Project funded by the Horizon 2020 Framework Program of the European Union,
Grant agreement Nº: ***951947.***
Start date: **01/09/2020**
Duration: 48 months

D5.3 Pre-integration and functional validation of railway use case

WP	WP5
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Dissemination Level	PU
Nature	RE

Dissemination Level:	
PU	Public

Nature	
RE	Report

Synopsis	This deliverable describes the development, the integration and the functional validation of all the hardware and software components of the railway use case (UC3) of 5GMED. It presents the results of the functional validation of UC3 performance and business services deployed on the small-scale test site located in the cross-border corridor using a maintenance train of LFP (Linea Figueres Perpignan) and a 5G connected van. The van is used to accelerate the tests and trials of UC3 in cross-border conditions on the highway.
List of Keywords	In train test bed, 5GMED network infrastructure, development and integration, validation, initial tests, LFP maintenance train.

DOCUMENT HISTORY

Version	Status[1]	Date	Comments	Author
0	DRAFT	24/10/2022	First draft version	Philippe Veyssiere
0.1	DRAFT	02/03/23	Second draft	Philippe Veyssiere
2	Revision 2	10/10/2023	Ready for peer review	Philippe Veyssiere
2.1	Peer reviewed	20/10/2023	Ready for review by main editor	Chahrazed Ksouri
2.2	Reviewed by main editor after peer review	21/10/2023	Ready for review by TM and PM	Philippe Veyssiere
2.3	ISSUED	23/10/2023	Issued	Philippe Veyssiere

PEER-REVIEWED BY

Partner	Reviewer
VEDE	Chahrazed Ksouri

1
Status (a status is associated to each step of the document life cycle)
Draft. This version is under development by one or several partner(s)
Under review. This version has been sent for review
Issued. This version of the document has been submitted to EC

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List of Acronyms

5G NR	5G New Radio
5G-SA	5G Standalone architecture
ACS-GW	Adaptive Communication System-Gateway
ADS	Autonomous Driving System
AI	Artificial Intelligence
AMF	Access and Mobility Management Function
AP	Access Point
ATC	Automatic Train Control
BS	Base Station
CA	Consortium Agreement
CEF	Connecting Europe Facility program
CG	Communication Gateway
DoA	Description of Action
DL	Down-Link
EC	European Commission
ES	Edge Server
ETBN	Ethernet Backbone Node
GA	Grant Agreement
GPS	Global Positioning System
H2020	Horizon 2020
HD	High Definition
HLS	HTTP Live Streaming
KPI	Key Performance Indicator
LFP	Linea Figueras Perpignan
MNO	Mobile Network Operator
NQoF	Network Quality of Service Function
NS	Network Service
P2P	Peer To Peer
PDV	Packet Delay Variance
PLMN	Public Land Mobile Network
QoE	Quality of Experience
QoF	Quality of Service Function
QoS	Quality of Service
R&D	Research & Development
RAN	Radio Access Network
RAT	Radio Access Technology
RTT	Round Trip Time

SC	Slice Classifier
SSTB	Small Scale Test Bed
TAN	Train Access Network (Radio Access from Train to Ground)
TCN	Train Communication Network
TGV	Train Grande Vitesse (High-speed Train)
TLAN	Train Local Area Network
UC	Use Case
UE	User Equipment
UL	Up-Link
VPN	Virtual Private Network

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Executive Summary

This deliverable D5.3 gathers the results of the phase B of WP5, which was dedicated to the development and integration of the hardware and software components of the railway use case as well as the deployment and functional validation on the small scale test site. Its objective is to have the railways use case (UC3) fully validated and ready for the small-scale trials that will be conducted in the context of WP6 for the performance evaluation of the use case services.

Regarding the Follow-Me Infotainment use case (UC4), it is not specific to the railways scenario, but covers both transport modes: automotive and railway. Since the full UC4 will be showcased on the highway, only a subset of UC4 services will be demonstrated in the railway scenario with the UEs on-board the train directly connected to the 5G SA networks. Therefore, the integration and functional validation of UC4 will be carried out in the automotive scenario and the results will be presented in D4.3.

This deliverable presents the developments and validation of the high level functionalities of UC3 services, describing the components and their deployment and integration in the small-scale test site. Finally, it presents the validation results of the UC3 services together with the first service KPI measurements collected with the service KPI collection platform presented in D6.1. The results of functional validation demonstrate that UC3 services are ready for the execution of the small-scale trials.

Additionally, this document also addresses the temporary changes implemented in the small-scale test site due to the damage of the LFP maintenance train that is to be used for the small-scale trials.

1. Introduction

1.1. Purpose of the document

The aim of this deliverable is to present the results of the functional validation of the railway use case (UC3) deployed on the small-scale test site. It describes the developments of hardware/software components, their integration, and the procedures followed to test and validate the UC3 functionalities. The developments in UC3 are based on previous deliverables of WP5. The definition of the UC3 requirements was presented in D5.1 [1] and the design of functional components and interfaces was presented in D5.2 [2].

1.2. Structure of the document

This document is divided into three main parts:

- Section 2 provides a high level description of the hardware and software components required for the deployment of UC3 on the small-scale test site, both on the 5GMED network and compute infrastructure and on-board the train.
- Section 3 presents the status of development and validation of UC3 components, including those functional components that are common to all UC3 services as well as those components that are specific of each use case. This section describes the status of the high-level functionalities of each component deployed on the small-scale test site, the status of interfaces between components, and the status of deployment on the small-scale testbed.
- Section 0 presents the functional validation of each UC3 service. It describes the components involved in the validations with the different Train Access Networks (TAN), the test procedures, and the results obtained.

1.3. Overview of Railway Use Case Services

The purpose of this section is to provide a short summary of the UC3 services that must be demonstrated in 5GMED. These services are classified in two different types: performance services (P), and business services (B). They were defined in D2.1 and are briefly described below.

- **P1 service: Advanced Sensor Monitoring on Board**. Generation of machine-type data traffic, with the same characteristics as real on-board sensors, from a simulator of a Wireless Sensor Network (WSN). This data traffic is transmitted to a server in the cloud imitating the information system of a train operator.
- **P2 service: Railway Track Safety - Obstacle Detection**. The aim is to detect and locate potential obstacles that may block rail tracks. A LiDAR on the train cockpit scans the parallel track in the opposite direction of the movement and sends data to an Edge node on-ground equipped with a detection algorithm. When an obstacle is detected, the detection module will send a warning message

to a module at the Train Control Centre which in turn will send without delay a warning to the trains moving on the adjacent track.

- **B1 service: High Quality Wi-Fi to passengers**. The aim is to provide high-performance Wi-Fi access to the train passengers. This service will have to be seamless on the whole corridor, including the tunnel and cross-border section between France and Spain.
- **B2 service: Multi-tenant Mobile Service.** The aim is to explore the rollout of a "train MNO". The letter is composed of an on-board 5G small cell which is backhauled through the different existing TANs to an on ground 5G-Core. In that way, the passengers stepping into the train will directly benefit from a high-quality 5G access from the "train MNO" through their own 5G device without any action required from them.

2. Overview of Small-Scale Testbed in Railway Scenario

This section provides an overview of the small-scale testbed for the demonstration and performance evaluation of the railways use case. The main difference between the railways small-scale and large-scale testbed is the type of train, because the network and compute infrastructure on-ground is basically the same infrastructure deployed in the cross-border corridor. In the small-scale testbed, the train is a low-speed train (maintenance train of LFP), whereas in the large-scale test bed, it is a high speed train from SNCF (Société Nationale de Chemins de Fer).

The small-scale testbed consists of the rail track along the corridor, the facilities of the LFP maintenance base, the facilities in Castelloli, and some public cloud servers used in UC3 services. This small-scale testbed integrates the network and compute infrastructure (Section 2.1) and all the functional components of UC3 services (Section 2.2).

2.1. Network and Compute Infrastructure Overview

below represents the network infrastructure deployed in the cross-border corridor to provide connectivity on the rail track. The network infrastructure is described in detail in D3.3 [3].

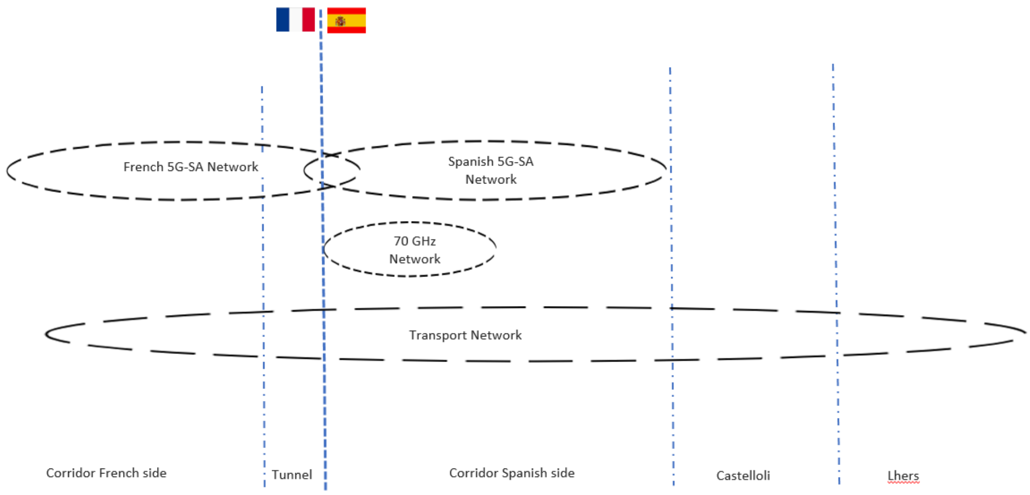

Figure 1 Network infrastructure of 5GMED in the cross-border corridor rail track

The compute infrastructure is deployed in several locations in the form of data centres hosting Virtual Machines (VMs) where the software components of UC3 are allocated: in Castelloli, in Llers, and Le Perthus. The compute infrastructure is described in detail in D3.3 [3].

2.2. UC3 Functional Components Overview

This section describes the functional components, hardware and software, which are specific to UC3. These functional components can be classified according to their location. There are functional components deployed on the network and compute infrastructure on-ground (Section 2.2.1) and other functional components are deployed on-board the train (Section 2.2.2).

2.2.1. Components on Network and Compute Infrastructure On-Ground

Figure 2 below shows the location of the functional components of UC3 deployed on the 5GMED infrastructure. The different colours of the boxes correspond to different UC3 services. A detailed description of these components can be found in deliverable D5.2 [2].

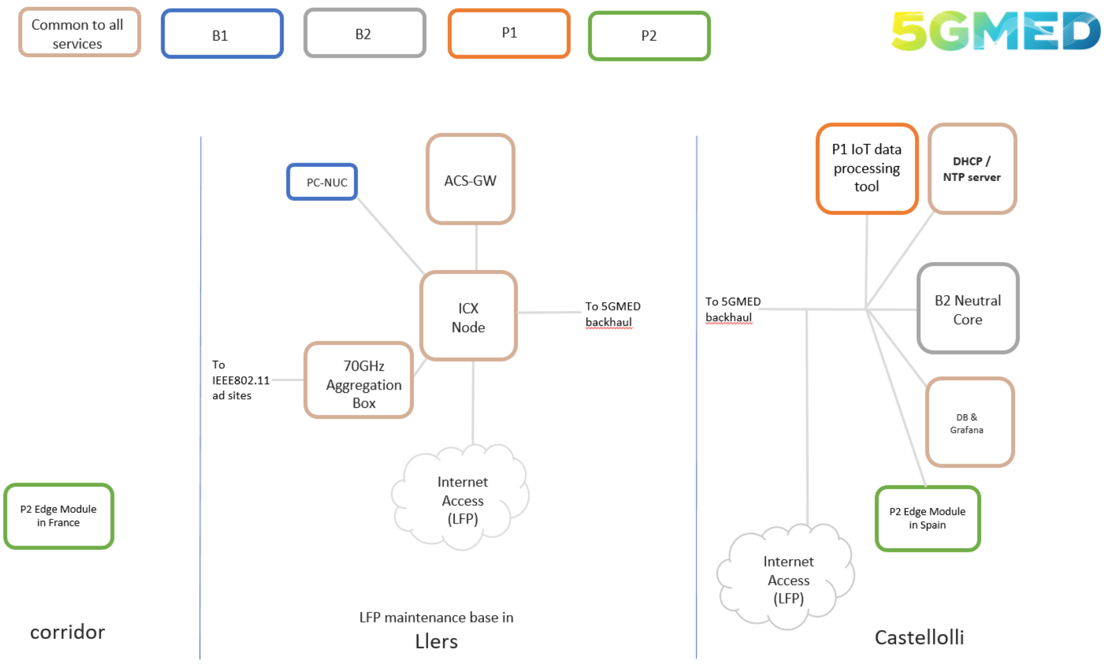

Figure 2 : Location of UC3 functional components deployed on the network and compute infrastructure on-ground

2.2.2. Components on-board the LFP Maintenance train

Figure 3 below shows the functional components of UC3 deployed on-board the train. The different colours of the boxes correspond to different UC3 services. A detailed description of these components can be found in deliverable D5.2 [2].

The PC-NUC 1 connects to the Wi-Fi AP to simulate the traffic of a Gigabit train (and obtain B1 KPI's). The other end-point is the ground PC-NUC (two units: one in the French MEC; the other in the Spanish MEC). The traffic generation script will use the geolocation module to define the endpoint of the tests. The PC-NUC traffic will go through the ACS-GWs train and ground. The PC-NUC 2 manages the 5G modem on-board the train.

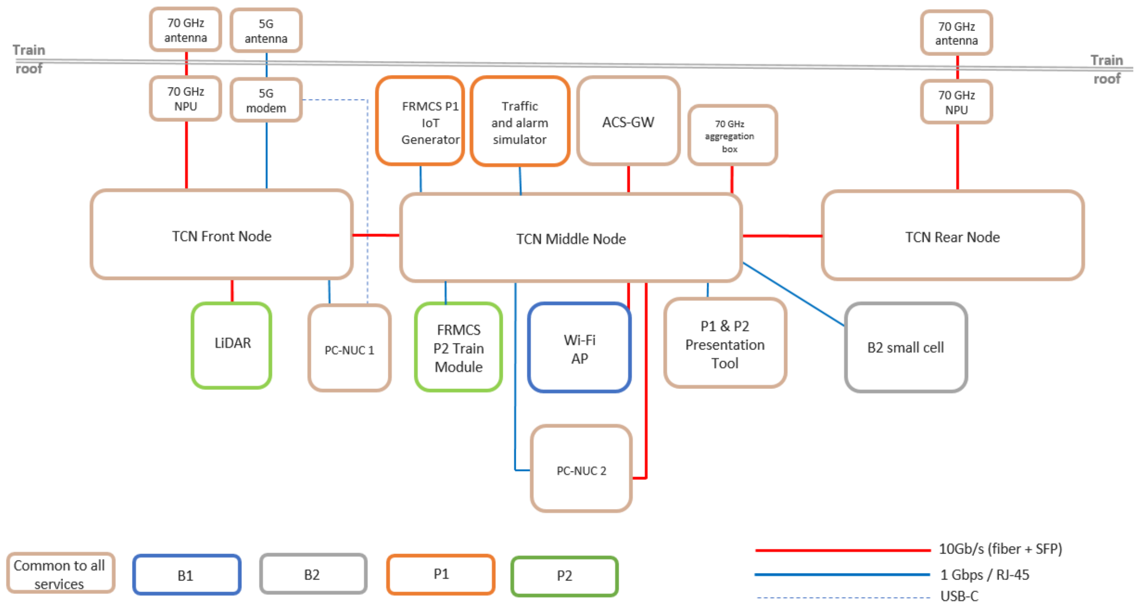

Figure 3 UC3 Functional components deployed on-board the train

3. Status of UC3 Development and Validation

The integration and the functional validation of the UC3 components took place between May to October 2023. At that time, the network infrastructure was almost fully functional and the 5G coverage on the corridor has nearly reached its target for the small-scale trials.

The status of the functionalities of the main UC3 components is described in Section 3.1. The status of the interfaces between components inside each UC3 service is described in Section 3.2. The status of UC3 components deployment on the small-scale testbed is described in Section 3.3.

3.1. Status of UC3 Functionalities

This section describes the status of all functionalities performed by the components of UC3. For each functionality, it describes the following:

- The tests done to validate the correct functional operation of the component.
- The status of development.
- The status of validation in the laboratory.
- The status of deployment and validation on the 5GMED network and compute infrastructure (if applicable).
- The status of deployment and validation on-board the train (if applicable).

Two categories of UC3 functionalities are considered: the functionalities of components that are common to all UC3 services, and the functionalities of components that are specific to each service. Each functionality has been assigned a reference number in order to facilitate communication in the project.

3.1.1. Functionalities Common to All Services

This section describes the status of the functionalities performed by those components of UC3 that are common to all services. These components are the geolocation module, Adaptive Communication System-Gateway (ACS-GW), Network Time Protocol (NTP) server, Train Control Network (TCN), and Management of Train Components. A detailed description of each component design is provided in D5.2.

3.1.1.1. Geolocation Module Functionalities

The geolocation module is required to correlate the values of the different KPIs with the spatial coordinates where they are measured, as well as for the correct functioning of the services for which geolocation information is needed. The developed component runs alongside the NTP server in a Raspberry Pi on train, and queries the 70GHz antennae for geolocation information and, if unavailable, uses its own GPS receiver. A service that runs on startup of the Raspberry PI is in charge of both getting the information and making it available for all devices on train through the use of python and flask via HTTP requests. The NUC on ground also gets this information and makes it available in the same way to the components on ground.

