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D2.1 Use Case story definition, requirements and KPIs

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Synopsis

Deliverable D2.1 defines the 5GMED use cases, describes their functional and performance requirements, and identifies the service Key Performance Indicators (KPIs) of each use case. It is instrumental for WP2 as it constitutes the baseline for the coming D2.2, where concrete test cases for each 5GMED use case will be defined. The deliverable D2.1 is also used as input by WP3, WP4 and WP5 to derive the network's initial requirements and the CCAM and FRMCS applications requirements.

List of Keywords

Use cases definitions, services, applications, KPIs, CCAM, FRMCS, functional system architectures

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List of acronyms

5G NR	5G New Radio
5G-SA	5G Standalone architecture
AAE	Autopistas España
ACS-GW	Adaptive Communication System-Gateway
AD	Autonomous Driving
ADS	Autonomous Driving System
ADAS	Advanced Driver Assistance Systems
AI	Artificial Intelligence
AMF	Access and Mobility Management Function
AP	Access Point
AR	Augmented Reality
ATC	Automatic Train Control
BS	Base Station
CA	Consortium Agreement
CAPEX	CAPital EXpenditure
CAV	Connected Autonomous Vehicle
CCAM	Cooperative, Connected and Automated Mobility
CCTV	Closed Circuit Television
CDN	Content Delivery Network
CEF	Connecting Europe Facility program
CG	Communication Gateway
CV	Connected Vehicle
DASH	Dynamic Adaptive Streaming over HTTP
DDT	Dynamic Driving Task
DoA	Description of Action
DL	Down-Link
EC	European Commission
ES	Edge Server
ETBN	Ethernet Backbone Node
FHD	Full High Definition
FRMCS	Future Railways Mobile Communication System
FSTP	Financial Support to Third Parties
GA	Grant Agreement
GPS	Global Positioning System
H2020	Horizon 2020
HD	High Definition
HLS	HTTP Live Streaming
HMI	Human Machine Interface
ISAD	Infrastructure Support for Automated Driving
KPI	Key Performance Indicator
LFP	Linea Figueras Perpignan
M&O	Management and Orchestration
M2M	Machine-to-Machine
MCM	Maneuver Coordination Message
MEC	Multi-Access Edge Computing
MNO	Mobile Network Operator
MR	Mixed Reality
MRM	Minimum Risk Maneuver

NF	Network Function
NFV	Network Function Virtualization
NS	Network Service
OBU	On-Board Unit
ODD	Operational Design Domain
OPEX	OPErational EXpenditure
P2P	Peer To Peer
PDV	Packet Delay Variance
PLMN	Public Land Mobile Network
POI	Point Of Interest
QoE	Quality of Experience
QoS	Quality of Service
R&D	Research & Development
RAN	Radio Access Network
RAT	Radio Access Technology
RRA	Request for Remote Assistance
RTT	Round Trip Time
SDN	Software-Defined Network
SME	Small Medium Enterprise
TAN	Train Access Network (Radio Access from Train to Ground)
TCN	Train Communication Network
TCU	Telematics Control Unit
TDC	Throughput Disturbance Coefficient
TGV	Train Grande Vitesse (High-speed Train)
TLAN	Train Local Area Network
TM	Teleoperation Maneuver
TMC	Traffic Management Center
TOD	Tele-Operated Driving
UC	Use Case
UE	User Equipment
UL	Up-Link
VLO	Valeo
VoD	Video on Demand
VPN	Virtual Private Network
VR	Virtual Reality
V-SMF	Visited Session Management Function
XR	eXtended Reality

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Executive Summary

The present document is deliverable D2.1 “Use Case story definition, requirements and KPIs”. The main objective of D2.1 is to describe the results and findings of task T2.1 (“use case story definition, requirements and KPIs”) of WP2, the first technical work package of 5GMED. In WP2, T2.1 aims at defining the use cases of 5GMED, the technical requirements and service KPIs of each use case, and T2.2 aims at providing the testing scenarios to be considered for each use case. D2.1 is needed as an input for D2.2 and for subsequent work packages to derive the requirements of the 5GMED network infrastructure in WP3, and to define the requirements of the applications and technologies needed for the automotive and railway use cases, respectively, in WP4 and WP5.

Firstly, D2.1 introduces the **technology enablers** and the **high-level common 5GMED architecture** that have been considered to support the automotive and train use cases of 5GMED in cross-border scenarios. The technology enablers include wireless technologies to provide connectivity (with 5G SA networks as the core technology, and other complementary technologies such as IEEE802.11ad and C-V2X/ITS-G5 for Vehicle-to-Infrastructure (V2I) communications and satellite); sensors on the infrastructure to monitor the traffic flow and to detect hazards; service orchestration to dynamically deploy applications and 5G core network functions; network slicing to isolate the different use cases and services running on the same 5G network infrastructure; computing resources in the cloud and at the edge and artificial intelligence.

Secondly, D2.1 describes the main **technical challenges** that must be faced in the cross-border scenario of 5GMED to deploy the automotive and railway use cases, using a common 5GMED architecture and the identified technology enablers. For example, seamless service continuity for all the use cases along the cross-border corridor will require to optimise the roaming in order to avoid the interruption of the services. Finally, in the perspective of a massive deployment of 5G network infrastructure along European corridors, another challenge will be to deploy self-sustainable mobile network infrastructure components.

Thirdly, D2.1 describes the **four use cases of 5GMED in detail**. For each use case, D2.1 provides a definition of its main functionalities, a list of components required to build the use case, a definition of service KPIs, the expected performance in terms of target values for each service KPI, a high-level functional architecture of the use case with its main components mapped on the common 5GMED architecture, and the main technical challenges of the use case. The main features of the four use cases are summarized below.

Use case 1 and 2 will be deployed in the automotive scenario, use case 3 will be deployed in the railway scenario, and use case 4 will be deployed in the automotive and partially deployed in the railway scenario. The aim of **use case 1** is to provide remote assistance for a Connected and Autonomous Vehicle (CAV) experimenting a failure or complex traffic situation that is outside of its normal domain of operation. In these conditions, the operation of the vehicle can be controlled by a remote driver, i.e. remote assistance. Use case 1 includes three services: the Minimum Risk Manoeuvre (MRM),

which allows the CAV to autonomously park on the emergency lane; the Request for Remote Assistance (RRA), which assesses whether the teleoperation manoeuvre will be manageable given the current situation; and the Teleoperation Manoeuvre (TM), which follows the RRA when remote assistance conditions are fulfilled.

The aim of **use case 2** is to ensure safe and efficient mobility in highways where Connected Vehicles (CVs) coexist with legacy non-connected vehicles. It is based on data provided by CVs' sensors (i.e., LiDAR, radar, GPS, etc.) and data from other heterogeneous information sources, such as traffic cameras and roadside sensors. A Traffic Management Centre (TMC) processes these data and generates intelligent traffic management strategies that are transmitted to the CVs. Two types of traffic management strategies are considered: local warning traffic strategies and global traffic strategies. The local warning traffic strategies focus on the detection of hazards (e.g., accident, stopped vehicle, etc.) and low-latency distribution of warnings to those vehicles that are approaching the risk area. Two services will be implemented. The Relay of Emergency Message (REM) service, in which the hazards are detected by vehicles' on-board sensors. The Automatic Incident Detection (AID) service, in which the hazards are detected by cameras installed on the infrastructure. In the global traffic strategies, the TMC analyses the traffic status in the highway to detect abnormal behaviours (e.g., traffic jam, vehicle at abnormal reduced speed), generates a traffic strategy, and transmits regulation commands (i.e., change lane, adjust speed) to groups of vehicles driving near the risk area.

Use case 3 addresses two groups of services of the Future Railways Mobile Communication System (FRMCS): performance services and business services. For the "performances services" group, three services will be deployed. First service is "advanced sensor monitoring on-board" to monitor the status of non-critical systems of the train by facilitating data communication between on-board sensors, the train control information systems on-ground, and the train staff. Second service is the "railway track safety obstacle detection" to detect hazards on the rail tracks by using a LIDAR sensor on-board and AI-based processing at the edge. Third service is "Passenger safety and comfort" to detect dangerous situations on-board (e.g., fights, etc.) by using video cameras and AI-based processing on the edge. The "business services" group includes two services: the "high-quality Wi-Fi for passengers" and the "Multi-tenant Mobile service". The latter uses a 5G small cell on-board the train to provide high-bandwidth and low-latency access to a neutral MNO service

The aim of **use case 4** is to distribute several types of high-quality media content, synchronously and keeping high Quality-of-Experience (QoE) to passengers travelling at high speed by car or train along the cross-border corridor. The concept is to have the application following the user equipment along its journey, always close enough to offer low latency. This is enabled by the 5G-SA technology and the ability to orchestrate both the network functions and the applications. Two services are included in use case 4. In the Enjoy Media Together service, among other functionalities, the user in the vehicle will watch a high-definition movie in synch with another user on ground. Both will be able to interact in real time to comment the movie. The Tour Planning service, among other functionalities, provides the users with virtual reality (VR) video streaming for specific Points of Interest (PoI) along their journey, so that they can decide to make a stop-off at any of the PoIs. In the railway scenario, the use case 4 will not be fully deployed, but the

EMT and TP applications will be deployed in the cloud, with the purpose to test their functionalities and behaviour when the connectivity goes through the Train Access Network.

1 Introduction

1.1 Project Summary

5GMED brings together key stakeholders of the "Figueras – Perpignan" cross-border section of the Mediterranean corridor, including Mobile Network Operators (MNOs), road and rail operators, and telecom neutral hosts, complemented with innovative SMEs developing Artificial Intelligence (AI) functions, and selected Research and Development (R&D) centers with a proven track record in 5G research and innovation.

The 5GMED project takes considerable advantage of the proximity of the E-15 European route and the high-speed rail track in the chosen Spain-France cross-border section of the corridor, where the 5GMED Consortium will demonstrate the potential for future full deployment of a technological approach based upon:

- a multi-stakeholder 5G infrastructure featuring a variety of radio technologies, including 3GPP Release 16 5G NR at 3.5 GHz, C-V2X at 5.9 GHz, IEEE 802.11ad at 70GHz unlicensed mm-wave, etc.
- Edge computing,
- network slicing, and
- service orchestration,

which can be used to deliver pervasive Cooperative, Connected and Automated Mobility (CCAM) and Future Railways Mobile Communication System (FRMCS) services jointly.

The 5GMED project has defined a set of use cases to represent the challenges related to both CCAM and the applications of FRMCS.

The considered CCAM use cases include several services. The main objectives of this services are:

- Remote driving use case including cross-border open roads, which enables a new safe countermeasure in case that an autonomous driving (AD) vehicle fails.
- Road infrastructure digitalization use case, which needs the massive deployment of road infrastructure sensors enabling AI-powered traffic management algorithms in mixed traffic scenarios where connected and autonomous vehicles coexist with conventional vehicles.

The considered FRMCS use cases include several performance and business services for both inside and outside the rail convoys. The main objectives of these services are described below:

- Inside the train: to monitor the status of non-critical systems on-board the train, ensure safety of passengers, and provide advanced telecom services so that passengers can get access to high-speed Internet.
- Outside the train: to detect potential hazards on the rail tracks using AI-functions that analyse sensors data streams from high-speed trains in real-time.

In addition to the CCAM and FRMCS use cases, the 5GMED project considers a *Follow Me Infotainment* use case that demonstrates the live migration of media distribution functions (from one compute node in the edge to another compute node in the edge, belonging to the same side of the border or cross-border) for high-mobility cross-border scenarios both in automotive and railway environments.

5GMED ambitions to become the lighthouse project for future deployment of integrated 5G CCAM and FRMCS deployment in cross-border scenarios, which can be replicated across Europe, and well beyond just the cross-border, so targeted towards its expansion into the European transport corridors, and trigger further tangible investments through the support of the CEF2 program.

1.2 Deliverable overview

The main objective of this document is to establish the initial conditions under which the project will operate in terms of services and technical requirements. For that purpose, a set of relevant use cases have been chosen, so that they can be used as representative of the targeted challenges and of the boundaries for the future deployment phase. All use cases will be mapped later into the different trial sites (i.e., small-scale testbeds and the cross-border corridor) where the use cases will be validated and tested.

For each of the services and use cases considered in the project, this document:

- Identifies qualitative and quantitative functional requirements and design specifications.
- Provides a detailed description of target service KPIs in terms of performance, such as data-rate, latency, acceptable service interruption times at the cross border, and other parameters.

This document constitutes the baseline for the next deliverable, D2.2 (“Initial definition of test cases, deployment options, and trials methodology”), and for subsequent work packages to derive the requirements of the 5G network architecture (WP3) and the functional requirements of the use case applications in WP4 and WP5, respectively, for the automotive and railway scenarios.

This document is organized as follows. First, it describes in Section 2 the technology enablers of 5GMED, including wireless connectivity, infrastructure sensors, orchestration, network slicing, computing resources, and artificial intelligence. Section 3 describes the technical challenges that the project will have to face, including the seamless availability of all the services across different Radio Access Technologies (RATs), across multiple MECs, and across Mobile Network Operators (MNOs) in different countries; the rollout of 5G Standalone (SA) networks in the two countries connected by the cross-border corridor. The four use cases of 5GMED are described in Section 4. For each use case, this section contains the main functionalities, technical requirements, service KPIs and associated target values, a high-level functional architecture with the main building components of the use case mapped on a common 5GMED architecture, the technical challenges of the use case, and a brief description of why 5G is needed. Finally, Section 5 concludes the document.

1.3 Cross-border corridor description

In the segment of the Mediterranean cross-border corridor between Figueras and Perpignan, four different zones can be considered:

- **Zone 1**: between Perpignan and Mas Cantarana (11 km approx.) The railways and the E-15 highway are far away from each another.
- **Zone 2**: between Mas Cantarana and Le Boulou (12 km approx.) The railway and the E-15 highway are very close.
- **Zone 3**: between Le Boulou and La Junquera (14 km approx.) There is an 8.3 km railway tunnel across the border between France and Spain. It is composed of two parallel tubes, one for the trains from France to Spain and the other for the trains running in the opposite direction.
- **Zone 4**: between La Junquera and Figueras (25km approx.). The railway and the E-15 highway are very close.

Figure 1 below shows the four zones of the cross-border corridor indicating those that may require a specific 5G RAN to provide coverage on the highway (HIRAN), a specific 5G RAN for the railway (RRAN), a shared RAN for both the highway and railway (SRAN), and a RAN to provide coverage inside the tunnel (TRAN). The geographical features of the cross-border corridor will be analyzed in detail in D3.1 to design the complete radio access network of 5GMED.

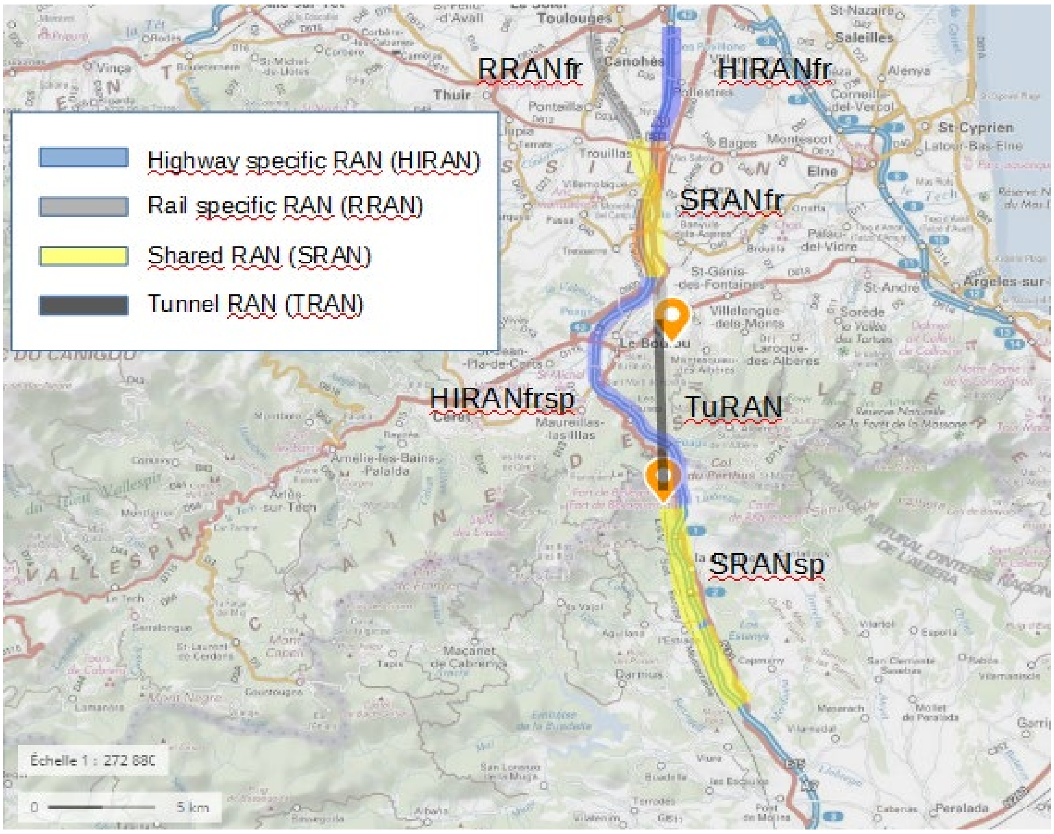

Figure 1. Mediterranean cross-border corridor between Figueras and Perpignan

2 Technology Enablers

This section describes the enabling technologies that will be considered in 5GMED for supporting the deployment of the 5GMED use cases in the cross-border corridor between Perpignan and Figueras. These enabling technologies will be integrated in a common 5GMED network architecture for cross-border scenarios where the main functional blocks of the four use cases will be mapped.

Figure 2 depicts a high-level representation of the 5GMED network architecture that will be further developed in WP3, where the detailed design of the building blocks and interfaces in each layer will be generated. This architecture includes six layers (i.e, network infrastructure layer, MEC layer, orchestration layer, slice management layer, cloud layer, and data analytics layer) and several cross-border interfaces.

