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Deliverable 4.1
Requirements and Initial Design for Automotive Test Cases

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Dissemination Levels:	
PU	Public
PP	Restricted to other programme participants (Including the Commission Services)
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CO	Confidential, only for members of the consortium (Including the Commission Services)

Nature:	
PR	Prototype
RE	Report
SP	Specification
TO	Tool
OT	Other

Synopsis	This Deliverable D4.1 is the first deliverable of the Work Package 4 in the 5GMed project. It presents the requirements and the initial design for the automotive test cases. It represents the main outcome of Task 4.1 (automotive application requirement analysis), which uses the previous Deliverable D2.1 (Definition of 5GMed use cases) as main input. The deliverable is intended to be used as input by Task 4.2 (Automotive application development), Task 4.3 (In-car V2X extensions), Task 4.4 (Follow-ME infotainment application), Task 6.1 (Test case definitions) and Task 7.1 (Cross-border corridor cost/benefit analysis).
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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Acronyms and Abbreviations

Term	Description
5G	Fifth generation of broadband cellular network technology
AI	Artificial Intelligence
AID	Automatic Incident Detection
API	Application Programming Interface
AR	Augmented Reality
ATM	Advanced Traffic Management
CAN	Controller Area Network
CAV	Connected and Autonomous Vehicle
CCAM	Cooperative, Connected and Automated Mobility
CDN	Content Delivery Network
DDT	Dynamic Driving Task
EMT	Enjoy Media Together
EU	European Union
FRMCS	Future Railway Mobile Communication System
GA	Grant Agreement
GDPR	General Data Protection Regulation
GN	GeoNetworking
HD	High Definition
HMI	Human Machine Interface
HW	Hardware
I2V	Infrastructure-to-Vehicle
IM	Intelligent Mobility
IP	Internet Protocol
IPSec	IP Security
ISAD	Infrastructure Support for Automated Driving
ITS	Intelligent Transport System
NISD	Network and Information Security Directive

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ODD	Operational Design Domain
OEM	Original Equipment Manufacturer
OSS	Open-Source Software
QoE	Quality of Experience
QoS	Quality of Service
MEC	Mobile Edge Computing
MNO	Mobile Network Operator
MRM	Minimum Risk Manoeuvre
NR	New Radio
NS	Network Service
P2P	Peer-to-Peer
PiP	Picture-in-Picture
POI	Point of Interest
RAN	Radio Access Network
RAT	Radio Access Technology
RD	Remote Driving
REM	Relay emergency message
REST	Representational State Transfer
RRA	Request for Remote Assistance
RS	Remote Station
RSU	Roadside Unit
RV	Remote Vehicle
STUN	Session Traversal Utilities for NAT
SW	Software
TCU	Telematics Control Unit
TEN-T	Trans-European Transport Network
TFR	Traffic Flow Regulation
TLS	Transport Layer Security
TMC	Traffic Management Centre

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ToD	Teleoperation Driving
TP	Tour Planning
TURN	Traversal Using Relays around NAT
UC	Use Case
UE	User Equipment
XR	Mixed Reality
V2X	Vehicle-to-everything
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
VNF	Virtual Network Function
VoD	Video on-Demand
VoIP	Voice over IP
VR	Virtual Reality
VTC	Valeo Teleoperation Cloud
WebRTC	Web Real Time Communication
WP	Work Package
YOLO	You Only Look Once

Executive Summary

5GMed intends to demonstrate advanced Cooperative Connected and Automated Mobility (CCAM) and Future Railway Mobile Communications System services (FRMCS) along the “Figueres-Perpignan” cross border corridor between Spain and France. One of the main challenges is providing 5G connectivity along this cross-border corridor for both train and highway users. In this context the role of WP4 is the development of the technologies needed for the automotive Use Cases and their initial validation, where Task 4.1 brings the automotive application requirement analysis.

The present document D4.1 “Requirements and Initial Design for Automotive Test Cases” is delivered as part of WP4 and it is the main output of T.4.1 of the project. The deliverable objective is to provide the requirements and initial design for the automotive test cases aligned with the use cases defined in D2.1 [5GM20-D21]. This initial design goes in cross-coordination with Deliverable D2.2 [5GM21-D22], which is being addressed at the same time this document is written, and which is intended to provide a more detailed definition of the 5GMed test cases, together with their deployment options and associated tools. In a complementary way, this document is also intended to serve as input for other subsequent tasks in this WP4, namely Task 4.2 (Automotive application development), Task 4.3 (In-car V2X extensions) and Task 4.4 (Follow-ME infotainment application); also to other tasks in other WPs, such as Task 6.1 (Test case definitions) and Task 7.1 (Cross-border corridor cost/benefit analysis).

The document is composed of an introduction where the document purpose, structure and the methodology followed in producing the work are explained. After that, an overall introduction of the 5GMed project provides background information to the reader directly inside this document. This background information includes some comprehensive details about the 5GMed project purpose and scope, the three automotive use cases specifically addressed in the project (Remote Driving, Road Infrastructure Digitalisation and Follow-ME Infotainment) and the main technical challenges that are intended to be addressed by means of these use cases.

After that, the core part of the document focuses on the initial overall architectural design for implementing the test cases and the set of requirements they are expected to fulfil. Since what is presented here is still an initial design, the document also includes a final section where the connection with other work packages and project tasks where the work is planned to be continued is presented.

1. Introduction

1.1 Purpose of this document

The primary purpose of this document is to identify the requirements and provide the initial functional design of the test cases to validate the automotive use cases described in the previous Deliverable D2.1 (Definition of 5GMed use cases) [5GM20-D21]. This initial design has been performed in cross-coordination with Deliverable D2.2 (Initial definition of 5GMed test cases, deployment options and tools) [5GM21-D22], which has been produced in parallel with this deliverable.

The specific automotive Use Cases (UCs) in which this work is based are the following:

a) Remote Driving (UC1), intended to demonstrate that automated driving on highways can be carried out safely in emergencies.

b) Road infrastructure digitalisation for intelligent management of the connected and automated vehicles mobility (UC2). The target is to digitalise the road infrastructure with sensors to enable road operators to execute intelligent traffic management strategies that ensure uninterrupted, safe, and efficient mobility in situations with mixed conventional and automated traffic.

c) Follow-ME Infotainment (UC4)[2] provides car passengers with media-based entertainment activities (e.g., access to high-quality media contents), ensuring service continuity while travellers are on the move.

d) Aligned with the work performed in WP4, the information provided in this deliverable is related to the automotive use case technology development and the initial validation process in the project, taking the test cases defined in D2.2 as an initial validation point. The objective is to determine the baseline requirements to perform such test cases and to provide an initial design of the necessary architecture.

It should be noted that this deliverable should be taken as an initial effort in the context of the 5GMed project, since other relevant 5GMed technical deliverables are also in progress (Deliverable D3.1[3]) or even not started (Deliverable D3.2[4]) while this deliverable is being elaborated. This means that the requirements, and especially the designs that we offer here, are still at a high level, as they are still based on assumptions that could evolve when the project progresses towards more precise definitions. In any case, our approach here is to make the best effort, trying to provide as much detail as possible even at this early stage of work.

[2] This UC4 is not automotive specific but covers both transport modes in the 5GMed corridor: automotive and railway.
[3] Analysis of 5GMed infrastructure requirements and 5G HO between networks & cross-border.
[4] 5G-M ICT architecture and initial design.

1.2 Structure of the document

Following the introductory Section 1, the present document is divided into the following way:

Section 2, provides an overall description of the 5GMed project purpose and scope, focusing mainly on the automotive use cases description, since they are the main topic related to this deliverable. It also describes what we consider the main technical challenges associated with these use cases. Although some of this information was already introduced in other documents[5,6] we consider it can be useful for the reader to have a brief summary right on this document.

Section 3 presents the initial design of the three 5GMed automotive test cases: Remote Driving (UC1), Road Infrastructure Digitalisation (UC2) and Follow-ME Infotainment (UC4). Besides the high-level overall functional architecture integrating the three test cases, a more detailed architecture is presented for each single case, including a detailed functional blocks view (describing the main architectural blocks from a static perspective), a behavioural view (describing how the different blocks interact with each other) and a set of deployment notes that should be considered at the deployment stage for each use case.

Section 4 provides a set of tables with the requirements on which the architectural design is based. These requirements are presented here after the design (Section 3) because some of them can refer to some of the architectural elements introduced in the previous Section 3. In line with the common practice, the requirements are split in two: functional and non-functional requirements for each use case. The former is describing the required behaviour of the design for each test case, while the latter describe the overall required qualities.

Finally, Section 5 completes the core part of the document describing the main conclusions concerning the project objectives.

After that concluding section, an annex is also provided with some relevant information describing the connection with other WPs and tasks in the project. More specifically, this section includes tables with the different modules to be developed for each use case and the different WPs and tasks where the detailed design and development are expected to be addressed.

1.3 Methodology

This section introduces the methods used to collect requirements and generate initial designs to verify the 5GMed test cases of each automotive use case. Basically, two overall methods have been used: the main one consisting of collecting relevant information by interacting with other related WPs in the project (mainly WP2 and WP3); also, consulting related books and journal articles regarding the state-of-the-art (see the References section).

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[5] Deliverable D1.1. Project Handbook, Strategic Plan for QA and Risk Management [5GM20-D11].
[6] Deliverable D2.1: Definition of 5GMed use cases [5GM20-D21].

The baseline for producing this deliverable is the definition of the use cases provided in Deliverable D2.1 [5GM20-D21], which provides an initial high-level description of all the use cases of the project (train and automotive use cases). The target of the current deliverable is to produce an initial overall functional design of the test cases to validate the automotive use cases (UC1, UC2 and UC4 mentioned above). These test cases will be further elaborated in Deliverable D2.2 [5GM21-D22], which is being developed in parallel with this deliverable.

In general, the design of the test cases was done based on the interaction between the responsible partners and the correct handling of the collected feedback. Different communication methods were used at this stage, such as email exchanges, specific meetings to clarify the system components and behaviour, and regular conference calls. The resulting designs have also been shared and coordinated with other partners in the project, even if they were not directly involved in the production of this deliverable.

In order to identify the functional and non-functional requirements related to the test cases, the information of each test case has been collected by iterating with various partners involved in the use case. Similarly, given the nature of the work carried out in this project, a flexible approach was adopted when defining the initial design of different test cases, adjusting the requirements in a way that best suits the goals of the project.

The analysis of these requirements and the information provided by partners was used to generate the requirements and architecture diagrams provided in this document. This applies particularly to Sections 3 and 4, which explicitly correlate the specific test cases defined in Deliverable 2.2 to each requirement.

The result of this work has been an initial design approach employing a set of so-called "architecture views". This is a common practice when describing the architecture of complex systems [CBB+10] [CAA09] [RW05] [Kru95]. Together, these views can provide a consistent and complete description of the system architecture required by each test case, while each view conveys detailed information about different and more specific aspects. In this early stage of the project, two different views are provided for the different test case designs:

- The functional (structural) view, breaks down the design into different components, describing the basic functions of each one and the interfaces they use to communicate with each other.
- The behavioural view, deals with the dynamic aspects of each use case and explains how the different functional blocks presented in the previous functional view interact with each other to achieve the different required behaviours.

These two views are provided in Section 3 for the different services to be executed in each use case. Additionally, specific deployment notes are also provided. We consider that these deployment notes should be also considered in later stages of the project to give an additional Deployment View (once more concrete details about the physical deployment of the different use case components are available).

2. Overall Description

2.1 5GMed Project Purpose and Scope

5GMed brings a sustainable 5G deployment model for future mobility in the Mediterranean Cross-Border Corridor connecting the cities of Perpignan (France) and Figueres (Spain) through both: road traffic (via the E15 motorway) and rail (via a high-speed railway). This is the main east-west axis in the Trans-European Transport Network (TEN-T) south of the Alps (Figure 1).

Figure 1. Mediterranean Cross-Border Corridor

The intention is to demonstrate advanced mobility services along this corridor, enabled by a multi-stakeholder compute and network infrastructure, deployed by different Mobile Network Operators (MNOs), Neutral Hosts Operators, and Road and Rail Operators. However, providing advanced connectivity services in a scalable and replicable manner in such complex stakeholder's ecosystem can be quite challenging, and even more if we consider the cross-border scenario where different national operators must agree and interact with each other.

Also, an additional complexity in a multi-stakeholder ecosystem like this one is the heterogeneous nature of infrastructures and technologies in use. For instance, the radio infrastructure can include different technologies: e.g., 5G NR Rel.16 at 3.5 GHz, specific 5.9 GHz bands for road safety services, unlicensed millimeter wave, C-V2X and NR-V2X 5.9GHz technologies or even satellite connections to provision low data-rate IoT devices, among other.

Thus, in such a context, the new 5G mobile network technology should not be seen just as the only technology to be used in the corridor, but as another available technology that should coexist and be combined with the other technologies already deployed in this complex ecosystem (this can also offer the possibility to provide coverage for specific services in certain locations where the 5G technology is not available – e.g., areas with low or none 5G coverage). Of course, it makes the final solution more complex than in those cases where only one radio technology is considered. As an example, we can think of an end-user travelling throughout the corridor while using a network service that is, of course, expected to work without disruptions while hopping from one radio technology to another.

In few words, 5GMed intends to demonstrate how this novel multi-stakeholder infrastructure can deliver end-to-end innovative CCAM and FRMCS services. The WP4 targets automotive services, so this deliverable will focus on CCAM services. In this regard, the main 5GMed technical objectives related to CCAM are:

1. To specify and validate a scalable, cross-border and multi-stakeholder 5G and Artificial Intelligence enabled (AI-enabled) system architecture supporting CCAM services.
2. To design and develop cross-operator service orchestration that enables MNOs, neutral hosts and road/railways infrastructure operators to deliver service continuity to end-users.
3. To propose and establish novel practices on how MNOs, neutral hosts, Original Equipment Manufacturers (OEMs) and road operators can cooperate to deliver Remote Driving (RD), Advanced Traffic Management (ATM) and Infotainment use cases in cross-border scenarios.

The last objective is indeed the main one for this deliverable, that explicitly refers to the three automotive use cases that are our primary concern here (RD, ATM and Infotainment) already mentioned in Section 1.1.

Multiple innovations are required to fulfil the 5GMed vision for implementing these use cases; we can highlight the following:

i) cross-operator service orchestration (we have different MNOs in each country),
ii) innovations in multi-connectivity to support vehicles moving at high-speed
iii) speed up roaming and access technology transitions across MNOs and neutral hosts to provide service continuity to the end-users
iv) the ability to execute AI-enabled functions at the edge of the network to support the intelligent orchestration of the available network resources,
v) the ability to provide local traffic strategies for Connected and Autonomous Vehicles (CAVs), leveraging Artificial Intelligence (AI) techniques.

To address these innovations 5GMed will demonstrate the provisioning and operation of the necessary CCAM services across a multi-stakeholder 5G network infrastructure involving MNOs, road and railways infrastructure operators and neutral hosts. To do so, multi-domain Network Services (NSs) will be considered composed of: i) Virtual Network Functions (VNFs) deployed across the edge computing resources of the different stakeholders, ii) the multi-technology wireless access connectivity, connecting user traffic to the VNFs, and iii) on-demand inter-site connectivity to connect the various network functions and access points. Also, since the application functions need to be abstracted from the different available networks, 5GMed will develop a multi-connectivity solution compliant with the different automotive environments; The designed solution (designated as "aggregator function") enables the end-user devices to access to a plurality of networks from the different stakeholders (MNO, Road and Neutral Host Operators) in a transparent way.

Another key point is optimising the roaming process among the MNOs and neutral hosts participating in 5GMed. To achieve this, different techniques are being explored. Two of them are Prediction Optimization and MEC to MEC handover optimization. The former is based on the high predictability of the User Equipment's (UEs) movement along cross-border corridor sections, making it feasible to anticipate the different procedures necessary for the handover execution. The second one considers the problem from an edge computing perspective; this is applicable when an application needs to move across MEC nodes following or anticipating the end-user service demand.

In 5GMed all these innovations and features are highlighted through the different Use Cases previously mentioned: Remote Driving (UC1 - which demonstrates how a vehicle can be remotely managed in emergencies), Road Infrastructure Digitalization (UC2 - for the intelligent management of the connected and automated vehicles mobility) and Follow-ME Infotainment (UC4 – which provides the car passengers with media-based entertainment with high quality and service continuity through the road). All these use cases are described in more detail in the following Section 2.2.

2.2 Automotive Use Cases Description

2.2.1 UC1 – Remote Driving

Truly safe automated driving will depend on defining the exhaustive list of overlapping conditions an automated vehicle might encounter, which is defined as Operational Design Domain (ODD).

The objective of UC1 is the assistance of an automated vehicle getting outside its ODD. Using the 5G cellular network, 5GMed will demonstrate that a teleoperator can control the car from a remote location and ensure the Dynamic Driving Task fallback (DDT, specified by SAE J3016 [J3016]) with full safety. This means that 5GMed will add a new reliable mode to the DDT fallback procedure. Due to the stringent requirements of the use case, the 5GMed innovations that correspond to the current use case are:

- i) cross-operator service orchestration,
- ii) speed up roaming transitions across MNOs and neutral hosts to provide service continuity to the end-users,
- iii) the ability to support AI-enabled functions executing at the edge of the network,
- iv) the 5G technology will increase the safety of the teleoperation and strengthen the trust of users,
- v) the seamless service continuity across countries.

5GMed will build upon the ODD of the vehicle used for the tests (VLO Cruise4U [VloC4U]), a prototype automated driving on highway or motorway alike road that allows the driver to decide whether to drive manually or prefer to delegate this task) on the highway. The project approach consists of simulating a step outside the ODD by Hardware (HW) or Software (SW) failure (e.g. camera or Lidar Failure) or when the vehicle leaves the areas where there are appropriate conditions to support Automated Driving functions.

The vehicle used for UC1 is already capable of operating in automated modes SAE Level 3 and SAE Level 4 within its ODD (VLO Cruise4U vehicle) on the highway. SAE specifies the automation level of a car (it is further defined in annexe 1 at the end of this document), ranging from 1 to 5. At SAE Level 3, drivers are not in active driving control of the vehicle but may be requested to take over driving at any time. At SAE Level 4 and Level 5, no pedal nor steering wheel are necessary anymore in the car; the passengers are never requested to drive.

Three services may result from getting outside the ODD and will be tested in UC1:

1. Minimum Risk Manoeuvre (MRM)
2. Request for Remote Assistance (RRA)
3. Teleoperation Driving (ToD).

The first service to be tested in UC1 is the MRM, which is triggered when the vehicle steps outside its ODD. It is entirely automated in the autonomous vehicle without any assistance from the ground. The MRM will automatically park the car to an emergency safe harbour.
Once the vehicle has stopped, the Traffic Management Centre (TMC) will check whether the MRM was successfully achieved (the car is parked safely). The TMC will then decide whether the car can stay where it is parked or needs to be teleoperated to another safe harbour for a more permanent and safer parking place.
This will lead to the second service tested in the UC1, called Request for Remote Assistance. The TMC will send a request for remote assistance to the vehicle.
Once the request for assistance is over the third service tested in UC1 can start, called the Teleoperation Driving. A teleoperator will drive the vehicle from a remote cockpit.

2.2.2 UC2 – Road Infrastructure Digitalization

The UC2 scope is to test and check the feasibility of the digitalisation of the infrastructure [GZC18], enabling road operators to execute intelligent traffic management strategies, ensuring safety and efficient mobility in mixed conventional and automated situations traffic.

The infrastructure gives support for automated driving and provides services to Connected and Autonomous Vehicles (CAVs). The highway infrastructure will be equipped with a set of High Definition (HD) cameras transmitting video stream to AI computing resources hosted in the TMC Edge. The main tools to be tested are SW tools for automatic detection, using the latest technologies in video analysis through artificial intelligence algorithms that provide real-time data. All this data, including data from connected vehicles (CV), will be analysed in real-time to develop advanced traffic strategies to manage the various situations in mixed traffic to ensure smooth and safe traffic. These new traffic strategies will consist of Infrastructure-to-Vehicle (I2V) and Vehicle-to-Infrastructure (V2I) message to improve overall traffic safety.

The main purpose of UC2 is to verify that the 5GMed infrastructure can collect data, analyse it and, as a result, disseminate messages within very short times and low latency in the local and cross-border scenarios.

The main goal of the UC2 is to test these three services:

1. Relay emergency message sent by vehicle to infrastructure (REM).
2. Automatic incident detection and local area traffic management (AID) [KD+21].
3. Traffic Flow Regulation in real-time by using a selected group of CAVs (TFR).

The tests related to each service will be executed in a small-scale test site in Castelloli (Small Scale Specific Tests Cases), and in a real cross-border scenario placed from Figueres to Le Perthus in the AP7 (Large Scale Specific Tests Cases).

2.2.3 UC4 – Follow-ME Infotainment

The advent of autonomous and connected cars will create new demand for in-car entertainment. To target this, the Follow-ME Infotainment use case will provide innovative media contents on top of the 5GMed infrastructure to create enhanced end-user experiences that will be available while travelling through the highway in the 5GMed corridor.

The objective of this use case is to use the technical resources developed in the 5GMed project to enable end-users to access high quality multimedia content, while maintaining high levels of Quality of Experience (QoE)/Quality of Service (QoS) when travelling at high speed in the corridor. The main target is to optimise the distribution of multimedia content so that high-quality reception can be achieved even in cross-border situations while avoiding service interruptions.

UC4 focuses on two overall aspects:

a) The demonstration of the so-called "Follow-Me" [TKF19] mobility management concept consists of moving the VNFs of the media service along different edge nodes, as the user moves through the corridor. In this way, these VNFs are always located in the data centre closer to the end-user (VNFs “follow” the user’s movement). The main outcome associated with this is providing low latency, reducing media traffic, optimizing network performance and increasing user experience. Although, it imposes a challenge regarding ensuring the service continuity.

b) The Media Infotainment Application itself, consists of a set of advanced media services that will showcase the previous “Follow-Me” concept.

Furthermore, the Follow-ME Infotainment application consists of two different services:

- The Enjoy Media Together (EMT) service makes it possible to create a virtual “video sharing room”. It can be used to watch in sync high definition media and immersive 360^0 contents in community (i.e., together with other travellers or with other users far away). Besides the media content itself, the service provides specific resources for the users to interact among them: a chat-like application through peer to peer (P2P) video calls[7].
- The Tour Planning (TP) service provides an enriched multimedia application for planning trips with access to virtual reality contents, giving the car passengers enriched information regarding the surroundings, nearby points of interest, and the functionalities of Tour Planning, Tour suggestion and sharing experiences. An enhanced XR enabled experience is available to the end-user, using the related options to receive Virtual reality (VR) content.

In the following we describe each of these services in more detail.

[7] This service was referenced as “Watch Movies/Shows Together” in Deliverable D2.1 [5GM20-D21]. We’ve renamed the service as “Enjoy Media Together” here, although the service itself is basically the same.

2.2.3.1 Enjoy Media Together Service

User mobility makes the problem of end-to-end deployment and reliable/undisrupted operation of IP-based mobile media services such as IPTV and Video-on-Demand (VoD) very complex. In order to maintain high Quality-of-Experience for mobile clients the common practice is to employ Content Delivery Networks (CDN), deployed over geographically distributed infrastructure. Streaming proxies are deployed on edge nodes near the end-users, to discharge the core network from aggregate, high-throughput streams.

The EMT service is inspired by this concept of a CDN aiming to provide an immersive and personalized live streaming experience for end users travelling in the corridor, while supporting multiple formats (2D videos, 360-degree videos or audio) on a variety of end-user devices (smart phones, tablets, personal computer or head-mounted devices)[8]. It brings a new way to watch multimedia contents with peers online, even though the end-users are travelling on the corridor or not and creating the feeling of being together in a virtual room where media content can be enjoyed synchronously by all participants.

The service allows high-quality video content to be shared in two ways: VoD and real-time streaming. It also supports users who participate in the experience to record and thus stream their own real-time video content. The adaptive and immersive end-to-end media streaming solution relies on a virtual CDN architecture and a novel adaptive technology (adaptive streaming according to HTTP Live Streaming [8216] and Dynamic Adaptive Streaming over HTTP [Sto10] standards), through the merge and delivery of multi-source video streams with the ability to maximize the end user's QoE with personalized content and Augmented Reality (AR)/ VR immersive content.

In addition, the service allows the establishment of a P2P social network relying on Web Real-Time Communication (WebRTC) [JB12] to chat and video call to participant friends, family and peers, even privately. This feature is basically for agreeing and arranging what to watch, as well as sharing opinions in real-time about the experience they're just accessing. Therefore, users can invite people to create topics, schedule viewing content, chat or establish group video calls to share opinions, among other.

Besides the basic functionality of synchronizing video players, another relevant feature in the EMT service consists of the ability to adapt 360 content to the user's head movements. Depending on where the user directs their look, the media content will be updated in one way or another by adapting the contents to be presented on the screen, as well as their resolution (a higher resolution will be provided right at the front of the visual field). This will be made possible by relying on the strict low latency capabilities of the 5G network (in those areas with no 5G coverage this functionality will not be available).

[8] Other devices could be also considered. E.g., those already part of the vehicle's infrastructure, such as the screens available for the passengers in the back seat. This should be clarified in later stages in the project.

Figure 2 shows a conceptual diagram describing the EMT service. In Section 3.4 a more detailed design is provided.

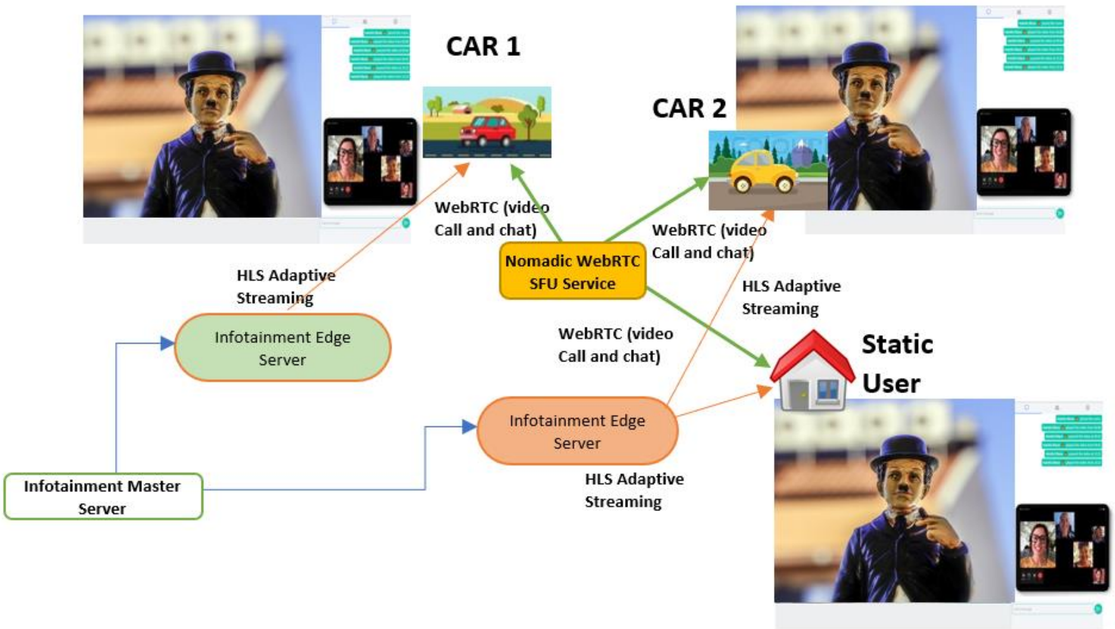

Figure 2. EMT Service concept diagram

2.2.3.2 Tour Planning Service

The TP service, provides and enriches multimedia application for planning trips. Provides access to virtual reality contents, giving the car or train passengers enriched information regarding the surroundings, nearby points of interest and the functionalities of Tour Planning, Tour suggestion and sharing experiences. An enhanced XR enabled experience is available to the end-user, using the related options to receive Virtual reality content.

The Tour planning service will deliver a tour planning mobile application that enables visitors/users (on-road or on-train) to select predefined tours or build personalized ones according to their preferences.

Through this app, the visitors benefit from the Tour Suggestion functionality, allowing users to enjoy the highlights of a region or city by promoting “ready-to-follow” tours and urge them to share what they liked most about these tours.

Apart from suggesting predefined tours, the Tour Planning functionality enables users to plan their tours. By setting their preferences on Points of Interest (POIs), i.e. types of places they would like to visit, the time available to visit the specific area, the starting point (which can also be automatically detected from the user’s mobile device) and preferable transportation means. The app proposes personalised tours, achieving the “best match” of “things to do” in the selected destination, which can be further customised with user intervention by re-ordering, adding and/or removing POIs.