The following functionalities of the Geolocation Module have been tested:

1. Get geolocation information from the GPS receiver.
2. Make geolocation information available to other components on-board train.
3. Make geolocation information available to other components on ground.

The test carried out to validate each functionality are briefly described in the tables below.

Functionality	*Get geolocation information from GPS receiver*	*ID*	*FUN-UC3-GEO-01*
Summary	Query the GPS receiver integrated into each 70GHz antenna unit for geolocation information.	*Components*	*Raspberry Pi on train* *70GHz Antennae* *TCN switches*
Description	Query the GPS receiver for geolocation information. There are two GPS receivers, one on each end of the train, at 4.2m of height. They are queried from the Raspberry Pi running the NTP server. If unavailable, the Raspberry Pi attempts to get this information from its own GPS receiver.		

Status of the development	*Finished*
Status of the Lab validation	*Validated.*
Status of the deployment & validation on the 5GMED infrastructure	*Validated.*
Status of the deployment & validation on the vehicle	*Validated*

Table 1 Query the GPS receiver integrated into each 70GHz antenna unit for geolocation information.

Functionality	*Make geolocation information available to all devices on train*	*ID*	*FUN-UC3-GEO-02*
Summary	Make the geolocation information acquired available to all components on the train.	*Components*	*Raspberry Pi on train* *70GHz Antennae* *TCN switches*
Description	Make the geolocation information acquired from the GPS receiver available to all components on the train. In order to do so, a systemctl service runs on startup launching a python script using flask to make the information available through HTTP requests.		
Status of the development	*Finished in April 2023.*		
Status of the Lab validation	*Validated in the COMSA network.*		
Status of the deployment & validation on the vehicle	*Validated.*		

Table 2 Make the geolocation information acquired available to all components on the train

Functionality	*Make geolocation information available to all devices on ground*	*ID*	*FUN-UC3-GEO-03*
Summary	Make the geolocation information acquired from the antennae available to all components on the ground.	*Components*	*Raspberry Pi on train* *70GHz Antennae* *TCN switches*
Description	Make the geolocation information acquired from the GPS receiver available to all components on the ground. This is achieved using the NUC on ground to acquire the information from the Raspberry Pi on train and making it available through a similar flask-python systemctl service serving HTTP requests.		
Status of the development	*Finished in April 2023.*		
Status of the Lab validation	*Validated in the COMSA network.*		
Status of the deployment & validation on the 5GMED infrastructure	*Deployed, pending validation.*		

Table 3 Make geolocation information available to all components

3.1.1.2. ACS-GW Functionalities

The ACS-GW provides connectivity between the train and ground components, functioning as a middlebox between services and Radio Access Networks. It is crucial for supporting all UC3 services, serving as the default gateway for all UC3 components. The ACS-GWs are tasked with aggregating, encapsulating, and forwarding packets to the correct RAN based on the configured policy. Further details on ACS-GW hardware and functional blocks can be found in deliverable D5.2.

The following functionalities of the ACS-GW have been tested:

1. Classify service flow by inspecting VLAN tags and packet headers.
2. Check connectivity over the 70GHz network.
3. Check connectivity over the 5G network.
4. Check connectivity over the satellite.
5. Tunnels establishment between the train ACS-GW and grounds ACS-GWs.
6. Automatic vertical handover enforcement.
7. Validate the ACS-GWs performance.

Functionality	*Classify service flow by inspecting VLAN tags and packet headers.*	*ID*	*FUN-UC3-ACS-GW-01*
Summary	Verify the capability of the ACS-GW of inspecting and forwarding the service flows.	*Components*	*ACS-GWs* *TCN switches* *-* *Link between ACS-GWs (70Ghz, 5G or Direct link)*
Description	Using the Netcat tool to emulate the services and verify the ACS-GWs behaviour.		
Status of the development	*Finished in May 2023.*		
Status of the Lab validation	*Validated in AXBRYD testbed.*		
Status of the deployment & validation on the 5GMED infrastructure	*Deployed and validated*		

Table 4 Classify service flow by inspecting VLAN tags and packet headers

Functionality	Check connectivity over the 70GHz network	ID	FUN-UC3-ACS-GW-02
Summary	Ping from the ACS-GW VMs on train to the ACS-GW VMs on ground with the ACS-GW program disabled.	Components	ACS-GWs 70GHz Network TCN switches
Description	Ping the ACS-GW on ground from the ACS-GW on train.		
Status of the development	Finished in May 2023.		
Status of the Lab validation	Validated in AXBRYD testbed.		
Status of the deployment & validation on the 5GMED infrastructure	Deployed and validated		
Status of the deployment & validation on the vehicle	Deployed and validated		

Table 5 connectivity over the 70GHz network

Functionality	Check connectivity over the 5G network	ID	FUN-UC3-ACS-GW-03
Summary	Ping from the ACS-GW VMs on train to the ACS-GW VMs on ground with the ACS-GW program disabled.	Components	ACS-GWs 5G Network TCN switches
Description	Ping the ACS-GW on ground from the ACS-GW on train.		
Status of the development	Finished in May 2023.		
Status of the Lab validation	Validated in AXBRYD testbed.		

Status of the deployment & validation on the 5GMED infrastructure	*Deployed and validated*

Table 6 Check connectivity over the 5G

Functionality	*Check connectivity over the Satellite network*	*ID*	*FUN-UC3-ACS-GW-03*
Summary	Ping from the ACS-GW VMs on train to the ACS-GW VMs on ground with the ACS-GW program disabled.	*Components*	*ACS-GWs* *Satellite Network* *TCN switches*
Description	Ping the ACS-GW on ground from the ACS-GW on train.		
Status of the development	*Finished in May 2023.*		
Status of the Lab validation	*Validated in AXBRYD testbed.*		
Status of the deployment & validation on the 5GMED infrastructure	*Deployed and validated*		

Table 7 Check connectivity over the Satellite

Functionality	*Tunnels establishment between the train ACS-GW and grounds ACS-GWs*	*ID*	*FUN-UC3-ACS-GW-04*
Summary	Tunnels established between the ACS-GW on train and the ACS-GW on ground.	*Components*	*ACS-GWs* *70GHz Network* *5G Network* *Satellite Network* *TCN switches*
Description	Start the ACS-GWs on ground and in train and establish the tunnel.		
Status of the development	*Finished in June 2023.*		
Status of the Lab validation	*Validated in AXBRYD testbed.*		
Status of the deployment & validation on the 5GMED infrastructure	*Deployed and validated*		

Table 8 Tunnels establishment between the train ACS-GW and grounds ACS-GWs

Functionality	*Automatic vertical handover enforcement*	*ID*	*FUN-UC3-ACS-GW-05*
Summary	When a connectivity loss is detected, the ACS-GWs perform an automatic vertical handover between the RANs	*Components*	*ACS-GWs* *70GHz Network* *Satellite Network* *TCN switches*
Description	Start an emulated service, disable one of the available RAN and check if the ACS-GW automatically perform a handover.		
Status of the development	*Finished in September 2023.*		
Status of the Lab validation	*Validated in AXBRYD testbed.*		
Status of the deployment & validation on the 5GMED infrastructure	*Deployed and validated*		

Table 9 Automatic vertical handover enforcement

Functionality	*Validate the ACS-GWs performance*	*ID*	*FUN-UC3-ACS-GW-06*
Summary	Performance assessment of the ACS-GW system.	*Components*	*ACS-GWs* *70GHz Network* *TCN switches*
Description	The ACS-GWs create the tunnel on the 70 GHz network, guaranteeing the best performance. Then, the B1 service performs throughput and forwarding latency measurements to validate that		

	the ACS-GW system doesn't impact the performance and the results satisfy the requirements.
Status of the development	*Finished in September 2023.*
Status of the Lab validation	*Validated in AXBRYD testbed.*
Status of the deployment & validation on the 5GMED infrastructure	*Deployed to be validated with the services in the small case testbed. Testing started in September.*

Table 10 Validate the ACS-GWs performance

3.1.1.3. NTP Servers Functionalities

The NTP servers provide GNSS-based synchronization for all the components deployed on-board the train and on-ground.

The following functionalities of the NTP servers have been tested:

1. Setting up a NTP server and obtain the date and time reference by all UC3 train components.
2. Obtaining the date and time reference by all UC3 Ground components.

Functionality	*Setting up a NTP server and obtain the date and time reference by all UC3 train components*	*ID*	*FUN-UC3-NTP-01*
Summary	*Synchronization of all the UC3 train devices. The devices to be sync. Are the components listed besides, on the right.*	*Components*	*P1 IoT Traffic Generator* *P2 Edge Module* *B1 PC-NUC2* *B2 gNB, OnePlus Smartphone*
Description	*Obtaining the date and time reference by all UC3 components from an external NTP Server. Measure and collect service KPI for UC3 services.*		
Related Requirements	*R-UC3-005*		
Status of the development	*Finished*		
Status of the deployment &	*Validated (synchro within 3ms max)*		

validation on the vehicle	

Table 11 Setting up a NTP server

Functionality	*Obtaining the date and time reference by all UC3 Ground components*	***ID***	*FUN-UC3-NTP-02*
Summary	*Synchronization of all the UC3 ground devices*	***Components***	*P1 Cloud Service* *P2 AI module* *B1 PC-NUC 1* *B2*
Description	*Obtaining the date and time reference by all UC3 ground components from an external NTP Server. Measurements and collect service KPI for UC3 services.*		
Related Requirements	*R-UC3-005*		
Status of the deployment & validation on the 5GMED infrastructure	*Validated*		

Table 12 Obtaining the date and time reference by all UC3 Ground components

3.1.1.4. TCN Functionalities

This section describes the functionalities of the set of the Train Communication Network (TCN) switches both on train and ground and their development, deployment, and status.

The following functionalities of the TCN switches have been tested:

1. Ensure communication between all components on-board the train.
2. Ensure communication between all components on ground.
3. Assign proper routing and Maximum Transmission Unit (MTU) to components connecting to B1.

Functionality 1	Ensure communication between all components on-board the train	ID	FUN-UC3-TCN-01
Summary	Interconnection between all components on train using three switches.	Components	TCN Switches on train
Description	The three switches on train, one in the front, one in the back and one in the middle, are connected between themselves and to all devices on train. They are configured to ensure proper VLAN behaviour.		
Status of the development	Fully developed		
Status of the Lab validation	Validated		
Status of the deployment & validation on the 5GMED infrastructure	Validated		
Status of the deployment & validation on the vehicle	Validated		

Table 13 Ensure communication between all devices on train

Functionality	Ensure communication between all components on ground	ID	FUN-UC3-TCN-02
Summary	Interconnection between all devices on ground using one switch.	Components	TCN Switch on ground
Description	The switch on ground connects all devices on ground among themselves and to the link to Castellolí.		
Status of the development	Fully developed		
Status of the Lab validation	Validated		
Status of the deployment & validation on the 5GMED infrastructure	Validated		
Status of the deployment & validation on the vehicle	Validated		

Table 14 Ensure communication between all devices on ground

Functionality	*Assign proper routing and MTU to devices connecting to B1*	*ID*	*FUN-UC3-TCN-03*
Summary	*Function as DHCP server to provide proper routing and MTU.*	*Components*	*Middle TCN Switch on train*
Description	*The middle switch on the train functions as DHCP server for B1, assigning the correct MTU and routing to any device that connects to it and accepts those parameters to be set via DHCP.*		
Status of the development	*Deployed*		
Status of the Lab validation	*Validated*		
Status of the deployment & validation on the 5GMED infrastructure	*Validated*		
Status of the deployment & validation on the vehicle	*Validated*		

Table 15 Assign proper routing and MTU to devices connecting to B1

3.1.1.5. Management of Train Components Functionalities

Before the 5GMED network is deployed and stable, it was required to have connectivity with the components on-board the LFP maintenance train. To this end, an LTE router was deployed. In order to manage the LTE router, we need to be in the same network of the device. Each partner had to setup a VPN between their facilities and the LTE router.

The following functionalities have been tested for the management of train components.

- LTE Management connection for components in the train

Functionality	*LTE Management connection for components in the train*	*ID*	*FUN-UC3-Mngt-01*
Summary	Check the remote access to all the B1 access component from COMSA Barcelona offices using the defined Internet access for this task (LTE router from Spanish MNO)	*Components*	*Access Point-(AP)* *LFP internet connection* *TCN switches*

Description	Check the remote access to all the B1 access component from COMSA Barcelona offices using the defined Internet access for this task
Related Requirements	*R-UC3-005*
New Added Requirements	Availability of a DHCP server in the network with a predefined pool of IP addresses provided by LFP / CELLNEX
Status of the development	*Finished in June-2023.*
Status of the Lab validation	*To be tested in LFP Train with all others on-board components.*
Status of the deployment & validation on the vehicle	*January 2023*

Table 16 LTE Management connection for components in the train

3.1.2. Functionalities Specific to UC3 Services

This section describes the status of the functionalities performed by the components of UC3 that are specific to each UC3 service. A detailed description of each UC3 service component design is provided in D5.2.

3.1.2.1. Service P1 Functionalities

This section describes the different functionalities developed for service P1 and their deployment and validation status.

1. Send massive IoT data from the train.
2. Receiving IoT data on the Cloud, and sending them back to the Train Presentation Tool for analysis.
3. Display statistics and information about the IoT data sent by the P1 IoT Traffic Generator to the P1 IoT Data Processing Tool.
4. KPI collection systems for P1.

Functionality	*Send massive IoT data from the train*	*ID*	*FUN-UC3-P1-01*
Summary	*Development of P1 IoT Traffic Generator*	*Components*	*P1 IoT Traffic Generator*
Description	*Development of P1 IoT Traffic Generator, for integration on the train. Its behaviour is described in Section 3.1.1.2 of D5.2 [add reference].*		
Related Requirements	*R-P1-001, R-P1-002*		
Status of the development	*Finished in W48-2022*		
Status of the Lab validation	*Fully tested in SNCF Lab with all others P1 components.*		
Status of the deployment & validation on the 5GMED infrastructure	*N/A (Train component)*		
Status of the deployment & validation on the vehicle	*Deployed on the train since February 2023. Successfully tested on the train with all 5GMED RAN in September/October 2023.*		

Table 17 Send massive IoT data from the train

Functionality	*Receiving IoT data on the Cloud, and sending them back to the Train Presentation Tool for analysis*	*ID*	*FUN-UC3-P1-02*
Summary	Development of P1 IoT Data Processing Tool	*Components*	*P1 IoT Data Processing Tool*
Description	*Development of P1 IoT Data Processing Tool, for integration on the 5GMED Cloud infrastructure. Its behaviour is described in Section 3.1.1.4 of D5.2 [add reference].*		
Related Requirements	*R-P1-004*		
Status of the development	*Finished in W48-2022.*		
Status of the Lab validation	*Fully tested in SNCF Lab with all others P1 components.*		
Status of the deployment & validation on the 5GMED infrastructure	*Deployed in 5GMED Cloud infrastructure in December 2022. Successfully tested with 5GMED telecom infrastructure in September/October 2023.*		

Table 18 Receiving IoT data on the Cloud, and sending them back

Functionality	*Display statistics and information about the IoT data sent by the P1 IoT Traffic Generator to the P1 IoT Data Processing Tool*	*ID*	*FUN-UC3-P1-03*
Summary	*Development of Train Presentation Tool*	*Components*	*Train Presentation Tool*
Description	*Development of Train Presentation Tool, for integration on the train. Its behaviour is described in Section 3.1.1.2 of D5.2 [add reference].*		
Related Requirements	*R-P1-003, R-P1-005, R-P1-006*		
Status of the development	*Finished in W48-2022.*		
Status of the Lab validation	*Fully tested in SNCF Lab with all others P1 components.*		
Status of the deployment & validation on the vehicle	*Deployed on the train since February 2023. Successfully tested on the train with all 5GMED RAN in September/October 2023.*		

Table 19 Development of Train Presentation Tool

Functionality	*KPI collection for P1*	*ID*	*FUN-UC3-P1-04*
Summary	Implementation of several systems to measure and collect service KPI for P1.	*Components*	*P1 IoT Traffic Generator, P1 IoT Data Processing Tool, Train Presentation Tool*
Description	*Implementation of KPI measurement methods in all P1 components, in order to measure uplink latency, data rate, packet loss and mobility interruption time. KPI are collected every 5 seconds, then sent every 30 seconds to common MongoDB database in the common KPI collection platform in the Cloud.*		
Status of the development	*Finished in W05-2023.*		
Status of the Lab validation	*Successfully tested in SNCF Lab with all others P1 components.*		
Status of the deployment & validation on the 5GMED infrastructure	*Deployed on the P1 IoT Data Processing Tool in February. Successfully tested in September 2023 alongside train components.*		

Status of the deployment & validation on the vehicle	*First version deployed on the train in February 2023. Final version deployed in September 2023. Successfully tested on the train with all 5GMED RAN in September/October 2023.*

Table 20 KPI collection for P1

3.1.2.2. Service P2 Functionalities

This section describes the different functionalities developed for service P2 and their deployment and validation status.

