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D2.2 Initial definition of 5GMED test cases, deployment options and tools

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Synopsis	Deliverable D2.2 is instrumental for WP2, as it presents and defines the methodology that will be applied within 5GMED for tests and trials. In addition, it presents the geographical location and the main characteristics of the small-scale and large-scale testbeds of 5GMED. This deliverable also presents an initial set of test cases associated to the different use cases to validate their functionalities and evaluate their performance. The tests cases of each use case have been mapped to the different small-scale and large-scale testbeds where they will be executed. The deliverable is used as input to WP6 to derive D6.1 and D6.2.
List of Keywords	Testing methodology, deployment options, small-scale and large-scale testbeds, test cases, service KPIs

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LIST OF ACRONYMS

5GS	5G System
ACS-GW	Adaptative Communication System-Gateway
AI	Artificial Intelligence
CA	Consortium Agreement
CAV	Connected and Autonomous Vehicle
CCAM	Cooperative, Connected and Automated Mobility
CIM	Container Infrastructure Manager
CV	Connected Vehicle
C-V2X	Cellular-V2X
DDT	Dynamic Driving Task
DoA	Description of Action
EC	European Commission
ETCS	European Train Control System
FRMCS	Future Railway Mobile Communication System
FSTP	Financial Support to Third Parties
GA	Grant Agreement
GPS	Global Positioning System
H2020	Horizon 2020
HD	High Definition
HMI	Human Machine Interface
I2V	Infrastructure-to-Vehicle
IOPS	Input/output Operations Per Second
IoT	Internet of Things
KPI	Key Performance Indicator
LAN	Local Area Network
LFP	Linea Figueras - Perpignan
MANO	Management and Network Orchestration
MCM	Maneuver Coordination Message
MEC	Mobile Edge Computing
MNO	Mobile Network Operator
MRM	Minimum Risk Maneuver
NR	New Radio
ODD	Operational Design Domain
OEM	Original Equipment Manufacturer
PLMN	Public Land Mobile Network
POI	Point of Interest
QoE	Quality of Experience
QoS	Quality of Service
R&D	Research and Development
RAN	Radio Access Network
RSU	Road-Side Unit
SIM	Subscriber Identity Module
SLA	Service Level Agreement
SME	Small and medium-sized enterprise

SNR	Signal to Noise Ratio
TAN	Train Access Network
TC	Test Case
TCU	Telematic Control Unit
TFR	Traffic Flow Regulation
TMC	Traffic Management Centre
ToD	Teleoperation Driving
UE	User Equipment
V2I	Vehicle-to-Infrastructure
V2X	Vehicle-to-Everything
VDI	Virtual Desktop infrastructure
vRAN	Virtual Radio Access Network
WLAN	Wireless LAN

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EXECUTIVE SUMMARY

This deliverable presents the 5GMED testbeds, the methodology for tests and trials, the initial test case definition for all four use cases, and the mapping of the test cases to the different small-scale and large-scale testbeds.

The testbeds are presented focusing on their geographic location, characteristics, and the existing and to-be-deployed network infrastructure equipment. There are three small-scale testbeds: Paris-Satory, Paris-TEQMO, and Castellolí. For the most part, these testbeds will host preliminary tests and small-scale trials, especially those related to initial configuration and functional verification, before passing to large scale. There is a large-scale testbed in the cross-border corridor between Figueres (Spain) and Perpignan (France). The large-scale testbed will host both automotive and railways test cases, for which the network infrastructure will be, for the most part, common. For the railways tests, two types of trains will be available: an SNCF TGV train (high speed) and a maintenance train from LFP (Linea Figueres-Perpignan).

The methodology for tests and trials is divided in three phases: (i) the deployment and integration phase, to get the overall infrastructure (network, computing, etc.) and use case services for WP4 and WP5 validated, up and running; (ii) the demonstration and KPI collection and analysis in small-scale testbeds; and (iii) the demonstration and KPI collection and analysis in the cross-border corridor (Large Scale Testbed). The latter two are related to WP6.

In the aim of providing a clear, harmonized, and well-organized analysis and reporting tool for the 5GMED performance evaluation tests and trials, a common KPI collection, storage and visualization platform is proposed. It is based on MongoDB (storage) and Grafana (visualization) and hosted in the 5GMED Cloud.

Finally, the initial description of the test cases for all four use cases is presented. This description focuses on five aspects: the test case type, pre-conditions, purpose, functional steps, results, and success criteria. For each of the use cases, its associated test cases are listed and identified, and each test case is mapped to its corresponding testbed(s).

1. Introduction

1.1 Deliverable purpose

This document aims at preparing small-scale testbeds and large-scale testbeds for the execution of the trials that will take place later within the lifetime of the project in the context of WP6. To this end, a first description of the test cases to be considered for each use case (UC) is provided. The test cases are defined to demonstrate the suitability of the 5G network for both automotive and railway use cases and to prove that all service Key Performance Indicator (KPIs) target values are met, and especially in the cross-border scenario. The service KPIs of each use case are defined in D2.1 [1]. For each use case, the test cases are mapped to one or several testbeds.

To accurately carry out the defined test cases and trialing activities, this document also presents the generic methodology to execute the corresponding trial plans.

This document will be the main input of D6.1 [2] and D6.3 [3], in which the detailed test procedures, the data collection and KPI analysis strategies, and measurement tools will be presented, for both the small-scale and large-scale testbeds, respectively.

1.2 Deliverable structure

This document is organized as follows. A description of the 5GMED small-scale and large-scale testbeds is provided in Section 2, an overview of the testing and trialing methodology is presented in Section 0, and finally, an initial description of the test cases is introduced in Section 4 for all the use cases of 5GMED. Section 5 concludes the document.

2. 5GMED Testbeds Description

The 5GMED project considers a set of four automotive and railways use cases (UCs) that require advanced connectivity provided by a 5GS [4] and other wireless technologies, such as Cellular V2X (C-V2X) [5], to meet the requirements of each use case. These uses cases will be deployed, validated, and tested first in the small-scale testbeds and later evaluated in the large-scale testbed in the context of WP6.

The large-scale testbed (described in Section 2.1) is located in the cross-border area between Figueres (Spain) and Perpignan (France), and three small-scale testbeds (described in Section 0) are located in France and Spain.

The description of each testbed contains information about the detailed geographical location of the testbed together with information about special conditions for both the automotive and railways scenarios. In addition, there is a brief information about the existing and to-be-deployed equipment in each of the testbeds, namely:

- Cellular Network,
- Radio Access Networks,
- Compute Resources, and
- Infrastructure sensors.

This information will be further detailed in upcoming project deliverables.

2.1 Large-scale Testbed (Cross-border corridor)

The geographical location of the large-scale testbed, situated between Figueres (Spain) – Perpignan (France), is depicted in Figure 1. It has a total length of 60 km and includes the highway E-15 and the rail track of the high-speed train between Spain and France. The highway and the rail track run close to each other, allowing the deployment of a single, multi-stakeholder 5G network and infrastructure for both the automotive and railways use cases of 5GMED. Within this corridor section, an area of particular interest is the 8 km cross-border tunnel of Le Perthus (highlighted in Figure 1**¡Error! No se encuentra el origen de la referencia.**), traversed by the high-speed train [6].

Figure 1 - Geographical location of the large-scale testbed area showing the highway and rail track of the Mediterranean cross-border corridor between Figueres and Perpignan.

On the Spanish side of the corridor, it has been foreseen to deploy an experimental 5G SA network at 3.5 GHz to cover both the highway and the rail track. Some small areas of the highway will also be covered with C-V2X roadside units at the south of the Spanish side. In addition, a set of 70GHz IEEE 802.11ad access points will be deployed along the Spanish rail track as well as a satellite backhauling service for delay-tolerant services. In addition, on the French side, an experimental 5G SA network at 3.5 GHz will be deployed. The following table details the existing and to-be-deployed network infrastructure equipment of the large-scale testbed for both the automotive and railways scenarios.

Table 1 - Network infrastructure at the large-scale testbed

Large-scale testbed		Existing equipment	To-be-deployed equipment	
		Automotive scenario	**Automotive scenario**	**Railways scenario**
Cellular Network	5GC (SA/NSA)	1x 5GC NSA (VDF)	2x 5GC SA (CLNX)	
	Roaming capability	-	Yes	
	Satellite backhauling	-	-	1x gNodeB (Spain)
Radio Access Networks	5G NR (3.5 GHz) gNodeB	2 (Spain)	2 - 4 (Spain) 4 - 6 (France)	
	C-V2X/ITS-G5 (5.9 GHz) Roadside Unit	-	4 - 6 (Spain)	-
	IEEE 802.11ad (70GHz) Access Points [7]	-	-	15 (Spain)
Compute Resources	MEC servers	-	1 (Spain) 1 (France)	
	GPU	-	Yes	Yes
	Cloud	-	Yes	Yes
Infrastructure sensors	HD camera	-	5 - 11 (Spain)	-

The geographical features of the cross-border corridor will be analyzed in detail later in D3.1 to design the complete radio access network of 5GMED, while also providing the detailed coverage areas of the deployed 5G radio access infrastructure. The network coverages from the French and Spanish MNOs will be investigated in the following months to have a better understanding of the cross-border conditions. To this end, specific drive tests will be performed to measure the 5G coverage areas.

On the E-15 highway segment, the automotive trials for the UC1, UC2 and UC4 will take place. The rail track segment used by the high-speed train (TGV) will host trials for UC3 and UC4, constituting the SSTB and LSTB testbed for the railways services. To be noted that the railways track bears a part in a tunnel.

2.1.1 Automotive scenario

The automotive part of the large-scale testbed is composed of 3 adjacent segments of the E-15 highway:

- **South segment**: around 29 km of the E-15 highway (AP-7 in Spain) between Figueres (Spain) and La Jonquera (Spain).
- **Cross-border segment**: a 6km three-lane highway connecting the AP-7 (Spain) and A-9 (France) in the cross-border region between Le Perthus (France) and La Jonquera (Spain).
- **North segment**: 25 km of the three-lane highway A-9 (France) connecting Le Perthus (France) and Perpignan (France).

In the south segment, the AP-7 highway includes two rest areas and one service area in both directions. The lineal scheme in the figure below shows the highway entrances and exits of the section between Figueres and La Jonquera, as well as the location of the resting and service areas.

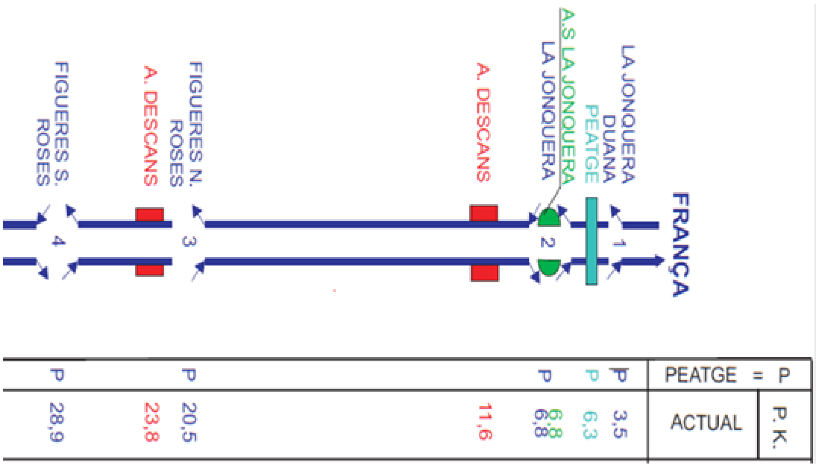

Figure 2 - AP-7 section of the cross-border corridor

2.1.2 Railways scenario

The railways part of the large-scale testbed is the Linea Figueras Perpignan (LFP) International section (shown in Figure 3), which is a double-track high-speed railway line between Llers and Le Soler (near Figueres and Perpignan, respectively) with a length of 44.4 km, divided into the following segments:

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- In France, an open-air section of about 17.3 km extending from the origin at Le Soler to the entrance to the Le Perthus Tunnel.
- An 8.3 km long twin-tube cross-border tunnel (Le Perthus Tunnel).
- In Spain, an 18.8 km open-air section extending from the tunnel exit to the southern end of the line at Llers.

The main characteristics of the LFP international section are summarised below:

- Maximum running speed: 300 km/h for passenger trains and 100 km/h for freight trains.
- 2 wildlife crossings in the form of cut-and-cover tunnels 162 m and 175 m in length.
- 2,143 m of viaducts in Spain (6 viaducts) and 983 m in France (4 viaducts).
- A flying junction for reversing direction.
- 14 bridges where the railway section to crosses roads or rivers.
- 11 road bridges cross over the railway section
- Operated using a signalling and safety system European Train Control System (ETCS) level 1 [8].
- 25,000 V AC electrification.

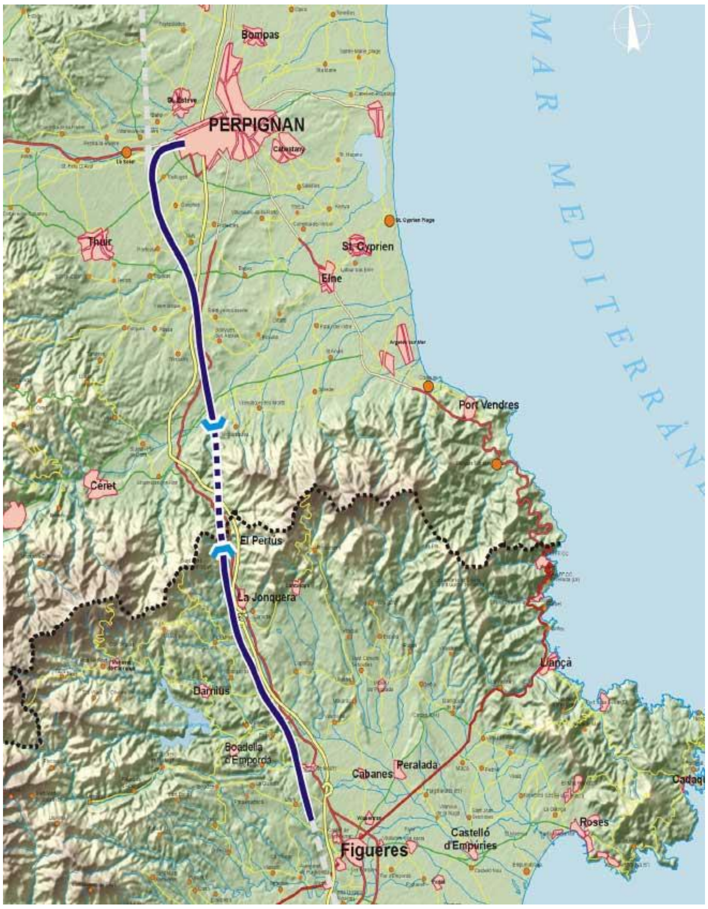

Figure 3 - LFP International railway section line

The railways part of the large-scale testbed will be covered with 5G NR at 3.5 GHz in the Spanish and French open-air sections, 5G NR at 3.5 GHz in the tunnel section, and IEEE 802.11ad (70 GHz) in part of the Spanish open-air section.