Finally, the Sharing Experiences functionality offers the end-user the option to receive content pushed to their mobile device by the app. This includes information about POIs and directions on how to reach the next stop close to the POI and is realized by continuously monitoring the user geolocation and as soon as they get close enough to the POI and enter within the predefined range. It also enables the users to rate the visits with a tour and share their feelings about it.

2.3 Main Technical Challenges for the Automotive Use Cases

In this section, we will highlight the global problematics for the automotive use cases. They will deal with the teleoperation, the cybersecurity, the network management and the QoS.

2.3.1 The *Phygital* experience of the remote driver

Phygital (contraction of physical and digital) [Phy21] refers the concept of using technology to bridge the digital and the physical worlds with the purpose of providing a unique interactive, immediate and immersive experience for the user. It allows to feel physically elsewhere, in real-time, in the real world with a Human Machine Interface (HMI). This is a key concept for the experience of the remote driver to ensure the teleoperation.

Indeed, driving a vehicle has become commonplace in today's society. However, there have been long years of research into making a car that can be controlled as naturally as possible. The result is the one we all know: a steering wheel to steer the vehicle sideways, an accelerator pedal to increase its speed, a brake pedal to reduce it and, incidentally, a gear lever to manage the engine speed. Each of these interfaces has been improved over time to arrive at what we have in our cars. With the current technologies and the atmosphere of tele operating a vehicle, we feel it is important to review these achievements to find new ways of interacting or simply to confirm that the duplication of interfaces is the best way to teleoperate.

What is essential for safe and smooth driving is to have an excellent perception of your surroundings, be attentive to them, and manage your vehicle movements according to the driving situation. In this sense, we want to enable a perception in a remote operation cockpit that is similar to that of a driving position in a vehicle, or even better, thanks to the vehicle's sensors and the roadside cameras.

The cause of motion sickness is an essential notion to consider in our use case. We are not always aware of it, but when we are in a moving vehicle, the perception of movement, thanks to the touch, in particular, and the vision, allows us to better situate ourselves in the present situation. The synchronicity of the remote actions with the vehicle's actual movement should be as accurate as possible to improve the comfort and safety of the remote operation. This will also require increased surveillance of the remote operator, who will not necessarily have the notion of critical ends since he will be presented as if he were behind a simulator.

2.3.2 The Mixed initiative driving

Another challenge is to address is mixed-initiative driving. This topic is slowly beginning to prove itself in the automotive world. Since the rise of autonomous driving, most of them were based on a single entity among the autonomous driving system and the driver in the vehicle capable of controlling the vehicle. There have been trials and attempts to achieve mixed-initiative functions. The simplest is when a vehicle has cruise control on, and the driver hits the accelerator to overtake, for instance. When the driver releases the accelerator, the cruise control takes over.

Systems of this type must comply with the Vienna Convention, which implies that all responsibility for a vehicle lies with the driver. That is why, in all manuals for automation systems up to SAE level 3, we have the clear statement: "The driver must at all times supervise the system."

In remote operation, the complexity is increasing by one when we consider 3 entities capable of controlling the vehicle: The driver, the automation system, and the teleoperator. The safety, supervision and control algorithms will have to be strengthened on this occasion to ensure the proper conduct of the use case 1.

2.3.3 Seamless handover and roaming

When a vehicle crosses a border, it has to switch the cellular network implying handover and network roaming operations that may interrupt the end-to-end communication for a non-negligible period of time (disconnection period). If the CAV is under remote driving manoeuvre during the handover procedure, communication interruption may lead to severe safety consequence to the teleoperation procedure. In other words, for UC1, the handover and roaming procedure must be made seamlessly with zero (or negligible) interruption time for the end-to-end communication. To achieve seamless communication, solutions at the individual cellular networks and cooperation among the cellular networks are necessary.

2.3.4 Cybersecure CCAM

Cybersecure CCAM is critical in UC1 and UC2; remote driver and TMC take decisions based on the information received. Those decisions are related to safety. In UC1, a teleoperator controls a CAV vehicle from a remote location. To enable such an operation, the CAV and the teleoperator communicate with each other, e.g., vehicle to operator (V2I) request to remote assistance message, V2I real-time vehicle sensor data, and I2V control command. In UC2, the perception of what is happening on the road is partly based on V2I messages received from connected vehicles. Additionally, traffic strategies elaborated in both TMC Edge and TMC Cloud are communicated to the vehicles through I2V messages with recommended control commands.

In ensuring the safe mobility of the CAVs and the surrounding vehicles, the security of the communication between the CAV and the teleoperator or the infrastructure is very important. Unfortunately, a number of components of the end-to-end system particularly, the vehicle sensors, the vehicle automotive bus system (CAN), the V2X communication module, the cellular communication channel and network, the teleoperator unit, and the vehicle control unit can be subject to cyber-attacks such as vehicle sensor spoofing, injection of false messages, manipulations of messages, GPS spoofing, jamming, eavesdropping, location tracking, and Sybil attack. Therefore, it is crucial to implement cybersecurity measures for the end-to-end system: Public Key Infrastructure, Transport Layer Security (TLS with X. 509 certificates, ITS certificates), IP Security (IPSec).

2.3.5 Image processing for traffic and incidents recognition

The video analytics [RF18] of the road in real-time will allow to properly identify specific traffic situations, namely incidents [NP+21], and better decide how to intervene in each case. For this purpose, cameras will be installed along the road connected to the TMC Edges. The TMC Edge roll is in charge of analysing the video from different sources (at least 8 IP cameras will be controlled by one TMC Edge). TMC Edges with enough capacity will host the AI algorithms responsible for analysing the video to obtain real-time traffic information at the lane level.

The development of video analytics of a computing platform capable of detecting, classifying and tracking [KD+21] vehicles is crucial. This analysis will associate characteristics such as the vehicle type, its estimated speed, its position in the lane, its geolocation, its colour, and other properties.

This video analysis system is based on two pillars. The first of them is You Only Look Once (YOLO), one of the fastest object detection algorithms out there, which provides state of the art real-time detection and classification accuracy. The detector processes each frame independently and identifies objects of interest in that particular frame.

The second pillar is DeepSORT [WBP17]. This detection tracking algorithm considers both the bounding box parameters of the detection results and the information about the appearance of the tracked objects to associate the detections in a new frame with previously tracked objects. One of the main use cases that this tracking algorithm solves is the counting of vehicles on a certain stretch. This is possible thanks to the model capacity of identifying one vehicle through the different frames, not just in a particular frame as detector does. One challenge is to implement this AI software in a centralized server controlling multiple 5G-Connected cameras, rather than a distributed approach where the AI is deployed in each camera.

Power access on the roads is limited. Cameras and the 5G communications equipment that connects them to the MEC needs power. One of the significant challenges is micro-power generation and low energy equipment consumption, making them independent of both electrical and communications networks being a very innovative concept. Each camera will have a pole with an aerogenerator and solar panels. The green power will be stored in batteries without connecting the camera to the electrical grid. In addition, a 5G module responsible for communications will be installed in each pole.

2.3.6 End-to-End Quality Control

The cellular networks on two sides of the border can have different characteristics, providing significantly different end-to-end communication performances in terms of throughput , delay, and reliability. This is especially true if the vehicle switches from 5G to 4G or 4G to 5G or 5G cmWave to 5G mmWave networks. Therefore, as soon as the handover procedure is made, the end-to-end communication between the CAV and the teleoperator may experience sudden performance degradation (throughput, delay, and reliability). This is undesirable for UC1, and hence it is necessary to smoothly handle or avoid such a situation by various QoS control solutions that can be made at the application and at the network levels.

Moreover, the degradation is crucial also for the user consuming high definition media content or AR/VR contents. The degradation in the performances might cause an interruption of service during service handover, which must be leveraged with advanced QoS mechanisms (which may involve AI) and continuous performance monitoring.

2.3.7 AI for traffic management

The AI will allow to recognise and classify specific situations defined by multiple parameters and facilitate the decision of the measure to adopt in order to obtain the appropriate impact. For this purpose, neural networks and/or clustering will be explored, defined and developed. One of the main challenges will be the identification and acquisition of the additional inputs and the lack of data on the actual behaviour of vehicles (conventional and especially CCAM) in front of given situations and instructions to predict the outcome. Simulation (based on synthetic data) can be an appropriate tool, its use will be explored

2.3.8 Unified repository for mobility data

Data is essential to many activities, from modelling or simulation to the implementation of Artificial Intelligence applications. Unfortunately, data is difficult to access and commonly not available in the transport context. It is necessary to have available an instrument to access and consolidate dynamic mobility data from siloed transport systems. This is especially relevant in the context of the 5GMed project. The integration of cooperative ITS, V2X and CAV data with existing systems requires a set of unified data schemas and common repositories accessible from different entities. This objective is currently difficult to achieve in the transport sector because data is not shared between companies and public administrations due to concerns around cost, privacy, security, data ownership, or cultural barriers that restrict data sharing between those actors. To avoid these limitations, Transport or Mobility Data HUBs are being promoted from different entities to create digital data and knowledge platforms that consolidate the transport data generated in their influence areas. The last objective is to enable the development of Intelligent Mobility (IM) solutions, powered by data, to tackle some of the Transport biggest economic, social and environmental challenges.

The unified repository for mobility data will be built following the specific requirements of 5GMed. It will be scalable, using autoscaling and load balancing schemes available in today's cloud technologies. Data ingestion in the repository will be done following push and pull methods and using standard data formats such as Datex II [Dat21]. When required, access to the data will be secured using virtual private networks and user access credentials. The last aim of the unified repository would be to manage any Mobility related data useful for the highway operation systems, including not only the traffic management related to the 5GMed project but also, data from other sources, like, toll systems, historical incidents, traffic flows, mobility restrictions or weather forecast. Finally, the unified repository for mobility data will assist data visualization in a flexible, dynamic and customer-oriented manner.

2.3.9 Cross-Operator 5G Orchestration for MEC and Radio

[Ber15] presented a 5G Exchange integration framework that considers multi-operator wholesale relationships, among others. To ensure services across multi-domains, a customer creates a service manifest for an operator, which is able to request resources from other operators if it cannot fulfil the manifest. The two main Open-Source Software (OSS) service orchestrators, Open Network Automation Platform (ONAP) [Ona21] and Open Source MANO (OSM) [Gko18] have lately started to address multi-domain service orchestration in real environments. For example, [Ona21] introduces Cross-Domain and Cross-Layer Virtual Private Network (VPN), which allows cross-domain orchestration, including path computation based on abstract topologies, cross-operator end-to-end service provisioning, and closed-loop reroute. In [Gko18], three domains were jointly orchestrated to deploy network services using a virtual network service composer allowing users to create and deploy inter-domain network services dynamically.

5GMed will advance the state-of-the-art on cross-operator 5G Orchestration for MEC and Radio by allowing the pooling of resources from multiple operators to provide a distributed compute platform that enables AI-powered services. Moreover, 5GMed will also provide vertical slices in multiple administrative domains, ensuring isolation of CCAM/FRMCS services through specific resource allocations in the RAN and MEC domains. Finally, 5GMed will introduce a cross-operator service orchestrator that can interact with MNOs, neutral hosts and road/rail operators.

2.3.10 Multi-Connectivity in high mobility environments

The proposed UE located in different means of transport (vehicles and trains) typically cross networks with multiple access technologies, focused on 5G, PC5 and possibly G5. Therefore, multi-connectivity is a key technological challenge. This issue was firstly analysed in [5gc21] in order to provide successful QoS delivery for some V2X use-cases, such as cooperative safety. To evaluate each combination of links/RATs for each use case, in the first step, the desired use-case should be defined as a series of V2X communications with pre-defined QoS requirements to enable its successful delivery. The second step is to consider the “completion time” of the use case. To address multi-connectivity, 5GMed envisages an on-board Traffic Aggregation Function, providing the necessary multi-connectivity to address the multi-technology and multi-network nature of the 5GMed system. This aggregator decides which links/RATs to attach to for each of the involved vehicles/UEs in the third step. The necessary parameters that are known or predicted by the coordinator are considered to predict the resulted QoS of each combination of multi-link/RAT connectivity. QoS prediction is another significant topic in V2X communications that have been detailed in [5ga19].

5GMed will advance state of the art on multi-connectivity by developing this solution capable of aggregating bandwidth from 5G, PC5 and possibly G5. Moreover, it will validate this multi-connectivity solution at high speed in automotive environments.

3. Initial Design for the Automotive Test Cases

3.1 High-level overall functional Architecture

This section introduces the high-level architecture designed to implement the automotive use cases (see section 2.2). This high-level architecture comprises a set of functional blocks connected between them and distributed in three different logical (and physical) layers. Figure 3 shows the high-level overview of this architecture (labels in yellow represent the responsible partners for each functional block):

In the emerging sector of Cooperative, Connected, and Automated Mobility (CCAM), the development of vehicle functions is often in focus. However, road infrastructure can play a key role in enabling and supporting automated driving. A classification scheme for infrastructure support for automated driving (ISAD) has recently been introduced, which groups the availability of static and dynamic infrastructure information together with communication capabilities into classes. Attached is a link to the description of the ISAD levels in the framework of the European INFRAMIX project [INF19-D54].

As we see, the following main layers are considered:

- Road layer: This layer is the one closest to the road. It contains the functional blocks related to the connected vehicles and the road equipment, such as the roadside video sensors. Also, the Roadside Communications (including the three channels: Uu; for direct connections between the vehicle and the MEC, C-V2X and ITS-G5; using RSUs placed on the road to cover 5G coverage blind spots) and the Networks Technology Aggregator are represented in the diagram as they are part of this layer. However, being components specific for the communication (e.g. not application-specific features of the use cases), they are not in the scope of WP4 and this deliverable. In particular, the Roadside Communications and the Network Aggregator will be described in more detail in WP3 deliverables.

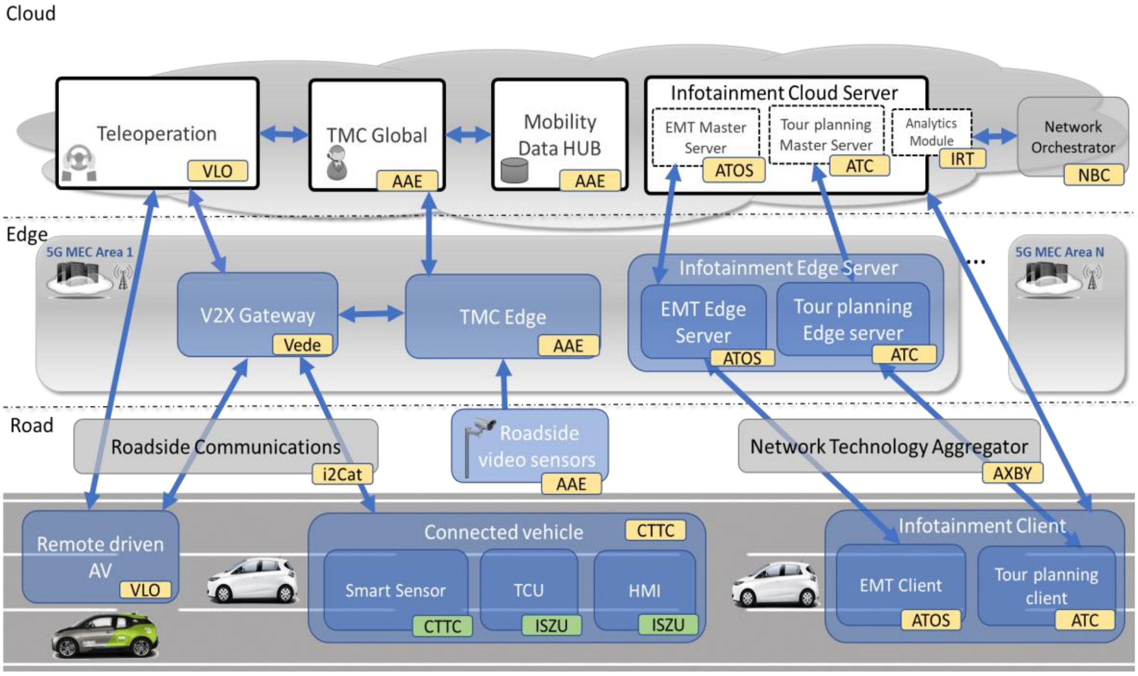

Figure 3. High-Level Overall Architecture

- Edge layer: That contains the functionals blocks that will be instantiated in the different MEC long the road. They will be deployed in a distributed way providing the key use cases functionalities in a MEC Area with ultra-low latency.
- The cloud layer: For each use case, it acts as an aggregator of the pieces of information managed by each MEC. It implements the functional components that must be instantiated once for all the site and physically are deployed in remote servers. This layer will implement the more performance demanding blocks but with slower latency compared with the MECs ones.

This overall high-level architecture and its main blocks are further detailed in the next sections with the detailed view of the functional components grouped by use cases.

3.2 UC1 detailed functional architectural elements

In this section we focus on the functional blocks that make UC1 Remote Driving possible. As explained earlier, UC1 can be split into 3 services (or phases): MRM, RRA, and ToD. It begins when the Remote Vehicle (RV) detects a system failure and triggers a MRM. Upon this MRM triggering, informative V2X messages are sent to the Road-Side Units (RSU) and surrounding CAV. The RV also informs the TMC Edge and the Valeo Teleoperation Cloud (VTC) via 5G. Depending on the situation of the RV, either the TMC or the VTC can trigger a RRA to find and assign a teleoperator. Once the request for teleoperation assistance is approved, we connect the RV with the Remote Station (RS), from where the teleoperator is able to communicate with the passengers of the RV and proceed with the ToD of the RV.

3.2.1 Detailed Functional Block View

Figure 4 gives an overview of the UC1 System made to enable the teleoperation for 5GMED. The main functional blocks are detailed in the next section. As explained in the UC1 description, the RV performs an MRM and inform via V2X and 5G of the need for an RRA. V2X warns surrounding vehicles of the manoeuvre. The roadside unit does the link with the V2X gateway to send data to the TMC. It will help to manage the safety of the manoeuvre. The VTC will inform the TMC of the result of the RRA and will proceed to the ToD. It will also send the end of service to the TMC.

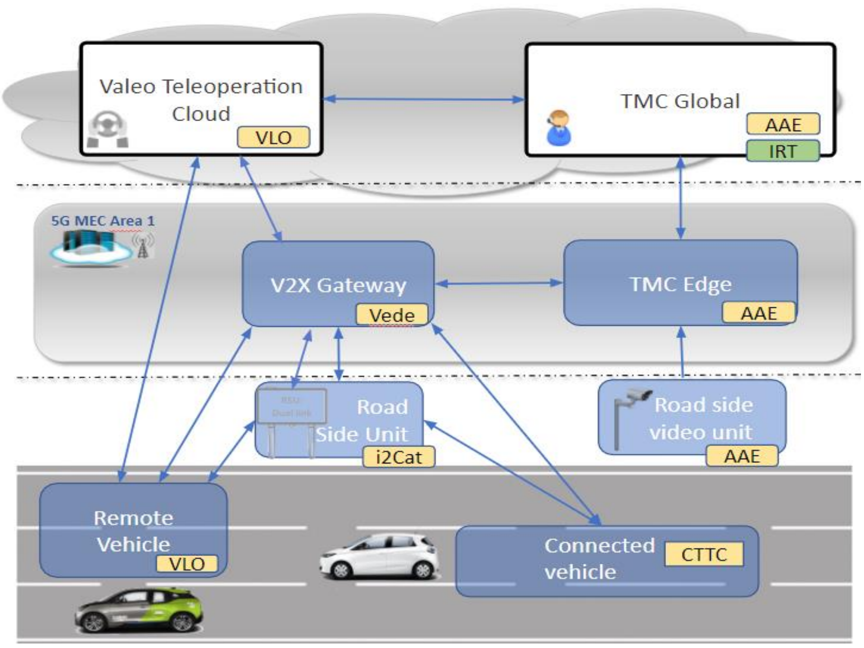

Figure 4. High-level functional architecture for UC1

For the UC1, we group the functional blocks into four different categories:

- TMC Global
- Remote Vehicle
- Remote Station
- Valeo Teleoperation Cloud

A detailed functional view is provided for each of the blocks composing those categories in the following sections.

3.2.1.1 I/O Remote driving support

Before starting remote driving, it needs authorization from the traffic authority and/or the road operator for safety reasons. The I/O Remote driving support is a component from TMC Global that process the requests for driving a vehicle remotely. It validates those requests in a secure way to accept or reject them depending on some criteria like the current road and traffic status. Alternatively, it could also modify the proposed destination of them to a more secure new one.

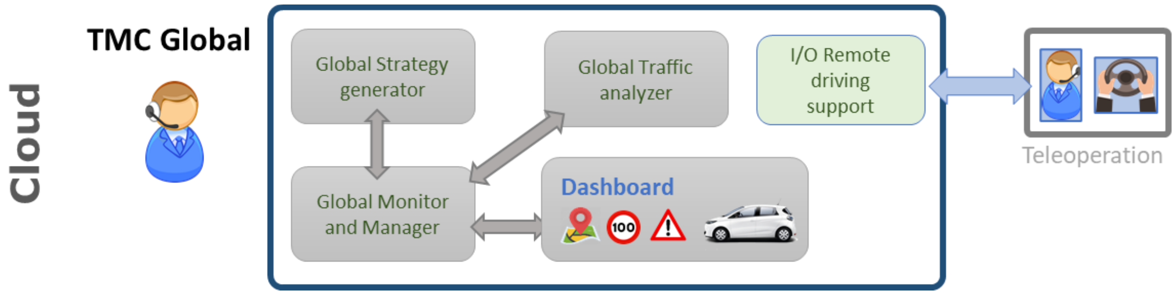

Figure 5. TMC Global Detailed Functional Architecture

3.2.1.2 Remote Vehicle

The RV is an L4 autonomous vehicle, that can track failures (equipment failure, external events, road markings, i.e., anything that causes the system to leave its operation domain) to trigger a Minimum Risk Manoeuvre. To get out of a possibly hazardous situation (if the MRM ends up with a stoppage on a highway emergency lane, for instance), the RV will Request Remote Assistance. Figure 6 illustrates the functional architecture of the remote vehicle sub-system, including the main interfaces (red circles).

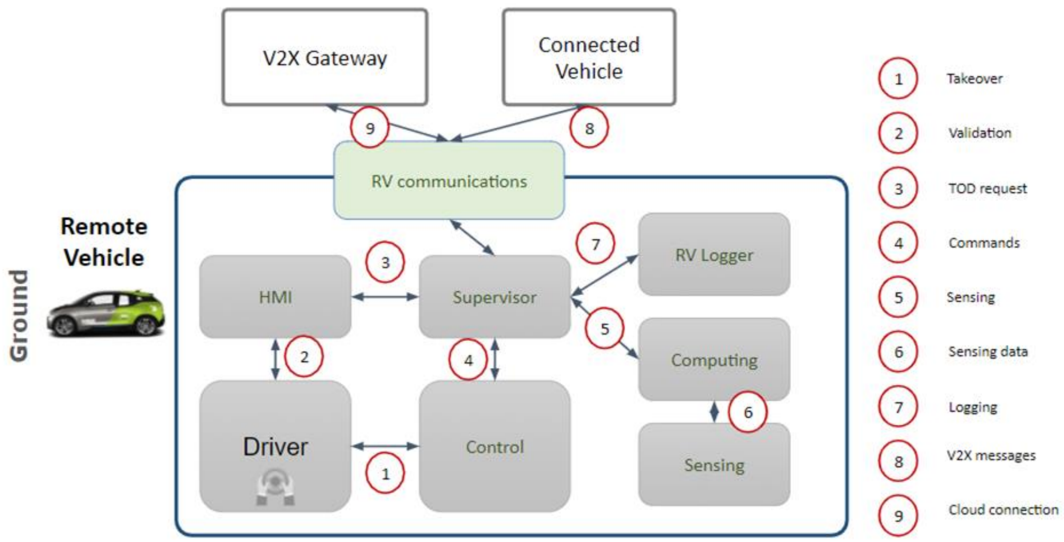

Figure 6. Remote vehicle functional block view

As we see the main functional blocks are:

- The **Computing** block transforms the raw data for all sensors into a single exploitable perception of the vehicle. It also creates trajectories to be followed according to the current driving situation.
- The **Control** block applies the validated commands to the vehicle according to the supervision block.
- The **Driver** is the human inside the RV also called "User" during the autonomous driving or teleoperation driving control phase.
- The **HMI** permits to exchange information between the Driver, the RV and the Remote Driver. Thanks to it, we will be able to do a RRA, communicate with the remote driver and accept/decline the teleoperation.

- The **RV communications** module is able to connect to 5G and manage V2X data encoding / decoding.
- The **RV logger** records all data within the RV as a black box.
- The **Sensing** represents all the sensors need to enable the automation of the vehicle and the teleoperation driving. Several cameras, radars, lidars and embedded information are collected to meet the requirements of the UC1.
- The **Supervision** is an intelligence able to judge the relevance and priority of events and data. It controls all the RV's decisions.

The main interfaces are:

1- **Driver takeover:** The driver is able to take back control at any moment by turning the steering wheel or pressing the brake pedal.
2- **Validation:** The passenger is able to accept the ToD and communication with the Remote Driver via the HMI.
3- **ToD request:** The HMI will send a ToD request.
4- **Commands:** The controls of the vehicle will send commands to the supervisor.
5- **Sensing:** The computing will interpret the raw data to create the vehicle perception.
6- **Sensing data:** The vehicle sensor set sends data raw to the computing.
7- **Logging:** Every single activity will be logged.
8- **V2X messages:** The RV will send V2X messages when the service is running.
9- **Cloud connection:** A V2X and 5G connection to make the RRA and proceed with the ToD.

3.2.1.3 Remote Station

The RS is a place where the Remote Driver will assess the need of ToD, communicate with the requester, and proceed with a ToD. Its block diagram is illustrated in Figure 7.

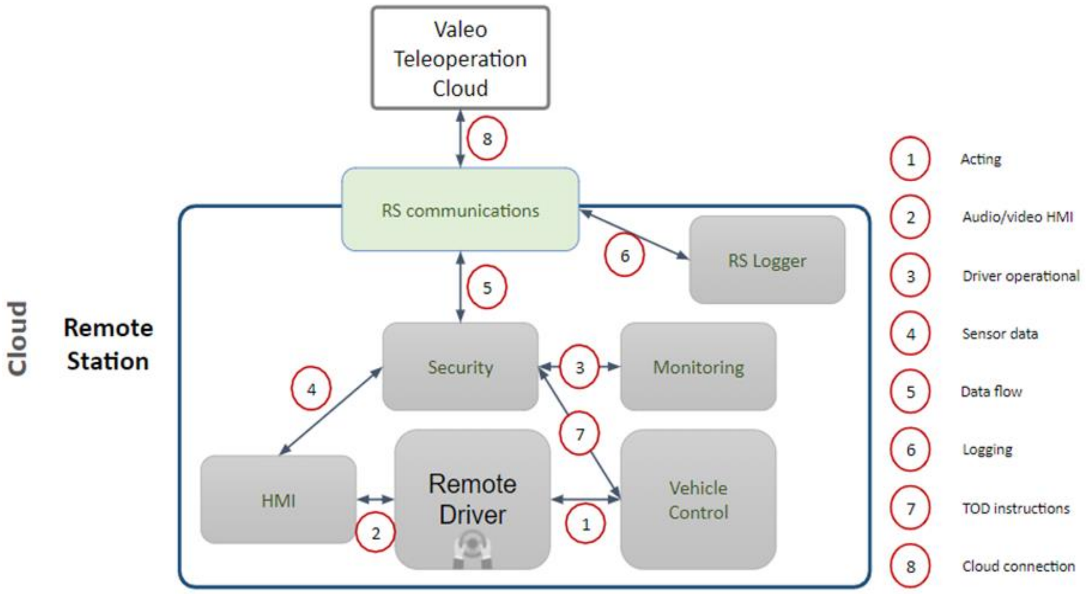

Figure 7. Remote Station functional block view

As we see, the main functional blocks are:

- The **HMI** will allow the remote driver to assess the RV situation and validate the RRA for a ToD. It will also let him be able to see as he would be in the RV to allow him to teleoperate safely.
- The **Monitoring** is a safety module to track the ability of the remote driver for teleoperation. It will detect the distraction and the drowsiness of the remote driver.
- The **Remote Driver** is the person able to teleoperate the remote vehicle.
- The **RS communications** are the bridge between the RS and the VTC.
- The **RS logger** records all data within the RS as a black box.
- The **Security** is a consistency data validation to enable the sending and receiving of relevant and applicable data for the RV.