1. Development of P2 Ground Module.
2. Development of P2 Edge Module.
3. Development of P2 Control Module.

Functionality	*Development of P2 Ground Module*	*ID*	*FUN-UC3-P2-1*
Summary	Implementation of P2 Ground Module	*Components*	*Ground Module*
Description	A LiDAR is installed in the train cabin and captures data of the train surrounding environment. The Ground Module is in charge of receiving LiDAR data and retransmit them to the Edge Module. Also, it allows to configure remotely the LiDAR parameters, like rotation speed or measure modes.		
Status of the development	*Development finished in September 2023.*		
Status of the Lab validation	*Successful implementation and lab validation of service on simulated conditions.*		
Status of the deployment & validation on the 5GMED infrastructure	*Successfully tested in September 2023.*		
Status of the deployment & validation on the vehicle	*Successfully tested in September 2023.*		

Table 21 : UC3/P2 Development of P2 Ground Module

Functionality	*UC3/P2 Development of P2 Edge Module*	*ID*	*FUN-UC3-P2 - 2*
Summary	Implementation of P2 Edge Module.	*Components*	*Edge Module*
Description	*The Edge Module is in charge of computational processing of LiDAR data. It is composed by several submodules, each representing an independent processing or algorithm. One of them is a SLAM*		

	algorithm which allow to geolocalize LiDAR frame from each other.
Status of the development	*Development finished in September 2023.*
Status of the Lab validation	*Successful implementation and lab validation of service on simulated conditions.*
Status of the deployment & validation on the 5GMED infrastructure	*Successfully tested in September 2023.*

Table 21 P2 Development of P2 Edge Module

Functionality	*UC3/P2 Development of P2 Control Module*	*ID*	*FUN-UC3-P2-3*
Summary	Implementation of P2 Control Module.	*Components*	*Control Module*
Description	*The Control Module is in charge of managing and controlling the whole system functioning. At a glance, the supervisor can see if all modules are connected and well parametrized. The current Edge processing results are displayed in real time.*		
Status of the development	*Development finished in September 2023.*		
Status of the Lab validation	*Successful implementation and lab validation of service on simulated conditions.*		
Status of the deployment & validation on the 5GMED infrastructure	*Successfully tested in September 2023.*		
Status of the deployment & validation on the vehicle	*Successfully tested in September 2023.*		

Table 22 P2 Development of P2 Control

3.1.2.3. Service B1 Functionalities

This section describes the different functionalities developed for service B1 and their deployment and validation status.

1. Passenger checks the Internet Access inside the train.
2. Establishing a Teams session inside the Train through the internet connection.
3. Traffic Generator test from train to ground.
4. Traffic Generator test from ground to train and KPI collection and display test.
5. IP address and MTU assignment.

<table>
<tr><td>Functionality</td><td>Passenger checks the Internet Access inside the train</td><td>ID</td><td>FUN-UC3-B1-01</td></tr>
<tr><td>Summary</td><td>Connect three different UEs (Android phone, IOS phone, Windows laptop, Unix laptop) to the train LAN (WiFi). Check the Internet is reachable. Verify the traffic goes through the aggregated connection.</td><td>Components</td><td>Access Point-(AP)

LFP internet connection

TCN switches</td></tr>
<tr><td>Description</td><td colspan="3">Verify the traffic goes through the aggregated connection. Evaluate user experience (navigate, YouTube, streaming, etc..)</td></tr>
<tr><td>Related Requirements</td><td colspan="3">R-B1-001, R-B1-002, R-B1-003</td></tr>
<tr><td>New Added Requirements</td><td colspan="3">Availability of a DHCP server in the network with a predefined pool of IP addresses provided by LFP / CELLNEX</td></tr>
<tr><td>Status of the development</td><td colspan="3">Finished in June-2023.</td></tr>
<tr><td>Status of the Lab validation</td><td colspan="3">-</td></tr>
<tr><td>Status of the deployment & validation on the 5GMED infrastructure</td><td colspan="3">Tested on Unix laptop, Windows laptop requires manual MTU assignation, Android and iOS devices can’t get MTU. Validated in September 2023.</td></tr>
<tr><td>Status of the deployment & validation on the vehicle</td><td colspan="3">Tested on Unix laptop, Windows laptop requires manual MTU assignation, Android and iOS devices can’t get MTU. Validated in September 2023.</td></tr>
</table>

Table 9 Passenger checks the Internet Access inside the train

Functionality	*Establishing a Teams session inside the Train through the internet connection*	*ID*	*FUN-UC3-B1-02*
Summary	Establish a Teams session between a train laptop connected to the train LAN (WiFi), other in the Llers base and another in a different location (Paris, Rome, Madrid).	*Components*	*Access Point-(AP)* *LFP internet connection* *TCN switches*
Description	Establish a Teams session between a train laptop connected to the train LAN (WiFi) and others, one in the Llers base and one in a different location.		
Related Requirements	*R-B1-001, R-B1-002, R-B1-003*		
New Added Requirements	Availability of a DHCP server in the train network with a predefined pool of IP addresses provided by LFP / CELLNEX		
Status of the development	*Finished in June-2023.*		
Status of the deployment & validation on the 5GMED infrastructure	*Tested on Unix laptop, Windows laptop requires manual MTU assignation, Android and iOS devices can't get MTU*		
Status of the deployment & validation on the vehicle	*Tested on Unix laptop, Windows laptop requires manual MTU assignation, Android and iOS devices can't get MTU*		

Table 10

Functionality	*Traffic Generator test from train to ground and KPI collection and display test*	*ID*	*FUN-UC3-B1-03*
Summary	Generate traffic from train to ground with the iPerf and python tools between the NUCs on train and ground. Use the centralized 5GMED Mongo DB/Grafana servers in Castellolí to store and represent data.	*Components*	*PC-NUC2 SFP+ 10GBASE-T* *Access Point-(AP)* *LFP internet connection* *TCN switches* *NTP Server*
Description	Generate traffic from train to ground using python, iPerf and pings, subsequently recording the generated data from the tools in a common MongoDB database and representing it using a common Grafana instance.		
Related Requirements	*R-B1-001, R-B1-002, R-B1-003 and R-B1-004*		
New Added Requirements	Availability of a DHCP server in the network with a predefined pool of IP addresses provided by LFP / CELLNEX		

	Availability of centralized 5GMED Mongo DB/Grafana servers in Castellolí.
Status of the Lab validation	*Validated September 2022*
Status of the deployment & validation on the 5GMED infrastructure	*Validated January 2023*
Status of the deployment & validation on the vehicle	*Validated January 2023*

Table 11 *Traffic Generator test from train to ground and KPI collection and display test*

Functionality	*Traffic Generator test from ground to train and KPI collection and display test*	*ID*	*FUN-UC3-B1-04*
Summary	Generate traffic from ground to train with the IPerf tool (Iperf client on the ground and server on the train). Use the centralized 5GMED Mongo DB/Grafana servers in Castellolí.	*Components*	*PC-NUC2 SFP+ 10GBASE-T* *Access Point-(AP)* *LFP internet connection* *TCN switches* *NTP Server*
Description	Generate traffic from ground to train using python, iPerf and pings, subsequently recording the generated data from the tools in a common MongoDB database and representing it using a common Grafana instance.		
Related Requirements	*R-B1-003 and R-B1-004*		
New Added Requirements	Availability of a DHCP server in the network with a predefined pool of IP addresses provided by LFP / CELLNEX Availability of centralized 5GMED Mongo DB/Grafana servers in Castellolí.		
Status of the development	*Finished in September 2022.*		
Status of the Lab validation	*To be tested in LFP Train with all others on-board components.*		
Status of the deployment & validation on the 5GMED infrastructure	*Validated January 2023*		
Status of the deployment &	*Validated January 2023*		

validation on the vehicle	

Table 12 Traffic Generator test from train to ground and KPI collection and display test

Functionality	*IP address and MTU assignment*	*ID*	*FUN-UC3-B1-05*
Summary	Verify the method to assign the IP address and the MTU of each B1 service component.	*Components*	*Access Point-(AP)* *LFP internet connection* *TCN switches* *ACS-GW* *NTP Server*
Description	Verify the method to assign the IP address and the MTU of each B1 service component.		
Related Requirements	*R-UC3-003*		
New Added Requirements	Availability of a DHCP server in the network with a predefined pool of IP addresses provided by LFP / CELLNEX		
Status of the development	*Finished in June-2023.*		
Status of the Lab validation	*To be tested in LFP Train with all others on-board components.*		
Status of the deployment & validation on the 5GMED infrastructure	*Deployed in June 2023*		
Status of the deployment & validation on the vehicle	*Validation is not yet finished : most of end device cannot manage a change in MTU.*		

Table 13 IP address and MTU assignment

3.1.2.4. Service B2 Functionalities

This service originally (in the Grant Agreement) limited to backhauling an in train gNB through a satellite link keeping E2E 5G slicing was extended to use the other TANs for the backhauling. The TAN chosen for backhauling being, in fine, decided by the status of each TAN and the policy implemented in the ACS-GW. Maintaining of the 5G slice on the backhauling will only be tested with the satellite TAN.

This section describes the different functionalities developed for service B2 and their deployment and validation status.

1. UC3/B2 Lab platform setup in IRT for testing service B2 in lab. The satellite link will be provided by Starlink.
2. Deployment of functions required for maintaining the sat slice on the sat backhauling
3. Development of multi-slicing.
4. Deployment and tests in Castelloli of required functions : Free 5GC, NQoF, SC et QoF
5. Test with the gNB and modem that will be used in the train, located in I2CAT
6. Integration of the ACS-GW in the loop
7. Addition of the Hispasat VSAT installed in Castelloli in the loop
8. Introduction of the KPITool
9. Deployment and validation test of gNB in the LFP train
10. Deployment and validation test of sat modem and antenna in the train
11. Functional validation test of B2 backhauling with 5G TAN
12. Functional validation test of B2 backhauling with the 70GHz TAN
13. Functional validation test of B2 backhauling with satellite

Functionality	UC3/B2 lab platform setup.	*ID*	*FUN-UC3-B2-01*
Summary	A scalable test platform is set up in IRT labs in order to test B2 service prior to deployment on the 5GMED testbeds. B2 components will be, step by step, integrated in this setup when they become available.	*Components*	*gNB, Free5GC, Starlink Terminal, U.E.,*
Description	*The test platform consists of a 5G-SA network:* gNB similar to the one that will be deployed in the train, an instance of the Free5GC , modified by IRT, a satellite link (Starlink terminal with Starlink subscription), a OnePlus smartphone (oneplus8 pro) and an access to internet.		
Status of the development	*finished S47 - year 2022*		
Status of the validation in the Lab	*VALIDATED. Simple backhauling OK in the lab. GoogleMeet tested with success. Good quality, fluid. No KPI measured.*		

Status of the deployment & validation on the 5GMED infrastructure	*Only lab*
Status of the deployment & validation in the vehicle	*Only lab*

Table 22 UC3/B2 lab platform setup

Below is the description of UC3/B2 lab test platform setup in IRT used for validation of FUN-UC3-B2 –01

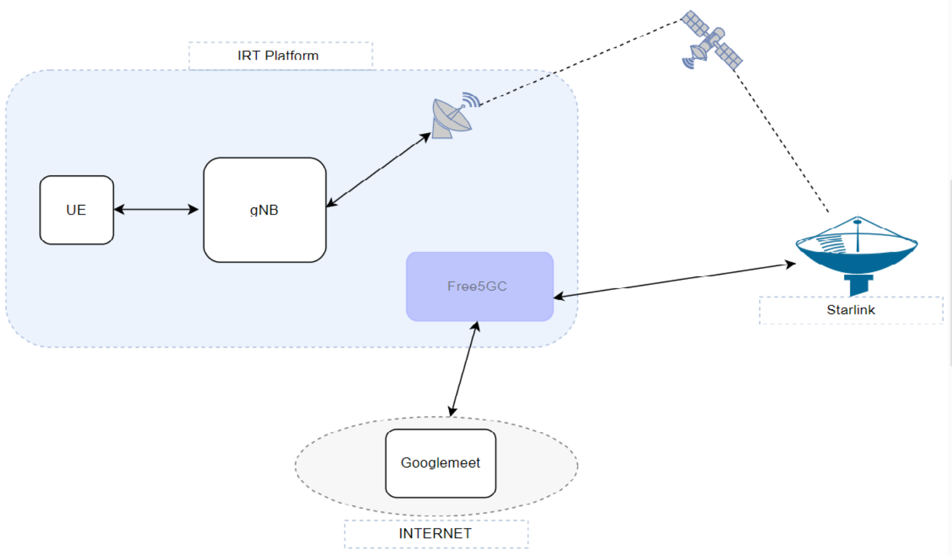

Figure 4 B2 lab test platform setup in IRT

Functionality	Maintain of 5G slice on the satellite backhauling.	*ID*	*FUN-UC3-005-2*
Summary	In order to ensure an E2E 5G slice through the satellite link, specific functions need to be developed or adapted (QoF, NQoF functions already developed by IRT). The 5GC must also be modified (the AMF need to be modified). Slice classifiers (SC), already developed by IRT, must be adapted.	*Components*	*gNB, Free5GC, Starlink Terminal, QoF, NQoF, Slice Classifier, U.E.*
Description	*NQoF, QoF, slice classifier allows to maintain the 5G slice through a non 3GPP satellite link. Those functions were developed in one VM. For the purpose of 5GMED, the functions were split, adapted and deployed in different VMs. This is a step forward for the 5GMED/UC3/B2 platform in IRT to get closer to the final deployment on the 5GMED infrastructure.*		
Related Requirements	*FR-EDG-004,*		
New Added Requirements	*None*		
Status of the development	Finished *in W51-2022.*		
Status of the validation – Lab	*VALIDATED. Successful split of the functions.*		
Status of the deployment & validation on the 5GMED infrastructure	*Scheduled for December*		
Status of the deployment & validation in the vehicle	*Scheduled for December.* At this stage all preliminary implementations have been performed and all is ready to be deployed in the train.		

Table 23 Maintain of 5G slice on the satellite backhauling

Below, one can see that in this test the components required for maintaining the slice through the satellite link.

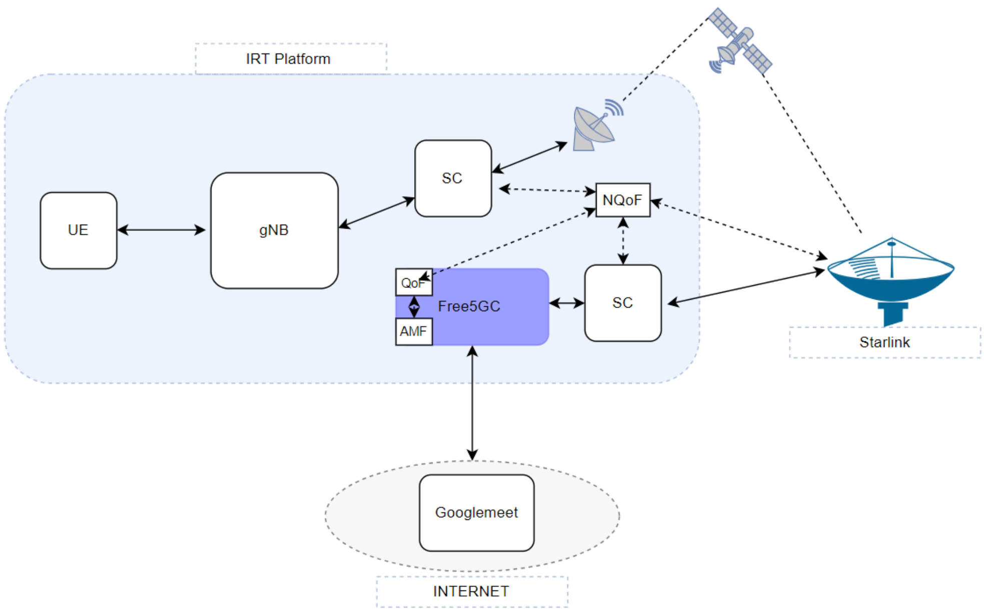

Figure 5 Backhauling with slicing

Functionality	*Development of multi-slicing*	*ID*	*FUN-UC3-005-03*
Summary	Implementation of multi-slicing in order to carry on the satellite link different traffic with different QoS and with isolation.	*Components*	*gNB, Free5GC, Starlink Terminal, QoF, NQoF, Slice Classifier, U.E.*
Description	*Implementation of 2 simultaneous slices - one for P1 and one specific for B2/GoogleMeet*		
Related Requirements	*FUN-UC3-B2 -01*		
New Added Requirements	*Rollout of another UPF in Castelloli*		
Status of the development	*Not started. Pushed after the October 2023 demo.*		
Status of the Lab validation	*Not developed yet*		
Status of the deployment & validation on the 5GMED infrastructure	*None*		

Table 24 Development of multi-slicing

Functionality	Deployment in Castelloli of required functions & tests : Free 5GC, NQoF, SC et QoF	*ID*	*FUN-UC3-005-04*

<table>
<tr><td>Summary</td><td>The functions required and tested in the lab are deployed in the 5GMED cloud in Castelloli on three specific VMs.</td><td>Components</td><td>gNB, Free5GC, Starlink Terminal, QoF, NQoF, Slice Classifier, ACS-GW, U.E., VSA</td></tr>
<tr><td>Description</td><td colspan="3">The IRT Free5GC with modified SMF with the associated QoF (Quality of Service Function) are deployed in the 5GMED cloud (in Castelloli) together with the NQoF (Network Quality of Service Function) and the slice classifier.
3VMs were required on the Castelloli infrastructure :
- One for Free5GC CP and QoF
- One for Free 5GC UPF
- One for SC and for NQoF
The functional validation was performed with Starlink and functions deployed in Castelloli, including the Free5GC.</td></tr>
<tr><td>Related Requirements</td><td colspan="3">FUN-UC3-005-2</td></tr>
<tr><td>New Added Requirements</td><td colspan="3">Need of new VMs in Castelloli</td></tr>
<tr><td>Status of the development</td><td colspan="3">OK</td></tr>
<tr><td>Status of the validation in the lab</td><td colspan="3">Test OK.</td></tr>
<tr><td>Status of the deployment & validation on the 5GMED infrastructure</td><td colspan="3">Deployed in April 2023</td></tr>
</table>