Table 1 details the equipment already available and the equipment to be deployed to implement the 5G network and infrastructure for the large-scale testbed. Apart from the tunnel section, the rest of the 5G network infrastructure is shared between the automotive and railways parts of the large-scale testbed.

In addition to the 5G network and infrastructure on-ground, two types of trains are available for tests and trials. On the one hand, a fully operative commercial SNCF TGV (depicted in Figure 4), which is a double-decker high-speed train certified to travel on the Perpignan - Figueres line. On the other hand, a maintenance train from LFP is available for testing at smaller speeds. Additionally, the LFP's maintenance site (see Figure 5), due to its proximity to the rail track, will be used to facilitate the integration process and perform additional testing, if necessary.

The equipment that will be mounted on board the SNCF TGV does not need to be compliant with all railway specifications, but some rules will still hold, e.g., the gauge limits for devices installed outdoors. Due to these rules, the total amount of time in which the tests and trials will be executed in the TGV is limited and usage restrictions will be applied.

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In addition, the use of this commercial train involves the following challenges:

- The maximum speed of the high-speed train is 300 Km/h. It is expected that the performance of the radio access network is degraded by this high-speed. The test cases described in this document will be designed to evaluate how the speed and position of the high-speed train along the track impact the network performance.
- All the tasks related to the installation, setup, tuning, and physical modifications on the high-speed train must be carefully planned, due to the restrictions on the use of the train.
- The availability of the high-speed train will be constrained to specific days and hours. SNCF has to book and approve these particular dates and hours to execute the tests.
- The journey of the high-speed train may be longer than the one of LFP maintenance train considered in the railways small-scale site described later in this document. This is because the TGV has to reach Perpignan to turn back; it is to say, this endpoint is out of the LFP domain.

Figure 4 - SNCF TGV train

It will be possible to use the two GNSS antennas that are already located on the roof of the high-speed train for project activities. No other existing equipment will be available for the experiments. Most of the 5GMED equipment, e.g., a LIDAR, will have to be in the same passenger area (probably the bar).

Figure 5 - LFP maintenance site for railways tests and trials

The LFP maintenance train (depicted in Figure 6) has some advantages with respect to the SNCF TGV in terms of flexibility, availability and suitability for initial setup procedures and testing, namely:

- As its maximum speed is 90 km/h, it will be used as an initial testbed to setup the different train radio access networks, making it easier to verify the performance of each radio access technology.
- All setup and maintenance activities can be performed faster and efficiently given the proximity of LFP's maintenance facilities.
- The availability of this train for testing is significantly higher than that of the SNCF TGV. The timetable has to be authorised and agreed with LFP.
- The itinerary (route) of this train can be restricted to the LFP International Section, which also allows more flexibility and efficiency for the test execution process.

Figure 6 - LFP maintenance train

2.2 Small-scale Testbeds

There are three small-scale testbeds in 5GMED: Paris-Satory (France), Paris-TEQMO (France), and Castellolí (Spain). These testbeds will be mostly used for initial functional verification and for completing the validation of the services and system architecture prior to the full large-scale trials at the cross-border corridor.

2.2.1 Paris Testbed 1: Satory

The main small-scale testbed in Paris is owned by VEDECOM and is located in Satory, 20 km south-west from Paris. It provides a test area to perform tests of connected and autonomous vehicles. It is a closed testbed composed of 3,7 km of urban and semi-rural roads (both separated lanes and the open road are available) to support different types of vehicular use cases.

Figure 7 - Paris small-scale testbed in Satory

The characteristics of the Paris small-scale testbed located in Satory are summarized in the table below, including the features of the equipment already available and the equipment to be deployed in the context of the 5GMED project.

Table 2 - Network infrastructure at the Paris-Satory small-scale testbed

Paris: main small-scale testbed (Satory)		**Existing equipment**	**Equipment to be deployed**
Cellular Network	5G (SA/NSA)	5G NSA	5G SA
	Roaming capability	-	No
Radio Access Networks	5G NR (3.5 GHz) gNodeB	-	No
	5G NR (2.6 GHz) gNodeB	1 eNB (one sector)	5G NR RAN to be done in 2023
	5G NR (26 GHz) gNodeB	1 (two sectors)	-
	C-V2X (5.9 GHz) Roadside Unit	-	1 - 2
	ITS-G5 (5.9 GHz) Roadside Unit	5	-
	IEEE 802.11ad (70 GHz) Access Points	-	-
Compute Resources	MEC servers	1	1
	GPU	-	Yes
	Cloud	1	-
Infrastructure sensors	HD camera	3	-
	Ground LIDAR	2	-

In Satory, an experimental 5G network is being deployed by VEDECOM and TDF using the 2.6 GHz and 26 GHz (mmWave) bands. The coverage of the mmWave radio access network will be as depicted in the simulation results shown in Figure 8. This 5G network will become standalone (SA) during the second half of 2022. It is flexible and extendible, and computing resources at the MEC level (such as GPUs) can be added according to the needs of the project. There is also the possibility to use a set of 5 ITS-G5 RSUs deployed along the circuit. The circuit is also equipped with 3 cameras and 2 LIDARs. As for the 2.6 GHz frequency band, it is currently operating on 4G, with one eNodeB with one sector. It is yet to be confirmed whether this eNodeB will be migrated to 5G NR at 2.6 GHz. The possibility of emulating roaming in the Satory site is under discussion with TDF at the time of writing this document. In the particular case of the UC2 tests, at least one camera and one specific NVIDIA GPU are needed. This GPU can be acquired upon confirmation of the corresponding tests taking place in the Paris site. The cameras already installed in the infrastructure can be used, but an extra camera can also be deployed upon request if it is determined that there is a need to install it on a specific spot, uncovered by the existing ones.

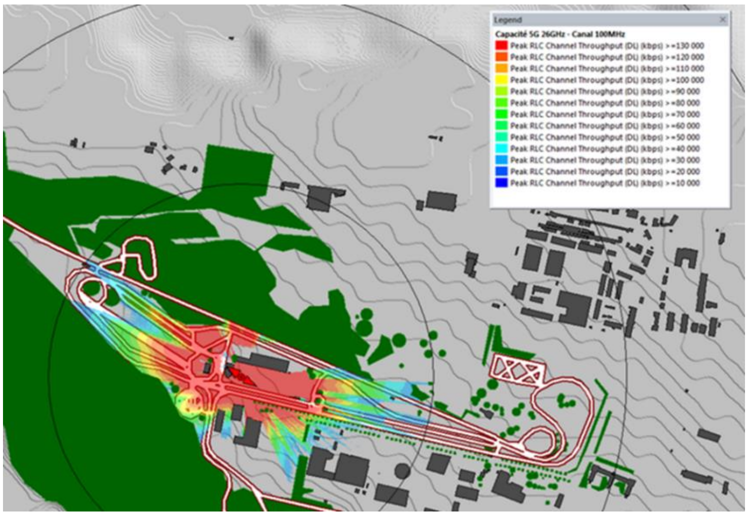

Figure 8 - 5G radio coverage at the Paris-Satory site

2.2.2 Paris Testbed 2: TEQMO (UTAC-CERAM)

The UTAC-CERAM's testbed, known as TEQMO, will be the secondary small-scale testbed in Paris. The characteristics of TEQMO small-scale testbed located in Monthlery are summarized in the table below, including the features of the equipment already available and the equipment to be deployed in the context of the 5GMED project.

Both Orange and Bouygues Telecom will operate 5G networks in TEQMO, as depicted in Figure 9. The 5G radio access network consists of the following network components:

- 2 macro 5G cells offering 5G NR coverage at 3.5 GHz.
- 4 C-V2X Road-Side Units (RSUs).
- Compute processing units control the radio connections with connected vehicles and manage radio cell resources including connection mobility control.
- The RAN network architecture for both telecom operators is implemented according to the 3GPP R15 NSA architecture. The two operators can completely cover the testbed.

Table 3 - Network infrastructure at the Paris-TEQMO small-scale testbed

Paris: secondary small-scale testbed (TEQMO)		**Existing equipment**	**Equipment to be deployed**
Cellular Network	5G (SA/NSA)	5G NSA (Orange) 5G NSA (Bouygues)	5G SA (Bouygues in 2022) 5G SA (Orange in 2023)
	Roaming capability	-	-
Radio Access Networks	5G NR (3.5 GHz) gNodeB	2	-
	5G NR (26 GHz) gNodeB	-	-
	C-V2X/ITS-G5 (5.9 GHz) Roadside Unit	20	-
	IEEE 802.11ad (70 GHz) Access Points	-	-
Compute Resources	MEC servers	1	-
	GPU	-	-
	Cloud	1	-
Infrastructure sensors	HD camera	-	-
	LIDAR	-	-

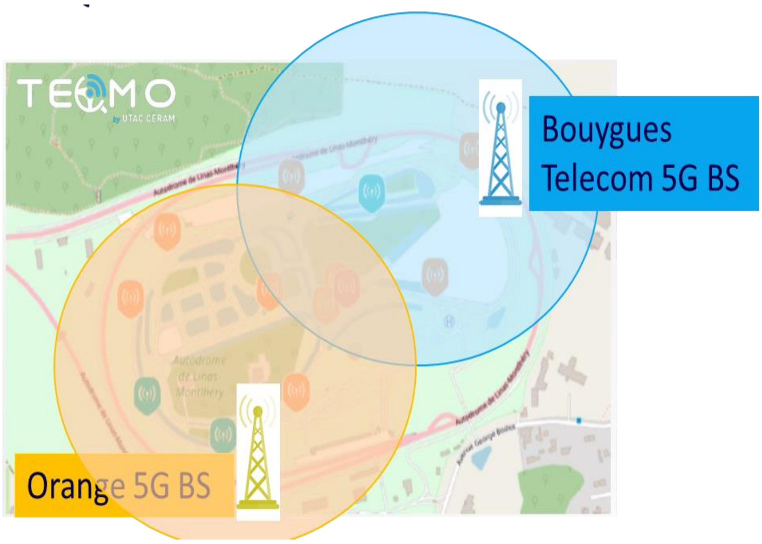

Figure 9 - 5G network deployment at the Paris-TEQMO small-scale testbed

2.2.3 Castellolí Testbed

The Castellolí small-scale testbed is located 55 km north-west of Barcelona and is part of the Parcmotor Circuit, a test track typically rented by OEMs for stress tests of vehicles and to evaluate the performance of specific car parts, thanks to its different angles of inclinations, tunnels, and bridges. The ParcMotor Circuit covers 100 hectares, and it features:

- A 4.1-kilometer-long technical racetrack with marked elevation changes and two crossovers.
- A 1.6-km-long and 10-meter-wide off-road track.

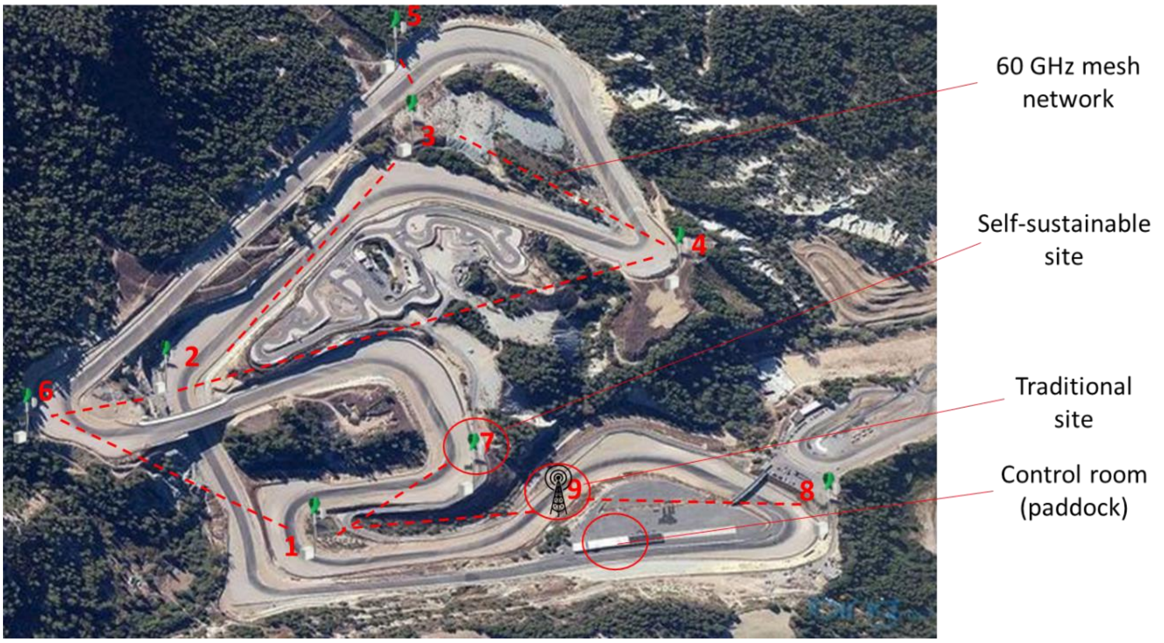

Figure 10 - Overview of the small-scale testbed at Castellolí Parcmotor circuit

Figure 10 shows the network infrastructure currently available in Castellolí, which is managed and operated by the Cellnex Mobility Lab. The circuit has been equipped with nine cell sites consisting of an 8-to-12-meter mast and a cabinet on the ground. Only one cell site (number 9) is connected to the power grid, while the other cell sites are self-sustainable, being supplied by the power generated by a solar panel and a wind turbine. These cell sites can ideally produce 3.18 kWh a day, depending on the time of the year and weather conditions, and that value is expected to increase thanks to the future deployment of cutting-edge solar panels promising 20% more efficiency. Furthermore, a control room located in the paddock gives the possibility to install additional equipment, such as servers, switches, etc.

