5GMOBIX

5G for cooperative & connected automated MOBIlity on X-border corridors

Deliverable D2.1

5G-enabled CCAM use cases specifications

Dissemination level	Public (PU)
Work package	WP2: Specifications
Deliverable number	D2.1
Version	V1.0
Submission date	30/04/2019

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 825496.

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Control sheet

Version history			
Version	**Date**	**Modified by**	**Summary of changes**
0.1	22/01/2019	Gorka Vélez (VICOM)	Initial Table of contents
0.2	25/01/2019	Gorka Vélez (VICOM)	Revised version of Table of Contents
0.3	13/02/2019	Gorka Vélez (VICOM)	Revised version of Table of Contents
0.4	18/02/2019	Gorka Vélez (VICOM)	Revised version of Table of Contents
0.5	18/03/2019	Gorka Vélez, Ángel Martín (VICOM)	Revised version of Table of Contents
0.6	29/03/2019	All authors	Complete draft version for internal review

0.7	01/04/2019	Tahir Sarı (FORD), Nazli Guney (TTECH), Gorka Vélez (VICOM)	Update of GR-TK corridor UCs description and Section 3.10
1.0	30/04/2019	All authors	Revised version ready for submission

Peer review		
	Reviewer name	**Date**
Reviewer 1	Daniela Carvalho (TIS)	10/04/2019
Reviewer 2	Céline Décosse (LIST)	10/04/2019

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ABBREVIATIONS

Abbreviation	Definition
AD	Autonomous/Automated Driving
5G NR	5G New Radio
5G-PPP	5G Infrastructure Public Private Partnership
ADAS	Advanced Driver Assistance System
AI	Artificial Intelligence
AV	Automated Vehicle
BS	Base Station
CAD	Connected and Automated Driving
CAM	Connected and Automated Mobility
CAN	Controller Area Network
CAV	Connected and Automated Vehicle
CBC	Cross Border Corridor
CCAM	Cooperative, Connected and Automated Mobility
C-ITS	Cooperative Intelligent Transport Systems
CN	China
CPE	Collective Perception of Environment
CPM	Collective Perception Message
C-RAN	Cloud-Radio Access Network
DE	Germany
DoA	Description of Action
DSRC	Dedicated short-range communications
EC	European Commission
ECU	Electronical Control Unit
EDM	Edge Dynamic Map

eMBB	enhanced Mobile Broadband
ES	Spain
EU	European Union
EV	Electronic Vehicle
FCD	Floating Car Data
FI	Finland
GA	General Assembly
GPRS	General Packet Radio Service
GPS	Global Positioning System
GR	Greece
HAD	Highly Automated Driving
HD	High Definition
HW	Hardware
ITS	Intelligent transport system
KPI	Key Performance Indicator
KR	Korea
L4	Level 4
LDM	Local Dynamic Map
LTE	Long-Term Evolution
MEC	Multi-access/Mobile Edge Computing
MIMO	multiple-input and multiple-output
ML	Machine Learning
mMTC	massive Machine Type Communications
MNO	Mobile Network Operator
NFV	Network function virtualization
NL	Netherlands

OBU	On Board Unit
ODD	Operational Design Domain
OEM	Original Equipment Manufacturer
PLMN	Public Land Mobile Network
PT	Portugal
RAN	Radio Access Network
RDV	Remote Driving Vehicle
RSU	Road Side unit
SAE	Society of Automotive Engineers
SDA	Strategic Deployment Agenda
SDN	Software-defined networking
SIM	Subscriber Identity Module
SW	Software
TK	Turkey
TS	Technical Specification
UC	Use Case
UE	User Equipment
UHD	Ultra-high-definition
URLLC	Ultra-Reliable Low Latency Communications
V2X	Vehicle to Everything
VRU	Vulnerable Road User
WP	Work Package
X-border	Cross-border

EXECUTIVE SUMMARY

This document is the deliverable D2.1 "5G-enabled CCAM use cases specifications". The main objective of the deliverable is to provide a detailed description of the 5G-MOBIX use cases. The use cases are classified into 5 categories (Advanced Driving, Platooning, Extended Sensors, Remote Driving and Vehicle quality of Service Support) and distributed among two cross-border corridors (Greece-Turkey and Spain-Portugal) and six local sites in France, Germany, Netherlands, Finland, China and South Korea. These are different corridors and trial sites in several domains and perspectives, enriching the project trials considering the distinct characteristics of each one. All these trials will address a set of complementary and diverse use cases of CCAM systems

The 29 signatory countries of a Letter of Intent[1] signed at Digital Day 2017 agreed to designate 5G cross-border corridors, where vehicles can physically move across borders and where the cross-border road safety, data access, data quality and liability, connectivity and digital technologies can be tested and demonstrated. 5G-MOBIX is aligned with the European Commission's ambition to focus on these corridors in CCAM use cases. The two cross-border corridors (Greece-Turkey and Spain-Portugal) that are part of 5G-MOBIX are the two pillars of the project and references for the rest of the local trial sites, providing a major contribution for the future large scale 5G deployments in the context of CEF 2 package. The use cases present at local sites contribute to the cross-border corridors in diverse ways. The concrete contribution is described for each local site use case.

The rest of the document is organised as follows:

- **Section 1, Introduction,** briefly presents 5G-MOBIX and describes the purpose of the document and its intended audience.
- **Section 2, 5G-MOBIX Use Case Categories,** describes the classification of 5G-MOBIX use cases into categories. In addition, an initial set of evaluation KPIs is introduced for each category. A complete set of KPIs will be presented in deliverable D2.5.
- **Section 3, 5G-MOBIX Use Cases,** describes the methodology for defining the 5G-MOBIX use cases and the actual use cases.
- **Section 4** gives an **overview of** the **use cases** showing their complementarity and their alignment with EC's vision.
- **Section 5** presents the **conclusions**

[1] http://ec.europa.eu/newsroom/dae/document.cfm?doc_id=43821

1. INTRODUCTION

1.1. 5G-MOBIX concept and approach

5G-MOBIX aims to showcase the added value of 5G technology for advanced Cooperative, Connected and Automated Mobility (CCAM) use cases and validate the viability of the technology to bring automated driving to the next level of vehicle automation (SAE L4 and above). To do this, 5G-MOBIX will demonstrate the potential of different 5G features on real European roads and highways and create and use sustainable business models to develop 5G corridors. 5G-MOBIX will also utilize and upgrade existing key assets (infrastructure, vehicles, components) and the smooth operation and co-existence of 5G within a heterogeneous environment comprised of multiple incumbent technologies such as ITS-G5 and C-V2X.

5G-MOBIX will execute CCAM trials along cross-border (x-border) and inland corridors using 5G core technological innovations to qualify the 5G infrastructure and evaluate its benefits in the CCAM context. The Project will also define deployment scenarios and identify and respond to standardisation and spectrum gaps.

5G-MOBIX will first define critical scenarios needing advanced connectivity provided by 5G, and the required features to enable some advanced CCAM use cases. The matching of these advanced CCAM use cases and the expected benefits of 5G will be tested during trials on 5G corridors in different EU countries as well as in Turkey, China and Korea.

The trials will also allow 5G-MOBIX to conduct evaluations and impact assessments and to define business impacts and cost/benefit analysis. As a result of these evaluations and international consultations with the public and industry stakeholders, 5G-MOBIX will identify new business opportunities for the 5G enabled CCAM and propose recommendations and options for its deployment.

Through its findings on technical requirements and operational conditions 5G-MOBIX is expected to actively contribute to standardisation and spectrum allocation activities.

1.2. Purpose of the deliverable

The present document, D2.1 "5G-enabled CCAM use cases specifications", is delivered as part of WP2 and defines the 5G-MOBIX use cases and proposes and initial set of Key Performance Indicators (KPIs). The overall purpose of the document is to serve as a reference to design the development, deployment and test of the 5G-MOBIX use cases. The present deliverable will directly feed the other 5 deliverables that are part of Work Package 2 (WP2):

- D2.2 "5G architecture and technologies for CCAM specifications". This deliverable will describe the reference 5G architecture and the dedicated 5G technologies relating to the deployment of advanced CCAM use cases.

- D2.3 "Specification of the infrastructure for 5G augmented CCAM". This deliverable will specify the architecture and the components, as well as their interaction with the vehicle to execute the CCAM use cases.

- D2.4 "5G augmented vehicle specifications". This deliverable will provide the detailed specification of vehicle enhancement using enhanced 5G connectivity for implementing the advanced CCAM use cases

- D2.5 "Initial evaluation KPIs and metrics". This deliverable will present the initial KPIs and relevant metrics to be used for the evaluation, including those resulting from the specification activities.

- D2.6 "Final set of 5G/CCAM systems and vehicle specifications". The Final set of 5G/CCAM systems and vehicle specifications at M30 will collect all the final agreed specifications.

The overlap between D2.1 and the rest of WP2 deliverables has been minimised as much as possible. Therefore, there is no detailed description of any system architecture, 5G infrastructure or test vehicle in this deliverable. The overlap between D2.1 and D2.5 was solved proposing a basic list of KPIs that is currently being refined and extended in Task T2.5 for its inclusion in D2.5.

1.3. Intended audience

The dissemination level of D2.1 is public (PU) and is meant primarily for (a) all members of the 5G-MOBIX project consortium, and (b) the European Commission (EC) services.

This document is intended to serve as an internal guideline and reference for all 5G-MOBIX beneficiaries, especially the trial site leaders.

2. 5G-MOBIX USE CASE CATEGORIES

2.1. Methodology for use case classification

During the proposal stage, the 5G-MOBIX consortium defined a set of use cases pivoting around some critical manoeuvres and autonomous driving enablers. Once the project started and during task 2.1 discussions, it was concluded that it was necessary to define some use case categories to classify use cases. This classification would enable the presentation of use cases under a common umbrella and would facilitate the demonstration of their complementarity and alignment.

The first step was to define the criteria for selecting the use case categories. The following requirements were defined:

- The use case categories need to cover all the use cases defined in 5G-MOBIX.
- The use case categories need to be aligned with European Commission's vision of Connected and Automated Driving in 5G Corridors[2].
- The use categories should be well-stablished in the 5G and automotive industries and ideally come from a standards organization.

In order to assess those well-established use categories, the current state of the art on 5G Connected and Automated Driving (CAD) use cases was studied. Firstly, all 5G-PPP Phase 2 projects providing a public deliverable with use cases definition were screened to select the ones including automotive use cases. Thus, 5GCar, 5G Transformer, 5G X Cast, Global 5G and One5G. Unfortunately, no consensus was found between the use case definition and classification as each project used their own terminology and classification criteria. Consequently, no use case classification met the requirements and ambition of 5G-MOBIX.

As a second step on the use case state of the art review, the recommendations and reports issued by 5G and automotive standardisation organization were screened. In this process, the following Technical Specification published by 3GPP was identified:

> *3GPP TS 22.186 V16.1.0 (2018-12). 3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Enhancement of 3GPP support for V2X scenarios; Stage 1 (Release 16)*

This document focuses on 5G radio technology and specifies service requirements to enhance 3GPP support for V2X scenarios in the following areas:

- Advanced Driving

[2] https://ec.europa.eu/digital-single-market/en/cross-border-corridors-connected-and-automated-mobility-cam

- Platooning
- Extended Sensors
- Remote Driving
- Vehicle quality of service Support

After a careful study of the 5G-MOBIX use cases, it was concluded that all of them could fall into one of those categories. Furthermore, the categories met all the requirements defined in the first step of the methodology.

In a first iteration, the Technical Coordinator assigned a category to each 5G-MOBIX use case. This classification was then reviewed by the trial site leaders and the Task 2.1 leader. Some minor issues regarding use case classification were discussed in T2.1 weekly conference calls. Finally, a broad agreement was met among task T2.1 participants on the use case classification.

2.2. UC Category 1: Advanced Driving

2.2.1. Description

According to 3GPP TS 22.186 R16, Advanced Driving "enables semi-automated or fully-automated driving. Longer inter-vehicle distance is assumed. Each vehicle and/or Road Side Unit (RSU) shares data obtained from its local sensors with vehicles in proximity, thus allowing vehicles to coordinate their trajectories or manoeuvres. In addition, each vehicle shares its driving intention with vehicles in proximity. The benefits of this use case group are safer traveling, collision avoidance, and improved traffic efficiency".

2.2.2. Initial set of evaluation KPIs

The initial set of evaluation KPIs derive from the performance requirements defined in the 3GPP TS 22.186 R16. The range of target values for each KPI is obtained from the target values defined in that document for each considered scenario.

Table 1 Initial set of evaluation KPIs for Advanced Driving UC category

Payload (Bytes)	Tx rate (Message/Sec)	Max end-to-end latency (ms)	Reliability (%)	Data rate (Mbps)	Min required Communication range (meters)
2000 - 12000	10-100	10-100	90-99.99	10-50	360-700

2.3. UC Category 2: Vehicles Platooning

2.3.1. Description

According to 3GPP TS 22.186 R16, Vehicles Platooning "enables the vehicles to dynamically form a group travelling together. All the vehicles in the platoon receive periodic data from the leading vehicle, in order to carry on platoon operations. This information allows the distance between vehicles to become extremely small, i.e., the gap distance translated to time can be very low (sub second). Platooning applications may allow the vehicles following to be autonomously driven".

2.3.2. Initial set of evaluation KPIs

The initial set of evaluation KPIs derive from the performance requirements defined in the 3GPP TS 22.186 R16. The range of target values for each KPI is obtained from the target values defined in that document for each considered scenario.

Table 2 Initial set of evaluation KPIs for Vehicles Platooning UC category

Payload (Bytes)	Tx rate (Message/Sec)	Max end-to-end latency (ms)	Reliability (%)	Data rate (Mbps)	Min required Communication range (meters)
50-6000	2-50	10-500	90-99.99	50-65	80-350

2.4. UC Category 3: Extended Sensors

2.4.1. Description

According to 3GPP TS 22.186 R16, Extended Sensors "enable the exchange of raw or processed data gathered through local sensors or live video data among vehicles, RSUs, devices of pedestrians and V2X application servers. The vehicles can enhance the perception of their environment beyond what their own sensors can detect and have a more holistic view of the local situation".

2.4.2. Initial set of evaluation KPIs

The initial set of evaluation KPIs derive from the performance requirements defined in the 3GPP TS 22.186 R16. The range of target values for each KPI is obtained from the target values defined in that document for each considered scenario.

Table 3 Initial set of evaluation KPIs for Extended Sensors UC category

Payload (Bytes)	Tx rate (Message/Sec)	Max end-to-end latency (ms)	Reliability (%)	Data rate (Mbps)	Min required Communication range (meters)
1600	10	3-100	90-99.999	10-1000	50-1000

2.5. UC Category 4: Remote Driving

2.5.1. Description

According to 3GPP TS 22.186 R16, Remote Driving "enables a remote driver or a V2X application to operate a remote vehicle for those passengers who cannot drive themselves or a remote vehicle located in dangerous environments. For a case where variation is limited, and routes are predictable, such as public transportation, driving based on cloud computing can be used. In addition, access to cloud-based back-end service platform can be considered for this use case group".

2.5.2. Initial set of evaluation KPIs

The initial set of evaluation KPIs derive from the performance requirements defined in the 3GPP TS 22.186 R16. The communication scenario involves an information exchange between a user equipment (UE) supporting V2X application and a V2X Application Server.

Table 4 Initial set of evaluation KPIs for Remote Driving

Max end-to-end latency (ms)	Reliability (%)	Data rate (Mbps)
5	99.999	Uplink: 25 Downlink 1

2.6. UC Category 5: Vehicle Quality of Service Support

2.6.1. Description

According to 3GPP TS 22.186 R16, Vehicle quality of service support "enables a V2X application to be timely notified of expected or estimated change of quality of service before actual change occurs and to enable the 3GPP System to modify the quality of service in line with V2X application's quality of service needs. Based on the quality of service information, the V2X application can adapt behaviour to 3GPP System's conditions. The benefits of this use case group are offerings of smoother user experience of service".

2.6.2. Initial set of evaluation KPIs

The 3GPP 22.186 R16 Technical Specification document defines 14 requirements to support Vehicle Quality of Service. Here we have selected the 5 most relevant requirements from 5G-MOBIX perspective to be used as the initial set of evaluation KPIs.

Table 5 Initial set of KPIs for Vehicle QoS Support

KPIs to be met by Vehicle QoS Support
The system shall be able to support an efficient and secure mechanism to gather information (e.g. location information, reliability information, timing information, latency information, velocity information), in order to generate information about quality of service in a resource efficient way.
The system shall be able to support continuity of reporting estimated quality of service even when the Public Land Mobile Network (PLMN) changes.
The system shall be able to support negotiating quality of service alternatives with the V2X application.
The system shall be able to provide V2X applications with updated quality of service from the quality of service alternatives previously negotiated by the V2X application, when the quality of service of the UE's ongoing connection changes.
The system shall be able to support a V2X application to request connectivity with specific quality of service parameter for a certain geographic area and time.

3. 5G-MOBIX USE CASES

3.1. Introduction

5G-MOBIX defined 18 use cases distributed among two cross-border corridors and six local sites. The following table maps the use cases with trial sites and use case categories.

