4.2.5. P4UC2-SKPI5: Time Synchronization between all Sensors.

The time synchronization commands sent by the control center to the smart sensors will need to guarantee the synchronization between all sensors equal to or less than 1ms. In order to keep the devices all timely synchronized, the connectivity among them needs to be of **low latency** and jitter should be as lower as possible in order to enable a predictive latency, which is an important aspect of time synchronization.

Therefore, this UC SKPI shares the same considerations as presented in P4UC2-SKPI-1 "Last-gasp information must reach the control center in less than 20ms (<20ms)" in section 5.4.2.1. Concretely, it also applies to the general 5Growth **5GR-SKPI-2** "Sync between communication components", which maps to the core CKPI-1 "e2e latency" and CKPI-2 "packet loss.

The KPI can be measured in the GSmart device, where the source time of the received low voltage event can be compared against the time configured on the LV Generator for firing that event, to measure the time synchronization accuracy.

5.4.2.6. Mapping between Functional Requirements (FR) and Specific Service KPIs.

This section includes the direct relationship between the functional requirements gathered in D1.1 [1] and the specific Service KPIs applied to the use case. In this way, the reader can directly observe the Service KPIs that will be evaluated in order to validate the fulfilment of the correspondent pilot functional requirements.

TABLE 13: EFACEC_E UC2 MAPPING BETWEEN FUNCTIONAL REQUIREMENTS AND SPECIFIC SERVICE KPIS

UC Functional Requirements [1]		UC Service KPIs
FR-P4UC2-01	The connection between the distribution cabinet (LV sensor) and LV Controller must be 5G	**P4UC2-SKPI-1** – Last-gasp information end-to-end latency **P4UC2-SKPI-3** – Secondary substation end-to-end latency
FR-P4UC2-02	The control centre must run an algorithm to detect the location of the fault	**Qualitative verification**
FR-P4UC2-03	The control centre must send controls to the LV sensors in order to reconfigure the LV network	**Qualitative verification**

FR-P4UC2-04	The control centre must send date and time to all the LV sensors installed in the low voltage network	**P4UC2-SKPI-5** – Time synchronization between all sensors
FR-P4UC2-05	The fault detection functionality must be implemented in the low voltage sensors	**Qualitative verification**
FR-P4UC2-06	The fault must be transmitted to the control centre whenever is detected	**P4UC2-SKPI-1** – Last-gasp information end-to-end late ncy **P4UC2-SKPI-3** – Secondary substation end-to-end latency
FR-P4UC2-07	A SCADA system must be implemented for monitoring and control of the low voltage network	**P4UC2-SKPI-2** – Last-gasp information availability **P4UC2-SKPI-4** – Secondary substation availability
FR-P4UC2-08	The SCADA system must have the capacity to send information to the maintenance crew whenever is needed	**Qualitative verification**
FR-P4UC2-09	The SCADA system must know the low voltage network topology to identify the location of the fault	**Qualitiative verification**
FR-P4UC2-10	The LV sensor must be connected to the low voltage network using Rogowski coils for currents and direct connection for the voltages	**Qualitiative verification**
FR-P4UC2-11	The SCADA system must be installed in the cloud with connectivity to the 5G network	**Qualitiative verification**
FR-P4UC2-12	LV sensor power supply with storage capability to ensure the conditions for the last-gasp message (before turning off)	**P4UC2-SKPI-2** – Last-gasp information availability
FR-P4UC2-13	5G communication services available	**P4UC2-SKPI-2** – Last-gasp information availability **P4UC2-SKPI-4** – Secondary substation availability
FR-P4UC2-14	Low latency communications: a. < 5ms for last gasp b. < 1ms for synchronization c. < 20ms for control plane latency	**P4UC2-SKPI-1** – Last-gasp information end-to-end latency **P4UC2-SKPI-3** – Secondary substation end-to-end latency **P4UC2-SKPI-5** – Time synchronization between all sensors.
FR-P4UC2-15	Wide Area Coverage at least 10 km2	**5GR-SKPI-7** – Extensive Network Coverage in Vertical Premises