Table 25 Deployment in Castelloli of required functions & tests : Free 5GC, NQoF, SC et QoF

Functionality	Integration of the ACS-GW in the loop	*ID*	*FUN-UC3-005-05*
Summary	The ACS-GW is introduced in the IRT UC3-B2 platform. A test was performed with the IRT platform, similar to *FUN-UC3-005-2*	*Components*	*gNB, Free5GC, Starlink Terminal, QoF, NQoF, Slice Classifier, ACS-GW, U.E., VSA*
Description	*The ACSW-GWs, one in the IRT lab and the other on the 5GMED infrastructure (in Llers) are introduced in the loop and the same tests as for FUN-UC3-005-02 was performed. No KPI measured*		
Related Requirements	*FUN-UC3-005-02*		
Status of the development	*Validation OK. A UDP tunnel could be created successfully between the ACS-GW in IRT (train ACS-GW) and the ACS-GW inground in Llers.*		
Status of the validation	*Validated in September 2023.*		

Table 26 Integration of the ACS-GW in the loop

Functionality	Addition of the Hispasat VSAT in the loop.	*ID*	*FUN-UC3-005-06*
Summary	The setup is now with the Free 5GC in Castelloli and slice related functions (QoF, NQoF, SC). The purpose is to replace the Starlink Link by a Satellite link by Hispasat link	*Components*	*gNB, Free5GC, Starlink Terminal, QoF, NQoF, Slice Classifier, ACS-GW, U.E., VSAT*
Description	A VSAT was integrated by Hispasat in Castelloli to replace the Starlink terminal used in IRT, to get closer to the end configuration with Hispasat satcom on the train.		
Related Requirements	*FUN-UC3-005-2*		
New Added Requirements	*Deployment of HSP VSAT in Castelloli*		
Status of the development	*OK*		
Status of the validation in the lab	*Partial tests. SATCOM in Castelloli works OK but is not integrated with IRT lab. Are faced problem of routing in Castelloli through the firewall deployed there, not solved yet.*		
Status of the deployment & validation on	*The development was stopped, the satcom on the LFP train being available before the VSAT integration with IRT platform could be finalized !*		

the 5GMED infrastructure	

Table 27 Addition of the Hispasat VSAT in the loop

Functionality	Integration of the KPI Tool.	*ID*	*FUN-UC3-005-07*
Summary	The tool was developed in order to measure the latency, throughput and block error rate on the backhaul link.	*Components*	*gNB, Free5GC, Starlink Terminal, QoF, NQoF, Slice Classifier, ACS-GW, U.E., VSAT*
Description	It consists of a software deployed in a PC-NUC (connected to the 5G modem that will be connected to the gNB in train) and in the Free5GC.		
Related Requirements	*FUN-UC3-005-2*		
Status of the validation in the lab	*Validated*		
Status of the deployment & validation on the 5GMED infrastructure	*Validated*		

Table 28 Introduction of the KPITool

Functionality	Connection test between B2 gNB and modem in I2CATand Free 5Gcore in IRT and then in Castelloli.	*ID*	*FUN-UC3-005-08*
Summary	The idea is to connect the Modem and gNB that will be used for the train and currently located in I2CAT with the free5GC in IRT and then in Castelloli.	*Components*	*gNB, Free5GC, Starlink Terminal, QoF, NQoF, Slice Classifier, ACS-GW, U.E., VSAT*
Description	A VPN was created form I2CAT to IRT in order to perform the tests		
Related Requirements	*FUN-UC3-005-2*		
Status of the validation in the lab	*Tested successfully*		
Status of the deployment & validation on the 5GMED infrastructure	Tested successfully in March 2023		

Table 29 Connection test between B2 gNB and modem in I2CATand Free 5Gcore in IRT and then in Castelloli

3.2. Status of Interfaces between UC3 Components

This section presents status of the interfaces between components inside each UC3 service. The "Interface Names" used next are the same as in D5.2 [2]. For each UC3 service, one table is provided showing the list of interfaces between components and detailing if the interfaces were successfully tested both in the lab and in the field.

3.2.1. Service P1 Interfaces

Interface Name	*Component 1*	*Component 2*	*direction*	*Lab results*	*Field results*
Get specific IoT data	*P1 IoT Data Processing Tool*	*Train Presentation Tool*	*C1 -> C2*	*OK*	*OK (tested in September 2023)*
Send massive IoT data	*P1 IoT Traffic Generator*	*P1 IoT Data Processing Tool*	*C1 -> C2*	*OK*	*OK (tested in September 2023)*

Table 30 Tests of service P1 interfaces

3.2.2. Service P2 Interfaces

Interface Name	*Component 1*	*Component 2*	*direction*	*Lab results*	*Field results*
Send alarm	*P2 Edge Module*	*Alarm Management Tool*	*C1 -> C2*	*OK*	*OK*
Get alarms	*Alarm Management Tool*	*Train Presentation Tool*	*C1 -> C2*	*OK*	*OK*

Table 31 Tests of service P2 interfaces

3.2.3. Service B1 Interfaces

Interface ID	*Component 1*	*Component 2*	*direction*	*Lab results*	*Field results*
Internet access	*Android phone IOS phone*	*WEB server*	*C1 <-> C2*	*Not tested*	*NOT OK*
Internet access	*Windows laptop*	*WEB server*	*C1 <-> C2*	*Not tested*	*OK (Manual configuration needed)*
Internet access	*Unix laptop*	*WEB server*	*C1 <-> C2*	*Not tested*	*OK*
Teams session	*Remote Train laptop*	*Remote laptop in Madrid connected to internet*	*C1 <-> C2*	*Not tested*	*OK*
Generate traffic train to ground (IPerf tool)	*PC-NUC2 on train*	*PC-NUC on ground*	*C1 -> C2 C2 -> C1*	*OK*	*OK*

Table 32 Tests of service B1 interfaces

3.2.4. Service B2 Interfaces

Interface ID	*Component 1*	*Component 2*	*direction*	*Lab results*	*Field results*
Air interface	*Android phone* (Oneplus pro)	*Amarisoft Callbox Classic (gNB)*	*C1 <-> C2*	*OK*	*OK*
Air interface	*Modem Quectel*	*Amarisoft Callbox classic (gNB)*	*C1 <-> C2*	*OK*	*OK*
backhauling	*Amarisoft gNB in IRT*	*5GC I Castelloli*	*C1 <-> C2*	*OK*	*OK*
Modem manageme nt	*Laptop con. to modem con. to gNB con. to*	*Modem Quectel*	*C1 <-> C2*	*OK*	OK

Interface ID	Component 1	Component 2	direction	Lab results	Field results
	Free5GC Castelloli				
Googlemeet session	*Laptop con. to modem con. to gNB con. to Free5GC Castelloli*	Googlemeet server on internet	*C1 <-> C2*	*OK*	*OK*
Googlemeet session	*Android phone* (Oneplus pro)	Googlemeet server on internet	*C1 <-> C2*	*OK*	*Not tested*

Table 33 Tests of service B2 interfaces

3.3. Status of UC3 Components Deployment on the Small-Scale Testbed

This section presents the status of deployment of all UC3 components on the small-scale testbed, both on the infrastructure and on the train.

3.3.1. Components on the Infrastructure

3.3.1.1. Components common to all UC3 services

The only components deployed on the infrastructure, common to all UC3 services are the ACS-GWs. They provide connectivity between the train and the ground. They act as a middlebox between the services and the train Radio Access Networks, so its support is required for all the UC3 services.

The ACS-GW system consists of a train unit and ground units (2 units: one in France and one in Spain). The train ACS-GW is connected to the TCN Middle Switch and acts as a default gateway for the application on board; the ground ACS-GW is connected to the UC3 Interconnection Switch and similarly acts as a default gateway for the ground applications. There are two ground units, one in France and the other in Spain. Depending on the country where the train is located, the train unit will be connected to one or the other ground unit. The Spanish ACS-GW is located in Llers. The UC3 validation tests will be performed with this unit. The ACS-GWs are responsible for aggregating, encapsulating and forwarding packets according to the configured policy.
A detailed description of the ACS-GW hardware and functional block is provided in the deliverable D5.1 [1].

3.3.1.2. Components Specific to UC3 Services

3.3.1.2.1. Service P1 Components

The service P1 IoT Data Processing Tool is the only P1 component which is not in the train. It is a software component that is hosted on the 5GMED Cloud infrastructure located in Castellolí. It will be able to communicate with the components in the train through a point to point link from Llers to Castellolí.

For the Train Presentation Tool to calculate the P1 KPIs, the P1 IoT Data Processing Tool must send to it the timestamps of the reception of each packet sent by P1 IoT Data Generator. In order to accomplish this task, its internal clock needs to be synchronized with the same source as the components in the train. To achieve this objective, the clock of the P1 IoT Data Processing Tool is synchronized with a NTP server in Castelloli.

3.3.1.2.2. Service P2 Components

The service P2 Edge Module is installed on each Edge running P2 service, that is for 5GMED, in the Edge in France (Le Perthus LFP facility) and in the Edge in Spain (Llers, LFP facility). The Control Module is installed in the cloud, that is, on the supervisor computer linked to the Edge via a VPN. KPIs are measured via a python program using “ping” commands for latency and interruption time, and “psutil” for LiDAR throughput.

3.3.1.2.3. Service B1 Components

The service B1 requires the following elements:

- One Access Point WiFi6.
    a. Availability of internet Access. Sharing existing internet access in LFP with 70GHz network through a firewall which implements the necessary NAT functionality.
    b. Availability of a DHCP server in the network with a predefined pool of IP addresses. Configuring the middle switch of the train to incorporate the DHCP server and the pool of IP addresses functionality.
- Availability of mobile phones (android and IOS), laptops or tablets (UEs).
- WiFi interface of the on-board PC-NUC enabled to implement KPIs tests.

Functionalities to test:

- Connect the UEs to the internet and evaluate user experience through apps (navigate, YouTube, streaming, Teams session, etc..).
- Generate traffic from train to ground and vice versa with iPerf tool using the centralized 5GMED Mongo DF/Grafana servers in Castellolí.

3.3.1.2.4. Service B2 Components

The service B2 needs several components to be deployed in Castelloli and in Llers

- <u>In Castelloli</u>

Several components for UC3-B2 were deployed and integrated in Castelloli’s datacenter (Lenovo SR 650 server):

- Free5GC (CP and UP)
- QoF : Quality of service Function interfaced with the SMF
- NQoF (Network Quality of Service function interfaced with the satellite operator API)
- SC (lice Classifier)
- KPI tool (in order to measure the real time throughput of service B2 and send it to the MongoDB).

For this purpose, several VMs were created. The different modules being deployed using K8 containers:

- VM1 hosts Free5GC CP + QoF Module + NQoF Module
- VM2 hosts Free5GC UPF + KPI tool
- VM3 : hosts the SC (Slice Classifier). Let's note here that the SC together with QoF and NQoF maintains the 5G slice upon the satellite link used for backhauling the in train 5G the small cell.
- VM4 : spare
- VM5 : dedicated to routing and "NATing" after the firewall in Castelloli in order IRT lab can reach the VSAT in Castelloli.

Note that VLAN split being used in Castelloli. All VMs for B2 are on the same VLAN.

The components deployed are shown in Figure 6 with their environment and locations.

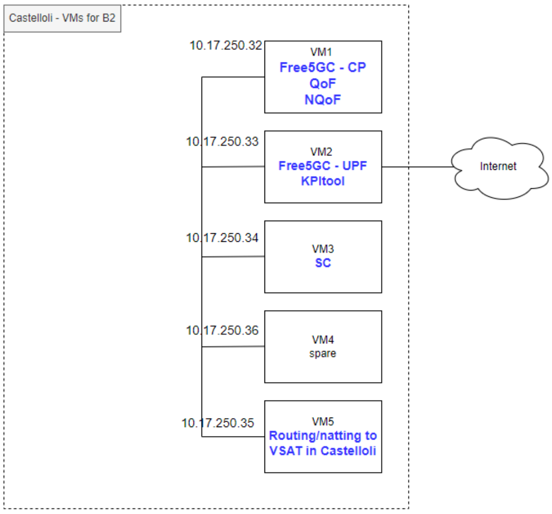

Figure 6 VMs and components for UC3-B2 in Castelloli

- <u>In Llers</u>

  A raspberry PI was deployed.

  The need for the 5G signalling protocols to go through the Firewall in Castelloli (the Cisco Meraki used as firewall in Castelloli filters SCTP with no option to change this), made it necessary to create a VPN between Llers and Castelloli on the point to point link. This was not possible directly from the ACS-GW ground, therefore a Raspberry PI was added in Llers for this purpose.

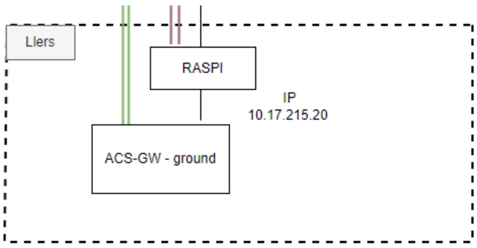

Figure 7 Raspberry PI to create a tunnel between ACS-GW ground and Free5GC

- In the cloud

  A temporary solution for KPI collection and display, a cloud MongoDB and a cloud Grafana servers are used. This solution, used for the first tests will be migrated to the 5GMED infrastructure, using the common MongoDB and the common Grafana server.

3.3.2. Components on-board the LFP train

This section presents the status of deployment of all UC3 components on-board the train of the small-scale testbed.

3.3.2.1. Common components to all services

The common components deployed on-board the LFP train are represented in the following figure.

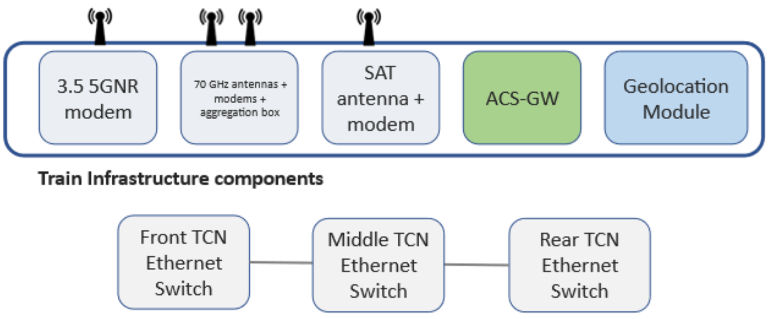

Figure 8 Train common on board components

One of the components common to all services in UC3 is the geolocation module. The geolocation module consists of a "querier" which gets the GPS information from the antennae (the 70GHz antennae or, if not available, the GNSS antenna that the NTP server also bears), a python flask application that serves the geolocation information through HTTP requests, and a second python flask application on ground making the information available to all devices on ground. This module is not intended to capture and store KPIs, each service is responsible to get and store GPS information as they need it.

The TCN currently deployed on the LFP train, like the one that will be deployed on the SNCF train, it will consist of three switches joined by a 10G fibre optic link (front-Cabin1, middle-BarCoach and rear-Cabin2 TCNs). The TCN enables communication among all the identified train components deployed on the train.

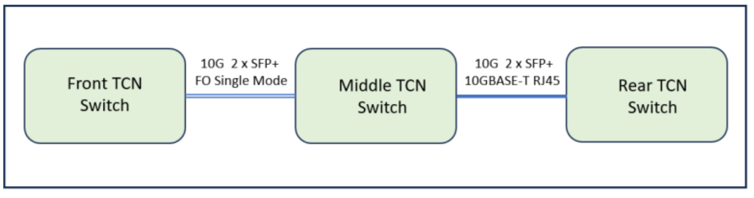

Figure 9 Train Communication Network (TCN) components

The TAN components that need to be hosted in the train to provide connectivity with the ground are the followings:

- *On-board Radio Access Units:* the set of devices that provide connectivity to each radio access network. These components are described in the section 4.1.1. of the D5.1 deliverable. The radio access systems are the followings:
    - 5G NR modem and antenna
    - IEEE 802.11ad at 70 GHz modem and antenna
    - Satellite modem and antenna
- *Geolocation module:* a specific module that provides the train location to the different train devices that need to obtain it. This module obtains the location from the NPU (Network Processing Unit) of the IEEE 802.11ad 70GHz antennas installed on both train heads.
- The Train ACS-GW unit. Section 4.2 of the D5.1 [1] deliverable is dedicated to describing the behaviour of the ACS-GW units.

In addition, an NTP server on-board the train is installed in a Raspberry PI (see Figure 10 below), composed of the following elements:

- One **embedded computer box** including one **Raspberry PI** and one **GNSS receiver**. The Pulse Per Second (PPS) signal and the serial port of the GNSS receiver are directly connected with the processor of the Raspberry PI. This allows the Raspberry PI to be synchronized with the PPS signal. The Raspberry PI is configured as NTP server.
- One **active GPS antenna** to receive signals from GPS satellites. This GPS antenna must be connected with the GNSS receiver inside the embedded box using a coaxial connector.
- One **USB cable** to power the device through the Raspberry PI USB-C connector.