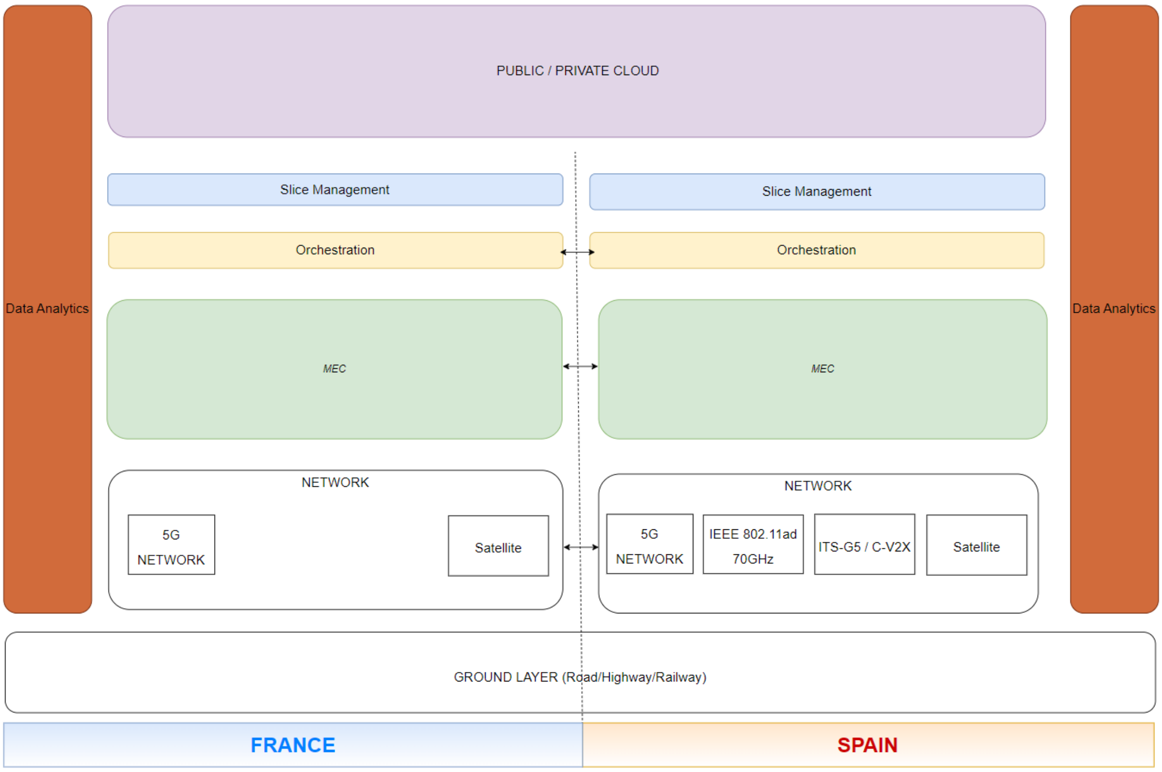

Figure 2. High-level cross-border 5GMED network architecture

The six layers of the high-level 5GMED network architecture are briefly described as follows.

- The **Cloud Layer** encompasses all backend applications running in a centralized fashion, including applications hosted by a private cloud and third-party applications that can be hosted in public clouds.
- The **Slice Management Layer** enables the creation of logical networks under a common shared physical network infrastructure, providing some critical 5G functionalities such as resource isolation, high level of reliability, and optimized topology with dedicated resources to support specific services and applications.

- The **Orchestration Layer** provides network and service orchestration in the cross-border scenario to allow seamless data flow and to guarantee end-to-end service quality and continuity among different administrative domains. The orchestration layer is capable of managing the lifecycle of applications and network cloud-native network functions.
- The **MEC layer** is a distributed compute platform that enables AI-powered services and distributed applications. It is used to host applications that require low latency and AI functions such as video analytics for object detection and tracking, obstacle detection, etc.
- The **Data Analytics layer** contains a set of AI modules managed by the network operator. It collects and stores network metrics and service KPI measurements from other layers that can be used by the AI modules or by the operator to optimize network configuration. An interface between the Data Analytics Layers in Spain and the one in France allows metrics exchanges that may be required for service continuity at cross border.
- The **Network Infrastructure Layer** provides wireless connectivity to both sides of the Mediterranean corridor in a holistic manner, providing a means to reach the expected KPIs of the 5GMED use cases in a cross-border scenario. The network infrastructure layer integrates a set of radio access network technologies as well as backhauling networks and computing resources

The remainder of this section describes the technology enablers of 5GMED, including the wireless technologies at the network infrastructure layer, sensors deployed on the infrastructure, orchestration, network slicing, cloud and edge computing, and artificial intelligence.

2.1 Wireless Connectivity

Several wireless technologies will be rolled out along the cross-border corridor to support the 5GMED use cases. These wireless technologies include:

- Cellular 5G SA networks in the 3.5 GHz band.
- Sidelink Vehicle-to-Infrastructure (V2I) communications systems in the 5.9 GHz band for connected vehicles on the highway.
- Sidelink IEEE 802.11ad [1] access points in the 70 GHz band for the rail track.
- Satellite communications for delay-tolerant services of the FRMCS use case.

2.1.1 Cellular 5G SA Network

On the French side, an experimental 5G SA network (5G-RAN and 5G SA Core) specific for 5GMED will be rolled out along the corridor. The network design will be based on the service requirements of all the 5GMED use cases, covering both the railway and the highway.

On the Spanish side, VDF will roll out 4 5G NR gNodeB's on existing 4G sites along the corridor and migrate from a Non-Standalone (NSA) core to a 5G SA core. To provide seamless service and full 5G NR coverage in the Spanish side, a densification operation might be required with new 5G NR sites to be rolled out by a neutral host (Cellnex). Due to the orography of the target area, the coverage provided by VDF may not be sufficient to ensure continuous connectivity across the corridor.

Furthermore, the tunnel will be also equipped with 3.5 GHz 5G RAN, although an agreement with the French and Spanish MNOs is required, since the N78 band has been already assigned to the operators and its use is exclusive to its owners. Alternatively, a portion of the experimental N77 band could be requested to both the Spanish and French national spectrum regulators, depending on the spectrum availability.

2.1.2 Sidelink V2I Communications at 5.9 GHz (C-V2X, ITS-G5)

Sidelink V2I communications systems allow to wirelessly transfer data between the Telematics Control Unit (TCU) installed in the vehicles and the roadside units (RSU) installed in the infrastructure of the highway. Contrarily to what is planned for the 5G SA network, it is not planned to cover the whole cross-border corridor with the sidelink V2I communications systems. The use of V2I communications has been considered only for CCAM use cases to complete the 5G NR coverage holes where needed.

There are two radio access technologies for sidelink communications at 5.9GHz:

- The European ETSI ITS-G5 and the American DSRC communication standards based on the IEEE 802.11p [2], which facilitate vehicles to directly communicate with other vehicles (V2V) and with the roadside infrastructure (V2I).
- The C-V2X technology based on the LTE-V2X standard specified in 3GPP Release 14, which has evolved into the NR-V2X standard specified in 3GPP Release 16. This technology is considered less mature that DSRC and ETSI ITS-G5. C-V2X provides two different radio communication interfaces: the Uu interface and PC5 interface. While the Uu interface uses the cellular link between the UE and the cellular base-station, operating in licensed cellular spectrum, the PC5 interface allows for V2V and V2I communications between TCUs and RSUs, and operates at 5.9 GHz.

Since both C-V2X (PC5) and ETSI ITS-G5 technologies will be or are deployed on the European corridors, they have been considered in 5GMED to provide sidelink V2I communications on those areas of the highway where there may be holes of 5G NR coverage.

2.1.3 Sidelink IEEE 802.11ad at 70 GHz

This sidelink communications system is based on the IEEE 802.11ad standard [1]. This technology is considered here as a low cost option (less expensive than 5G) for high data rate and low latency connectivity for high-speed trains. It is composed of:

- A set of radio access points bearing beam antennas and deployed on ground every 1 km along and next to the rail track.
- A set of radio units with antennas installed on the train roof top.
- The beams of the antennas on ground are steered in azimuth to follow the antennas of the train.

The user throughput specified for this IEEE 802.11ad-based system is 1 Gbps in average (over a distance of 10 km and at 250 km/h) with a minimum user throughput of 250 Mbps. Figure 3 shows a schema of the system with the railway track required network.

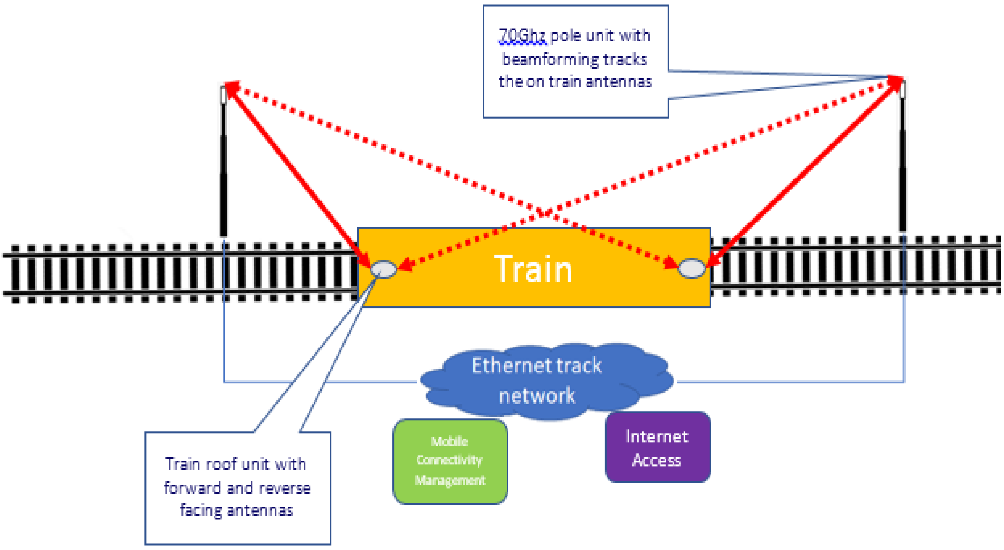

Figure 3. Sidelink IEEE 802.11ad-based system (70 GHz) with railway track network

Figure 4 shows the section of the rail track with the coverage of the 70 GHz sidelink system in the Spanish side of the corridor from Le Perthus tunnel to Llers (around 15km). Also, in blue is depicted the expected 5G coverage holes that might be covered with the 70 GHz system.

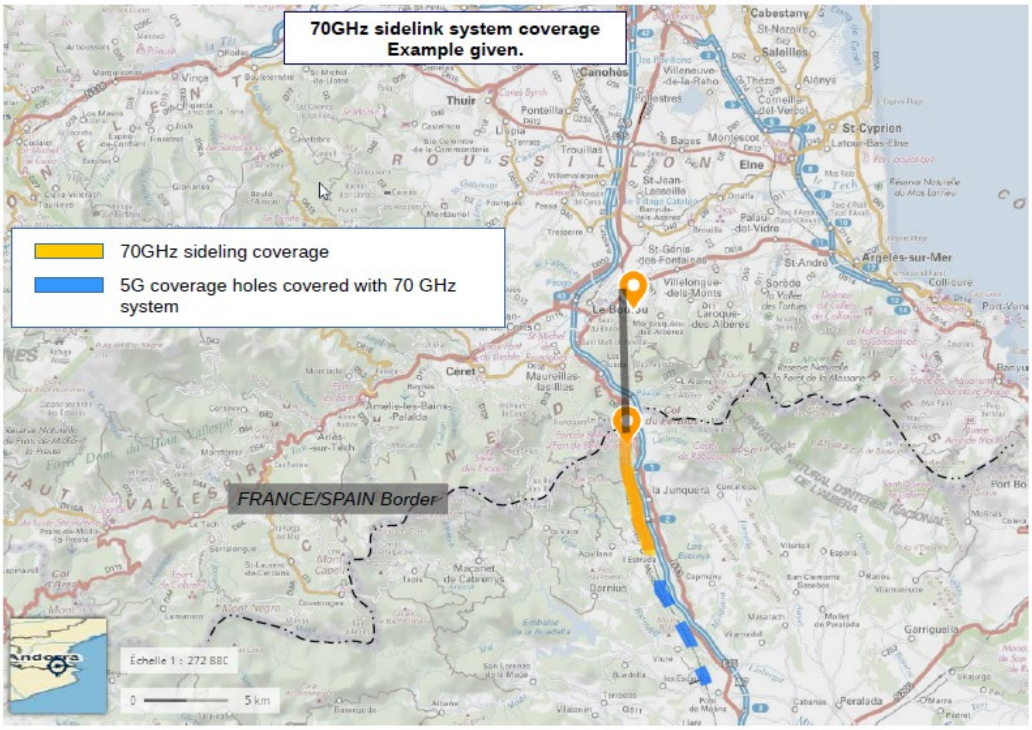

Figure 4. 70 GHz sidelink system coverage

2.1.4 Satellite

Satellite communications provide higher connectivity reliability when considering mobile platforms like the high-speed train. In those situations, service continuity is difficult to ensure due to the changing fixed networks accesses that may encounter coverage gaps in certain zones. In those scenarios, satellite communications can be employed for ensuring connectivity on the move, complemented with other fixed technologies to achieve the requested Quality-of-Service (QoS) and provide coverage in specific zones like the tunnels.

Satellite and terrestrial systems were traditionally considered as two separate worlds. Satellites were used primarily to address the "last mile" issue where fibre optic cable installation would be difficult or even impossible, or for specific use cases, e.g., oil gas stations in the ocean. Nowadays, industry is building an integrated 5G ecosystem in which satellites will play a key role complementing and supporting terrestrial networks.

In cities or densified areas, it is possible to access terrestrial fixed 5G network infrastructure, but when moving to more rural and remote areas, satellite communication is the only viable option to provide reliable coverage and adequate data-rate. Satellite will then participate to the seamless service provisioning along the corridors in Europe. A realistic business case may not allow to deploy 5G cellular or sidelink radio access all along the European corridors, thus, those access networks will be complemented by satellite networks. It is important to further extend the promise of 5G networks beyond urban and densely populated areas as the number of use cases and requirements of connectivity continue to increase. The main advantage of satellites is that they provide almost ubiquitous coverage independently on the geographical position or the status or availability of the terrestrial networks.

In particular, as shown in Figure 5, backhauling gNodeBs with satellite communication offers a solution when the 5G site is far from any other network.

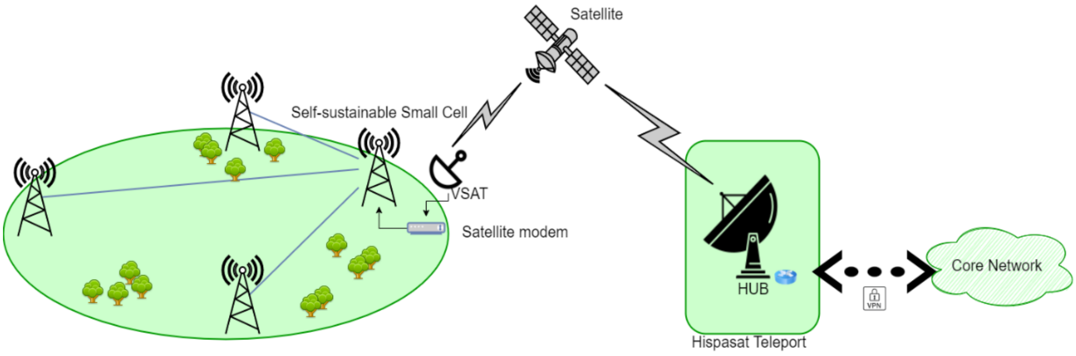

Figure 5. Fixed backhaul satellite system

This scenario is to be tested in 5GMED to address this question and allow scaling in the corridors at the European level. Satellite connectivity will be provided by HISPASAT through its geostationary (GEO) satellite fleet, covering a large geographical area. The GEO satellite link introduces longer propagation delays, with a roundtrip time between two earth stations typically between 500 and 600 ms, which do not match with the latency required by many of the CCAM use cases, e.g., in remote driving.

Broadcasting, backhauling, and communications are a few of the main uses for geostationary satellites. In 5GMED, satellite will be used for backhauling auto-sustainable small cells which are far away from any transport network and with no other possibility of transmission that will be powered by renewable energy sources.

Applications can be divided into delay-tolerant applications and delay-sensitive applications. Both types of applications can be supported by satellite communication when no other methods of connectivity are available, but delay-sensitive applications will be prioritized through the low latency network access when available.

Figure 6 depicts the high-level architecture that can be implemented for train-to-ground communications using satellite connectivity.

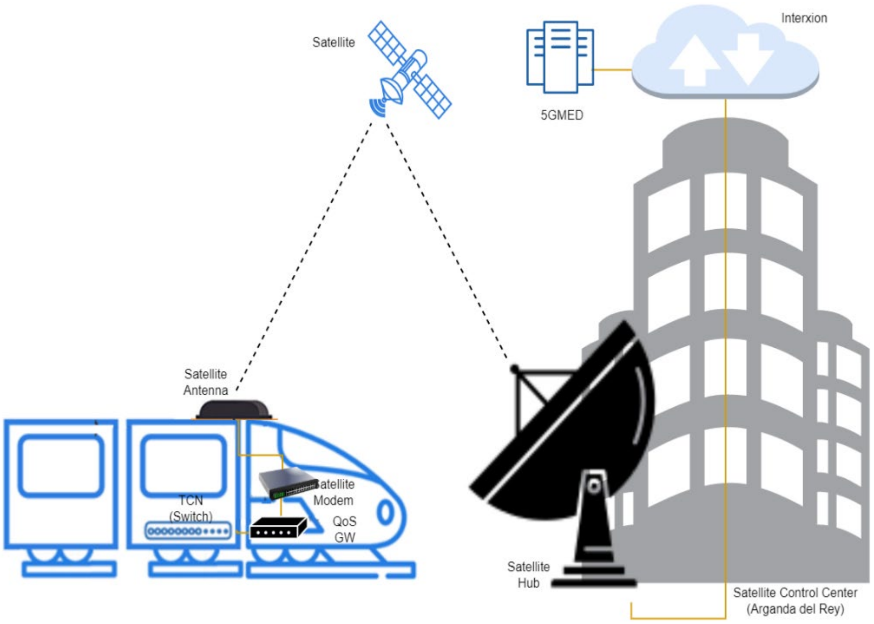

Figure 6. High-level architecture of train-to-ground communications using satellite

Note: Interxion is a data center which interconnects satellite traffic from the satellite operator to the 5GMED network.

As a summary, satellite connectivity will be used for ensuring continuity in some services that are delay-tolerant, like sensors monitoring inside the train and for terrestrial backhauling in remote zones.

2.2 Sensors on the infrastructure

Several types of sensors, such as cameras, radars, and LIDARs, are typically used to detect the presence of vehicles in highway lanes, estimate and track their geographical position and speed. In one of the CCAM use cases of 5GMED (use case 2), the cameras will be used to monitor the traffic flow on the highway and to detect hazardous situations

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such as a stationary vehicle, vehicles driving at very low speed, etc. For this purpose, as depicted in Figure 7 below, high-definition (HD) cameras will be installed on the infrastructure of the highway. It should be noted that the whole corridor will not be equipped, but only part of it in the Spanish side. Strategic locations will be identified, with some cameras installed close enough to the border between France and Spain to demonstrate and validate the use case in the cross-border scenario.

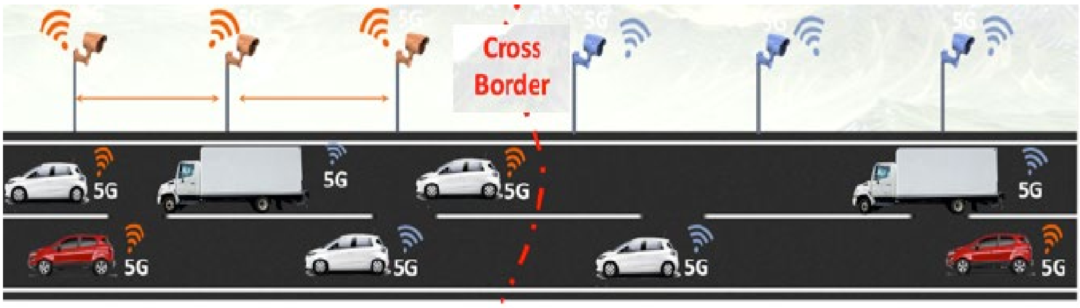

Figure 7. HD cameras deployed along the highway

2.3 Orchestration

An orchestrator will be used to provide end-to-end orchestration capabilities to the infrastructure, network functions, and applications. The orchestrator will cover the lifecycle management of these three pillars and aspects of the Edge domain.