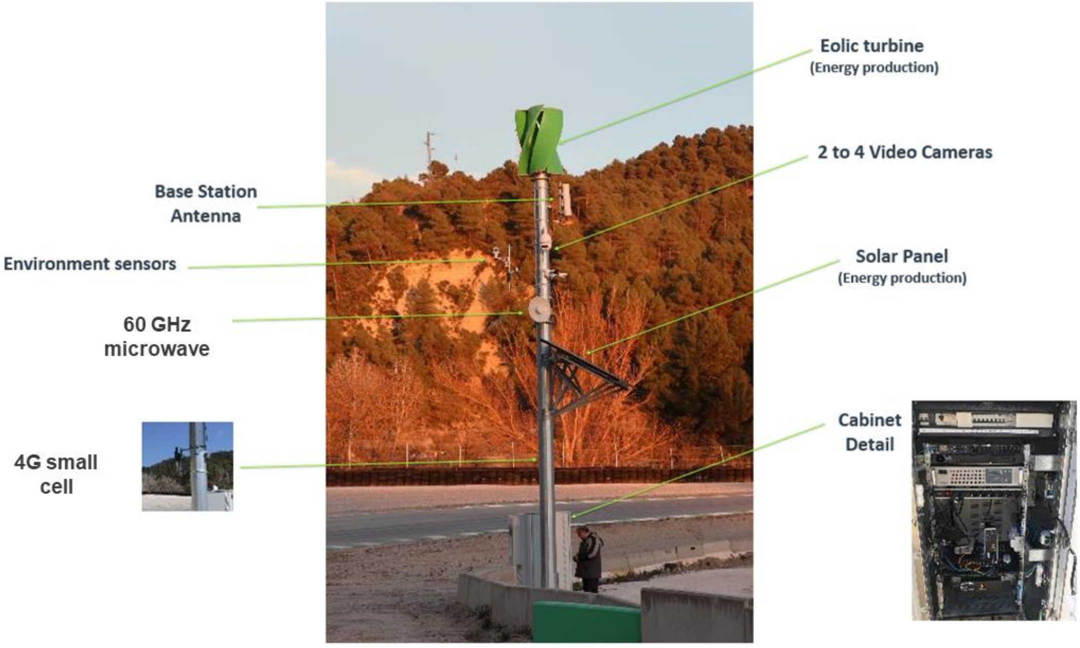

Figure 11 - View of one of the self-sustainable sites

Figure 11 shows one of the self-sustainable cell sites. Each cell site is equipped with two to four HD cameras employed for object recognition and classification. Furthermore, the cell site includes several environmental sensors to collect weather information. The 60 GHz directional antenna of the cell site provides connectivity with the rest of the sites, creating a self-organizing mesh network. The cabinet hosts a wide range of devices, including MEC servers (Lenovo ThinkSystem SE350), switches and a battery pack. Currently, cell site number 1 features an Accelleran 4G small cell which is connected to a DRUID 5GC running in a Lenovo ThinkSystem SR650 server located at the control room. In addition, the Castellolí small-scale testbed also employs the NearbyOne orchestrator to manage the network infrastructure and the lifecycle of applications and services. The orchestrator is currently hosted in one Lenovo ThinkSystem SR650 server available in the control room.

In Castellolí, an experimental 5G SA network at 3.5GHz is being deployed by Cellnex. The new equipment that will be installed are listed below:

- 5G RAN: three small-cell gNBs manufactured by SunWave operating at 3.5 GHz band, consisting of a radio unit (RU) and a baseband unit (BBU).
- 5GC: an additional 5GC supplied by DRUID for testing roaming procedures by setting up a virtual cross-border.
- Satellite backhaul: a VSAT supplied by HISPASAT and connected to a 5G gNB to be installed at site number 9 with the goal of testing 5G backhauling through satellite connection.
- V2X RSUs: three dual-radio RSUs (ITS-G5, C-V2X) will be installed at three different sites.
- MEC servers: additional Lenovo MEC servers will be deployed based on the requirements of the use cases.

Funded by the Horizon 2020 Framework Programme of the European Union

- GPU: a GPU card will be installed for processing multiple camera streams. Currently, an NVIDIA GPU A30 card is being considered.

The characteristics of small-scale testbed located in Castellolí are summarized in the Table 4 below, including the features of the already available equipment and the equipment to be deployed in the context of the 5GMED project.

Table 4 - Network infrastructure at the Castelloli small-scale testbed

Castellolí small-scale testbed		**Existing equipment**	**Equipment to be deployed**
Cellular Network	5G (SA/NSA)	1 instance of 5GC SA	1 instance of 5GC SA
	Roaming capability	-	Yes
	Satellite backhaul	-	Yes (1 gNodeB)
Radio Access Networks	5G NR (3.5GHz) gNodeB	-	3 gNodeBs
	C-V2X/ITS-G5 (5.9GHz) Roadside Unit	-	3 RSUs
	IEEE 802.11ad (70GHz) Access Points	-	-
Compute Resources	MEC servers	Control room: 2 ThinkSystem SR650, 2 ThinkSystem SE350 In cell sites 1, 4, 6, 8: 1 SE350	-
	GPU	-	1
	Cloud	-	-
Infrastructure sensors	HD camera	24	-
	LIDAR	-	-

3. Methodology for Tests and Trials

This section describes the overall methodology of the test and trial activities at the large-scale and small-scale testbeds. Figure 12 presents a comprehensive overview of the methodology that will be applied during the different phases of tests and trials of 5GMED, which are covered in Section 3.1. Subsequently, in Section 3.2, we introduce the common KPI collection, storage and visualization platform of 5GMED.

3.1 Methodology and Test Phases

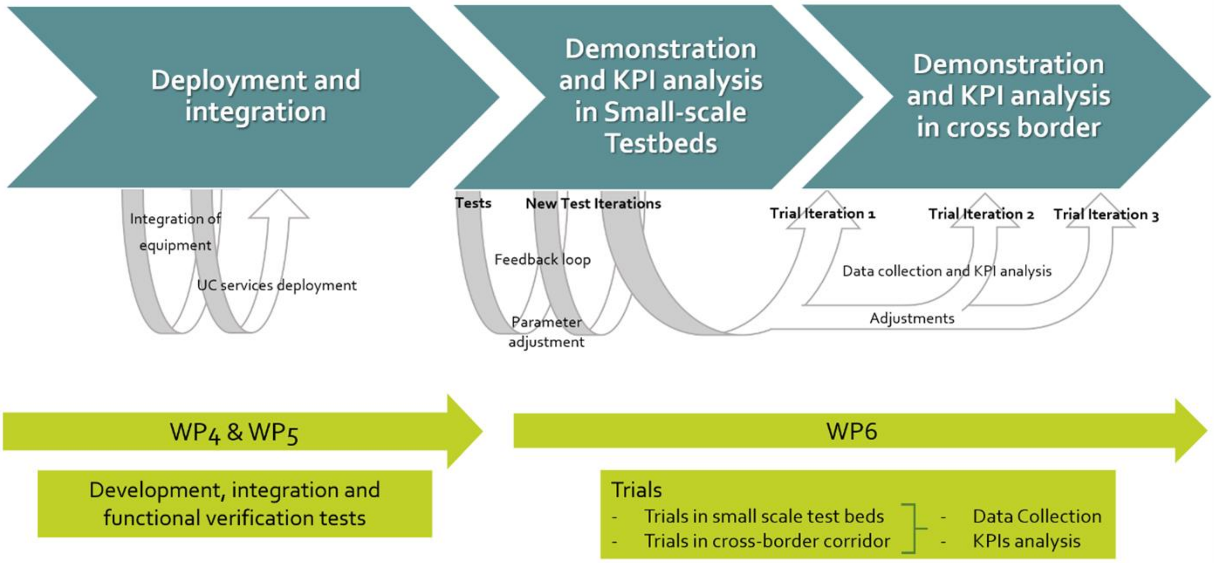

Figure 12 - Methodology for tests and trials in 5GMED

The methodology for carrying out the tests and trials is organized in three phases.

Phase 1: Deployment and integration

This phase aims at deploying and integrating the different components enabling the automotive and railways use cases already defined in deliverable D2.1 [1]. It will encompass all the processes involved in developing the different use cases, deploying or upgrading the 5G infrastructure, preparing vehicles, trains, roadside and cloud infrastructures, and getting use case services up and running functionally. The deployment and integration phase is considered the necessary foundation for testing, assessment and demonstration, and it is organized by the leading work performed by WP3, WP4 and WP5.

Phase 2: Demonstration and KPI collection and analysis in Small-Scale Testbeds

This phase will prepare and execute the use case validation in the small-scale testbeds to ensure the collection of consistent and useful data for performance evaluation. During this period, several test cases will be executed with the objective of completing the validation of the services and system architecture prior to the large-scale trials at the cross-border corridor on Phase 3. At the end of this phase, the collected KPIs will be analyzed to assess the performance of the evaluated technologies in the small-scale testbeds. In the particular case of the small-scale trials for the railways use case, these trials will be performed using the LFP maintenance train over on the cross-border corridor.

Phase 3: Demonstration and KPI collection and analysis in the Cross-border Corridor

This phase will demonstrate the functionalities and evaluate the performance of the use cases at the cross-border corridor. This will be achieved by consolidating the previously executed trials in small-scale testbeds. These experimentations will be coupled with data collection and performance evaluation through the analysis of a defined list of relevant KPIs. This final stage of the project will demonstrate the capabilities of 5G and other radio access technologies to deal with the challenges that arise in automotive and railways use cases on cross-border scenarios.

To ensure a clear planning of the trials, it is necessary to identify, define and organize them in a clear and harmonized way. This is why within phase 2 and phase 3 all the trial activities will be divided and organized in test cases. In this document, we focus on use case-specific test cases. The aim of these test cases is to collect the service KPIs and, by doing so, demonstrate the performance and suitability of the 5G-SA network for the implementation of each use case. The detailed description of each test case is carried out in the next section using the test case structure shown in Table 5.

Table 5 - Test case template structure

Test Case Field	Description
Test case type	Classifies the test case between three categories: • Functional verification • Performance evaluation • Functional verification and performance evaluation
Test pre-conditions	Describes all necessary conditions of any kind that must be met to be able to execute the test case. It must also list those test cases that are meant to be executed before this test case.
Test case purpose	A short purpose statement that includes a general description of the test case.
Test steps	A description of the sequence of actions to be performed during the execution of the test case to achieve its purpose.
Test results and success criteria	Description of the criteria and threshold values that must be met to consider that the test was successful, including the expected functional results and the monitored service KPIs.

3.2 KPI Collection, Storage, and Visualization Platform

In the aim of providing a clear, harmonized, and well-organized analysis and reporting tool for the performance evaluation tests and trials of 5GMED, a common KPI collection, storage, and visualization platform is proposed.

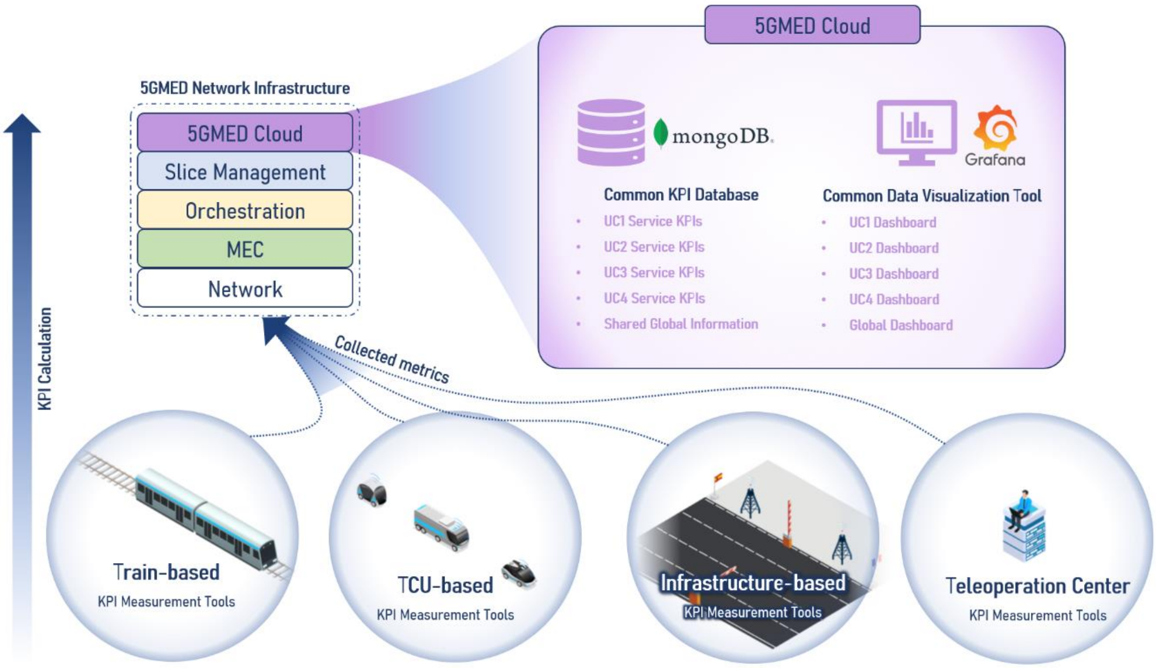

Figure 13 - High-level overview of the service KPI collection, storage, and visualization process on the common platform

Figure 13 represents the operation of the KPI collection, storage, and visualization platform used in 5GMED. The on-board, infrastructure, and user equipment will collect and store the metrics from which the KPIs can be measured or calculated. For every service KPI, the use case team must define the measurement methodology, including the metrics that must be collected in each entity of the UC architecture (e.g., TCU, UE, Edge application, etc.) and the steps to follow for the computation of the service KPI. The service KPIs measurement methodologies will be presented in deliverable D6.1 [2].