FR-P4UC2-16	The self-healing algorithm can run on the edge	**Qualitiative verification**
FR-P4UC2-17	A LV Controller must be installed in the secondary substation to concentrate all the information from the low voltage network	**Qualitiative verification**

6. Conclusions

Deliverable D4.1 consolidates the work performed in T4.1 with respect to KPI identification and definition, with the purpose of setting the basis for the evaluation of the vertical pilots implemented by the 5Growth project. Given the industrial and business nature of the 5G use cases implemented, an innovative classification of KPIs has been applied, dividing the KPIs identified into two different levels: Core 5G KPIs and Service KPIs. Core 5G KPIs are technical KPIs that evaluate performance paramaters at the network and infrastructure level of the use case. In most cases, these technical KPIs are transparent for the verticals, who are not aware of the underlying infrastructure of their services. Therefore, the need for Service KPIs that evaluate end-to-end 5G industrial scenarios from the vertical point of view arises. More in detail, Service KPIs evaluate qualitative aspects of the pilots that are not directly measurable, to ensure that the functional and business requirements [1] of the use cases are met. Due to Service KPIs are not directly measurable, a mapping between Service and Core 5G KPIs has been defined in this deliverable. This mapping states the specific components and interfaces where the Core 5G KPIs can be measured in the use cases infrastructure, in addition to how the Service KPIs are extrapolated from different Core 5G KPI combinations.

Regarding future work, task T4.2 of the project is dedicated to define the tools and methodology needed to measure the KPIs here identified. Furthermore, the validation trials for the 5Growth vertical pilots will leverage the KPIs and tools defined to evaluate whether the deployment of the different use cases satisfy the expected performance requirements. Ultimately, the objective is not restricting the KPIs defined only to evaluate the 5Growth use cases, but use them as well to define realistic vertical SLAs and extrapolate them to other 5G industrial scenarios.

7. References

[1] 5Growth, D1.1, Business Model Design, August 2019. https://5growth.eu/svn/5growth/execution/WP1/deliverables/D1.1/D1.1-Business_Model_Design.pdf

[2] TMV-WG, Validating 5G Technology Performance Assessing 5G architecture and Application Scenarios, June 2019. https://5g-ppp.eu/wp-content/uploads/2019/06/TMV-White-Paper-V1.1-25062019.pdf

[3] Ericsson, 5G Use Cases. https://www.ericsson.com/4a8d61/assets/local/5g/5g-use-cases-ericsson.pdf

[4] 5Growth, D3.2, Specification of ICT17 in-house deployment, May 2020. https://5growth.eu/svn/5growth/execution/WP3/deliverables/D3.2/D3.2-Specification_of_ICT17_in-house_deployment.pdf

[5] 5G-EVE, D4.1, Experimentation tools and VNF repository, October 2019. https://doi.org/10.5281/zenodo.3628201

[6] 5G-VINNI, D4.1, Initial report on test-plan creation and methodology, and development of test orchestration framework, July 2019. https://doi.org/10.5281/zenodo.3345626

8. Appendix A – COVID-19 Impact Analysis on Plans and Roadmaps

In the scope of WP3, the deliverable D3.2 [4] contains a dedicated section evaluating the impact analysis related to the COVID-19. According with this analysis, the COVID-19 restrictions may cause a worst-case scenario of four month of unavailability for on-site (COMAU premises, TIM premises, SMEs and universities, regarding vertical COMAU Pilot; 5TONIC premises, regarding vertical INNOVALIA Pilot; University of Aveiro, EFACEC premises and ALB laboratories, regarding vertical Energy EFACEC_E Pilot; and University of Aveiro, Aveiro Harbour, EFACEC premises and ALB laboratories, regarding vertical Transportation EFACEC_S Pilot) activities, motivating an impact in the original plan for all vertical pilots.

Therefore, in order to evaluate further implications in related Work Packages, in this section, a pilot basis impact analysis is performed related to WP4 activities (verification and validation campaigns) focusing on KPI measurements.