The software components provided by the 5G Core and applications providers are onboarded into the orchestrator to manage these third-party workloads. The following actions are performed by the orchestrator, aside from other capabilities, through the onboarding procedure:

- Render configurations of network functions and applications.
- Identify and place network functions and applications across the registered clusters dynamically.
- Monitor the KPIs of these elements for continuous SLA assessment.
- Perform lifecycle monitoring and management end-to-end.

The orchestrator will not only support the lifecycle management but also enable the network slicing that provides isolation between different use cases, and Edge federation, allowing the application providers to offer services to their customers transparently.

2.4 Network Slicing

5G networks were designed to serve distinct “vertical industries”, such as energy, automotive, manufacturing, healthcare, and telecommunications industries. These verticals have different requirements and KPIs. For instance, some services require ultra-high reliability and low latency whereas other services require extremely high data rates. Therefore, 5G network slicing [3] was proposed to provide tailor-cut solutions to these verticals, which is different than the “one size fits all” concept in the current wireless networks. In this framework, each vertical is mapped to one or multiple isolated logical networks, i.e., network slices, each providing specific network capabilities and characteristics.

The network slicing concept will allow operators to customize their operations to the requirements of the verticals. It is enabled by the concepts of Network Function Virtualization (NFV) and Software Defined Networks (SDN), which allow the implementation of each slice as a slice instance consisting of various Network Functions (NFs) and the associated resources, such as computing, storage, and networking.

5G slices are a must for 5GMED. Indeed, 5GMED will experiment multiple use cases with multiple services running on the same 5G infrastructure. Though each use case and service will have specific requirements and KPIs, the slicing feature will allow to deploy each one ensuring isolation from the others while keeping an optimized use of the 5G resources.

2.5 Computing resources

Depending on the latency requirements of the services and use cases, the computing resources may be in the cloud, at the edge, and on-board the vehicles. The computing resources will host data and applications, including AI modules. This is depicted in Figure 8:

- **Computing resources in the Cloud**: The cloud here designates public cloud or private cloud, i.e., in partners' premises. The cloud provides compute and storage resources that are far away from the corridor. These resources will be reached through 5G or sidelink radio access technologies deployed in 5GMED. Beyond the 5GMED network infrastructure, the available public network will be used.
- **At the Edge**: The 5GMED edge cloud is composed of collocated telecom and computing facilities deployed close to and along the highway or train track. Putting the equipment near the vehicles at the edge will improve the data rate and latency performances, enabling 5GMED use cases and avoiding overloading backhaul infrastructure.
- **On-board the vehicles or train**: The computing resource may be located in the vehicles or in the train depending on the use case requirements.

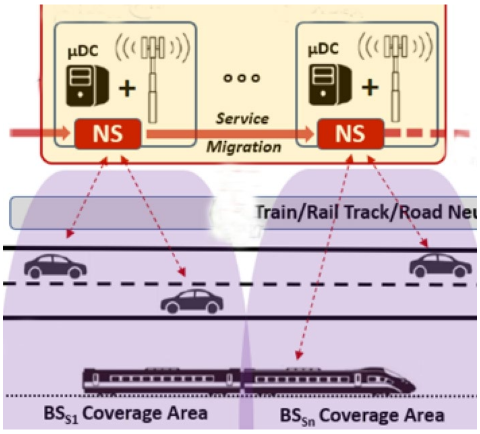

Figure 8. Example of computing resources and telecom equipment deployed at edge

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2.6 Artificial Intelligence

Whether it comes from increasingly performant sensors (e.g., HD cameras, LiDARs, etc.) or the growing number of personal devices equipped with sensors (e.g., cell phones, connected vehicles, etc.), the amount of data produced has been growing non-stop over the past decades.

In 5GMED, we aim at leveraging the tremendous amount of data made available by the increasing quality and performance of those sensors combined with the 5G network features. Several AI modules addressing different tasks are planned to be developed within the project, turning raw data into valuable information to optimize the performance of the applications using the 5G network.

A first example is the development of a Deep Learning based module that will take several data parameters from the 5G network to predict the QoS in the remote driving use case. Another example of AI applications is the detection of obstacles on train tracks to avoid potential damage or collision and eventually perform maintenance. For this application, a LiDAR sensor will be used. This type of sensor provides an enormous amount of data, which is becoming more than what current wireless network can handle. For those specific applications, the use of classical algorithms appears to be far less effective than machine learning algorithms which are way more adaptive.

3 Technical Challenges

This section describes the main technical challenges that will be faced during the deployment of 5GMED use cases in the cross-border scenario. These challenges will be taken into account and further analysed in WP3 for the detailed design of the 5GMED network architecture.

The technical challenges of 5GMED have been divided into:

- Seamless services along the corridor, which includes the cross-border issues associated to roaming and inter-MEC handover, as well as inter-RAT handover.
- Implementation of 5G SA network 3GPP Release 16 and beyond.
- Self-sustainable network infrastructures.

3.1 Seamless services along the corridor

3.1.1 Cross-border issues

3.1.1.1 Roaming for 5G Connectivity

One of the main challenges in the 5GMED project is to provide continuous and seamless services along the cross-border corridor. This is a challenging problem because most of todays' wireless communications systems pertain to different service providers in different countries. More specifically, when a device is connected to a Mobile Network Operator - including legacy 5G networks – and crosses a country border, it will undertake a roaming process. The roaming process includes several operations in both RAN and core network.

From a RAN point of view, the device experiencing the roaming must scan the spectrum and acquire access to the cell from the RAN of the other MNO. This will require relatively long time (in the order of hundreds of seconds), especially in those use cases in which a big number of devices might do this process simultaneously, which might lead to a flash crowd problem.

From a core point of view, the device must exchange signalling with the visited core (the core network of the MNO in the new country) to establish a new connection. Here, the 3GPP standard provided two main roaming solutions [4], namely Home-Routed (HR) roaming and Local Break-Out (LBO) roaming. In HR roaming, the device will be served by its home core network through the visited one, which keeps most of the control over device's traffic with its home MNO. In LBO roaming, the visited core network will have full control over device's traffic. In theory, roaming subscribers can choose one of the two solutions, or both, based on service access policy. HR is the roaming solution adopted by the operators today for voice services, whereas LBO is not used for such services; few operators use LBO solution and it is not expected to be used massively in early stages of 5G systems [5]. It should be noted that with HR roaming, end-to-end delay will increase due to the mandatory path through the visiting network and the connection between the latter and the home network, which is not always the fastest path between the device and its destination.

In summary, on one hand, the need to new connection establishment will require service interruption that can last for couple of minutes. This relatively long interruption time is not acceptable by most use cases and services. For instance: a voice call would be abruptly cut, a video streaming will freeze, critical information or commands to tele-operate a vehicle will not be delivered on time, etc. On the other hand, the additional delay introduced using HR roaming might negatively influence time-critical services and this should be considered when estimating end-to-end latency.

In 5GMED, all the above issues will be considered, and several approaches will be analysed to reduce service interruption time and latency. More specifically, 5GMED will study architectural enhancements proposed by standardization groups and associations, such as 3GPP and 5GAA, to speed up the process of attaching devices to new network by activating new interfaces in the core network and proactively initiate spectrum scanning and RAN connection.

3.1.1.2 Inter-MEC resource handover

Many services in 5GMED are based on Multi-access Edge Computing (MEC), which brings processing, storage and networking resources closer to the network edge and facilitates the compliance of high-bandwidth and low-latency requirements. The vehicle may change the MEC node where it is connected to during its journey. In that case, since in 5GMED we consider that the edge compute resource will be collocated with the telecom sites (gNodeBs) there will be a 5G cell hand over but also possibly a hand over from one compute resource to another. The edge nodes can be both on the same side of the border or cross-border.

At the cross-border, MEC platforms might have different MNOs. Then, if there is no coordination between the two MNOs, the MEC resources assigned to a service will be released in the source country without securing the MEC resources in the visited country. This situation will lead to a service interruption like in the case of roaming. Therefore, a service orchestrator will be implemented in 5GMED in order to transfer smoothly and without interruption service data from a MEC in one side of border to another MEC in the other side. This service orchestrator will take care of establishing communication between MECs on the two sides of the border and ensure that resources will be reserved in the MEC of the visited country before releasing the resources in the MEC of the source country.

3.1.2 Inter-RAT handover

The inter-RAT (Radio Access Technology) handover process occurs when the wireless connection changes from one RAT to another. In these transition areas the connectivity interruption may impair the service continuity and thus the inter-RAT handover must be taken into account and carefully optimized.

The main inter-RAT handover processes in 5GMED are:

- In the highway scenario: between 5G NR and C-V2X/ITS-G5.
- In the railway scenario: between 5G NR, IEEE 802.11ad (70 GHz), and satellite.

3.2 Implementation of 5G SA Network, R16 and beyond

5GMED aims at trialing (both at small-scale and large-scale) the latest 5G technologies in compliance with the 3GPP Release 16.

Nowadays, 5G NSA can already be found in commercial networks. However, 5G SA is not yet commercially available and the deployment of an experimental 5G SA network is another technical challenge in 5GMED; in particular, considering the roaming at the border between France and Spain.

In order to achieve the project objectives, the 5GMED consortium is continuously monitoring the progress of the different standardization bodies, and in particular 3GPP. In this context, the 5GMED consortium has identified several new features defined in the 3GPP Release 16 to serve its objectives:

- **2-step Random Access Channel (RACH) for NR**: This feature reduces the control plane latency needed to set up or resume a connection. This feature can help reducing roaming interruption times at the border and handover delays in both railway and highway.
- **NR-based Access to Unlicensed Spectrum**: This feature allows 5G devices to use unlicensed band. It can be used in the case of train operator in order to have only one carrier along train trip. However, let’s note that radio transmission levels are far less limited than with licensed spectrum leading to reduced covered areas.
- **Satellite access in 5G**: This feature enables 5G devices to use satellite links to connect to gNodeB. As satellite connection is one of the options used to connect devices in delay-tolerant services of the FRMCS use case, this feature may be used.
- **Enhancements to the Network Automation (eNA) architecture**: this feature allows the network to collect and expose a wider range of data. For instance, slice load level information and network performance information could be used in 5GMED to select best RAT.
- **Access Traffic Steering, Switching and Splitting (ATSSS)**: the enhancement in switching techniques allowing a faster moving of traffic data from one RAT to another can be also one of the solutions to reduce delay and service interruption time.
- **Enhanced Network Slicing (eNS)**: The enhancement that is of interest to 5GMED is the new procedure for allocating Access and Mobility Management Function (AMF) and Visited Session Management Function (V-SMF) in connected mode during mobility.

These features will be studied in the WP3 and their implementation will be conditioned by the existence of commercial compliant equipment. In case that commercial equipment with these features do not exist, non-3GPP compliant equipment could be used.

3.3 Self-sustainable network infrastructures

The European corridors will most likely run through large areas in the countryside where power grid may either not be available, or the high supply cost may heavily impact the operations and maintenance of the network infrastructure.

Recently, the introduction of new solutions for zero-emission micro-power generation has drawn the attention of MNOs and tower companies (TowerCo) looking to cut OPEX and foster green-power generation. In 5GMED, powering sites with solar and wind turbines will also be experimented. Specifically, a self-sustainable site will be deployed by 5GMED in an isolated region not connected to the power grid and not relying on fiber connectivity. This represents ideal conditions for investing in an innovative concept of radio sites that can lower the time required for the installation as well as reduce costs related to civil works, operations and infrastructure maintenance.

Figure 9 shows a prototype of self-sustainable site. This site features a rack hosting computing machines, sensors, and battery packs to extend the operations when weather conditions are not suitable for power generation.

Figure 9. Prototype of a self-sustainable site

4 Use Case Definitions, Technical Requirements and Service KPIs

This section describes the four use cases to be developed in 5GMED. The description of each use case is completed with a definition of the main functionalities of the services included in the use case, the main technical requirements, the service Key Performance Indicators, a high-level functional architecture, and the technical challenges to be addressed in the use case.

4.1 Use Case 1. Remote driving

4.1.1 UC1 Definition

Achieving truly safe automated driving requires addressing an exhaustive list of conditions an autonomous vehicle might encounter. This list is referred to as Operational Design Domain (ODD) and includes road types, speed ranges, time of day, weather, and many environmental conditions that may affect the operations of the autonomous vehicle.

Use case 1 (UC1) is about providing remote assistance to an autonomous vehicle that gets out of its ODD. In technical terms, the aim of this use case is to demonstrate that, in the case of an autonomous vehicle fails to accomplish its Dynamic Driving Task (DDT, specified by SAE J3016, [6]), a tele-operator (also called remote driver) may substitute an in-vehicle driver (if not present, not available or not responsive), and hence take control remotely in order to execute the expected DDT Fallback. SAE specifies several automation levels ranging from Level 1 to 5 (shown in Figure 10 below). At SAE Level 3, human drivers are no longer actively driving the vehicle but may be requested to take back control at any time. At SAE Level 4 and 5, passengers are never requested to drive, and vehicles may not have pedals nor steering wheels anymore.

Figure 10. SAE levels of connected and autonomous vehicles

In the context of 5GMED, this new type of "remote driving" DDT Fallback will be demonstrated over a 5G network, on a highway in a cross-border scenario, where safety is a paramount goal in this implementation. Also, trained onboard technical staff will supervise the testing autonomous vehicle at all times.

The testing autonomous vehicle will be a Valeo's Cruise4U, a prototype autonomous vehicle that can operate in SAE Level 3 and 4 within a given ODD on a highway. The use case approach will consist in simulating the exit of the vehicle's ODD by provoking a hardware or software failure (e.g., on cameras or LiDARs) or by encountering unmanageable road conditions, e.g., a hazard like a car accident.

To enable this "remote driving" DTT Fallback, three services will be implemented and tested in UC1:

- **Service 1: Minimum Risk Manoeuvre (MRM)**
  MRM is triggered as soon as the vehicle gets out of its ODD and if no one is present for a DDT Fallback, e.g., a driver who may not react to visual and sound alerts. It is entirely automated in the autonomous vehicle without any assistance from the ground. MRM can result in several outcomes and will eventually end up automatically stopping the vehicle into the safest place according to the onboard computer, e.g., in the emergency lane on a highway.

- **Service 2: Request for Remote Assistance (RRA)**
  As soon as the MRM is triggered, and possibly before the vehicle has even come to a full stop on the emergency lane, the vehicle will initiate a request for remote assistance to the Valeo Teleoperation Cloud (VTC). VTC will make a quick assessment of whether remote driving would be manageable in given circumstances and of where to drive the vehicle for safety.

- **Service 3: Teleoperation Maneuver (TM)**
  If RRA is conclusive, an assigned remote driving human operator will take control of the vehicle from his/her remote cockpit, and then drive it to the recommended safe location.

The following sections describe the actions performed in each service of the remote driving use case.

4.1.1.1 Minimum Risk Manoeuvre (MRM)

This first service, called MRM, will simultaneously execute the following actions:

1. **MRM execution**
   If the in-vehicle driver does not react to the ODD exit alerts, then the vehicle will initiate the MRM. On the highway, the vehicle will autonomously move to the rightmost lane and then look for a safe harbour that is within its operational reach. In case of upmost emergency, this may be the emergency lane.

2. **MRM alerting**
   The vehicle will broadcast a warning message to the local road infrastructure and to nearby vehicles.

3. **RRA initiation**
   The vehicle will initiate contact with the Teleoperation service on the VTC for immediate assessment of the situation.

4.1.1.2 Request for Remote Assistance (RRA)

This second service, called RRA, originates from the vehicle and is then handled by the VTC and the operator sitting at the Remote Station. The goal is to check that all the conditions required for teleoperation of the vehicle are met: conditions at the remote station (e.g., availability, acceptance of remote driver), conditions on the vehicle (e.g., status, operational capabilities), conditions along the road (e.g., traffic, weather or connectivity), etc.

To do so, the following actions will be executed:

1. **Remote Station allocation**
   In the cloud, a specific service in charge of orchestrating the teleoperated driving (ToD) will handle the incoming RRA request, allocate the ToD operation to a free Remote Station, and set up a ToD connection to the vehicle. Sensors' data will start streaming from the vehicle and be displayed on the remote driver's screen right away.

2. **Safe destination query**
   The VTC will inform the Traffic Management Center Global of the situation and request for a safe destination where the vehicle shall be remotely driven.

3. **QoS prediction query**
   An AI module will be queried for the predicted QoS for remote driving over one or several possible routes.

Upon these actions, the remote driver shall decide whether to accept or reject proceeding to a Teleoperation Manoeuver.

4.1.1.3 Teleoperation Manoeuvre (TM)

This last service is the one where remote driving actually happens. It will be enabled by the following actions:

1. **Optimal bidirectional data streaming**
   The communication between the autonomous vehicle (also named as remote vehicle) and the remote station will go through the 5G network and the VTC cloud service. Since the necessary data throughput will be significant (i.e., camera video streams) and the end-to-end latency is extremely critical (i.e., time between the image sent by the vehicle and the reception of adequate steering commands), a crucial part of the implementation will be to optimize the data streaming, e.g., re-encoding data, reprioritizing flows or cutting-off the non-essential.

2. **Remote driving adaptation**
   In addition to the technical solutions in place to counter connectivity issues, the remote driver may have to adapt its driving, for example, lower the speed, limit the manoeuvres like no lane change, or increased reliance on

embedded ADAS such as lane keeping.

3. **Extra 3rd party analysis**
   Some 3rd party services, such as an external analysis and rendering of LiDAR data, will be relied on to help the remote driver in his/her task. This shall result in a complementary visualization accessible at the Remote Station in addition to the raw camera video streaming from the vehicle.

4. **Destination and QoS updates**
   The same requests as the one initiated for RRA will be repeated for the duration of the teleoperation manoeuvre. Indeed, circumstances may change and require an update of the final destination and the route to follow for best teleoperation conditions.

5. **MRM fallback**
   Finally, despite being remotely operated, the vehicle shall keep its automation capabilities in order to be able to trigger a new MRM in case that teleoperation fails, for example, due to the loss of connectivity breaking the teleoperation and endangering vehicle and passengers.

4.1.2 UC1 Technical Requirements

The mandatory components that must be available in the functional architecture of UC1 to satisfy the requirements of the use case are:

- Autonomous vehicle that can operate in SAE Level 4 or greater, with on-board automotive Telematics Control Unit (TCU) capable of 4G/5G and sidelink V2X communications (described in Section 2.1.2).
- Cloud service supporting teleoperation.
- One Remote Station, with an operator, linked to the Cloud teleoperation service.

The recommended components that should be available in the architecture of UC1 are:

- Traffic Management Center (TMC).
- QoS prediction service fed with data from the 5G network.

The optional components that might be available in the architecture of UC1 are:

- Roadside Units with V2X support.
- Roadside cameras for TMC use.
- Connected vehicles with V2X support.
- Environmental analysis to assist teleoperation.
- MEC computing, to host the VTC and Remote Station closer to the highway to optimize latency.

The following table summarizes the requirements of UC1, including the main components, the types and number of vehicles, the types of radio access technologies, and the AI functions which are needed to implement the use case.