During the trials, the KPI measurements are stored in a common database (mongoDB) that is hosted in a private cloud server of 5GMED. In addition, the common database will store global information that will provide insight on the context, conditions and parameters of the trials (e.g., configuration of roaming optimization technique, etc.) that will provide a better understanding of the measurements of the KPIs and their evolution. The visualization tool will be based on Grafana and will provide one UC-specific dashboard for each of the use cases, as well as a global dashboard summarizing the most relevant information of the 5GMED trials as well as the common context information and parameters.

This common KPI collection, storage, and visualization platform will allow different use cases to assess the results of their different tests cases, hence benefiting from a global, high-level view of all different factors potentially affecting the services' performance. From this tool, they eventually adapt their components to ensure that the 5G network resources are fairly shared and reasonably used to guarantee that all the functional constraints and requirements are met.

To illustrate the integration of the KPI collection, storage and visualization platform across the different use cases and the 5GMED network architecture, let us take an example of the life cycle of a particular service KPI. For instance, in the UC2 we can imagine the analysis of the "Hazard Notification End-to-End Latency" defined in D2.1 [1]. In that case, there are several elements involved across the field and the 5GMED architecture: the TCUs of the vehicles involved in each sector or country, the different local V2X Gateways, and the concerned instance or instances of the Traffic Management Center (TMC).

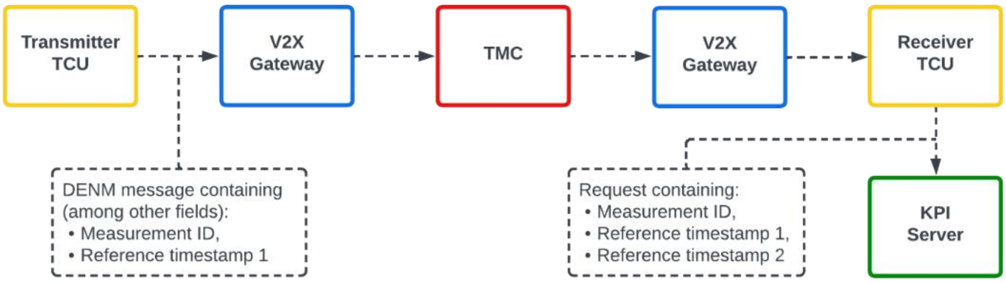

Figure 14 - Example scheme of the methodology to collect and store an UC2 service KPI

According to the methodology defined to measure the end-to-end latency, the different elements in the UC2 architecture (i.e., TCUs, V2X Gateways, TMC, etc.) send data to the database every time that they transmit or receive a V2X message (i.e., DENM, MCM). The data sent to the database includes timestamp, identity of the element transmitting or receiving the V2X message, number of the message, type of message, geographical position of the TCU, etc. Then, the end-to-end latency KPI can be computed using the data logged in the database and it can also be split into different segments: TCU to V2X Gateway, V2X Gateway to TMC, V2X Gateway to TCU. In the example represented in Figure 13, it is one of the TCUs that sends the summary of the needed data for the KPI calculation to the database in the KPI platform in the server. However, it is important to note that any application component on ground or in the network is allowed to connect to the KPI platform, and we can collect either measurement parameters (metrics used for the final calculation of the service KPI) or the KPI value itself. If only measurement parameters are sent, the service KPI can be calculated using the platform.

Every use case focuses on measuring service KPIs (i.e., application-level information). There is also a separate collection process for 5G network-specific KPIs. The measurements of the network-specific KPIs will be correlated with the service KPI results for understanding the observed results and the impact of network events (e.g., handovers, roaming) on the service performance. This is also used to validate in real-time during the execution of the performance evaluation test cases (or later) whether or not the test is performed in the right conditions according to the test requirements.

Finally, all use cases have service KPIs that are not independent from one another, as the effect of the coexistence of the different UC services on the network performance, cannot be considered as negligible. The KPI platform allows for the analysis of this effect and to detect any associated phenomena.

The KPI platform will be used in real-time for controlling live testing and demonstrations, and also for offline analysis to build the trial results that will be presented in deliverables of WP6.

4. Test cases definition

This initial definition of the test cases is organized per use case. For each of the four use cases, we will first briefly introduce the services that we intend to deploy and test. A more detailed description of the services can be found in deliverable D2.1. Also, at the use case level, we will list and identify all of its test cases and map them to the corresponding testbed(s). Finally, we proceed to provide the initial definition of all test cases for each use case, following the template defined in Table 5 above.

4.1 UC1: Remote Driving

As defined in D2.1, UC1 is about providing remote assistance to a connected and autonomous vehicle, also named as Remote Vehicle (RV), getting out of its Operational Design Domain (ODD) and failing to accomplish its intended autonomous driving task for all sorts of reasons (e.g. component failure). In this situation, we need to cover the three main services that follow this event:

- Minimum Risk Maneuver (MRM), in which the RV will broadcast an alert for its hazardous status at destination of its environment while executing the safety MRM maneuver itself.
- Request for Remote Assistance (RRA), in which the vehicle will contact the Valeo Teleoperation Cloud (VTC) for assistance. Technically, RRA will be implemented to initiate simultaneously with MRM, hence saving time in the processing of the request and assessment by the remote driver. This RRA encompasses queries to external services in addition to the VTC.
- Teleoperation Maneuver (TM), in which the remote driver operates the RV from its Remote Station (RS). During this service, the VTC may continue to query external services for updates, the RV may broadcast its status to its environment and teleoperation shall fail (i.e., in the case of network loss), the RV may lead to executing an MRM again.

Table 6 shows the test cases of UC1 that will be carried out in both small-scale and large-scale testbeds. Small-scale test beds will be ideal to validate the main functionalities, while large-scale test beds will allow to challenge them further and evaluate the performance in cross-border conditions. The rest of this section provides the test case descriptions following the template presented in Table 5.

Table 6 - UC1 test cases and testbed mapping

Test Case	Test title	Testbed	
		Paris small-scale	Cross-border
UC1-TC01	System failure detection and Minimum Risk Maneuver	✓	
UC1-TC02	Request for Remote Assistance	✓	✓
UC1-TC03	Teleoperation in Highway Insertion	✓	✓
UC1-TC04	Teleoperation at High-speed	✓	
UC1-TC05	Teleoperation at High-speed in Cross-Border Scenario		✓
UC1-TC06	Teleoperation Failure and Minimum Risk Maneuver	✓	
UC1-TC07	Prevention from Dangerous Teleoperation	✓	

4.1.1 Test case 1: System failure detection and Minimum Risk Maneuver

Test case type

Functional verification of service 1 (MRM) in UC1.

Test pre-conditions

Remote Vehicle driving autonomously.

Test case purpose

The purpose of this test case is to generate a virtual failure on one of the systems or one of the sensors of the connected and autonomous vehicle to trigger and evaluate the minimum risk maneuver as defined for service 1. The virtual failure is used to simulate that the vehicle exits its ODD. Failure detection is mandatory and essential to allow the autonomous vehicle to report its state so that the remote station is aware of the risky situation and can therefore take control of the vehicle.

Test steps

The steps of this test case are described below:

1. A virtual failure is generated and detected by the vehicle.
2. The vehicle broadcasts a warning message and performs a minimum risk maneuver.

Test results and success criteria

All the steps of the minimum risk maneuver must be successfully executed no longer than 5 minutes since the failure is detected by the vehicle. The failure has to be detected under 200 ms. During the minimum risk maneuver, the vehicle must move autonomously at a speed between 10 and 50 km/h until it stops on the emergency lane or a safe harbor.

4.1.2 Test case 2: Request for Remote Assistance

Test case type

Functional verification of service 2 (RRA) in UC1.

Test pre-conditions

Test case 1 successful

5G network fully working

Test case purpose

The purpose of this test case is to evaluate the steps performed during the Request for Remote Assistance procedure as defined for service 2. The test starts as soon as the vehicle has detected it is going to exit its ODD and has triggered the minimum risk maneuver service. MRM and RRA run in parallel, and one or the other may complete first.

Tests steps

The steps of this test case are described below.

1. The Remote Vehicle sends a RRA message to the Valeo Teleoperation Cloud, which allocates one Remote Station.

2. The VTC queries external services for complementary information such as a suggested safe destination for the Remote Vehicle and the predicted Teleoperation Driving (ToD) QoS along a given route.
3. The remote driver (teleoperator) at the Remote Station assesses the demand for assistance with the given information and a pre-established ToD session with the Remote Vehicle.

Test results and success criteria

All the steps of the RRA procedure must be successfully executed in less than 30 s.

4.1.3 Test case 3: Teleoperation in Highway Insertion

Test case type

Functional verification and performance evaluation of service 3 (TM) in UC1.

Test pre-conditions

Test case 2 successful and Remote Vehicle stopped.

Test case purpose

The purpose of this test case is to evaluate the teleoperation of the connected and autonomous vehicle to take it safely back onto the highway traffic, on the rightmost lane, at the minimum legal speed. The test starts with the vehicle stopped on the emergency lane and when all technical conditions are met to initiate the teleoperation maneuver. The remote driver (teleoperator) has accepted to intervene for assistance on that vehicle.

Test steps

The steps of this test case are described below. The remote driver proceeds with the following actions:

1. Observe and ensure a proper perception of the environment (e.g., good view of the rear, good view at the front, view inside the cabin),
2. Make a good assessment of the safety of an insertion maneuver (incoming traffic in particular),
3. Proceed with adequate timing to engage ToD and chooses a proper reinsertion speed relatively to the incoming traffic
4. Accelerate the vehicle until it reaches the minimum legal speed on the highway rightmost lane.

Test results and success criteria

All the steps of the teleoperation maneuver in the highway insertion must be successfully executed in safety conditions. To this end, it is of great importance that the remote driver is fully aware of the vehicle’s situation and can evaluate the incoming traffic, including distances to other vehicles, relative speeds, and times-to-reach. Thus, video images and sensors data must be perceived by the remote driver with sufficient quality and short delay. Furthermore, the vehicle’s actuators must execute commands reliably and with low latency to facilitate full control by the remote driver.

The following service KPIs, defined in Section 4.1.3 of D2.1, will be measured, analyzed and monitored during the realization of this test case.

- Command End-to-End Latency
- Data End-to-End Latency
- Command Reliability
- Sensing Data Reliability
- Uplink Service Data-Rate
- Downlink Service Data-Rate

For the successful completion of the test case, the corresponding target values (detailed in D2.1) must be reached for each service KPI.

4.1.4 Test case 4: Teleoperation at High-speed

Test case type

Functional verification and performance evaluation of service 3 (TM) in UC1.

Test pre-conditions

Test case 3 successful.

Test case purpose

The purpose of this test case is to evaluate the teleoperation of the connected and autonomous vehicle at high speed, i.e., 80 km/h in France and 60km/h in Spain (respective minimum car speeds on the highway). The test starts with the vehicle on the right lane of the highway. The remote driver must be able to operate the vehicle as efficiently, safely, and comfortably as a driver seated inside, adapting the vehicle position inside the ego lane (laterally), maintaining the speed, anticipating the traffic flow, and changing lanes.

Test steps

The remote driver executes a sequence of teleoperated maneuvers that are common in the situation of stabilized highway driving: speed variations, lane changes, and activation and deactivation of ADAS functions.

Test results and success criteria

All the steps of the teleoperation maneuver at high speed must be successfully executed in safety conditions. As in test case 3, video images and sensors data must be perceived by the remote driver with sufficient quality and short delay, the vehicle’s actuators must execute commands reliably and with low latency to facilitate full control to the remote driver.

The following service KPIs, defined in Section 4.1.3 of D2.1, will be measured, analyzed, and monitored during the realization of this test case.

- Command End-to-End Latency

- Sensing data End-to-End Latency
- Command Reliability
- Sensing Data Reliability
- Uplink Service Data-Rate
- Downlink Service Data-Rate

For the successful completion of the test case, the corresponding target values (detailed in D2.1) must be reached for each service KPI.

4.1.5 Test case 5: Teleoperation at High-speed in Cross-Border Scenario

Test case type
Functional verification and performance evaluation of service 3 (TM) in UC1.

Test pre-conditions
Test case 4 successful.

Test case purpose
The purpose of this test case is to evaluate the performance of teleoperation at different speeds when the vehicle is crossing the border and must switch the cellular network (i.e., roaming) from a PLMN on the one side of the border to another one on the other side. In this situation, the vehicle may experience disconnection and performance degradation in terms of end-to-end latency, throughput, and reliability, which may negatively impact the operation of teleoperation.

Test steps
The steps of this test case are the same as in test case 4 but with the vehicle driving in the cross-border area.

Test results and success criteria
The following service KPIs, defined in Section 4.1.3 of D2.1, will be measured, analyzed, and monitored during the realization of this test case.

- Command End-to-End Latency
- Sensing data End-to-End Latency
- Command Reliability
- Sensing Data Reliability
- Uplink Service Data-Rate
- Downlink Service Data-Rate
- Mobility interruption time

For the successful completion of the test case, the corresponding target values (detailed in D2.1) must be reached for each service KPI.

4.1.6 Test case 6: Teleoperation Failure and Minimum Risk Maneuver

Test case type

Functional verification of service 3 (TM) and service 1 (MRM) in UC1.

Test pre-conditions

Test case 3 successful.