Table 6 5G-MOBIX use case list

UC #	Site	UC Name	UC Category
1	Spain-Portugal	Interurban complex scenarios for private automated vehicles	Advanced Driving
2	Spain-Portugal	Interurban scenario for public transport	Vehicle QoS Support
3	Spain-Portugal	Last Mile EV automated shuttle vehicles in cross-border and urban environment	Advanced Driving, Remote Driving
4	Greece-Turkey	Truck platooning with "see-what-I-see" functionality	Vehicles Platooning
5	Greece-Turkey	Assisted truck border-crossing & increased cooperative awareness	Extended Sensors
6	Germany	Cooperative perception with HD maps and surround view	Extended Sensors
7	Germany	SAE L-4 Platooning	Vehicles Platooning
8	Finland	Video-based Cooperative Perception	Extended Sensors
9	Finland	Remote driving	Remote Driving
10	France	Automated Overtaking	Advanced Driving
11	France	Remote Driving	Remote Driving
12	Netherlands	Cooperative Collision Avoidance	Advanced Driving
13	Netherlands	L4 automated vehicle tele-operation and tele-monitoring services	Remote Driving
14	Netherlands	Collective perception of environment	Extended Sensors

15	China	Automated driving (Coordinated overtaking and collision avoidance + Remote Manoeuvre)	Advanced Driving, Remote Driving
16	China	Road safety and traffic efficiency services	Extended Sensors, Vehicles Platooning
17	Korea	Tethering via Vehicle	Vehicle QoS Support
18	Korea	Remote Driving	Remote Driving

Section 3.2 describes the methodology that was followed to define these use cases. Then, each trial site and the use cases planned for that trial site are presented.

3.2. Methodology for use case definition

According to the 5G-MOBIX vision, leveraging 5G technologies for addressing the Cooperative, Connected and Automated Mobility (CCAM) application challenges is expected to be of great benefit. The promising benefits of 5G in many fields needs to be stressed in representative CCAM applications to assess its maturity level. In the context of 5G-MOBIX, the 5G networks are intended to support automation of driving actions, which will also be done potentially using different technological and business models. The core idea behind the methodology is that 5G-MOBIX will show the impact of applying 5G in selected use cases through cross border trials along 5G corridors presented in this document.

During the proposal stage, the trial sites designed a set of use cases that were supported by the added value of 5G connectivity. This initial use case list was added to the Grant Agreement and included several automated mobility candidates to benefit and even more be enabled by the advanced features and performance of the 5G technologies. For instance, cooperative overtake, highway lane merging, truck platooning, valet parking, urban environment driving, road user detection, vehicle remote control, see through, HD map update or media & entertainment.

From this preliminary list the consortium has reformulated its approach to better consolidate the 5G-MOBIX vision. Specifically, four different ingredients have been considered as common drivers for all the use cases:

1. Relevance of 5G technologies in AD functions with use cases enabled by core technological innovation from 5G, such as new frequency bands, Cloud Radio Access Network (C-RAN), Mobile Edge Computing and network virtualisation infrastructures.

2. Applicability on cross border context which may include several operator's domains and business models.

3. Use of L4/L5 AD modes at cross border kind of roads, mainly highways.

4. Contribution to the cross-border trial sites to widen the project outcomes. Use cases deployed in local sites need to complement the cross-border corridor use cases in aspects such as AD technology, 5G components, driving situations or business models.

To double check that the use case ecosystem from 5G-MOBIX is consistent, complementary, solid and relevant the following methodology has been implemented. First a committee was appointed formed by the T2.1 leader (VICOM with use cases at Germany site), the WP2 leader (AALTO with use cases at Finland site), the Technical Coordinator (WINGS with use cases at Greece-Turkey cross border site) and the Project Coordinator (ERTICO).

Each one has performed a peer review with binary (YES/NO) and enumerated lists (trial site and use cases) responses to a set of content and structure related metrics. The goal is to check that all the aspects have been fulfilled and the criteria items are satisfied. Specifically, these criteria items have been evaluated:

- Use Case Category. As agreed by the consortium the use case categories were taken from the document "Enhancement of 3GPP support for V2X scenarios (Release 16)" 3GPP TS 22.186 V16.1.0 (2018-12). This classification has already been described in Section 2. Thus, the use cases are forced to be in the scope of one of them.

- Template compliance. To cover all the different angles from stakeholders with similar structure and details, the consortium follows a template. Firstly, the descriptions identified the target Autonomous Driving functions and the sequence of communications and data exchanged among the actors. Secondly, to show a real impact at cross-border use cases, the different use cases identify a use case from a cross border trial site, underlining how the use case complements the one defined at a cross border trial site with added value from Autonomous Driving functions, 5G technologies or business models. Thirdly, based on the Autonomous Driving features and connectivity challenges, the use cases identified the expected progress beyond the state of the art. Finally, the use cases map required connectivity features in relation to expected 5G services that the networks will provide.

- Mapping to a cross border trial site. 5G-MOBIX has to impact cross border 5G deployments enabling CCAM along 5G corridors potentially including several operator's domains. Thus, the identification of a cross-border trial site with valid environment, in terms of driving situations and 5G features to exercise the use case is essential.

- Mapping to a use case present at a cross border. To maximize the efficiency of the project activities, developments and deployments, it is crucial to keep use cases aligned from the ones identified from cross border trial sites. Hence, the implementation and validation of a use case in a trial site can be a prior stage that would provide valuable information, techniques, settings and technologies for the deployment and validation of the same use case in a cross-border trial site.

- Explicit and convincing declaration of the contribution of the use case to cross-border corridors. The use case should provide a delta or complementary aspect in terms of 5G technology, AD functions or innovative business models to maximize its impact.

- Applicability of the use case in a cross-border environment with potential handover and roaming connectivity implications. The dynamics and timeline of the use case must have sense in a cross-border corridor environment potentially including several operator's domains.

- Necessity of 5G services and performance. The 5G network must be a catalyser of the CCAM use case enabling the use case, not just providing an enhanced performance from LTE.

- L4/L5 Autonomous Driving functions are the main use case enabler. The use case must pivot around L4/L5 AD functions with a clear scope in improving driving or safety.

- Overlap with another use case claiming similar contribution. Different trial sites can target the same use case category (e.g. remote driving) but each use case implementation needs to add some differential value.

Once the first review of all those aspects have been done by all the members of the committee, the results have been reported to use case leaders and trial site leaders to invite them to fix all the aspects. This report is a table that includes the vision of all the reviewers for all the evaluated aspects. Looking like a dashboard, green and red colours point out the satisfied or insufficient aspects. This table has been produced and shared online to ease a live update of any aspect by the reviewers and an instant awareness of the current status by the use case and trial site leaders. To ease this use case update or reshape, specific comments were done by the Technical Coordinator in each of the documents describing use cases. The Figure depicts the review work flow.

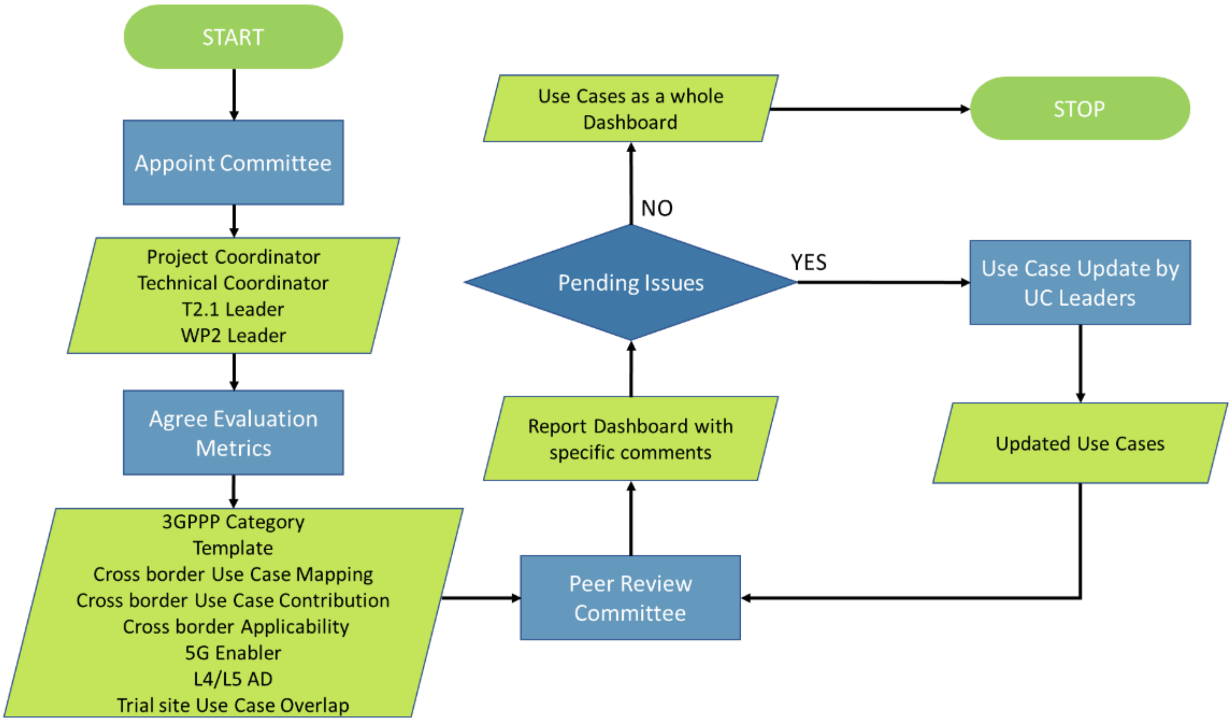

Figure 1 Use Case review workflow.

The use case leaders and trial site leaders made the changes accordingly. An overview of the resulting use cases is included after the detailed use case descriptions to fast check the consistency, complementarity, strength and relevance of selected use cases. Once the methodology to formulate and align the use cases has been described, the use cases are detailed below under the pilot site which will host the use case deployment and demonstration.

3.3. Spain-Portugal (ES-PT) Cross-Border Corridor

The ES-PT cross-border corridor is located in the border of the north of Portugal with Spain. This border is established by the Minho/ Miño river, disposing of several bridges providing the road infrastructure serving trucks, cars and pedestrian. A rail and road bridge are also available however not targeted by the current project. International trade as well as large passenger commuting flows are of great importance and provide ideal conditions for the execution of diversified trials to showcase the advantages offered by the 5G connectivity to CCAM use cases.

3.3.1. Location

Table 7 ES-PT location overview

Trial site class	Corridor
Country/Countries	Spain/Portugal
City/Cities	Vigo / Tui / Valença / Porto

Figure 2 Old bridge over Miño/Minho river in Spain-Portugal Border (where UC3 will take place)

The Spanish-Portuguese corridor connects the cities of Vigo and Porto, with a distance of around 250 Km, and using next roads/highways:

Spain:
- Urban Roads in the city of Vigo (4 Km)
- A55 (10 Km)
- AP9 (5 Km)

Portugal:
- A3 (4 Km)
- N13 (1km)
- A28 (10 Km) near the Porto Airport and Boat Passenger Terminal (7 Km)

Current infrastructure in the pilot area is composed by:
- 3G/4G Cellular Communication.
- 1 MEC Node (based on CONCORDA Project)
- ITS-G5
- In-Vehicle Communication Units, developed by CTAG
- Road Side Units, developed by CTAG
- C-ITS Platform to manage the corridor events.

The 5G infrastructure that has been planned for the development of the 5G-MOBIX project is the following:
In the Spanish side:
- MEC node with additional capabilities for interconnection with MEC nodes from another operator.
- A number of macro / small cells, initially based on 4G LTE but eventually upgradeable to 5G NR, to reinforce the coverage. The exact number of nodes will depend on the corridor area to be reinforced.
- A network slicing framework for proper isolation between V2X and eMBB services, based on either SDN/NFV technologies or more traditional means (like e.g. local breakout and QoS differentiation) .
- A number of SIM cards properly registered in Telefonica's provisioning systems for access to V2X services

In the Portuguese side:
- MEC
- 5G base stations. BTSs.
- 5G core
- Optical fibre interconnections
- IP/MPLS fixed network
- Energy power supply

According to this, the 5G-MOBIX Scenario will be the one indicated in Figure 3.

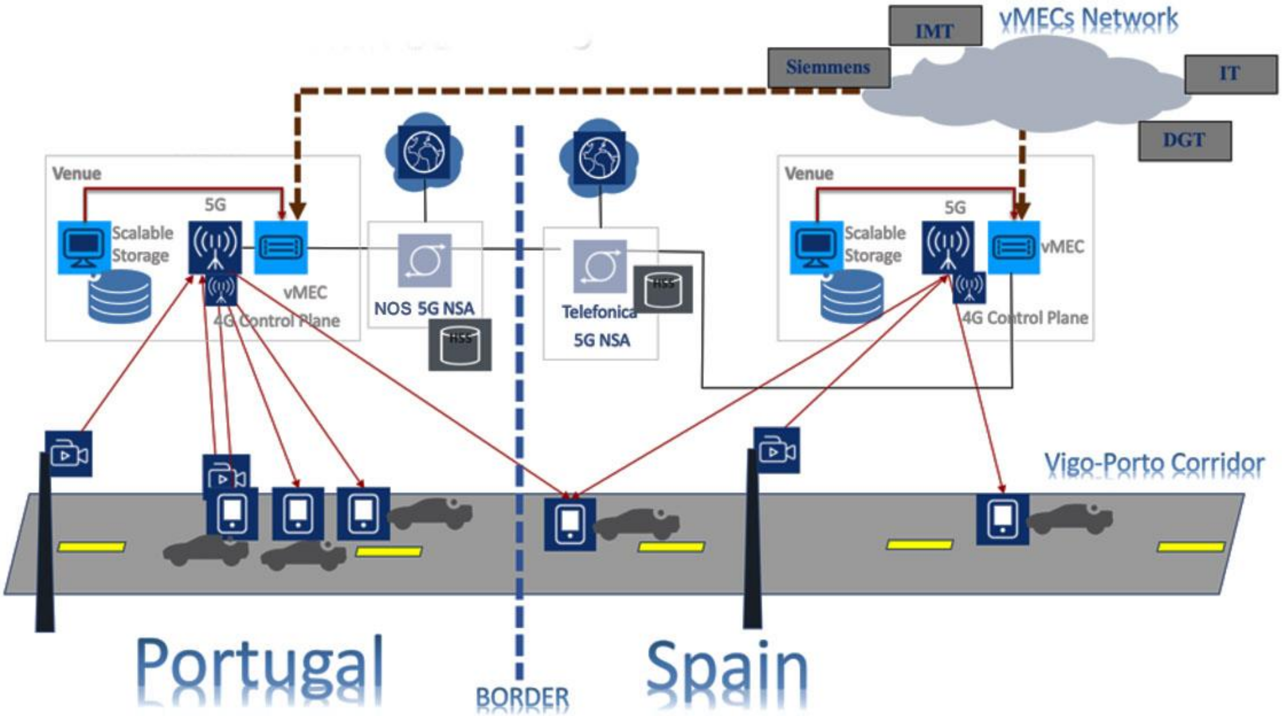

Figure 3 5G-Mobix Scenario.

The Spain-Portugal corridor includes the following use cases locations:

- Spain - Vigo bay. UC3
- Spain - A-55 and AP-9 (near CTAG). UC1
- Border - Old bridge. UC3
- Border - New bridge. UC1
- Portugal - A-28 (segment near the Porto airport and the Boat Passenger Terminal). UC1
- Portugal - Vigo-Porto highway roads with 5G tests in the new bridge. UC2

Figure 4 Spain-Portugal corridor and their Use Cases

3.3.2. Local Consortium

Spanish partners:

Table 8 Spanish partners

Role	Partner	Contribution
Full Partner	CTAG	Trial coordinator, 5G OBUs, Technical Evaluation, Vehicle
Full Partner	DGT	Specifications to the related infrastructure in interurban environment
Full Partner	Telefónica I+D	Network & frequency provider, 5G integration and maintenance
Full Partner	ALSA	Bus vehicle provider, integration in bus
Full Partner	Nokia Bell Labs	Remote control, BTSs, MEC and Roaming Strategy
Full Partner	Vigo Council	Specifications to the related infrastructure in the city
Full Partner	Universidad de Murcia	Support in the integration of 5G
Full Partner	Dekra	Support technical evaluation
Full Partner	AEVAC	Business models and dissemination
Associate partner	PSA	OEM
Associate partner	Telefónica Móbiles	5G Infrastructure
Advisory Board	Telefónica SA	Recommendations, regulation discussions, invitation to events…

Portuguese partners:

Table 9 Portuguese partners

Role	Partner	Contribution
Full Partner	TIS	Support in Evaluation
Full Partner	IT	R&D related with road sensing technologies, 5G security and the extension of C-ITS messages
Full Partner	A-to-B	Support in development of use cases
Full Partner	IP	National Road Infrastructure Manager and Private MNO
Full Partner	SIEMENS	Support in use cases and Horizontal activities
Full Partner	CCG	Coordination on the Portuguese corridor side, use cases co-development, human factors.
Full Partner	IMT	National Traffic Authority and dissemination
Full Partner	AENL	Highway Concession Manager
Full Partner	NOKIA	5G technology provider
Full Partner	ISEL	5G network performance in the technical context
Full Partner	NOS	Network & frequency provider, 5G integration

3.3.3. Use Case 1: Interurban complex scenarios for private automated vehicles

3.3.3.1. Motivation

In the scope of CAD (Connected and Automated Driving), connectivity and road sensing technologies will provide an extra perception layer to automated vehicles, in order to guarantee the safety and provide a more comfortable solution to the driver.

At the same time, a key element in the automated driving is the availability of an HD-Map, that describes not only a high definition of the road (description, lanes, references, attributes, hazards, road works, etc.) but also is able to have it updated in real time, in order to show changes in the lane path or other updates as soon as they occur.

3.3.3.2. Description

This use case consists of two different scenarios where connectivity will support automated manoeuvres:

- **Scenario 1: Lane merge for automated vehicles:**

This Use Case manages the situation where automated vehicles are in a lane merge scenario, analysing the traffic flow of the target lane. In this way, the system is able to detect existing vehicles including their lane position, acceleration, speed, size, etc. providing an extended perception layer which is taken into account by the automated vehicle to determine the best merge manoeuvre according to the current situation.

Vehicles in the lane to be merged are connected vehicles that share their vehicle data with the use of a Communication Unit with 5G capabilities and through a MEC Node. Road sensing technologies, such as traffic radars, are also used to detect the presence of vehicles in the target lane and to transmit their position and speed to the automated vehicle.