The interfaces in this case are:

1- **Acting:** The remote driver is able to control the RV.
2- **Audio/video HMI:** The remote driver will receive all relevant information about the RV for a ToD.
3- **Driver Operational:** A camera will track the distraction and the drowsiness to the remote driver.
4- **Sensor data:** Surrounding cameras and all vehicle data will be displayed on the HMI
5- **Data flow:** The voice communication and the vehicle data will be retrieved from the RV.
6- **Logging:** Every single activity will be logged.
7- **ToD instructions:** For safety purposes, the actions on the RV will be validated as ToD instructions.
8- **Cloud connections:** This is the secure connection to VTC.

3.2.1.4 Valeo Teleoperation Cloud

The VTC is a part of the Valeo Cloud Services. It is focused on the requested low latency performance for automotive use cases, the high volume of data (often videos) and the high security. Figure 8 illustrates the functional architecture of the VTC sub-system:

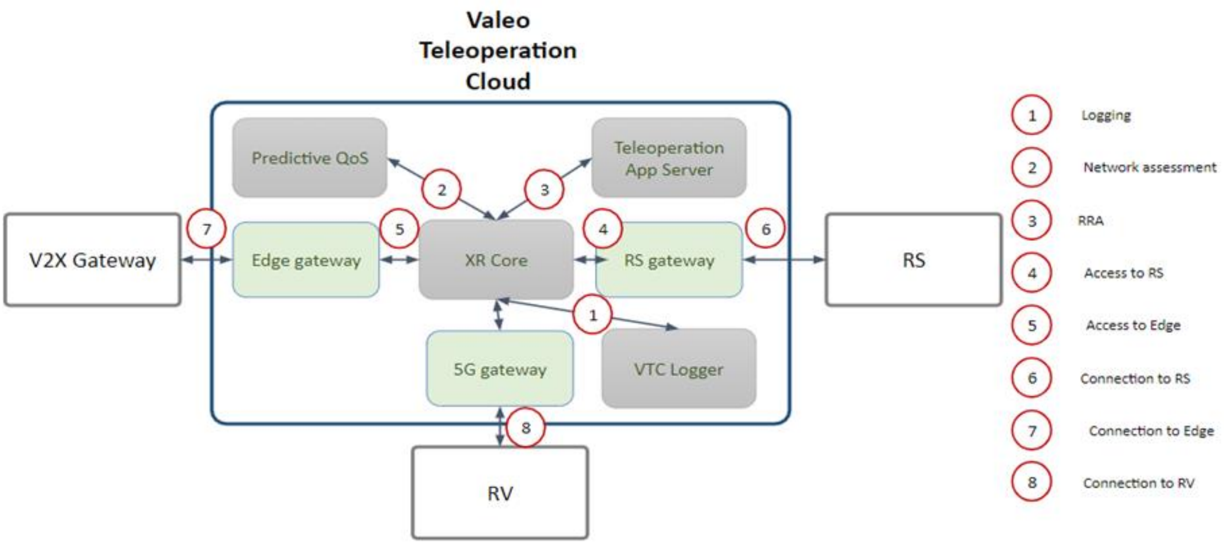

Figure 8. Valeo Teleoperation Cloud functional block view

As we see, the main functional blocks composing the VTC are:

- The **Predictive QoS** module will be hosted into the VTC. It will collect data from multiple systems (Remote Station, Remove Vehicle, Network, the VTC itself too) and compute a QoS indicator. This QoS indicator will give an estimate of the capability to teleoperate the given vehicle at any time.
- **XR Core** is a data routing application capable of handling a high volume of traffic and numerous end points with low latency. Almost all the data flows (especially as they are media-intensive) shall be routed through it.
- The **Teleoperation App Serve**r is a dedicated application for the teleoperation of 5GMed. It manages and supervises both the vehicles and remote stations and approves teleoperation sessions.
- The **VTC Logger** stores all meaningful events of what is occurring in the VTC block.

Also,

the main interfaces are presented below:

1- **Logging:** Every single activity will be logged.
2- **Network assessment:** The predictive QoS will consume the status from the network and send back QoS assessment.
3- **RRA:** The Teleoperation App server will receive a Request for Remote Assistance. It will look for an available RS.
4- **Access to RS:** This is all the date of connection of camera for the teleoperation.
5- **Access to Edge:** This is the access and validation to the Edge side.
6- **Connection to RS:** This is the entry point for the RS.
7- **Connection to Edge:** This is the entry point for the Edge.
8- **Connection to RV:** This is the entry point for the RV.

3.2.2 Behavioural View

In this section, we will show the behaviour for the services of the UC1 which are the MRM, the RRA and the ToD. This will use sequence diagrams: An overall concerning the sequence of the services, the MRM, the RRA and the ToD.

3.2.2.1 UC1 Global sequence diagram

Below, we have the complete sequence diagram (Figure 9) describing all the services. To start the first service of UC1 (i.e., MRM), some conditions needs to be met. Initially, the CAVs need to drive autonomously, then, there must be a safety driver behind the steering wheel, and finally, the connection to the remote station must be acknowledged through a QoS assessment. Once these conditions are met, we enter in the MRM Service's sequence diagram (Figure 10). At its end, we have the remote vehicle parked on the emergency lane. The process of RRA (Figure 11) may start to find a solution to get out of this situation. If the teleoperation is the assistance, the selected Remote Cockpit will send a request of teleoperation to the Remote Vehicle. Via its HMI, the driver will accept it and the last service of Remote Driving will begin (Figure 12). This service will end when the Remote Vehicle arrives at a safe harbour, to be defined according to the starting situation.

3.2.2.2 UC1 MRM sequence diagram

During all the action, the roadside video unit from the road operator may monitor the autonomous vehicle to verify that everything is going-on and this is no MRM triggered. In parallel, we will always have an assessment of QoS to manage the possibility of teleoperation. The description of the QoS is not part of this deliverable. It is under definition.

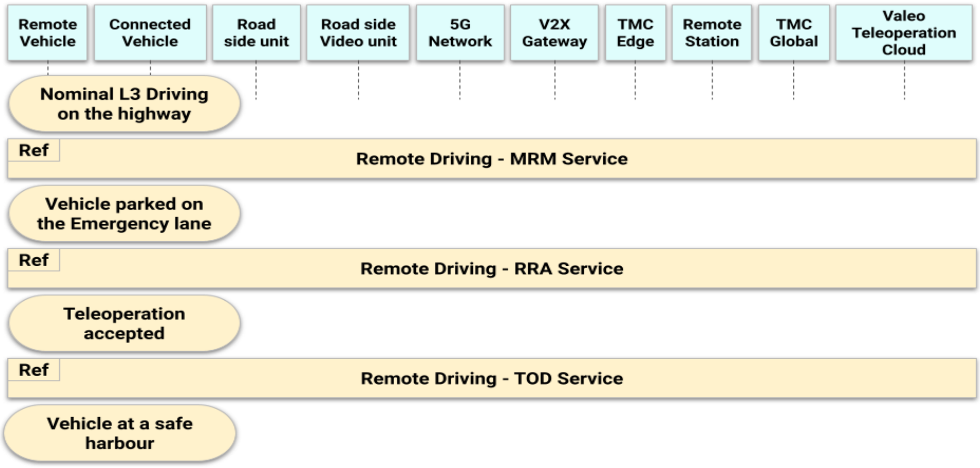

Figure 9. UC1 Remote Driving global sequence diagram

Once the vehicle detects a significant failure, the Remote Vehicle will self-evaluate the need for an MRM. In the nominal case, the MRM will be applied and started. The Remote Vehicle will inform the TMC and will proceed till reaching an emergency lane.

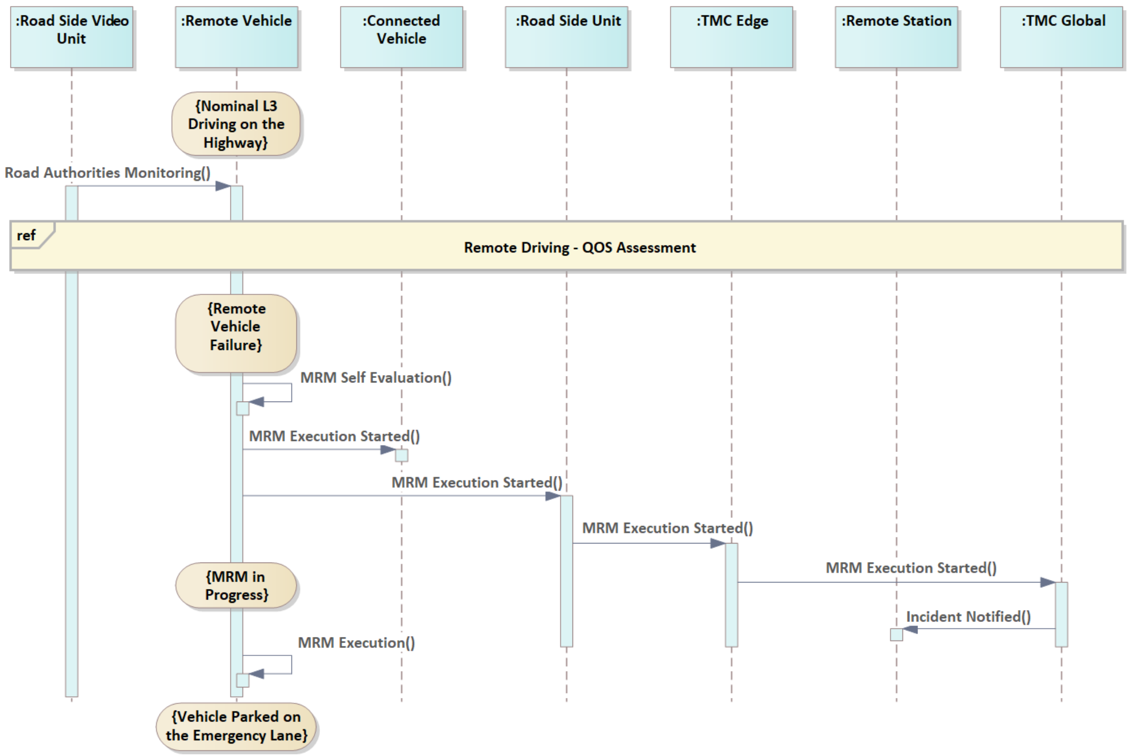

Figure 10. UC1 Remote Driving MRM sequence diagram

3.2.2.3 UC1 RRA sequence diagram

The vehicle is parked. The TMC still monitors the Remote Vehicle and the QoS is being evaluated. While the vehicle is stopped, it will send V2X messages to inform the direct surrounding vehicles. This action is similar to turn on warnings while you are in the same situation on a normal vehicle. The Remote Vehicle sends an RRA to the Valeo Teleoperation Cloud. It sends a description of a mission to the Remote Cockpit. After its acceptance, the Remote Cockpit will request access to data from the Remote Vehicle to evaluate the current situation to teleoperate. The teleoperator will validate the request for remote assistance with direct teleoperation driving. The Remote Vehicle accepts it and the teleoperation will start.

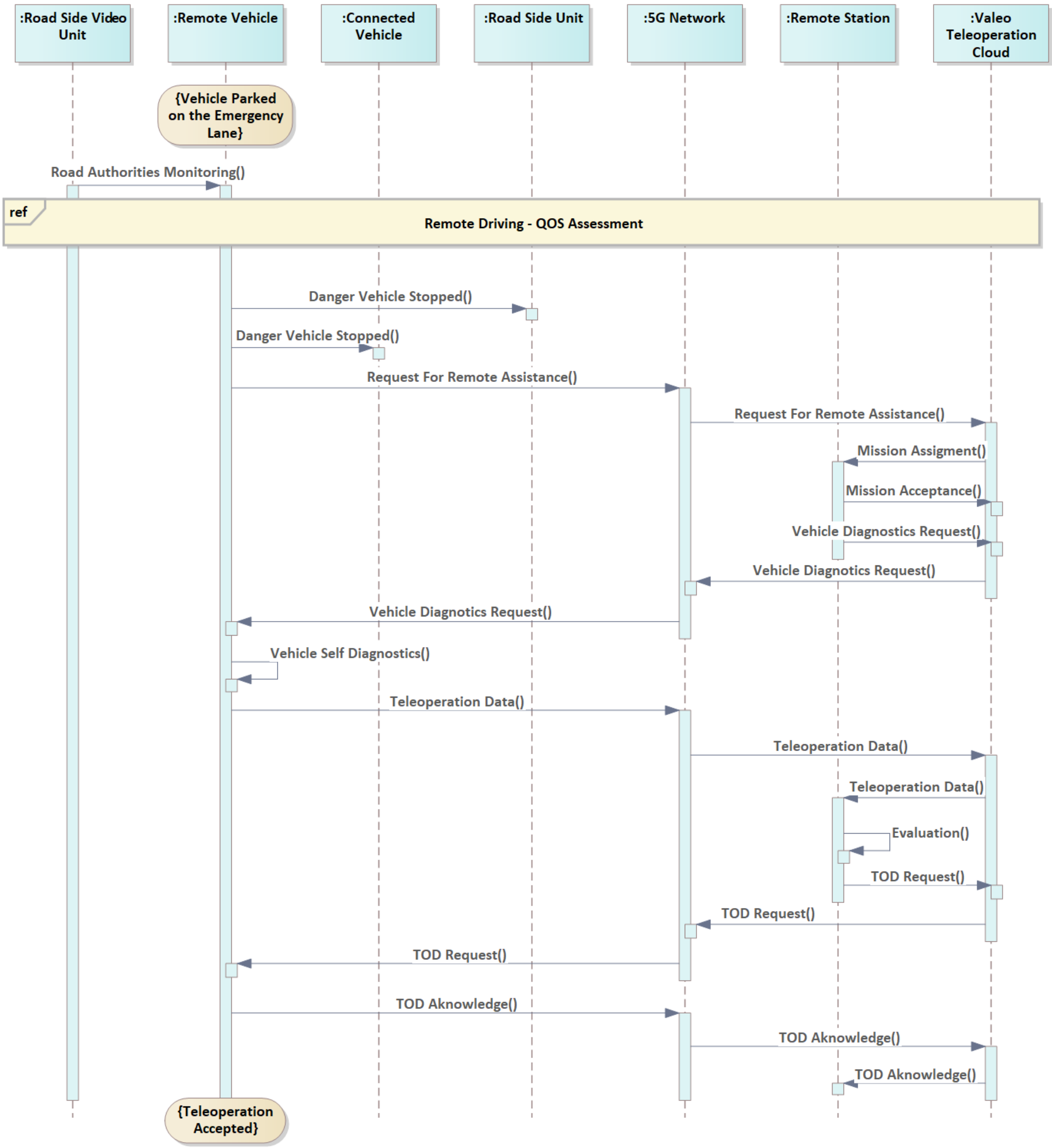

Figure 11. UC1 Remote Driving RRA sequence diagram

3.2.2.4 UC1 ToD sequence diagram

Like the two previous services, we still have the monitoring from the TMC and the assessment of the QoS. The remote vehicle creates a specific set of data to enable teleoperation. These data are directly displayed to the remote driver via its HMI. According to this information, the remote driver will remotely drive the remote vehicle. During the transit of the data through the Valeo Teleoperation Cloud, it will check the consistency of the ToD commands to avoid any hazardous situations. Another consistency check will be done in the Remote Vehicle before applying the ToD commands. This behaviour is repeated till the Remote Vehicle reaches a safe harbour.

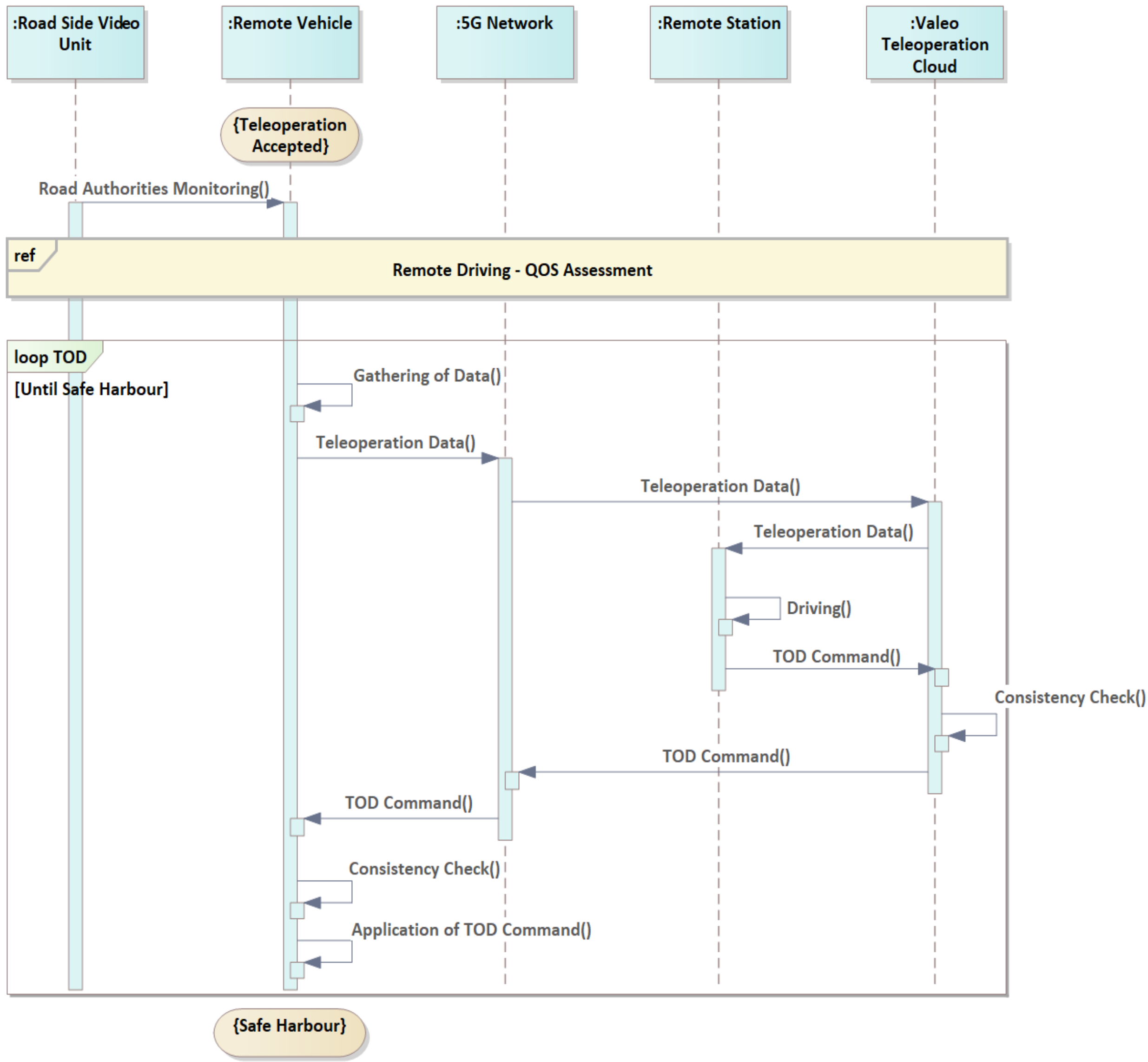

Figure 12. UC1 Remote Driving ToD sequence diagram

3.2.2.5 TMC Global Block Diagram

Figure 13 shows the behavioural view of the I/O Remote driving support in the TMC Global and its interaction with the Teleoperation component.

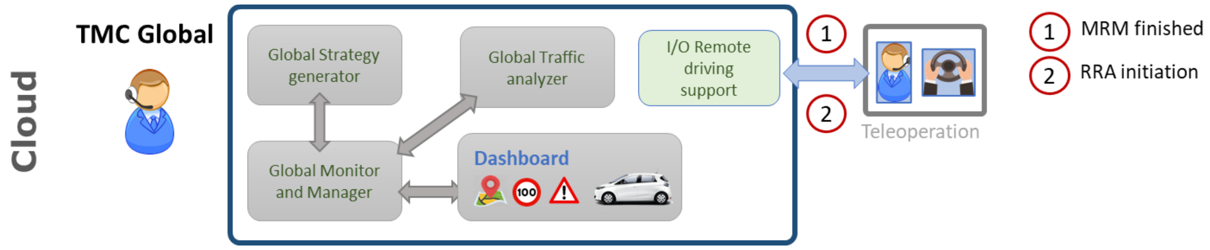

Figure 13. TMC Global Behavioural View

As we see only two actions are envisaged:

1- **MRM finished:** At the end of MRM, the CAV is stopped and asks the TMC Global if it is stopped in a safe place.

2- **RRA initiation:** If the TMC determines that the car is stopped in a dangerous location, it will provide you with a safe location to go to and request an RRA.

3.2.3 Deployment notes

In section 3.2, we have seen a split of the architecture between the Ground, the Edge and the Cloud levels. Indeed, in this project, the deployment of systems is made on different sites and we will have to ensure the very low latency between them. To succeed with this constraint, we have to optimize the physical distance between them and optimize the transmission speed of the actor in the chain of the information. We are studying all solutions to teleoperate safely. Now, for each part of the system, we can find the deployment notes of each.

3.2.3.1 Traffic Management Control

The following notes shall be considered for the deployment of the TMC Cloud and Edge, and Road Video Sensors for the UC1 (same as UC2):

- The TMC Cloud must run on a cloud platform accessible through the internet by every MEC.
- The TMC Cloud will provide global computation capabilities and storage services to enable the implementation and execution of AI models for predicting and optimizing road traffic flows,
- The TMC Cloud will provide secure REST API interfaces and a dashboard as user operation console.
- The TMC Edge computing node has the availabilities: access the internet, access 5G RAN and access RSU placed on road using 5G RAN or alternative path.
- Every MEC will contain an Edge TMC and a V2X Gateway covering a known highway area.
- Every MEC should have enough performance to manage video analysis computing (for at least 8 cameras) & V2X Gateway.
- Every roadside sensor will include HD Video Cameras and a5G router.

3.2.3.2 Remote Vehicle

The following notes shall be considered for the deployment of the sensors, the TCU and the HMI inside the Remote Vehicle for the UC1:

- The antennas of the V2X radio interfaces (5G, C-V2X, ITS-G5) can be installed on the roof or the trunk of the vehicle, facilitating the cabling of coaxial cables between the antennas and the TCU located inside the vehicle.

- The front camera must be installed in the front of the vehicle, on the windshield, which must facilitate cabling between the video-camera and the GPU-based embedded computer of the Smart Sensor located inside the vehicle.
- The vehicle must provide an interface with a GPS antenna, which must be connected with the TCU for clock synchronization and to determine the position of the vehicle.
- The vehicle must provide an interface port with the CAN bus in order to facilitate the exchange of data between the TCU, the HMI and other systems.
- The vehicle must provide measurements of current speed and position through the CAN bus.
- The vehicle must provide the power supply to computers, the TCU and the HMI.
- The TCU will be composed of a CPU, a 5G modem, a C-V2X module, an ETSI ITS-G5 module, a CAN bus interface, an Ethernet interface, and a GPS receiver for CPU clock synchronization and vehicle's positioning.
- The HMI will be a touch screen deployed in the front panel of the vehicle to facilitate the interaction with the driver.

3.2.3.3 Remote Station

The following notes shall be considered for the deployment of the modules of the Remote Station for the UC1:

- The system may provide information to an external supervision system of what's going at the given Remote Station (availability of operator, video feed, ongoing operations, logs, etc) to allow central management of a Remote Assistance service pool.
- The Remote Station should provide to the Remote Vehicle a Certificate to validate its identity and the validity of all control commands.
- All communication happening between the Remote Driver (in the RS) and the Remote Vehicle (e.g., incoming sensors info, controls sending, videoconference) shall be encrypted to prevent from eavesdropping or cyber-attacks.
- The system shall implement safety mechanisms to mitigate obvious dangerous manoeuvres (e.g., brutal steering wheel turn at high velocity).

3.2.3.4 Valeo Teleoperation Cloud

The following notes shall be considered for the deployment of the sensors, the TCU and the HMI inside the Remote Vehicle for the UC1:

- The VTC is under the operation of Valeo at its cloud provider, AWS. Any access has to be validated by Valeo.
- The VTC has to be scalable, redundant and always active.
- The API access will be provided to each partner within the UC1.

3.3 UC2 detailed functional architectural elements

To achieve UC2, it must be stepped up from conventional infrastructure to the digitization of managed information. This provides more capabilities, such as real-time data exchange, but increases physical equipment and data handling requirements. Five classes of infrastructure (ISAD) were designed, and the 5GMed project aims to reach a high level to achieve the UC2 objectives. Having defined the system elements, the process to classify them in a certain category is a difficult task. Some indicative examples of the multiple potential dimensions used to classify the road infrastructure are the following:

- TMC involvement grade in automated functions control
- Readiness for specific levels of vehicle automation
- Physical infrastructure adherence to specific technical standards or condition of repair
- Availability of additional physical infrastructure support elements (e.g. special markers)
- Wireless communication infrastructure capabilities (V2I & I2V)
- Digital infrastructure (Local Dynamic Map Layers)
- Back-office information support functionality

The components in UC2 are divided among the three main architecture layers at which the 5GMed project has to work in order to achieve the use cases goals:

- The Road layer: digitization of the infrastructure by cameras which generate the video streaming in real-time and send it to the MEC. In this layer, CAVs are circulating while sending vehicle's information and receiving traffic recommendations from the MEC's V2X Gateway by 5G communications.
- The Edge layer of the UC2 develops:
    1. Algorithms for traffic video-analysis
    2. The edge HUB with the whole data from connected cars and digital cameras.
    3. Traffic analysis and incidents detection.
    4. Strategies to achieve the test cases that required very low latency and a short-range.
    5. V2X Gateway for the communications of the CAV with the infrastructure.

  The video streaming from cameras is analysed by the algorithms located in the MEC infrastructure, detect real-time information such as the vehicle number per lane, classification, speed, vehicle colour, and so on. Together with CAV information and floating data, this information will help develop future proactive traffic management.
- The Cloud layer of UC2 develops:
    1. Global TMC with:
        - Traffic modelling and traffic flow estimation methods for mixed traffic.
        - Traffic strategies to achieve the test cases with a macroscopic perception of the road.
    2. Real-time management.

3. Mobility HUB with whole data from connected cars, floating data, and digital cameras. Cloud solutions, Big data (integration with 3rd parties).

3.3.1 Detailed Functional Block View

For the UC2, we can group the functional blocks into 4 different categories:

- TMC and road video sensors
- Mobility Data HUB
- V2X Gateway
- Connected vehicle

In the following sections, a detailed functional view is provided for each of the blocks composing those categories.

3.3.1.1 Traffic Management Control and road video sensors

This section introduces the detailed functional architecture of the main application components of the UC2 at the Edge and Cloud layers (the TMC Edge and the TMC Global). Those components with their subcomponents and their connections between them and the external ones are depicted in Figure 14.

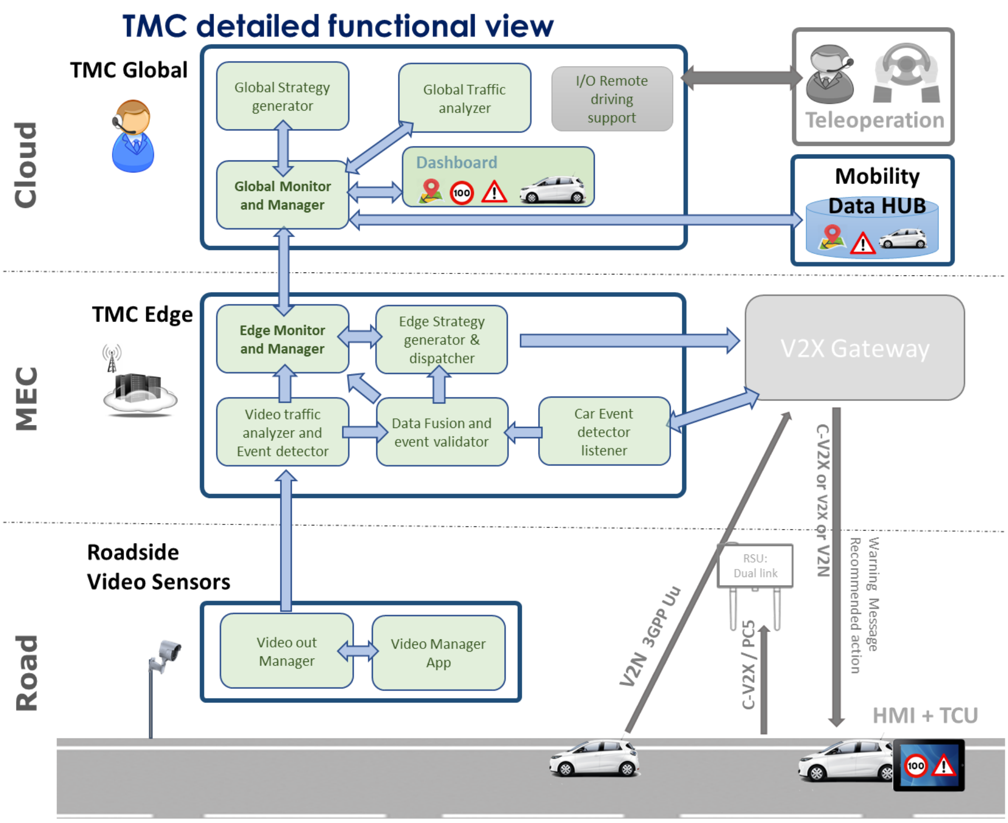

Figure 14. TMC and Road video sensors functional architecture

The TMC edge centralised in a distributed way through communications with the roadside video sensors and CAVs via the V2X Gateway for each MEC area. After that, the TMC Global gets the information generated in all the TMC edges and centralises them. With a full vision of the real state for each TMC, The TMC Global could generate global strategies for the traffic management in the whole site. For each of the main blocks, the detailed components are listed next:

TMC Global

- **Global strategy generator**: It generates global and edge-adapted traffic management strategies for the whole road site.
- **Global Traffic analyser**: It analyses the traffic status at a global level from the traffic info received from the edges.
- **Global Monitor and Manager**: It manages the traffic, incidents and strategies info at global level. Interface the data between the TMC Global components and dispatch the global traffic strategies to the edges.
- **I/O Remote driving support**: This component supports the remote driving use case. It analyses the requests to remote driving a vehicle to validate, modify or reject them.
- **Dashboard**: It supports the traffic management process by providing a user interface with visual and numeric metrics available to the traffic management operators.