Test case purpose

The purpose of this test case is to evaluate the execution of a minimum risk maneuver when there is a failure during teleoperation. The test starts with the vehicle teleoperated and driving on the right lane of the highway. The teleoperation process fails, and the vehicle performs a minimum risk maneuver to stop on the emergency lane.

Test steps

The steps of this test case are described below.

1. The remote driver moves the vehicle at the minimum legal speed on the highway rightmost lane.
2. The autonomous driving system of the vehicle detects a failure in the teleoperation process when the time between consecutive teleoperation commands is above a predefined threshold. The cause of the failure can be a loss of network connectivity, no response from the remote station, etc.
3. The autonomous driving system of the vehicle de-activates the teleoperation process and triggers a minimum risk maneuver as in test case 1.

Test results and success criteria

All the steps of teleoperation, detection of failure during teleoperation, and minimum risk maneuver must be successfully executed in safety conditions.

4.1.7 Test case 7: Prevention from Dangerous Teleoperation

Test case type

Functional verification of service 3 (TM) in UC1.

Test pre-conditions

Test case 3 successful.

Test case purpose

The purpose of this test case is to validate the overall safety against dangerous teleoperation from an unwary remote driver. The remote driver has direct control of the vehicle's actuators (steering, throttle, brakes, etc.). To ensure safety against dangerous teleoperation, some software mechanisms shall ignore, mitigate, or drop any hazardous commands. The following elements must be tested:

- Each software mechanism independently at remote station level and at remote vehicle level.
- The embedded ADAS systems as latest safety means.
- The smooth continuity of remote driver TOD operation in case some commands are rejected.

Test steps

The remote driver will send a series of teleoperation commands, valid and invalid, to observe whether the two safety layers in place do work according to expectations. It may be necessary to force cross over the first (at the remote station) so that an invalid teleoperation command does reach the remote vehicle. Finally, a check is done to verify that a supposedly valid teleoperation command is successfully overridden by the remote vehicle ADAS safety system when necessary.

Test results and success criteria

All the steps of teleoperation, check and acceptance of valid command, check and rejection of invalid command, and ADAS functionality must be successfully executed in safety conditions.

4.2 UC2: Road infrastructure digitalization

This section describes the test cases considered to validate the functionalities and evaluate the performance of UC2. The services of UC2, which are described in D2.1, are the following:

- **Service 1**: Relay of emergency messages (REM).
- **Service 2:** Automatic incident detection (AID).
- **Service 3:** Traffic Flow Regulation (TFR).

Table 7 shows the test cases of UC2 that will be carried out in both small-scale and large-scale testbeds.

Table 7 - UC2 test cases and testbed mapping

Test Case	Test title	Testbed	
		Castellolí small-scale	Cross-border
UC2-TC01	Relay of Emergency Messages (REM) with one MEC	✓	✓
UC2-TC02	Relay of Emergency Messages (REM) in Cross-Border Scenario	✓	✓
UC2-TC03	Automatic Incident Detection (AID) with one MEC	✓	✓
UC2-TC04	Automatic Incident Detection (AID) in Cross-Border Scenario	✓	✓
UC2-TC05	Traffic Flow Regulation (TFR) in Cross-Border Scenario	✓	✓

The UC2-TC01 and UC2-TC03 are functionality testing to verify that all components and services are functioning properly before carrying out the performance evaluation in the cross-border scenario (UC2-TC02 and UC2-TC04). These tests will be done with one MEC while the performance evaluation will be done with two MECs, one on each side of the border. UC2-TC05 encompasses both functionality testing and performance evaluation.

The rest of this section provides the test case descriptions following the template presented before in Table 5.

4.2.1 Test case 1: Relay of Emergency Messages (REM) with one MEC server

Test case type

Functional verification of service 1 (REM) in UC2.

Test pre-conditions

- One MEC server in service with the TMC Edge and V2X Gateway up and running.
- A minimum of two connected vehicles equipped with on-board sensors for object detection.
- The coverage of the MEC will be segmented in a way that makes it easy to locate the areas where the hazards are detected. Therefore, TMC Edge and V2X Gateway will share the same highway segmentation.
- At least three connected vehicles (CV) to receive warning messages and traffic strategies and display them on HMI or dashboard.
- One connected and autonomous vehicle (CAV) is expected to execute the traffic strategies autonomously instead of just displaying them as recommendations on the HMI or equivalent dashboard.

Test case purpose

The purpose of this test case is to verify the intelligent relay of emergency messages received by the TMC Edge to the approaching connected vehicles after consolidation of hazard information sent by vehicles. In this test case, the feasibility of the TMC Edge tools, such as traffic analysis and management, and the dissemination of I2V and V2I messages and traffic strategies through the V2X Gateway will be validated while the global traffic security is guaranteed.

Test steps

The steps of this test case are described below:

1. One vehicle is stopped in one of the lanes or on the hard shoulder occupying part of the slow lane on the highway.
2. One CV approaching the hazard detects it through its on-board sensors and sends an emergency message via the V2X Gateway to the TMC Edge that provides coverage of the entire defined test site divided into different segments.
3. A second CV detects the same hazard and sends an emergency message to the TMC Edge via the V2X gateway.

4. Once the hazard information from two different vehicles is consolidated in the TMC Edge, it builds and sends an alert message including the geographical coordinates of the hazard to the V2X Gateway indicating which segments of the MEC coverage are affected.
5. The V2X Gateway transforms this information into Decentralized Environmental Notification Messages (DENM) and disseminates them to the CVs driving in those segments.
6. At the same time, the TMC Edge reports all warning information to the TMC Global hosted at the cloud.
7. In parallel, the TMC Edge designs a traffic strategy (e.g., speed, lane change), under the supervision of the TMC Global, and sends via the V2X Gateway a warning traffic strategy/recommendation (MCM with embedded MAP Messages) to connected vehicles within the segments considered unsafe because they are close to the hazard.

Test results and success criteria

All the steps described above must be successfully executed to validate the correct functional operation of service 1. This test case will validate the consolidation of the emergency messages transmitted by vehicles to ensure reliable hazard information, the correct segmentation of the defined test site coverage area and the verification of the functionality of the warning strategy adjusted to the needs of hazard events to keep road users safe assuming a reliable and efficient IV2 and V2I communication through the V2X Gateway.

4.2.2 Test case 2: Relay of Emergency Messages (REM) in Cross-Border Scenario

Test case type

Functional verification and performance evaluation of service 1 (REM) in UC2.

Test pre-conditions

- Test case 1 successful.
- At least one MEC server in each country with the TMC Edge and V2X Gateway up and running. Each MEC server covers several segments of the highway.
- TMC Global at the Cloud up and running.
- At least one CV to trigger the periodical transmission of emergency messages with "fake" hazard information.
- At least four vehicles, three or more CVs to receive warning messages and traffic strategies and display on HMI or dashboard.

Test case purpose

The purpose of this test case is to evaluate the performance of service 1 and stress the system in the cross-border scenario. The service KPIs will be validated by replicating several messages from the TCU of a vehicle that will simulate the detection of several hazardous situations along the cross-border scenario triggering the corresponding warning messages and the consequent generation and transmission of traffic strategies, from both the TMC Edge and the TMC Cloud, to the vehicles driving behind that may be affected by the simulated hazards.

Test steps

The steps of this test case are described below:

1. One CV will transmit emergency messages periodically. The emergency messages will contain information of simulated hazards along the cross-border corridor separated at a certain distance that will depend on the speed of the vehicle and the time period between consecutive emergency messages.
2. All other CVs will drive behind the vehicle that transmits emergency messages, at a safe distance, but close enough so that their driving could be affected by the simulated hazards. These vehicles will cross the different segments defined for each TMC Edge and they will receive warning messages and recommendations through the corresponding V2X Gateways.
3. TMC Global will establish the best warning strategy throughout the corridor when vehicles drive between the segments of two different TMC Edges.
4. By driving the entire cross-border corridor, the vehicles will cross the border where they will be able to test the effectiveness of 5G roaming to the service, as well as the handover between radio technologies ,5G and C-V2X from gaps where there is no 5G coverage on the Spanish side.

It is considered that the necessary number of samples will be taken for a meaningful evaluation of the KPIs. In addition, in order to ensure road safety for all road users, this test case will be carried out in a real traffic scenario in the cross-border scenario and therefore the warning strategies will be recommendations to be displayed on the HMIs or on the dashboards

Test results and success criteria

The following service KPIs, as defined in Section 4.2.3 of D2.1, shall be measured, analyzed, and monitored during the execution of this test case:

- Hazard End-to-End Latency.
- Traffic Regulation End-to-End Latency.
- Hazard Notification Reliability.
- Traffic Regulation Reliability.
- Mobility interruption time.

The criterion for success is that these KPIs reach the theoretically established targeted values (see Section 4.2.3 of D2.1).

4.2.3 Test case 3: Automatic Incident Detection (AID) with one MEC server

Test case type

Functional verification of service 2 (AID) in UC2.

Test pre-conditions

- One MEC server in service with the TMC Edge and V2X Gateway up and running. The MEC server covers several segments of the highway.
- Roadside video cameras connected via 5G to the corresponding TMC Edge.
- At least four CVs to receive warning messages and traffic strategies and display on HMI or dashboard.

Test case purpose

The purpose of the test case is to validate an infrastructure capable of performing automatic hazard detection based on video analytics. Roadside video sensors (HD cameras) placed on poles covering an extended section of some hundreds of meters each will be connected through 5G cells with low latency and high data rate to the TMC Edge. Data will be pre-processed locally at the TMC Edge with tailored video analytics algorithms to obtain real-time data of each lane (i.e., position, timestamp, speed, distance gap, type, etc.). The TMC Edge will then automatically detect any hazardous situations based on the result of the video analysis and will disseminate warning messages and strategies for approaching vehicles via the V2X gateway in the corresponding segment of the TMC Edge.

Test steps

The steps of this test case are described below:

1. The video cameras upload video streaming through a 5G modem to the TMC Edge, which hosts the video analytics.
2. A vehicle stops inside the area covered by one of the cameras connected to the TMC Edge.
3. The TMC Edge detects the hazardous situation associated to the vehicle stopped.
4. At the same time the TMC Edge analyses the traffic flow in real time in the segment where the unsafe situation occurs using the cameras distributed along the segment.
5. The TMC Edge calculates a traffic control strategy from a predictive model to control traffic based on the traffic flow status in the affected segment.
6. The TMC edge sends out warning messages and the resulting strategy to the vehicles approaching the hazard location through the V2X Gateway. The TMC Edge also communicates these events to TMC Global.
7. The CVs approaching the hazard receive the warning messages and the traffic strategy and will start to execute it based on the assessment of their own on-board systems, always prevailing their own safety and that of the surrounding traffic.

Test results and success criteria

All the steps described above must be successfully executed in safety conditions.

This test case is very similar to test case 1, the only difference is that the source application that triggers the hazard detection are the roadside cameras, which communicate directly with the video analytics in the TMC Edge without going through the V2X Gateway.

4.2.4 Test case 4: Automatic Incident Detection (AID) in Cross-Border Scenario

Test case type

Functional verification and performance evaluation of service 2 (AID) in UC2.

Test pre-conditions

- Test case 3 successful.
- At least one MEC server in each country with the TMC Edge and V2X Gateway up and running.
- TMC Global at the Cloud up and running in the server.
- Roadside video cameras connected via 5G to the corresponding TMC Edge.
- At least four vehicles, three or more CVs to receive warning messages and traffic strategies and display on HMI or dashboard.

Test case purpose

The purpose of this test case is to evaluate the performance of service 2 and stress the system in the cross-border scenario. As the purpose is to validate the KPIs of the service based on the detection of hazard events from the video analysis executed in the TMC Edge in different MECs, it will be necessary to reproduce several events in MECs simulating that a hazard situation occurs in front of supposed cameras that were deployed in different points of the cross-corridor. These hazard events will be replicated at such a distance that the CVs driving along the corridor will be affected. The CVs will receive a warning message as well as a maneuver or strategy to mitigate the potential risks. The messages will be created by the TMC and sent through the V2XGW.

Test steps

In this test case, traffic status information monitored by cameras is necessary. As only the Spanish side is equipped with roadside cameras, the test will start at a short distance from the border in the southern direction, as the first camera is located right at the border and controlled by the TMC Edge at the first Spanish MEC. The first “fake” hazard event will be generated as if it was taking place in that camera and synchronized with the arrival of the vehicles from France, which will be roaming at that moment. The hazard detection will be simulated at the output of the video analysis as if the camera/s that will be installed at the locations of the different segments of the Spanish MECs will detect different hazard situations just before the different CVs cross the border.

The next step will be that the CVs, located in France, will receive via the corresponding V2X Gateway the warning messages and the necessary strategies to avoid collision with this simulated hazard. TMC Global will be responsible for defining the best strategy to be applied by the different TMC Edges to the vehicles circulating in the segments affected.

Like in test case 2, 5G roaming as well as handover between radio technologies, 5G and C-V2X will be tested for gaps where there is no 5G coverage on the Spanish side.

Test results and success criteria

The following service KPIs, as defined in Section 4.2.3 of D2.1, shall be measured and monitored during the execution of this test case:

- Hazard End-to-End Latency.
- Traffic Regulation End-to-End Latency.
- Hazard Notification Reliability.
- Traffic Regulation Reliability.
- Mobility interruption time.

The criterion for success is that these KPIs reach the theoretically established targeted values (see Section 4.2.3 of D2.1).

4.2.5 Test case 5: Traffic Flow Regulation (TFR) in Cross-Border Scenario

Test case type

Functional verification of service 3 (TFR) in UC2.

Test pre-conditions

- At least one MEC server in each country with the TMC Edge and V2X Gateway up and running.
- TMC Global at the Cloud up and running in the server.
- Roadside video cameras connected via 5G to the corresponding TMC Edge.
- Real-time analysis of external traffic data from third-party providers, such as INRIX, managed by the TMC Global.
- At least four vehicles, three or more CVs to receive global traffic strategies and display on HMI or dashboard.
- As this test case will be tested with real traffic, for security reasons of other road users outside the test, the global strategies will be only recommendations that will be displayed on the HMIs or dashboards of the connected vehicles.