		UC1 Services		
		Service 1: Minimum Risk Maneuver	**Service 2: Request for Remote Assistance**	**Service 3: Teleoperation Maneuver**
Main components	Traffic Management Center	-	R	R
	Remote Station	-	M	M
	MEC servers	-	-	-
	Valeo Teleoperation Cloud	-	M	M
	Road sensors (HD Cameras)	O (1)	-	O (1)
	TCU	M (1) + O (1)	M (1)	M (1) + O (1)
	On-board sensors	LIDAR M (1) Camera M (1)	LIDAR O (1) Camera M (1)	LIDAR O (1) Camera M (1)
Vehicles in use	Connected, autonomous	M (1)	M (1)	M (1)
	Connected, no autonomous	O (1)	-	O (1)
	No connected, no autonomous	-	-	-
	Connected train	-	-	-
Wireless connectivity	5G NR (3.5GHz)	-	M	M
	5G NR (26GHz)	-	O	O
	C-V2X (5.9GHz)	-	O	O
	IEEE 802.11ad (70GHz)	-	-	-
	Satellite	-	-	-
AI	In Vehicles	Autonomous Driving	-	Autonomous Driving
	In MEC	-	-	-
	In Cloud	-	R (QoS Prediction)	R (QoS Prediction), O (Environmental Analysis)

Table 1. Requirements of the remote driving use case

M = Mandatory
R = Recommended
O = Optional
The figures between brackets are the number of equipment required

4.1.3 UC1 Service Key Performance Indicators

This section provides the definitions of the service KPIs of UC1 and lists the target values associated to each KPI. These service KPIs will be measured and monitored during the realization of the trials according to the purpose of the test cases defined in D2.2. The table below provides the definition of the service KPIs.

Service KPI Name	Unit	Definition
Command End-to-End Latency	[ms]	Time elapsed between the transmission of a command message (i.e., desired speed, steering wheel angle, etc.) by the remote station application and its reception by the destination application in the remote vehicle
Data End-to-End Latency	[ms]	Time elapsed since a sensors data message (i.e., camera images, LIDAR data, current speed, etc.) is transmitted by a source application in the remote vehicle until the sensors data message is received by the destination application in the remote station
Command Reliability	[%]	Ratio between number of command messages successfully received by the destination application in the remote vehicle divided by the number of command messages sent by the remote station
Sensing Data Reliability	[%]	Ratio between number of sensors data messages successfully delivered to the destination application in the remote station divided by the total number of sensors data messages sent by the remote vehicle
Uplink Service Data-Rate	[b/s]	Amount of application data bits (i.e., sensors data) transmitted by a source application in the remote vehicle within a certain time window
Downlink Service Data-Rate	[b/s]	Amount of application data bits (i.e., commands) received by the destination application in the remote vehicle within a certain time window
Mobility interruption time	[s]	Maximum time interval in which the application in an autonomous vehicle cannot exchange messages with the application in the remote station

Table 2. Definition of service KPIs for the remote driving use case

Table 3 below provides the target values of the KPIs for the services of UC1. In those services where a service KPI does not have a target value assigned, it is because that KPI is not relevant for that specific service. For example, since service 1 consists in an autonomous maneuver of the vehicle, that service does not require communication with the remote station and, consequently, no target values of KPIs have been assigned for service 1.

Service KPI Name	Service 1: Minimum Risk Maneuver	Service 2: Request for Remote Assistance	Service 3: Teleoperation Maneuver
Command End-to-End Latency (DL)	-	-	<20 ms, <50ms (1)
Data End-to-End Latency (UL)	-	<100 ms	<100 ms
Command message Reliability	-	-	99 %
Sensing Data Reliability	-	>95 %	>95 %
Uplink Service Data-Rate	-	> 5 Mb/s	>10 Mb/s
Downlink Service Data-Rate	-	>0.5 Mb/s	>1 Mb/s
Mobility interruption time	-	<1 s	<100 ms

Table 3. Target values of service KPIs for the remote driving use case

Note (1): the maximum command end-to-end latency required will depend on the speed of the car. At 80 km/h (lowest speed allowed on the motorway in France) the maximum command end-to-end latency is 50 ms, but it is 20 ms at 130 km/h. During the trials, the speed of the teleoperated autonomous vehicle will be adapted according to the latency experienced.

The end-to-end latencies in the remote driving process are composed of several latencies: at sensors' acquisition level, transmission level, processing level, etc. The required network latencies will be derived in WP3 from all other known latencies, once all the components are defined.

The services of UC1 will target the speeds of the autonomous vehicle shown in Table 4.

Service 1: Minimum Risk Maneuver	Service 2: Request for Remote Assistance	Service 3: Teleoperation Maneuver
>80 km/h	-	> 80km/h

Table 4. Speed conditions for the remote driving use case

4.1.4 UC1 High-Level Functional Architecture

Figure 11 illustrates the high-level functional architecture of UC1. This block diagram shows the main components (introduced in Section 4.1.2) required for implementing UC1, and the mapping of these components on the high-level 5GMED network architecture represented in Figure 2. The detailed description of functionalities and interfaces of all the UC1 components will be presented in D4.1 and D4.2.

As depicted in Figure 11, the main components required for UC1 can be classified as belonging to three different layers:

1) **Road layer**, which includes all the lanes of the highway and the emergency lane. On the highway, we find the teleoperated autonomous vehicle (also named as remote vehicle) and other connected vehicles. In addition to the highway lanes, UC1 will make use of the emergency lane and available safe harbours (e.g., emergency stop areas, rest areas). The road layer may also include several optional elements installed in the infrastructure, such as roadside units, HD cameras, and road signs controlled by the TMC Edge.
2) **Cloud layer**, an unrelated location such as different cities or public cloud, where we find the cloud services and the Remote Station. Cloud services are the Valeo Teleoperation Cloud and other services on which UC1 relies, such as the service provided by the TMC and the Environmental Analysis to assist teleoperation.
3) **Data Analytics Layer**, which hosts the QoS prediction module required for UC1.

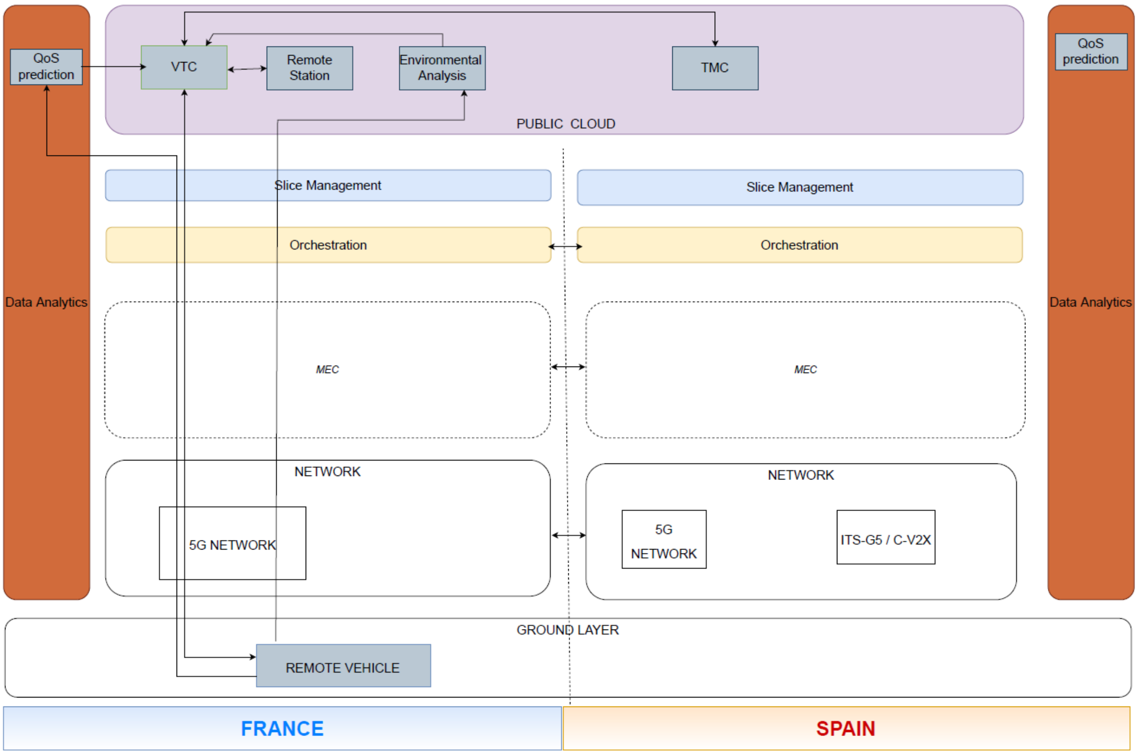

Figure 11. High-level functional architecture of UC1

4.1.5 UC1 Technical Challenges

This section identifies the technical challenges that are most critical for UC1 to meet the functional and performance requirements of its services. A description of the 5GMED technical challenges was introduced before in Section 0. In Table 5, those technical challenges that could degrade the performance of a service are marked as "Yes".

Technical Challenges		**Service 1: Minimum Risk Maneuver**	**Service 2: Request for Remote Assistance**	**Service 3: Teleoperation Manoeuver**
Seamless services along the corridor	Roaming for 5G connectivity	-	-	Yes
	Inter MEC resource handover	-	-	-
	Inter RAT handover	-	-	-
Implementation 5G cellular SA, R16 and beyond		-	Yes	Yes

Table 5. Technical challenges of UC1

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To enable seamless services between two countries at cross border, mobile network roaming is mandatory. During the roaming operation, the mobility interruption time as defined in Table 2 above must be kept below 100 ms for the vehicle teleoperation to be safe at usual speeds. Beyond roaming, all along the path of the vehicles, low latency is required for the teleoperation service to be safely delivered.

4.1.6 Why do we need 5G SA for UC1?

According to the service KPIs' target values, the following table shows on a per service basis why 5G is required in UC1.

5G Features	**UC1 Services**		
	Service 1: Minimum Risk Maneuver	**Service 2: Request for Remote Assistance**	**Service 3: Teleoperation Maneuver**
Very high data-rate	-	-	-
Very low latency	-	-	Yes
Very high reliability	-	Yes	Yes
Distributed network functions	-	-	-
Very low connectivity interruption time at the border	-	Yes	Yes
5G slicing	-	-	Yes

Table 6. Why do we need 5G-SA for UC1?

From Valeo's past experiences using 4G technology, we were able to achieve low-speed teleoperation by fine-tuning the video streams so that they were not too demanding in terms of bandwidth.

With the promise of 5G, we expect to be able to increase the speed of safe teleoperation, not being constrained anymore by bandwidth. We will endeavor to make the most of our sensor capabilities and have a standardized analysis of the network on which we operate.

Also, it would be very advantageous to isolate the bandwidth allocated to teleoperation operations for stability and safety using network slicing.

4.2 Use Case 2. Road Infrastructure Digitalisation

4.2.1 UC2 Definition

In a future CCAM scenario, data provided by vehicle sensors (including LiDAR, radar, GPS, etc.) and data from surrounding heterogeneous information sources (e.g., traffic cameras, smart road sensors and signs, smart phones, etc.) will be used to create more intelligent traffic management systems that based on cooperative sensing will be more aware of the environment. The transmission of all this data will require a reliable, ultra-fast and ultra-low latency network connection such as that offered by 5G, which combined with AI and predictive analytics techniques, will leverage edge/cloud computing capabilities, and enable a road environment that will offer various value-added functionalities to users and road operators.

In this framework, UC2 focuses on communications between Infrastructure-to-Vehicle (I2V) and Vehicle-to-Infrastructure (V2I). The target of UC2 consists in an innovative use case scenario of road infrastructure digitalization that requires a 5G network for high bandwidth and low latency demanding services to improve the safety and efficiency of traffic management.

Based on a network of sensors deployed along the road infrastructure, the digitalization process will help road operators to execute intelligent traffic management strategies to ensure uninterrupted, safe, and efficient mobility in situations of mixed conventional, connected, and automated vehicles.

The objective of UC2 is to bring road infrastructure closer to Level A as defined in the Infrastructure Support for Automated Driving (ISAD) classification. ISAD levels are explained in [7]. The road infrastructure will be equipped with a set of HD cameras that will transmit the video stream to AI computing resources located at the edge. Software tools for automatic analysis, management, and dissemination of I2V and V2I messaging will be deployed at the highway infrastructure to improve global traffic safety and efficiency.

The purpose of UC2 is to prove that a 5G network infrastructure can collect, analyze, and disseminate messages of different weight and nature with low latency and in a highway cross-border scenario as well as testing solutions for areas where 5G coverage is not complete.

Two different types of services will be deployed in UC2:

- **Warning Traffic Strategies**, which is a "real time" service that implies traffic management procedures in a segment of the highway in the cross-border corridor. These warning traffic strategies imply the dissemination in real-time of warning messages and driving actions for automated and connected vehicles close enough in order to anticipate the detection and reaction in hazardous situations. These situations can be an accident, a stopped vehicle, an obstacle on the highway, etc. In this context, real-time means that there is a stringent requirement in terms of latency because the warning message should reach the concerned incoming cars in time to facilitate a safe and efficient reaction to avoid accidents. Simple calculations based on the length of the highway segment under local control, the maximum speed of vehicles, and the braking distances can give an idea on the required latencies. Within the warning traffic strategies service type, two different services are considered:

  - **Service1: Relay of emergency messages (REM)**

    In this service, the hazard detection is performed by in-vehicle on-board sensors. The aim of this service is to consolidate the warning emergency messages (also named as hazard notification messages) sent by vehicles to the infrastructure and then send the warning and a traffic strategy from the infrastructure to other vehicles approaching to the hazard.
  - **Service 2: Automatic incident detection (AID)**

    In this service, the cameras deployed along the infrastructure are responsible for the hazard detection. When a hazard is detected, the infrastructure sends warning emergency messages to the vehicles, as well as a traffic strategy.

- **Global Traffic Strategies** imply traffic management procedure on a large portion of the highway or the whole highway. Somewhat like regulating the traffic lights in a city, this will help to regulate the flow of vehicles all along the highway, taking into account all kinds of unexpected events (e.g., prevent or regulate traffic jam, avoid accordion phenomena, suggest offloading actions, etc.). Within this global traffic strategies service type, one service is considered:
  - **Service 3: Traffic Flow Regulation (TFR)**

    In this service, the infrastructure regulates the traffic flow by detecting abnormal behavior (e.g., low speed, etc.) and sends regulation commands to a group of connected vehicles in circulation.

The rest of this section describes the functional operation of each service of the road infrastructure digitalization use case: (1) relay of emergency messages in Section 4.2.1.1, (2) automatic incident detection in Section 4.2.1.2, and (3) traffic flow regulation in Section 4.2.1.3. Later, the high-level functional architecture of UC2 is presented in Section 4.2.4.

4.2.1.1 Relay of Emergency Messages (REM)

The functional operation of the relay emergency messages service is depicted in Figure 12. In this service, when a vehicle detects a hazard on the highway with its on-board sensors, it sends a warning or emergency message to a Traffic Management Center (TMC) allocated in the infrastructure. The TMC is divided in two parts: TMC Edge and TMC Global. The TMC Edge monitors a specific segment of the highway. The TMC Global is located in the Cloud and is in charge of managing the whole highway and of coordinating the operations of multiple TMC Edge elements along the highway.

Emergency messages sent by vehicles are received by the TMC Edge, through a gateway (called V2X Gateway) that is also mapped on the Edge infrastructure, and reports to the TMC Global. The TMC Global will decide whether that hazard affects vehicles driving within the coverage of a single TMC Edge or more, or even in a cross-border scenario involving two TMC Edges in different countries. When the TMC Edge consolidates a warning message, it identifies those areas that can be under risk according to their distance to the hazard, road occupancy, vehicle types, speed, etc. Then, the TMC Edge devises a traffic strategy (i.e., velocity, distance gap, lane change), under the supervision of the TMC Global, and sends a hazard emergency message and traffic regulation commands to the vehicles driving within the area considered unsafe by being close to the hazard.

In addition to the emergency messages sent by the vehicles, the TMC Edge and TMC Cloud also use the information collected from the cameras installed in the infrastructure in order to calculate the traffic strategies.

The following figure shows the events, entities involved in the service in a cross-border scenario and the actions performed to replicate the emergency messages. As it can be observed, the yellow car has an emergency and stops on the emergency lane. The connected vehicles (CV) and connected autonomous vehicles (CAVs) driving behind detect the hazard with their on-board sensors and send the emergency message to the TMC Edge. The emergency message is a Decentralized Environmental Notification Message (DENM) defined in the ETSI ITS standards [8]. This information is analyzed by the TMCs, which sends emergency messages to those vehicles included in the red zone and a strategy for recommended driving actions, via Maneuver Coordination Message (MCM) to those vehicles driving closer to the hazard in the brown zone.

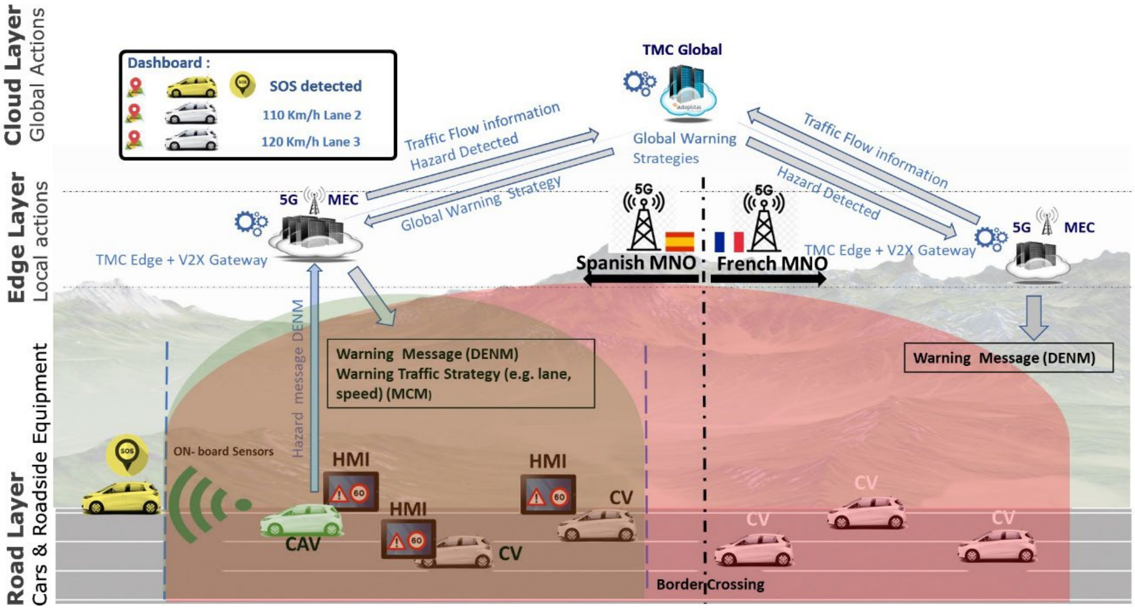

Figure 12. Relay of emergency messages (REM) service of UC2

4.2.1.2 Automatic Incident Detection (AID)

The functional operation of the AID service is depicted in Figure 13. In this service, using the cameras located in the infrastructure in the section under supervision by the TMC Edge, a hazard (e.g., stopped vehicle in the emergency lane) will be detected by the TMC Edge by analyzing the video streams from the cameras.