Automated vehicle uses the Communication Unit as well in order to receive the information sent by surrounded vehicles and the road-side infrastructure, and therefore determine the status of the lane merge and the best way to operate to success in a safe and comfortable lane merge.

- **Scenario 2: Automated Overtaking:**

When an automated vehicle needs to overtake a vehicle that precedes it, additional information provided by communication technologies will drastically improve and complement the information provided by its sensor constellation.

There are many situations where the dimensions of other vehicles can cover the field of view of the autonomous vehicle sensors (for example, a truck can reduce the vision of a camera, a laser or a radar sensor). Moreover, according to the route followed by the vehicle, it can happen that a highway exit or a toll is near to the point where the overtaking takes place, and a queue of vehicles can complicate the scenario reducing free space and therefore producing a less appropriate manoeuvre.

Other complex scenario can appear when there are vehicles behind the automated vehicles that occludes the vision of rear sensors. Considering that we are driving on a two-lane road with a right-hand traffic regulation, this occlusion can produce that the automated vehicle is not able to perceive a vehicle driving fast in the left lane.

The purpose of this use case is to extend the 360º perception layer of the automated vehicle by integrating communication capabilities in the different vehicles of the scenario and additional road sensors (e.g. traffic radars) in the infrastructure. In this way, vehicles will be able to share their positions, speeds, sizes, etc., as well as the road-side infrastructure, helping automated vehicle to understand current situation and thus take the best decision of how to proceed with the automated overtaking.

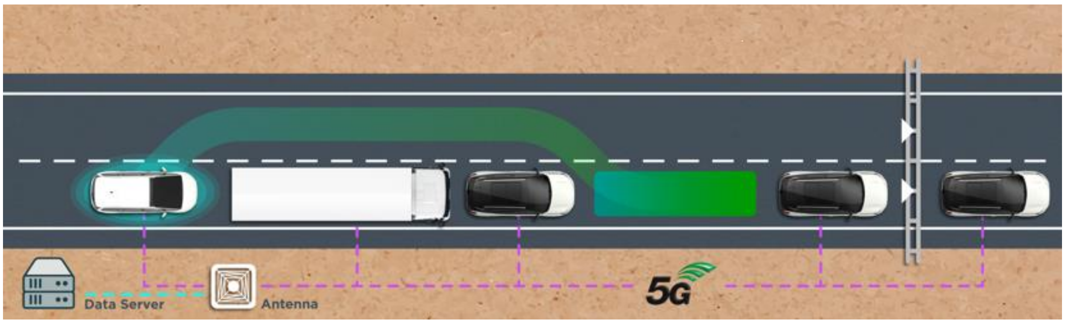

Figure 4 Overtaking example

- **<u>Scenario 3: HD maps:</u>**

This use case focusses in the capability of automated vehicles and road-side infrastructure to detect changes in the road and the HD-Map used for driving, and in sending these changes to the ITS-Centre in order to centralise and broadcast this information to the other approaching vehicles.

Lasers, cameras and traffic radars information can be fused with D-GPS and HD-Maps data, in order to determine changes in the stored information. This information can be measured in terms of length of the event, changes in road description (number of lanes, width of the lanes), dangerousness of the situation, etc.

Finally, obtained data is shared with the ITS-Centre in order to be stored and shared with other vehicles, ensuring the information reaches all the relevant vehicles.

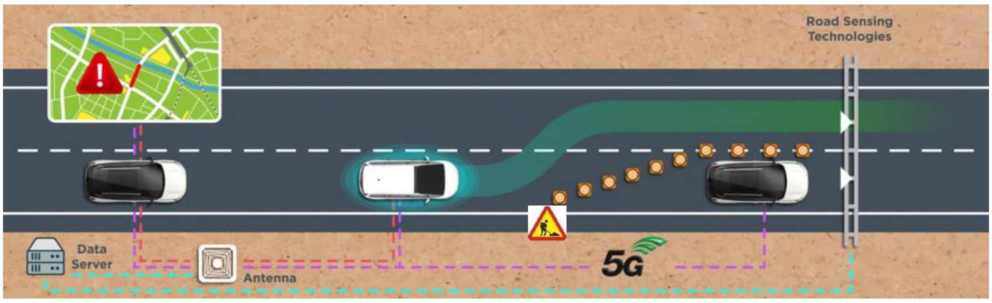

Figure 5 Use Case HD Maps Scenario.

Table 10 Overview of Interurban complex scenarios use case

Use Case Short Name	Interurban complex scenarios
Use Case Category	Advanced Driving
Use Case Leader	CTAG
Other partners	DGT, Telefónica I+D, Nokia Bell Labs, Dekra, UMU, Vigo, CCG, NOKIA PT, NOS, INFRAPT, IT, ISEL, SIEMENS, A-TO-B, NORTE, TIS and IMT
Objective	To execute merge manoeuvre according to the traffic flow of the target lane
Actors Scenario 1	Autonomous vehicle Communication unit Road sensing technologies (e.g. traffic radar) MEC node ADAS system
Pre-conditions Scenario 1	• Autonomous vehicle shall be equipped with a communication unit connected to the 5G network and connected to the vehicle CAN data related with vehicle attributes (speed, acceleration, position, size, etc.). • Other vehicles shall be driving in the target lane of the lane merge scenario. • Other vehicles shall be equipped with a communication unit connected to the 5G network and connected to the vehicle CAN data related with vehicle attributes (speed, acceleration, position, size, etc.). • Road-side infrastructure shall be equipped with additional sensors

	(e.g. traffic radar) to detect other vehicles in the target lane. • Road sensing technologies shall be equipped with a communication unit connected to the 5G network. • A MEC node is available and enabled to forward vehicle data between the vehicles.
Use Case flow Scenario 1	1. Vehicles driving in the highway share their attributes in real time, with the nearby vehicles, using the capabilities of 5G Network and the MEC node. 2. The road sensing technologies also disseminate information regarding vehicles driving in the highway by using the capabilities of 5G network. 3. An autonomous vehicle is driving towards the lane merge scenario. 4. The autonomous vehicle receives the information shared by the road-side infrastructure and by the other vehicles according to their attributes. 5. ADAS system of the autonomous vehicle analyses the information received and takes decisions about the best speed to safely incorporate at the highway lane. 6. In case there is not enough space between vehicles, autonomous vehicle will reduce its speed (stopping if necessary) in order to perform a safely and comfortable manoeuvre.
Post conditions Scenario 1	Cooperative Lane merge is done.
Actors Scenario 2	Autonomous vehicle Communication unit Road sensing technologies (e.g. traffic radar) MEC node ADAS system
Pre-conditions Scenario 2	• Autonomous vehicle shall be equipped with a communication unit connected to the 5G network and connected to the vehicle CAN data related with vehicle attributes (speed, acceleration, position, size, etc). • Other vehicles shall be driving in the same road of the autonomous vehicle (in front or behind, faster or slower). • Other vehicles shall be equipped with a communication unit connected to the 5G network and connected to the vehicle CAN data related with vehicle attributes (speed, acceleration, position,

	size, etc). • Road-side infrastructure shall be equipped with additional sensors (e.g. traffic radar) to detect vehicles and measure their attributes. • Road sensing technologies shall be equipped with a communication unit connected to the 5G network. • A MEC node is available and enabled to forward vehicle data between the vehicles.
Use Case flow Scenario 2	1. Vehicles driving in the road share their attributes in real time, with the nearby vehicles, using the capabilities of 5G network and the MEC node. 2. The road sensing technologies also disseminate information regarding vehicles driving in the highway by using the capabilities of 5G network. 3. An autonomous vehicle is driving faster than the vehicles driving in the same lane, in front of it. 4. The autonomous vehicle receives the information shared by the road-side infrastructure and by the other vehicles according to their attributes. 5. ADAS system of the autonomous vehicle analyses the information received and triggers a safely automated overtaking manoeuvre. 6. In case the autonomous automated overtaking manoeuvre is not safely enough to be performed, autonomous vehicle will adapt its speed in order to drive behind the next vehicle.
Post conditions Scenario 2	Potential accident has been avoided. Overtaking manoeuvre is analysed.
Actors Scenario 3	• Autonomous vehicle • Driver • ITS-Centre • Communication unit • ADAS system • Sensor devices such as lasers, cameras and radars
Pre-conditions Scenario 3	• Autonomous vehicles shall be equipped with a communication unit connected to the 5G network and connected to the vehicle ADAS system. • Autonomous vehicles shall be equipped with an HD-Map Unit that contains the information of the route to be followed by the vehicle.

	• An ITS-Centre is available and ready to receive, update and share HD-Map information. • Other autonomous vehicle is driving the same route as the first autonomous vehicle but keeping a long distance between them (>2 Km).
Use Case flow Scenario 3	1. An autonomous vehicle is driving in a highway road. 2. The ITS-Centre notifies about a road works event that takes place in the route that the autonomous vehicle is following. 3. The autonomous vehicle receives the information and checks if its HD-Map has been updated with the related road works information. 4. In case the HD-Map has not been updated, automated vehicle requests the driver to take back the control of the driving. 5. The driver drives the vehicle through the road works area, and the autonomous system records the new path based on its sensors information. 6. When the vehicle passes completely the road works event, the autonomous systems sends recorded data to the ITS-Centre. 7. The ITS-Centre receives the data of the changed route and generates and updates the HD-Maps information for the road works area. 8. The ITS-Centre shares the new HD-Map with other relevant vehicles. 9. Other upcoming vehicles receive the updated HD-Maps from the ITS-Centre and follow the new path.
Alternative flows Scenario 3	In case the HD-Map has already been updated including road works path data, autonomous vehicle follows the path through road works area.
Post conditions Scenario 3	• Enhanced HD-Map service information with data provided by vehicles and road-side infrastructure. • Improvement in safety by giving a more secure path in a road works event

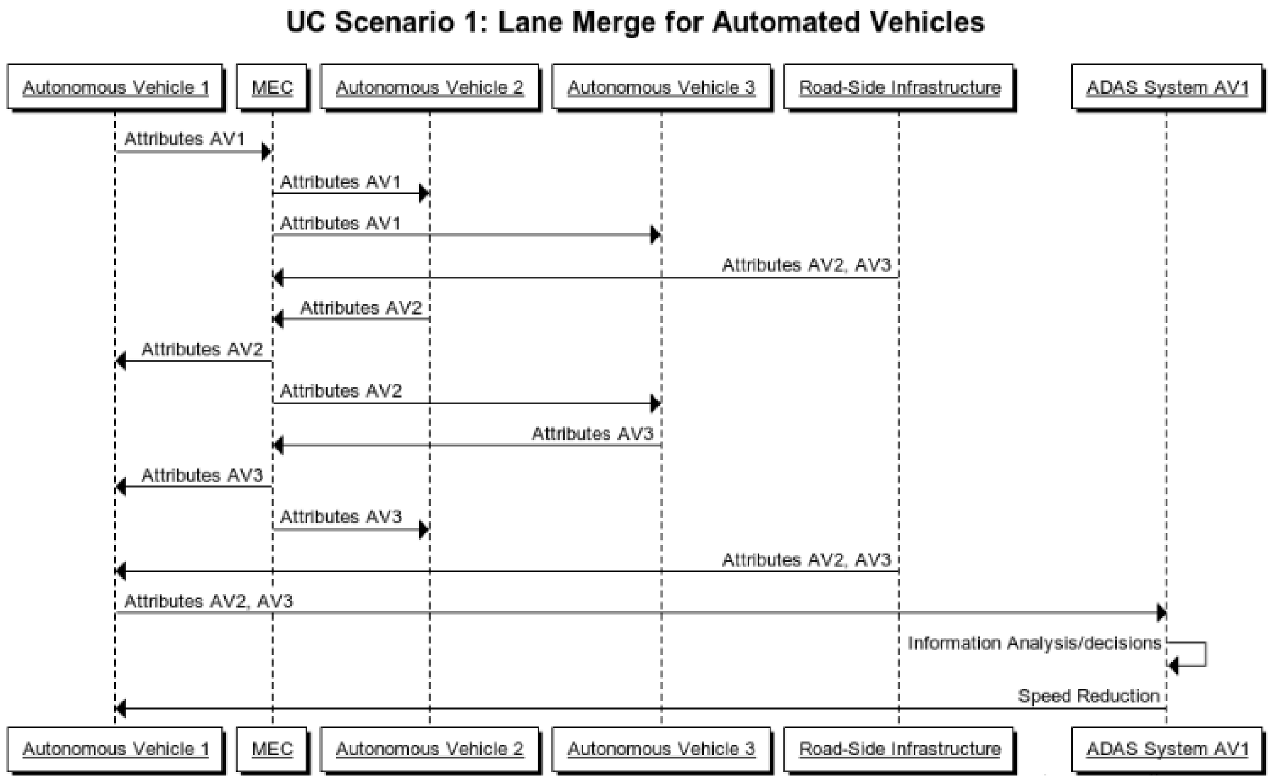

Figure 6 Sequence diagram for Scenario 1

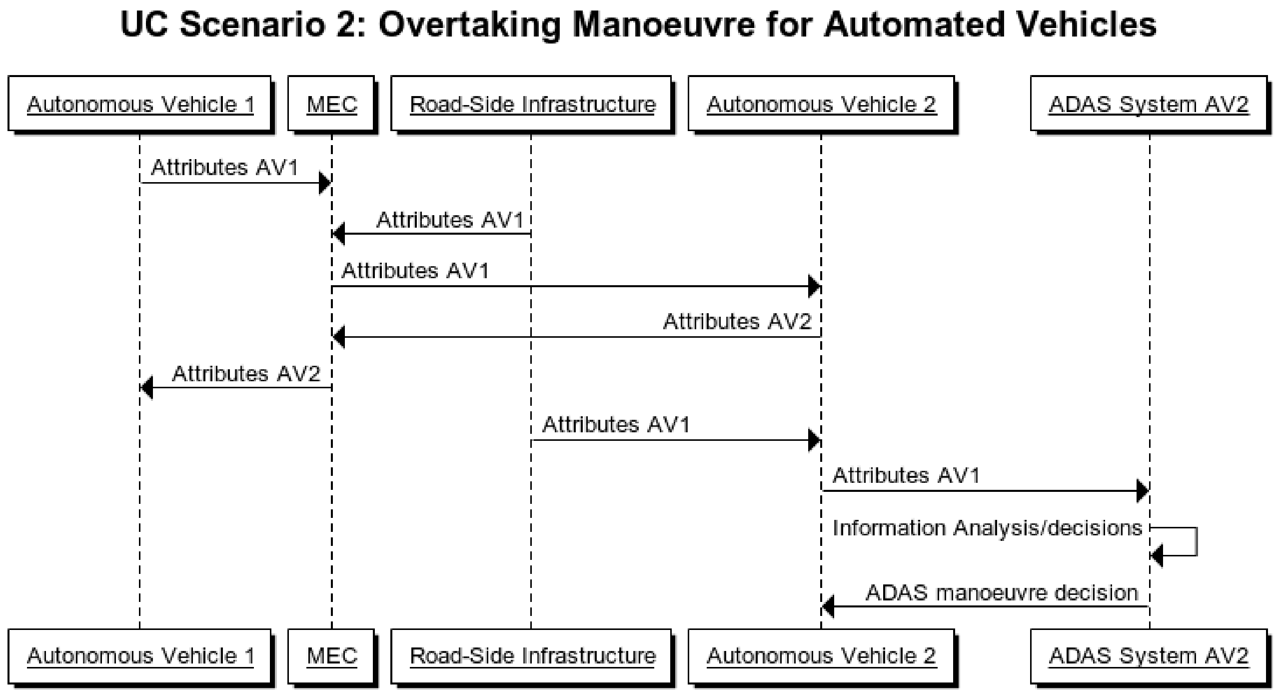

Figure 7 Sequence diagram for Scenario 2

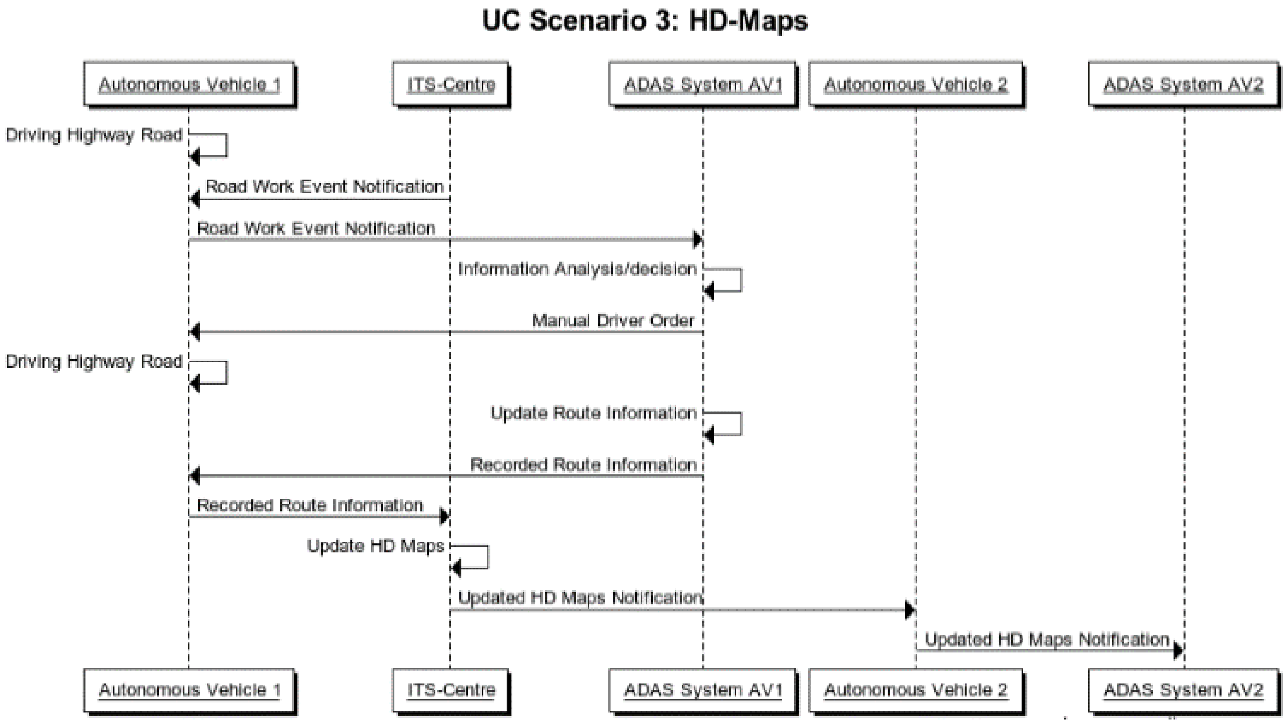

Figure 8 Sequence diagram for Scenario 3.