Test case purpose

The purpose of this test case is to evaluate the performance and validate the functionalities of service 3 that facilitate remote guidance of CAVs for traffic flow regulation and guarantees the safety for the rest of the users in a real cross-border scenario. The test case also simulates the operation of traffic flow without the need for human inspection on a high-speed/occupation road in a safe manner. TMC global through real-time traffic conditions sends recommendations such as speed and lane change to a specific and key group of CVs that are driving within the different segments of the cross-border corridor test site.

Test steps

The steps of this test case are described below:

1. Roadside video cameras upload the video stream to the TMC Edge.
2. The TMC Edge analyses the video streams to detect any abnormal traffic situation (i.e., more than a vehicle driving at very low speed at the same segment) affecting the flow of the road.
3. The TMC Edge detects a situation that may evolve into a high-risk situation and reports to the TMC Global in the cloud.
4. The TMC Global detects potentially conflicting segments of the cross-border corridor that may affect the traffic flow through the data received by the TMC Edges and real-time analysis of external traffic data from third-party providers.
5. The TMC global sets a traffic management strategy to ensure safe and efficient management to mitigate abnormal traffic situations.
6. As a result, the TMC global sends out global strategies (speed regulation and change of lane) to the TMC Edges.
7. CVs driving in that/those segment/s will receive the global strategy in MCM message format via the relevant V2X Gateway(s).
8. The driver adapts the behaviour to the global strategies by executing them according to the evaluation of their own on-board systems in the vehicle while their own safety and that of the surrounding traffic always prevailing.

Test results and success criteria

All the steps described above must be well executed to achieve a successful test case and verify the correct functional operation of service 3 as described in Section 4.2.1.3 at D2.1.

4.3 UC3: FRMCS applications and business service continuity

This section describes the test cases considered to validate the functionalities and evaluate the performance of UC3. The services of UC3 to be deployed in the train are the following, which are described in D2.1 [1] and classified as performance (P) or business (B) services:

- FRMCS P1 service: Advanced Sensor Monitoring on Board.
- FRMCS P2 service: Railway Track Safety - Obstacle Detection.
- FRMCS P3 service: Passenger safety and comfort.
- B1 service: High Quality Wi-Fi to passengers.
- B2 service: Multi-tenant Mobile Service.

It must be highlighted that, as it was defined in D2.1, the Train Access Network (TAN) will be divided into four segments along the rail track with different radio access network coverages. Table 8 shows the types of radio access networks available in four different segments of the rail track.

Table 8 - Radio coverage available in each segment of the rail track

Radio Access Network coverages per segment	Track segment
5G NR 3.5 GHz (France) + Satellite	**A**
5G NR 3.5 GHz Le Perthus Tunnel (each direction has a separate tube)	**B / B'**
5G NR 3.5 GHz + 70 GHz + Satellite (Spain)	**C**
5G NR 3.5 GHz + Satellite (Spain)	**D**

The test cases will be used for the tests and trials in the railways testbed using both the LFP maintenance train (small-scale testbed) and the TGV high-speed train (large-scale testbed). The facilities of the LFP maintenance base will be available for static tests for both the LFP maintenance train and the TGV train. Table 9 provides an overview of the test case list and the associated testbeds.

Table 9 - UC3 test cases and testbed mapping

Test Case	Test title	Testbed	
		Cross-border LFP train	Cross-border TGV train
UC3-TC01	Service Continuity during Inter-RAT Handovers	✓	✓
UC3-TC02	Service Continuity during Cross-Border 5G Roaming	✓	✓
UC3-TC03	FRMCS P1 service	✓	✓
UC3-TC04	FRMCS P2 service	✓	✓
UC3-TC05	FRMCS P3 service	✓	✓
UC3-TC06	B1 service	✓	✓
UC3-TC07	B2 service	✓	✓

The rest of this section describes the test cases to be performed for UC3. Test case UC3-TC01 and UC3-TC02 will be used to validate the operation of the radio access selection procedure of the Adaptative Communication System-Gateway (ACS-GW), while test cases UC3-TC03 to UC3-TC07 are specified to verify the functionalities and evaluate the performance of the UC3 services by measuring the corresponding service KPIs.

4.3.1 Test case 1: Service Continuity during Inter-RAT Handovers

Test case type

Functional verification of the ACS-GW in UC3.

Test pre-conditions

- Train Access Network (TAN) on ground up and running.

- Radio units installed on top of the train up and running.

Test case purpose

The purpose of this test case is to validate the functional operation of the ACS-GW when it makes the inter-RAT handover process due to the movement of the train across different segments of the cross-border corridor. The ACS-GW is responsible for aggregating/disaggregating the traffic delivered from/to the different application components to/from the different Radio Access Networks that compose the TAN that insure connectivity between the train and the ground.

It is required that the ACS-GW selects the radio access technology according to the application and the train position. To do this, the ACS-GW uses a table of priorities assigned to the different radio access networks for each one of the services. Lower numbers denote higher priority. The priorities shown in Table 10 below are defined as an example; the exact definition of priorities will be provided in deliverable D5.1.

Table 10 - Forwarding Policy of the ACS-GW

UC3 Services	ACS-GW forwarding priority		
	5GNR 3.5 GHz	IEEE 802.11ad 70 GHz	Satellite
FRMCS P1 service	2	3	1
FRMCS P2 service	2	1	-
FRMCS P3 service	1	2	3
B1 service	2	1	3
B2 service	1	2	3

According to the priorities shown in Table 10 above, the ACS-GW will select first the 802.11ad 70 GHz access for the B1 application flows when the train is in the track segment C, where we can have 5G NR 3.5 GHz, 802.11ad 70 70 GHz, and Satellite, because is defined with priority 1 in Table 10 . Out of segment C, the ACS-GW will select the 5G NR 3.5 GHz access, because segment C is the only that has 802.11ad 70 GHz coverage: an automatic handover must occur, and the table 10 indicates 5G NR 3.5 GHz has priority 2. According to this table, B1 application will only use Satellite connectivity in the case the other two technologies failed.

Test steps

The steps of this test case are described below.

1. Check the status of the Train Network Access links. When all links are available, then check that the ACS-GW recognizes all the TAN links as active.
2. Start the traffic flow for all the services simultaneously.
3. Move the train along the entire cross-border corridor.
4. Check the radio access network selected by the ACS-GW for each service along the different track segments.
5. Disable and enable some TAN links. The ACS-GW must react to these changes as follows:

a. When a preferred link is disabled, all the services' traffic flows that are using that link will hand over to the next-preferred link (i.e., with lower priority), without the need to be re-initiated.

b. When a link is enabled, all the services' traffic flows that declared this link with higher priority with respect to the current one in use, will start using that link without the need to be re-initiated.

Test results and success criteria

All the steps described above must be successfully executed. It must be checked that the ACS-GW forwarding table policy works as designed. Here is an example based on the values defined in the table above:

- The train starts moving from one corridor end (e.g., Perpignan). We are in segment A, which has 5G NR and satellite coverage. The services' flows will be delivered over their preferred access network. In this example, all of them will use the 5G NR at 3.5 GHz access, except the FRMCS P1 service that must use the satellite connection.
- The train enters into the tunnel (segment B). All the application flows must be delivered over the radio access network technology used inside the tunnel without the need to be re-initiated.
- The train exits the tunnel and enters segment C. In this example, the FRMCS P1 service will use the satellite link. The FRMCS P3 service will use the 5G NR at 3.5 GHz, and the rest of the flows will use the 70 GHz link. None of the service flows will need to be re-initiated due to the hand-over.
- When the train moves to segment D, all service flows will be delivered over their preferred access network. In this example, again, all of them will use 5G NR at 3.5 GHz, except the FRMCS P1 service that will use the satellite connection.

To check step 5.(a), disable the 5G NR at 3.5 GHz unit on-board when the train is in the middle of segment A, for example. All the service flows will be moved over the satellite access (except FRMCS P3, that does not use it). Similar tests must be done in other segments. When the train arrives to segment C, all the flows must be moved over the 70 GHz link, except FRMCS P1, that will remain on the satellite connection. At the same time FRMCS P3 must start to work.

To check step 5.(b), enable the 5G NR at 3.5 GHz unit on-board when the train is in the middle of segment C. FRMCS P3 and B2 flows must be moved to this link without need to be re-established. The rest of the service flows must still be working properly, because his preferred type of access is the same as before the train enters in segment C.

Similar tests enabling and disabling different network links must be done, for example, from the ground side. These last group of tests are not necessary to be tested in the TGV.

4.3.2 Test case 2: Service Continuity during Cross-border Roaming

Test case type

Functional verification of the ACS-GW in UC3.

Test pre-conditions

- Train Access Network (TAN) on ground and radio units on top of the train up and running.
- Test case 1 successful.

Test case purpose

The purpose of this test case is to validate the functional operation of the TAN when the train cross the border between Spain and France, changing the 5G Core used by the 3.5G NR train modem and performing predictable handovers for some applications (according to the ACS-GW forwarding table) . Le Perthus tunnel contains the border between both countries, but It is assumed that the 5G roaming process will be executed at the Spanish exit of the tunnel. The coverage inside the tunnel corresponds to the French

Apart from the 5G roaming process when the 3.5 5GNR train modem is used, the TAN will route the traffic from the train to the ground according to the train location. When the train is in Spain, the traffic flows will be delivered to the Spanish ACS-GW; and when the train is in France, the traffic flows will be delivered to the French ACS-GW. The service components on-board the train will communicate with the MEC server in the Spanish or French side, respectively, when the train moves along Spain or France. Thus, they will have to handover between one MEC to another when the train crosses the border.

Test steps

The steps of this test case are described below.

1. Move the train along the entire corridor. Verify the correct operation of the different services of UC3 during the roaming process.
2. Verify that the TAN switches the traffic to each country, according to the train position.
3. Verify that the MEC servers are used according to the train position.
4. Move the train in the corridor, but in opposite direction. Repeat steps 1 to 3.

Test results and success criteria

All the steps described above must be successfully executed for all the services of UC3. All the services KPI's must be fitted in the cross-border scenario.

4.3.3 Test case 3: FRMCS P1 service

Test case type

Functional verification and performance evaluation of the FRMCS P1 service of UC3.

Test pre-conditions

- Test case 1 successful.

- Test case 2 successful.
- Train Control Centre operative.

Test case purpose

The purpose of this test case is to validate the correct operation of the FRMCS P1 service and evaluate the performance of the service along the cross-border corridor. Machine-type data traffic will be generated from a simulator of wireless sensor networks (WSN) on-board the train and the data will be transmitted by the ACS-GW through the Train Access Network to the Train Control Centre deployed on the cloud.

Test steps

The steps of this test case are described below.

1. Move the train along the entire cross-border corridor with all the functionalities of the FRMCS P1 service running.
2. Repeat the test in the other train direction.

Test results and success criteria

All the functionalities of the FRMCS P1 service must work properly along the entire cross-border corridor.

The following service KPIs, defined in Section 4.3.3 of D2.1, will be measured, analyzed, and monitored during the realization of this test case. The results of the service KPIs will be presented to show the performance obtained along the different track segments shown in Table 8.

- Uplink Data Rate
- Downlink Data Rate
- Uplink Cloud End-to-End Latency
- Downlink Cloud End-to-End Latency
- Uplink Reliability
- Downlink Reliability
- Mobility interruption time

For the successful completion of the test case, the corresponding target values (detailed in D2.1) must be accomplished for each KPI of the FRMCS P1 service.

4.3.4 Test case 4: FRMCS P2 service

Test case type

Functional verification and performance evaluation of the FRMCS P2 service of UC3.

Test pre-conditions

- Test case 1 successful.

- Test case 2 successful.
- Train Control Centre operative.
- AI module for obstacle detection fully operative allocated in the Edge nodes.
- LiDAR sensor installed and fully operative in the front cabin of the train.

Test case purpose

The purpose of this test case is to validate the correct operation of the FRMCS P2 service and evaluate the performance of the service along the cross-border corridor. The LiDAR sensor will send data to an AI module allocated at an Edge node on ground for processing and obstacle detection on the adjacent rail track. When the obstacle is detected, the AI module sends warning message to the Train Control Centre, which finally sends a warning to trains in the monitored track.

Test steps

The steps of this test case are described below.

1. Introduce the obstacle near the track.
2. Move the train along the entire corridor.
3. When the train arrives at the end of the corridor, move the obstacle to a different segment in the other track.
4. Repeat the test moving the train in the opposite direction.

Test results and success criteria

All the functionalities of the FRMCS P2 service must work properly along the entire cross-border corridor.

The following service KPIs, defined in Section 4.3.3 of D2.1, will be measured, analyzed, and monitored during the realization of this test case. The results of the service KPIs will be presented to show the performance obtained along the different track segments shown in Table 8.

- Uplink Data Rate
- Uplink Edge End-to-End Latency
- Downlink Edge End-to-End Latency
- Uplink Reliability
- Downlink Reliability
- Time for service warning
- Mobility interruption time

For the successful completion of the test case, the corresponding target values (detailed in D2.1) must be accomplished for each KPI of the FRMCS P2 service.

In addition, the following data will be recorded during the realization of the test case:

- Train direction
- Position where the obstacle is located.
- Results of the obstacle detection process by the AI module (i.e., detected or not detected, and estimated position of obstacle).

4.3.5 Test case 5: FRMCS P3 service

Test case type

Functional verification and performance evaluation of the FRMCS P3 service of UC3.

Test pre-conditions

- Test case 1 successful.
- Test case 2 successful.
- Train Control Centre operative.
- AI module for detection of tense or dangerous situations inside the train fully operative allocated in the Edge nodes.
- Cameras installed and fully operative inside the train.