TMC Edge

- **Edge Monitor and Manager**: It manages the traffic, incidents and strategies info at the edge level. Interface the data between the TMC Edge components and communicate the traffic status and strategies info the to the TMC Global.
- **Edge Strategy generator & dispatcher**: It generates traffic management strategies at the edge level and dispatches them to the connected vehicles via V2X Gateway.
- **Video traffic analyser and Event detector**: It analyses the video stream data to get the traffic status of the road at real-time.
- **Data Fusion and event validator**: It validates the events/incidents data received from the connected vehicles. After that, it fuses all the ones received from about a single event. Either from the connected vehicles as well as the ones get from the cameras when they exist.
- **Car Event detector listener**: It receives the events/incidents data communicated by the connected vehicles via the V2X Gateway.

Roadside Video Sensors

- **Video out manager**: This component manages the communication of the video data get from the cameras to the external sources.
- **Video Manager app**: This component provides a user interface to the end-users for managing the cameras and their setup.

3.3.1.2 Mobility Data HUB

In this section, the detailed functional architecture of the Mobility Data hub is presented. The following Figure 15 shows the diagram of the detailed functional components of this:

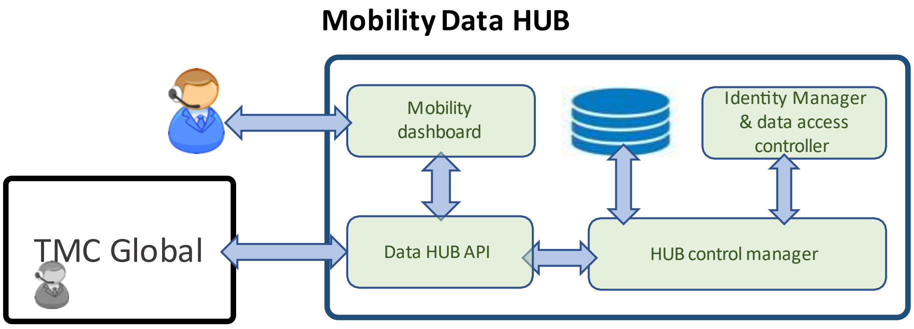

Figure 15. Mobility Data HUB functional architecture

This unified repository manages any data necessary for mobility solutions including traffic-related data and data from other sources; for example, they could be toll systems, historic of incidents and traffic flows, mobility restrictions or weather forecast. As shown in the previous figure, the Mobility Data HUB is composed of the following functional components:

- **HUB control Manager**: Manages the data access requests by checking permissions and providing the data access when granted. Allows to store, retrieve, modify or remove any kind of mobility data. It also performs data verification providing data filtering or small data elaboration for data homogenization when necessary.
- **Identity Manager & data access controller**: Manages (add, edit, remove) data access identities and roles and checks data access control via validation of the identity credentials and permissions or via the establishment of secure communication channels such as virtual private networks.
- **Data HUB API**: Provides an open interface for all data exchange functionalities available on the Mobility Data HUB from and to external components. It consists of a set of APIs to upload and download data based on different technologies such as REST, graphQL [Gra21] and others. It also provides standardized data formats such as Datex II [Dat21] and supports the ingestion of raw data and metadata from applications in real-time up to high throughputs.
- **Mobility dashboard**: Provides a web interface to visualize sets of data in pre-configured dashboards. Assists data visualization with geolocated data and analytic queries for a flexible, dynamic and customer-oriented visualization.

3.3.1.3 V2X Gateway

A V2X gateway is used to disseminate Vehicle-to-Vehicle (V2V) and V2I messages over multiple technologies, particularly, 5G/4G, C-V2X, and ITS G5. As illustrated in Figure 16 the gateway is installed in a MEC, interfaces with different telecommunication roadside infrastructure, particularly RSUs installed with C-V2X and/or ITS-G5 technologies and gNB of 5G networks.

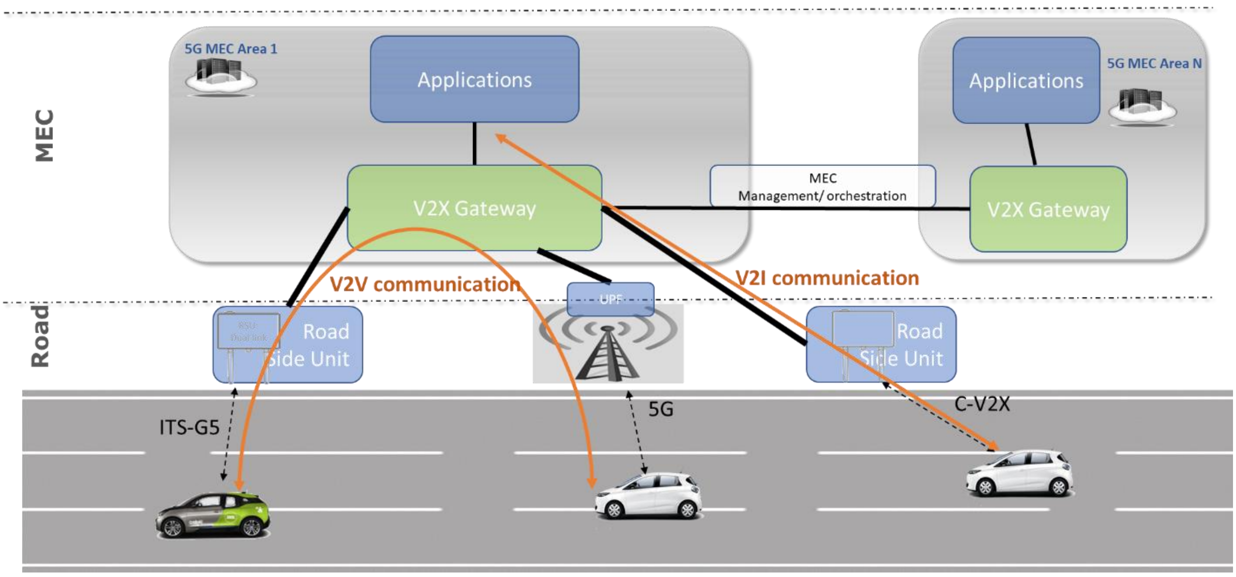

Figure 16. V2X Gateway enabling V2X communication over multiple communication technologies

The main objective of the V2X gateway to disseminate messages over the geographical area, called the V2X service area, covered by the RSUs and the gNB, with which it interfaces directly. V2X gateways are operating in different cooperative MECs so that a message can be disseminated beyond the service area of a given V2X gateway.

Figure 17 shows the functional design of a V2X gateway.

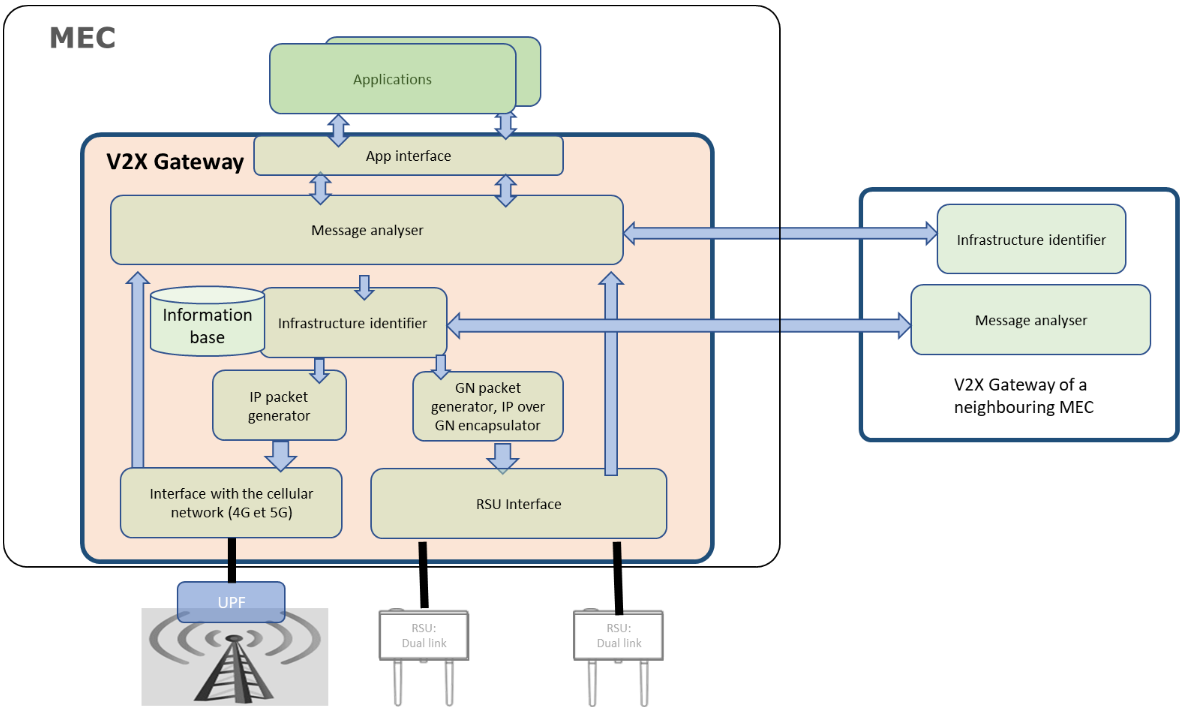

Figure 17. V2X Gateway Modules

As illustrated in Figure 17, a V2X gateway consists of message analyser, infrastructure identifier, IP and GN packet generators, interfaces with the gNB, the RSUs, and applications. The roles of individual modules are as follows:

- Interfaces with the gNB and the RSUs are for direct communication with these telecommunication roadside infrastructures.
- App interfaces are for message exchanges with applications installed in the MEC.
- Message analyser analyses the messages received from gNB, RSUs, applications, and neighbouring V2X gateways. It identifies mainly the message type and the destination area.
- The interface identifier is to identify the gNB and the RSUs that shall disseminate the message in their coverage area. If the message needs to be disseminated beyond the V2X service area, the next-hop V2X gateway is identified, and the message is forwarded to the message analyser of the next-hop V2X gateway.
- The information base contains the necessary for interface identifier in identifying the appropriate gNB, RSUs, and V2X gateway for disseminating of the message. The information can be static information such as gNB, RSU, neighbour v2X gateway positions and their coverage/service areas. It can also be more dynamic information such as vehicles positions or application requirements.
- IP and GeoNetworking (GN) packet generators generate IP and GN packets. When necessary, it performs packet encapsulation operation particularly, IP over GN encapsulation to transmit GN packets to RSUs over IP interface.

3.3.1.4 Connected vehicle

The Connected Vehicle for the UC2 will be equipped with the functional blocks represented in Figure 18: Telematics Control Unit (TCU), HMI and Smart Sensor. For each of these functional blocks, the detailed components are briefly described as follows.

Telematics Control Unit:

- **5G, C-V2X/ITS-G5 Radio Interfaces:** They provide connectivity with the V2X Gateway via 5G or through the Roadside Units using either C-V2X or ITS-G5.
- **V2X Protocol Stack:** In transmission, the V2X Protocol Stack encodes V2X messages and sends them to the V2X Gateway through the radio interfaces. Upon reception of V2X messages from the radio interfaces, the V2X Protocol Stack decodes the messages received, and forwards data to the UC2 Application Client.
- **UC2 Application Client**: It receives information of hazards/events detected by the Smart Sensor, sends the hazards/events' data to the HMI, and triggers the transmission of V2X messages through the V2X Protocol Stack. The UC2 Application Client gets data from the V2X messages received by the V2X Protocol Stack and forwards data to the HMI.
- **GPS Receiver**: It is used to determine the vehicle's position and for clock synchronization.

Human Machine Interface:

- **HMI**: It displays on a map the current position and speed of the vehicle, the location of hazards/events detected by the Smart Sensor, and the location of hazards/events received by the TCU from the V2X Gateway. In addition, the HMI shows warning messages and recommendations received by the TCU from the V2X Gateway.

Smart Sensor:

- **Video-camera**: It acquires real-time video images on the front of the vehicle.

- **AI-based event detection and classification**: It processes video streams, detects, and classifies hazards/events in front of the vehicle.

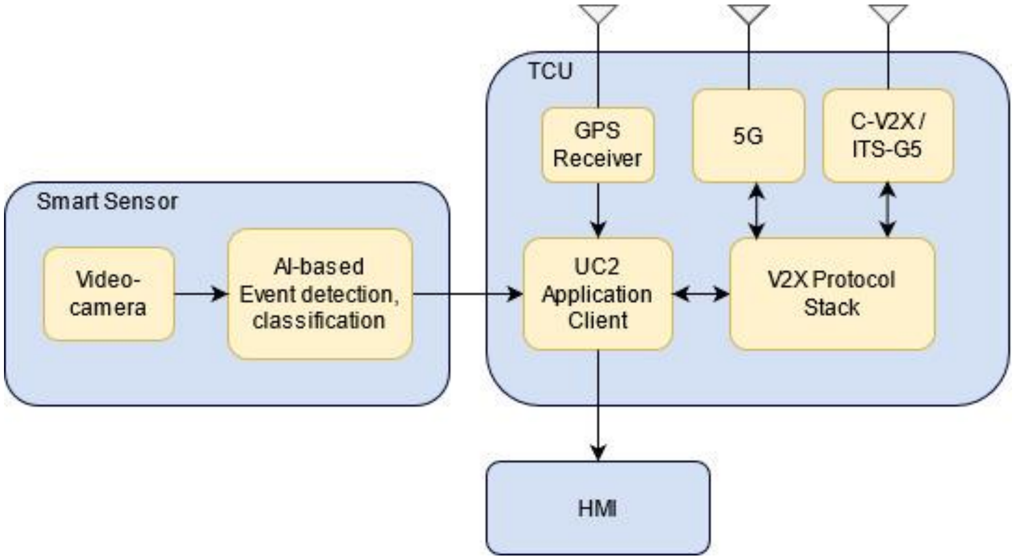

Figure 18. Block diagram of the connected vehicle used in UC2

3.3.2 Behavioural View

For showing the interaction among the different functional blocks, the next sections provide a behavioural view diagram divided following the same structure as presented in previous section 3.3.1. For the TMC components, a detailed flow diagrams combining all the blocks will be depicted for each of the three services of the UC2 defined in T2.2 and depicted in D2.2 [5GM21-D22]. For the other components (Mobility Data HUB, V2X Gateway and Connected Vehicle), the flow diagram will focus on the interaction of their own internal components.

3.3.2.1 Relay Emergency Message sent from vehicle to infrastructure

In this service the connected vehicles communicate the TMC edge an incident/event from the road. With this information, the TMC edge generate and communicate a traffic strategy both to the TMC global the connected vehicles in its road area. Figure 19 shows a diagram with the behavioural view of this service. As we see, the sequence of actions is as follows:

1- **Detection**: The connected vehicles detected an incident/event in the road and communicated it via 5G or the RSU.
2- **Gateway**: The gateway centralizes the messages of the connected vehicles arriving by using different network technologies in the road and send them to the Car Event detector listener of the TMC Edge.
3- **Event listener**: The event listener gets the car events communicated through the V2X Gateway
4- **Event validation**: The event is validated after some conditions, for example, when it has been communicated from different vehicles.
5- **Strategy generation**: From the validated event and considering the current traffic flow in the road, a traffic regulation strategy is generated.
6- **Strategy execution**: The traffic strategy is sent to the V2X Gateway (6b) and registered in the Edge Monitor and manager (6a).

7- **Strategy communication**: The V2X Gateway communicates the traffic strategy to the connected vehicles in the road (7b) and to the TMC Global (7a). The traffic flow and the detected road events information at the TMC edge level is also communicated to the TMC global.
8- **Global strategy generation**: If the detected event affects the area covered by the adjacent TMC Edge, the TMC Global generates a global traffic strategy.
9- **Global strategy to TMC edges**: The global traffic strategy is communicated to the TMC edges.
10- **From global to local traffic strategy**: A local traffic strategy is composed based on the orders received from the global traffic strategy.
11- **Global Strategy executed locally**: As done in step (5), recommended actions derived from the global traffic strategy are sent to the V2X Gateway (10).
12- **Strategy communication**: As done in step (6), the traffic strategy is communicated by the V2X Gateway to the connected vehicles in the road (6b).

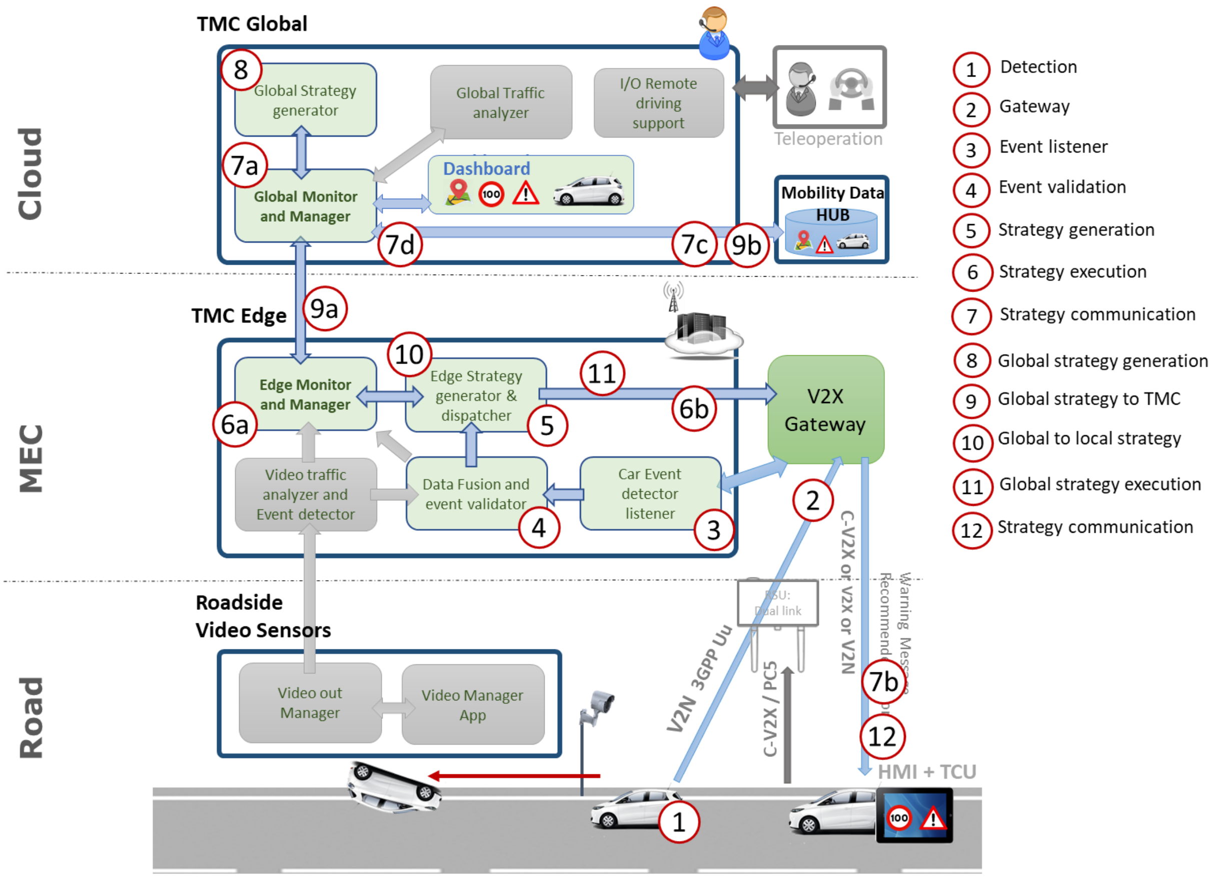

Figure 19. Relay emergency message sent by vehicle to the infrastructure flow diagram

3.3.2.2 Automatic Incident Detection and local area traffic management

This service is similar to the previous (REM), but in this case the incident is detected and communicated by the roadside video sensors to the TMC edge. As in the previous case, with this information, the TMC edge generates and communicates a traffic strategy both to the TMC global the connected vehicles in its road area. The following Figure 20 shows a diagram with the behaviour view of this service:

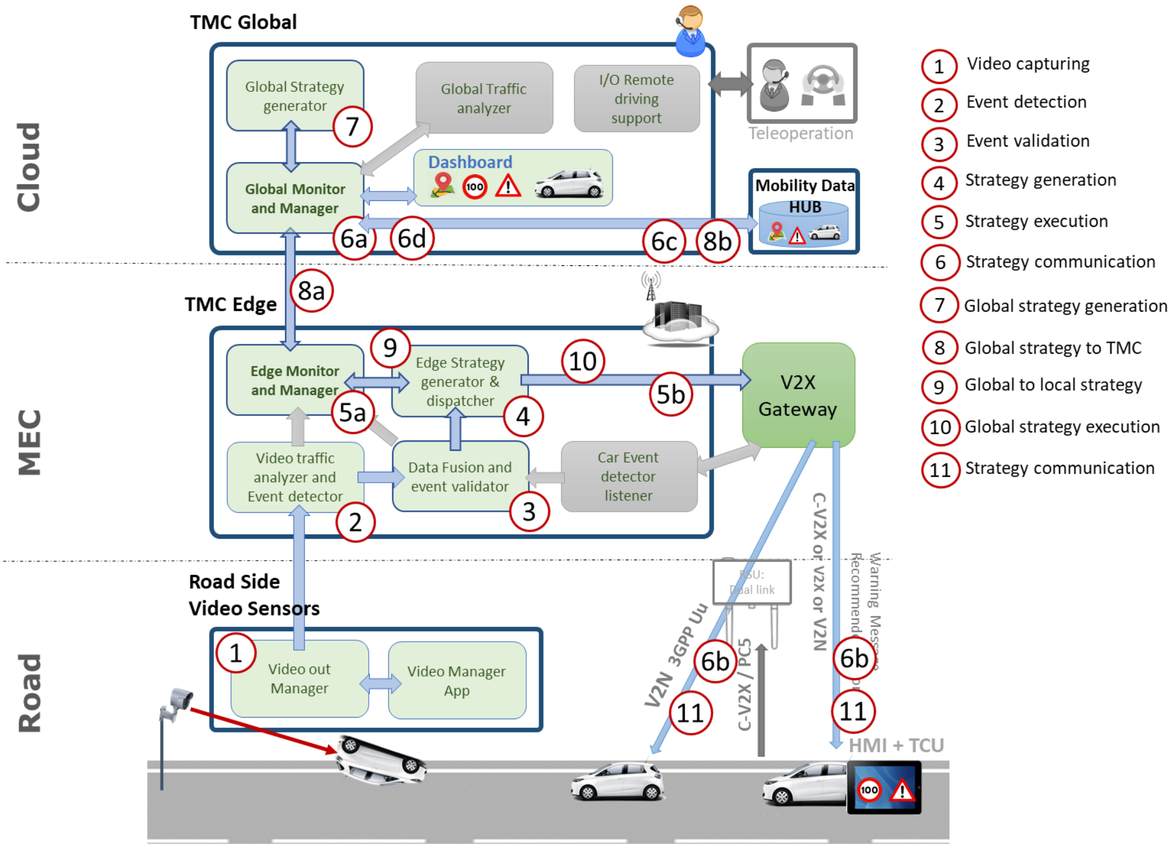

Figure 20. Automatic incident detection and local area traffic management flow diagram

As we see the main steps are:

1- **Video capturing**: The roadside Video Sensors capture the video of the road flow and send it to the TMC Edge.
2- **Event detection**: The analysis of the video received from the roadside video sensors allows to detect road events.
3- **Event validation**: The event is validated and registered
4- **Strategy generation**: From the validated event and taking into account the current traffic flow in the road, a traffic regulation strategy is generated.
5- **Strategy execution**: The traffic strategy is sent to the V2X Gateway (5b) and registered in the Edge Monitor and manager (5a).
6- **Strategy communication**: The traffic strategy is sent to the TMC Global (6a) and converted into recommended actions to be communicated by the V2X Gateway to the connected vehicles in the road (6b). The traffic flow and detected road events information at TMC edge level is also communicated to the TMC global.
7- **Global strategy generation**: If the detected event affects the area covered by the adjacent TMC Edge, the TMC Global generates a global traffic strategy.
8- **Global strategy to TMC edges**: The global traffic strategy is communicated to the TMC edges.
9- **From global to local traffic strategy**: A local traffic strategy is composed based on the orders received from the global traffic strategy.
10- **Global Strategy executed locally**: As done in step (5), the traffic strategy derived from the global one is sent to the V2X Gateway (10).

11- **Strategy communication**: As done in step (6), the traffic strategy is communicated by the V2X Gateway to the connected vehicles on the road (11).

3.3.2.3 Traffic Flow Regulation by using a selected group of C-AVs

In this service the roadside video sensors are continuously sending video to the TMC Edges that monitor the traffic of the road at edge level in real-time. This information is send to the TMC Cloud that, depending on the traffic state, could implement different traffic regulation strategies that will be communicated to the TMC Edges that will implement it by sending specific instructions to the connected vehicles via the V2X Gateway. The following Figure 21 shows a diagram with the behaviour view of this service:

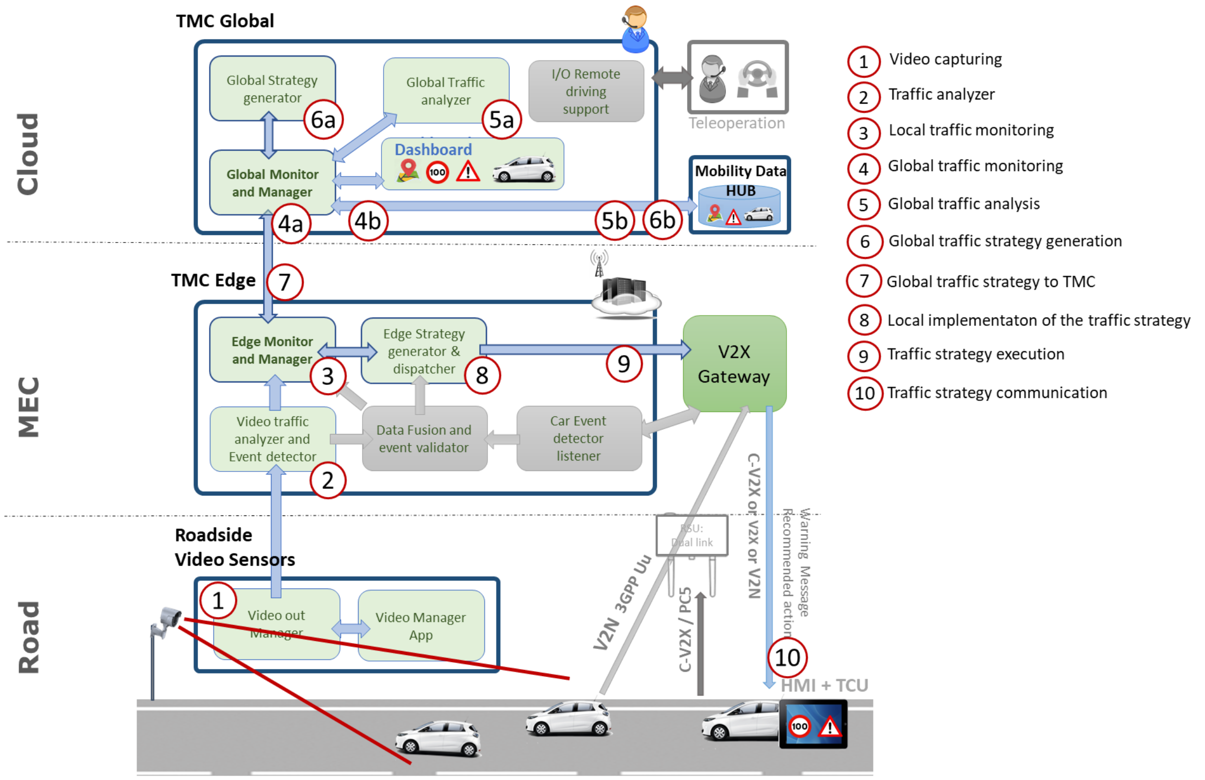

Figure 21. Real-time flow regulation by using a selected group of C-AVs flow diagram

As we can see, the main steps are:

1- **Video capturing**: The roadside Video Sensors capture the video of the road flow and send it to the TMC Edge.