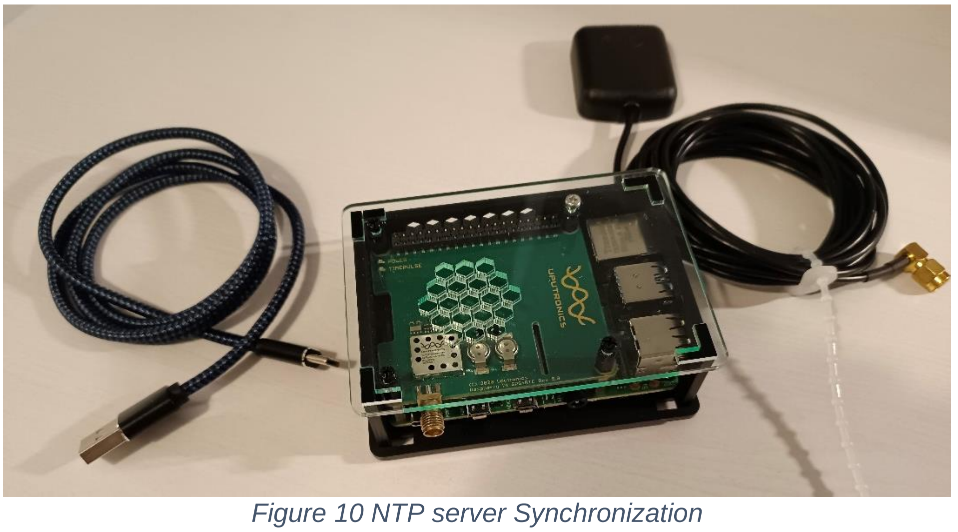

Figure 10 NTP server Synchronization

3.3.2.2. Specific components to each service

3.3.2.2.1. Service P1 Components

The service P1 IoT Traffic Generator is located in the train. More specifically on a laptop connected to the central switch of the train with a 1Gbps Ethernet connection. It is powered with a standard EU plug at 230V. The laptop is simply laid on a table in the train. It is connected to the ACS-GW train and the data flow will, depending on the conditions (availability of each TAN) use 5G NR, 70GHz mmWave 802.11ad and satellite for Train to Ground communication and to reach the Cloud components.
To calculate accurate KPI, its internal clock is synchronized with the same source as the Cloud component. Here, the common on-board NTP server with a GPS source is used.

The Train Presentation Tool is located on the train, in the same way as P1 IoT Traffic generator, but in another laptop also connected to the central switch of the train with a 1Gbps Ethernet connection. It is powered with a standard EU plug at 230V.
It is connected to the ACS-GW train and it will use 5G NR, 70GHz mmWave 802.11ad and satellite for ground to train communication and to be reached by the Cloud component.

3.3.2.2.2. Service P2 Components

For service P2, the following components are deployed in the train:

- Lidar: sensor installed in the train which capture the track parallel to the train's one and sending it to the P2 train module.
- Service P2 Train Module: receives the Lidar data and sends them to the P2 edge module located on ground.

3.3.2.2.3. Service B1 Components

This section describes all the components that implement the B1 service and deployed on the 5GMED infrastructure and in the train. These components are shown below in boxes with an orange contour with other environing components.

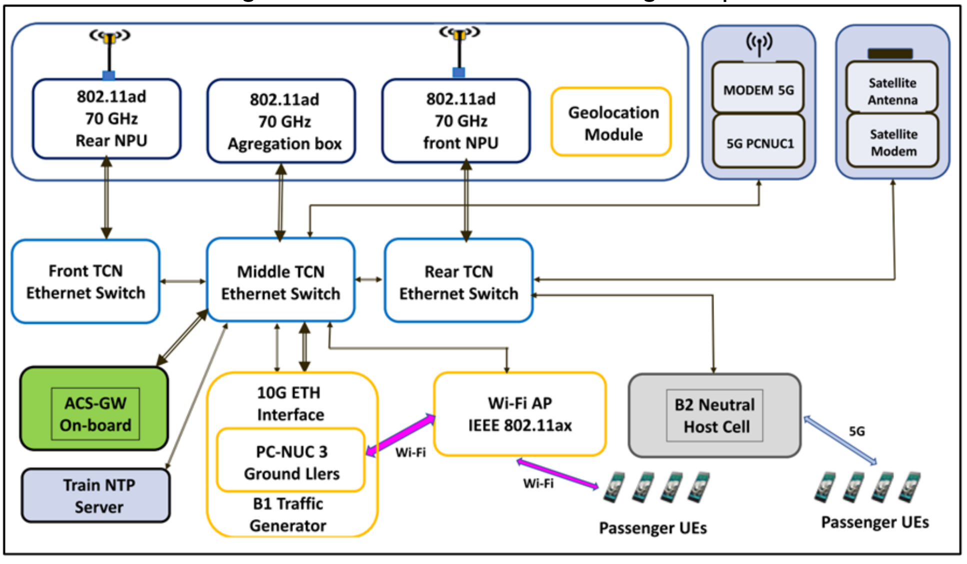

Figure 11 Components that implement the B1 service

B1 Wi-Fi AP:
The G-AP-IX450 Access Point from Galgus meets the new standards IEEE 802.11ax. The equipment has an integrated antenna inside, which will facilitate installation on the train with a standard support. The equipment is powered through an Ethernet PoE+ port of the TCN.

Figure 12 Wi-Fi Access Point 802.11a/b/g/n/ac/ax 2x2 MU-MIMO ref. G-AP-IX450

B1 Onboard Traffic Generator: an INTEL NUC has been used to host a Traffic Generator for the B1 service. The PC NUC has been equipped with a transceiver Thunderbolt™3 to 10GBASE-T Ethernet port (RJ45) interface to connect to a 10G port of the TCN and be able to generate traffic at this rate. It is shown below.

Figure 13 Thunderbolt™- 10G SFP+ transceiver

The on-board PC-NUC2 has three network interfaces through which traffic is generated:

1. 1G Ethernet port
2. 10G Ethernet port
3. Wi-Fi interface for connect to de AP

B1 Passengers UEs:

Passengers UEs will be smartphones, laptops PC or tablets. It can be seen in Figure 4 that the terminals are grouped into two subgroups based on the type of network they are using: Wi-Fi or 5G NR (small cell in the train). For the traffic tests through the Wi-Fi interface, the UEs isn't required to have 5G NR compatibility, while the passenger UEs to be used for testing the small cell is. Host Cell network is a necessary condition to use 5G NR network compatibility.

B1 Ground Traffic Generator:
Another INTEL NUC has been used as a Traffic Generator for the B1 service on LFP ground. The PC-NUC3 has also been equipped with a transceiver Thunderbolt™3 to 10GBASE-T Ethernet port (RJ45) interface to connect to a 10G port to the UC3 ICX Node. From this PC-NUC we can generate traffic to any other PC-NUC located on-board or Castellolí.

B1 Internet Access
For the Internet connection, the Internet access provided by LFP will be used.
The AP will assign an IP address to each of the registered terminals. In order to assign IP addresses, it is necessary to have a DHCP server that has a pool of IP addresses reserved for users within the network numbering plan.
The switches of the TCN will be used for this purpose: they have the functionality of implementing a DHCP server and of programming a pool of reserved addresses within the network addressing plan.

3.3.2.2.4. Service B2 Components

The train components of service B2 are the following:

- A 5G modem Quectel RMU500EK

Figure 14 Quectel 5G Modem

- A gNB (Amarisoft Box Classic)

Figure 15 Amarisoft callbox Classic

- A PC-NUC to control the 5G modem (connected by a USB cable) and to host the KPI tool measuring the Latency and the block Error Rate
- a smartphone (one plus pro)

Figure 15 illustrates the interconnection of these components (in blue) in the train environment in the case when the 5G small cell uses of the 5G TAN for backhauling. Please note that for the moment, the SC in the train is not present since not tested.

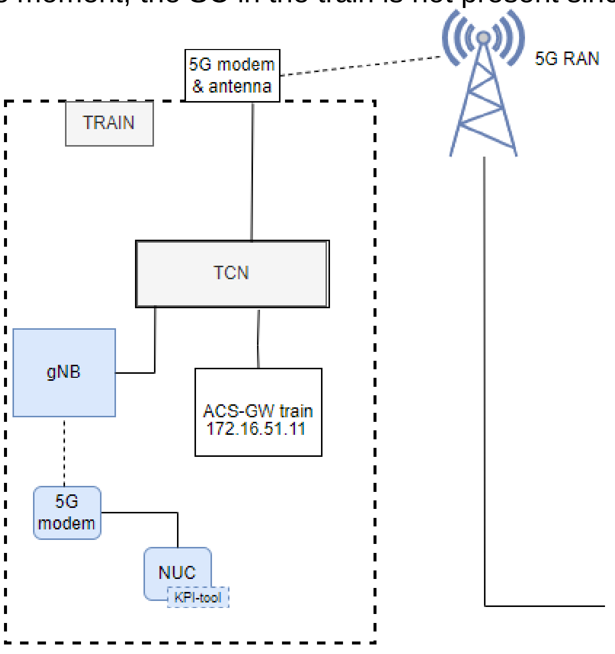

Figure 16 Components for UC3-B2 in the train

4. Functional Validation of UC3 Services on the Small-Scale Testbed

The purpose of the functional validation tests is to validate that all UC3 services work properly in the small-scale testbed and that the service KPIs defined in D2.1 [4] are measured, stored, and displayed. Once the service functional validation is successful, the small-scale trials of WP6 can start. Therefore, this section shows the functional validation tests and the service KPIs obtained for each service. No analysis of the service KPIs are included in this document because this will be presented in D6.2. The measurement methods are briefly described (more details can be found in D6.1).

Each UC3 service has been validated with each of the three TANs, statically for satellite and IEEE802.11ad, and dynamically with 5G as explained below.

Indeed, due to an unforeseeable event, we had to change the plan for the functional validation of the UC3 services. Prior to the readiness of the service components for deployment in the small-scale testbed, the LFP maintenance train had a serious damage (broken drive shaft and ancillaries). Therefore, for the deployment and validation on the small-scale testbed we made the choices described further. Let's first recall that, on the LFP maintenance base where the train is parked, there is no 5G cellular coverage of 5GMED network. However, there is satellite and 802.11ad coverage. Hence, it was decided the following:

- To run the functional validation tests using with 802.11ad and the satellite TANs statically on the LFP maintenance train parked in the LFP facilities on a spot where both 802.11ad and satellite are available.
- To run the functional validation with 5G in a van, in which all the train service components will be moved. Thanks to the early idea in the project of gathering all the UC3 train components in a mobile rack that can be moved easily from a place to another.

Besides, we also had the option, when neither the train nor the van were available, to have all the train equipment in the room of the data center in Llers which already hosts the Spanish ground ACS-GW. In that way, we could also run tests when the TANs were not available, connecting directly the two ACS-GWs, train and ground, with a cable.

To be noted, in this section, the graphs presented for the KPIs for each service shows a first draft of the KPI. This will be improved since recent discussions showed an agreement to have two separate displays: one with a synthesis of the Services KPIs of each service (for example, there will be one graph showing throughput for all services and one with the network KPIs and a map showing the position of the vehicle). Besides, there will be a graph showing on which TAN is used by each service.

4.1. Validation of Vertical-Handover from one TAN to another

This describes the case of vertical handover between the TANs available in the train: from 802.11ad to Satellite. The other handover combinations including the 5G TAN were not tested since during the validation period, the train is still stuck in the LFP parking place with no 5G coverage.

The vertical HO was successfully tested between the Satellite TAN and the IEEE.802.11ad TAN for B1. The default TAN for B1 being the 70GHz network; B1 used the 70GHz TAN, which is unplugged; then the ACS-GW switches immediately on the Sat TAN with no measurable interruption time. The validation was then successful. For the display, there will be a graph with ACS-GW data showing on which TAN each service is backhauled.

4.2. Validation of Service P1

The validation of service P1 is described below, recalling briefly the components involved and the path followed by the data stream.

4.2.1. Components Involved

The following figures show for the three TANs the different components involved in the validation of UC3-P1 and their environment. In blue are the components specific for P1 and in white the other UC3 components in the train or on the 5GMED infrastructure, used by the service.
Meraki is the Firewall used in Castelloli. Interxion it the interconnection point between HSP and Cellnex.

Figure 17 represents the involved components for the 5G NR scenario, Figure 18 for the 70GHz scenario and the Figure 19 for the satellite scenario.

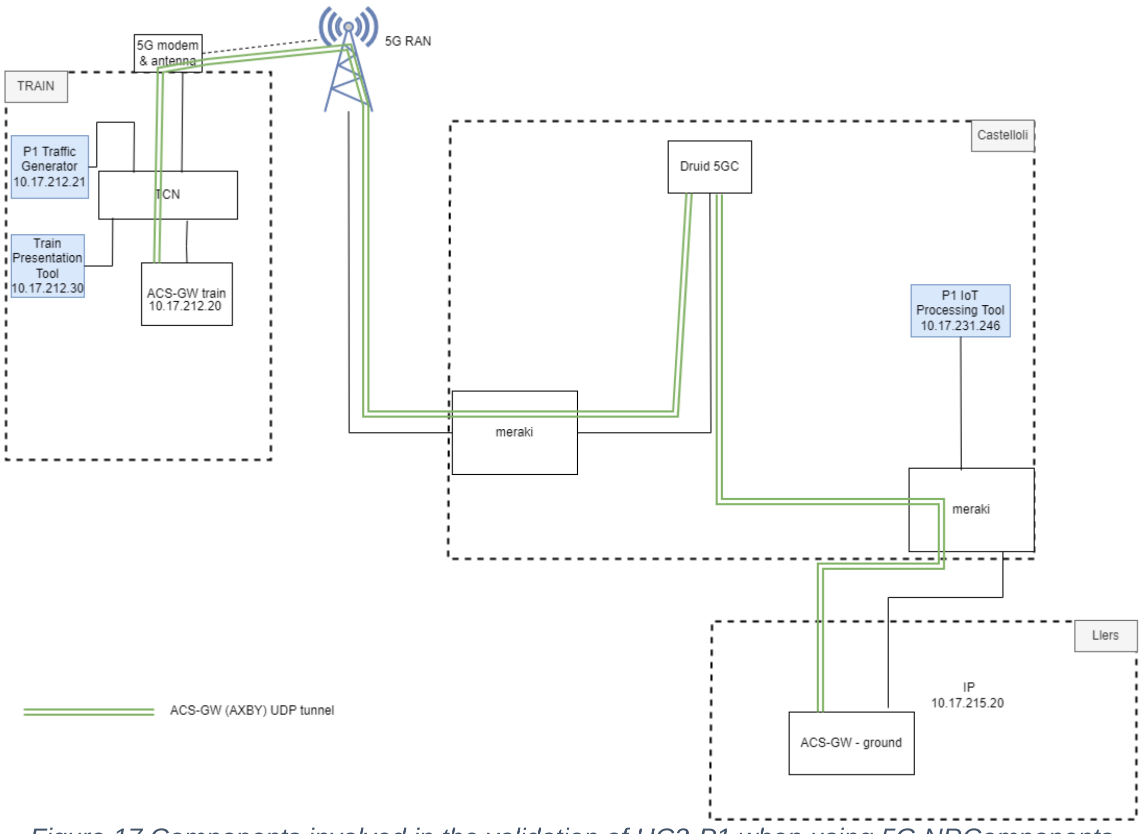

Figure 17 Components involved in the validation of UC3-P1 when using 5G NRComponents involved in the validation of UC3-P1 when using 5G NR