3.3.3.3. *Beyond state of the art*

This use case will improve safety and comfortability on connected and automated vehicles by giving them, not only an extra perception layer, but also a real-time updated high definition map of the road. Advances in communication technology that 5G brings (like low latency, high bandwidth, massive devices capacity or multicast/broadcast capability) will help to become real the scenarios considered in this use case.

3.3.3.4. 5G services

Table 11 Overview of 5G services to be implemented in the Interurban complex scenarios use case

5G service	Implementation
Embb	Yes, to allow the big amount of data related to the HD maps to be uploaded/downloaded between vehicles and the ITS-Centre.
URLLC	Yes, to avoid delays and high latencies on vehicle-to-vehicle or vehicle-to-infrastructure communication.
mMTC	Yes, to allow these services to work with big amounts of devices connected at the same time.
C-RAN	Yes
Network Slicing	Yes, to guarantee the quality of service for the communication channel.

3.3.4. Use case 2: Interurban Scenario for Public Transport

3.3.4.1. Motivation

There are several motivations to develop this Use Case:

- 5G capacities enhance user's comfortability and user access to multimedia content.
- Enhanced monitoring capabilities for the transport services by accessing the 4k camera in the vehicle.
- Streaming the information of in vehicle sensors to other vehicles in the area.

3.3.4.2. Description

The objective of this use case is to provide real time connected services to the public transport fleet that connects the cities of Vigo and Porto (considering the way to the Francisco Sá Carneiro airport). According to this approach, users will be able to enjoy different multimedia services while travelling in the public transport, including high bandwidth data consumption applications as well. On the other hand, the public transport vehicle will be equipped with a 4K Camera in order to be able to remotely access the video stream for Control Centre management and monitoring tasks. Added to this, in vehicle sensor data will stream to the vehicles behind, in order to extend the vision field of those vehicles helping to improve the execution of autonomous driving manoeuvres in terms of safety and comfort.

The Use Case can include a multimedia device which will be used as user interface, allowing users to make use of the multimedia application installed on this device.

Another option is to allow users to connect their own devices through a Wi-Fi connection which will be connected to the high capabilities mobile network.

These options will be studied and decided during the deployment of the use case.

4K Front camera and in vehicle sensors will be connected to the communication unit, opening the stream channel from the bus to the Control Centre and other vehicles behind. ALSA, as the public transport operator, will have the remote connection to the 4k camera stream in order to visualize the image of where the vehicle is passing by.

Figure 9 Interurban Scenario for Public Transport

Table 12 Overview of Interurban public transport use case

Use Case Short Name	Interurban public transport
Use Case Category	Vehicle Quality of Service Support
Use Case Leader	CTAG
Other partners	DGT, Nokia Bell Labs, Telefónica I+D, ALSA, UMU, Dekra, CCG, NOKIA PT, NOS, INFRAPT, IT, ISEL, SIEMENS, A-TO-B, NORTE, TIS and IMT
Objective	Monitoring Public transport service and improve user's comfortability
Actors	• Public Transport Bus. • Control Centre. • 4k camera. • In vehicle sensors. • Multimedia devices. • Bus passengers.
Pre-conditions	• A public transport bus shall be equipped with a communication unit with 5G capabilities. • 4K Camera shall be installed in the front side of the vehicle, and it shall be connected to the communication unit. • The bus shall be equipped with sensors to recognize de environment. • Through a multimedia device (to be defined) users shall be able to access to high definition multimedia content.
Use Case flow	1. Users (bus passengers) access to multimedia services through a device, and they are able to reproduce high quality content without delay. 2. ALSA Control Centre is able to remotely access to the 4K camera content and visualise in real time outside-bus image where the bus is driving. 3. Vehicles behind will be receiving sensors data including the list of objects detected by the different sensors in the bus. 4. Vehicles behind are able to access to the list of objects detected and sent by the bus.
Post conditions	• 5G capacities enhance users comfortability and user access to multimedia content. • Enhanced monitoring capabilities regarding outside-bus image for the transport services is added thought a 4K camera. • Improve of safety by using the systems in the bus as remote sensors for other vehicles.

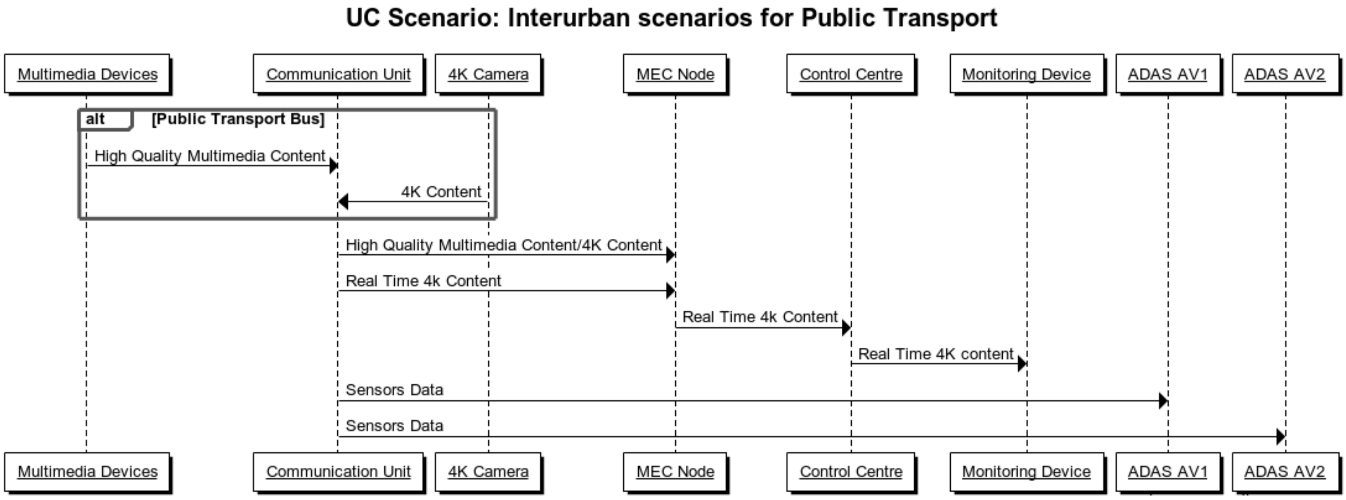

Figure 10 Sequence diagram for Interurban scenario Public Transport

3.3.4.3. *Beyond state of the art*

This Use Case aims to take advantage of 5G technologies to improve monitoring systems in a fleet of public transport vehicles, as well as increasing the comfort of the occupants using these vehicles by providing them with high definition multimedia content services. All these goals just become achievable through the capacities of 5G technologies.

3.3.4.4. *5G services*

Table 13 Overview of 5G services to be implemented in the for Interurban scenario public transport use case

5G service	Implementation
eMBB	Yes, High bandwidth capabilities in order to provide a 4K Camera Stream from the Public Bus towards the Control Centre and to allow high quality multimedia services to the bus users.
URLLC	Yes, Low latency to avoid transmission information delay among bus and other actors like control centre and vehicles around.
NR-SA	Yes, connecting directly to the 5G Core allows a best performance for the services of the use case.
C-RAN	Yes, the improvement in network performance provided by C-RAN allows the deployment of the services included in the use case.
Network Slicing	Yes, to prioritize 4K camera quality of service, in case in a concrete area, network coverage is not good enough to provide network to all the bus services.

3.3.5. Use Case 3: Last Mile EV Automated Shuttle vehicles in Cross Border and urban environment

3.3.5.1. Motivation

Last mile EV Automated shuttle vehicles will play an important role in the near future of European cities. The cooperation of these vehicles with VRUs (Vulnerable Road User) in order to increase comfortability and safety of these users, as well as the fact of having an alternative solution when the path of these vehicles becomes obstructed, suppose a valuable advance in connected cities. 5G technology will enable these developments even in cross-border areas or close to country boundaries.

3.3.5.2. Description

This use case is focussed in the deployment of last mile EV Automated shuttle vehicles in different environments:

- Cross Border environment: The shuttle will cover a route between Spain and Portugal connecting the cities of Tui and Valença though the old international bridge.
- Urban environment: The shuttle will cover a route in the city of Vigo.

Figure 11 Cross Border Environment.

Figure 12 Urban Environment.

For both environments we will consider these two scenarios:

Scenario 1: Cooperative automated operation: In this scenario, the EV Autonomous shuttle is able to receive information coming from other actors (like a Vulnerable Road User) and adapt its behaviour according to specific needs.

Scenario 2: Remote Control: In this scenario the EV autonomous vehicle is driving following a predefined route, and suddenly an obstacle appears in its path blocking the original route. In this situation, an operator is alarmed, and he/she is able to remotely take the control of the EV autonomous vehicle or issue a set of new navigation commands in order to handle a new route.

Table 14 Overview of Last Mile Automated Shuttle use case

Use Case Short Name	Last Mile Automated Shuttle
Use Case Category	Advanced Driving
Use Case Leader	CTAG
Other partners	DGT, Nokia Bell Labs, Vigo Council, Telefonica I+D, AEVAC, UMU, Dekra, Vigo, CCG, NOKIA PT, NOS, INFRAPT, IT, ISEL, SIEMENS, A-TO-B, NORTE, TIS and IMT
Objective	To adapt EV Autonomous shuttle behaviour according to specific needs
Actors Scenario 1	• EV Autonomous Shuttle. • Vulnerable Road User (VRU).
Pre-conditions Scenario 1	• EV Autonomous Shuttle shall be equipped with a communication unit connected to the 5G Network, and able to receive cooperative information. • A vulnerable road user (VRU) shall be equipped with a connected device (like a smartphone, wearables or communication units in VRU's vehicles) in order to share its position, speed and characteristics (mobility, vulnerability, etc.).

Use Case flow Scenario 1	1. The EV Autonomous Shuttle is driving following a predefined route. 2. The vulnerable road user (VRU) is sharing its position and speed through the connected device. 3. The vulnerable road user (VRU) is moving towards the EV Autonomous Shuttle route, and they will cross. 4. The EV autonomous shuttle receives the information shared by the vulnerable road user (VRU) and analyses it in order to check if they will cross. 5. The EV autonomous shuttle reduces its speed until it brakes, in order to prioritise the vulnerable road user.
Post conditions Scenario 1	5G Networks allows the detection of VRU by the EV Autonomous Shuttle
Actors Scenario 2	• EV Autonomous Shuttle. • Control Centre. • Operator. • Remote Control device.
Pre-conditions Scenario 2	• EV Autonomous Shuttle shall be equipped with a communication unit connected to the 5G Network, and able to receive remote commands coming from the control centre. • The control centre is equipped with a remote control system in order to remotely control the EV autonomous shuttle when needed. • An operator is working in the control centre, monitoring the EV autonomous shuttle and able to use the remote control system.
Use Case flow Scenario 2	1. The EV Autonomous Shuttle is driving following a predefined route. 2. While driving, the EV autonomous shuttle detects an obstacle that cannot be avoided following the defined route. 3. EV autonomous shuttle sends an alert to the control centre to inform about the situation. 4. An operator receives the alert in the control centre and verifies the obstacle using the camera of the remote control system. 5. The operator remotely controls the EV autonomous shuttle, in order to avoid the obstacle and return the vehicle to the predefined path. 6. The EV autonomous shuttle continues the normal route.
Post conditions Scenario 2	5G Networks allows remote control of an EV autonomous shuttle.

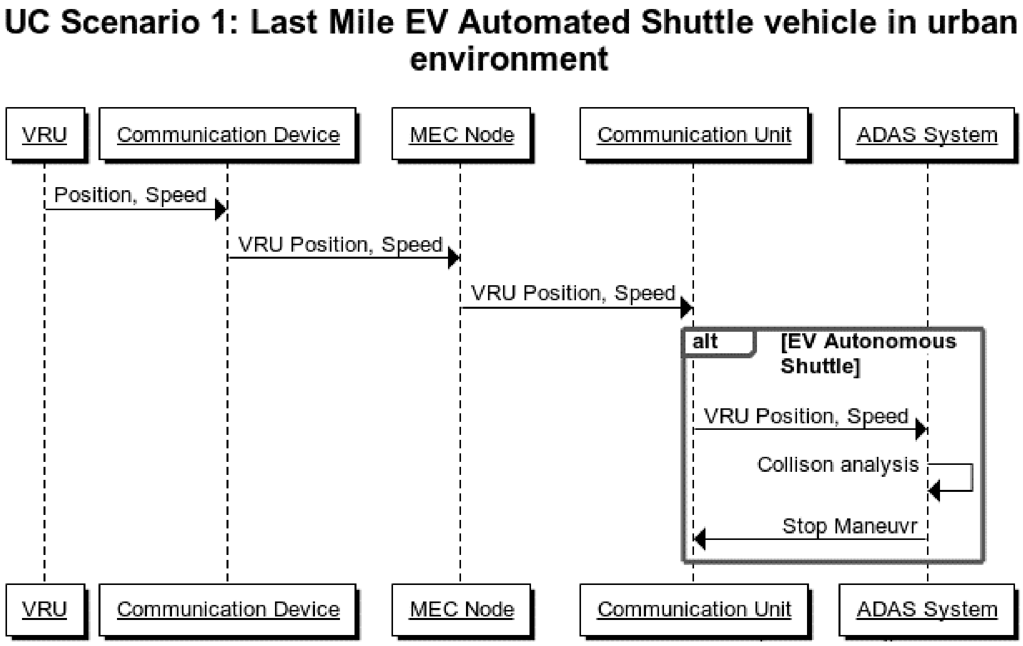

Figure 13 Sequence diagram Scenario 1 Last Mile EV Automated Shuttle vehicles in urban environment

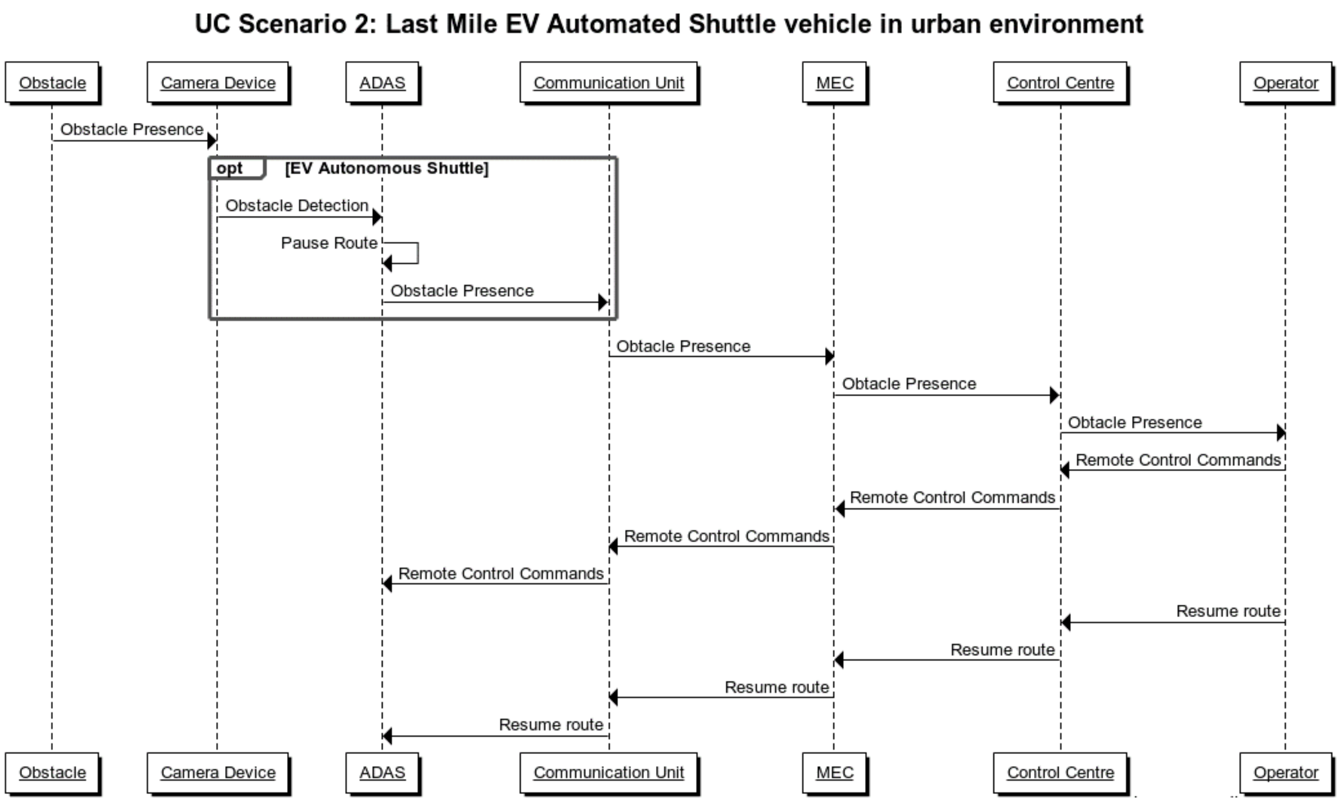

Figure 14 Sequence diagram Scenario 2 Last Mile EV Automated Shuttle vehicles in urban environment

3.3.5.3. *Beyond state of the art*

The aim of these Use Cases is to improve safety and comfortability in last mile autonomous shuttle services and vulnerable road user lives. These advances will be built on 5G technologies that will allow us to immediately communicate different vehicles/VRUs with very low latency, connect a huge number of devices simultaneously, as well as transfer big amounts of data on real-time.