Once a hazard is detected, the TMC Edge will analyze the situation, immediately sends a warning message and traffic strategy to vehicles in its area of influence and informs the TMC Global in the cloud. The TMC Global will decide if that hazard affects vehicles circulating within the coverage of a single TMC Edge or more, or in a cross-border scenario involving two TMC Edges in different countries. In case of two TMC Edges in a single country or in different countries, the TMC Global will send the warning emergency messages (DENM) and traffic strategies (MCM) to the corresponding TMC Edges. Then, the TMC Edges will disseminate the warning emergency messages (through the V2X Gateway allocated in the edge) to those vehicles approaching (red area in the figure below) and a warning traffic strategy to those vehicles under the unsafe area (brown area in the figure). All this process, the transmission of the video data, its processing, and the reception of warning emergency messages and warning strategy messages by the surrounding vehicles must be within a short time lapse.

Figure 13 shows a summary of the events and entities involved in the automatic incident detection service in a cross-border scenario. The dashed line represents the border between France and Spain.

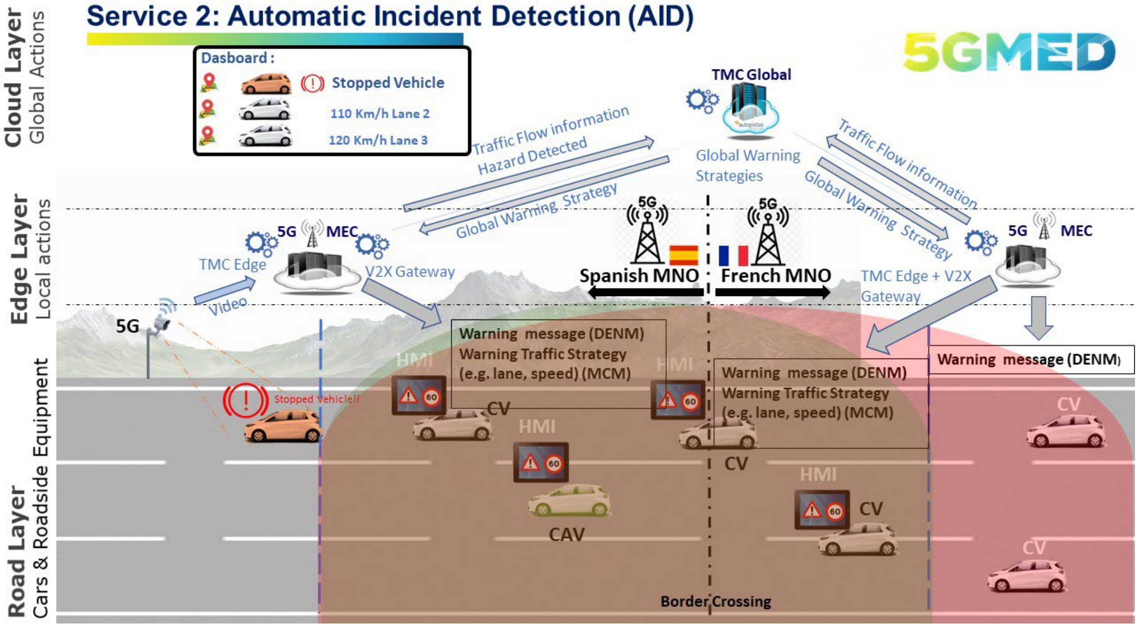

Figure 13. Automatic incident detection (AID) service of UC2

4.2.1.3 Traffic flow regulation (TFR)

The functional operation of the traffic regulation service is depicted in Figure 14. In this service, the TMC Global analyzes the traffic situation in real-time all along the highway composes and sends traffic strategies (e.g., speed and lane change) to groups of CVs and CAVs that are circulating in different areas in order to improve the traffic efficiency and safety in the highway. Those vehicles that are not connected will drive by imitation of the actions performed by the group of connected vehicles that are regulated by the TMC Global.

For the generation of traffic strategies, the TMC Global will use the information collected from the analysis of roadside cameras' video streams and, potentially, other sources of information (e.g., position, speed, and type of vehicle) transmitted by CVs and CAVs in Cooperative Awareness Messages (CAM) and Cooperative Perception Messages (CPM), and external data such as bulletins, real-time data traffic analysis and road weather conditions from external entities.

Figure 14 shows an example of the events and entities involved in the traffic flow regulation service in a cross-border scenario. In this example, traffic flow starts to slow down in one area of the highway (represented with blue cars in the left side of the highway). The TMC Edge detects the abnormal situation with HD cameras deployed in the infrastructure and sends the information to the TMC Global. The TMC Global, based on the different data sources mentioned above, will send a global traffic strategy (e.g., speed reduction, etc.) through the TMC Edge and V2X Gateway, which will send the traffic strategy (MCM) in specific commands for the CVs and CAVs circulating in the affected area (represented in the green area).

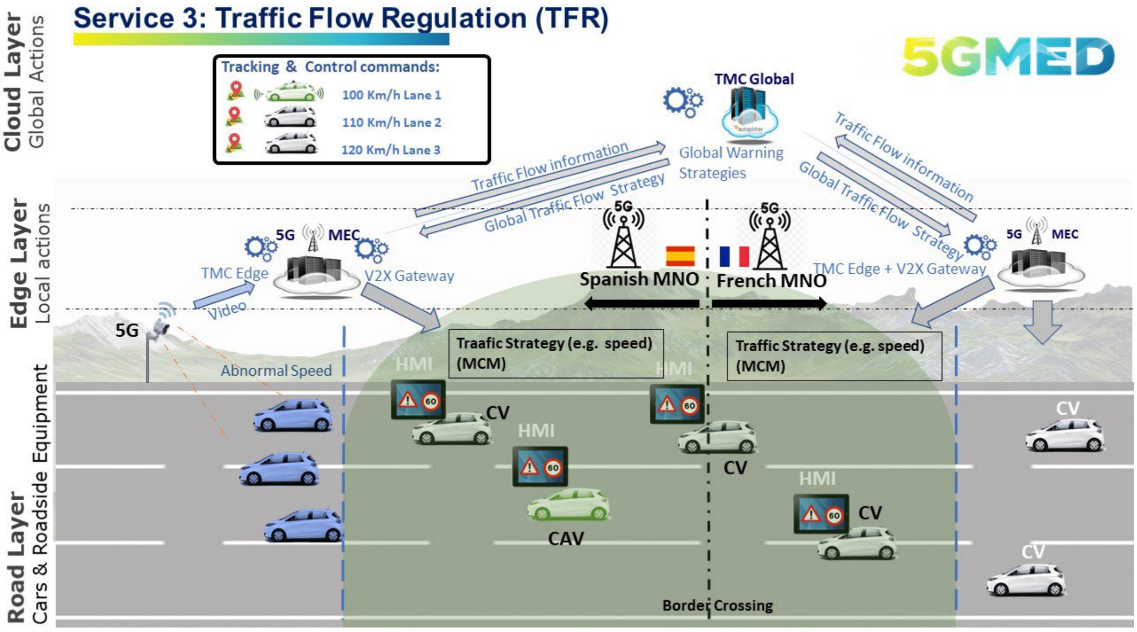

Figure 14. Traffic Flow Regulation (TFR) service of UC2

4.2.2 UC2 Technical Requirements

The following table summarizes the requirements of UC2, including the main components, the types and number of vehicles, the types of radio access technologies, and the AI functions needed to implement each service of the use case.

		UC2 Services		
		Service 1: Relay of emergency messages	**Service 2: Automatic Incident Detection**	**Service 3: Traffic Flow Regulation**
Main components	Traffic Management Center	M	M	M
	V2X Gateway	M	M	M
	MEC servers	M (2)	M (2)	M (2)
	Cloud	M	M	M
	Road sensors (HD Cameras)	M (≤11)	M (≤11)	M (≤11)
	TCU	M (>5)	M (>5)	M (>5)
	HMI/Dashboard	M (>5)	M (>5)	M (>5)
	On-board sensors	M (3)	M (3)	M (3)
Vehicles in use	Connected autonomous vehicle (SAE ≥ L3) [9]	M (1)	M (1)	M (1)
	Connected vehicle	M (≥ 4)	M (≥ 4)	M (≥ 4)
	Not connected, not autonomous	M (1)	M (1)	M (3)
Wireless connectivity	5G NR (3.5GHz)	M	M	M
	C-V2X (5.9GHz)	M	M	M
	IEEE 802.11ad (70GHz)	-	-	-
	Satellite	-	-	-
AI	In Vehicles	M (Hazard detection)	-	-
	In MEC	M (Traffic analysis and strategy)	M (Hazard detection), M (Traffic analysis and strategy)	M (Hazard detection), M (Traffic analysis and strategy)
	In Cloud	R (Traffic analysis and strategy)	M (Traffic analysis and strategy)	M (Traffic analysis and strategy)

Table 7. Requirements of the road infrastructure digitalisation use case

Note: Number of items are put between brackets.
M = Mandatory
R = Recommended
O = Optional

4.2.3 UC2 Service Key Performance Indicators

This section provides the definitions of the service KPIs of UC2 and lists the target values associated to each KPI. These service KPIs will be measured and monitored during the realization of the trials according to the purpose of the test cases defined in D2.2.

Table 8 below provides the definition of the service KPIs. Since the goal of the 5GMED project is to evaluate the capabilities of 5G technologies to meet the service KPIs in a cross-border scenario, the service KPIs of UC2 do not include any KPI associated to sensors' performance (e.g., hazard detection reliability), which is out of the scope of the trials of 5GMED in UC2.

Service KPI Name	Unit	Definition
Hazard End-to-End Latency	[ms]	Time elapsed since a hazard notification message is transmitted by a source application, which detects the hazard, until the hazard notification message is received by the destination application in a vehicle driving in the area affected by the hazard
Traffic Regulation End-to-End Latency	[ms]	Time elapsed since an abnormal traffic situation is detected by the source application until a traffic regulation message is received by the destination application in a vehicle that is driving in the affected area
Hazard Notification Reliability	[%]	Ratio between number of hazard notification messages successfully delivered to a destination application in a vehicle divided by the total number of hazard notification messages sent
Traffic Regulation Reliability	[%]	Ratio between number of traffic regulation messages successfully delivered to a destination application in a vehicle divided by the total number of traffic regulation messages sent
Uplink Service Data-Rate	[b/s]	Amount of application data bits transmitted by a source application in the road layer (e.g., roadside sensor, vehicle) within a certain time window
Downlink Service Data-Rate	[b/s]	Amount of application data bits received by a destination application in a vehicle within a certain time window
Mobility Interruption Time	[s]	Maximum time interval in which the application in a vehicle cannot exchange data messages with the backend applications due to roaming or inter radio access technology handover

Table 8. Definition of service KPIs for Road Infrastructure Digitalisation

Table 9 below provides the target values of the KPIs for the services of UC2. In those services where a KPI does not have a target value assigned is because that KPI is not relevant for that specific service. To define the target values, a mixed traffic scenario has been considered in which connected, autonomous and conventional vehicles coexist.

The target values of the end-to-end latencies in Table 9 have been calculated taking into account the following parameters:

- **Safety distance:** it is defined as the distance between two circulating vehicles that ensures that the vehicle behind will have sufficient time to react and stop safely in the event of danger to the vehicle in front. The safety distance depends on the speed.
- For Service 1 and Service 2, we have considered that vehicles move at 120km/h (maximum speed allowed in Spain), the pavement is wet and there is a fluid traffic density. For Service 3, we have considered that vehicles drive in a congested traffic scenario and a vehicle is slowing down. In this case, 40 m would be the distance between the first vehicle slowing to 80 km/h and the second vehicle travelling at a speed of 120km/h.
- **Driving reaction distance:** it is defined as the distance a vehicle travels when a human being needs to respond to a situation by moving the foot from the

accelerator pedal to the brake pedal. It is considered that the driver is not tired. This distance should be considered for the three services.

- **Braking distance:** it is defined as the distance a vehicle travels from the moment when the brakes are fully applied until it comes to a complete stop. This distance has been taken into account in Services 1 and Service 2 for the vehicle in front.

Service KPI Name	Target Value		
	Service 1: Relay of Emergency Messages	**Service 2: Automatic Incident Detection**	**Service 3: Traffic Flow Regulation**
Hazard End-to-End Latency	< 200 ms	< 200 ms	-
Traffic Regulation End-to-End Latency [5]	< 500 ms	< 500 ms	< 600 ms
Hazard Notification Reliability	99,90 %	99,90 %	-
Traffic Regulation Reliability	99,90 %	99,90 %	99,90 %
Uplink Service Data-Rate	10 kb/s	5 Mb/s	5 Mb/s
Downlink Service Data-Rate	7 kb/s	7 kb/s	3 kb/s
Mobility Interruption Time	< 80 ms	< 100 ms	< 100 ms

Table 9. Target values of service KPIs for Road Infrastructure Digitalisation

These target values are theoretical approximations and will have to be revised once experiments are started. They shall be adjusted according to real data.

4.2.4 UC2 High-Level Functional Architecture

Figure 15 illustrates the high-level functional architecture of UC2. This block diagram shows the main components (introduced in Section 4.2.2) required for implementing UC2 and the mapping of these components on the high-level 5GMED network architecture represented in Figure 2. The detailed description of functionalities and interfaces of all the UC2 components will be presented in D4.1 and D4.2.

As depicted in Figure 15, the components of UC2 can be classified as belonging to three different layers:

1) **Road layer**, which includes all the lanes of the highway, vehicles, roadside units, and HD cameras installed in the infrastructure.
2) **Edge layer**, which includes the TMC Edge and the V2X Gateway.
3) **Cloud layer**, which includes the TMC Global.

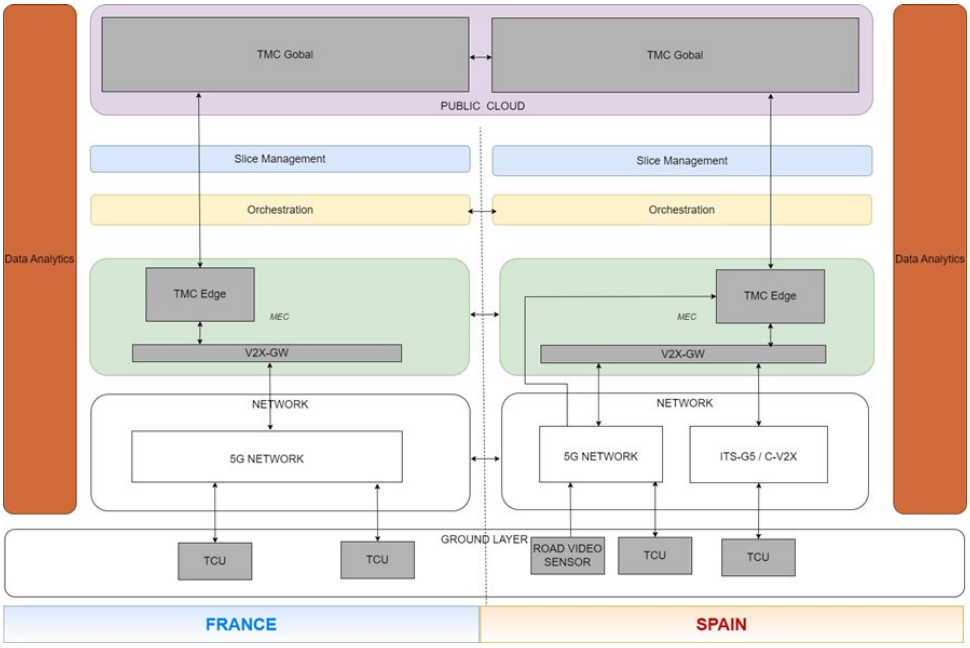

Figure 15. High-level functional architecture of UC2

4.2.5 UC2 Technical Challenges

This section identifies the technical challenges that are most critical for UC2 to meet the functional and performance requirements of its services. A description of the 5GMED technical challenges was introduced before in Section 0. In Table 10, those technical challenges that can degrade the performance of a service are marked as “Yes” in the corresponding cell.

Technical Challenges		Service 1: Relay of emergency messages	Service 2: Automatic Incident Detection	Service 3: Traffic Flow Regulation
Seamless services along the corridor	Roaming for 5G connectivity	Yes (1)	Yes (1)	Yes (1)
	Inter MEC resource handover	-	-	-
	Inter RAT handover	Yes (2)	Yes (2)	Yes (2)
Implementation 5G cellular SA, R16 and beyond		Yes (3)	Yes (3)	Yes (3)

Table 10. Technical challenges of UC2

(1) If the roaming time is too long, communication between road infrastructure and vehicles would be lost for a too long period of time for the road operators to guarantee the safety of road users during cross-border.
(2) idem as for roaming

(3) Current networks do not allow a road operator to fully automate road safety and traffic management services due not providing the required high reliability, service prioritization offered by the slicing and optimized roaming.

4.2.6 Why do we need 5G SA for UC2?

According to the service KPIs' target values, the following table shows on a per service basis why 5G is required in UC2.

5G Features	**UC2 Services**		
	Service 1: Relay of emergency messages	**Service 2: Automatic Incident Detection**	**Service 3: Traffic Flow Regulation**
Very high data-rate	Yes	Yes	Yes
Very low latency	Yes	Yes	Yes
Very high reliability	Yes	Yes	Yes
Distributed network functions	Yes	Yes	Yes
Very low mobility interruption time at the border	Yes	Yes	Yes
5G slicing	Yes	Yes	Yes

Table 11. Why do we need 5G-SA for UC2?

5G is necessary for UC2 to ensure very high reliability and very low latency of critical traffic control and regulation services in a future CCAM environment to avoid catastrophic traffic accidents where road users' life is at risk. In the automation of road infrastructure, reliable information on hazards is mandatory, and it becomes more critical when it comes from several sources such as vehicles and roadside sensors.

In addition, the network slicing supported by 5G is expected to give the prioritization, isolation, and robustness to these types of services. Today, it is more common for road operators to own their own networks and data centers to achieve privacy and have the necessary network resources to achieve high performance. This implies a high CAPEX and OPEX costs. In a future CCAM scenario in which performance requirements will be so stringent and high, this is neither feasible nor affordable. 5G network slicing will guarantee the performance, scalability, support for multi-vendor and multiple-operator scenarios allowing road operators to reduce CAPEX and OPEX costs through these new business models based on network and edge computing services.

4.3 Use Case 3. FRMCS Applications and Business Service Continuity

4.3.1 UC3 definition

FRMCS [10] is the future worldwide railways telecommunication system, designed by the International Union of Railways (UIC) in close cooperation with the different stakeholders from the rail sector, as the successor of GSM-R but also as a key enabler for rail transport digitalization.

FRCMS divides the services into three categories:

- **Critical services**: essential applications for train movements and safety or legal obligation, e.g., emergency communication, shunting, presence, Automatic Train Control (ATC), etc.
- **Performance services**: applications that help to improve the performance of the railway operation, e.g., train departure, telemetry, etc.
- **Business services**: applications that support the railway business operation in general, e.g., wireless internet, voice calls, etc. Business services are offered to passengers.

Critical services are currently provided via the GSM-R system. They have not been considered in 5GMED, but in the twin H2020 ICT-53 project called 5GRAIL [11], which is focused on critical services. The FRMCS user requirement specifications include a set of new applications, broader than the critical ones. FRMCS is sometimes identified only with the set of critical services, but as it was defined by the UIC, the performance and business services are also part of the FRMCS User Requirements Specification.