Industry 4.0 Pilot – INNOVALIA

As described in D3.2 [4], the COVID-19 restrictions cause three major impacts in INNOVALIA Pilot: i) Equipment availability for performing initial integration and testing with 5TONIC ii) 5G equipment with Stand Alone option and iii) 5Growth integration with 5G-EVE at 5TONIC. Before COVID-19 the initial plan estimation was to achieve this goal at March 2020, June 2020 and December 2020 respectively. The COVID-19 restrictions have motivated a change in the goal related to the realization of preliminary tests at 5TONIC, by performing tests at INNOVALIA premises but considering a commercial 4G network, also have motivated an estimated delay of three months in the second goal (Stand Alone option) and finally have motivated to relax the ambition of the 5Growth integration with 5G-EVE at 5TONIC , performing the integration at INNOVALIA premises but only in April 2021.

These considerations affect the activities of KPI measurements causing delays in the initial plan and roadmap and cause some changes in the initial goals.

Use Case 1: Connected Worker Remote Operation of Quality Equipment

Table 14 shows the SKPIs of the INNOVALIA use case 1 and the estimated impact (delays/initial goals) motivated by COVID-19.

TABLE 14: ESTIMATED COVID-19 IMPACT ON INNOVALIA USE CASE 1

UC-SKI- ID	KPI description	Impact on M18	Impact on initial goal
P1UC1-SKPI-1	Teleworker-CMM Synchronization	To be performed at M18	To be performed at 5TONIC, even though 5Growth solution will not be fully integrated with 5G-EVE platform.

P1UC1-SKPI-2	High-resolution Real-time Video Quality	To be performed at M18	To be performed at 5TONIC, even though 5Growth solution will not be fully integrated with 5G-EVE platform.
P1UC1-SKPI-3	Service Setup Time	To be performed after M18	Not possible to be performed at M18, since it requires 5Growth integration with 5G-EVE and first SW release
P1UC1-SKPI-4	Radius of Operation	To be performed at M18	To be performed at 5TONIC, even though 5Growth solution will not be fully integrated with 5G-EVE platform.
P1UC1-SKPI-5	Integrated Multitype Communications	To be performed at M18	To be performed at 5TONIC, even though 5Growth solution will not be fully integrated with 5G-EVE platform.
P1UC1-SKPI-6	Extensive Network Coverage in the Factory Premises	To be performed at M18	To be performed at 5TONIC, even though 5Growth solution will not be fully integrated with 5G-EVE platform.

Use Case 2: Connected Worker: Augmented Zero Defect Manufacturing (ZDM) Decision Support System (DSS)

Table 15 shows the SKPIs of the INNOVALIA use case 2 and the estimated impact (delays/initial goals) motivated by COVID-19

TABLE 15: ESTIMATED COVID-19 IMPACT ON INNOVALIA USE CASE 2

UC-SKI- ID	KPI description	Impact on M18	Impact on initial goal
P1UC2-SKPI-1	Service Operation Time	To be performed after M18	Not possible to be performed at M18, since it requires 5Growth integration with 5G-EVE and first SW release.
P1UC2-SKPI-2	Service Operation Capacity	To be performed after M18	Not possible to be performed at M18, since it requires 5Growth integration with 5G-EVE and first SW release.
P1UC2-SKPI-3	Service Creation Time	To be performed after M18	Not possible to be performed at M18, since it requires 5Growth integration with 5G-EVE and first SW release.
P1UC2-SKPI-4	AGV-Edge Control Synchronization	To be performed at M18	To be performed at 5TONIC, even though 5Growth solution will not be fully integrated with 5G-EVE platform.

P1UC2-SKPI-5	Network support for user mobility	To be performed at M18	To be performed at 5TONIC, even though 5Growth solution will not be fully integrated with 5G-EVE platform.
P1UC2-SKPI-6	Concurrency of simultaneous users in a given area	To be performed at M18	To be performed at 5TONIC, even though 5Growth solution will not be fully integrated with 5G-EVE platform.

Industry 4.0 Pilot – COMAU

Taking in consideration the original plan, the KPI measurements of COMAU Use Cases will start at month 10 (M10) and will end by month 24 (M24). Even considering the COVID-19 restriction, this plan will be kept for Use Case 1 and 2 and it is assumed that all KPI will be provided according to the initial plan. Regarding the Use Case 3, a two month delay is estimated regarding M24. Additionally, taking in consideration month 18 (M18) a gap is being considered. At M18, the measurements will be provided without monitoring platform implementation and and all measurements related to KPI planned for M18 will be done using a point-to-point transport network. In parallel, E2E latency measurements on the target transport network (based on a ring) will be done to assess the impact on transport before integration with the E2E infrastructure which is planned in M24.