2- **Event detection**: The video received from the roadside video sensors is analysed to transform it into traffic flow data.

3- **Local Traffic Monitoring**: The traffic flow data is monitored, registered and sent to the TMC Global

4- **Global Traffic Monitoring**: The traffic flows from all the TMC edge is monitored globally.

5- **Global Traffic analysis**: The traffic flows data of all the TMC edges is analysed to obtain the global view of the traffic flow in all the road segments.

6- **Global traffic strategy generation**: According to the traffic flows detected in the TMC edges, the TMC Global generates a global traffic strategy.

7- **Global traffic strategy to TMC edges**: The global traffic strategy is communicated to the TMC edges.
8- **Local implementation of the traffic strategy**: A local traffic strategy is composed based on the orders received from the global traffic strategy.
9- **Traffic strategy execution**: The traffic strategy derived from the global one is sent to the V2X Gateway.
10- **Traffic strategy communication:** The traffic strategy is communicated by the V2X Gateway to the connected vehicles on the road.

3.3.2.4 Mobility Data HUB

To show the behaviour between the components of the Mobility Data HUB, two different flows will be depicted. The first is the one depicted in the Figure 22 that occurs once a request is sent to the Mobility Data HUB, for example, from the TMC Global, via its API.

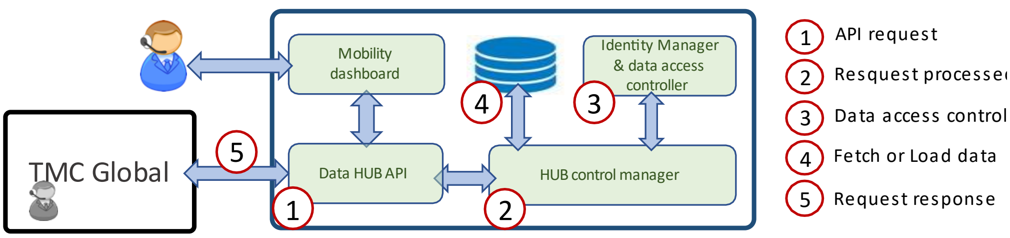

Figure 22. Flow view of a request sent to the Mobility Data Hub.

As we see the main steps are:

1- **API request**: A new request is received via the API interface of the Mobility Data HUB.
2- **Request processed**: The HUB control manager processes the request, decides if an access control has to be checked and manages the access to the data storage.
3- **Data access control**: The Identity Manager validates the request's credentials and checks the permissions for accessing the block of data required.
4- **Fetch or load data**: If the access is grand, then the data is fetched or loaded from/to the data storage.
5- **Request response**: The response is returned to the caller with the success or failed message and the content data when needed.

The second flow is the one depicted in Figure 23, which shows the interaction of the components when a data visualization is requested to the dashboard of the Data Hub.

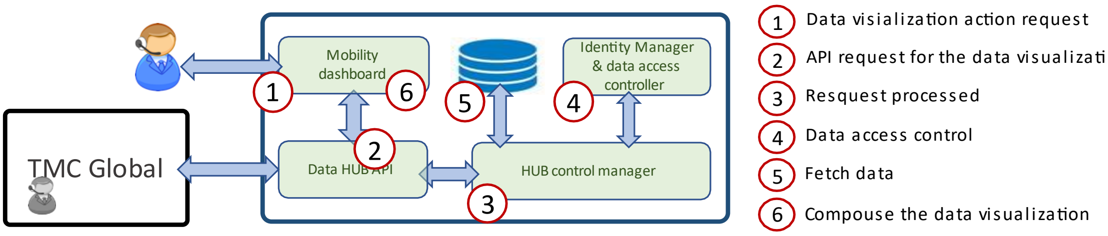

Figure 23. Flow view for a data visualization on the dashboard of the Mobility Data Hub

As we can see, the main steps are:

1- **Data visualization requested**: The end user uses the Mobility dashboard to visualize a specific set of data.
2- **API request for the data visualization**: Depending on the data needed, a set of requests are sent to the API interface of the Mobility Data HUB.
3- **Request processed**: The HUB control manager processes the requests, decides if an access control has to be checked and manages the access to the data storage.
4- **Data access control**: The Identity Manager validates the credentials of the requests and checks the permissions for accessing the block of data required.
5- **Fetch or load data**: If the access is grand, then the data is fetched or loaded from/to the data storage.
6- **Request response**: The response is returned to the caller with the success or failed message and the content data when needed.

3.3.2.5 V2X Gateway

In UC2, the V2X Gateway is used for V2I and I2V communications. In the service of "Relay emergency message sent by vehicle to infrastructure", the V2X gateway forwards messages (event/incident information) received from vehicles to the Car Event Detector Listener (V2I communication). On the other hand, I2V communications are made all of the services of UC2, where the V2X gateway forwards messages from Edge Strategy Generator & Dispatcher to vehicles. Figure 24 depicts the behavioural view of the V2X Gateway for V2I communications (blocks in grey do not intervene in this case).

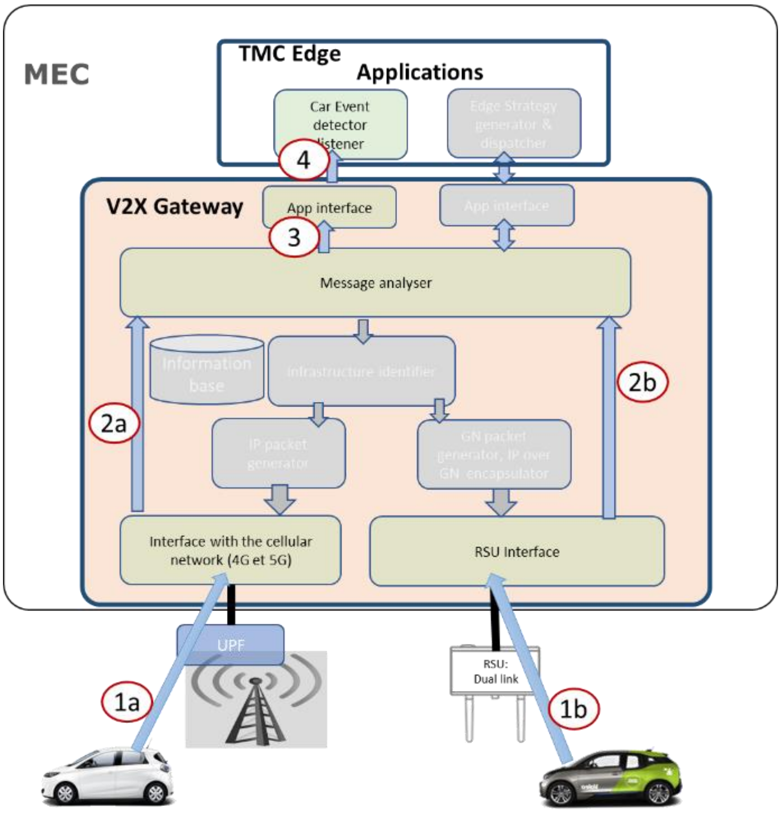

Figure 24. V2X Gateway for V2I communication.

As shown in the figure, the V2I communications consist of the following 4 steps.

1- **Detection**: The connected vehicles detected an incident/event in the road and alerts the incident/event via 5G (1a) or the RSU in the road (1b).
2- **V2X Gateway Interfaces**: The V2X Gateway receives the alert message through its cellular or RSU interfaces that forward the message to the Message analyser (2a and 2b).
3- **Message analyser**: Upon reception of the message, the Message analyser identifies that the destination of the message is the TMC edge, particularly Car Event detector listener, and forwards the message to the corresponding App interface.
4- **Event listener**: The event listener receives the car events via the App interface.

Figure 25 depicts the behavioural view of the V2X Gateway for I2V communications consisting of 6 steps.

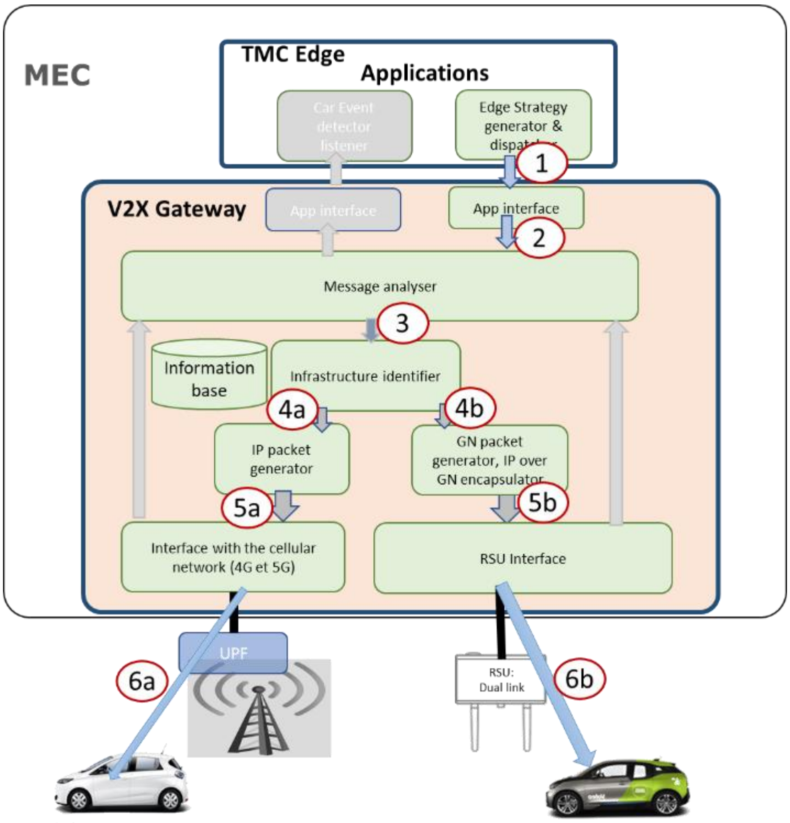

Figure 25. V2X Gateway for I2V Communication

As we see the steps are:

1- **Edge Strategy**: Edge Strategy Generator & Dispatcher module of the TMC edge transmits traffic strategy information to the application interface of the V2X Gateway.
2- **App interface**: The application interface forwards the message to the Message analyser.
3- **Message analyser:** Upon reception of the message, the message analyser identifies that the message shall be transmitted in the V2X Gateway service area and hence forwards the message to the interface identifier.
4- **Interface identifier**: The interface identifier analyses, if needed exploiting the information base, the destination area of the message, and identifies the best communication technology to transmit the message. If the 5G gNB is identified to be the most appropriate to disseminate the message, it is sent to the IP packet generator module (4a). If the C-V2X/ITS-G5 RSU is

identified to be the most appropriate to disseminate the message, it is transmitted to the GN packet generator module (4b).

5- **Packet generator**: The IP packet generator module creates an IP packet, containing the traffic strategy information in the data field, and transmits the packet over the cellular network interface (5a). The GN packet generator module generates a GN packet, containing the traffic strategy information module in the data field. If necessary, the GN packet is encapsulated with an IP packet, and sends the packet to RSU (5b) interface.
6- **V2X Gateway Interfaces**: Upon reception of the message, the V2X gateway cellular or RSU interfaces forwards the message to the vehicles via 5G (6a) or C-V2X/ITS-G5 (6b) technologies.

3.3.2.6 Hazard/event detected by Connected Vehicle and transmission to V2X Gateway

The diagram in Figure 26 shows the sequence of operations performed by the functional blocks of the Connected Vehicle (i.e., Smart Sensor, TCU, and HMI) since the Smart Sensor detects a road hazard/event until a V2X message is transmitted by the TCU to the V2X Gateway.

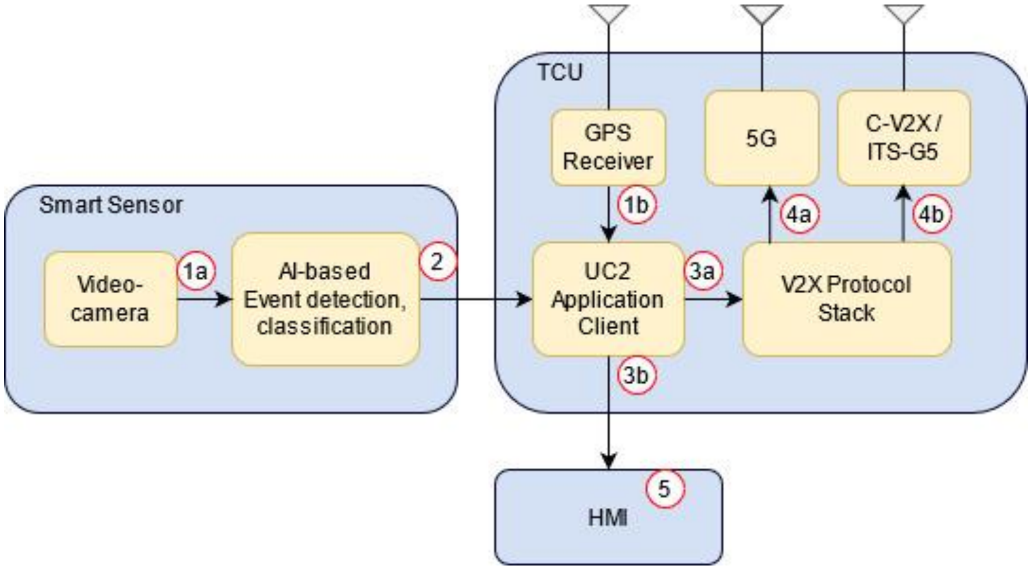

Figure 26. Hazard/event detected by a Connected Vehicle and transmitted to the V2X Gateway.

As shown in the figure, the process consists of the following steps:

1- The **video-camera** continuously captures video images on the front of the vehicle and sends them to the AI-based event detection and classification component (1a). The **GPS receiver** periodically calculates the location of the vehicle and sends it to the UC2 Application Client (1b).
2- The **AI-based event detection and classification** component processes the video images, successfully detects and classifies a new road hazard/event and transfers the hazard/event information to the TCU.
3- The **UC2 Application Client** estimates the geographical coordinates of the hazard/event, selects the best radio interface (5G, C-V2X/ITS-G5) to transmit the message, and forwards the hazard/event information to both the V2X Protocol Stack (3a) and the HMI (3b).
4- The **V2X Protocol Stack** encodes a V2X message with the hazard/event information and sends that V2X message to the V2X Gateway through the radio interface that has been selected, either 5G (4a) or C-V2X/ITS-G5 (4b).

5- Finally, the **HMI** displays the location of the hazard/event on a map and shows a warning to the driver.

3.3.2.7 Hazard/event and recommended action messages transmitted from V2X Gateway to Connected Vehicle

The diagram in Figure 27 shows the sequence of operations performed by the functional blocks of the Connected Vehicle (i.e., Smart Sensor, TCU, and HMI) since the TCU receives a V2X message from the V2X Gateway (i.e., road hazard/event or recommended action) until the HMI displays a warning or driving indication to the driver. As shown in the figure, the process consists of the following steps:

1- The **5G** (1a) or **C-V2X/ITS-G5** (1b) **radio interfaces** of the TCU receive a V2X message and forward it to the V2X Protocol Stack.

2- The **V2X Protocol Stack** decodes the V2X message and forwards the relevant information of the message to the UC2 Application Client.

3- The **UC2 Application Client** transfers the V2X message information to the HMI.

4- If the V2X message contains a hazard/event, the **HMI** displays the location of the hazard/event on a map and shows a warning to the driver. If the V2X message contains a recommended action, the **HMI** shows the corresponding indication to the driver (e.g., change lane, reduce speed).

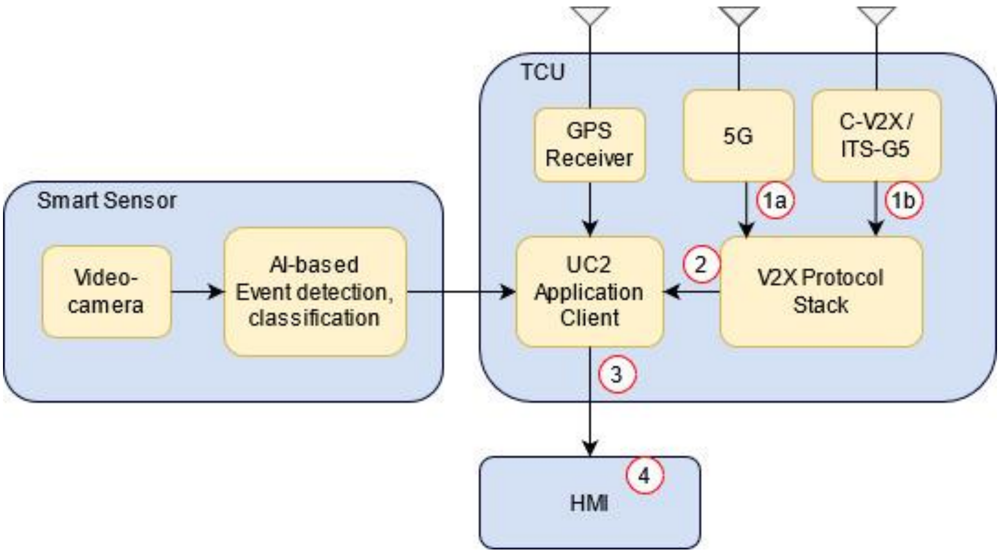

Figure 27. Hazard/event and recommended action messages transmitted by the V2X Gateway.

3.3.3 Deployment notes

3.3.3.1 Traffic Management Control and road video sensors

The following notes shall be considered for the deployment of the TMC Cloud and Edge and Road Video Sensors for the UC2:

- The TMC Cloud must run on a cloud platform accessible through the internet by every MEC. Also, it will provide global computation capabilities and storage services to enable the implementation and execution of AI models for predicting and optimizing road traffic flows. Finally, the TMC Cloud will provide secure REST API interfaces and a dashboard as user operation console.

- The TMC Edge computing node will need access to the internet and the 5G RAN. Also, the availability to access RSU placed on road using 5G RAN or alternative path. The Edge TMC will be contained in every MEC together with a V2X Gateway covering a known highway area. For that reason, every MEC should have enough performance to manage video analysis computing (for at least 8 cameras) and the V2X Gateway.

The HW references for video detection (considered for every 3 cameras) are:

- GPU 512-core Volta GPU
- CPU 8-core ARM v8.2 64-bit CPU
- Memory: 32GB 256-Bit LPDDR4x
- Storage: 64GB

Roadside Sensors:

Every roadside sensor will include:

- HD Video Cameras
- A 5Grouter

3.3.3.2 Connected Vehicle

The following notes shall be considered for the deployment of the Smart Sensor, the TCU and the HMI inside the Connected Vehicle for the UC2:

- The antennas of the V2X radio interfaces (5G, C-V2X, ITS-G5) must be installed on the roof the vehicle, facilitating cabling of coaxial cables between the antennas and the TCU located inside the vehicle.
- The video-camera of the Smart Sensor must be installed in the front of the vehicle, which must facilitate cabling between the video-camera and the GPU-based embedded computer of the Smart Sensor located inside the vehicle.
- The vehicle must provide an interface with a GPS antenna, which must be connected with the TCU for clock synchronization and to determine the position of the vehicle.
- The vehicle must provide an interface port with the CAN bus to facilitate the data exchange between the TCU and the HMI.
- The vehicle must provide measurements of current speed and position through the CAN bus.
- The vehicle must provide the power supply to the Smart Sensor, the TCU and the HMI.
- The vehicle must facilitate cabling between the Smart Sensor, the TCU and the HMI.

- The TCU will be composed of a CPU, a 5G modem, a C-V2X module, an ETSI ITS-G5 module, a CAN bus interface, an Ethernet interface, and a GPS receiver for the CPU clock synchronization and vehicle's positioning.
- The Smart Sensor will be composed of a Graphics Processing Unit (GPU) based embedded computer, a video camera, an Ethernet interface, and a Wi-Fi interface.
- The HMI will be a touch screen deployed in the front panel of the vehicle to facilitate the interaction with the driver.

3.4 UC4 detailed functional architectural elements

3.4.1 Detailed Functional Block View

In this subsection, the detailed functional block view of the Follow-me Infotainment use case will be presented. The diagrams are divided for each service included in the UC4, namely the Enjoy Media Together and the Tour Planning.

3.4.1.1 Enjoy Media Together Service

The EMT service includes three different types of service: The EMT Streaming in synch among multiple users, the EMT video conferencing and the EMT livestreaming of 360-degree video. The following functional architecture has been designed to support the abovementioned services.

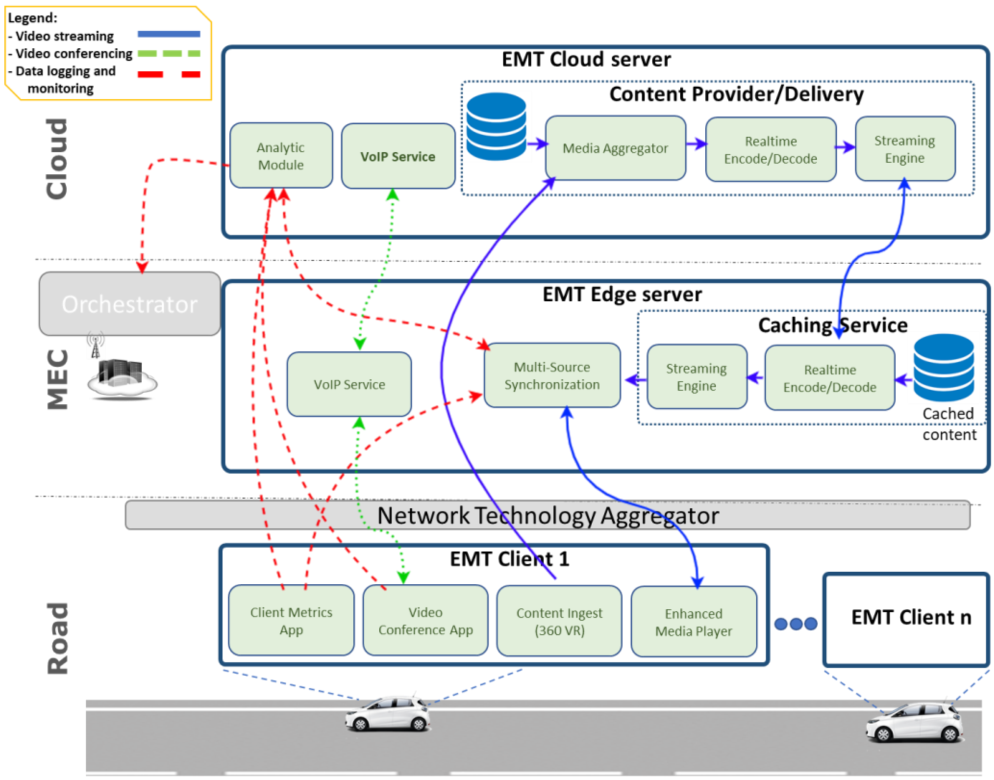

Figure 28. EMT Detailed Functional Block View

Figure 28 depicts the Functional Block View envisioned for the EMT service. It is divided into three main building blocks: the EMT Client, running in the end user's UEs, the EMT Edge Server, located at the edge of the network and the EMT Master Server, placed in the cloud.

EMT Client

The EMT Client is the application module that enables the EMT Service for the end-user. It is composed of four functional blocks, namely:

- The **Client Metrics App** is used to gather and send metrics regarding the quality of the service provided. In particular, the data are sent to the Analytics Module, to be processed and used to trigger the migration of the Network Service (NS) in a closer edge node, and to the Multi-Source Synchronization, used to select the appropriate video stream to be used when multiple edges are streaming at the same time.
- The **Video Conference App** is the main responsible for the P2P communications among different users. It serves as a session description creator, with the correspondent edge module, and direct audio and video content sharing with other users.
- The **Content Ingest** allows the user to share a live 360-degree video with multiple users. Specific hardware is needed to enable this feature, such as a 360-degree camera. It communicates directly with the EMT Master Server, ingesting content into the Media Aggregator, to make the live stream available in all the edge nodes.
- The **Enhanced Media Player** is the core of the EMT Client. It enables the video sync among multiple video streaming to implement the “watch together” functionality. It is the main end point of the video streams, showing the media content (both live and VOD), while overlaying the video conferencing media content following the picture-in-picture (PiP) paradigm. Moreover, it can select among multiple video streams the more suitable in terms of video quality.

EMT Edge server

The EMT Edge server is responsible of caching and synchronizing the media content at the edge of the network. It is composed of three functional blocks, that are the following:

- The **Caching Service** is responsible for bringing the media content closer to the user. If the content is not present at the edge, it is requested to the EMT Master Server. Note that bringing the content closer to the user provides a higher quality of experience (i.e. in terms of jitter, framerate and latency). It also it enables the ultra-low latency capabilities needed to consume the 360-degree video streaming.
- The **Multi-Source Synchronization** is the manager of the synchronization among multiple users. The shared experience is enabled by this module, which acts as a filter between the Caching Service and the EMT Client. This additional step performed at the edge, enables the synchronization with no perceived latency among multiple users.
- The **VoIP Service** is responsible for negotiating the session parameters for the P2P communications among multiple users. The definition of the session includes the selection of all the parameters needed for the real-time audio, video and chat communications (e.g. audio codec, video codec, bitrate, framerate). Moreover, it acts as a proxy service to enable the P2P communication, following the TURN [RMM09] and STUN [3489] mechanisms, supported by WebRTC [JB12]. Finally, the session description and the proxy entries are sent to the VoIP Service module in the EMT Master Server, to make it available to all the edge nodes.

EMT Master Server

The EMT Master Server acts as a repository of available media content (both live and VoD) and of the available P2P communication rooms. Moreover, it enables the analysis of the metrics received by the modules below, to trigger scaling and migration actions. It is composed of:

- The **Content Provider/Delivery** is the repository of all the media content (live and VoD). It contains all the movies and shows available in the EMT service in multiple video resolutions.
- The **VoIP Service** is the repository of all the P2P communications rooms. It includes the session descriptions and the information needed to reach the users participating in each room.

Analytics Module

The **Analytics Module** is responsible for logging and processing the metrics received by all the modules in UC4. The processed data is used to understand if there is the need for a service migration from one edge to another.

As depicted in Figure 29, the Analytics Module is composed of three blocks, namely:

- The Data Acquisition Module is responsible for gathering data from heterogeneous sources and normalizing this data to be consumed by the QoS Prediction Module.
- The QoS prediction module can process the normalized data to provide QoS alerts if degradation is foreseen. The processing might be implemented using artificial intelligence capabilities, but this point is still open and will be further explored in future deliverables.
- The Output module, able to interact with the Orchestrator to warn that a possible NS migration has to be performed. The Orchestrator itself is the one that finally decides if and how the migration should be performed.

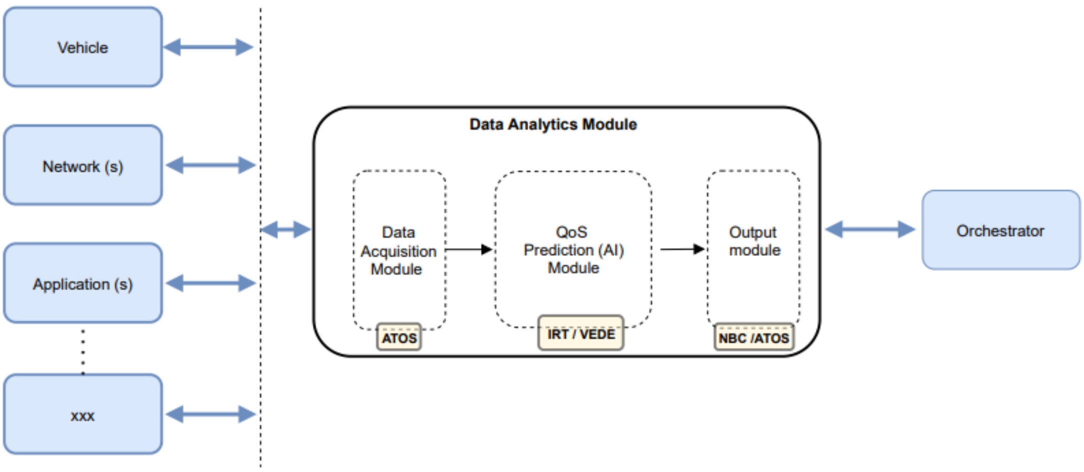

Figure 29. Functional architecture of the Analytics module

The Analytics module is presented as a separate block because it will have the same architecture for both the EMT and the TP services. Although, the module will present different QoS prediction and data normalization algorithms in both services. For that reason, the Analytics module is represented as part of the EMT Master Server and the TP Cloud Server.