In this context, the performance and business services that 5GMED will demonstrate in UC3 are selected examples of non-critical applications that will introduce additional heavy requirements to the train-to-ground connectivity. In this way, UC3 will require the use of 5G technologies as well as specialized radio access technologies dedicated to railways, such as the 70 GHz IEEE 802.11ad [1], and the introduction of alternative radio access as satellite, which will be shown as complementary ways to improve the performance of the Train Access Network (TAN).

UC3 targets to demonstrate representative FRMCS performance and business services in a high mobility environment. Not only FRMCS services will be considered. But also additional services, such as the indoor MNO service for passengers provided by a 5G small cell on-board the train. The railways scenario of UC3 services has some specific features that need to be highlighted:

- The services will be deployed and evaluated in a high-speed train moving at 300 km/h.
- Multiple radio access technologies will be deployed along the rail track segment of the cross-border corridor represented in Figure 16 (5G NR, side-link connectivity using 70 GHz IEEE 802.11ad, and satellite connectivity). It should

be noted that not all the radio access technologies will cover the complete rail track segment of the corridor.

- The rail track segment of the cross-border scenario between France and Spain includes Le Perthus Tunnel and open areas.

The TAN must be able to support a multi-stakeholder service delivery architecture that facilitates the establishment of virtual networks over the communication and computing architecture.

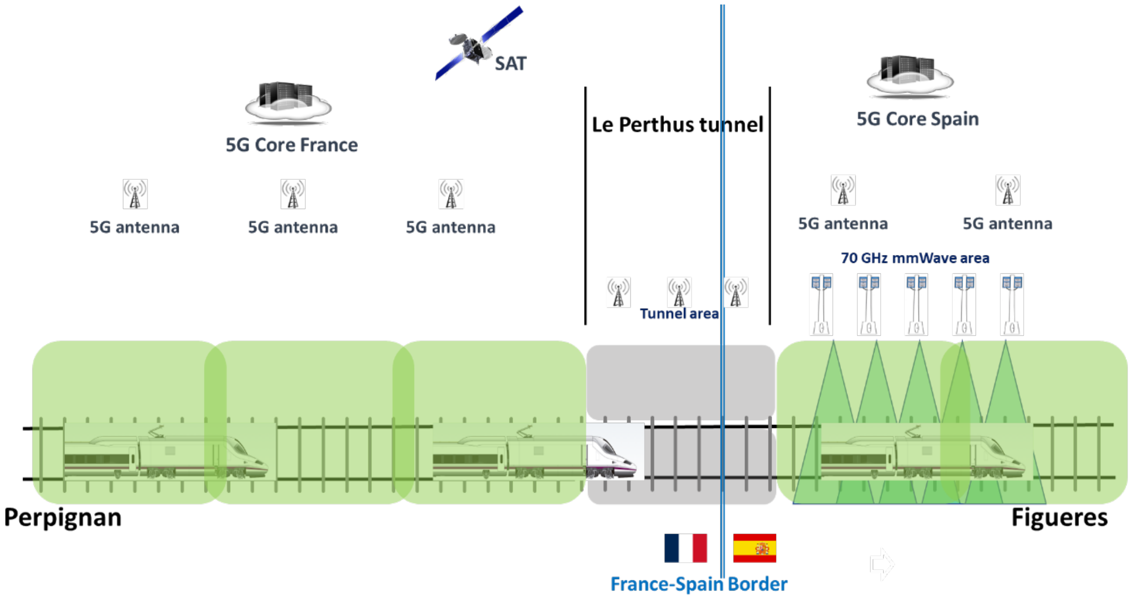

Figure 16. Coverage of the radio access technologies deployed in the rail track segment of the cross-border corridor (5G NR, 70 GHz IEEE 802.11ad, and satellite)

Train users (i.e., passengers, staff, and machines) should enjoy service continuity throughout the journey with different performance levels, depending on the capabilities of the radio access technologies existing in each track segment of the cross-border corridor. All the radio systems will be managed as if only one radio system were in place, providing a unique bearer transport service, transparent to the application layer.

The services of UC3 to be deployed in the train are listed below. Each service has been classified as performance (P) or business (B) service type:

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

The following sections describe the functional operation of each service of UC3. Later, the high-level functional architecture of UC3 is presented in Section 4.3.4.

4.3.1.1 Advanced Sensor Monitoring on Board (FRMCS P1)

The aim of the FRMCS P1 service of UC3 is to monitor the status of non-critical systems of the train by facilitating data communication between on-board sensors, the train control information systems on ground, and the railway staff.

The train is equipped with a large number of sensors where each sensor typically sends few data bytes to the network, periodically or in bursts, depending on the sensor type.

Nowadays, the on-board sensors are connected to the train operator information system through several wireless networks, such as LoRaWAN gateways or Machine-to-Machine services (M2M) provided by MNO's. Besides those sensors already available on-board commercial trains, several new sensors with their applications are currently under development by train operators.

To illustrate the FRMCS P1 application, Table 12 shows several types of on-board sensors currently in use or in development by SNCF in high-speed trains.

Sensing application	**Description**
Shock detection	The goal of this sensor is to detect a shock on the train and immediately warn the Train Control Centre about a potential accident
Vibration recording	The goal of this sensor is to detect and record the vibrations of the bogie. By analysing the records, the system can detect an abnormal degradation of the rail track. In such a case, preventive action shall be triggered.
Pantograph control	The contact between pantograph and catenary is critical for train operations. Controlling the quality of this contact allows detecting the abnormal degradation of the catenary and triggering preventive maintenance. Control is typically based on electric arc occurrence detection.
Connected locker	The goal of this sensor is to notify the train driver and maintenance team when a locker is opened or closed. Indeed, the train shall not move if a locker is open.
Connected baggage	The goal of this sensor is to inform the passenger with some information about its baggage, e.g., location/movement .
Occupied seat detector	The goal of this sensor is to detect if a seat is occupied, making train staff work easier.
CO2 sensor control	This sensor is used to estimate the number of passengers.
Toilets water tank level monitoring	Toilets water tank level shall be monitored in order to avoid unpleasant situations for the passengers

Table 12. Train on-board sensors

As an example, the location of sensors inside the train is shown in Figure 17.

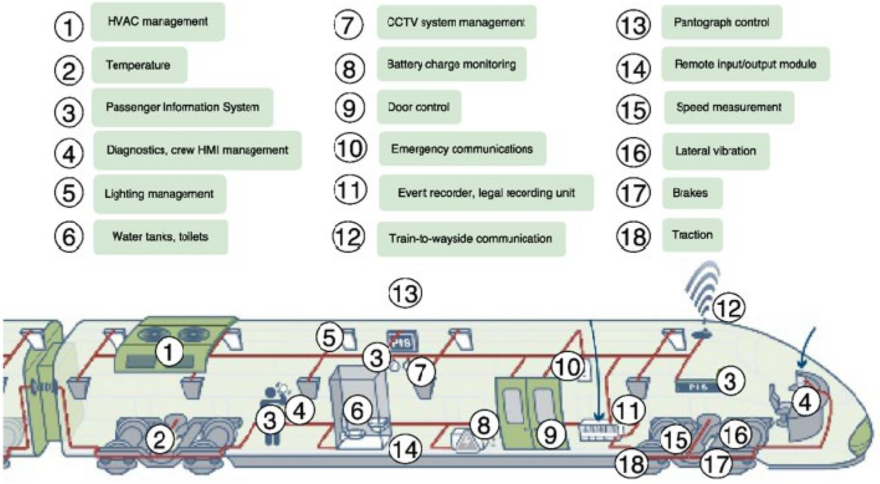

Figure 17. Location of sensors inside the train

The implementation of the FRMCS P1 service will be based on the generation of machine-type data traffic, with the same characteristics as real on-board sensors, from a simulator of wireless sensor networks (WSN). This data traffic will be transmitted to a server on the cloud functioning as the information system of the SNCF. The traffic sent by the simulator will include 10.000 sensors' parameters periodically transmitted every 100 ms. The time delay for reception of the sensors' data will be monitored from a user front-end application that will request the data to the information system of the SNCF Train Control Centre.

4.3.1.2 Railway track safety – obstacle detection (FRMCS P2)

The aim of the FMCS P2 service of UC3 is to detect and locate potential obstacles that may block rail tracks. The operation of the P2 service is described as follows:

- A LiDAR on the train cockpit scans the parallel track in the opposite direction of the movement. It is useless trying to locate obstacles on the current track of the train due to the high-speed and inertia of the vehicle, which makes in-time reaction impossible.
- The LiDAR sends data to an Edge node on-ground equipped with an AI algorithm.
- The AI module processes the data stream to detect potential obstacles.
- When an obstacle is detected, the AI module will send a warning message to a module at the Train Control Centre.
- Then, the Train Control Centre will send a warning to the trains moving on the track where the obstacle is located and also adjacent tracks.

LiDAR are sensors able to measure an important number of distance points in short time and in a large portion of space. The resulting data allows to build a distance map (i.e., a points cloud) which corresponds to a three-dimensional representation of the immediate surrounding of the sensor location. Contrarily to standard camera systems, LiDAR are active sensors which give precise spatial information and can be used by night or inside a tunnel.

4.3.1.3 Passenger safety and comfort (FRMCS P3)

The aim of the FRMCS P3 service of UC3 is to monitor different situations and parameters related to the safety and comfort of the train passengers by using CCTV cameras with integrated microphones. The operation of the P3 service is described below:

- Two cameras inside the train vehicle are permanently sending live video and audio streams to an AI module deployed on the ground.
- The video and audio streams are analysed by the AI module to
  - Monitor passengers and objects on-board (e.g., count passengers, spot abandoned suitcase, etc.)
  - Detect risk situations (e.g., fight in the coach, fire, etc.)
  - Monitor audio from the train coaches.
- The AI module also stores a temporary copy of the last minutes of those video and audio streams, so it can be reviewed later if necessary.
- When the AI module detects a tense or dangerous situation, it sends a warning to the Train Operation Centre, which will retrieve a copy of the file with the last minutes of video and audio.
- Actions will be decided on the ground from the Train Operation Centre and dispatched back to the train crew. It shall be possible for the Train Operation Centre to remotely activate the CCTV with audio in the area where the alarm was raised to provide security teams on ground with some real time contextual information related to the alarm.
- A live video request can be sent by the Train Control Centre to establish a streaming connection with the train cameras located in the same passenger coach in which the alert was produced.

In the implementation of the FRMCS P3 service of UC3, only one of the vehicles of the train will be monitored, but the idea is to replicate the solution for each vehicle.

The use of cameras on the outside of the train has not been considered in UC3 mainly due to mechanical constraints related to high speed and gauge.

4.3.1.4 High-quality Wi-Fi for passengers (B1)

The aim of the B1 service is to provide high-performance Wi-Fi access to train passengers. This service will have to be seamless on the whole corridor segment, including the tunnel and cross-border section between France and Spain.

The increasing number of rail passengers and their usage of digital applications generate a high demand for wireless connectivity on-board trains. Forecasts until 2020 predicted the demand to be at least 1 Gb/s per train carrying 1000 passengers, without accounting for future applications and usage rates per passenger [12] [13]. The goal of the Gigabit Train concept is to ensure that connectivity for passengers travelling at high-speed across borders is similar to connectivity at home or at work, in terms of high capacity, low latency, and high reliability.

To offer sufficient throughput to every user on a Gigabit Train via Wi-Fi, multiple networks need to be aggregated as the spectrum typically available from a single provider cannot fulfil the users' requirements on its own. The use of certain radio access technologies, specifically designed to provide high bandwidth and low latency, such as the 70 GHz IEEE 801.11ad, have to be considered.

The idea is to provide aggregated high-speed Internet Breakout Points for all the train users. These aggregated points will interconnect the TAN with the Internet for all trains in a particular rail track area. They will be typically deployed every forty or fifty kilometers, depending the number of the simultaneous trains on the area, the expected number of simultaneous users, the global traffic demand, etc.

In the implementation of the B1 service of UC3, only one of the vehicles of the test train will be equipped with a Wi-Fi Access Point (AP). For this reason, traffic generators will be used to stress the TAN and verify the different network performances that can be obtained in the multiple configurations along the corridor. In fact, the use of this application in the context of the use case is not to test Wi-Fi access inside the train, something that has already been demonstrated in the past, but to have a simple and effective way to saturate the TAN and measure its maximum performance.

4.3.1.5 Multi tenant Mobile service (B2)

Train passengers have today two options for connectivity with their smart phones: connect to the Wi-Fi on board the train when available or connect directly to their MNO on ground. With the direct connection to their MNO, passengers will usually experience a fast-changing QoE, often poor, due to the fact that most national operators do not directly target to cover train tracks. Therefore, train tracks coverage is often poor, and the attenuation introduced by the train structure worsens the problem. The Wi-Fi system inside the train helps improving the QoE: the train to ground connection uses either a satellite link (a solution that is expensive for the train company) or a Wi-Fi router connected to all national MNOs with an external antenna on the train rooftop. In that way, the train structure attenuation is avoided and the diversity of operators can be used since all of them do not cover the train track with the same QoS. However, there are two drawbacks: the passenger has to take an action to connect to the Wi-Fi and the Wi-Fi connection is not as secure as 5G RAN can be. Besides, many areas will have poor coverage from all the national MNOs resulting in poor Wi-Fi QoE in the train. The objective of the B2 service is to solve these problems by providing train indoor coverage with an on-board 5G small cell.

The aim of the B2 service is to explore the rollout of a train MNO. The goal here is to propose a train MNOs as a new alternative architecture to provide mobile connectivity inside trains. This architecture shall be secure, with a high QoE, and without any action needed from the passenger when entering the train. The train MNO will use an on-board 5G small cell, which will be backhauled through the TAN to an on ground 5G-Core. In that way, the passengers will have a high-quality 5G access to the MNO services in the train though their own devices, secured and without any action required to connect to it. This assumes an existing TAN with performances meeting the in train gNB backhauling requirements in terms of throughput and latency.

The passenger stepping into the train will roam from his/her ground MNO to the Train MNO, and vice versa, when stepping outside the train. Let's note here that depending on the 5GMED infrastructure that will finally be deployed, this roaming might not be implemented for the trials. This architecture will have several design challenges that must be studied, as for example, to define the most suitable model to interconnect the on-board small cells with the ground 5G-core network of the Train MNO. In addition, in the cross-border scenario there is a set of issues to be identified and addressed. For example, the spectrum allocation might be different in each country and the frequencies used by the 5G small cells in the train may have to be changed when crossing borders.

To be noted that these 5G small cells should not be confused with the on-board 5G modems that are part of the TAN. The 5G small cells in train are really an application that uses the TAN, but they are not part of the TAN itself.

Besides, let’s note that the TAN rolled out for the train will also include a satellite link provided by one of the partners. An equipment provided by another partner, will ensure that 5G slices can be maintained throughout the satellite link.

This service is rendered meaningful by the recent Low Earth Orbit (LEO) satellite constellations which propose latency performances far better than the one offered by the GEO satellites. Then, large portion of railway tracks connectivity could be addressed in that way in the future, the satellite completing the 5G access for the TAN.

The applications to be tested in the B2 service of UC3 will be video conference and downlink video streaming.

4.3.2 UC3 Technical Requirements

Due to the high capacity required by most of the services of UC3, a specific Train Communication Network (TCN), based on a 10 Gigabit Ethernet optical fibre, will be required inside the train to interconnect all the devices on board. This optical fibre will also avoid any interferences with the in-service train control systems.

In addition, and to provide service continuity across the different radio access technologies deployed along the rail track (i.e., 5G NR, 70 GHz IEEE 802.11ad, and satellite), a multi-technology TCU will be required to aggregate the train traffic and manage the connectivity of the train through the different RATs. This multi-technology TCU is usually named as Adaptive Communication System Gateway (ACS-GW) in the railway language [14]. This name will be used in 5GMED to refer to the multi-technology TCU required in the railway scenario. The ACS-GW will have to intelligently select the most suitable radio access link to deliver the data traffic for a particular service and at a given location of the train along the corridor. As an example, some specific services may accommodate the use of satellite connectivity, while other services may need the use of the radio link providing the maximum throughput and minimum delay. It means that the forwarding policies to be implemented in the ACS-GW must be able to select a different access link for each service. The ACS-GW should meet at least the following requirements:

- The ACS-GW must support very high throughput interfaces to avoid constituting a bottleneck in the system. As the ACS-GW must be prepared for the implementation of the Gigabit Train concept introduced in Section 4.3.1.4, the ACS-GW should support up to 10 Gbps physical interfaces and at least 4 Gbps bidirectional flows.
- The ACS-GW must minimize the delay for packet processing.

- The ACS-GW forwarding policies must select the preferred access link for each service.
- The ACS-GW does not need to meet the requirements of critical applications (e.g., redundancy, application registering, etc.), because they are out of the scope of the services provided in UC3.
- The ACS-GW must ensure seamless connectivity to all the services along the cross-border scenario.

The following table summarizes the requirements of UC3, including the main components, the types and number of trains, the types of radio access technologies, and the AI functions which are needed to implement each service of the use case.

		UC3 Services				
		FRMCS P1	**FRMCS P2**	**FRMCS P3**	**B1**	**B2**
Main components	Train Operation Centre	M	M	M	-	-
	Internet Break-Out Points	-	-	-	M	-
	Neutral MNO 5G-Core	-	-	-	-	M
	Additional MNO 5G-Cores	-	-	-	-	M
	ACS-GW on-board	M	M	M	M	M
	ACS-GW on-ground	M (2)	M (2)	M (2)	M (2)	M (2)
	Nodes for Network Interconnection	M	M	M	M	M
	MEC servers	-	M (2)	M (2)	-	-
	Geolocation information	O	M	M	-	M
	Train monitoring sensors	M (10.000)	-	-	-	-
	LiDAR Sensors	-	M (2)	-	-	-
	Cameras with integrated micros	-	-	M (2)	-	-
	On-train Presentation Tool	M	M	M	-	-
	Passengers' UE's	-	-	-	M (note 1)	M (4)
	5G small cell in train					M
Trains in use	Maintenance train	M	M	M	M	M
	High-speed train	M	M	M	M	M
Wireless connectivity	5G NR (3.5GHz)	M	M	M	M	M
	C-V2X (5.9GHz)	-	-	-	-	-
	IEEE 802.11ad (70GHz)	M	M	M	M	M
	Satellite	M	O	O	O	O
AI	In train	-	-	-	-	-
	In MEC	-	M (Obstacle detection)	M (Incident detection)	-	-
	In Cloud	-	-	-	-	-

Table 13. Requirements of the FRMCS use case

M = Mandatory
R = Recommended
O = Optional
The figures between brackets are the number of equipment
note 1: a traffic generator will be used for simulating several users

4.3.3 UC3 Service Key Performance Indicators

This section provides the definitions of the service KPIs of UC3 and lists the target values associated to each KPI. These service KPIs will be measured and monitored during the realization of the trials according to the purpose of the test cases defined in D2.2. Table 14 below provides the definition of the service KPIs.