Next subsections show, for the three COMAU Use Cases, the plan and estimated roadmap impact.

Use Case 1: Digital Twin Apps

Figure 14 illustrates the delays (in red) caused by the COVID-19 impact on the original roadmap (in green) planned for the COMAU use case 1.

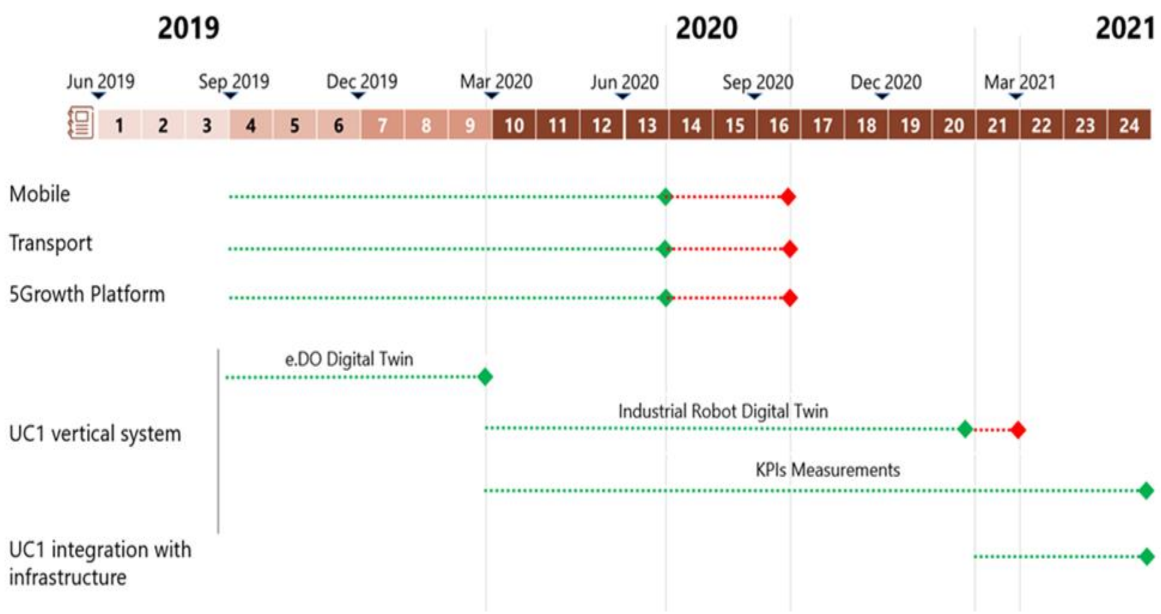

FIGURE 14: COMAU USE CASE 1 ROADMAP DELAY DUE TO COVID-19

Use Case 2: Telemetry/Monitoring Apps

Figure 15 illustrates the delays (in red) caused by the COVID-19 impact on the original roadmap (in green) planned for the COMAU use case 2.