3.3.5.4. *5G services*

Table 15 Overview of 5G services to be implemented in the Last Mile Automated Shuttle use case

5G service	Implementation
eMBB	Yes, High bandwidth capabilities in order to provide a 4K Camera system from the EV autonomous shuttle towards the Control Centre.
URLLC	Yes, Low latency to guarantee camera image is according to the reality of where the EV autonomous shuttle is driving. Low latency to ensure remote command are received in real time.
Network Slicing	Yes, to prioritize remote control commands and camera when the EV autonomous shuttle is being controller by the operator.

3.4. Greece – Turkey (GR-TK) Cross-Border Corridor

The GR-TR cross-border corridor constitutes the south-eastern border of the European Union providing a challenging geo-political environment due to the existence of actual, physical borders, where customs agents perform rigorous border checks. These unique conditions comprise a commensurate testing ground for the operation of CCAM use cases at EU border conditions with heavy traffic and will help determine how the involved stakeholders should adapt to accommodate such functionality. The heterogeneity of traffic going through these borders, i.e. trucks with commercial goods, tourists, as well as the co-existence of multiple differentiated vehicles with pedestrians (security personnel, customs agents, etc.) provides ideal conditions for the execution of diversified trials to showcase the advantages offered by the 5G connectivity to CCAM use cases.

The GR-TR partners will develop the necessary 5G-enabled technology and perform advanced trials for two main CCAM use cases, namely i) truck platooning with "see-what-I-see" functionality and ii) Assisted truck border-crossing & increased driver awareness.

3.4.1. Location

Table 16 GR-TK location overview

Trial site class	Cross-border Corridor
Country/Countries	Greece / Turkey
City/Cities	Kipoi / Ipsala

The GR-TR trials will take place on the most commonly used border crossing between Greece and Turkey in the area of Kipoi (GR) - Ipsala (TR) where the E90 (GR) highway becomes the E84 (TR) highway when crossing into Turkey. Figure 15 depicts the exact location of the GR-TR cross-border trials and the route to be followed by the participating vehicles, covering a stretch of 2.5 kms for testing.

Currently significant efforts are being made on both Greek and Turkish sides to contact all the relevant authorities and ministries in order to guarantee a permit for the actual border crossing of the vehicles. This is a challenging issue since this border crossing is one of the busiest ones in South-East Europe, and security concerns need to be addressed. Irrespective of the trial permit, the trials will have a cross-border character, since coverage from the Greek operator can extend into Turkey to provide handover conditions for the trials. The envisioned direction of trials will be for Ford trucks to start from the Greek side of the borders (communicating over the Cosmote 5G network) and progressively drive towards the Turkish side and handover (one by one) to the Turkcell 5G network.

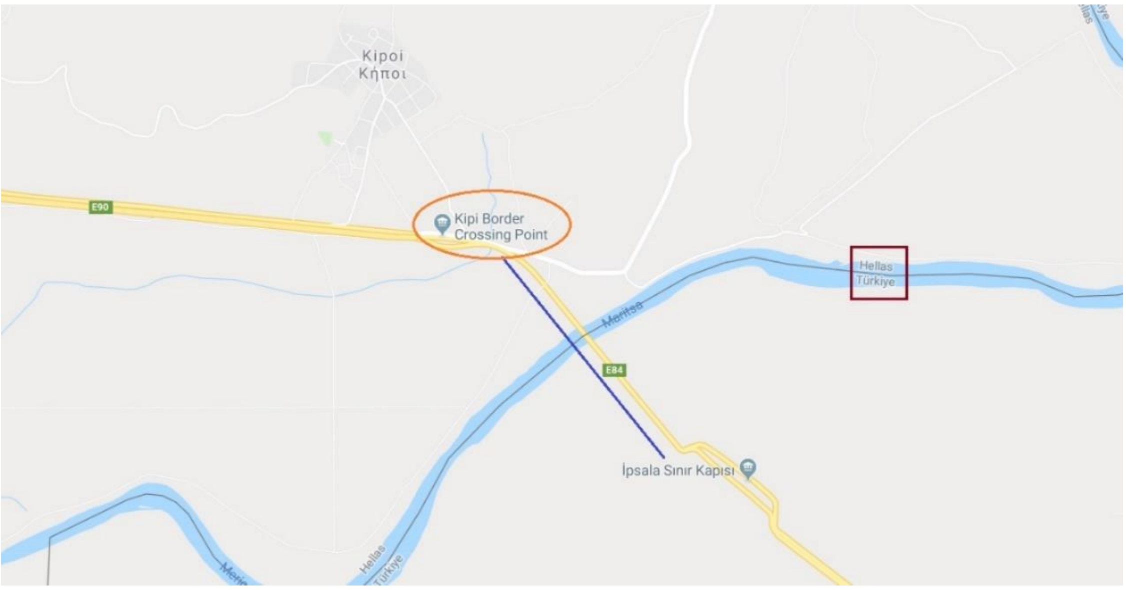

Figure 15 GR-TR border-crossing trial location

Besides the trials at the GR-TR border, initial tests will also be carried out in the Ford Otosan Inonu trial site (see Figure 16) where development of functionality and testing will take place to support the cross-border trials. The knowledge & technology transfer from this trial site will enable the advanced trials taking place at the border, while it also provides an area for long-term development and testing (such long-term activities are prohibitive at the border location).

Figure 16 Ford Otosan trial site to be used for long-term functionality development & testing

3.4.2. Local Consortium

Table 17 GR-TK consortium

Role	Partner	Contribution
Full partner	Turkcell	GR-TR corridor leader, MNO, Network & Frequency provider (gNB site, transport network, core functionality)
Full partner	Cosmote	MNO, Network & Frequency provider (gNB site, transport network, core functionality)
Full partner	Ford Otosan	OEM providing the CCAM enabled trucks to be used in the trials
Full partner	Ericsson GR	Vendor, providing the 5G technology for the Cosmote network (gNB HW & SW, vEPC, Cloud functionality)
Full partner	Ericsson TR	Vendor, providing the 5G technology for the Turkcell network (gNB HW & SW, vEPC, Cloud functionality)
Full partner	WINGS ICT Solutions	SW developer providing the data fusion capability at the edge (CCAM info + environmental sensors / cameras), providing the AI enabled platform to be used.
Full partner	ICCS	SW developer & integrator providing data fusion modules, ML enabled KPI processing. KPI evaluation.
Full partner	Intrasoft	SW developer providing cloud platform expertise
Full partner	IMEC	Provider of 5G enabled OBUs and 5G-modules
Full partner	TÜBİTAK BİLGEM	Enabling the cross-border trials through available equipment and securing of permits on the Turkish side
Advisory Board	Hellenic Ministry of Infrastructure and Transport	Strategic advice and guidance during the project (signed LoS)
Advisory Board	Ministry of Digital Policy, Telecommunications and Media (GR)	Strategic advice and guidance during the project (signed LoS)
Advisory Board	Turkish Ministry of Transport and Infrastructure	Strategic advice and guidance during the project (signed LoS) / Represented by Deputy Minister Dr. Ömer Fatih SAYAN

3.4.3. Use case 4: Truck platooning with "see-what-I-see" functionality

3.4.3.1. Motivation

A platoon is a group of vehicles that "move like a train with virtual strings attached between each other" [1]. In order to better make use of road space and render transportation of goods more efficient, a convoy is formed in which the vehicles move much closer together than can be safely achieved by human drivers [2], resulting in significant fuel consumption savings, as well [1]. To maintain the distance between the vehicles and the operation of the platoon, the vehicles need to share their states such as location, speed, heading and their intentions such as braking, acceleration, etc over the C-V2X links established between them, which does not necessarily require a network operator to be present, and thus a SIM card.

Despite the numerous advantages of platooning, from the point of view of the vehicles that are at the back, following the lead vehicle in a platoon (the gap distance translated to time is 0.3 seconds or even shorter) can cause lack of attention and anxiety while driving, since trailers are wide and high enough to cover driver sight. These problems are quite common also among today's truck drivers. To circumvent them, a "see-what-I-see" application will be designed and implemented for truck platooning, which will be providing the road view of the leader truck to the others in the platoon. Here, the goal is to enable the trailing truck drivers to be alert and aware of the road conditions, which is especially critical for SAE L4 and below autonomous vehicles that might need human intervention at some point.

The resolution requirement for the "see-what-I-see" functionality is that a 4K – Ultra HD high quality and precise video is shared with the follower vehicle drivers. Since a huge bandwidth (eMBB) is needed to transfer such a high volume of data coupled with very low latency (URLLC) due to the real-time nature of the video transmission from the leader truck to the others in the platoon, 5G technology is a must for this application to be realized. Current technology falls short of the bandwidth and latency requirements of the "see-what-I-see" functionality to be developed for the platoons as described.

In order to fully demonstrate a cross-border platooning scenario with "see-what-I-see" functionality, "truck routing in customs site" between Turkey and Greece is included in the use case, as well, which will enable the transfer of the platoon members from one end of the border to the other much faster. As can be seen in Figure 1, the border between the two countries is characterized with long queues, traffic jam, and strict controls such as document and X-ray checks, demanding that such an addition to the use case is made. The process of passing from Turkey to Greece requires that the truck drivers stop more than once: Document delivery at the customs site entrance, entire truck x-ray check if customs officer has the decision to do so, customs counters to receive/deliver "all clear to pass" documents are some of the stop points.

By deploying additional sensors at the customs site to apply the sensor fusion technique for the "truck routing in customs site", the tough manoeuvres that are to be handled in a small area due to the other vehicle and pedestrian traffic, will be carried out autonomously, and the truck will be able to move from one point to another without the driver. This will enable the driver to save time to expedite other procedures required to get border pass approval while, at the same time, traffic efficiency will be increased, and the average vehicle border crossing time as well as the number of traffic accidents due to human error will be decreased at customs sites.

Figure 17 How does the GR-TR Border look like?

Traffic flow example at the Turkish customs site can be seen in Figure 2. Note that this is just a descriptive figure of the customs site to show the related infrastructure and functionality, drawn not to scale.

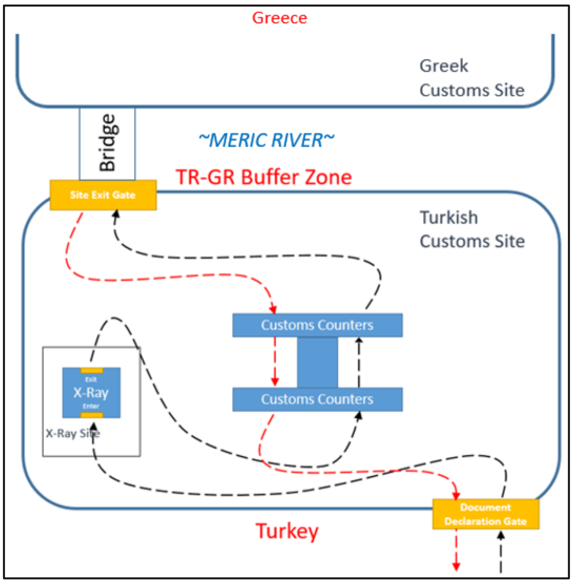

Figure 18 Traffic Flow between the GR-TR Borders

3.4.3.2. *Description*

Observing that there is at least another vehicle on a road, which does not involve intersections and merging with other lanes for a certain time, the two or more vehicles on the move will decide to *form a platoon*. In the platoon, while one of the vehicles take on the role of the leader, which may or may not have an active driver depending on the SAE level of the vehicle itself, the rest of the drivers in the other vehicles may be put the rest, being controlled automatically by the movements of the leading vehicle.

Once the platoon is formed and the "see-what-I-see" application is informed about the presence of the platoon as well as its members with distinct roles to identify the leader and the follower vehicles, a specific ID is assigned to the platoon by the application. Then, the platoon leader will start transmitting a compressed (with H.265/HVEC codec standard) 4K video stream captured by a camera viewing the road in the front of the vehicle, along with the platoon ID, first to the base station, then to the vEPC, which is to transfer the streaming data to the "see-what-I-see" application server. Matching the video with the recipient vehicles that are the follower trucks in the platoon by using the platoon ID, the application server begins sending the video stream to these through the vEPCs and base stations serving them.

As can be seen in Figure 3 below, all platoon members will be equipped with on board units (OBU) that have the C-2VX communication capability and a connection to the in-cabin displays of the vehicle (such as a dedicated tablet). Additionally, the platoon leader will share road information collected from its sensors such as short and mid-range radars and cameras as well as internal data about its manoeuvres (i.e. emergency brake, speed up-down etc.) over the PC5 interface with the follower vehicles.

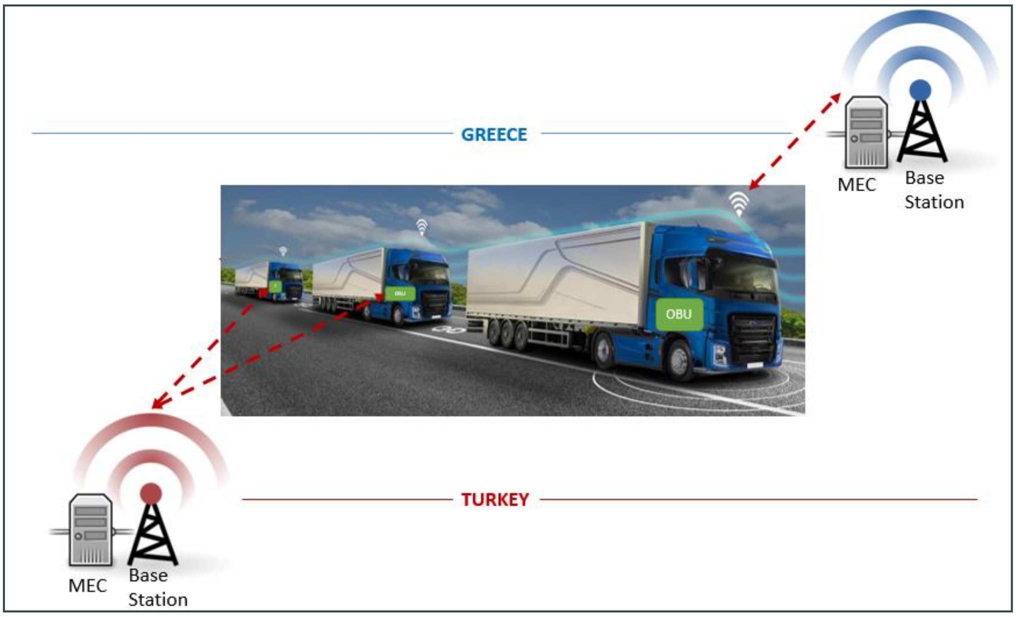

Figure 19 Cross Border Platooning with "see-what-I-see" Functionality

When the platoon arrives to the customs site between Turkey and Greece borders, the platoon is dissolved for further controls at the borders. At this stage, the objective is to allow the truck drivers handle required documentation while the trucks move autonomously at the customs site to visit each of the checkpoints as dictated by the customs agency. For the autonomous crossing of the trucks between the borders, the customs site will be equipped with several sensors and road side units (RSUs) in addition to the 5G network infrastructure. All sensory information from the vehicles and the surrounding will be gathered at the network edge to be processed by an application, which will determine the safest paths for each of the vehicles at the customs site, dynamically shaping their whole trajectory.

After the "truck routing in customs site" is over with no obstacles detected for passage through the border and the drivers have completed their paperwork, they will return to their vehicles. Upon exiting the customs site, the platooning operation and thus the "see-what-I-see" functionality will be initiated again. The final destination of the platoon will be Greece.

While the platoon goes from Turkey to Greece, it is anticipated that at some point, which depends specifically on the radio signal propagation characteristics of the 5G networks, the vehicles in the platoon will roam from the Turkish (Turkcell) operator to the Greek (Cosmote) operator, where an uninterrupted video stream will flow from the leader truck to the follower trucks throughout the roaming procedure.

Table 18 Overview of Truck platooning with "see what I see" use case

Use Case Short Name	Truck platooning with "see what I see
Use Case Category	Vehicles Platooning
Use Case Leader	Ford Otosan
Other partners	IMEC, Turkcell, Cosmote, Ericsson TR, Ericsson GR
Objective	Real time 4K UHD video transfer between trucks in a platoon and autonomously route a truck in customs site
Actors	• Autonomous Truck • 5G Telecom Networks • "See-what-I-see" application • "Truck-routing" application
Pre-conditions	• All the vehicles support C-V2X (PC5 & Uu) communication. • Each vehicle has a unique label for identification when interacting with others, the "see-what-I-see" and "truck routing" application. • The platoon has more than one active vehicle, driving in the same lane. All the platoon members are within the communication range of its direct neighbour, which is also a member of the platoon.