3.4.1.2 Tour Planning Service

The architecture of the Tour Planning application is based on the principles of the Service-oriented design and the logical components that comprises it are grouped into three layers: the Cloud layer, the MEC layer and the Road layer. Each one contains related modules to provide different aspects of the service as depicted in the following diagram.

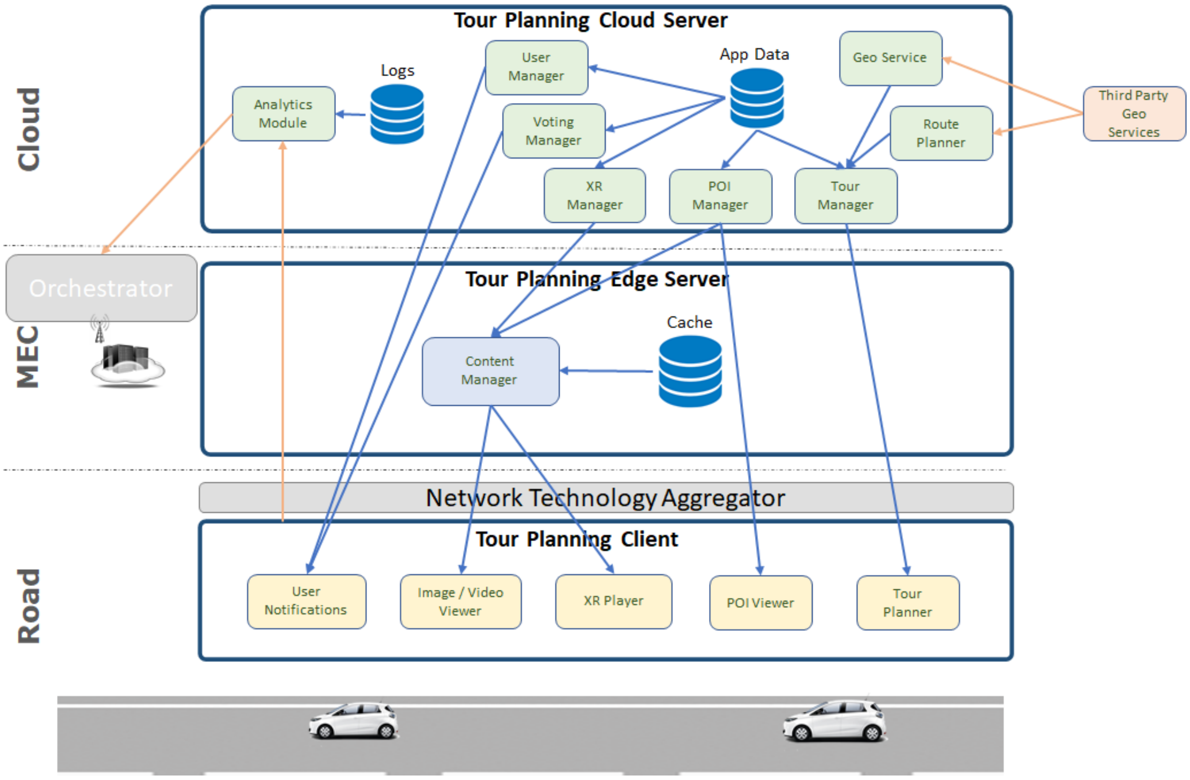

Figure 30. Functional Architecture of the TP Service

The original Tour Planning application is structured on the basis of a typical architecture consisting of a Server side infrastructure, namely the "Tour Planning Cloud Server" which communicates with the Client side application, namely the "Tour Planning Client" and provides services to the end user's device.

In terms of the current project, this will be restructured to include a third Server-side component placed in the intermediate position of the 5G Edge Layer. This will be the Tour Planning Edge Server component, containing modules that will serve to cache content in this layer and serve it to the end client application on request, to make full use of this 5G network Edge layer functionality, reduce latency and make content accessible to enhance Quality of Experience for the user.

In a nutshell the components of the application are:

Tour Planning Cloud Server

The Tour Planning Cloud server resides on the Cloud side and includes the components required to provide the full set of application services. The following modules reside in this layer:

- The User Manager provides user services like user registration, authentication, and account update/deletion.

- The Voting Manager enables the user to vote for a POI of the system or view the votes of other users.
- The Geo Service and Route Planner provides geolocation and route planning services utilizing the relevant Google APIs
- The POI Manager is a component invoked each time the user adds, removes or updates a POI and allows the addition/update and deletion of POI data, including images and video.
- The XR Manager that allows the management of the Mixed Reality (XR) content for the POIs
- The Tour Manager allows users to plan a new tour and manage their personalized tours.

Tour Planning Edge Server

The Tour Planning Edge server resides in the Edge and includes the modules related to caching data and media content. This server enables synchronization among users and provides access to cached data by reducing the required time compared to the time to access the same content if it was placed in the Cloud.

As we see, the main functional block here is the Content Manager, which caches part of the POI contents to decrease service latency, which is essential to preserve Quality of Experience when providing high-quality media content (video or images) or XR content.

Tour Planning Client

The Tour Planning Client is a mobile application installed on the client device, which may be a mobile phone or a tablet and is comprised of the necessary User Interfaces for the user to interact with the system. This is the main channel user interaction with the application and contains the interfaces for them to view the POI metadata and data like images, video and XR content, plan a new tour, and receive user notifications.

Analytics Module

The Analytics Module in the TP service has the same functional view as the one defined for the EMT Service (see Figure 29). The main difference is the metrics that it will evaluate and, consequently, the specific algorithms. Also, the Analytics Module used by the Tour Planning, might be placed either in the Cloud Layer or in the MEC Layer. Invoking an instance of the module in the selected Cloud or MEC layer, whichever will be defined at a later stage of the project as appropriate to demonstrate the functionalities of the Tour Planner.

3.4.2 Behavioural View

This subsection describes the behaviour of the services composing the Follow-ME Infotainment use case. As it was for the previous sections, it is divided in two parts, the Enjoy Media Together service and the Tour Planning service.

3.4.2.1 EMT Service

As abovementioned, the EMT Service provides three different functionalities. The EMT Video streaming in synch among multiple users, the EMT Video conferencing and the EMT Livestreaming of 360-degree video. Moreover, a fourth functionality is shown in this section, which is the case of the Follow-Me concept for the EMT Video Streaming. A complete list of test cases defined for this service is presented in the deliverable D2.2 [5GM21-D22].

EMT Video Streaming in synch among multiple users

The first feature foreseen in the EMT Service is the EMT Video Streaming in synch among multiple users. The synchronization is performed at the edge so that all the users consuming the media content is receiving the same frame at each time step.

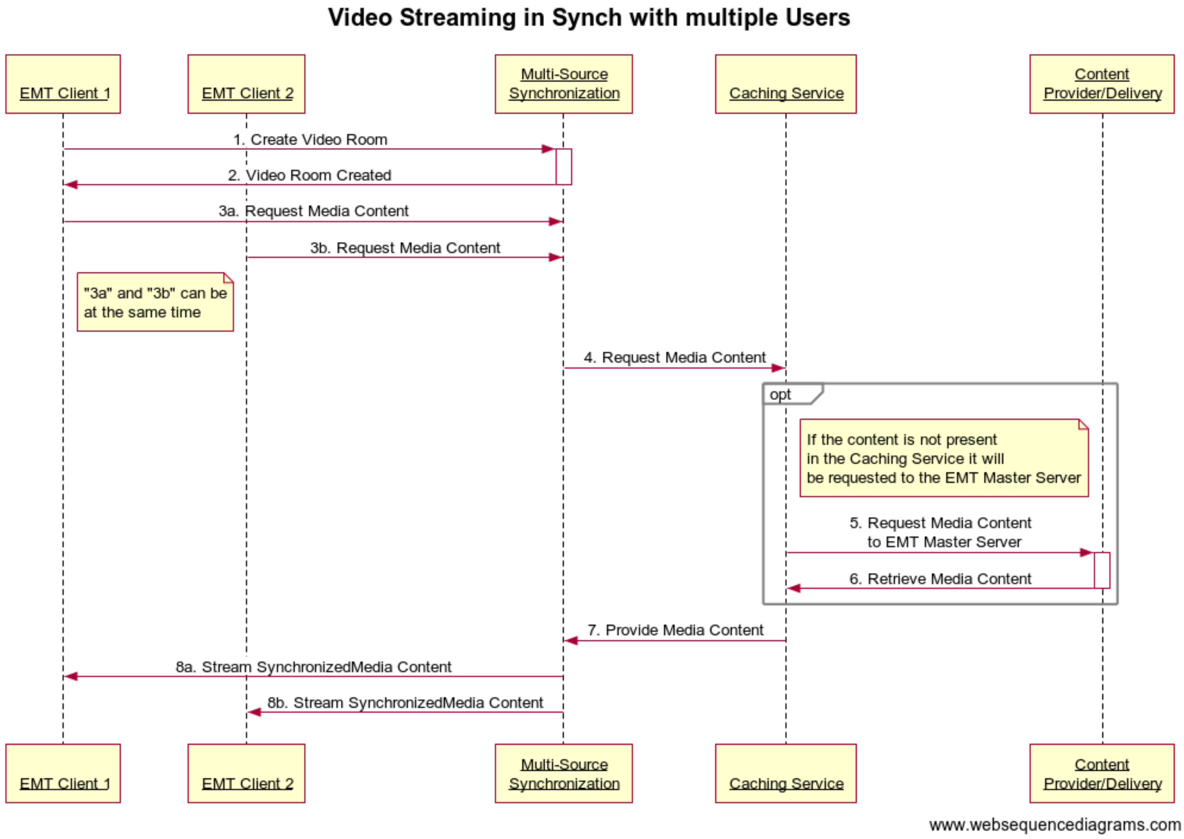

Figure 31. Sequence diagram of the EMT Video Streaming

Figure 31 depicts the actions required to enable the EMT Video Streaming feature. The EMT Client1 creates a Video Room (choosing a particular media content to watch) interacting with the Multi-Source Synchronization (step 1 in Figure 31). The Video room is created and notified back to the EMT Client 1 (step 2). Once the room is created, both EMT Client1 and EMT Client2 can join the room (step 3a and 3b). This action can be performed at the same time by both users. After that, the Multi-Source Synchronization requests the media content to the Caching Service (step 4). If the content is not cached, the Caching Service requests it to the Content Provider/Delivery (step 5), which returns the portion of the media content requested back to the Caching Service (step 6). As long as the Caching Service has the content cached, it returns it to the Multi-Source Synchronization (step 7). The content is then synchronized by the Multi-Source Synchronization module and streamed to the EMT Client1 (step 8a) and EMT Client2 (step 8b).

EMT Video Conferencing

The second feature of the EMT Service is the EMT Video Conferencing. Even if it is separated, this feature is supportive of the EMT Video Streaming. It allows users to watch their media while being in a video call. The separation is needed to highlight the EMT Video Conferencing specific interactions, while keeping the diagrams simple and readable.

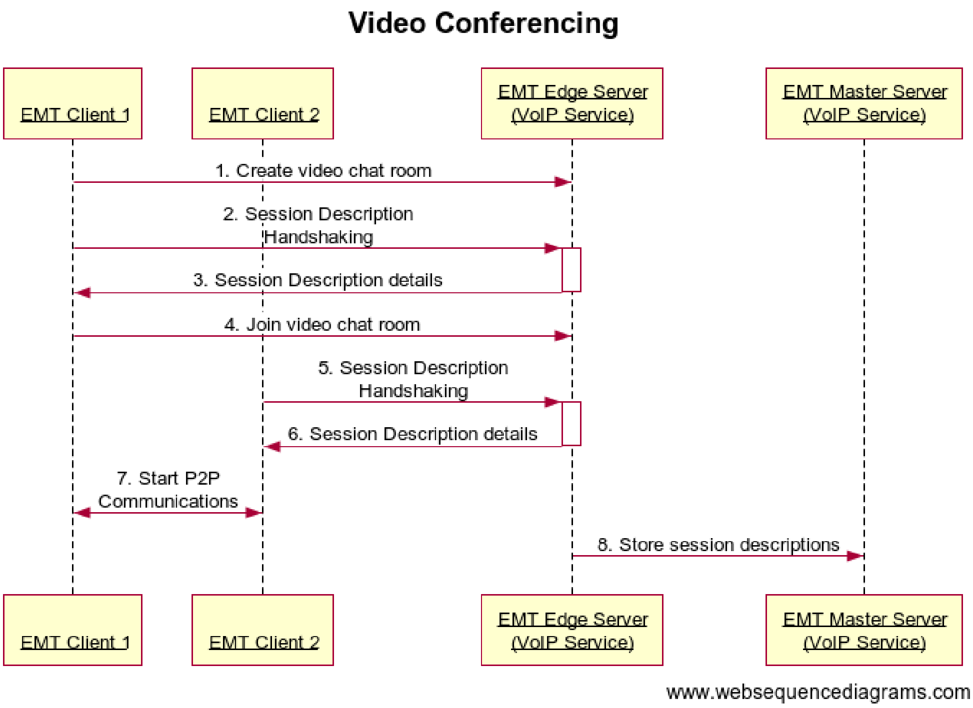

Figure 32. Sequence Diagram of the EMT Video Conferencing

As shown in Figure 32, the EMT Client1 creates a video chat room interacting with the VoIP Service present at the EMT Edge Server (step 1). After that, the definition of the session description starts (step 2), including the audio and video codec selection, desirable resolution and the definition of other parameters needed to enable P2P video and audio communication among users (e.g. the information needed by the STUN/TURN servers [3489][RMM09]). Once the session handshake is completed (step 3), the EMT Client1 joins the video chat room (step 4). In a similar way, the EMT Client2 performs the session description handshaking and joins the room (step 5 and 6). Once both clients have defined the session and have joined the video chat room, they are able to communicate in a P2P fashion (step 7). Finally, the session details are stored to the VoIP Service present in the EMT Master Server to make it available to all the edge nodes.

EMT Livestreaming of 360-degree video

The third feature of the EMT Service is the EMT Livestreaming of 360-degree videos. This feature allows users to produce a livestream using a 360-degree camera and to consume this stream using specific Virtual Reality capable head-mounted devices. In the example brought here, the EMT Client1 produces the livestream, while the EMT Client2 consumes it.

Figure 33 presents the sequence diagram of the EMT Livestreaming feature. Since the EMT Client1 is the producer, it uses a 360-degree camera to ingest content into the Media Aggregator present at the EMT Master Server (step 1). Then, the Media Aggregator encodes the live media content forwarding it to the Content Provider/Delivery to make it available in all the edge nodes (step 2). As the EMT Client2 is the consumer, it requests the live media content to the Multi-Source Synchronization (step 3). Similarly to what happens in the EMT Video Streaming, the content is requested to the Caching Service (step 4), which forwards the request to the Content Provider/Delivery if it is not cached (step 5). Once the content is available at the Caching Service (step 6) and forwarded to the Multi-Source

Synchronization (step 7), it is finally streamed with a low-latency constraint to the head-mounted device of the EMT Client2 (step 8).

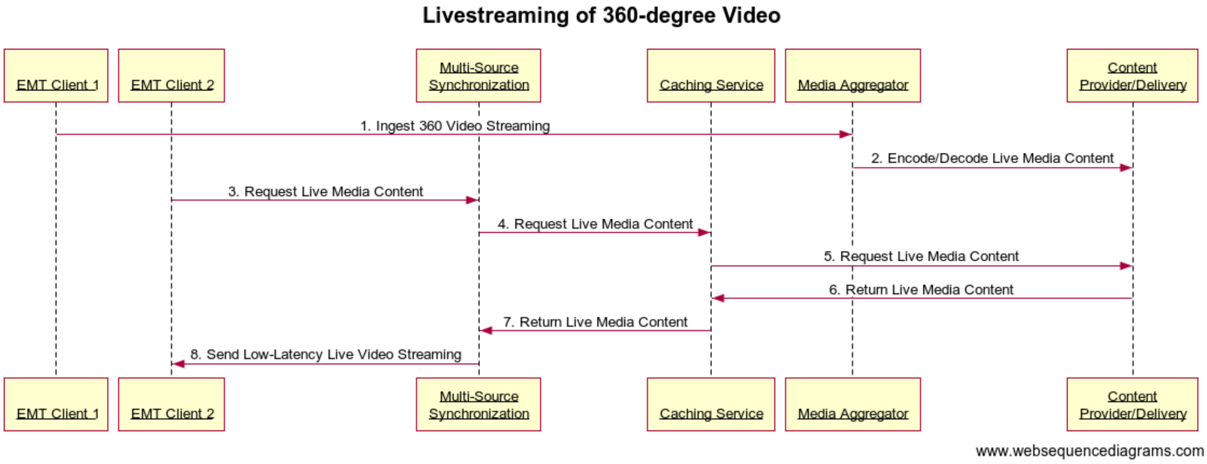

Figure 33. Sequence Diagram of the EMT Live streaming

Follow-Me concept for the EMT Video Streaming

Additionally to the three features presented before, the "Follow-Me" concept represents the key innovation showcased in the EMT Service. Although it applies to the three abovementioned services, an example of applying Follow-Me concept for the EMT Video Streaming feature is presented.

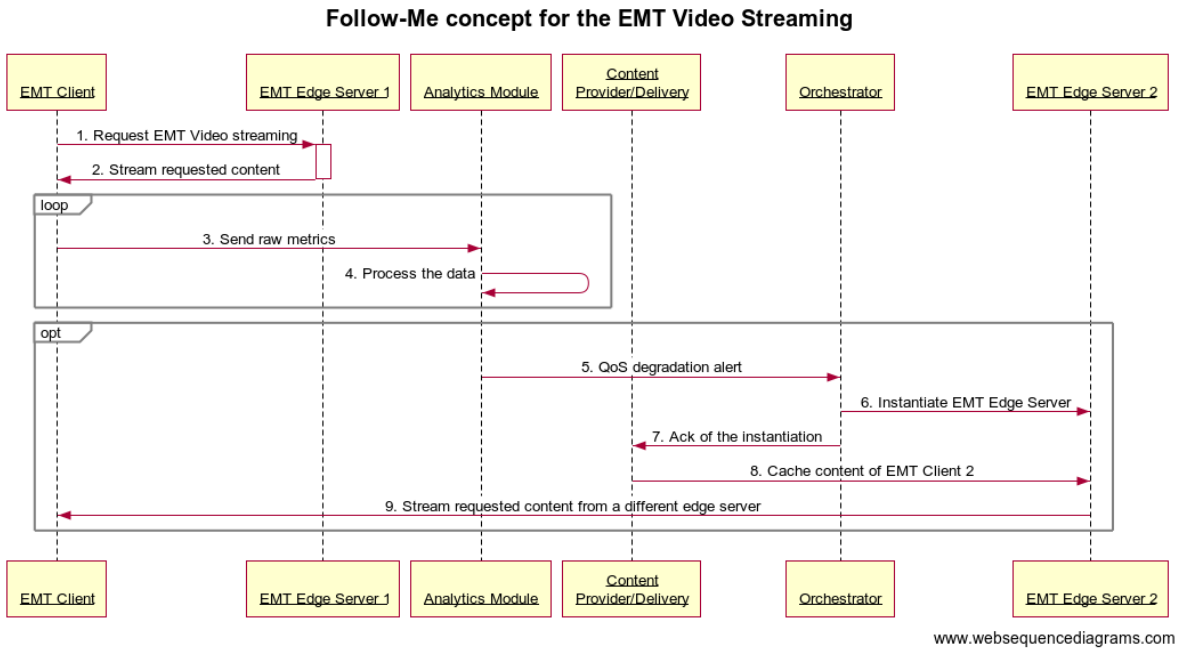

Figure 34. Sequence Diagram of the Follow-Me concept for the EMT Video Streaming

Figure 34 depicts the interactions needed to implement the Follow-Me concept in the EMT Video Streaming feature. The interactions described for the EMT Video Streaming are summarized in step 1 and step 2 for simplicity. While the EMT Video Streaming service is running, the EMT Client continuously sends raw metrics to the Analytics Module available at the EMT Master Server (step 3). The raw data include network metrics, video quality metrics and geolocation data. The Analytics Module processes the received data (step 4) to detect eventual degradation in the video quality, network degradation related events and/or mobility of the user from one base station to another (Note that the three events described above can happen simultaneously). If the Analytics Module detects degradation in the performances, it sends a QoS degradation Alert to the Orchestrator (step 5). Therefore, the Orchestrator takes charge of instantiating a new EMT Edge Server in the new edge location (step 6). Once the instantiation is complete, the Orchestrator notifies the Content Provider/Delivery that a new EMT Edge Server has been added (step 7). In this way, the Content Provider/Delivery can cache the content that the user was consuming in the old edge node into the new one (step 8). Finally, the EMT Client continues receiving the stream but from a new edge location and, more importantly, without service interruption.

3.4.2.2 Tour planning service

The following sections provide the behavioural view diagrams for each of the services invoked by the users whilst implementing the test cases of the Tour Planning Service, as these are defined in D2.2 [5GM21-D22].

Consumption of high-quality media

The flow of actions is depicted in Figure 35; they are in summary the following:

- The user has selected a POI and requests to view the related POI media
- The Client app communicates with the Content Manager at the edge to retrieve the POI's content (Step 1)
- The Content Manager checks first its cache and retrieves the POI's media if these exist in the cache (Steps 2-2.1)
- Next, the Content Manager communicates with the POI Manager in the cloud to retrieve any POI information not in the cache and returns the data to the client app. (Steps 3-6)

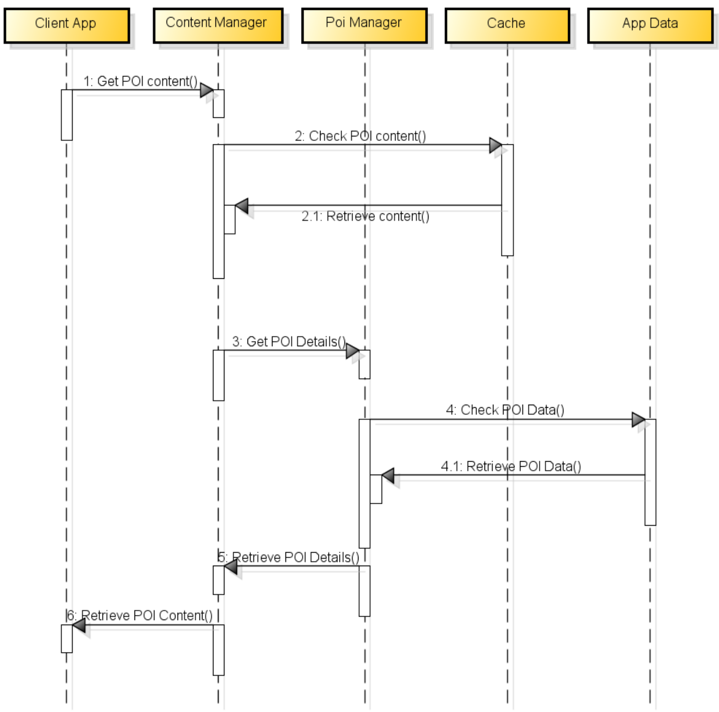

Figure 35. Tour Planning - Consumption of high-quality media

Plan customized tour

Figure 36 depicts the steps needed for planning a custom tour. These steps are:

- The user inserts his / her tour criteria to the Client app and requests suggestions based on these criteria (Step 1)
- The Tour Manager requests possible routes from the External Geo services and nearby POIs from the POIs Manager and calculates the possible tours that match the user's preferences. (Steps 2-7)
- The user selects a suggested tour and searches for new POIs to add or deletes one or more POIs of the selected tour. (Steps 8-12)
- The user saves the finalized tour. (Steps 13-15)

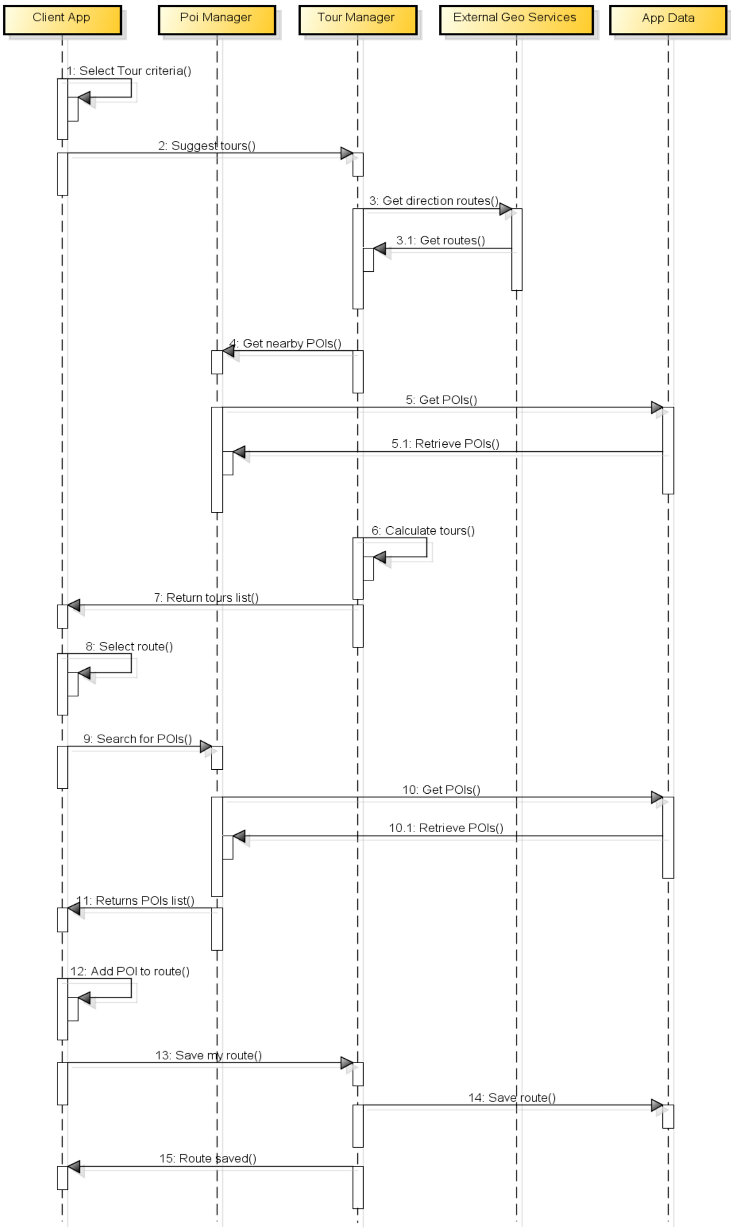

Figure 36. Tour Planning - Plan customized tour

Push nearby POI info

The steps for the third test case for the Tour Planning service are depicted in Figure 37:

- The Tour Manager returns to the Client app the user's saved tours (Steps 1-3)

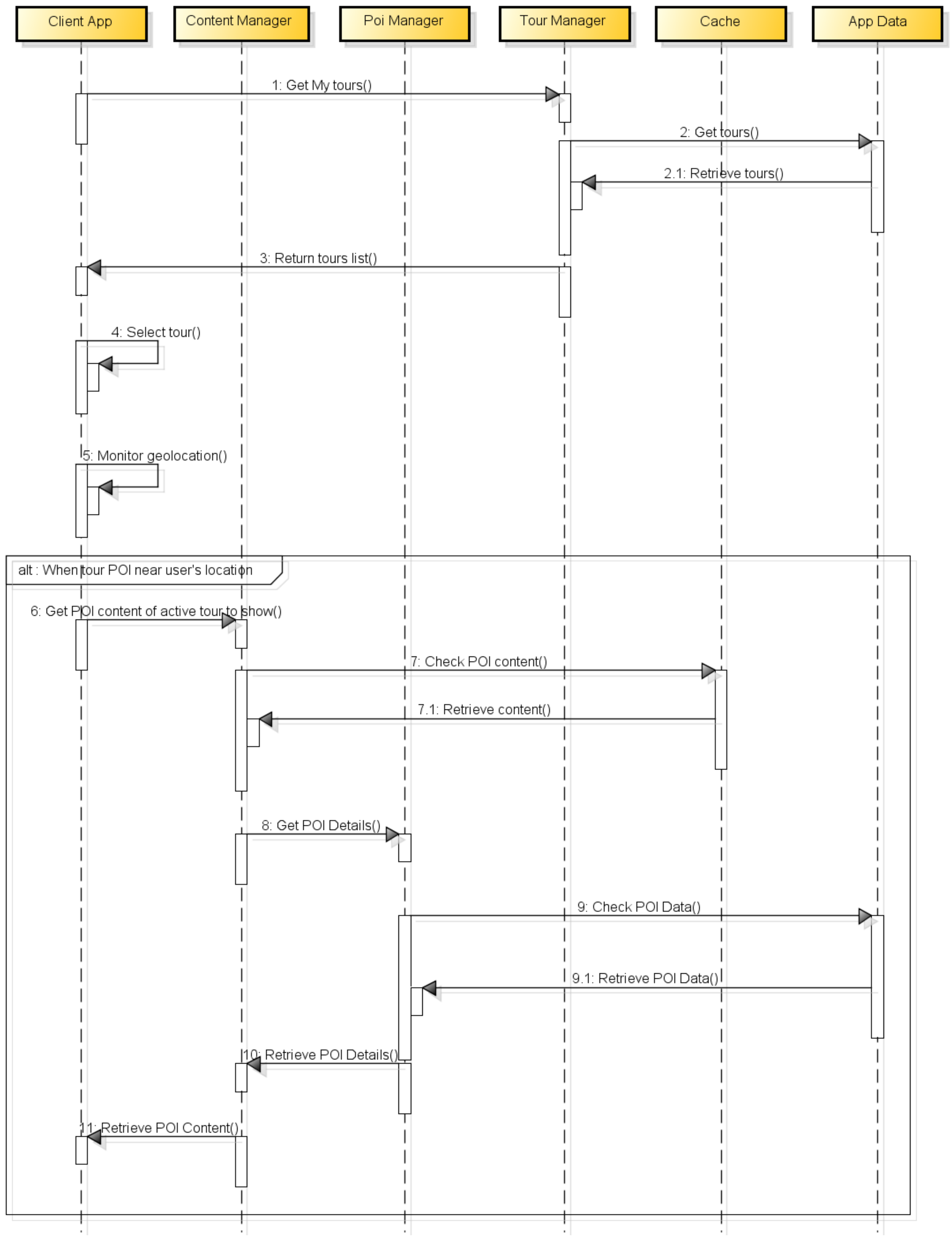

Figure 37: Tour Planning - Push nearby POI info

- The user selects one of his tours to complete and the Client app starts to monitor his / her position. (Steps 4-5)
- Once the user is at a certain distance from the next POI of the active tour, it communicates with the Content Manager to retrieve the POI's information to present. (Step 6)
- The Content Manager checks first its cache and retrieves the POI's data if these exist in the cache (Step 7)
- Next, the Content Manager communicates with the POI Manager in the cloud to retrieve any POI information not in the cache and returns the data to the client app. (Steps 8-11)

Serve XR POI content

The flow of actions is depicted in Figure 38; they are the following:

- The user selects an XR compatible POI and requests to view the related content (Step 1)
- The Content Manager checks first its cache and retrieves the POI's content if this exist in the cache (Step 2)
- If not, the Content Manager communicates with the XR Manager to retrieve it from its data storage (Steps 3-5)
- Next, the Content Manager communicates with the POI Manager in the cloud to retrieve any POI information not in the cache and returns the data to the client app. (Steps 6-9)

3.4.3 Deployment notes

This subsection presents the deployment constraints of the two services of UC4, namely the EMT Service and the TP Service

3.4.3.1 EMT service

Being the EMT service a fully virtualized service, it will be deployed on the available servers in the different testbeds. Both in the small-scale and the large-scale testbeds. In this phase of the project, it is still early to define resource requirements for the deployment of this service. Therefore, it will be defined in subsequent stages of the project.