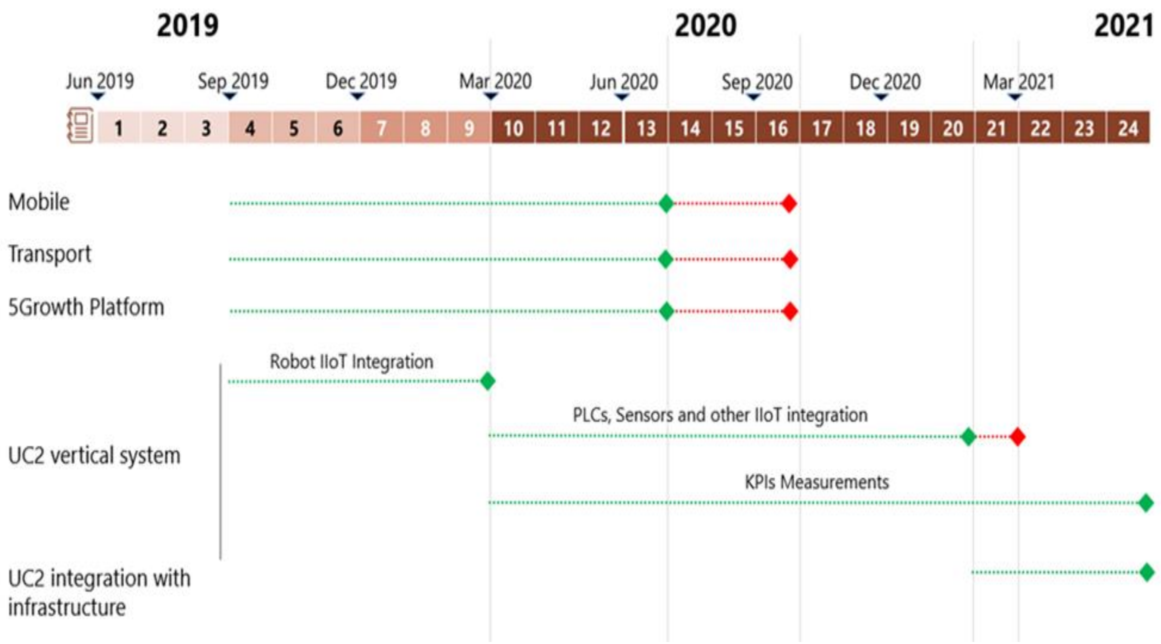

FIGURE 15: COMAU USE CASE 2 ROADMAP DELAY DUE TO COVID-19

Use Case 3: Digital Tutorial and Remote Support

Figure 16 illustrates the delays (in red) caused by the COVID-19 impact on the original roadmap (in green) planned for the COMAU use case 3.

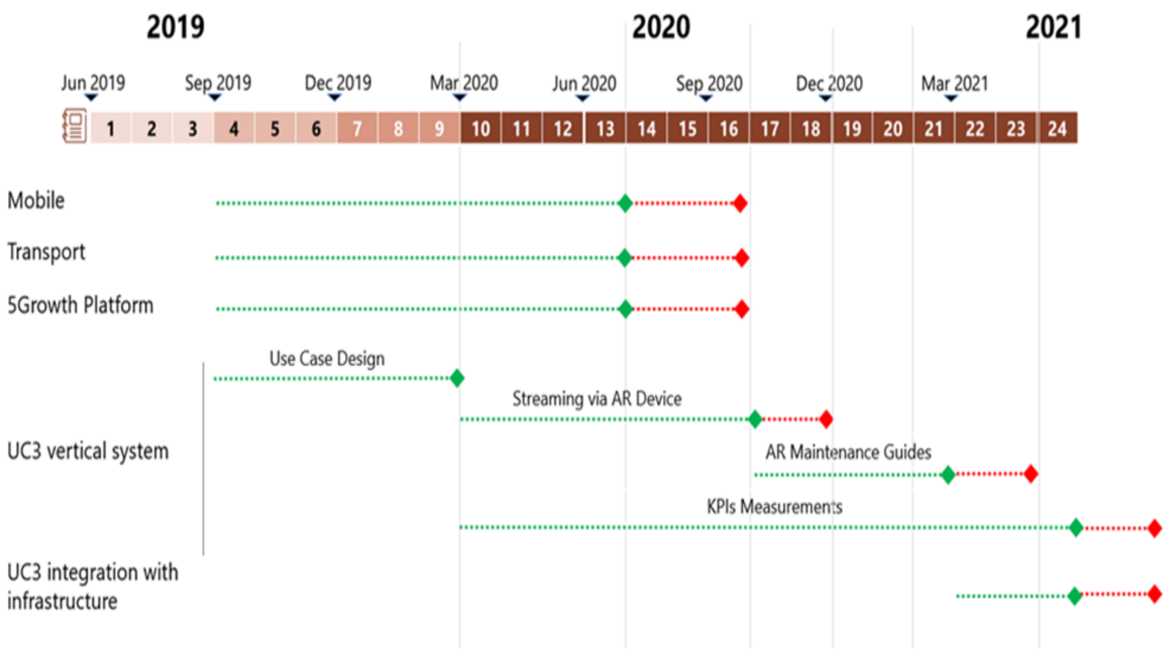

FIGURE 16: COMAU USE CASE 3 ROADMAP DELAY DUE TO COVID-19

Transportation Pilot – EFACEC Engenharia e Sistemas

As detailed in D3.2 [4] the COVID-18 restrictions caused several major impacts; i) Pilot availability at EFACEC_E premises ii) 5G network infrastructure availability at IT Aveiro premises iii) 5G network full functionalities and iv) Pilot complete integration at IT Aveiro premises.