Test case purpose

The purpose of this test case is to validate the correct operation of the FRMCS P3 service and evaluate the performance of the service along the cross-border corridor. Cameras will send live video and audio streams to AI module allocated in Edge nodes for the detection of a risk situation inside the train. When an event of this kind is detected, a warning is sent to the Train Operation Centre.

Test steps

The steps of this test case are described below.

1. Move the train along the entire corridor.
2. Simulate the disruptive situation inside the train test vehicle.
3. Establish a Real Time Streaming Protocol (RTSP) remote session between the vehicle's cameras and the Train Control Centre to send the video stream.
4. Repeat the test moving the train in the opposite direction.

Test results and success criteria

All the functionalities of the FRMCS P3 service must work properly along the entire cross-border corridor.

The following service KPIs, defined in Section 4.3.3 of D2.1, will be measured, analyzed, and monitored during the realization of this test case. The results of the service KPIs will be presented to show the performance obtained along the different track segments shown in Table 8.

- Uplink Data Rate

- Uplink Edge End-to-End Latency
- Downlink Edge End-to-End Latency
- Uplink Reliability
- Downlink Reliability
- Time for service warning
- Mobility interruption time

For the successful completion of the test case, the corresponding target values (detailed in D2.1) must be accomplished for each KPI of the FRMCS P3 service.

In addition, the results of the disruptive situation detection process by the AI module (i.e., detected or not detected) will be collected.

4.3.6 Test case 6: B1 service

Test case type

Functional verification and performance evaluation of the B1 service of UC3.

Test pre-conditions

- Test case 1 successful.
- Test case 2 successful.

Test case purpose

The purpose of this test case is to validate the correct operation of the B1 service and evaluate the performance of the service along the cross-border corridor. A train full of passengers using the Wi-Fi will be simulated with a set of traffic generators able to saturate the network interfaces. Loopback traffic points will be established on-ground and close to the high-speed Internet Access break-out points using PC-NUCs (one in the train, one in each country). In this way, all the service KPIs can be monitored properly.

It is expected to proof service continuity, but with different performance results according to the train position.

Test steps

The steps of this test case are described below.

1. Move the train along the entire corridor, generating enough traffic to saturate the TAN links, and measure application performance KPI's periodically in each track segment.
2. Repeat the test in the other train direction.

Test results and success criteria

The following service KPIs, defined in Section 4.3.3 of D2.1, will be measured, analyzed, and monitored during the realization of this test case. The results of the service KPIs will be presented to show the performance obtained along the different track segments shown in Table 8.

- Uplink Data Rate
- Downlink Data Rate
- Uplink Edge End-to-End Latency
- Downlink Edge End-to-End Latency
- Uplink Reliability
- Downlink Reliability
- Mobility interruption time

For the successful completion of the test case, the corresponding target values (detailed in D2.1) must be reached for each KPI of the B1 service.

4.3.7 Test case 7: B2 service

Test case type

Functional verification and performance evaluation of the B2 service of UC3.

Test pre-conditions

- Test case 1 successful.
- Test case 2 successful.
- Neutral 5G-Core fully operative and connected to 5G cores of both 5GMED Spanish MNOs and 5GMED French MNO.

Test case purpose

The purpose of this test case is to validate the correct operation of the B2 service and evaluate the performance of the service along the cross-border corridor.

Test steps

The steps of this test case are described below.

1. Move the train along the entire corridor.
2. Verify the B2 small cell is properly identified by the neutral 5G core while the train is in the first country.
3. Verify the B2 small cell radiates the appropriate frequencies in the first country.
4. Verify the B2 test users can communicate between them properly while the train is in the first country:
    a. Users belonging to the same MNO (in national and international calls).
    b. Users belonging to different MNO's (national and international calls).
5. Verify the B2 small cell is properly identified by the neutral 5G core while the train is in the second country.

6. Verify the B2 small cell radiate the appropriate frequencies in the second country.
7. Verify the B2 test users can communicate between them properly:
    a. Users belonging to the same MNO (in national and international calls).
    b. Users belonging to different MNO's (national and international calls).
8. Repeat the test in the other train direction.

Test results and success criteria

The following service KPIs, defined in Section 4.3.3 of D2.1, will be measured, analyzed, and monitored during the realization of this test case. The results of the service KPIs will be presented to show the performance obtained along the different track segments shown in Table 8.

- Uplink Data Rate
- Downlink Data Rate
- Uplink Reliability
- Downlink Reliability
- Mobility interruption time
- End-to-End latency between UE's using the 5G small-cell on-board

For the successful completion of the test case, the corresponding target values (detailed in D2.1) must be accomplished for each KPI of the B1 service.

4.4 UC4: Follow-Me Infotainment

This section describes the test cases considered to validate the functionalities and evaluate the performance of the services included in UC4. The services associated to this UC4 are described in D2.1, which are:

- The Enjoy Media Together (EMT) service.
- The Tour Planning (TP) service.

4.4.1 Enjoy Media Together service Test Cases

The EMT service allows users to enjoy media contents while travelling through the 5GMED corridor. Basically, it enables users to create virtual rooms to watch the media contents in synchronization with other users (both static and moving in the car or train), while overlaying videocalls and chat on top of the media content, to keep live contact with content consumers.

To implement the EMT service, an initial definition of the functional software components has been presented in D4.1 [9] (see **¡Error! No se encuentra el origen de la referencia.¡Error! No se encuentra el origen de la referencia.**5).

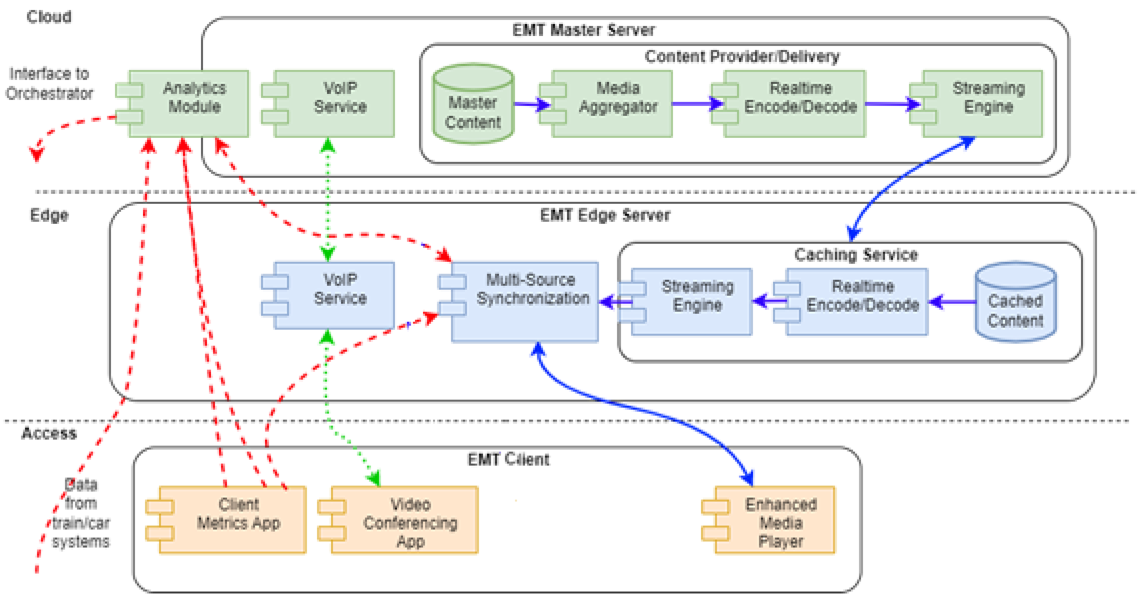

Figure 15 - UC4 (EMT service): Detailed Functional Block View (extracted from D4.1)

As it can be observed, the EMT service is composed of the following main functional blocks:

- The EMT client (bottom of **¡Error! No se encuentra el origen de la referencia.**), composed of the modules needed to reproduce the media contents and enable participants communications, and ingest live media content. A monitoring module (client monitoring app) is also envisioned to log metrics on the video quality and the network performance "on the fly".

- The EMT edge server (middle), comprising the functional blocks needed for caching of media content at the edge, enabling synchronization of media content among different users, and of defining and storing the session information for the communication rooms.
- The EMT master server (top), including the modules needed to provide the complete catalogue of available media content, the main server to share livestreaming content, a repository for the session information of the communication rooms and an analytic module to process and evaluate the metrics collected by the EMT client.

Table 11 shows the specific test plan with incremental test cases that has been defined for testing the EMT service. The tests presented in the table are intended to be executed sequentially. The initial test cases are the most fundamental ones, and they are contained in the subsequent test cases.

Table 11 - UC4 (Enjoy Media Together Service) test cases and testbed mapping

Test Case	Test title	Testbed			
		Automotive		Railways	
		Castellolí small-scale	Cross-border	LFP train	TGV train
UC4-TC01	Watch media content in synchronization among static users	✓	✓	✓	✓
UC4-TC02	Video call among static users	✓	✓	✓	✓
UC4-TC03	Integration of UC4-TC01 and UC4-TC02 among static users	✓	✓	✓	✓
UC4-TC04	Repeating the UC4-TC03 with two static users and a user in motion	✓	✓	✓	✓
UC4-TC05	Repeating UC4-TC04 in the cross-border scenario		✓		
UC4-TC06	Repeating UC4-TC04 in a High-Density Traffic Cross-border Scenario		✓		

The test cases of the EMT service of UC4 in the automotive scenario are expected to be executed in the testbed of Castelloli. In particular, test cases UC4-TC01 to UC4-TC04 will be performed in the small-scale testbed. The test cases applicable for the large-scale testbed include all the test cases described for the small-scale testbed plus test cases UC4-TC05 and UC4-TC06, defined specifically for the large-scale testbed.

For the railway scenario, just a reduced set of test cases will be performed for the EMT service of UC4, using the internal train Wi-Fi for the connectivity and an over-the-top (OTT) deployment in the cloud (as detailed in Section 4.4.4 of D2.1). Tests involving edge resources are excluded in the railway scenario. The test cases to be executed in this scenario will be an adaptation of the test cases from UC4-TC01 to UC4-TC04 shown in Table 11.

4.4.1.1 Test case 1: Watch Media Content in Synchronization among Static Users

Test case type

Functional verification and performance evaluation of the EMT Service of UC4.

Test pre-conditions

Testing infrastructure ready and application deployed.

Test case purpose

The purpose of this preliminary test case is to showcase the feature of streaming high-definition media content synchronized with multiple users. As it is preliminary, users are not moving through the testbed and no network service (NS) migration between edge nodes is envisioned.

Test steps

The following steps describe the flow to enable synchronized video streaming between two clients.

1. Initially, Client1 requests the creation of the video room to the multi-source synchronization module, which creates it.
2. After that, Client1 selects the media content to watch and requests it to the Multi-Source Synchronization module, which forwards the request to the caching service.
3. At this point, if the caching service already has the content, it will send it to the user through the multi-source synchronization module. If not, the caching service will need to request it from the EMT master server.
4. Once the content is completely downloaded at the edge, the caching service can forward it to the multi-source synchronization, arriving finally to Client1. In the meantime, Client2 also requested to join the video room and receive the same content as Client1.
5. Finally, the multi-source synchronization module will complete both client's requests synchronizing the audio and video and streaming the content for both of them.

Test results and success criteria

The success of this test case is judged by the correct execution of the previous flow resulting in the two clients viewing the same content with synchronized audio and video.

The service KPIs for this test case are the ones related to the network and the application quality of experience (QoE). Namely, end-to-end latency, data-rate, jitter, reliability, and framerate, described in Section 4.4.3 of D2.1.

4.4.1.2 Test case 2: Video Call among Static Users

Test case type

Functional verification and performance evaluation of EMT Service of UC4.

Test pre-conditions

Testing infrastructure ready and application deployed.

Test case purpose

The purpose of the second preliminary test case is to showcase the video call functionality of the EMT service. Also, here, the users are not moving through the testbed and no NS migration is envisioned at the edge.

Test steps

The key phases of this test case are described as follows:

1. Client1 creates a videocall/chat room leveraging the functionalities of the VoIP service.
2. After that, the handshaking procedure to define the session parameters (e.g., codec, protocol, resolution) is triggered.
3. Once the handshake is completed, the room is available in the VoIP service module. At this point, Client2 requests VoIP service to discover the available chat and video call rooms.
4. Again, this action triggers the handshaking for the session description definition, so that both clients can communicate.
5. In this way, Client1 and Client2 can start the communication.
6. Finally, the session description is stored in the EMT master server, to be available for all the edge nodes.

Test results and success criteria

The result of this test case is assessed by the correct execution of the aforementioned steps and resulting in an effective peer-to-peer communication between Client1 and Client2.

The service KPIs to be measured and logged for this test case are the ones related to the videocall quality of experience. Namely, the end-to-end latency, the framerate, the jitter, and the reliability as it was described in Section 4.4.3 of D2.1.

4.4.1.3 Test case 3: Integration of UC4-TC01 and UC4-TC02 among Static Users

Test case type

Functional verification and performance evaluation of EMT Service of UC4.

Test pre-conditions

Successfully completed UC4-TC01 and UC4-TC02.

Test case purpose

The purpose of this test case is to show the integration of the previous tests, UC4-TC01 and UC4-TC02, considering two static users.

Test steps

The flows of the previous tests are summarized into one single flow. In fact, Client1 requests the media streaming service described in the UC4-TC01 and then proceeds with the request of the P2P video call service of UC4-TC02 towards the EMT Edge Server. The two services are then presented to the Client in a single screen, with the video stream service in the background and the video call service in the Picture-in-Picture (PiP) format. Client2 follows the same steps as Client1, enabling the complete Enjoy Media Together service.

Test results and success criteria

This test case will be successful if Client1 and Client2 are able to consume the media content synchronized among them, while talking in video call at the same time.

The service KPIs to be measured in this test are a combination of both the P2P video calls metrics and the media content streaming metrics defined in Section 4.4.3 of D2.1.

4.4.1.4 Test case 4: Repeating the UC4-TC03 with two Static Users and a User in Motion

Test case type

Functional verification and performance evaluation of the EMT Service of UC4.