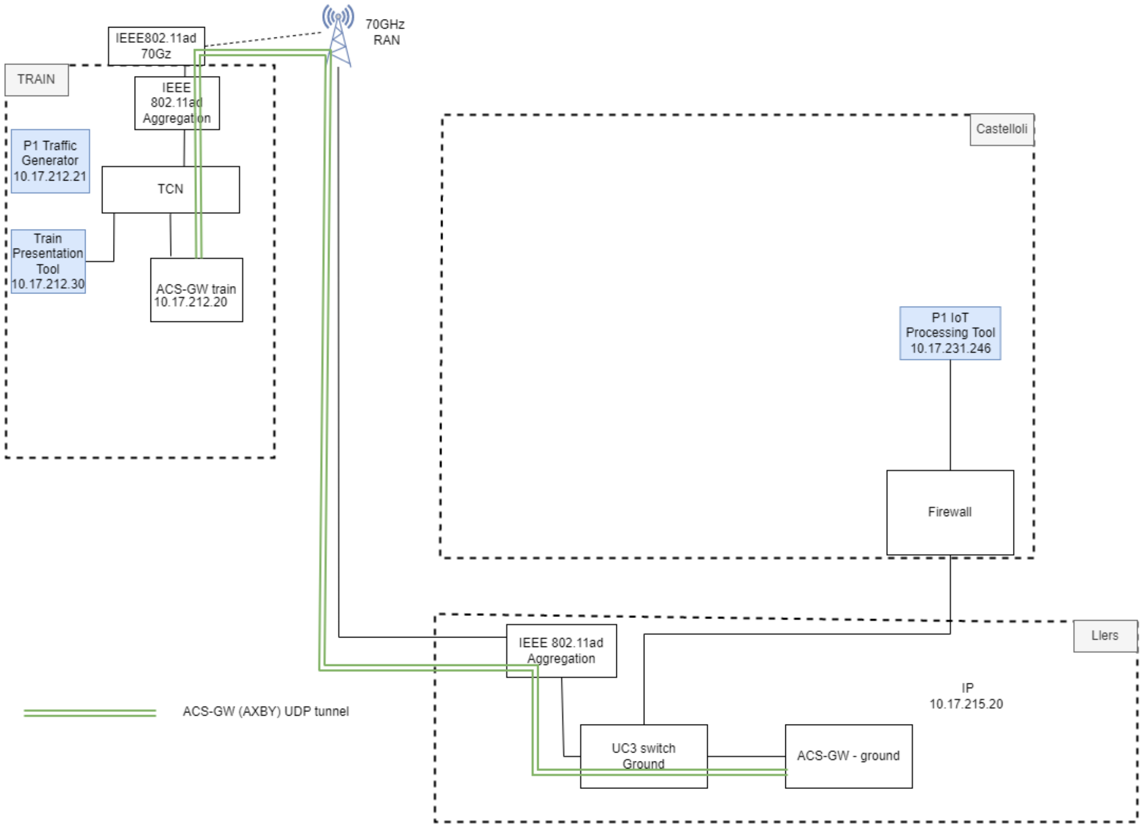

Figure 18: Components involved in the validation of UC3-P1 when using 70GHz

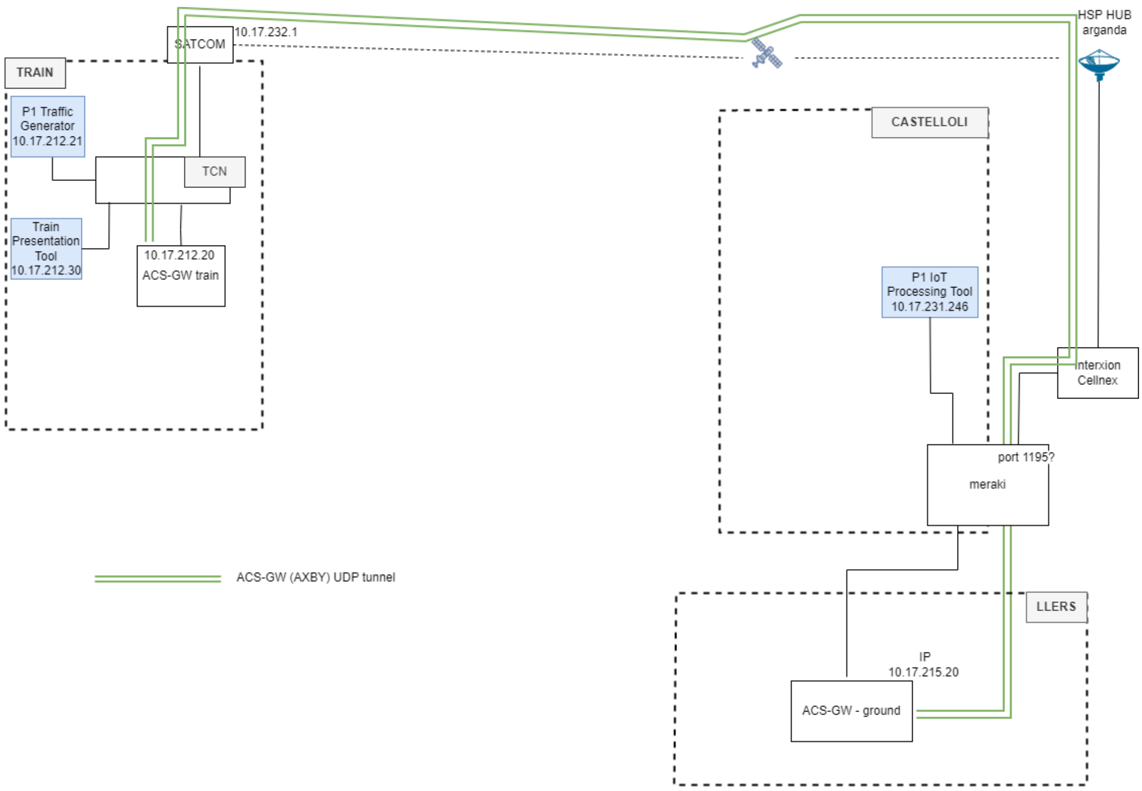

Figure 19: Components involved in the validation of UC3-P1 when using satellite

4.2.2. Test Procedure

The following table describes the validation tests that were performed.

5GMED	UC3: Performance/Business Services	
Service: P1	**Testcase description/objective:** Check the IPv4 and VLAN configuration 1) Boot both laptops on-board the train. 2) Look if both PC have their respective IPv4 address. 10.17.212.21/24 is expected for P1 IoT Traffic Generator, and 10.17.212.30/24 for Train Presentation Tool. 3) Check the switch configuration to see if the VLAN configuration is OK. Expected VLAN id is 10 for both PC. 4) Check the MTU is reduced to 1472 bytes.	**Testcase #: 1**
Additional partners involved: No	**Referred to:** -	**Approx. time to complete the test: (min):** 10 min
Does the test need train movement? No	**Assigned timeslot: -**	**Additional requirements:** None

Table 34 Validation test 1 for service P1

5GMED	UC3: Performance/Business Services' Continuity	
Service: P1	**Testcase description/objective:** Check if cloud server (P1 IoT Data Processing Tool) is reachable through each network interface. 1) Select the configuration of ACS-GW to priority of network interface #1 (5GNR 3.5 GHz) 2) Execute a ping from the PC with P1 IoT Traffic Generator to the P1 IoT Data Processing Tool (10.17.231.30) 3) Redo with 70Ghz then satellite.	**Testcase #: 2**

Additional partners involved: AXBRYD (for ACS-GW configuration)	**Referred to:** --	**Approx. time to complete the test: (min):** 45 min
Does the test need train movement? No	**Assigned timeslot: -**	**Additional requirements:** The train should be in 70GHz and satellite coverage.

Table 35 Validation test 2 for service P1

5GMED	**UC3: Performance/Business Services' Continuity**	
Service: P1	**Testcase description/objective:** Check if downlink and uplink are working when the train is stopped 1) Disconnect 5G NR and satellite modem. 70GHz modem should be the only running modem. 2) Start the IoT Traffic Generator. 3) Start the IoT Presentation tool. 4) Look at the latency and packet loss. 5) These KPI should be good (no handover, no movement). 6) The test should last at least 10 minutes. 7) Redo with 5G NR then satellite.	**Testcase #: 3**
Additional partners involved: AXBRYD (for ACS-GW configuration)	**Referred to:** D5.1 [1] D5.1 functional requirement	**Approx. time to complete the test: (min):** 45 min
Does the test need train movement? No	-	**Additional requirements:** The train should have 70GHz and satellite coverage.

Table 36 Validation test 3 for service P1

4.2.3. Tests Results

Testcase 1: Check the IPv4 and VLAN configuration

Setup: This test was conducted in the train parked at LFP maintenance base.

Test results:

First, we check in the train laptops if the IPv4 configurations are respecting the planned configuration shown in the testcase description.

```
5: vlan10-P1@enp0s31f6: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1472 qdisc noqueue
 state UP group default qlen 1000
    link/ether c8:5b:76:54:c5:c0 brd ff:ff:ff:ff:ff:ff
    inet 10.17.212.21/24 brd 10.17.212.255 scope global vlan10-P1
       valid_lft forever preferred_lft forever
```

Figure 20: IPv4 configuration of P1 IoT Traffic Generator

```
4: vlan10@enp0s31f6: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1472 qdisc noqueue st
ate UP group default qlen 1000
    link/ether 54:e1:ad:16:f1:e5 brd ff:ff:ff:ff:ff:ff
    inet 10.17.212.30/24 brd 10.17.212.255 scope global vlan10
       valid_lft forever preferred_lft forever
```

Figure 21: IPv4 configuration of Train Presentation Tool

Then we check the vlan configuration of the switch where the above laptops are connected.

```
<CENTRAL-SW>display vlan 10
--------------------------------------------------------------------------------
U: Up;         D: Down;         TG: Tagged;         UT: Untagged;
MP: Vlan-mapping;               ST: Vlan-stacking;
#: ProtocolTransparent-vlan;    *: Management-vlan;
--------------------------------------------------------------------------------

VID  Type    Ports
--------------------------------------------------------------------------------
10   common  UT:MTIGE0/0/6(D)   MTIGE0/0/7(D)   MTIGE0/0/8(U)   MTIGE0/0/9(D)
                MTIGE0/0/10(D)  XGE0/1/5(D)
             TG:MTIGE0/0/1(U)   MTIGE0/0/2(D)   MTIGE0/0/3(U)   MTIGE0/0/4(U)
                MTIGE0/0/5(U)   MTIGE0/0/11(U)  MTIGE0/0/13(U)  MTIGE0/0/23(D)
                MTIGE0/0/24(D)  XGE0/0/1(U)     XGE0/0/2(D)     XGE0/0/4(U)
                XGE0/1/1(D)     XGE0/1/2(D)

VID  Status  Property      MAC-LRN Statistics Description
--------------------------------------------------------------------------------
10   enable  default       enable  disable    TOFRMCS
```

Figure 22: Switch configuration for VLAN 10

In Figure 22 we can see that the ports “MTIGE0/0/4” and “MTIGE0/0/5” accept tagged (TG) VLAN 10 packets. “MTIGE0/0/4” is the switch port where P1 IoT Traffic Generator is connected. “MTIGE0/0/5” is the switch port where the Train Presentation Tool is connected.

➔ Test OK

Testcase 2: Check if cloud server (P1 IoT Data Processing Tool) is reachable through each network interface.

Setup: For 70GHz and satellite validation, we conducted this test in the train parked at LFP maintenance base.

For 5G NR validation, the test was conducted in van parked on the parking lot near Buffet Restaurante Mont-Roig in Spain (N-2, 1869, 17723 Biure, Girona, Spain) close to BTS-10. During this test, an omnidirectional antenna was used to connect the van 5G modem to BTS-10.

Test results:

We could ping the cloud server with the 3 RAN without issue. The RTT was around 10ms with 70GHz, 600ms with satellite and 36ms with 5G NR.

- ➔ Test OK

Testcase 3: Check if downlink and uplink are working when the train is stopped

Setup: For 70GHz and satellite validation, we conducted this test in the train parked at LFP maintenance base.

For 5G NR validation, the test was conducted in van parked on the parking lot near Buffet Restaurante Mont-Roig in Spain (N-2, 1869, 17723 Biure, Girona, Spain) close to BTS-10. During this test, an omnidirectional antenna was used to connect the van 5G modem to BTS-10.

Test results:

We managed to run the P1 service over 5G NR, 70GHz and satellite.

We also managed to collect one of P1 KPI, which is the uplink latency. The following figures show the uplink latency for P1 over 5G NR (Figure 23), 70GHz (Figure 24) and satellite (Figure 25).

Figure 23: P1 uplink latency over 5G NR

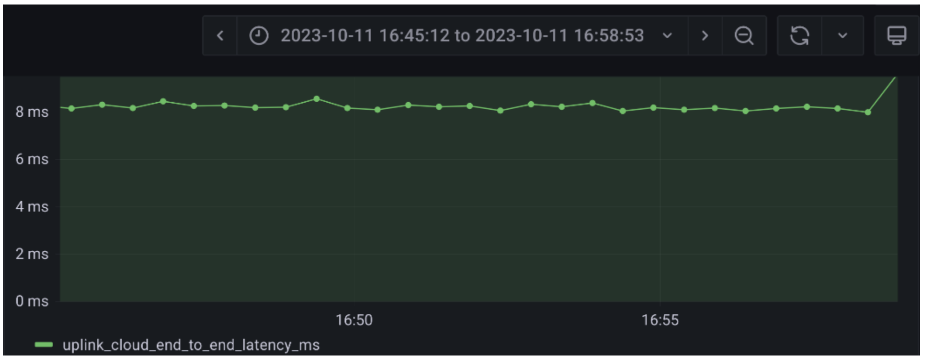

Figure 24: P1 uplink latency over 70GHz

Figure 25: P1 uplink latency over satellite

➔ Test OK

4.3. Validation of Service P2

4.3.1. Components Involved

The validation of service P2 is described below.

4.3.2. Test Procedure

The following table describes the validation tests that were performed.

5GMED	UC3: Performance/Business Services' Continuity	
Service: P2	Testcase description/objective: Software initialization 1. Check if all system modules are present and ready to be launched on Train computer, Edge server and Cloud computer 2. Run each docker module one by one 3. Make parameter configuration on the Control module on the Cloud computer (e.g	**Testcase #** 1

	IP, port number) 4. Check on the Control module if all connections are established 5. Run the LiDAR 6. Check the proper execution of the whole system on the three TANs	
Additional partners involved: No	**Referred to:** -	**Approx. time to complete the test: (min):** 30 min
Does the test need train movement? No	**Assigned timeslot:** -	**Additional requirements:** None

Table 37 Validation test 1 for service P2

4.3.3. Tests Results

The following graphs show the KPIs measured during the tests. The Lidar being not installed in the train, not all the KPIs are available.
However, the mechanism of the service as well as the collection and display of the KPIs with the common database and Grafana server were validated.

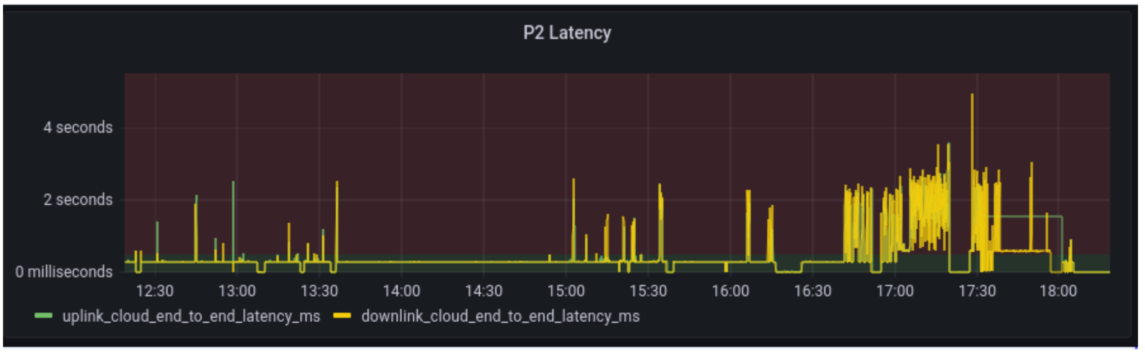

Figure 26 P2 latency

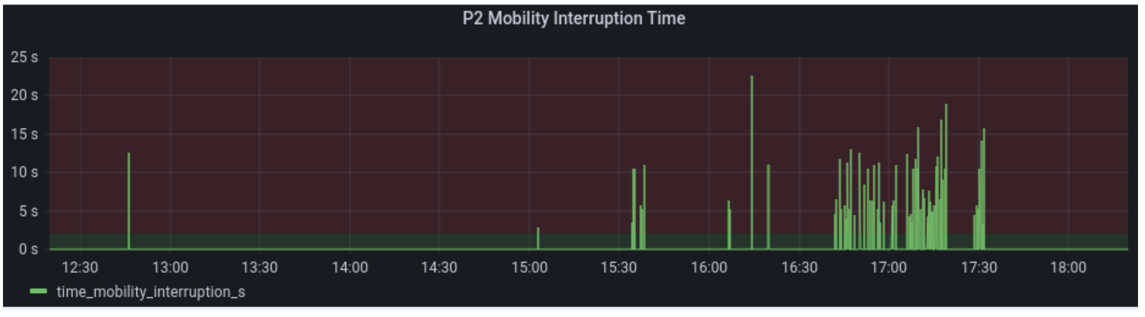

Figure 27 interruption time

4.4. Validation of Service B1

The validation of service B1 is described below, recalling briefly the components involved and the path followed by the data stream.

4.4.1. Components Involved

4.4.2. Test Procedure

The following table describes the validation tests that were performed.

5GMED		UC3: Performance/Business Services' Continuity
Service: **TCN**	**Testcase description/objective:** Verify that the Ethernet ports are enabled and configured according to the train's Ethernet network specifications (IP address, mask, gateways, VLANs, speed (Fast, 1G, 10G, others) and DNS servers	**Testcase #:** 1
Additional partners involved: Locally or remotely if necessary	**Referred to:** Commissioning & set-up	**Approx. time to complete the test: (min)** 10 minutes
Does the test need train movement? No	**Assigned timeslot:** -	**Additional requirements:** it is only necessary to power all the on-board devices.

Table 38 Validation test 1 for service B1

5GMED	UC3: Performance/Business Services' Continuity	
Service: TCN	**Testcase description/objective:** Verify that the console and management ports are accessed in local mode. Opening a telnet SSH session to the switch management network.	**Testcase #:** 2
Additional partners involved: No need	**Referred to:** Select area	**Approx. time to complete the test: (min)** 5 min
Does the test need train movement? No	**Assigned timeslot:** -	**Additional requirements:** Power supply available

Table 39 Validation test 2 for service B1

5GMED	UC3: Performance/Business Services' Continuity	
Service: **TCN**	**Testcase description/objective:** Check the connection of the various devices connected to the Ethernet ports of the TCN. Verify the connection between devices of different VLANs. Command used: ping Ping sends ICMP packets, the status, speed, and quality of a TCN is diagnosed.	**Testcase #:** 3
Additional partners involved: Locally or remotely if necessary	**Referred to:** Select area	**Approx. time to complete the test: (min)** 25 min
Does the test need train movement? No	**Assigned timeslot:** -	**Additional requirements:** it is necessary to have a train-ground connection with the 70 GHz and 5G network. it is only necessary to power all the on-board devices.