Before COVID-19, the initial plan estimation was to achieve these goals at June 2020, September 2020, March 2021 and August 2021 respectively. Except the final Pilot integration, which is expected to keep the initial planned date, the COVID-19 restrictions had motivated a four month delay in the other goals. Nevertheless, motivated by these delays in previous activities it is expected less time for final integration, less time for verification and validation and less time for global performance evaluation of the Pilot. Because of these limitations and since according these dates the 5G network is not available at IT Aveiro premises in month 18 (M18) it was decided to perform the preliminary integration and KPI's measurements at IT Aveiro Lab (instead of being performed in the physical secondary substation).

These considerations affect the activities of KPI measurements causing delays in the initial plan and roadmap and cause some changes in the initial goals.

Use Case 1: Safety Critical Communications

Table 16 shows the SKPIs of the EFACEC_S use case 1 and the estimated impact (delays/initial goals) motivated by COVID-19.

TABLE 16: ESTIMATED COVID-19 IMPACT ON EFACEC_S USE CASE 1

UC-SKI- ID	KPI description	Impact on M18	Impact on initial goal
P3UC1-SKPI-1	Communication Latency between LX Detectors and LX Controller	To be performed at M18	To be performed at IT Aveiro/lab environment (ICT-17/5Growth) instead of Aveiro Harbour premises. Safety critical components and simulations will be used instead of a real Pilot scenario.
P3UC1-SKPI-2	Communication Availability between LX Detectors and LX Controller	To be performed after M18	Service availability will be performed in a real Pilot scenario.

Use Case 2: Non-Safety Critical Communications

Table 17 shows the SKPIs of the EFACEC_S use case 2 and the estimated impact (delays/initial goals) motivated by COVID-19.

TABLE 17: ESTIMATED COVID-19 IMPACT ON EFACEC_S USE CASE 2

UC-SKI- ID	KPI description	Impact on M18	Impact on initial goal
P3UC2-SKPI-1	High-Definition Surveillance Video	To be performed at M18	To be performed at IT Aveiro/lab environment (ICT-17/5Growth) instead of Aveiro Harbour premises. An automotive solution instead of a train
P3UC2-SKPI-2	Real-time Sensors Monitoring Latency	To be performed at M18	To be performed at IT Aveiro/lab environment (ICT-17/5Growth) instead of Aveiro Harbour premises
P3UC2-SKPI-3	Real-time Sensors Monitoring and Visualization Data Connection Availability	To be performed after M18	Service availability will be performed in real Pilot scenario

Energy Pilot – EFACEC Energia

As detailed in D3.2 [4] the COVID-18 restrictions caused several major impacts; i) Pilot availability at EFACEC_E premises ii) 5G network infrastructure availability at IT Aveiro premises iii) 5G network full functionalities and iv) Pilot complete integration at IT Aveiro premises.

Before COVID-19, the initial plan estimation was to achieve these goals at June 2020, September 2020, March 2021 and August 2021 respectively. Except the final Pilot integration, which is expected to keep the initial planned date, the COVID-19 restrictions had motivated a four month delay in the other goals. Nevertheless, motivated by these delays in previous activities it is expected less time for final integration, less time for verification and validation and less time for global performance evaluation of the Pilot. Because of these limitations and since according these dates the 5G network is not available at IT Aveiro premises in month 18 (M18) it was decided to perform the preliminary integration and KPI's measurements at IT Aveiro Lab (instead of being performed in the physical secondary substation).

These considerations affect the activities of KPI measurements causing delays in the initial plan and roadmap and cause some changes in the initial goals.