3.4.3.2 Tour planning

In summary the components of the Tour Planning service will be deployed on the cloud, edge and client app as follows:

Tour Planning Cloud Server:

- The Analytics Module
- The User Manager
- The Voting Manager
- The Geo Service and Route Planner
- The POI Manager
- The XR Manager
- The Tour Manager

Tour Planning Edge Server:

- The Content Manager
- The Cache Service

Tour Planning Client:

- Tour Planner
- XR Player
- Image/Video Viewer
- POI Viewer
- User notifications

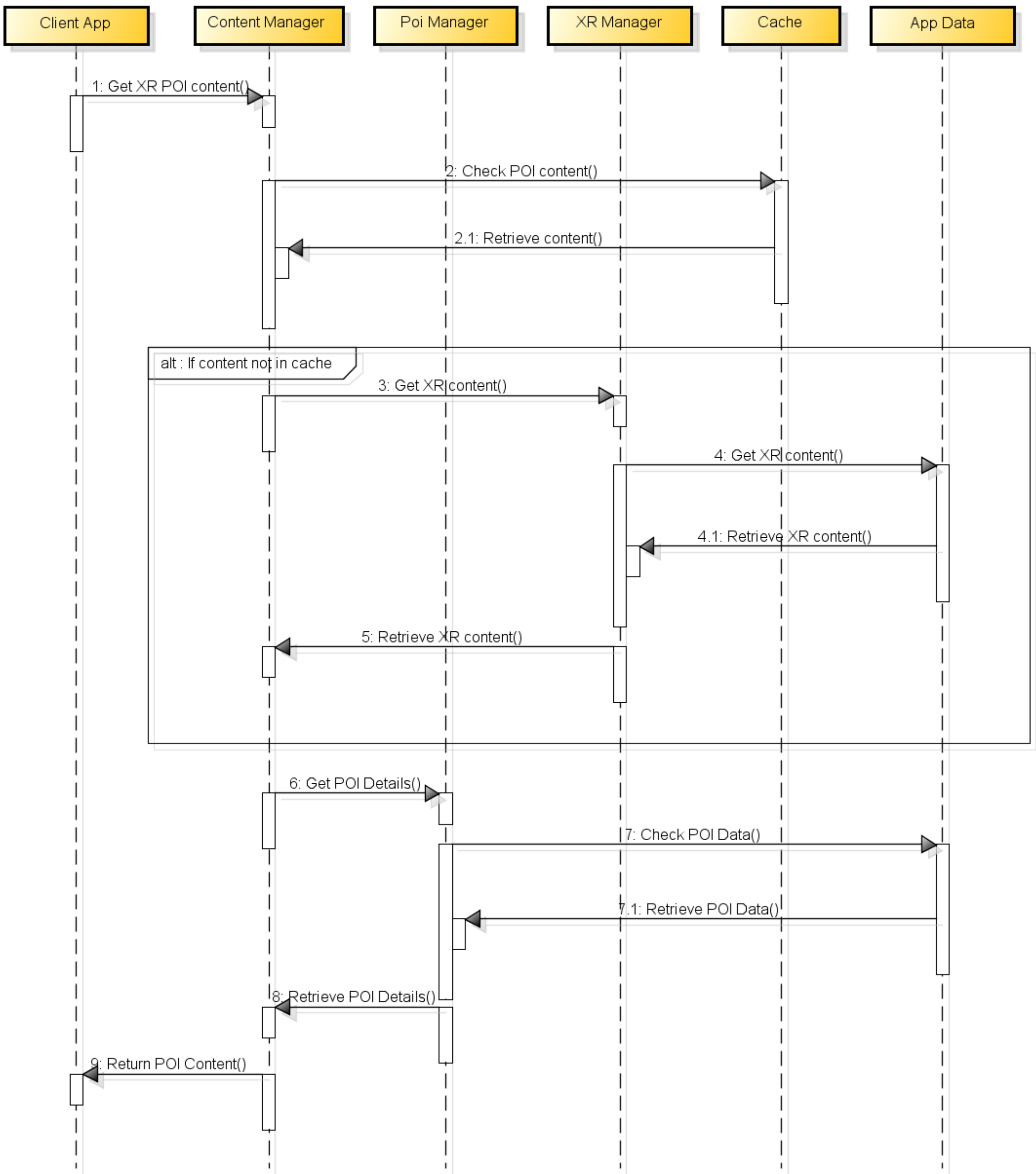

Figure 38: Tour Planning - Serve XR POI content

4. Requirements for the Automotive Test Cases

This section presents the requirements analysis for the test cases of the automotive use cases of the 5GMed project. The analysis is highlighting the functional and non-functional requirements for each automotive use case. In particular, the functional requirements are divided per each functional block presented in the detailed functional block view of each UC, while the non-functional requirements are presented as quality of the whole UC.

The tables of the functional requirements comprehend the following information:

- ID, following the structure of FR-AAA-XXX. In which AAA is an acronym for the macro module to which the requirements apply and XXX is an incremental number.
- Description: explanation of the functional requirement
- Service: indicates to which testcase this functional requirement applies. The full list of test cases can be found in D2.2.
- Functional Block(s): shows the functional blocks inside the macro module that is providing the functional requirement.
- Importance: shows the necessity for the functional requirements and follows the MoSCoW notation (i.e. Must, Should, Could, Won't)

The tables of the non-functional requirements show the following information:

- ID: following the structure of NFR-UCX-XXX. In which UCX represents the use case and XXX is an incremental number.
- Requirement: Is the typology of non-functional requirement shown as a set of "-ilities" of the software.
- Description: explanation of the non-functional requirement
- Importance: shows the necessity for the functional requirements and follows the MoSCoW notation (i.e. Must, Should, Could, Won't)

4.1 Requirements for UC1 – Remote Driving

4.1.1 Functional Requirements

In this part, we will find the high-level requirements for the UC1 - Remote Driving divided by block diagrams: TMC Global, Remote Vehicle, Remote Station and Valeo Teleoperation Cloud. Each of them has:

- a specific identifier (ID) in the format ["FR/NFR"-" Component name"-" Number"];
    - FR/NFR is for Functional Requirement or Non-Functional Requirement.
    - The component name is GLO for TMC Global, RV for Remote Vehicle, RS for Remote Station and VTC for Valeo Teleoperation Cloud.
- a short description.
- a service allocated.
- a functional block
- an Importance which can be Must, Should, Could, Won't.

4.1.1.1 TMC Global

The Follow Table 1 summarizes the functional requirements of the TMC Global for UC1. Note that those use a global identifier (FR-GLO-XXX) with an incremental numbering that continues in the related section for the functional requirements of this component in the UC2.

Table 1: Functional requirements for the TMC Global in UC1

ID	Description	Service	Funct. Block(s)	Importance
FR-GLO-001	Receive and register requests for teleoperating a vehicle to a specific location	UC1-RRA	I/O Remote driving support	Must

FR-GLO-002	Accept or deny the teleoperation of a vehicle to a specific location	UC1-RRA	I/O Remote driving support	Must
FR-GLO-003	Propose a different location as destination for the teleoperation of a vehicle	UC1-TOD	I/O Remote driving support	Should

4.1.1.2 Remote Vehicle

The functional requirements for the RV are listed in Table 2.

Table 2. Functional Requirements for the Remote Vehicle

ID	Description	Service	Functional Block(s)	Importance
FR-RV-01	The Remote Vehicle shall process incoming ToD controls and local events.	UC1-TOD	Remote Vehicle	Must
FR-RV-02	The Remote Vehicle shall setup communication channels and data transfers to outside systems necessary for ToD sessions.	UC1-RRA	Remote Vehicle	Must
FR-RV-03	The RV shall be able to handle RRAs and offer QoS and self-diagnosing necessary for/during ToD sessions.	UC1-RRA	Remote Vehicle	Must
FR-RV-04	The system shall record all relevant data and events.	UC1-MRM UC1-TOD	Remote Vehicle	Must
FR-RV-05	While not running on ToD, the Remove Vehicle shall operate in AD mode (full, degraded or MRM).	UC1-MRM UC1-TOD	Remote Vehicle	Must

4.1.1.3 Remote Station

The functional requirements for the RS are listed in Table 3.

Table 3. Functional Requirements for the Remote Station

ID	Description	Service	Functional Block(s)	Importance
FR-RS-01	The RS shall allow the central VTC system to supervise all actions involving the Remote Driver.	UC1-RRA UC1-TOD	Remote Station	Must
FR-RS-02	The RS shall process RRAs (acceptance, rejection, diagnostic) before a ToD session can take place.	UC1-RRA	Remote Station	Must
FR-RS-03	The RS shall set everything up (secure link, com' channel, HMI) for	UC1-RRA UC1-TOD	Remote Station	Must

	a ToD session start and adapt as it goes.			
FR-RS-04	The RS shall set everything up (particularly at HMI level) for a ToD session start and adapt as it goes.	UC1-TOD	Remote Station	Must
FR-RS-05	The system shall propose the Remote Driver 1 or more ways (or modes) and a set of actions to operate the Remote Vehicle.	UC1-RRA UC1-TOD	Remote Station	Must
FR-RS-06	The system shall provide mechanisms to help the Remote Driver execute correct ToD.	UC1-TOD	Remote Station	Must
FR-RS-07	The system shall continuously monitor, record, report on what's going on with the Remote Driver and ToD session.	UC1-MRM UC1-TOD	Remote Station	Must

4.1.1.4 Valeo Teleoperation Cloud

The functional requirements for the VTC are listed in Table 4.

Table 4. Functional Requirements for the Valeo Teleoperation Cloud

ID	Description	Service	Functional Block(s)	Importance
FR-VTC-01	The VTC shall collect QoS-related data from miscellaneous sources, compute and provide QoS indicators on ToD capabilities, availabilities and performances.	UC1-RRA UC1-TOD	Valeo Teleoperation Cloud	Must
FR-VTC-02	The VTC, via the XR platform, shall orchestrate data transfers across all the solution entities.	UC1-MRM UC1-RRA UC1-TOD	Valeo Teleoperation Cloud	Must
FR-VTC-03	The VTC shall manage RRAs, establish ToD sessions and supervise them all along.	UC1-MRM UC1-RRA UC1-TOD	Valeo Teleoperation Cloud	Should

4.1.2 Non-functional Requirements

The non-functional requirements for the UC1 are listed in Table 5.

Table 5. Non-Functional requirements for the UC1

ID	Requirement	Description	Importance
NFR-UC1-001	Compatibility	The service **shall be** compatible with different UEs (TCU and HMI)	Must
NFR-UC1-002	Availability	The service **shall be** available in the whole project area (from Figueres to Perpignan)	Must

NFR-UC1-003	Concurrence	The service **shall be** capable of operating in normal conditions for not less than 1000 vehicles at the same time	Should
NFR-UC1-004	Continuity	The service shall be provided with continuity, without disruptions, even in the cross-border scenario.	Must
NFR-UC1-005	Internationalization	The service **shall be** operable at the same time in not less than two different Countries (France and Spain)	Should
NFR-UC1-006	Performance	The service **shall be** capable of processing video images from (at least) 8 cameras	Should
NFR-UC1-007	Exploitability	The service **shall be** viable as a basis for future commercial exploitation.	Should
NFR-UC1-008	Modifiability	The service **shall be** easily modifiable to add new features.	Should
NFR-UC1-009	Isolation	The service **shall be** isolated from the critical road infrastructure managing systems.	Must
NFR-UC1-010	Performance	The service **shall be** enabled to provide traffic strategies in enough time for a smooth reaction of the vehicles	Must
NFR-UC1-011	Adaptability	The service **shall be** provided even if there is no 5G coverage using alternative networks	Should
NFR-UC1-012	Trust	The service shall use all means to maximize the trust and safety perception from end-users.	Must
NFR-UC1-014	Efficiency	The service should be designed to assist vehicles with efficiency (ex: expertise of road and vehicle).	Should

4.2 Requirements for UC2 – Road infrastructure digitalization

4.2.1 Functional Requirements

This section presents the functional requirements related to the Use Case 2. The requirements are grouped for each of the macro components depicted in Section 3. For each of them, a dedicated sub-section and requirements table is presented.

4.2.1.1 TMC Edge

The following Table 6 summarizes the functional requirements of the TMC Edge for the UC2. The global identifier for those functional requirements follows the structure FR-EDG-XXX.

Table 6. Functional requirements for the TMC Edge

ID	Description	Service	Funct. Block(s)	Importance
FR- EDG-001	Analyse real-time video streams for traffic flow detection	UC2-REM UC2-AID UC2-TFR	Video traffic analyser and event detector	Must
FR- EDG-002	Analyse real-time video streams for on-road event detection	UC2-AID	Video traffic analyser and event detector	Must
FR- EDG- 003	Detect a stopped vehicle in the hard shoulder by analysing real-time video streams	UC2-AID	Video traffic analyser and event detector	Should
FR- EDG- 003	Detect a stopped vehicle in a traffic lane by analysing real-time video streams	UC2-AID	Video traffic analyser and event detector	Must
FR- EDG-004	Get on-road events data from connected cars event detection	UC2-REM	Car Event detector listener	Must
FR- EDG-005	Get data about existing obstacle in the road (lane and hard shoulder) from connected cars advice messages	UC2-REM	Car Event detector listener	Must
FR- EDG-006	Fuse events data received from car advice messages and validate it into a confirmed event	UC2-REM	Data Fusion and event validator	Must
FR- EDG-007	Confirmed events detected from video streams analysis	UC2-AID	Data Fusion and event validator	Must
FR- EDG-008	Use video event detection functionality for further validation of fused events generated from advice messages received from the connected on-road cars	UC2-REM	Data Fusion and event validator	Could
FR- EDG-009	Receive and register information about the current traffic flow in the Edge Area	UC2-REM UC2-AID UC2-TFR	Edge Monitor and Manager	Must
FR- EDG-010	Receive and register information about the current on-road detected events in the TMC Edge Area	UC2-REM UC2-AID	Edge Monitor and Manager	Must
FR- EDG-011	Receive and register information about the current traffic management strategies activated on the TMC Edge Area	UC2-REM UC2-AID UC2-TFR	Edge Monitor and Manager	Must
FR- EDG-012	Provide to the TMC Global information about the current traffic flow in their own TMC Edge Area	UC2-REM UC2-AID	Edge Monitor and Manager	Must
FR- EDG-013	Provide to the TMC Global information about the current on-	UC2-REM UC2-AID	Edge Monitor and Manager	Must

	road detected events in their own Edge Area			
FR- EDG-014	Provide to the TMC Global information about the current traffic management strategies activated on their own Edge Area	UC2-REM UC2-AID UC2-TFR	Edge Monitor and Manager	Must
FR- EDG-015	Receive instructions from the TMC Global about specific traffic management strategies to be activated on their own TMC Edge Area	UC2-AID UC2-TFR	Edge Monitor and Manager	Must
FR- EDG-016	Define a local traffic strategy based on the traffic status and detected events on the TMC Edge Area	UC2-REM UC2-AID	Edge Strategy generator & dispatcher	Must
FR- EDG-017	Apply the traffic strategy according to the orders received from the TMC Global through the Edge Monitor and Manager	UC2-AID UC2-TFR	Edge Strategy generator & dispatcher	Must
FR- EDG-018	From the traffic and event status, can generate a strategy based on speed limitation	UC2-REM UC2-AID UC2-TFR	Edge Strategy generator & dispatcher	Must
FR- EDG-019	From the traffic and event status, can generate a strategy based on vehicle's distance gap	UC2-REM UC2-AID UC2-TFR	Edge Strategy generator & dispatcher	Must
FR- EDG-020	From the traffic and event status, can generate a strategy based on recommend a lane to be used	UC2-REM UC2-AID UC2-TFR	Edge Strategy generator & dispatcher	Should
FR- EDG-021	Can dispatch traffic strategies to the connected vehicles on the Edge Area through the V2X Gateway	UC2-REM UC2-AID UC2-TFR	Edge Strategy generator & dispatcher	Must

4.2.1.2 TMC Global

The following Table 7 summarizes the functional requirements of the TMC Global for the UC2. Note that those use a global identifier (FR-GLO-XXX) with an incremental numbering that starts in the related section for the functional requirements of this component in the UC1.

Table 7. Functional requirements for the TMC Edge in UC2

ID	Description	Service	Funct. Block(s)	Importance
FR-GLO-004	Receive and register information about the current traffic flow from the Edge Monitors of the TMC Edge	UC2-REM UC2-AID UC2-TFR	Global Monitor and Manager	Must
FR-GLO-005	Receive and register information from the Edge Monitors about the current on-road detected events in the TMC Edge	UC2-REM UC2-AID	Global Monitor and Manager	Must
FR-GLO-006	Receive and register information from the Edge Monitors about the current traffic management	UC2-REM UC2-AID UC2-TFR	Global Monitor and Manager	Must

	strategies activated on every TMC Edge			
FR-GLO-007	Get from the global Traffic analyser, information about the traffic flow in the global area	UC2-TFR	Global Monitor and Manager	Must
FR-GLO-008	Get from the global Strategy generator information about the strategies to implement in the TMC Global area	UC2-TFR	Global Monitor and Manager	Must
FR-GLO-009	Sent to the TMC Edges instructions about the traffic strategies they have to fulfil based on the Global traffic strategy implemented	UC2-AID UC2-TFR	Global Monitor and Manager	Must
FR-GLO-010	Define a global traffic strategy based on the traffic status, detected events and current traffic strategies implemented on the different TMC Edge Areas	UC2-AID UC2-TFR	Global Strategy generator	Must
FR-GLO-011	From the traffic, detected events and current TMC Edge strategies, it can generate a strategy based on speed limitation	UC2-AID UC2-TFR	Global Strategy generator	Must
FR-GLO-012	From the traffic, detected events and current TMC Edge strategies, it can generate a strategy based on vehicle's distance gap	UC2-AID UC2-TFR	Global Strategy generator	Must
FR-GLO-013	From the traffic, detected events and current TMC Edge strategies, it can generate a strategy based on recommend a lane to be used	UC2-AID UC2-TFR	Global Strategy generator	Should
FR-GLO-014	Inform the Global Monitor and Manager about the current Global traffic strategies to be implemented by the different TMC Edges	UC2-AID UC2-TFR	Global Strategy generator	Must
FR-GLO-015	Analyse traffic flows at TMC Global for generating information of the traffic flow at a global level	UC2-AID UC2-TFR	Global Traffic analyser	Should
FR-GLO-016	Provide visual and detailed information about the overall traffic flows at Edge and global level	UC2-REM UC2-AID UC2-TFR	Global Dashboard	Must
FR-GLO-017	Provide visual and detailed information about current detected events at each of the different TMC Edges areas	UC2-REM UC2-AID UC2-TFR	Global Dashboard	Must
FR-GLO-018	Provide visual and detailed information about the implemented traffic strategies at Edge and global level	UC2-REM UC2-AID UC2-TFR	Global Dashboard	Must

4.2.1.3 Roadside Video Sensor

The following Table 8 summarizes the functional requirements of the Roadside Video Sensors for the use case 2. The global identifier for those functional requirements follows the structure FR-RSV-XXX.

Table 8. Functional Requirements for the Roadside Video Sensor

ID	Description	Service	Funct. Block(s)	Importance
FR-RSV-001	Register real-time video	UC2-REM UC2-AID UC2-TFR	Video out Manager	Must
FR-RSV-002	Provide real-time video data to the local TMC Edge	UC2-REM UC2-AID UC2-TFR	Video out Manager	Must
FR-RSV-003	Provide the necessary controls to configure and manage the video register system	UC2-REM UC2-AID UC2-TFR	Video Manager App	Should
FR-RSV-004	Show the real-time video into a visual interface	UC2-REM UC2-AID UC2-TFR	Video Manager App	Should

4.2.1.4 Mobility Data Hub

The following Table 9 summarizes the functional requirements of the Mobility Data HUB for the UC2. The global identifier for those functional requirements follows the structure FR-MDH-XXX.

Table 9. Functional Requirements for the Mobility Data HUB

ID	Description	Service	Funct. Block(s)	Importance
FR-MDH-001	Provides an open interface for all the data access functionalities available on the Data HUB from external components	UC2-REM UC2-AID UC2-TFR	Data HUB API	Must
FR-MDH-002	Manages the data access requests by checking permissions and providing the data access when grand	UC2-REM UC2-AID UC2-TFR	HUB control manager	Must
FR-MDH-003	Allows to store, retrieve, modify or remove any kind of mobility data	UC2-REM UC2-AID UC2-TFR	HUB control manager, Data Storage	Must
FR-MDH-004	Manage (add, edit, remove) data access identities and roles	UC2-REM UC2-AID UC2-TFR	Identity Manager & data access controller	Should
FR-MDH-005	Provides a Login/logout or an authentication mechanism for enabling a data access control	UC2-REM UC2-AID UC2-TFR	Identity Manager & data access controller	Must

FR-MDH-006	Check data access control via validation of the identity credentials and permissions	UC2-REM UC2-AID UC2-TFR	Identity Manager & data access controller	Must
FR-MDH-007	Provides a web interface to visualize sets of data in configured dashboards	UC2-REM UC2-AID UC2-TFR	Mobility dashboard	Should

4.2.1.5 V2X Gateway

Table 10 lists the functional requirements for the V2X Gateway in realising UC2 services.

Table 10. V2X Gateway Functional Requirements

ID	Description	Service	Funct. Block(s)	Importance
FR-V2XG-001	V2X Gateway has direct communication interfaces with at least one C-V2X/ITS-G5 RSU and 5G network (via UPF).	UC2-REM UC2-AID UC2-TFR	V2X Interface	Must
FR-V2XG-002	V2X Gateway has communication interfaces with Car Event Detection Listener and Edge Strategy Generator & Dispatcher modules of TMC edge	UC2-REM UC2-AID UC2-TFR	App Interface	Must
FR-V2XG-003	V2X Gateway identifies standardised C-ITS message types	UC2-REM UC2-AID UC2-TFR	Message analyser	Must
FR-V2XG-004	V2X Gateway identifies message types specific to the UC2 (if any)	UC2-REM UC2-AID UC2-TFR	Message analyser	Must
FR-V2XG-004	V2X Gateway identifies the destination of received messages for both IP and GN packets	UC2-REM UC2-AID UC2-TFR	Message analyser	Must
FR-V2XG-005	V2X Gateway is aware of the coverage areas of gNBs and RSUs with which it has direct interfaces	UC2-REM UC2-AID UC2-TFR	Infrastructure Identifier	Must
FR-V2XG-006	V2X Gateway communicates with the neighbouring V2X gateways at the other MECs	UC2-REM UC2-AID UC2-TFR	Message analyser	Should
FR-V2XG-007	V2X Gateway is aware of the service areas of the V2X gateways at the neighbouring MECs	UC2-REM UC2-AID UC2-TFR	Infrastructure Identifier	Should
FR-V2XG-008	V2X Gateway is aware of the positions of the vehicles in its service area	UC2-REM UC2-AID UC2-TFR	Information base	Should

FR-V2XG-009	V2X Gateway is aware of the communication capabilities of the vehicles in its service area	UC2-REM UC2-AID UC2-TFR	Information base	Should
FR-V2XG-009	V2X Gateway is aware of the applications requirements of the UC2 services	UC2-REM UC2-AID UC2-TFR	Information base	Should
FR-V2XG-010	V2X Gateway creates IP and GN packets	UC2-REM UC2-AID UC2-TFR	IP and GN packet generator	Must
FR-V2XG-011	V2X Gateway performs IP over GN encapsulation	UC2-REM UC2-AID UC2-TFR	GN packet generator	Must

4.2.1.6 Connected vehicle

The functional requirements for the connected vehicle are listed in Table 11.