Test pre-conditions

Successful UC4-TC03.

Test case purpose

The purpose of this test case is to show the coexistence of two static users and a moving user. The static users do not need any kind of migration of NS. The moving user, instead, will need the migration of the appropriate NS to another edge server when moving from the area of coverage of one MEC server to another.

Test steps

The following steps will be carried out:

1. Client1, Client2 and Client3 request the full service as per the UC4-TC03 to the EMT edge server to which they are connected.
2. While Client3 is moving, it continuously sends raw metrics to the analytic module. Those metrics may include location data, video quality specific metrics, or network metrics.
3. The analytics module processes this data and interfaces with the orchestrator when the service performance is at risk (e.g., the user getting far from the MEC server).
4. In the meantime, Client3 moves across the network and passes from the area of coverage of one base station, served by a MEC server, to the area of coverage of the next base station, served by a different MEC server.
5. The orchestrator instantiates an EMT edge server in the new location.
6. The content consumed by Client3 and the session description details, needed by the video call service, are gathered from the cloud and migrated to the newly deployed EMT edge server.
7. Finally, Client3 receives a redirected stream of the content he was consuming and the updated session description for the video call service.

Test results and success criteria

The result of this test case will be assessed by the correct execution of the defined steps, resulting in a reasonable continuity of the service for Client3 during the transfer.

Differently from the previous test cases, in this one it is important to evaluate the service migration specific metrics among two consecutive edges, i.e., service migration time, defined in Section 4.4.3 of D2.1.

4.4.1.5 Test case 5: Repeating UC4-TC04 in the Cross-Border Scenario

Test case type

Functional verification and performance evaluation of EMT Service of UC4.

Test pre-conditions

Successful UC4-TC04.

Test case purpose

The purpose of this test case is to showcase the edge migration of the services for a user crossing the border between France and Spain, while having two static users in the Spanish side. The initial flow instantiation is the same as the one defined in UC4-TC04. Note that this test case needs to work in both directions, from France to Spain and from Spain to France.

Test steps

Client1 and Client2 are static users while Client3 is a moving user that is passing the border between France and Spain. The following steps will be carried out:

1. The three users are requesting the Enjoy Media Together service as in the UC4-TC04.
2. Client3 is sending raw data (e.g., location data, video quality metrics, network metrics) to the analytics module continuously.
3. The analytics module processes this data and interfaces with the orchestrator when the service performance is at risk (e.g., the user getting far from the MEC server).
4. The orchestrator triggers the service migration, instantiating the edge server replica in the facilities in France.
5. After the edge instantiation, if the requested content is not available in the newly deployed EMT edge server, the EMT master server in Spain forwards the content to the EMT master server in France.
6. Afterwards, the content is forwarded to the newly deployed EMT edge server.
7. Finally, the Client3 is receiving the redirected stream, and the session description.

Test results and success criteria

The success of this test case will be dictated by the correct execution of the handover of the service across the border.

For this test it is important to gather migration specific service KPIs (i.e., service migration time, mobility interruption time, and reliability), together with the network and video quality metrics defined in Section 4.4.3 of D2.1. Also, in the large-scale scenario, the car speed could be an issue for the connectivity, so it needs to be evaluated as a parameter.

4.4.1.6 Test case 6: Repeating UC4-TC04 in a High-Density Traffic Cross-border Scenario

Test case type

Functional verification and performance evaluation of EMT Service of UC4.

Test pre-conditions

Successful UC4-TC04.

Test case purpose

The aim of this test case is to evaluate the loading capabilities of the integrated P2P and video streaming service in the 5GMED infrastructure, operating in a high-density road traffic scenario in the cross-border scenario.

Test steps

This test case is based on the UC4-TC04 flow. The main difference is the presence of a traffic generator that will generate background traffic, simulating a high-density scenario. The simulated scenario is due to the fact that in the scope of this project it is not considered to have as many real users (people and UEs) as needed to test high density scenarios. The rest of the test is performed in the same way as UC4-TC04.

Test results and success criteria

Being a density test case, the main service KPI to be evaluated is the number of concurrent users (simulated) that guarantees a high quality of service. Also, the same service KPIs of the UC4-TC04 need to be evaluated and logged.

4.4.2 Tour Planning service Test Cases

The Tour Planning (TP) service provides high resolution and immersive media content to travellers and a full set of functionalities for planning trips, giving them enriched information regarding the surroundings, nearby points of interest along with the functionalities of TP, Tour suggestion and sharing experiences. An enhanced XR enabled experience is available to the end-user, making use of the related options to receive virtual reality content if she has an XR capable mobile device and a head mounted device with her.

An initial approach of the design of the Tour Planning service and the modules that comprises it are grouped into three different layers, namely the cloud layer, the edge layer and the application layer, each one containing related modules to provide different aspects of the service as depicted in **¡Error! No se encuentra el origen de la referencia.**.

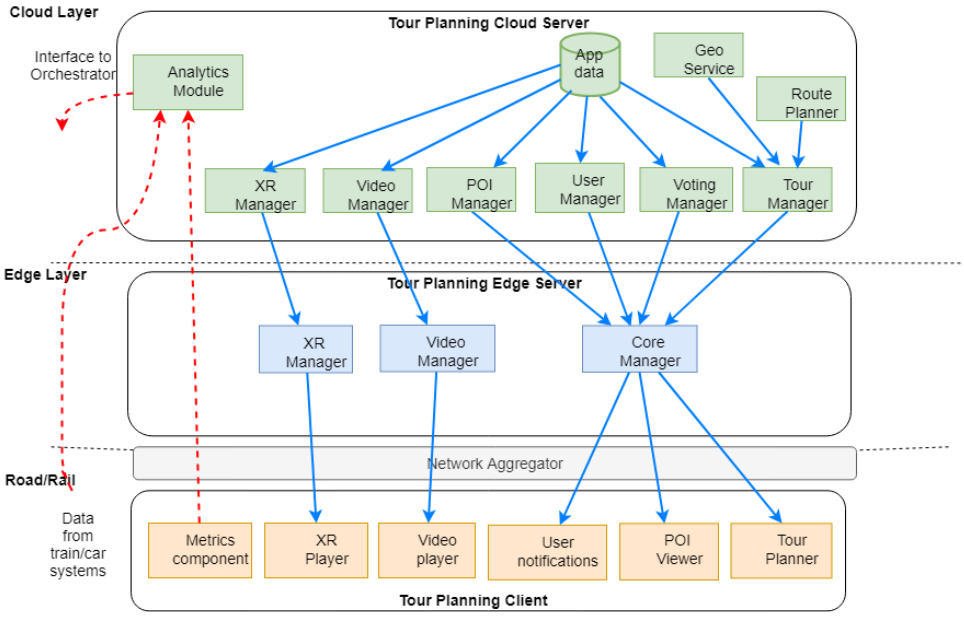

Figure 16 - UC4 (TP service): Detailed Functional Block View (extracted from D4.1)

Briefly, the TP service is decomposed in the following three layers.

- **Tour Planning Cloud Server:** includes the modules required to provide the full set of the available functionalities of the service. Different components represent the several functionalities on the cloud side and manage the transfer of the available media content (4K, VR, etc.) in the other layers that follow.
- **Tour Planning Edge Server**: resides in the edge and includes the modules related to caching of data and media content to decrease service latency, which is important to preserve Quality of Experience (QoE) when providing high-quality media content (video or images) or XR content. This server enables synchronization among users and provides access to cached data, thus reducing required time compared to the time to access the same content if it was placed in the Cloud.
- **The Tour Planning Client**: a mobile application installed on the client device, which may be a mobile phone or a tablet and comprises of the necessary user interfaces for the user to interact with the system. This is the main channel of interaction of the users with the application and contains the interfaces for viewing the POI metadata and data like images, video and XR content, plan a new tour and receive user notifications.

In Table 12 below, we specify the plan for testing the functionalities and evaluating the performance of the TP service deployed on the 5GMED network architecture. A more detailed description of the different test cases follows. It is worth noting that these test cases will be primarily executed on the automotive testbeds. As explained in D2.1, for the railway scenario just a reduced set of test cases will be performed using the internal train Wi-Fi for the connectivity and an over-the-top (OTT) deployment in the cloud (tests involving edge resources will be excluded in this case). The test cases to be executed in the railway scenario will be an adaptation of the most basic test case UC4-TC7 shown in Table 12, and UC4-TC13.

Table 12 - UC4 (Tour Planning Service) test cases and testbed mapping

Test Case	Test title	Testbed			
		Automotive		Railways	
		Castellolí small-scale	Cross-border	LFP	TGV
UC4-TC7	A number n of static users and m=0 users in motion consuming high resolution content, 360° video streaming and XR content	✓		✓	✓
UC4-TC8	Repeat UC4-TC7 with n=0 static users and m=2 users in motion with local handover	✓			
UC4-TC9	Repeat UC4-TC8 with n=0 static users and m=2 users in motion in cross-border scenario	✓	✓		
UC4-TC10	Repeat UC4-TC9 with n=0 static users and m=2 users in motion at high-speed in cross-border scenario	✓	✓		
UC4-TC11	Repeat UC4-TC10 with n=0 static users and m≥2 users in motion at high-speed in cross-border and high-density scenario	✓	✓	✓	✓

4.4.2.1 Test case 7: A number n of static users and m=0 users in motion consuming high resolution content, 360° video streaming and XR content

Test case type
Functional verification and performance evaluation of the TP service of UC4.

Test pre-conditions
Testing infrastructure ready and application deployed.

Test case purpose
The purpose of this test case is to display the feature of consuming high-resolution and XR media content when multiple users residing under the same 5G cell and hence testing 5G connectivity through a specific base station. Since users are not moving through the testbed, migration between edge nodes does not occur.

Test steps
The users connect to the network through their mobile device and then open the TP service. Then they start receiving content.

Test results and success criteria

This test case will be considered successful if all the participants will be connected to 5G network and receive high resolution and immersive media content on demand with no interruptions.

4.4.2.2 Test case 8: Repeat UC4-TC7 with n=0 static users and m=2 users in motion with local handover

Test case type

Functional verification and performance evaluation of the TP service of UC4.

Test pre-conditions

UC4-TC7 to be successful.

Test case purpose

This test case involves two users who are moving with the same means of transport and both are consuming high-resolution and XR media content and thus interfering one another since they are using the same base station. Moreover, migration between edge nodes is taking place as they move from one MEC node zone to another.

Test steps

The users connect to the network through their mobile device while moving by car (or train) and then open the TP service. Then they start receiving content.

Test results and success criteria

This test case will be considered successful if all the participants are connected to 5G network and receive high resolution and Immersive media content on demand and all the target values of the service KPIs defined in Section 4.4.3 of D2.1 [1] are met.

4.4.2.3 Test case 9: Repeat UC4-TC8 with n=0 static users and m=2 users in motion in cross-border scenario

Test case type

Functional verification and performance evaluation of the TP service of UC4.

Test pre-conditions

UC4-TC8 to be successful.

Test case purpose

This test case repeats UC4-TC8 but in this instance the users are crossing the borders and thus roaming is also necessary since different MNOs provide the network service in the two countries. Furthermore, migration of the content between edge nodes will also be tested but in a cross-border scenario.

Test steps

The users connect to the network through their mobile device while moving by car (or train) and then open the TP service. Then they start receiving content.

Test results and success criteria

This test case will be considered successful if all the participants will be connected to 5G network and receive high resolution and Immersive media content on demand and all the target values of the service KPIs defined in Section 4.4.3 of D2.1 [1] are met.

4.4.2.4 Test case 10: Repeat UC4-TC9 with n=0 static users and m=2 users in motion at high-speed in cross-border scenario.

Test case type

Performance evaluation of the TP service of UC4.

Test pre-conditions

UC4-TC9 to be successful.

Test case purpose

With this test case, UC4-TC9 is repeated but this time the performance of the network will be tested when the users are moving at a high speed, the content is migrated from one edge node to another and also roaming is activated since they are crossing the borders.

Test steps

The users connect to the network through their mobile device while moving by car (or train) at a high speed and then open the TP service. Then they start receiving content.

Test results and success criteria

This test case will be considered successful if all the participants will be connected to 5G network and receive high resolution and Immersive media content on demand and all the requested requirements in D2.1 [1] are met.

4.4.2.5 Test case 11: Repeat UC4-TC11 with n=0 static users and m≥2 users in motion at high-speed in cross-border and high-density scenario.

Test case type

Performance evaluation of the TP service.

Test pre-conditions

UC4-TC11 to be successful.

Test case purpose

This test case simulates a situation with many users travelling by train and a high number, n, of them are consuming high resolution and XR content. The network will be tested under very difficult circumstances since besides the many users the train is moving at a high speed while migration between edges is also happening.

Test steps

The users connect to the network through their mobile device while moving by train at a high speed and then open the TP service. Then they start receiving content.

Test results and success criteria

This test case will be considered successful if all the participants will be connected to 5G network and receive high resolution and Immersive media content on demand and all the requested requirements in D2.1 are met.

5. Conclusion

This document provides a short description of the different testbeds that will be available for 5GMED and the infrastructure updates that will be needed, and proposes a methodology to perform the tests and trials with consistency throughout the use cases. An initial definition of the tests for each use case was derived with, for each test case, the necessary pre-conditions, the steps to follow and the targets to reach. These test cases may be subject to several updates based on the progress made in the development and deployment activities in different test beds that will be reported in D6.1.

References

[1] 5GMED, «D2.1. Use Case story definition, requirements and KPIs».

[2] 5GMED, «D6.1. Test cases definition for the small-scale trials».

[3] 5GMED, «D6.3. Test case definitions for the cross-border trials».

[4] 3GPP, «"5G; Service requirements for enhanced V2X scenarios (3GPP TS 22.186 version 15.3.0 Release 15)».

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[6] LFP Perthus, *https://www.lfpperthus.com/la-ligne.html.*

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[9] 5GMED, «D4.1 Requirements and Initial Design for Automotive Test Cases».