Use Case 1: Advanced Monitoring and Maintenance Support for Secondary Substation MV/LV Distribution Substation

Table 18 shows the SKPIs of the EFACEC_E use case 1 and the estimated impact (delays/initial goals) motivated by COVID-19.

TABLE 18: ESTIMATED COVID-19 IMPACT ON EFACEC_E USE CASE 1

UC-SKI- ID	KPI's description	Impact on M18	Impact in initial goal
P4UC1-SKPI-1	Monitoring Sensors Information Collection and Visualization End-to-End Latency	To be performed at M18	To be performed at IT Aveiro/lab environment (ICT-17/5Growth) instead of IT physical secondary substation
P4UC1-SKPI-2	Monitoring Sensors Information Collection and Visualization Availability	To be performed after M18	Service availability will be performed in a real Pilot scenario
P4UC1-SKPI-3	High Definition Surveillance Video	To be performed at M18	To be performed at IT Aveiro/lab environment (ICT-17/5Growth) instead of IT physical secondary substation
P4UC1-SKPI-4	Augmented Reality Information Real-time End-to-End Latency	To be performed after M18	EFACEC_E-UC1 is not fully deployed by M18. It lacks the interactions with the maintenance team mobile interface (HD Video Streaming, Augmented Reality)

P4UC1-SKPI-5	Augmented Reality Information Real-time Availability	To be performed after M18	EFACEC_E-UC1 is not fully deployed by M18. It lacks the interactions with the maintenance team mobile interface (HD Video Streaming, Augmented Reality)

Use Case 2: Advanced Critical Signal and Data Exchange Across Wide Smart Metering and Measurement Infrastructures

Table 19 shows the SKPIs of the EFACEC_E use case 2 and the estimated impact (delays/initial goals) motivated by COVID-19.

TABLE 19: ESTIMATED COVID-19 IMPACT ON EFACEC_E USE CASE 2

UC-SKI- ID	KPI's description	Impact on M18	Impact in initial goal
P4UC2-SKPI-1	Last-gasp Information End-to-End Latency	To be performed after M18	No impact, since the initial plan was considering to perform KPI's measurements after M18
P4UC2-SKPI-2	Last-gasp Information Connectivity Availability	To be performed at M18	No impact is expected, since, in line with the initial plan, KPI's measurements will take place only after M18
P4UC2-SKPI-3	Secondary Substation End-to-End Latency	To be performed after M18	No impact is expected, since, in line with the initial plan, KPI's measurements will take place only after M18
P4UC2-SKPI-4	Secondary Substation Availability	To be performed after M18	No impact is expected, since, in line with the initial plan, KPI's measurements will take place only after M18
P4UC2-SKPI-5	Time Synchronization between all Sensors	To be performed after M18	No impact is expected, since, in line with the initial plan, KPI's measurements will take place only after M18

9. Appendix B – Technical KPIs defined by 5G-PPP TMV-WG, 5G-EVE and 5G-VINNI

As stated in the White paper[4], the priority for the 5GPPP TMV group was to identify those technical KPIs that were supporting the 5G PPP contractual KPIs validation[5]. The initial identified KPIs support mostly the following two contractual KPIs:

- **P1:** Providing 1000 times higher wireless area capacity and more varied service capabilities compared to 2010.
- **P4:** Creating a secure, reliable and dependable Internet with a "zero perceived" downtime for services provision.

Those two contractual KPIs can be translated in a series of Technical KPIs, summarized in Table 20. In the table, the KPIs are classified into two types: Service Level Agreement (SLA) or Technology validation. In the former meaning, they are related to performance specified in the SLA in the latter meaning they refer to testing technology capabilities. In addition to the chosen KPI their definition, the measurement points in the 5G architecture are provided. Finally, the last column reports the contractual KPI to which a specific KPI is contributing.