Service KPI Name	Unit	Definition
Uplink Data Rate	[Mb/s]	Amount of application data bits transmitted by a source application in the train within a certain time window
Downlink Data Rate	[Mb/s]	Amount of application data bits transmitted by a source application on the ground within a certain time window
Uplink Cloud End-to-End Latency	[ms]	Time elapsed since a message is transmitted by a source application in the train until the message is received by the destination application in the cloud server on ground
Downlink Cloud End-to-End Latency	[ms]	Time elapsed since a message is transmitted by a source application in the cloud server on ground until the message is received by the destination application in the train
Uplink Edge End-to-End Latency	[ms]	Time elapsed since a message is transmitted by a source application in the train until the message is received by the destination application in the edge server on ground
Downlink Edge End-to-End Latency	[ms]	Time elapsed since a message is transmitted by a source application in the edge server on ground until the message is received by the destination application in the train
Uplink Reliability	%	Ratio between number of messages successfully delivered to a destination application on the ground divided by the total number of messages sent by a source application in the train
Downlink Reliability	%	Ratio between number of messages successfully delivered to a destination application in the train divided by the total number of messages sent by a source application on the ground
Uplink Jitter	[ms]	Mean difference in latency between fastest and slowest packets sent by a source application in the train to a destination application on the ground
Downlink Jitter	[ms]	Mean difference in latency between fastest and slowest packets sent by a source application on the ground to a destination application in the train
Time for service warning	[ms]	In the FRMCS P2 service: it is the time elapsed between the LiDAR detects the object and the Obstacle Track Detection alarm is displayed in the Alarm Presentation Tool. In the FRMCS P3 service: it is the time needed to process the audio, detect the presence of emergency, and display the Tense Situation Detection alarm on the Alarm Presentation Tool.

Service KPI Name	Unit	Definition
Mobility interruption time	[s]	Maximum time interval in which an application in train cannot exchange data messages with the applications in the edge or cloud
End-to-End latency between UE's using the 5G small-cell on-board	[ms]	End-to-End latency between UE's using the 5G small-cell on-board (Neutral Host Cell) of B2 service

Table 14. Definition of service KPIs for the FRMCS use case

Table 15 below provides the target values of the KPIs for the services of UC3. In those services where a KPI does not have a target value assigned, it means that the KPI is not relevant for that specific service.

Service KPI Name	Target Values				
	FRMCS P1	FRMCS P2	FRMCS P3	B1	B2
Uplink Data Rate	5-6 Mb/s (Note 1)	5-20 Mb/s (Note 2)	32-256 Kb/s (audio) 2-8 Mb/s (video) (Note 3)	600-750 Mb/s (Note 4)	0.6-3.8 Mb/s (Note 5)
Downlink Data Rate	-	-	-	600−750 Mb/s (Note 4)	0.6-3 Mb/s (Note 5)
Uplink Cloud End-to-End Latency	< 1 s	-	< 250 ms	-	-
Downlink Cloud End-to-End Latency	< 1 s	-	< 250 ms	-	-
Uplink Edge End-to-End Latency	-	< 200 ms	< 200 ms	< 100ms (Note 4)	-
Downlink Edge End-to-End Latency	-	< 200 ms	< 200 ms	< 100ms (Note 4))	-
Uplink Reliability	>= 99,9 %	>= 99 %	>= 99 %	>= 97 % (Note 4)	>= 97 % (Note 6)
Downlink Reliability	>= 99,9 %	>= 99 %	>= 99 %	<= 98 % (Note 4)	>= 97 % (Note 6)
Uplink Jitter	-	-	-	< 5 ms (Note4)	< 40 ms (Note 6)
Downlink Jitter	-	-	-	< 5 ms (Note 4)	< 40 ms (Note 6)
Time for service warning	-	1 - 2 s	1 - 2 s	-	-
Mobility interruption time	< 1s	< 1s	< 10s	< 10s	< 1s
End-to-End latency between UE's using the 5G small-cell on-board	-	-	-	-	< 200ms (Note6)

Table 15. Target values of service KPIs for the FRMCS use case

Notes for specific target values in Table 15:

- Note (1): This is equivalent to the traffic generated by 10.000 sensors that periodically transmit data to ground every 100ms.
- Note (2): This corresponds to the range of the LiDAR data rates. 5 Mb/s is the minimum data rate required for the LiDAR at 600 rpm in single-return mode, and 20 Mb/s is the maximum data rate required for the LiDAR at 1200 rpm in dual-return mode (which is more precise than single-return mode).
- Note (3): Service KPI's established for one train vehicle, corresponding to two cameras with integrated micros.
- Note (4): All the B1 service KPIs will be measured between a computer on-board the train, generating data traffic equivalent to 1000 passengers, and a computer on ground.
- In the case of the data rates, the target values refer to a complete train of 10 coaches full of passengers. Note (5): these target values were defined from the performance requirements of the Zoom application: https://support.zoom.us/hc/en-us/articles/201362023-Zoom-system-requirements-Windows-macOS-Linux
- Note (6): these target values are defined from the performance requirements of videoconferencing. https://support.zoom.us/hc/en-us/articles/202920719-Accessing-meeting-and-phone-statistics

4.3.4 UC3 High-Level Functional Architecture

Figure 18 illustrates the high-level functional architecture of UC3. This block diagram shows the main components (introduced in Section 4.3.2) required for implementing UC3, and the mapping of these components on the high-level 5GMED network architecture represented in Figure 2. The detailed description of functionalities and interfaces of all the UC3 components will be presented in D5.1 and D5.2.

As depicted in Figure 18, the components required for UC3 can be classified as belonging to three different layers: train, edge, and cloud layer.

1) **Train layer**: all the devices on-board the train are interconnected through an Ethernet Network, namely the Train Communication Network (TCN). In this way, both the application components and the network access units can access to the ACS-GW on-board and interact if necessary. For simplicity, the TCN is not shown in the figure below. The passengers in the train will connect to the on-board 5G small cell or to a Wi-Fi access point. The ACS-GW in the train aggregates the data streams from the different applications and dispatch them to one or several radio access networks depending on the forwarding policies that are defined inside the ACS-GW.

   The TAN provides connectivity between the ACS-GW on-board the train and the edge and cloud layers through the ACS-GW on ground.
2) **Edge layer**: it contains the AI modules needed by the FRMCS P2 and P3 services. In addition, the Wi-Fi APs on the train can reach the Internet through the break-out points located at trackside.

3) **Cloud layer**: it contains the Train Control Centre and the 5G-Core of the neutral MNO. The Data Plane and Control Plane of the 5G small-cell on-board the train are connected to the 5G-Core of the neutral MNO.

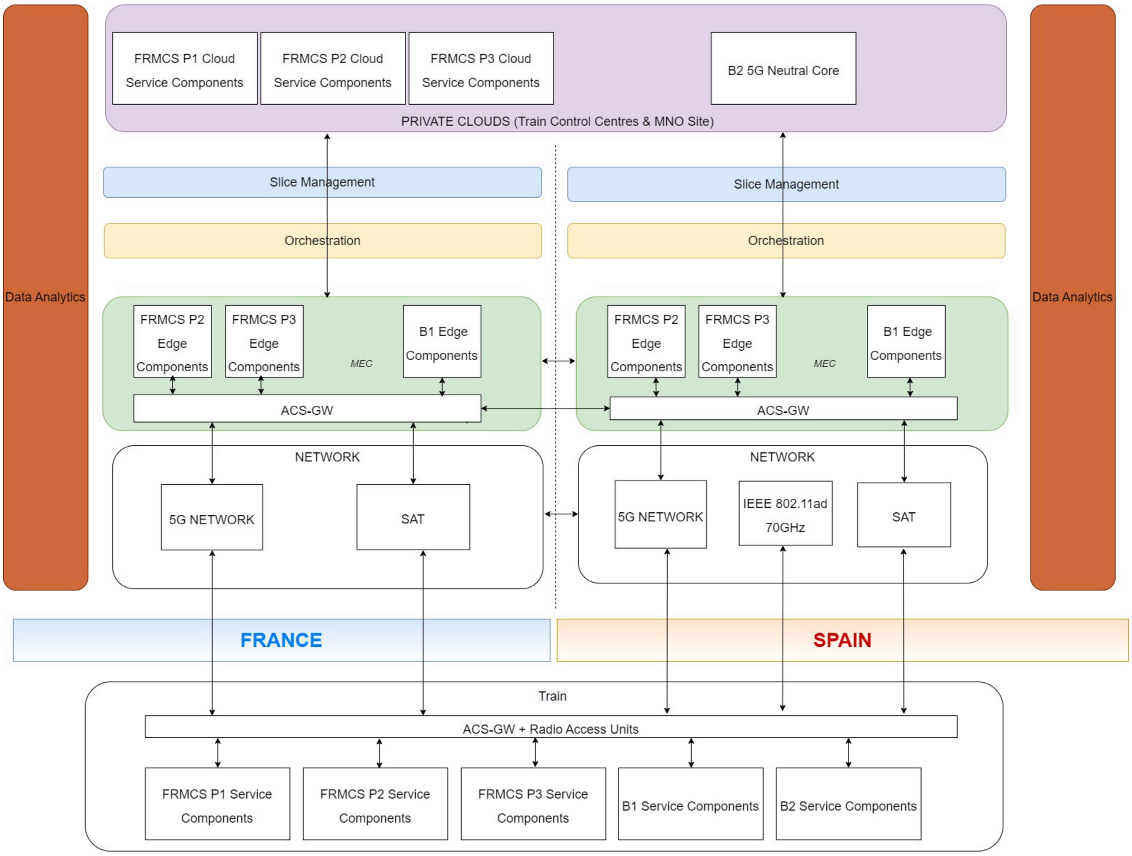

Figure 18. High-level functional architecture of UC3

4.3.5 UC3 Technical Challenges

This section identifies the technical challenges that are most critical for UC3 to meet the functional and performance requirements of its services. A description of the 5GMED technical challenges was introduced before in Section 0. In Table 16, those technical challenges that can degrade the performance of a service are marked as "Yes" in the corresponding cell.

Technical Challenges		**FRMCS P1**	**FRMCS P2**	**FRMCS P3**	**B1**	**B2**
Seam-less services along the corridor	Roaming for 5G connectivity	Yes	Yes	Yes	Yes	Yes
	Inter MEC resource handover	-	Yes	Yes	-	-

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Technical Challenges		**FRMCS P1**	**FRMCS P2**	**FRMCS P3**	**B1**	**B2**
	Inter RAT handover	Yes	Yes	Yes	Yes	Yes
Implementation 5G cellular SA, R16 and beyond		Yes	Yes	Yes	Yes	Yes

Table 16. Technical challenges of UC3

UC3 is not intended to present FRMCS critical services. Then, the technical challenges are related to the service quality and the service KPIs. The technical challenges will not impact the train safety in any way, but the quality of the services might be degraded if the target values of the service KPIs are not met.

With the announced end of GSM-R support, a new generation of FRMCS services is expected, which must be accomplished with a good quality, similar to the fibre-based service that the Telecommunication operators provide for residential and business markets. That implies a sustainable growth in terms of the necessary bandwidth to accomplish the digitalization process of the railway business. In a similar rationale, the passengers' experience must be improved without any doubt. Long-distance trains are increasing, but also the number of passengers that the high-speed trains can accommodate. Also, service continuity is expected along the train journey. That means that the current interruption times must be significantly decreased: legacy networks can provoke minutes of interruption in a cross-border scenario.

4.3.6 Why do we need 5G SA for UC3?

According to the service KPIs' target values, the following table shows on a per service basis why 5G is required in UC3.

5G Features	**UC3 Services**				
	FRMCS P1	**FRMCS P2**	**FRMCS P3**	**B1**	**B2**
Very high data-rate	-	Yes	Yes	Yes	Yes
Very low latency	-	Yes	-	Yes	Yes
Very high reliability	-	-	-	-	-
Distributed network functions	-	-	-	-	-
Very low mobility interruption time at the border	Yes	Yes	Yes	Yes	Yes
Slicing	Yes	Yes	Yes	Yes	Yes

Table 17. Why do we need 5G-SA for UC3?

4.4 Use Case 4. Follow-Me Infotainment

4.4.1 UC4 Definition

5G is a crucial technology for improving end-user Quality of Experience (QoE) enabling new approaches and services for in-car and in-train entertainment such as multimedia and multi-format contents delivery, allocation, and interaction through enhanced Video Streaming Service with XR (eXtended Reality) interactive technologies that empower ultra-low latency human-machine interaction with high bandwidth transition. The exploitation of such media technology is enabled by reliable 5G network connectivity to provide faster and more uniform data rates as well as lower latency that is capable of supporting nomadic media services.

The Follow-Me Infotainment use case will integrate multimedia streaming and interactive technologies on top of a 5G orchestrated infrastructure. The aim is to create new and enhanced end-user experiences to be consumed while travelling in car or train through the Mediterranean cross-border corridor, being reactive to user requirements as well as environmental and platform-specific aspects.

UC4 is intended to demonstrate how, by means of the technology resources developed in the 5GMED project, it will be possible for general users travelling at high speed by train or car to access high-quality media contents while keeping high QoE/QoS levels. The target is to optimize the media contents distribution, resulting in a high-quality reception and avoiding service disruptions, even when crossing the border.

Based on this, UC4 focuses on two aspects:

- The demonstration and performance evaluation of the "Follow-Me" concept [15] , which consists on moving the virtual functions of the media service that end-users are accessing (or part of them) along with different Edge nodes as the user moves along the corridor, so that these virtual functions are located in data centres in the vicinity of user's position at all times (i.e., virtual functions "follow" the user in his/her movement, hence the name of this concept). Aligned to the MEC concept [16], this helps reducing latency and increasing throughput, although it poses a challenge in terms of service continuity (i.e., the service must be provided without interruptions, even when the associated network functions are being migrated to follow the user trip, especially on the cross-border scenario).
- To provide a set of Infotainment Media Applications, that will be used to showcase the "Follow-Me" concept.

The UC4 infotainment applications will consist of two media services that are common for both, train and car passengers, namely:

1) The Enjoy Media Together (EMT) Service, oriented to provide high-quality and interactive media contents to the corridor users.
2) The Tour Planning (TP) Service, oriented to provide tour planning utilities (maps, routes suggestions…) enriched with high-quality media contents.

Each of these services will have different functionalities. In particular, the functionalities of the EMT Service are:

- The EMT video streaming functionality, which will provide to users the functionality to enjoy high quality video contents in a synchronized way.
- The EMT Video conferencing functionality, which will provide users to communicate each other using a video-conference or messaging services.

The functionalities of the TP service are:

- TP high resolution media, to allow users to watch on their portable devices relevant Points of Interest (POIs) through their route.
- TP 360º high resolution media, oriented to provide users a more complete view of certain POIs.
- TP Immersive media, intended to provide the users with virtual reality (VR) video streaming for specific POIs.

The components to implement these functionalities will be deployed as a set of network functions (NFs) that will be deployed and orchestrated on the 5GMED network infrastructure. Moreover, the needed performance will be guaranteed leveraging the network slicing feature of 5G.

The services together with their functionalities are described in more detail in the following subsections.

4.4.1.1 Enjoy Media Together

The Enjoy Media Together service, as stated before, is composed of two main functionalities. The first functionality is the so-called “EMT Video Streaming” and it allows users to create a virtual "video room" that can be used to watch high-definition media contents in sync with other users (e.g., together with other users in the corridor and not).

The second functionality is the “EMT Video Conferencing”, which provides specific resources for the users to interact among them (e.g., chat-like application and video calls).

Service description.

The Enjoy Media Together service implements the above-mentioned functionalities to enable a new way of watching multimedia content with friends, family, and peers online. Thus, the service allows the consumption of high-quality media content (e.g., 4K video contents) with friends/family in sync, meaning that users in different locations can enjoy the same content at the same time (e.g., in a similar way like when they were together at home). It intends to deliver a reliable, secure, and efficient end-to-end video streaming service supporting different types of media content with a high streaming resolution, for the end users to receive them in perfect synchronization. This synchronization implies not only the delivery of the media contents at the same to the different users, but also the processing of the asynchronous pausing/resuming signals the end-users could generate on the application, as well as facilitating the communication channels for the users to comment on the media contents they are accessing at the same time.

The target end user for the Follow-Me Infotainment service is a general user who, while travelling in car or train, wish to access (through a variety of devices such as smart phones, tablets or personal computers) to a media service to consume multimedia contents. The following describes a brief storyline showcasing how this EMT service could be used in practice:

Storyline

John, 15 years old, is travelling with his family from Figueres to Perpignan. It is not a long trip and is quite enjoyable doing it by car. John is an active member of the "Doctor Who" fan club. Some members of the club usually meet each Thursday at 9:00 PM to watch together some old episodes of the famous series. Later, the group usually discuss about the episode just seen recapping their favourite scenes, dissecting details, and speculating on what to come.

This time, John is travelling, so it will not be possible to physically meet his friends to watch Doctor Who. So, what to do?

John, heard about a recently released EMT Service that can distribute through the internet high quality media contents. In addition, the service allows to watch contents with friends, family and peers synching the streams. On the other hand, the streaming functionality is enriched with enhanced P2P group video call functionality where friends can discuss what is going on in the movie.

John thinks: "this is much as I would if we were sitting together on the couch" the service is perfect!

When the time comes, John logs in to the media streaming service portal and sets up a social network room to invite his friends so to start a short video call to organise the session. Later, John chooses the Doctor Who chapter episode 9 of the season 2 and generates (with the assistance of the service) a link to share with his friends through the social network room. From this time on everyone's player is synchronized with the chosen chapter.

One of his friends, Emma, is travelling by train to Girona (from Perpignan). Luckily, she has with her a Head Mounted Device. Thus, through the link sent by John Emma is able to consume the wonderful experience of walking through Perpignan.

User equipment

In terms of end-user hardware equipment, the service is meant, by definition, to avoid devices lock-in so the service will be compatible with a wide range of devices. Typical UE for this service will be 5G mobile phones, tablets and laptops. Also, if the devices were not compatible to 5G, they could be connected through Wi-Fi to a 5G modem.

4.4.1.2 Tour Planning

The Tour Planning service, as stated before, is composed of three main functionalities that give users the opportunity to customize the rest of the tour if they decide to make changes before arriving at their destination.

The first functionality consists in providing high-quality media content (HD, FHD or UHD/4K resolution videos and photos) to users to make them able to watch them on their portable device. The provided media contents would be related to points of interest (POIs) along their route, which would be provided on demand.

Complementary to the previous one, a second functionality is the providing of 360-degree high quality videos, aiming to give the user a more comprehensive view of some POIs.

Finally, the third functionality would consist in an immersive media functionality, providing virtual reality (VR) video streaming about specific POIs, and giving the user an enriched extended reality experience, also on demand.

Service description

The Tour Planning service will give passengers the ability to discover the area they are passing through, relevant places (e.g., lakes, restaurants, museums, etc.), or activities during the trip. In this direction, the service will allow the consumption of high-quality media (HD, FHD, 4K videos, video streaming, and VR video streaming) to provide the passengers a full sense of immersion. Also, if a passenger decides to visit a specific place after the immersive experience, then the service could also provide additional functionalities to organize the rest of the trip.