	• The direction of the platoon is towards the borders between Turkey and Greece. • Platoon vehicles moves a zone that covered by 5G technology.
Use Case flow	*Platooning with "see-what-I-see" functionality* 1. The platoon leader transfers vehicle data, such as speed, brake, position to the follower vehicles through the respective OBUs to sustain the operation of the platoon. 2. The platoon is created, and the "see-what-I-see" application is informed about this decision, which in return sends a confirmation message to the leading vehicle. 3. The platoon leader sends the compressed UHD camera image of the road as seen from its windshield to the application through the 5G network, which consists of the 5G base station (gNB) and the vEPC (i.e., 5G EPC which can connect to gNBs). 4. The application sends this video stream to the follower vehicle OBUs again through the 5G network. Normally, the vEPC and most likely the base station serving the following vehicles are expected to be the same as the leader. 5. The OBUs of the follower vehicles transfer the video stream to the in-vehicle display. 6. Platoon is dissolved when vehicles reach to TR-GR border. *Truck routing in customs site* 1. Driver initiates "truck routing" application. 2. All sensory information (i.e., from the vehicles and the environment) at the customs site will be collected, and sent to the edge through the 5G network. 3. Collected data will be transferred to an application server, which is in charge of processing and aggregating the information collected from different sensors and construct a high definition map of the environment. The role of the application at the server is to assist the vehicles during their checkpoint visits at the customs site, calculating the dynamic safe waypoints individually for each of the vehicles, where a continuous flow of information between the application, the sensors and the vehicles will take place. 4. The 5G network will get the calculated trajectory data from the application server and transfer it to the OBUs of the vehicles, which are tasked with starting an internal set of operations to complete the manoeuvring of the vehicles. Internally, each OBU will have the following mode of operation: a. The OBU will gather safe waypoint data and transmit it to the Vehicle Central Control Unit (VCCU), a proprietary module whose software development is

	done by Ford Otosan, via the vehicle Ethernet connection. b. The VCCU will send the required Controller Area Network (CAN) messages to the other electrical control units (ECU) of the vehicle, such as the brake and the steering ECU. c. The related ECU receiving the CAN messages will perform the pre-defined manoeuvring. *Moving into Country 1 from Country 2: Platooning with "see-what-I-see"functionality* 1. The customs tasks and all checkpoint visits are completed, and thus the vehicles leave the customs area to start the platooning operation again as in Steps 1-5. 2. The platoon roams from one operator to the other when the signal strength received from the other is higher, with no interruption observed for the "see-what-I-see" functionality. In Step 4, an extreme scenario may be observed, during which while the leading vehicle roams into the operator in Country 1, the trailing vehicles are still in Country 2. This is depicted in the sequence diagram shown in Figure 4 below.
Post conditions	• The platoon follower vehicles can view the road, which lies ahead the leader vehicle of the platoon. • The trucks moves from one country to another in the fastest and the most comfortable way possible. • Driver experience is enhanced. • Accelerated passage across the borders.

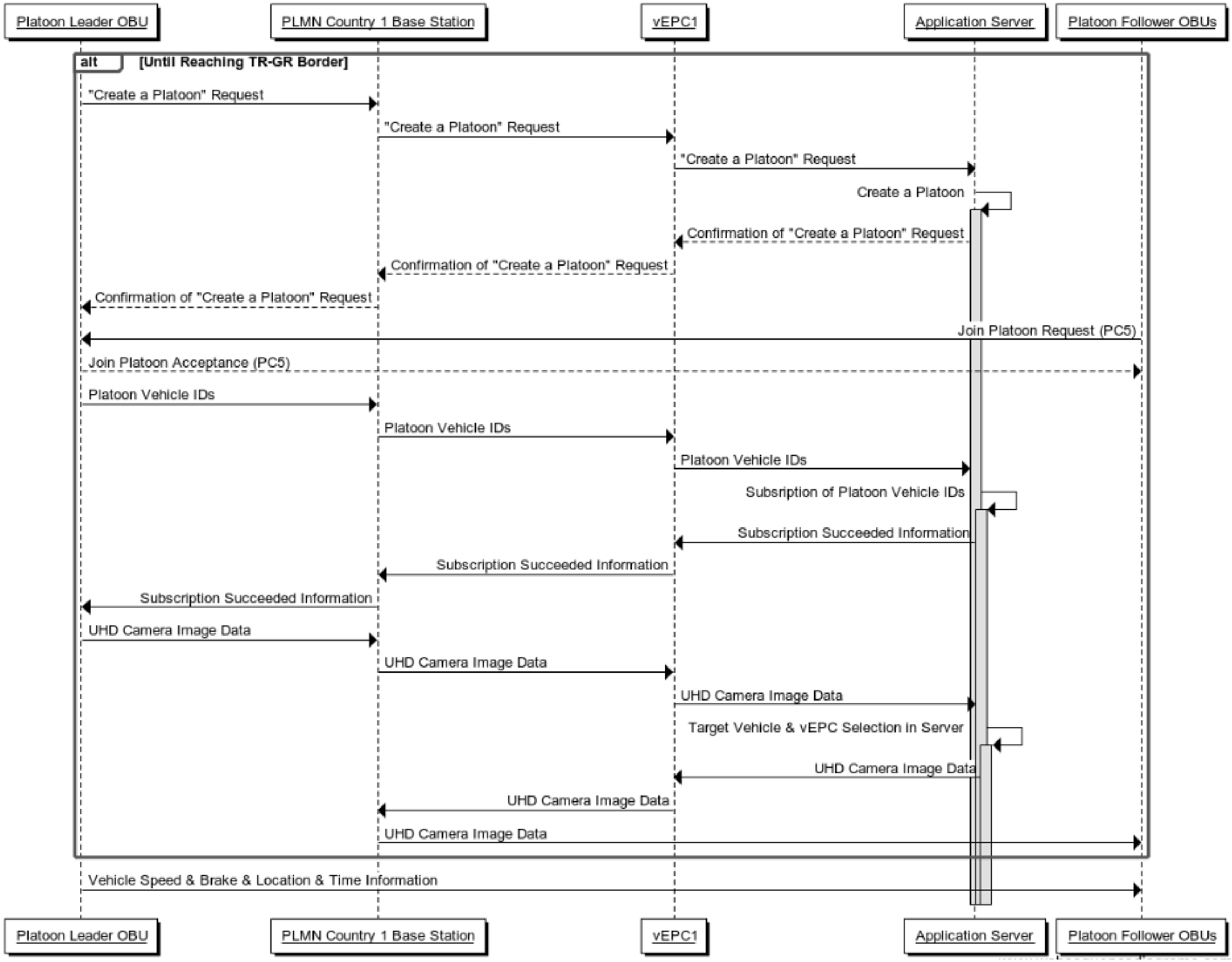

Figure 20 Sequence diagram for the platooning use case with "see-what-I-see" functionality (Until Platoon Reaching TR-GR Border)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 825496.

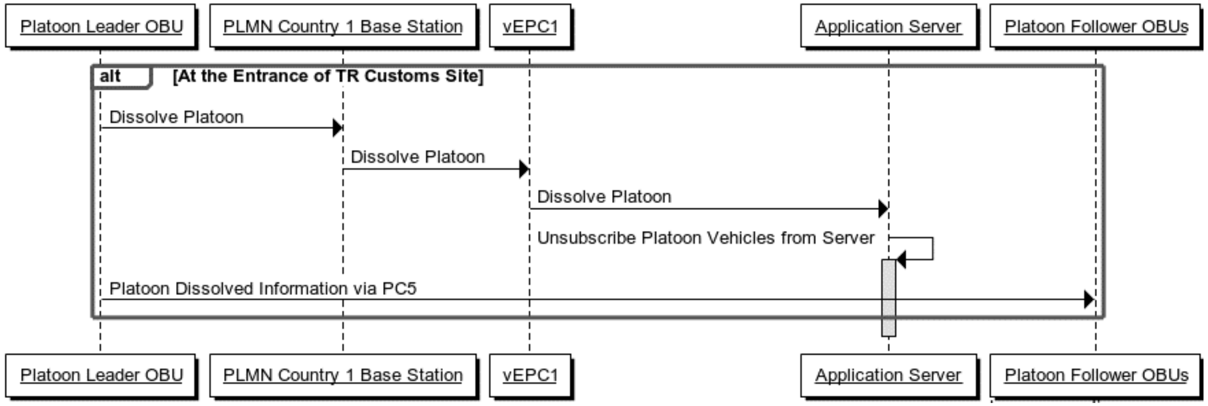

Figure 21 Sequence diagram for the platooning use case with "see-what-I-see" functionality (At the Entrance of TR Custom Site)

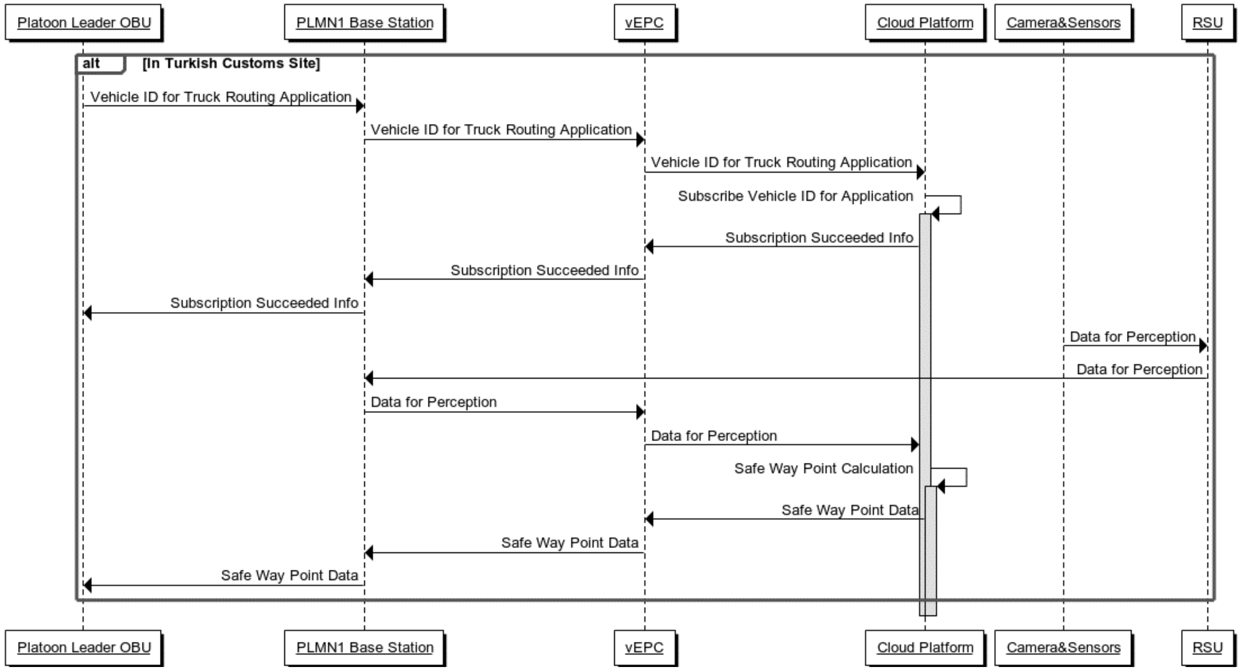

Figure 22 Sequence diagram for the "truck routing in customs site" functionality

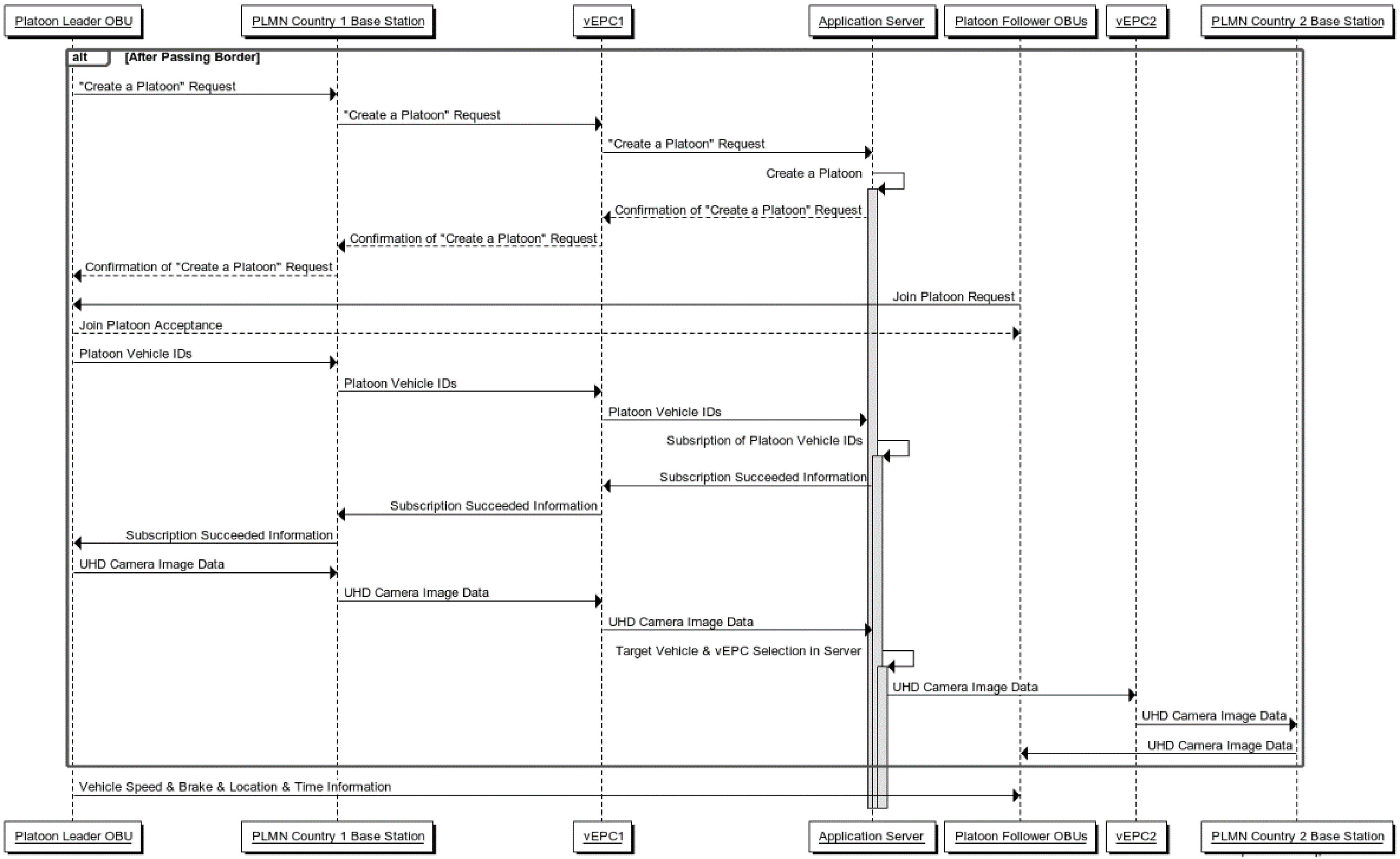

Figure 23 Sequence diagram for the platooning use case with "see-what-I-see" functionality (After Passing the TR-GR Border)

3.4.3.3. *Beyond state of the art*

With the help of the enormous data transfer capability of the 5G network, this use case can be evolved in the future to encompass different purposes. For example, 4K video data can be collected from the lead vehicle and transferred to a local centre to observe the driver – vehicle status or with the addition of an extra in-cabin camera, driver health and security can be tracked remotely. Fleet owners and insurance companies can take advantage of such systems in the future, even making it mandatory for all vehicles.

3.4.3.4. *5G services*

Table 19 Overview of 5G services to be implemented in the use case

5G service	Implementation
eMBB	Yes. The high bandwidth requirements of the video generated by the camera viewing the road that lies ahead of the leading truck in the platoon and data generated by sensors to route truck in customs site.
URLLC	Yes. The transmission of the video has to be performed in real-time to prevent any incidents that may result from a sudden intervention of one of the drivers in the trailing trucks in the platoon to leave the platoon and get on the road.
mMTC	No. The number of sensors existing on the vehicles and at the roadside is not sufficient to justify the mMTC use case.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 825496.

3.4.4. Use case 5: Assisted truck border-crossing & increased cooperative awareness

3.4.4.1. Motivation

According to recent studies [1], a large portion of time of international transport is wasted at European border crossing in South East Europe (SEE), significantly raising the cost and delivery time of goods and contributing to the segmentation of international logistics. The study in [1] has shown that on average most border crossings take between 30 and 60 minutes but can easily surpass 90 minutes depending on traffic conditions and other factors (counting both waiting and procedural times). The largest portion of this delay is attributed to inefficient flow of information regarding the necessary documentation (33.4%), custom agent's inefficiency (21.9%) and lack of necessary infrastructure and equipment (21.3%). Since border control cannot be alleviated due to security and smuggling concerns, improving the average control time by addressing the weak points of the process can significantly benefit the transport and logistics industry and can greatly reduce both the time and cost of international transportation of goods.

Additionally, border crossing areas with actual customs stations are vibrant and busy multi-actor areas where heterogeneous vehicles, people and infrastructure coexist, leading to a complex environment. Large queues of trucks, large signs, infrastructure (traffic lights, antennas, buildings) can all act as obstacles, minimizing the awareness of the drivers at the borders and amplifying the threat of an accident involving a customs agent, police officer or other more vulnerable road users. The concept of ***assisted cooperative driving*** has the potential to significantly increase the active road safety of the users based on AI/ML techniques which are applied on heterogeneous information from various distributed data sources (UEs, sensors, cameras, etc.) in order to predict certain events and based on this knowledge assist humans by automating certain task (in this case driving). This can be combined with the concept of "live" maps, where the user may be assisted by "live updates" of the maps he/she is using for his/her geolocation / navigation service (GPS, Galileo, etc.) presenting the position of all surrounding road users, potentially providing also additional information regarding the latter (e.g. the users' trajectory, speed) or even updates regarding the road conditions (e.g. road construction ahead, slippery road, etc.).