Table 40 Validation test 3 for service B1

<table>
<tr><td colspan="2">5GMED</td><td>**UC3: Performance/Business Services' Continuity**</td></tr>
<tr><td>**Service:**
TCN</td><td>**Testcase description/objective:**

Examples:
1. Check the interfaces between on board PC NUC and the TCN.
2. Check the interface between PC NUC Castellolí and the switch.
3. Verify connectivity between on board PC NUC and PC NUC Castellolí using the ping command.
4. Use iperf program to measure KPIs.
5. Save the results in a database.
6. Perform the test for the two networks (5GNR and 70 GHz).</td><td>**Testcase #:**
4</td></tr>
<tr><td>**Additional partners involved:**
AXBRYD (for ACS-GW configuration)
Local or remote if needed.</td><td>**Referred to:**

Select area</td><td>**Approx. time to complete the test: (min)**
20 min</td></tr>
<tr><td>**Does the test need train movement?**
No</td><td>**Assigned timeslot:** -</td><td>**Additional requirements:**
Availability of on-board PC NUC and another PC NUC in Castellolí.
Train-ground connectivity.</td></tr>
</table>

Table 41 Validation test 4 for service B1

5GMED	UC3: Performance/Business Services' Continuity	
Service: B1	**Testcase description/objective:** Passenger checking the Internet Access inside the train: the user must be able to connect its UE to the Wi-Fi AP, and then reach the Internet. **STATIC and DYNAMIC TESTS** UEs: Tablets / Laptops / Smartphones reach the internet.	**Testcase #:** 5
Additional partners involved: Remote access if it is needed	**Referred to:** Select area	**Approx. time to complete the test: (min)** 30 min
Does the test need train movement? Yes	**Assigned timeslot:** -	**Additional requirements:** Choose a section of road where have 70GHz and/or 5GNR(Le Perthus or Pont de Molins) Internet connectivity

Table 42 Validation test 5 for service B1

5GMED	UC3: Performance/Business Services' Continuity	
Service: **B1**	**Testcase description/objective:** Examples: 7. Check the WiFi interface of the PC-NUC. 8. Check the interface between PC-NUC Castellolí and the switch. 9. Verify connectivity between on board PC NUC and PC NUC Castellolí using the ping command. 10. Use iperf program to measure KPIs. 11. Save the results in a database. 12. Perform the test for the two networks (5GNR and 70 GHz).	**Testcase #:** 6
Additional partners involved: Local or remote if needed.	**Referred to:** Select area	**Approx. time to complete the test: (min)** 20 min
Does the test need train movement? No	**Assigned timeslot: -**	**Additional requirements:** Availability of on-board and Castellolí PC NUCs WiFi coverage inside the train. Train-ground connectivity.

Table 43 Validation test 6 for service B1

5GMED		UC3: Performance/Business Services' Continuity
Service: Click to select options	**Testcase description/objective:** Examples: 13. Check the MTU size is reduced to 1480 bytes 14. Passenger checking the Internet Access inside the train: the user must be able to connect its UE to the Wi-Fi AP, and then reach the Internet. 15. Check the interface between the P2 AI module and the Cloud Alarm Management Tool	**Testcase #:** 7
Additional partners involved: (really needed to be present simultaneously) :	**Referred to:** Select area	**Approx. time to complete the test: (min)**
Does the test need train movement? No	**Assigned timeslot:** -	**Additional requirements:** For example, vehicle near the track

Table 44 Validation test 7 for service B1

4.4.3. Tests Results

So far B1 has been validated on the train parked in LFP facilities, over the 70GHz network and satellite and both in a static and dynamic manner for 5G in the van. The tests consisted of connecting to the WiFi AP on the train with a NUC running Ubuntu Server (DHCP enabled) and with a Windows laptop (DHCP enabled. It was determined that the windows laptop could not get MTU via DHCP so it had to be manually set. It was found that MTU for the 70GHz TAN had to be 1328 instead of 1428 for the other TANs. In both cases internet navigation was successful. Furthermore, the KPI collection tool has been shown to correctly produce values and store them in the common MongoDB instance, as well as representing them in Grafana, using the Grafana common server in Castelloli.

The following figure, shows a first draft of the KPI display for B1. This will be improved since further discussions shoed an agreement to have two displays : one with a synthesis of the Services KPIs and one with the network KPIs and a map showing the position of the vehicle.

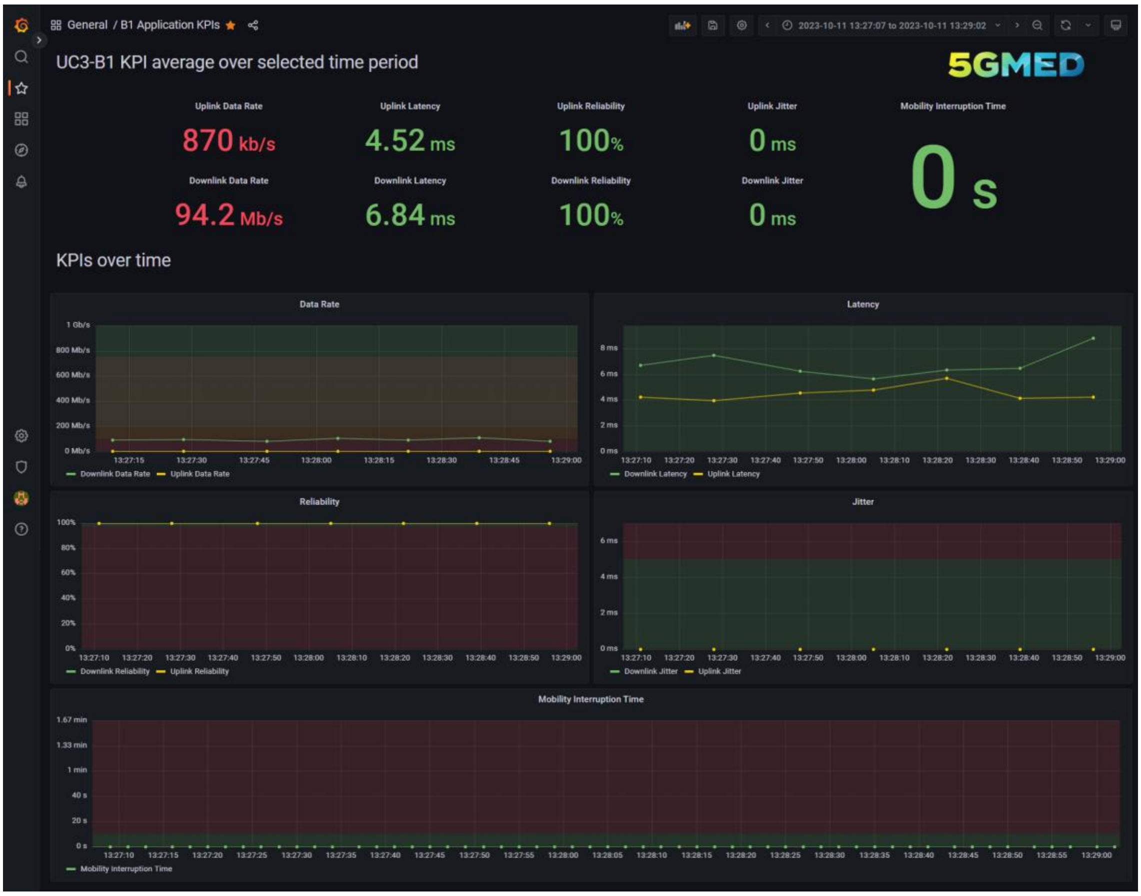

Figure 28 gafana panel for B1

This dashboard shows all required B1 KPIs as collected by the service, sent to the common MongoDB and displayed from the common Grafana server.

4.5. Validation of Service B2

The validation of service B2 is described below, recalling briefly the components involved and the path followed by the data stream. The validation of Service B2 was performed with the three different TANs.

4.5.1. Components Involved

The following figures shows, for the three TANs, the different components involved in the validation of UC3-B2 and their environment (components connected to them). In blue are the components specific for B2 and in white the other UC3 components in the train or on the 5GMED infrastructure, used by the service.

Meraki is the Firewall used in Castelloli. Interxion it the interconnection point between HSP and Cellnex.

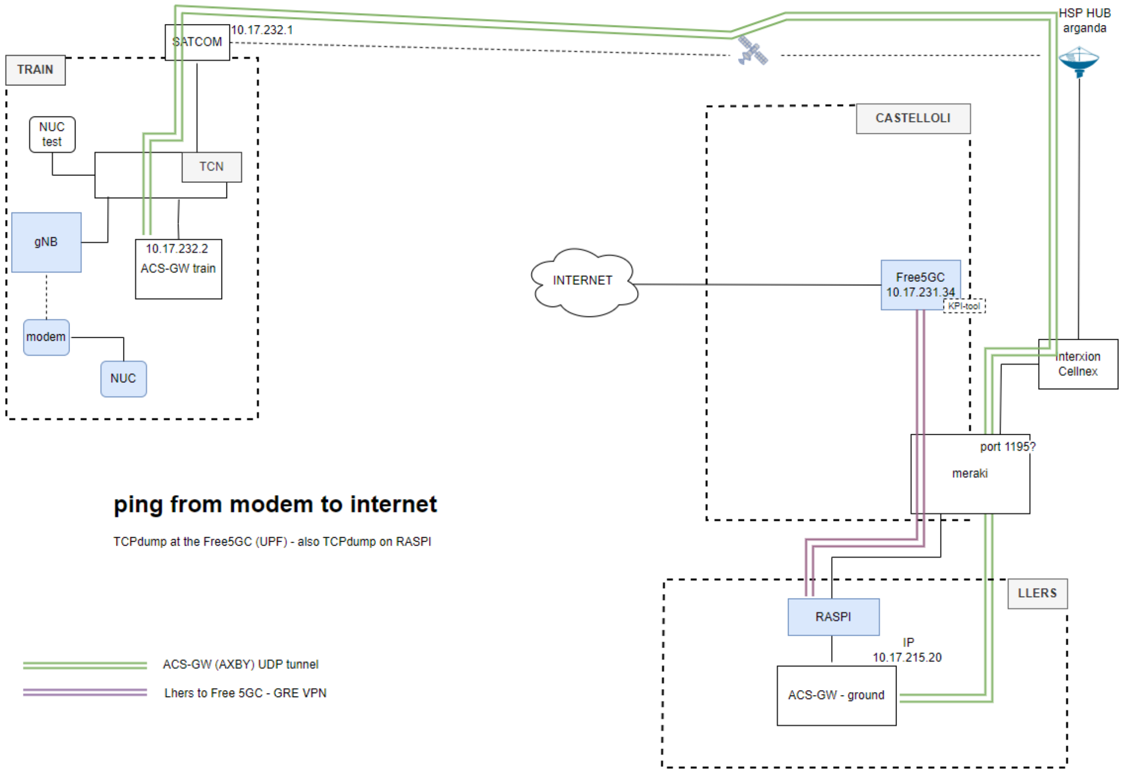

Figure 29 Components involved in the SSTB functional validation tests with the Satellite TAN

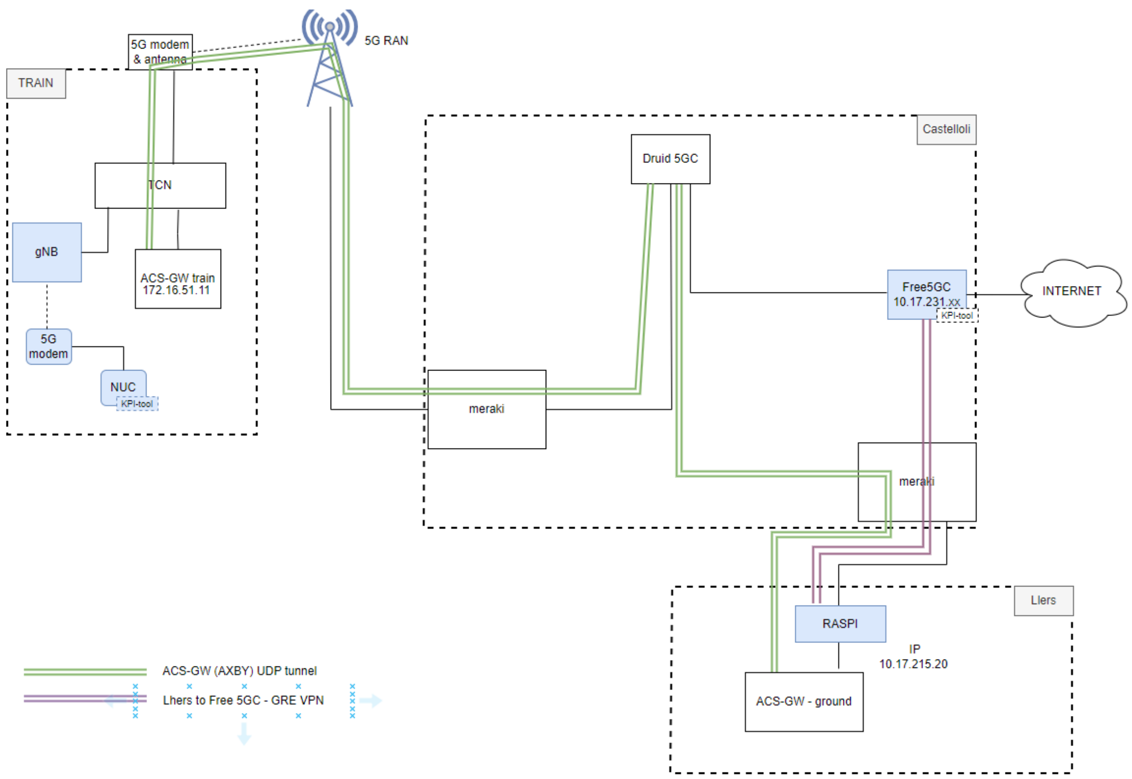

Figure 30 Components involved in the SSTB functional validation tests with the 5G TAN

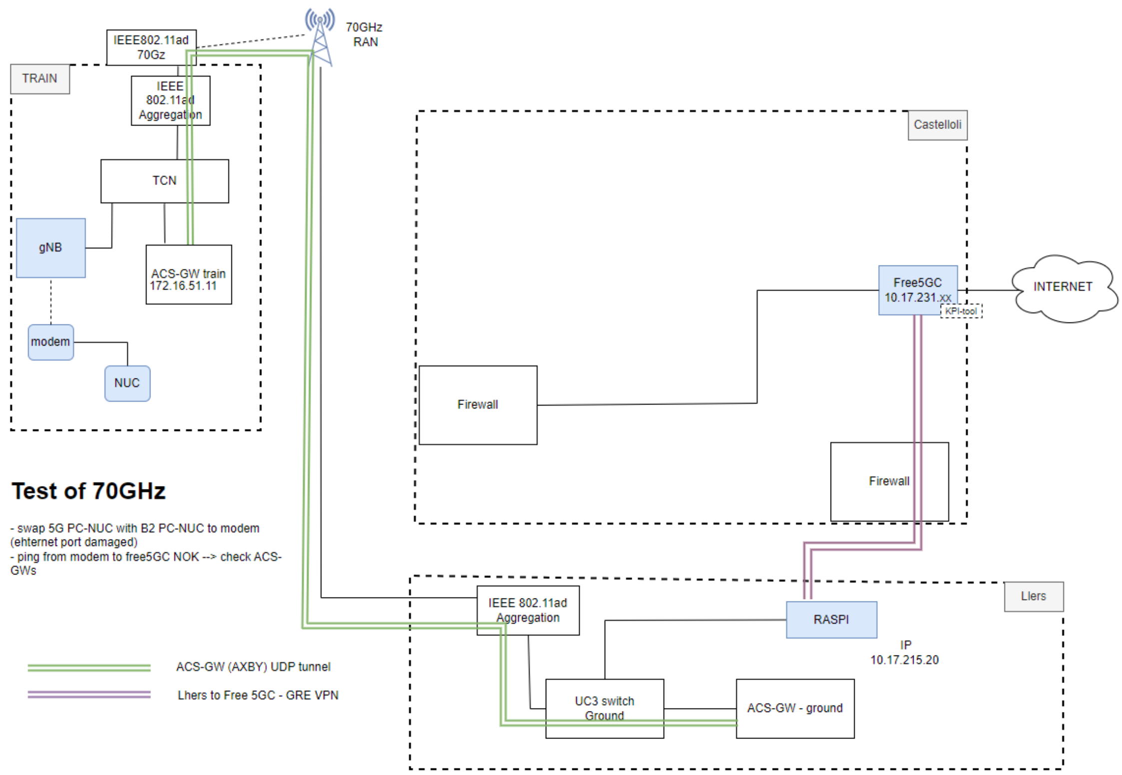

Figure 31 Components involved in the SSTB functional validation tests with the IEE802.11ad TAN

4.5.2. Test Procedure

As explained before in the introduction of chapter 4, when the IEEE802.11ad and Satellite TANs are used, the tests are performed with the LFP train parked in the LFP facilities in Llers, in a place where the satellite view is not obstructed and where there is IEEE802.11ad coverage. For the 5G TAN, the tests were made with all the UC3 components installed in a van. It will allow to reach 5GMED 5G coverage since there is no such coverage in the LFP facility in Llers. This also will allow to run dynamic tests.

The list of service KPIs to be measured (reference D2.1 [4]) is :

- Uplink and downlink data rates
- Uplink and downlink reliability
- Uplink and downlink jitter
- E2E latency between gNB and Free5GC in Castelloli. This KPI replaces the latency between two U.E. in train defined in D2.1 for it is easier to implement according to the equipment we have and not less relevant than the original one. Indeed, the latency between the U.E. and the gNB is negligible.

4.5.2.1. B2 with Satellite TAN

Below table shows the validation tests for B2.