The target end user for the Follow-Me Infotainment service is a general user who, while travelling in car or train wants to access to a media service to consume multimedia contents (audios, 2D videos, 360-degree videos, XR) and plan/alter the rest of his/her trip. Below a brief storyline to showcase a possible use case for this service:

Storyline

John and Mary are travelling from Figueres to Perpignan, where they will spend a few days in their holiday period. Since the distance is not very long and they really enjoy discovering new places, they decide to travel by car. As they did not have much time to plan their trip, they will rely on a new service that they heard from some friends.

The service provides immersive media experiences, so John, who is a technology enthusiast, will be searching along the route while Mary is driving. Once they start their trip, John opens the TP planning service and starts investigating the POIs that are available by the service and are pinned along the route on a map. Fortunately, he is equipped with a 5G smartphone and is able to utilize the capabilities of the 5G network with higher bandwidth, ultra-low latency, and the guaranteed continuity of the service.

Some of these POIs are shown using high-resolution photos and HD or UHD/4K videos. They are referring interesting information about castles and ancient ruins, but John, who has been in many such places, is not much impressed about the content, so keeps searching among other POIs. Then he sees a zoo park along the way and tells Mary, who gets excited, and starts receiving the video, but he quickly realizes that this zoo is more likely a farm and gets disappointed.

Then it comes to his notice the VR icon in some diving sites not very far from their route. John carries with him his new gadget, a new head mounted device, and immediately *wears it and chooses to see some of these VR videos. Mary and he are certified divers, so he is immediately excited with the unique underwater immersive experience, so he invites Mary to make a stop and watch with her eyes what he is describing to her. After that they decide to make a small detour and go for a dive before they continue to their destination.*

The TP service also help them to organize the rest of the trip, and makes suggestions for restaurants nearby and more.

User equipment

Any portable device that can support 5G connectivity will be appropriate for the use of the service, typically, these are smartphones, tablets, and laptops. Furthermore, a head mounted device is also required to experience the VR capabilities offered by the service.

4.4.2UC4 Technical Requirements

The following table summarizes the requirements of UC4, including the main components, the types and number of vehicles, the types of radio access technologies, and the AI functions which are needed to implement each one of the services of the use case. The implementation of UC4 will require service orchestration mechanisms to make possible the live-migration of certain network functions through the edge nodes, in order to implement the above mentioned “follow-me” feature. This mechanism should be available not only within a single country, but also in the cross-border scenario. This mechanism is considered a key functional enabler to ensure service continuity.

		UC4 Services	
		Service 1: Enjoy Media Together	**Service 2: Tour Planning**
Main components	Traffic Management Center	-	-
	Remote Station	-	-
	Train Control Center	-	-
	MEC servers	M (≥ 2 per country)	M (≥ 2 per country)
	Cloud	M	M
	Road sensors	-	-
	TCU (U.E., tablet, etc)	M (≥ 2)	M (≥ 2)
	On-board sensors	GPS (≥ 2)	GPS (≥ 2)
Vehicles in use	Connected, autonomous	-	-
	Connected, no autonomous	-	-
	No connected, no autonomous	M (≥ 2)	M (≥ 2)
	Connected train	M	M
Wireless connectivity	5G NR (3.5GHz)	M	M
	5G NR (26GHz)	-	-
	C-V2X (5.9GHz)	-	-
	IEEE 802.11ad (70GHz)	-	-
	Satellite	-	-
AI	In Vehicles	-	-
	In MEC	-	-
	In Cloud	To be considered to trigger the VNFs migration through the Edge nodes	

Table 18. Requirements of the follow-me infotainment use case

Note: Number of items are put between brackets.
M = Mandatory
R = Recommended
O = Optional

4.4.3UC4 Service Key Performance Indicators

This section provides the definitions of the UC4 service KPIs and lists the target values associated to each KPI. These service KPIs will be measured and monitored during the realization of the trials according to the purpose of the test cases defined in D2.2. Table 19 below provides the definition of the service KPIs.

KPI Name	Unit	Definition
End-to-end Latency	[ms]	The time it takes to transfer a given piece of information from a source to a destination, measured at the communication interface, from the moment it is transmitted by the source to the moment it is successfully received at the destination [17]
Data-rate	[Mbps]	Amount of application data bits received by a destination application within a certain time window
Jitter	[ms]	Variation in time delay between when a signal is transmitted and when it's received over the network connection
Framerate	[fps]	Frames per second
Mobility Interruption time	[ms]	Amount of time with interrupted traffic that the application supports
Reliability	[%]	Ratio between the number of data messages successfully delivered to a destination application divided by the total number of data messages sent
Service Migration Time	[s]	Time elapsed since the migration of a service (which is available at a specific server) is triggered until the service is available at the target server

Table 19. Definition of service KPIs for UC4.

Table 20 and Table 21 below provide the target values of the service KPIs for the Enjoy Media Together and the Tour Planning services, respectively.

Service KPI	Target Values	
	Functionality 1: Video Streaming	**Functionality 2: Video Conferencing**
End-to-end Latency	< 4 s [18]	< 20-100 ms (*)
Data-rate	> 20 Mbps [18] (per connection)	>1 Mbps
Jitter	< 0.4 s	< 2 ms [19]
Framerate	> 30 fps	> 30 fps
Mobility Interruption time	< 1 s	< 100 ms
Packet Loss	< 5 %	< 1%
Service Migration Time	20-35 s [18]	20-35 s [18]
Reliability	99.9 %	99.9 % [21]

(*) 100ms is considered acceptable, though the optimal would be a range from 20 to 40 ms (see [19]).

Table 20. Target values of service KPIs for the EMT service

Service KPI	**Target Values**		
	Functionality 1: High resolution media	**Functionality 2: 360-degree high resolution media**	**Functionality 3: Immersive media**
End-to-end Latency [note d]	<1 s [22]	< 20-100ms [23] [note a]	< 20-80 ms [23], [24], [25][note b]
Data-rate	> 20 Mbps [18]	> 100 Mbps [23]	> 100 Mbps [24] [26][note c]
Jitter	< 10-50 ms [19]	< 10 ms	< 10 ms
Framerate	> 30 fps	> 30 fps	> 30 fps
Mobility Interruption time	1s	< 30 ms	< 30 ms
Packet Loss	< 5%	<1% [21]	<1%
Reliability	99.9 %	99.9 %	99.9 %
Service Migration Time	20-35 s [20]	20-35 s [20]	20-35 s [20]

[Note a] 100 ms is an acceptable value, but the optimal value proposed in the bibliography (see references) is 20-40 ms.
[Note b] 80 ms is acceptable, but the optimal value proposed in the bibliography (see references) is less than 20 ms.
[Note c] 100 Mbps per user will suffice, but a premium experience would require more than 350 Mbps per user.
[Note d] In this service the end-to-end latency is essentially the round-trip time because source and destination are the same.

Table 21. Target values of service KPIs for the TP service

The target values of the service KPIs are estimations based on the partners' knowledge and the provided references. These numbers may vary once the actual services are deployed, especially those related to the most innovative aspects, which will be under research during the project lifetime. Note also that the provided numbers are per-user, but that the plan is to stress the network with up to 5 simultaneous users for each service.

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4.4.4 UC4 High-Level Functional Architecture

Figure 19 illustrates the high-level functional architecture of UC4. This block diagram shows the main components (introduced in Section 4.4.2) required for implementing UC3, and the mapping of these components on the high-level 5GMED network architecture represented in Figure 2.

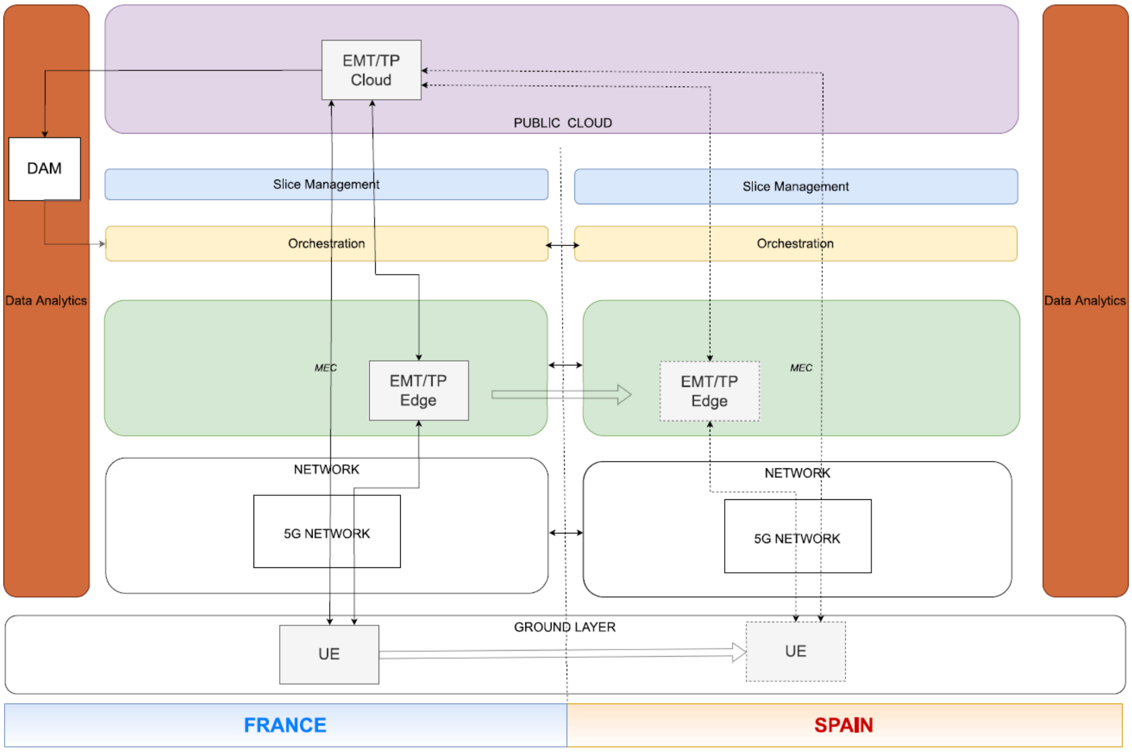

Figure 19. High-level functional architecture of UC4 (automotive scenario)

As depicted in Figure 19, the components required for UC4 are:

- The **User Equipment** (UE) represented at the bottom. In practice, different UE types are expected to be supported: 5G phones, tablets, laptops, and head mounted devices. Obviously, it is considered they could be moving at a high speed through the corridor, either on-board the vehicles in the highway, or in the high-speed train.
- The 5G Network block represents the 5G Network connectivity itself. The UC4 services are agnostic regarding this, assuming that 5G connectivity will be available through the entire corridor, including also the Le Pertus tunnel crossing the Pyrenees under the border in the railway scenario. The network coverage is assumed to be provided by two independent MNOs in each country. Of course, the UC4 services will be designed assuming the 5G Network provides the necessary networking functionality, including all the necessary service orchestration functions for implementing the “follow-me” concept, and the handovers in both, local and cross-border scenarios. However, specific interfaces between the UC4 services and the 5G network should be defined and implemented, in order to provide the necessary service continuity in those scenarios.

- The **EMT/TP Edge block** in the MEC layer represents a server that provides the media contents for the EMT and the TP services from locations that are close to the end users. Aligned to the MEC concept [15], this provides low latency and high bandwidth capabilities. Certain components of UC4 will be deployed on these edge servers in the form of virtual appliances, and will be live migrated through the different available edge nodes in the infrastructure to follow the different UE movements in order to ensure service continuity while providing the necessary QoS regarding latency and bandwidth. As mentioned, the UC4 services will rely on the network management and orchestration capabilities of the orchestration layer.
- The **Data Analytics Module** (DAM) is the component in charge of interfacing with the orchestration layer. Basically, the DAM will trigger the service orchestrator when the QoS may start degrading due to the movements of the users along the corridor. It is intended that the DAM collects metrics from both the network and from the UC4 services. Some examples of metrics collected from the UC4 services are the position and speed of the users, which could be used to predict when a handover between edge nodes is necessary. Other metrics will be considered during the project development. The prediction algorithms in the DAM can be based on AI/ML techniques.
- The **EMT/TP Cloud** bock represents the cloud components for both the EMT and TP services. This is basically intended to act as media repositories to store and provide the necessary media contents (i.e., movies, VR content, etc.) for these services. The EMT/TP Edge servers will dynamically request to these cloud servers the necessary chunks of the media contents while users are moving through the corridor. As it can be observed in Figure 19, there are also direct connections between UEs and these EMT/TP Cloud blocks, which are intended to provide those functions non requiring low latency and high bandwidth (e.g., end-user registry processes, access to the catalogues with the available media contents, etc.)

The service migration across adjacent Edge Servers belonging to each MNO is a challenging task itself; however, what is even more challenging is the "cross-border migration", since it involves two different network operators. A detailed definition of the final approach for addressing this will be needed globally, in the context of the whole project, to define how this capability could be implemented considering aspects regarding the network, orchestration, and the UC4 services themselves. At this early stage, three possibilities are envisaged:

1. To rely on an “upper” cross-domain management and synchronisation entity, which would be common to both MNOs. That entity could contain NFV management resources and SDN controllers having visibility (and capacity to act) over the resources from both operators, and would be in charge of migrating the virtual functions in the cross-border scenario, as well as to set-up the new interconnection routes covering both domains. However, this option is considered difficult to implement in practice, since a specific entity would have to be designated to take responsibility for this overlying layer.
2. To rely on a 5G network connectivity layer including a Neutral Host network that would be managed by the train and the railway infrastructure providers. This connectivity would bring together the edge network resources in both, France and Spain. Of course, specific interfaces should be enabled between the eventual Neutral Host provider and the MNOs. In practice, this option would be a

particularization of option (a), where the above mentioned “upper cross-domain” entity role would be played by the infrastructure providers.

3. To implement a cross-domain synchronization mechanism between the two MNOs. By means of this, operators could proactively interact each other with information regarding the end-user movements in the corridor. This method is considered cleaner than the previous ones, in the sense that each operator could continue working independently, keeping full control of its own domain.

The high-level functional architecture of UC4 represented in Figure 19 is the one that will be used for the automotive scenario. Although UC4 applies to both automotive and railway scenarios, it has been decided that, to avoid duplication of work, the EMT and TP Edge-related functionalities will be fully demonstrated only in the automotive scenario. The demonstrations of UC4 in the railway scenario will include just some basic functionalities. More specifically, those UC4 tests involving the “follow-me” concept will be considered out of scope for the railways scenario. Considering this, it is envisaged that the specific functionalities to be tested in the railway scenario will probably be some of the test cases related to the EMT Video Streaming and the TP High-Resolution Media functionalities, although the specific test cases will be decided in the context of WP6 during the project lifetime. These functionalities would be deployed in an over-the-top (OTT) manner on the available train network infrastructure and the Public Cloud resources, so only the EMT/TP Cloud server would be involved for the demonstration of UC4 in the railway scenario.

4.4.5UC4 Technical Challenges

Table 22 identifies the technical challenges that are considered more relevant to meet the specific UC4 functional and performance requirements. A more general description of the 5GMED technical challenges was already introduced in Section 3. Those technical challenges that could degrade the performance are labeled with a “Yes” in the corresponding cell.

Technical Challenges		**EMT Service**	**TP Service**	**Remarks**
Seamless services along the corridor	Roaming for 5G connectivity	Yes	Yes	Required for the cross-border follow-me seamless implementation
	Inter MEC resource handover	Yes	Yes	Follow-me concept requires migration between MECs of resources hosted at the edge
	Inter RAT handover	Yes	Yes	5G NR and 70 GHz will be used in the railway scenario. However, only 5GNR will be used in the highway scenario. However,
Implementation 5G cellular SA, R16 and beyond		Yes	Yes	Required to be able to meet the challenging KPIs of throughput and latency.

Table 22.Technical Challenges of UC4.

4.4.6 Why do we need 5G SA for UC4

According to the service KPIs' target values, the following table shows on a per service basis why 5G is required in this use case.

5G Features	UC4 Services		
	Service 1: Enjoy Media Together	**Service 2: Tour Planning**	**Remarks**
Very high data-rate	Yes	Yes	Required due to the heavy weight of media content
Very low latency	No	Yes	Required for the interactive features, such as XR
Very high reliability	Yes	Yes	Required for smooth quality of experience.
Distributed network functions	Yes	Yes	Required to demonstrate the follow-me concept along the corridor, i.e., distributed UPFs
Very low mobility interruption time at the border	Yes	Yes	Required for smooth quality of experience.
Slicing	Yes	Yes	It is required to differentiate the different types of traffic to guarantee different QoS needs and optimal use of the infrastructure.

Table 23 Why do we need 5G-SA for UC4

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5 Conclusion

This document describes the four use cases and their services that will be developed, deployed, and evaluated in 5GMED. For each use case, technical requirements, specific service KPIs, and a high-level functional architecture have been presented, and the technical challenges and the need for 5G have been emphasized.

Table 24 summarizes the 5GMED use cases with their services and acronyms.

Use case	Service	Acronym
UC1 - **Remote driving** (Automotive scenario)	Minimum Risk Maneuver	MRM
	Request for Remote Assistance	RRA
	Teleoperation Maneuver	TM
UC2 - **Road Infrastructure digitalisation** (Automotive)	Relay of emergency messages	REM
	Automatic incident detection	AID
	Traffic Flow Regulation	TFR
UC3 - **FRMCS applications and business service continuity** (Railway)	Advanced Sensor Monitoring on Board	FRMCS P1
	Railway Track Safety - Obstacle Detection	FRMCS P2
	Passenger safety and comfort	FRMCS P3
	High Quality Wi-Fi to passengers	B1
	Multi-tenant Mobile Service	B2
UC4 - **Follow-Me Infotainment** (Automotive & Railway)	Enjoy Media Together	EMT
	Tour Planning	TP

Table 24. Summary of 5GMED use cases and services

The use cases and their services will take profit of the enhancement brought by cellular 5G SA to handle performance demanding automotive and railway services seamlessly and across borders and in the presence of other Radio Access Technologies.

The impacts on the 5GMED network and compute infrastructure requirements will be specific to each use case, their service KPIs and functional architecture. Besides, the dimensioning of the telecom and compute architecture will also be driven by other factors like:

- Whether use cases and services will be tested simultaneously or not (service simultaneity).
- Whether the services will be tested in the same area or different areas of the corridor (service colocation).
- The number of users for each service.
- The allocated spectrum for each deployed radio access technology.
- The deployed 5G features.

The simultaneity or colocation of the services under test in the corridor will be made possible by the network slicing feature which will be used throughout 5GMED for the 5G cellular network. Indeed, one promise of the slicing feature is that all the services can run at the same time, on the same network infrastructure, without affecting their respective performance.

Once the network design is frozen and deployed, the number of users may be considered as a variable for the tests performed in the corridor in order to stress the deployed 5G network to its maximum performances or, conversely, in order to keep the tests performed within the actually reached network performances. Indeed, due to the initial stage of developments while this deliverable is written, it is still not fully clear which features will be deployed and consequently the 5G network performances that will be reached.

The number of users specified for each service aimed at testing the service performances but sometimes will be limited by budget contingencies like the number of connected vehicles.

We also keep in mind that one of the purposes for this trialing in the cross-border corridor between Figueras and Perpignan is to be able to extrapolate the test results for a pan European corridor upscaling scaling.

All these points will be trimmed, as 5GMED powers up, with subsequent tasks and work packages, in particular with task T2.2 (test cases definition and deployment options) and task T3.1 (infrastructure requirement analysis).

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