3.4.4.2. Description

By utilizing the detailed data provided by the CCAM enabled truck's sensors (Lidar, radar, GPS, etc.) as well as the data from surrounding heterogeneous information sources such as traffic cameras, road side sensors, smart phones, wearables and more, increased intelligence can be created based on a cooperative awareness of the borders' environment. The transmission of these data over reliable, ultra-fast and ultra-low latency 5G network connection combined with modern AI and predictive analytics techniques (at the edge) allows for the creation of a virtual environment of the driver enabling various added-value functionalities. As part of this use case the functionalities that will be showcased at the Greek / Turkish borders are:

- Border inspection preparation based on predictive CCAM truck routing

- Secure CCAM truck border crossing with increased inspection confidence
- Increased border cooperative environment awareness for incoming vehicles
- Increased border personnel safety

The above functionalities will showcase a significant minimization of inspection times at all European "hard" borders through the collaboration feasible of different 5G network operators which could even offer "zero touch" inspection (no human intervention needed) in optimal cases. The same solution offers increased cooperative awareness for passing vehicles at the chaotic border-crossing environment and taking advantage of the CCAM functionalities of vehicles, such as automated braking, to prevent accidents involving border personnel (customs agents, police officers).

This intelligent border control functionality may be realized through the following trial set-up. Data originating from the truck sensors in areas around the borders are transmitted over 5G networks and analysed in a cloud-based AI platform after fusion. Once a trajectory towards the border crossing is predicted, special measures may be taken to facilitate further exchange of information and immediate response to predicted events (e.g. the assisted driving application may be downloaded from the Cloud to the edge server to minimize latency, a slice may be provisioned towards a cloud server on the neighbouring county's PLMN, etc.) An exchange of available information is commencing towards the border authorities via 5G network (mMTC type of communication from the truck OBU itself or even from the cargo which may be equipped with relevant sensors / transmitters (e.g. NB-IoT)) which will facilitate the border inspection and prepare the customs agents for the appropriate checks. All relevant information is transmitted to the edge / MEC servers available at the trial site where they are processed by the downloaded AI/ML platform instantiating this functionality.

Additional information can be exchanged over the 5G networks of the neighbouring countries facilitating the acquisition of relevant information about the specific truck (e.g. driver's information, travel history, cargo inventory, etc.) which could speed-up the control process. Extra security and control measures can be deployed which are controlled and managed through 5G networks such as drones, street cameras, thermal or x-ray cameras, etc. and which can feed large amounts of data (eMBB functionality) in a very short amount of time. In the case that all the acquired data from on-board as well as surrounding sensors / devices agree with the information that is fetched by national archives regarding this truck (and potentially its driver) and provided material (video, thermal imaging, x-ray imaging) clears the truck of any suspicion, then a case of "zero touch" inspection may be realized in which case the truck may be allowed to cross-the border without any manual inspection performed on it.

Additionally, the data originating from other vehicles, road side infrastructure, smart phones and wearables may also be fused and analysed at the edge generating a "live" cooperative update of the surrounding environment which can be fed on to the vehicles navigation system, thus increasing the environmental awareness of the vehicle (covering blind spots, pedestrian locations and trajectories, assigned inspection lane by the authorities, etc.) and actively contributing to the safety of the border ground personnel (i.e. automated trajectory alignment or braking upon detection of a potential incident).

In all cases, the same services continue being provided as the truck passes the border from the neighbouring country's network, based on exchanged information in such inter-PLMN scenarios. Service continuity during the inter-PLMN HO is of utmost importance in such cases, and the existence of such intelligence deployed at the edge close to the border greatly facilitates continuous service by identifying imminent HO's and helping the MNOs prepare for it based on the available information. This could lead to the provisioning of a roaming slice before the HO even takes place.

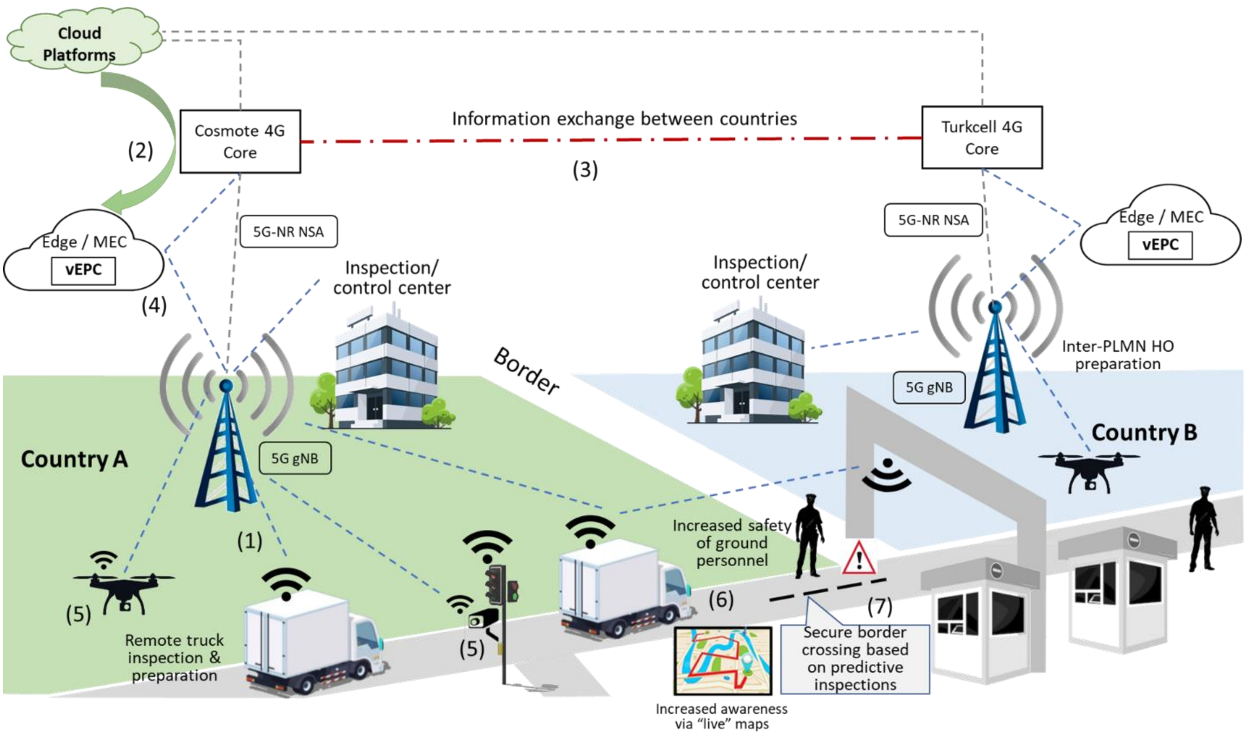

Figure 24 Assisted truck border-crossing & increased cooperative awareness

To implement this use case a laptop onboard the truck will be acting as the UE/gateway that will connect truck and/or cargo devices/systems (e.g. additional sensors deployed in the cargo hold of the truck) to the rest of the system via 5G connectivity (and 4G / NB-IoT during testing & development). These additional sensors are crucial in this case since they have the capability of raising alarms by cross-checking their data with nominal values. For instance, a thermal camera (or even CO2 sensor) installed in the cargo hold of the truck may provide indications of a human presence in the cargo hold (smuggling / human trafficking attempt) which will enable alerted reaction by the border officers upon the arrival of the truck at the border.

Additional measures may take place in case contradicting information is gathered regarding a truck, in which case drones equipped with cameras for live feed may be deployed or thermal or x-ray imaging may be requested to rule out the possibility of smuggling goods and people. The AI based inspection functionality residing in the edge platform will fuse all available information from these heterogeneous sources (potentially originating from different 5G networks in the case of a cross-border scenario) and will locate potential inconsistencies, assigning a certain risk factor to each truck which will affect the degree (and thoroughness) to which border agents will perform a manual inspection. For the realization of this trial a single autonomous truck is needed equipped with additional sensors (as described in Table 20).

Table 20 Overview of Assisted border crossing use case

Use Case Short Name	Assisted border crossing
Use Case Category	Extended Sensors
Use Case Leader	WINGS ICT
Other partners	Cosmote, Turkcell, Ericsson GR, Ericsson TR, ICCS, IMEC
Objective	• Border inspection preparation based on predictive CCAM truck routing • Secure CCAM truck border crossing with increased inspection confidence • Increased border environment awareness for incoming drivers • Increased border personnel safety
Actors	• Autonomous truck • Border control agents • Additional devices (sensors, cameras, drones, wearables)
Pre-conditions	• Autonomous truck equipped with a multitude of sensors driving towards a border crossing • Border control agents equipped with smart-phones / tablets / wearables • 5G network infrastructure with edge / MEC capabilities available at both sides of the border • Additional infrastructure at the site capable of communicating to the edge / MEC
Use Case flow	1. As the truck approaches the border, the truck itself and potentially its cargo (sensors in the cargo hold) start transmitting relevant information towards the border authorities (mMTC). This could take place with a number of different technologies such as GPRS, NB-IoT, 5G-NR slice, etc. 2. Based on the transmitted information and on information

gathered by surrounding environmental sensors, the cloud based intelligence can predict the trucks route towards the border, hence initiating the inspection preparations (e.g. download relevant applications from the cloud to the edge / MEC to minimize functional interaction with the network, request information from authorities, setup additional slices if necessary, etc.). The goal is to identify the truck, the kind/type of cargo, the size of the cargo, etc. (**5-10 km before the border crossing**).

3. The information transmitted by the truck can potentially be exchanged over 5G networks with the neighbouring country's authorities and request all relevant information for this truck, driver, cargo etc. For instance, if the truck is registered in the neighbouring country, information such as the driver's identity and license, his/her track-record, the truck's travel history and cargo inventory can be transferred to the border authorities to facilitate verification & control.
4. Fusion of available information such as traffic on the road, traffic light status, feeds from street cameras, border control traffic, type of cargo and risk level to determine the trajectory / speed of the truck towards the border (e.g. assigned to specific control lane or crossing based on the type of material transported, or based on risk assessment, etc.) and to enable an increased cooperative environmental awareness. (**2-5 km before the border crossing**).
5. Deployment of extra remote inspection methods in order to acquire additional information about the approaching truck and to verify the received information (eMBB). This could be the deployment of drones, the feed from mounted cameras, thermal or x-ray imaging, weight analysis of the truck, etc. (**0-2 km before the border crossing**).
    i. The feed from the cameras / drones can optionally be transmitted over 5G networks to the neighbouring country authorities to prepare them for the arrival of the truck and for cross-checking purposes.
6. Based on data fusion originating from the truck, environmental sensors and cameras and wearables / smart phones that the customs agents are equipped with, the integrated assisted driving platform hosted at the edge server provides live updates of the maps to the navigation software of the truck, depicting the live location of the other road users and potentially additional information.
    i. Increased cooperative environmental awareness is

	achieved for the truck, identifying all road users and border ground personnel (even in blind spots) ii. Increased safety for the ground personnel in case of a predicted accident with an incoming truck. The Predictive analytics platform may issue a warning or order to the truck's OBU to brake or slow down (trajectory alignment is also possible) as well as warn the ground personnel about the imminent danger. 7. Final data fusion including all acquired information to perform predictive analytics and risk level assessment of the specific truck and to classify it according to the level of verification that was possible. i. If all data checks out, then the truck will be potentially capable of going through the border without human intervention ("zero touch" scenario). ii. If there are uncertainties, then different levels of risk assessment or doubt will trigger differentiated treatment by the border officers, according to the predicted level of risk. 8. Human intervention at the actual border crossing will depend on whether the gathered information was verified and on the assessment of the risk level for each truck.
Post conditions	• A truck that has successfully passed all remote inspection methods crosses the border without human intervention • Border inspection is categorized and prioritized based on risk assessment • Border inspections become more efficient and less time consuming • Border ground personnel is protected from potential accidents • Increased cooperative awareness of the surrounding, making more advanced CCAM scenarios possible.

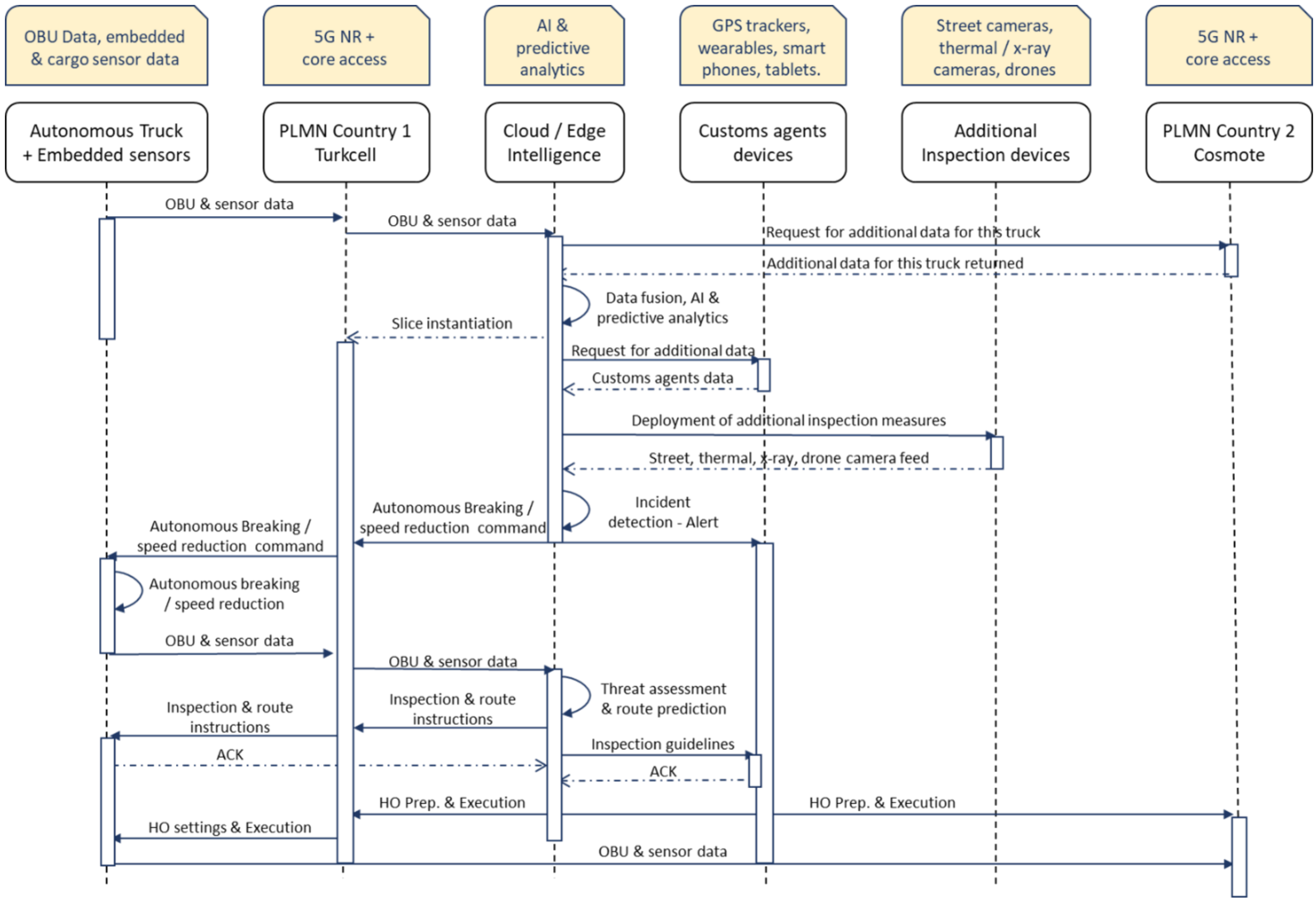

Figure 25 Assisted border crossing sequence diagram

3.4.4.3. Beyond state of the art

The use of 5G networks in combination with advanced CCAM functionality can significantly contribute to the mitigation of the border control delays by providing customs agents with advanced functionalities which enable inspection preparation, enhanced flow of information and instant status verification and which can under the right circumstances realize a "zero-touch" border crossing. Moreover, the increased ultra reliable and low latency gathering of information from various sources around the border-crossing can increase the cooperative environmental awareness through "live maps" and even actively assist in the protection of the customs agents and police officers offering immediate and reliable feedback to the vehicles and enabling automated driving reactions.

3.4.4.4. 5G services

Table 21 Overview of 5G services to be implemented in the Assisted border crossing use case

5G service	Implementation
eMBB	Yes. eMBB slices will be used in this use cases for the transmission of 4K video from street cameras and deployed drones as additional inspection measures.
URLLC	Yes. uRLLC slices will be used for the transmission of data from the truck sensors to the edge platform and for the communication of CCAM related commands back to the truck (e.g. to brake upon the detection of a collision possibility).
mMTC	Yes. mMTC slices will be used to gather the data from surrounding road side sensors and equipment as well as human devices such (e.g. environmental sensors, traffic sensors, smart phones, wearables, etc.)

3.4.5. References

[1] "Cellular Vehicle-to-Everything (C-V2X): Enabling Intelligent Transport," GSMA Whitepaper
[2] 3GPP TR 22.866 : "Study on enhancement of 3GPP Support for 5G V2X Services"
[3] M. Miltiadou, E. Bouhouras, S. Basbas, G. Mintsis and C. Taxiltaris, "Analyis of border crossings in South East Europe and measures for their improvement", Aristotle University of Thessaloniki, Faculty of Rural and Surveying Engineering, WCTR 2016 Sanghai, July 2016

3.5. German (DE) Trial Site

3.5.1. Location

Table 22 German location overview

Trial site class	Local site
Country	Germany
City	Berlin & Stuttgart

Germany has one trial site located in Berlin. The Berlin corridor builds on the national flagship project Diginet-PS (www.diginet-ps.de) and comprises the full dynamics of a dense urban environment. The tests and trials of the project's use cases are conducted in a fully dynamic dense urban setting. The Berlin corridor is situated in the centre of Berlin, Straße des 17. Juni and is a 4km long road extending from Ernst-Reuter-Platz to Brandenburger Gate. The corridor is open and urban with three lanes in each direction, two complex roundabouts (with 5 roads and multiple lanes), and a high traffic intensity during working hours. The corridor is equipped with a number of different types of sensors including traffic analysis, object detection, queue detection, parking, road-condition, environment, intelligent light. The sensors are connected to the extended roadside units, which are equipped with compute infrastructure, machine learning toolboxes, and communication infrastructure. The central cloud / data-centre is equipped with GPUs and Hyperflex compute infrastructure using industry grade aggregation software. The transport network is SDN enabled. The traffic light control systems with group control for vehicles, bicycles, pedestrians, and handicapped citizens, are equipped with communication infrastructure. The trial site presents complex parking situations including marked, non-marked, parallel, slanted, centre island, and separate parking areas. Currently, 4G and DSRC communication is used on the trial sites, for 5G-MOBIX, 5G network infrastructure (from Deutsche Telecom) is planned.