TABLE 20: TECHNICAL KPIS DEFINED BY THE 5G-PPP TMV-WG

Type	KPI name	KPI measurement points	5G PPP KPI Validated
SLA	Minimum Expected Upstream Throughput	UE transmitting IP packets to the N6 interface.	P1
SLA	Minimum Expected Downstream Throughput	UE receiving IP packets from the N6 interface	P1
SLA	Maximum Expected Latency	RTT of UE IP packets transmitted to the N6 interface.	P1, P4
SLA	Network Reliability	Transport layer packets are lost between the UE and the N6 interface	P4
SLA, Technology Validation	Quality of Experience	Measured at the UE side at application or application API level	P1, P4

[4] 5G-PPP Test, Measurement, and KPIs Validation Working Group (5G-PPP TMV), "Validating 5G Technology Performance Assessing 5G architecture and Application Scenarios", 25/06/2019

[5] "Contractual Arrangement Setting up a Public Private Partnership in the Area of Advanced 5G Network Infrastructure for te Future Internet between the European Union and the 5G Infrastructure Association", December 17, 2013 (https://5g-ppp.eu/contract/ latest access 07/05/2019)

Technology Validation	UL Peak Throughput	Single UE transmitting IP packets to the N6 interface.	P1
Technology Validation	DL Peak Throughput	Single UE receiving IP packets from the N6 interface	P1

5G-EVE and 5G-VINNI, identified KPIs to be collected in their experimental platforms are reported in [5] and in [6]. For easy consultation the 5G-EVE KPIs are reported in Table 21.

TABLE 21: 5G-EVE KPIS AS IN 5G-EVE-D1.4

5G-EVE KPI	Definition	Measurement methodology
User Data Rate or Speed	Minimum user experienced data rate required for the user to get a quality experience of the targeted application/use case (it is also the required sustainable date rate).	To measure this KPI, for each individual UE and end-user application, the application throughput across time is measured and recorded. For DL, UE device application must be able to provide this info in some format (e.g. Built-in KPI log file managed by android smartphones). For UL, several alternatives exist such as a PC equipped with Wireshark sniffing traffic.
Peak Data Rate - Broadband connectivity	It is the high data rate provisioned during high traffic demand periods (It is also a measure of the peak data rate required).	The measurement procedure for Peak Data Rate is the same as User data Rate or Speed measurement procedure described above.
Capacity	It is measured in bit/s/m2 is defined as the total amount of traffic exchanged by all devices over the considered area.	The KPI requirement on the minimum Traffic Volume Density/Areal Capacity for a given use case is given by the product: [required user experienced data rate] x [required connection density]. "Number of 5G System Connected Users": Counter available in NG-RAN node (gNB). Counter reports average number of connected users in the cell in the reporting period (typically 15 minutes) multiplied by the user data rate or speed, as defined above.
Latency (end-to-end or E2E Latency)	Measures the duration between the transmis-sion of a small data packet from the application layer at the source node and the successful reception at	To measure this KPI, for each individual UE and end-user application, the application latency across time must be measured and recorded. An alternative way is to deploy an application that can send ping commands to a UE (RTT is

	the application layer at the destination node plus the equivalent time needed to carry the response back.	measured). This application could be deployed as a VNF close to Application Server.
Device Density	It is the number of simultaneous active connections per square kilometer supported for massive sensor deployments. Here, active means the devices are exchanging data with the network.	"Number of 5G System Connected Users": Counter available in gNB. Counter reports average number of connected users in the cell in the reporting period (usually 15 minutes).
Reliability	It is the amount of sent packets successfully delivered to the destination within the time constraint required by the targeted service, divided by the total number of sent packets.	To measure this KPI, for each individual UE and end-user application, the packet loss rate across time must be measured and recorded. For UL, UE device application must be able to provide this info in some format (e.g. Built-in KPI log file managed by android smartphones). For DL, several alternatives exist like a PC equipped with Wireshark sniffing traffic from a mirrored port in a switch or Wireshark on a Linux machine involved with connectivity to Application server.
Availability	It is the network availability characterized by its availability rate X, defined as follows: the network is available for the targeted communication in X% of the locations where the network is deployed and X% of the time.	"Cell Availability": Counter available in gNB. Counter reports the length of time that a cell is available for service (usually every 15 minutes).
Mobility	It refers to the system's ability to provide seamless service experience to users that are moving. Seamless service experience means that UE achieves QoS required by the service/ application.	To measure this KPI, the following PIs will be used: Latency, Availability, Reliability, User Data Rate or Speed, Capacity and Device Density as defined above. In addition, the "UE speed" that will be provided by UE application or measured through alternative means.