5GMED		October 2023 tests UC3-B2 SAT test 1
Service: B2 with Satellite TAN Static	**Testcase description/objective:** Verify that the Amarisoft 5G cell in the train connects to the Free5GC in Castelloli. Verify that the 5G modem gets an IP@ from the Free5GC. Setup a Googlemeet session with a partner on ground. Check that the KPI tool sends the KPIs to the MongoDB in the cloud, check that the KPIs can be displayed on a laptop in the train (from Grafana server in the cloud)	**Testcase #:** 1
Pre-requisites	Satcom OK. Required routing and IP addresses set and verified. Tunnel established from the ACS-GW train to the ACS-GW ground in Llers. TCN OK.	
Partners involved:	**I2CAT-IRT-CMS-HSP**	**Approx. time to complete the test: (min)** 60 minutes
Does the test need train movement? No	The train is out of its building and parked in the LFP facilities where the satellite view is not obstructed. The train receives electrical power supply.	**Additional requirements:**

		it is only necessary to power all the on-board devices.

Table 45 test 1 for B2 validation with Satellite

4.5.2.2. B2 with 5G TAN

Below table shows the validation tests for B2.

4.5.2.2.1. Test 1: B2 static test

5GMED		October 2023 tests UC3-B2 5G test 1
Service: B2 with 5G TAN Static	**Testcase description/objective:** Verify that the Amarisoft 5G cell in the train connects to the Free5GC in Castellolí. Verify that the 5G modem gets an IP@ from the Free5GC. Setup a Googlemeet session with a partner on ground. Check that the KPI tool sends the KPI to the MongoDB in the cloud, check that the KPIs can be displayed on a laptop in the vehicle.	**Testcase #:** 1
Pre-requisites	5G TAN OK. Required routing and IP addresses set and verified. Tunnel established from the ACS-GW train to the ACS-GW ground in Llers. TCN OK.	
Partners involved:	**I2CAT-IRT-CMS**	**Approx. time to complete the test: (min)** 60 minutes
Does the test need train movement? No	The train is replaced by a van that will start in Llers and will drive to get a 5GMED cell coverage (under the site Pont De Molins for example). The tests will be carried out with the car parked.	**Additional requirements:** it is only necessary to power all the on-board devices.

Table 46 Test 1 for B2 with 5G TAN: end to end connection validation

4.5.2.2.2. Test 2: change of small cell frequency at cross border

5GMED		October 2023 tests UC3-B2 test 2
Service: B2 with 5G TAN	**Testcase description/objective:**	**Testcase #:** 2

Moving along the corridor	Verify that the Amarisoft 5G cell in the train connects to the Free5GC in Castelloli. Verify that the 5G modem gets an IP@ from the Free5GC. Setup a Googlemeet session with a partner on ground. Check that the KPI tool sends the KPI to the MongoDB in the cloud, check that the KPIs can be displayed on a laptop in the vehicle. Start the car in the direction of France. At the border, check that the 5G cell carrier for Spain is changed to the 5G carrier in France. Even if the connection is lost at cross border, this test can still be performed since its purpose is to check the carrier change mechanisms. On the return way, check the reverse	
Pre-requisites	5G TAN OK. Required routing and IP addresses set and verified. Tunnel established from the ACS-GW train to the ACS-GW ground in Llers. TCN OK.	
Partners involved:	**I2CAT-IRT-CMS**	**Approx. time to complete the test: (min)** 60 minutes
Does the test need train movement? Yes	The train is replaced by a van that will start in Llers and will drive to get a 5GMED cell coverage (under the site Pont De Molins for example). The tests will be carried out with the car driving along the corridor from Spain to France and return. Alternatively, the test can be run using a virtual border, that is, with setting the trigger on coordinates closer to Llers.	**Additional requirements:** it is only necessary to power all the on-board devices.

Table 47 Test 2 for B2 with 5G TAN : change in frequency at cross border

4.5.2.3. B2 with IEEE802.11ad TAN

		October 2023 tests **UC3-B2 70GHz test 1**
Service: B2 with 802.11ad TAN Static	**Testcase description/objective:** Verify that the Amarisoft 5G cell in the train connects to the Free5GC in Castelloli. Verify that the 5G modem gets an IP@ from the Free5GC. Setup a Googlemeet session with a partner on ground. Check that the KPI tool sends the KPI to	**Testcase #:** 1

	the MongoDB in the cloud, check that the KPIs can be displayed on a laptop.	
Pre-requisites	IEEE 802.11ad TAN OK. Required routing and IP addresses set and verified. Tunnel established from the ACS-GW train to the ACS-GW ground in Llers. TCN OK.	
Partners involved:	**I2CAT-IRT-CMS**	**Approx. time to complete the test: (min)** 60 minutes
Does the test need train movement? No	The train is out of its building and parked in the LFP facilities where the IEEE.11ad offers good coverage. The train receives electrical power supply.	**Additional requirements:** it is only necessary to power all the on-board devices.

Table 48 B2 test with 70GHz TAN

4.5.3. Tests Results

4.5.3.1. B2 with Satellite TAN

No graphs available at time of edition of D5.3.

4.5.3.2. B2 with 5G TAN

The B2 test with 5G TAN is divided into two parts: static and dynamic testing. Dynamic testing is dedicated to check the in train gNB frequency change mechanism when the border is crossed. However, for both tests, we run the service KPI tool to capture the real-time network performance of the service.

1- Test 1 : B2 static testing

Setup: The van is parked on the parking lot near **Buffet Restaurante Mont-Roig** in Spain (N-2, 1869, 17723 Biure, Girona, Spain) close to BTS-10. During this test, an omnidirectional antenna was used to connect the van 5G modem to BTS-10.

In the following, we illustrate some results obtained by the service KPI tool and displayed in a Grafana dashboard. It is to be noted that due to malfunctioning of the reliability tool, this measure is not done during these tests.

Figure 32 Network infrastructure of 5GMED in the cross-border corridorFigure 1shows the van GPS location (green circle) during the static test. The green marker also indicates that service interruption status. When the marker is green, the link between the vehicle and the core network is available. Otherwise, the marker becomes red. This will be shown more clearly in the dynamic test when the vehicle loses 5G coverage in several locations along the road, and hence the link is broken between the vehicle and the core network.

Figure 33 shows the service interruption time visualization.

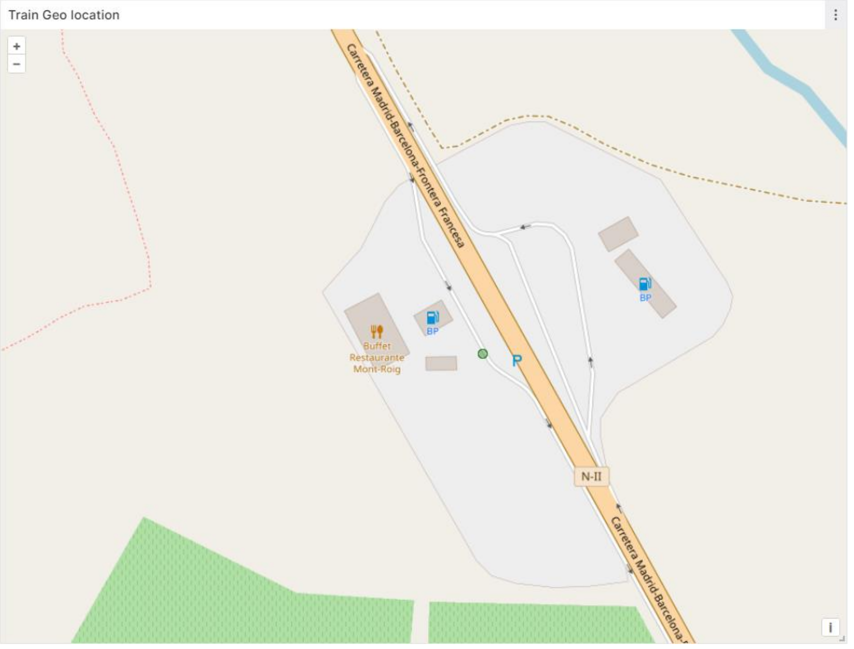

Figure 32 Static Test - Vehicle Geolocation

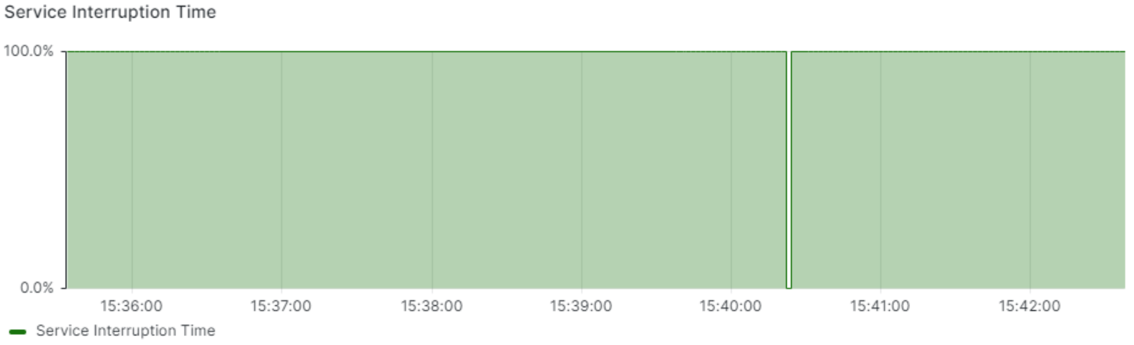

Figure 33 Static Test - Service Interruption Time

Service Downlink and Uplink Throughput KPI

The below figures show the downlink and uplink throughputs measured during a video call session with Google Meet application.

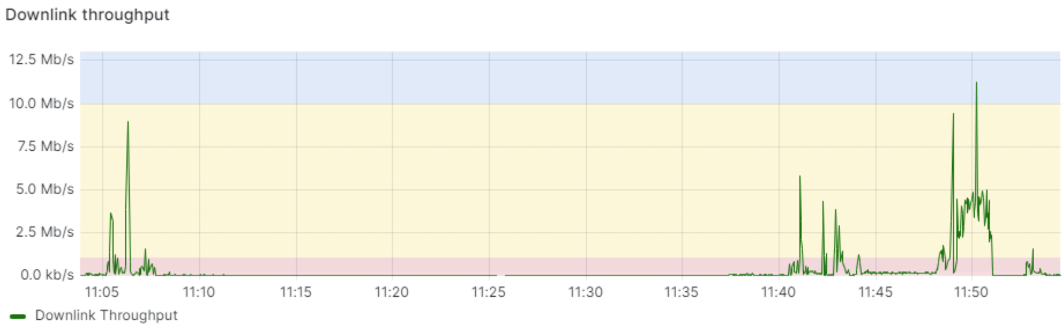

Figure 34 Static Test – Service Downlink Throughput

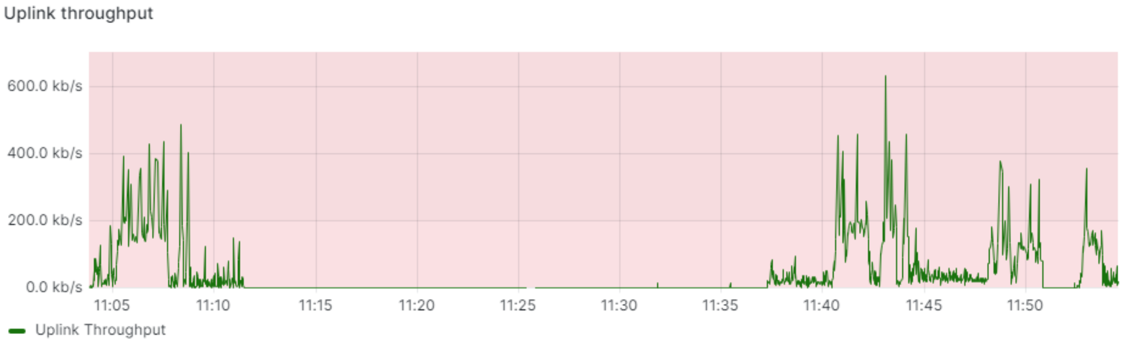

Figure 35 Static Test – Service Uplink Throughput

Service Downlink and Uplink Latency KPI

The below figures show the downlink and uplink latencies measured during a video call session with Google Meet application. During this test, we encountered high latency with a lot of fluctuations due to the bad performance of the directional antenna that was later replaced during the dynamic test.

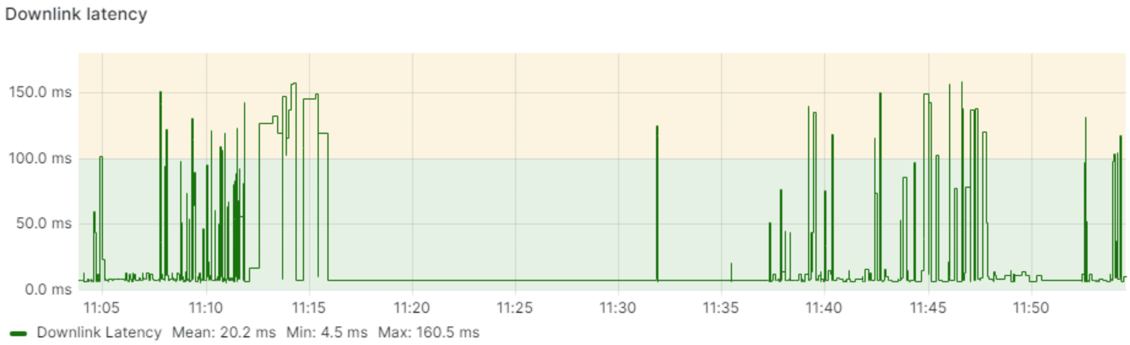

Figure 36 Static Test - Service Downlink Latency

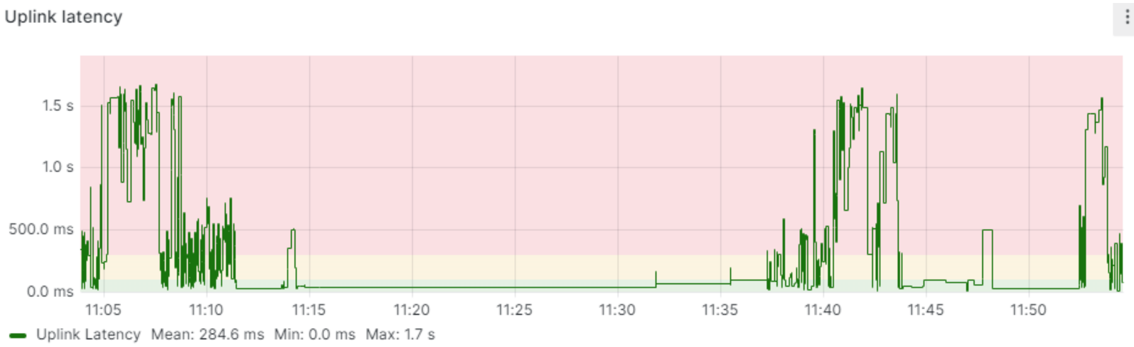

Figure 37 Static Test - Service Uplink Latency

Serving Cell

The Amarisoft gNB used for B2 services bears two 5G cells. This helped solve the issue of changing the 5G small cell frequency at cross border (two different test frequencies were obtained from the frequency regulations authorities in France and in Spain and therefore, the gNB has to change frequency at cross border). The was implemented by attributing to cell 1 the “Spanish” frequency whereas the “French” frequency was attributed to cell 2. At cross border there will be a switch from one cell to the other cell.

The below KPI shows to which cell the user is connected to. This is captured from the amount of bitrate the cell is providing. In the example below, one can observe that the serving cell is Cell 1 as Cell 2 is not providing any throughput.

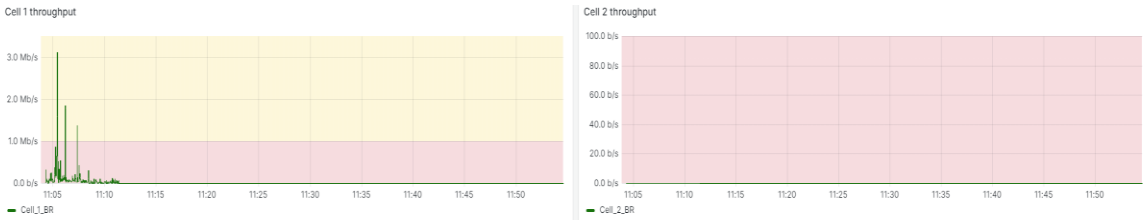

Figure 38 Static Test - Serving Cell

2 – Test 2: Change of the small cell frequency at cross-border - Dynamic Testing

Services were running on the Satellite TAN which was degraded artificially (Ethernet cable to the satellite modem unplugged); automatically the link was handed over to the 70GHz IEEE802.11ad TAN. No interruption was noticeable. We conclude, the tests were successful.

4.5.3.3. B2 with 802.11ad TAN

No graphs available at time of edition of D5.3.

5. Conclusion

This document closes the Phase B of WP5. The different steps required throughout the phase B for the successful implementation of UC3 services are detailed in the document:

- Development and validation of the high level functionalities
- Test of interfaces between main components
- Components deployment in the SSTB
- Functional validation of the services

The 5GMED common KPI collection and display have also been successfully implemented and demonstrated. The first graphs obtained are shown for the 5G Train Access Network.
It can be concluded that each service of UC3 has successfully passed the functional validation tests on the small scale testbed and is therefore ready for the small-scale trials that will be conducted in the context of WP6 for the performance evaluation.

6. References

[1] 5GMED, "D5.1 Railways application requirement analysis report," 2023.

[2] 5GMED, "D5.2 Initial design for performance and business railways test cases," 2023.

[3] 5GMED, "D3.3 First release of 5G-MED ICT infrastructure," 2023.

[4] 5GMED, "D2.1 Use case story definition, requirements and KPIs," 2023.