Table 11. Functional requirements for the Connected Vehicle

ID	Description	Testcase	Funct. Block(s)	Relevance
FR-CV-001	Acquire real-time video images on the front of the vehicle	UC2-REM	Video-camera	Must
FR-CV-002	Real-time processing of video streams for hazards/events detection	UC2-REM	AI-based event detection and classification	Must
FR-CV-003	Classification of detected hazards/events into: stationary, slow vehicle, pedestrian and animal	UC2-REM	AI-based event detection and classification	Must
FR-CV-004	Estimate the distance between the Connected Vehicle and the detected hazards/events	UC2-REM	AI-based event detection and classification	Could
FR-CV-005	Estimate the velocity of the detected hazards/events	UC2-REM	AI-based event detection and classification	Could
FR-CV-006	Transfer the locally detected hazards/events' information to the TCU	UC2-REM	AI-based event detection and classification	Must
FR-CV-007	Provide connectivity with the V2X Gateway using 5G (V2N)	UC2-REM UC2-AID UC2-TFR	5G radio interface	Must

FR-CV-008	Provide connectivity with the V2X Gateway through the Roadside Units (V2I) using ETSI ITS-G5 and/or C-V2X	UC2-REM UC2-AID UC2-TFR	ITS-G5 / C-V2X radio interfaces	Must
FR-CV-009	Decode hazards/events notification messages received from the V2X Gateway through any of the radio interfaces: 5G, C-V2X or ETSI ITS-G5	UC2-REM UC2-AID	V2X Protocol Stack	Must
FR-CV-010	Decode recommended actions messages received from the V2X Gateway through any of the radio interfaces: 5G, C-V2X or ETSI ITS-G5	UC2-REM UC2-AID UC2-TFR	V2X Protocol Stack	Must
FR-CV-011	Encode and transmit to the V2X Gateway (through the radio interfaces) the notification messages of hazards/events detected by the Smart Sensor	UC2-REM	V2X Protocol Stack	Must
FR-CV-012	Forward hazards/events information to the HMI	UC2-REM UC2-AID	UC2 Application Client	Must
FR-CV-013	Forward recommended actions information to the HMI	UC2-REM UC2-AID UC2-TFR	UC2 Application Client	Must
FR-CV-014	Forward to the V2X Protocol Stack the information of hazards/events detected by the Smart Sensor	UC2-REM	UC2 Application Client	Must
FR-CV-015	Select the best radio interface for the transmission of hazards/events	UC2-REM	UC2 Application Client	Must

	notification messages to the V2X Gateway			
FR-CV-016	Read the current speed and position from the CAN bus of the vehicle	UC2-REM UC2-AID UC2-TFR	UC2 Application Client	Must
FR-CV-017	Display on a map the current position and speed of the vehicle or GPS receiver	UC2-REM UC2-AID UC2-TFR	HMI	Must
FR-CV-018	Display on a map the location of hazards/events locally detected by the Smart Sensor	UC2-REM	HMI	Must
FR-CV-019	Display on a map: the location of remote hazards/events the TCU has received from the V2X Gateway	UC2-REM UC2-AID	HMI	Must
FR-CV-020	Show warning message when a new hazard/event is sent from the TCU to the HMI	UC2-REM UC2-AID	HMI	Must
FR-CV-021	Show driving indication (e.g., change lane, reduce speed) when a new recommended action is sent from the TCU to the HMI	UC2-REM UC2-AID UC2-TFR	HMI	Must
FR-CV-022	Receive hazards/events information from the TCU	UC2-REM UC2-AID	HMI	Must
FR-CV-023	Receive recommended actions information from the TCU	UC2-REM UC2-AID UC2-TFR	HMI	Must
FR-CV-024	Read the current speed and position from the CAN bus of the vehicle	UC2-REM UC2-AID UC2-TFR	HMI	Must
FR-CV-025	Generate a Pulse Per Second signal to synchronize the clock of the TCU processor	UC2-REM UC2-AID UC2-TFR	GPS Receiver	Must

FR-CV-026	Determine the current position of the vehicle and transfer it to the UC2 Application Client	UC2-REM UC2-AID UC2-TFR	GPS Receiver	Must

4.2.2 Non-functional Requirements

The following Table 12 summarizes the non-functional requirements of the UC2. The global identifier for those requirements follows the structure NFR-UC2-XXX.

Table 12. Non-Functional Requirements for the UC2

ID	Requirement	Description	Importance
NFR-UC2-001	Compatibility	The service **shall be** compatible with different UEs (TCU and HMI)	Must
NFR-UC2-002	Availability	The service **shall be** available in the whole project area (from Figueres to Perpignan)	Must
NFR-UC2-003	Concurrence	The service **shall be** capable of operating in normal conditions of not less than 1000 vehicles at the same time	Must
NFR-UC2-004	Continuity	The service shall be provided with continuity, without disruptions, even in the cross-border scenario.	Must
NFR-UC2-005	Internationalization	The service **shall be** operable at the same time in not less than two different countries (France and Spain)	Should
NFR-UC2-006	Performance	The service **shall be** capable of processing video images from (at least) 8 cameras per MEC	Should
NFR-UC2-007	Exploitability	The service **shall be** viable as a basis for future commercial exploitation.	Should
NFR-UC2-008	Modifiability	The service **shall be** easily modifiable to add new features.	Should
NFR-UC2-009	Isolation	The service **shall be** isolated from the critical road infrastructure managing systems.	Must
NFR-UC2-010	Performance	The service **shall be** enabled to provide traffic strategies in sufficient time for a smooth reaction of the vehicles	Must
NFR-UC2-011	Reliability	The service **shall be** reliable	Must
NFR-UC2-012	Adaptability	The service **shall be** provided even if there is no 5G coverage using alternative networks (if available)	Must
NFR-UC2-013	Resilience	The service **shall be** fault-tolerant regarding the MEC nodes	Should

4.3 Requirements for UC4 – Follow-ME Infotainment

4.3.1 Functional Requirements

In this section we will present the functional requirements for UC4 – Follow-Me Infotainment. As for the previous sections, this section will be divided into the two services composing the UC4, namely EMT service and TP service.

4.3.1.1 EMT Service

The functional requirements for the EMT Service are divided into the three main building blocks of the service. Namely the EMT Client, the EMT Edge Server and the EMT Master Server. The functional requirements are identified according to the following template:

- FR-EMTC-XXX, define the EMT Client functional requirements
- FR-EMTES-XXX, define the EMT Edge Server functional requirements
- FR-EMTMS-XXX, define the EMT Master Server functional requirements

EMT Client

The functional requirements of the EMT Client are presented in Table 13:

Table 13. Functional Requirements for the EMT Client

ID	Description	Testcase	Funct. Block(s)	Importance
FR-EMTC-001	The client must allow users to consume high definition media content	WMTest-01, IntegrationTest-01, -02, -03, -04	Enhanced Media Player	Must
FR-EMTC-002	The client must allow users to consume high definition media content together with other users (moving or static)	WMTest-01, IntegrationTest-01, -02, -03,-04	Enhanced Media Player	Must
FR-EMTC-003	The client must allow users to produce 360 livestreaming content	LSTest-01, -02, -03, -04	Content Ingest	Must
FR-EMTC-004	The client is able produce video quality metrics (e.g. framerate, latency, jitter, throughput)	IntegrationTest-02, -03, -04	Client Metrics App	Must
FR-EMTC-005	The client provides peer-to-peer VoIP communication among users	WMTest-02, IntegrationTest-01, -02, -03, -04	Video Conferencing App	Must
FR-EMTC-006	The client provides peer-to-peer video calls among users	WMTest-02, IntegrationTest-01, -02, -03, -04	Video Conferencing App	Must
FR-EMTC-007	The client must select the best edge video source available	IntegrationTest-03, -04	Enhanced Media Player	Could

FR-EMTC-008	The client should integrate the following functionalities: Enhanced Media Player, Content Ingest for 360 livestreaming video, Video conferencing App and Client App for QoS monitoring	IntegrationTest-02, -03, -04, LSTest-02, -03, -04	Infotainment Client	Should
FR-EMTC-009	The client must allow users to consume all the media contents in synchronization with other users (e.g., if a user pauses the video playback, the other users also pauses it)	WMTest-01, IntegrationTest-01, -02, -03, -04	Enhanced Media Player	Must
FR-EMTC-010	The client must allow users to consume 360 livestreaming video content, adjusting the video resolution based on the user's head movement tracking.	LSTest-01, -02, -03, -04	Enhanced Media Player	Must

EMT Edge Server

The functional requirements of the EMT Edge Server are presented in Table 14. Functional Requirements for the EMT Edge Server:

Table 14. Functional Requirements for the EMT Edge Server

ID	Description	Testcase	Funct. Block(s)	Importance
FR-EMTES-001	The edge server must provide media content close to the users	WMTest-01, IntegrationTest-01, -02, -03, -04	Caching Service	Must
FR-EMTES-002	The edge server must synchronize the media content for users watching the content together, consuming metrics from the Client Metrics App and from the Analytic Module	WMTest-01, IntegrationTest-01, -02, -03, -04	Multi-Source Synchronization	Must
FR-EMTES-003	The edge server must provide the definition of peer-to-peer sessions for video conference call among users	WMTest-02, IntegrationTest-01, -02, -03, -04	VoIP Service	Must
FR-EMTES-004	The edge server must update its catalogue if a media content is missing	WMTest-01, IntegrationTest-01, -02, -03, -04	Caching Service	Must

FR-EMTES-005	The edge server must keep updated the content requested by the users	WMTest-01, IntegrationTest-01, -02, -03, -04	Caching Service	Must
FR-EMTES-006	The edge server must delete the content not anymore requested by the users	WMTest-01, IntegrationTest-01, -02, -03, -04	Caching Service	Must

EMT Master Server

The functional requirements of the EMT Master Server are presented in Table 15:

Table 15. Functional Requirements for the EMT Cloud Server

ID	Description	Testcase	Funct. Block(s)	Importance
FR-EMTMS-001	The cloud server must provide the full media content repository	WMTest-01, IntegrationTest-01, -02, -03, -04	Content Provider/Delivery	Must
FR-EMTMS-002	The cloud server must allow users to share their live stream 360 videos with other users	LSTest-01, -02, -03, -04	Media Aggregator	Must
FR-EMTMS-003	The cloud server must provide an interface with the orchestrator for the service placement	IntegrationTest-02, -03, -04, LSTest-02, -03, -04	Analytic Module	Must
FR-EMTMS-004	The cloud server must log metrics of the video quality	IntegrationTest-02, -03, -04, LSTest-02, -03, -04	Analytic Module	Must
FR-EMTMS-006	The cloud server must log metrics of the car system (Geolocation and speed)	IntegrationTest-02, -03, -04, LSTest-02, -03, -04	Analytic Module	Must
FR-EMTMS-007	The cloud server must share the peer-to-peer session information for the edge nodes	IntegrationTest-02, -03, -04	VoIP Service	Must

4.3.1.2 TP Service

Tour planning Client

The functional requirements of the Tour Planning Client are listed in Table 16. Functional Requirements of the TP Client..

Table 16. Functional Requirements of the TP Client.

ID	Description	Test case	Funct. Block(s)	Importance

FR-TPC-001	The client must allow users to consume high definition media content	TPTest-01	Image/Video Viewer	Must
FR-TPC-002	The client must allow users to customize their tour plans	TPTest-02	Tour Planner, POI Viewer	Must
FR-TPC-003	The client must allow users to view POI details	TPTest-01,02,03,04	POI Viewer	Must
FR-TPC-004	The client must allow users to consume XR content	TPTest-04	XR Player	Must
FR-TPC-005	The client must monitor the user's position when a tour is active and push details about the POI	TPTest-03	Tour Planner, POI Viewer	Must

Tour Planning Edge Server

The functional requirements of the Tour Planning Edge Server are listed in Table 17.

Table 17. Functional Requirements of the TP Edge Server

ID	Description	Test case	Funct. Block(s)	Importance
FR-TPE-001	The edge server must provide media content related data close to the users	TPTest-01	Content Manager	Must
FR-TPE-002	The edge server must provide XR content related data close to the users	TPTest-04	Content Manager	Must

Tour Planning Cloud Server

The functional requirements of the Tour Planning Cloud Server are listed in Table 18.

Table 18. Functional requirements of the TP Cloud Server

ID	Description	Test case	Funct. Block(s)	Importance
FR-TPCS-001	The cloud server must provide the full media content repository	TPTest-01	App Data	Must
FR-TPCS-002	The cloud server must provide the full XR repository	TPTest-04	App Data	Must
FR-TPCS-003	The cloud must provide the mechanisms to allow users to customize their tours	TPTest-02	Tour Manager	Must
FR-TPCS-004	The cloud server must keep track of application metrics	TPTest-01,02,03,04	Analytic Module	Must

FR-TPCS-005	The cloud server must provide user authentication and authorization methods	TPTest-01,02,03,04	User Manager	Must
FR-TPCS-006	The cloud server must provide the mechanisms to suggest tours to the users	TPTest-02	Tour Manager	Must

4.3.2 Non-functional Requirements

In this section, we will present the non-functional requirements for the UC4 – Follow-Me Infotainment. As for the functional requirements section, also this section will be divided into the two services composing the UC4, namely EMT service and TP service.

4.3.2.1 EMT Service

The non-functional requirements for the EMT Service are described in Table 19. Non-Functional Requirements of the EMT Service. As they represent the service qualities, they are defined for the whole service, not for each component of it.

Table 19. Non-Functional Requirements of the EMT Service

ID	Requirement	Description	Importance
NFR-EMT-001	Compatibility	The service **shall be** compatible with different UEs (smartphones, laptops, tablets and head-mounted devices)	Must
NFR-EMT-002	Availability	The service **shall be** available in the whole project area (from Figueres to Perpignan)	Must
NFR-EMT-003	Usability	The service **shall be** usable with no required training	Must
NFR-EMT-004	Concurrence	The service **shall** allow between 25 and 50 users, depending on the channel bandwidth.	Must
NFR-EMT-005	Continuity	The service **shall be** provided with continuity, without disruptions, even in the cross-border scenario.	Must
NFR-EMT-006	Internationalization	The service **shall be** accessible in not less than two different languages (French and Spanish).	Should
NFR-EMT-007	Performance	The service **shall be** accessible with a latency lower than 16ms	Should
NFR-EMT-008	Accessibility	The service **shall be** available to users with different functional capacities.	Should
NFR-EMT-009	Exploitability	The service **shall be** viable as a basis for future commercial exploitation.	Should
NFR-EMT-010	Modifiability	The service **shall be** easily modifiable to add new features.	Should
NFR-EMT-011	Isolation	The service **shall be** isolated from the critical vehicle infrastructure systems.	Must
NFR-EMT-012	Quality	The service **shall be** enabled to provide	Must

		high-quality media contents (4K and 360 videos)	
NFR-EMT-013	Reliability	The service **shall be** reliable	Must
NFR-EMT-014	Adaptability	The service **shall be** provided even if there is no 5G coverage using alternative networks (if available) using a best-effort approach regarding QoS.	Must
NFR-EMT-015	Resilience	The service **shall be** fault-tolerant regarding the MEC nodes (although using a best-effort approach regarding QoS)	Should
NFR-EMT-016	Compliance	The service **shall be** compliant with the relevant EU regulations, specifically regarding: a) Intellectual property laws, regarding both: the deployed software resources and the provided media contents (to ensure the service continuity in the cross-border scenario media contents must have the appropriate rights for viewing in both: France and Spain). b) GDPR [679] and NISD [1148], regarding the implementation of the appropriate technical and organisational measures to secure personal data and manage the risk posed to operation.	Must

4.3.2.2 Tour Planning Service

Table 20 shows the non-functional requirements of the TP Service. These are requirements related to service operation capabilities and enhance the overall efficiency of the system

Table 20. Non-Functional Requirements for the Tour Planning Service

ID	Requirement	Description	Importance
NFR-TP-001	Compatibility	The service **shall be** available through a mobile phone or tablet	Must
NFR-TP-002	Availability	The service **shall be** available in the whole project area (from Figueres to Perpignan)	Must
NFR-TP-003	Usability	The service **shall be** usable with no required training	Must
NFR-TP-004	Concurrence	The service **shall** allow between 25 and 50 users, depending on the channel bandwidth.	Must
NFR-TP-005	Continuity	The service shall be provided with continuity, without disruptions, even in the cross-border scenario.	Must
NFR-TP-006	Internationalization	The service **shall be** accessible in not less than two different languages.	Should

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NFR-TP-007	Performance	The service **shall be** accessible with a latency lower than 16ms	Should
NFR-TP-008	Exploitability	The service **shall be** viable as a basis for future commercial exploitation.	Should
NFR-TP-009	Modifiability	The service **shall be** easily modifiable to add new features.	Should
NFR-TP-0010	Isolation	The service **shall be** isolated from the critical vehicle infrastructure systems.	Must
NFR-TP-0011	Quality	The service **shall be** enabled to provide high-quality media contents (images and video)	Must
NFR-TP-0012	Quality	The service **shall be** enabled to provide XR content	Must
NFR-TP-0013	Reliability	The service **shall be** reliable	Must
NFR-TP-0014	Adaptability	The service **shall be** provided even if there is no 5G coverage using alternative networks (if available) using a best-effort approach regarding QoS.	Must
NFR-TP-0015	Compliance	The service **shall be** GDPR Compliant	Must

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5. Conclusion

After an overall introduction of the 5GMed project and the related use cases and challenges, this document has provided the list of the requirements and the initial design of the test cases for the three automotive use cases in the context of this 5GMed project: Remote Driving (UC1), Road Infrastructure Digitalisation (UC2) and Follow-ME Infotainment (UC4). The presented requirements have been collected from the partners participating in the implementation of each use case. They have been provided in this document by means of different tables grouped for each use case, and providing for each case two different sets of requirements: functional (describing how each use case is required to work) and non-functional (describing the overall expected qualities for each use case).

The initial design of the automotive test cases has been described providing a high-level architecture, which is envisaged to be implemented in order to execute the different test cases. For each use case two different architectural views have been provided: a functional view (describing the main functional blocks) and a behavioural view (illustrating the main interaction among them). Also, some initial deployment notes have been provided for each use case. Further details should emerge as the project definition and implementation progresses. These details are expected to be provided in other deliverables, specifically the abovementioned Deliverable D2.2, D4.2, D4.3 and D4.4 (where the specific applications for the automotive test cases are expected to be defined in more detail), as well as other deliverables and tasks of the 5GMed project (Annex 1 of this document has been provided to describe the connection with these other work packages and tasks).

Annex 1 – Relation to other WPs and Tasks

This Annex presents a collection of tables showing the relation of the functional blocks illustrated in this deliverable with other WPs and Tasks (developed in this or other WPs). In particular, the section presents a table for each functional block in each use case, showing:

- The name of the functional block
- The description of the functional block
- The partner responsible for this functional block
- The related innovation/challenges embodied in this functional block, and
- The WP/Task in which it will be developed

Below the collection of tables per component.

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Table 21. RS Component - Relation with other WPs/Tasks.

Module	Description	Partner	Related Challenge	WP/Task
Remote Station	This macro-block will permit teleoperation to evaluate the RV situation ,communicate with the people inside the RV, and take control of the RV.	Valeo I2CAT	2.3.1 The *Phygital* experience of the remote driver	T4.3
Remote Station	This block will ensure the safety of a ToD by monitoring the teleoperator.	Valeo	2.3.3 Cybersecure teleoperation	T4.3

Table 22. VTC Component - Relation with other WPs/Tasks.

Module	Description	Partner	Related Innovation	WP/Task
Valeo Teleoperation Cloud	Predictive assessment of Quality of Service for ToD	IRT VED	2.3.4 Seamless handover and roaming 2.3.5 End-to-End Quality Control	T4.2
Valeo Teleoperation Cloud	Teleoperation application server which allows the ToD	Valeo	2.3.3 Cybersecure teleoperation	T4.4

Table 23. Remote Vehicle - Relation with other WPs/Tasks.

Module	Description	Partner	Related Innovation	WP/Task
Remote vehicle	Communication to the 5G network	IRT VED	2.3.4 Seamless handover and roaming	T4.3

Remote vehicle	Communication to the Edge/V2X Gateway	IRT VED	2.3.4 Seamless handover and roaming	T4.3

Table 24. TMC Global component - Relation to other WPs/Tasks.

Module	Description	Partner	Related Innovation	WP/Task
Global strategy generator	It generates global and edge-adapted traffic management strategies for the whole road site	AAE	AI for traffic management	T4.2
Global Traffic analyser	It analyses the traffic status at global level from the traffic info received from the edges	AAE	AI for traffic management	T4.2
Global Monitor and Manager	It manages the traffic, incidents and strategies info at global level. Interface the data between the TMC Global components and dispatch the global traffic strategies to the edges	AAE	AI for traffic management	T4.2
I/O Remote driving support	This component supports the remote driving use case. It analyses the requests to remote driving a vehicle to validate, modify or reject them	AAE	The *Phygital* experience of the remote diver	T4.2
Dashboard	It supports the traffic management process by providing a user interface with visual and numeric metrics available to the traffic management operators	AAE	AI for traffic management	T4.2

Table 25. TMC Edge - Relation to other WPs/Tasks

Module	Description	Partner	Related Innovation	WP/Task
Edge Monitor and Manager	It manages the traffic, incidents and strategies info at the edge level. Interface the data between the TMC Edge components and communicate the traffic status and strategies info to the TMC Global	AAE	AI for traffic management	T4.2 WP3

Edge Strategy generator & dispatcher	It generates traffic management strategies at the edge level and dispatches them to the connected vehicles via V2X Gateway	AAE	AI for traffic management	T4.2 WP3
Video traffic analyser and Event detector	It analyses the video stream data to get the traffic status of the road in real-time	AAE	Image processing for traffic and incidents recognition	T4.2 WP3
Data Fusion and event validator	It validates the events/incidents data received from the connected vehicles. After that, it fuses all the ones received from about a single event. Either from the connected vehicles as well as the ones get from the cameras when they exist	AAE	AI for traffic management	T4.2 WP3
Car Event detector listener	It receives the events/incidents data communicated by the connected vehicles via the V2X Gateway	AAE	AI for traffic management	T4.2 WP3

Table 26. Roadside Video Sensors - Relation to other WPs and tasks

Module	Description	Partner	Related Innovation	WP/Task
Video out manager	This component manages the communication of the video data get from the cameras to the external sources	AAE	Image processing for traffic and incidents recognition	T4.2
Video Manager app	This component provides a user interface to the end-users for managing the cameras and their setup	AAE	Image processing for traffic and incidents recognition	T4.2

Table 27. Mobility Data Hub - Relation with other WPs/Tasks

Module	Description	Partner	Related Innovation	WP/Task
HUB control Manager	It manages the data access requests by checking permissions and providing the data access when grand. Allows to store, retrieve, modify or remove any kind of mobility data	AAE	AI for traffic management, Unified repository for mobility data	T4.2

Identity Manager & data access controller	Manages (add, edit, remove) data access identities and roles and checks data access control via validation of the identity credentials and permissions	AAE	AI for traffic management, Unified repository for mobility data	T4.2
Data HUB API	Provides an open interface for all the data access functionalities available on the Data HUB from external components	AAE	AI for traffic management, Unified repository for mobility data	T4.2
Mobility dashboard	Provides a web interface to visualize sets of data in pre-configured dashboards	AAE	AI for traffic management, Unified repository for mobility data	T4.2

Table 28. V2X Gateway - Relation with other WPs/Tasks

Module	Description	Partner	Related Innovation/Challenge	WP/Task
Message analyser	Analyse message contents and defines the destination area	VEDE	Ability to support AI enabled functions executing at the edge	T4.2
Infrastructure identifier	Technology selection based on the destination area and other application and communication quality	VEDE	Multi-connectivity to support vehicles moving at high-speed the ability to support AI enabled functions executing at the edge	T3.4
GN generator and IP over GN *encapsulator*	GN/IP dual mode communication	VEDE	Multi-connectivity to support vehicles moving at high-speed	T3.4
Message analyser	Cooperation with neighbouring V2X Gateways in order extend the service coverage	VEDE	Service continuity to the end users	T4.2 WP3

Table 29. Connected Vehicle - Relation with other WPs/Tasks

Module	Description	Partner	Related Innovation/Challenge	WP/Task
Smart Sensor	Detection and Classification of Hazards on the road	CTTC	AI for traffic management	T4.3 WP3
TCU	Provides connectivity through 5G, C-V2X and/or ETSI ITS-G5 radio interfaces	ISZU, VALEO, CTTC	Multi-Connectivity in high mobility environments	T4.3 WP3

HMI	Displays hazards' locations, warnings and recommended actions to the driver	ISZU	None	T4.3

Table 30. EMT Client - Relation with other WPs/Tasks

Module	Description	Partner	Related Innovation/Challenge	WP/Task
Client Metrics App	Log and metrics provider to monitor the QoS	ATOS	End-To-End QoS Control, Cross-operator 5G Orchestration for MEC and Radio	T4.4
Video Conferencing App	Enabler for P2P video conference communications and chat	ATOS	Seamless handover and roaming, Cross-operator 5G Orchestration for MEC and Radio	T4.4
Content Ingest	Ingest live 360-degree media content	ATOS	Seamless handover and roaming, Cross-operator 5G Orchestration for MEC and Radio	T4.4
Enhanced Media Plater	VOD and live media content player	ATOS	Seamless handover and roaming, Cross-operator 5G Orchestration for MEC and Radio	T4.4

Table 31. EMT Edge Server - Relation with other WPs/Tasks

Module	Description	Partner	Related Innovation/Challenge	WP/Task
VoIP Service	Establish sessions description for P2P video conference rooms	ATOS	Seamless handover and roaming, Cross-operator 5G Orchestration for MEC and Radio	T4.4
Multi-Source Synchronization	Synchronizes media content for multiple users	ATOS	Seamless handover and roaming, Cross-operator 5G Orchestration for MEC and Radio	T4.4
Caching Service	Brings content closer to the user to fulfil the network constraints	ATOS	Seamless handover and roaming, Cross-operator 5G Orchestration for MEC and Radio	T4.4

Table 32. EMT Master Server - Relation with other WPs/Tasks

Module	Description	Partner	Related Innovation/Challenge	WP/Task
VoIP Service	Stores P2P Videoconference room session descriptions	ATOS	Seamless handover and roaming, Cross-operator 5G Orchestration for MEC and Radio	T4.4
Content Provider/Delivery	Store and provides all the multimedia content (VOD and live)	ATOS	Seamless handover and roaming, Cross-operator 5G Orchestration for MEC and Radio	T4.4

Table 33. Analytics Module - Relation with WPs/Tasks

Module	Description	Partner	Related Innovation/Challenge	WP/Task
Data Acquisition Module	will gather, consolidate, and forward to the AI module relevant QoS parameters from various sources relevant to media placement	ATOS / ATC	QoS monitoring for smart orchestration	T4.4
AI Prediction Module	this module will make some prediction of the QoS parameters from the current and previous ones	IRT / VEDE	Use of network data analytics together with other relevant parameters: vehicle speed, vehicle position, status of different equipment, etc. to predict DoS parameters and improve QoE	T4.4
Output Module	Forwards to the orchestrator the predictions of QoS parameters	NBC / ATOS	QoS monitoring for smart orchestration	T4.4

Table 34. TP Client - Relation with WPs/Tasks

Module	Description	Partner	Related Innovation/Challenge	WP/Task
User notifications	Displays system notifications to the user	ATC	Seamless handover and roaming	T4.4
XR Player	Displays XR content to the user	ATC	Seamless handover and roaming, Cross-operator 5G	T4.4

			Orchestration for MEC and Radio	
Image/Video Viewer	Displays video or image content to the user	ATC	Seamless handover and roaming, Cross-operator 5G Orchestration for MEC and Radio	T4.4
POI Viewer	Allows the user to view POI information	ATC	Seamless handover and roaming	T4.4
Tour Planner	Provides tour related services	ATC	Seamless handover and roaming, Cross-operator 5G Orchestration for MEC and Radio	T4.4

Table 35. TP Edge - Relation with WPs/Tasks

Module	Description	Partner	Related Innovation/Challenge	WP/Task
Caching Service	Brings content closer to the user to fulfil the network constraints	ATC	Seamless handover and roaming, Cross-operator 5G Orchestration for MEC and Radio	T4.4 WP3

Table 36. TP Cloud - Relation with WPs/Tasks

Module	Description	Partner	Related Innovation/Challenge	WP/Task
User Manager	Provides user services	ATC	Seamless handover and roaming	T4.4
Voting Manager	enables the user to vote for a POI of the system	ATC	Seamless handover and roaming	T4.4
Geo Service and Route Planner	provide geolocation and route planning service	ATC	Seamless handover and roaming, Cross-operator 5G Orchestration for MEC and Radio	T4.4
POI Manager	Provides POI related services	ATC	Seamless handover and roaming	T4.4
XR Manager	Allows the management of the Mixed Reality (XR) content for the POIs	ATC	Seamless handover and roaming, Cross-operator 5G Orchestration for MEC and Radio	T4.4

Tour Manager	Provides tour related services	ATC	Seamless handover and roaming, Cross-operator 5G Orchestration for MEC and Radio	T4.4

Table 37. Other Components – Relation to other WPs/Tasks

Module	Description	Partner	Related Innovation/Challenge	WP/Task
Roadside Communications	The road will be equipped with Road-Side Units providing G5 802.11p and also PC5 connectivity, providing V2I connectivity	I2Cat, CNX	Multi-connectivity in high mobility environment.	WP3
Network Orchestrator	The network orchestrator (NearbyOne [Nea21]) will be in charge of orchestrating the deployed virtual network services. It will also interact with the Analytics Module to take actions (e.g., migration of virtual network functions) according to the collected data.	NBC	Seamless handover and roaming.	WP3
Network Technology Aggregator	This component provides the 5GMed On-board Traffic Aggregation Function, providing the necessary multi-connectivity to address the multi-technology and multi-network nature of the 5GMed system.	AXBY	Multi-connectivity in high mobility environment. Seamless handover and roaming.	WP3

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