Figure 26 German (DE) trial site

3.5.2. Local Consortium

Table 23 German consortium

Role	Partner	Contribution
Full Partner	TUB	Trial site leader. Provider of the data-centre, road infrastructure, communication infrastructure, and vehicle provider. Responsible for use case development and testing.
Full Partner	FH	Infrastructure provider & responsible for Stuttgart site, Software Development & network solutions integration, use-cases development
Full Partner	GT-ARC	Software Development, support for network solution & integration, use-cases development & support for execution
Full Partner	VALEO	Horizontal partner, use-cases development, solutions integration, and support for use-cases execution
Full Partner	VICOM	Horizontal partner, use-cases development, solutions integration, and support for use-cases execution

3.5.3. Use Case 6: Cooperative perception with HD maps and surround view

3.5.3.1. Motivation

Cooperative perception represents an important technology for automated vehicles. Traditional four (front, left, right, rear) camera based individual detections might not be sufficient for L4/L5 automation, posing the risk that the field of view can be blocked by the car's surroundings (vehicles, buildings, etc.). Even if there are no obstacles, the field of view obtained by the on-board sensors can be compromised due to blind spots, weather conditions (direct sunlight, heavy rain, etc) or other environmental factors. A cooperative perception functionality that continuously updates a Local Dynamic Map (LDM) representing the real world by fusing on-board sensor data with the data of other traffic participants and HD maps is proposed in this use case. Using current communication technologies, the bandwidth is not enough to support the exchange of for example video raw data between vehicles. While it could be sufficient for some ADAS application to share only pre-processed sensor data (objects) today's network latencies pose a risk to potentially safety relevant functions. Still, sharing pre-processed data is not enough if it should be visualized to the driver to support manoeuvre planning, for instance, during vehicle handover from L4 automation to manual human driving, when the vehicle drives out of its operational design domain (ODD), thus, the specific conditions under which the driving automation system was designed to function. The proposed cooperative perception technology generates a surround view to support the driver in "building" his/her situational awareness according to the current driving context, and then to help him/her to take the control of the car in an appropriate way, in order to manually manage the situational risk and/or to safely perform the driving task. The enhanced surround view can also be provided to the driver or the passengers to keep them in the loop while the car is doing something that can be considered risky like a lane change or an overtake. This way they can be calm and feel safe, knowing that the autonomous vehicle is taking the right action. Consequently, their user experience will be increased.

3.5.3.2. Description

The objective of this use case is to share LDM data and raw sensor data for real-time prediction and planning tasks made possible by 5G technology. More precisely, the use case deals with a situation when the perception obtained by the on-board sensors is not enough and needs to be enhanced by sensor data from other traffic participants.

The use case scenario contains several connected vehicles equipped with sensors as well as roadside infrastructure comprising sensors and edge computing infrastructure (eRSU). The vehicles and the eRSU using their respective sensor data build their individual situational awareness, identifying objects, lane markings or the road condition to support their prediction and planning functions. However, each individual vehicle's sensors as well as roadside sensors are limited in the perception in different ways. The sensors view could be obstructed by objects, limited by weather conditions, or not covering a specific area. To mitigate the lack of environment information, vehicles share extracts (regions of interest) from their LDMs and/or sensor raw data and the eRSU shares its Edged Dynamic Map (EDM).

In the proposed setup, the eRSU assisted map update is valid within the coverage area of the eRSU. Cars not within the coverage area are relying on updates of their respective eRSU and their neighbouring vehicles. To assist cars moving from one coverage area to another, the future eRSU's EDM will be provided. As shown in Figure 27, neighbouring eRSUs exchange their EDMs to provide the vehicles with map information when approaching a new coverage area.

The storyline of the use case goes like this. There are three connected autonomous cars driving on the same lane. The three cars are sending relevant LDM data to the corresponding eRSU where the EDM is updated. Suddenly, there is an unexpected event that makes the first car brake and start a lane changing manoeuvre. The event can be for instance a vehicle that stops and blocks the lane (like the truck depicted in Figure 27) This sudden action is propagated to the rest of the cars that perceive that something is happening. The three connected and automated cars request the EDM to the eRSU under their coverage and they fuse it with their LDM to analyse the situation. They determine that a lane changing manoeuvre is necessary as the lane is blocked some meters ahead. Using the collected information, they start planning and executing the manoeuvre. The EDM contains only processed lightweight data of traffic participants (mainly position, heading, size and speed) that is sufficient for rapid risk estimation and decision making but it is not enough to create a 360º surround view. The rear vehicle has its field of view severely restricted and determines that a surround view generation would help keeping the driver in the loop and decreasing the risk of the lane changing manoeuvre. The other two vehicles have better visibility and the do not require a surround view. Consulting the EDM, the rear vehicle selects to which vehicles it needs to request raw sensor data to enhance its field of view. The car generates a 360º surround view by fusing internal sensors (cameras and Lidar) and data (video and Lidar's 3D cloud) coming from the selected traffic participants. This is done by direct Vehicle to Vehicle (V2V) communication.

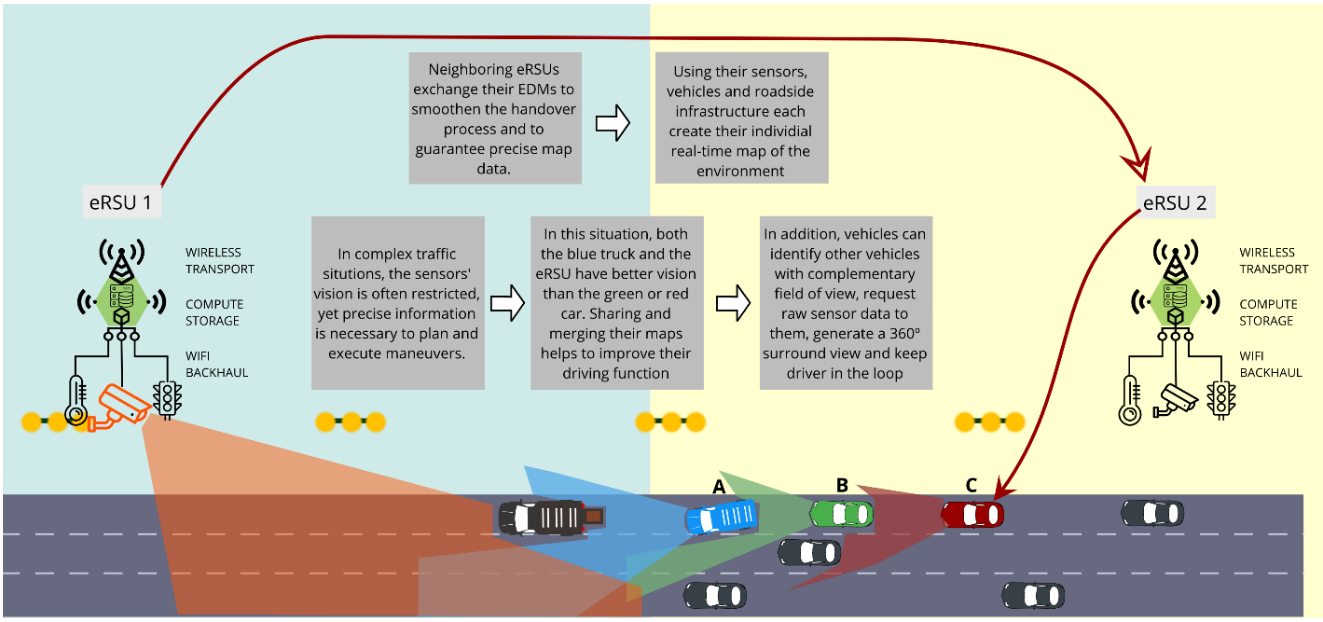

Figure 27 Cooperative perception with HD maps and surround view.

Table 24 Overview of use case "Cooperative perception with HD maps and surround view".

Use Case Short Name	Cooperative perception
Use Case Category	Extended sensors
Use Case Leader	Valeo
Other partners	Vicomtech, TUB
Objective	Exchange and fusion of sensor data from different vehicles for safe and user-friendly automated and cooperative driving.
Actors	Vehicle A, Vehicle B, Vehicle C, eRSU 1, eRSU 2
Pre-conditions	• Vehicle A, B and C support 5G connectivity • Vehicle A, B, and C equipped with sensors (cameras, lidar, GPS, odometry,...) • At least Vehicle B and C have computing capabilities for advanced sensor fusion and HD maps. • Vehicles A, B and C are driving on the same lane one after the other. Vehicle A goes on the front, then Vehicle B and finally Vehicle C on the rear. The three vehicles are sharing messages with common data exchange format with their corresponding eRSU. This information would include the ego vehicle position, speed, heading, its planned trajectory and other relevant LDM data. eRSU1 and eRSU2 synchronise their EDMs
Use Case flow	1. Vehicle A finds the lane blocked as the front vehicle has suddenly stopped. 2. Vehicle A brakes and starts a lane changing manoeuvre. 3. The brake is propagated (Vehicle B reduces its speed because Vehicle A has done it and then Vehicle C reduces its speed as Vehicle B has done it), keeping the safety distance between vehicles. 4. Vehicles B and C have their field of view restricted, so they request the EDM to eRSU1 to enhance their LDM, understand current situation and plan next manoeuvre. 5. eRSU 1 sends EDM to Vehicles B. and C. 6. Vehicles B and C fuse the received EDM with their LDMs and HD maps. 7. Vehicle C determines that it needs raw sensor data from Vehicles A and B. 8. Vehicle C requests perception sensor raw data from Vehicle A and Vehicle B 9. Vehicle A sends data from its sensors to Vehicle C.

	10. Vehicle B sends data from its sensors to Vehicle C. 11. Fusion module in vehicle C generates a 360º surround view using its own sensor data, the sensor data from Vehicles A and B, the LDM, the EDM and HD maps. 12. The surround view is used for a safe lane changing and overtaking manoeuvre of Vehicle C, keeping the passengers in the loop. Vehicles A and B have a less obstructed view and find the EDM+LDM information enough for the lane change.
Post conditions	Vehicle A, Vehicle B and Vehicle C have successfully changed lane and overtake the obstacle. Due to the dramatic limitation of Vehicle C's field of view, during the manoeuvre, enhanced surround view is provided in Vehicle C to the driver and passengers to keep them in the loop and improve manoeuvre planning and safety.

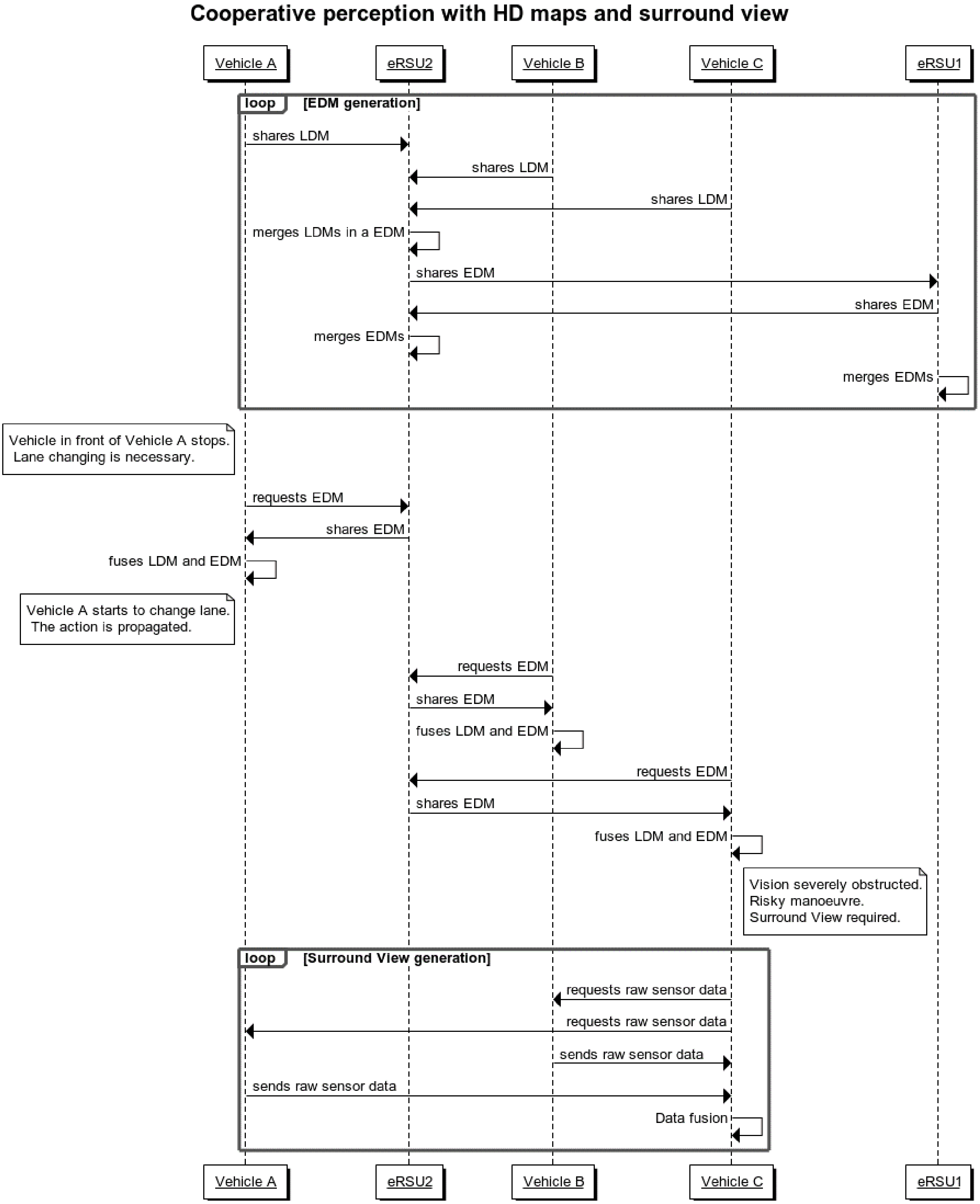

Figure 28 Sequence diagram for Cooperative perception use case

3.5.3.3. *Contribution to cross-border corridors*

Cooperative perception is a key enabling technology for L4 and L5 Autonomous Driving. This is also true in a cross-border corridor scenario, where trucks account a significant share of traffic participants. These large vehicles can obstruct the field view of other vehicles and can cause safety issues, and ultimately decrease the Operational Design Domain of L4 autonomous cars, which is a major concern for the automotive industry and public authorities alike.

This use case complements the "Assisted truck border-crossing & increased cooperative awareness" use case deployed in the Greece-Turkey cross-border corridor in two main AD technological aspects:

1. Following a different but complementary approach on the compilation, structuring and processing of sensor data. The focus is on building an LDM on top of a static HD map minimizing as much as possible the blind spots and occlusions (regions with no Line of Sight). The HD map is updated locally by the observations made by the autonomous vehicle and the rest of traffic participants. These updates could potentially be sent to the cloud to trigger an update of the "static" HD map from the map provider.

2. Generating a 360º surround view of the vehicle that could be used in several situations. For instance:

    a. To support the driver in the manual operations that need to be taken when the vehicle is out of its ODD in L4 Autonomous Driving (AD).

    b. To enable the teleoperation of the vehicle if the AD system fails and needs to be stopped and the driver cannot resume the driving (L4 AD) or there is no driver (L5 AD).

    c. To enhance the information received by the driver and passengers about the driving situation

Although being a local trial site, the German site has a similar infrastructure required for cross-border corridor allowing corridor use-cases and beyond to be tested. This is demonstrated in this use case with the involvement of macro and small cells coverage, MEC infrastructure and the co-existence of multiple V2X technologies.

Additionally, the developed IoT-middleware and virtual network orchestration platform allow complex SPs interactions, data access regulation, ePrivacy, net neutrality and licensing schemes, which are not readily available and agreed among EU regulators. Despite the clear objective of the EC policy on CCAM regarding data regulation, implementation and enforcement of the regulation are challenging at international corridors. The trial made possible in German site can provide important insights for the real deployment in the future.

In the Dutch site trial, there is a use case involving Cooperative perception of environment (CPE). In this implementation, CPE will be evaluated in a merging scenario where the on-ramp from Nuenen to A270 will considered on the route from Helmond to Eindhoven. Traffic information from the RSU (fixed cameras from SISSBV) will be used for a safe merging manoeuvre. In the Finnish trial site, a "Video-based cooperative perception" use case with focus on edge computing services in x-border scenarios is described. In the present UC we are targeting a different manoeuvre (lane changing with overtake). The generation of a surround view is another added value of the present use case that it is not present in the rest of use cases under the extended sensors category. This surround view generation feature can be useful in any driving situation, including driving on cross-border corridors.

3.5.3.4. *Beyond state of the art*

Current L3 Autonomous Driving vehicles only depend on on-board sensors. The technology deployed in this use case exploits also the sensor data received from other vehicles, thus mitigating the limitations faced by using solely on-board sensors and enabling L4 Autonomous Driving.

One of the main novelties that the use cases proposes is the concept of providing the driver and the passengers with a 360º surround view to keep them in the loop.

3.5.3.5. *5G services*

Table 25 Overview of 5G services to be implemented in the Cooperative perception use case

5G service	Implementation
eMBB	Yes, the different data flows provided by infrastructures and vehicles and consumed by vehicles would produce a big amount of High-Quality video streams being rapidly published, subscribed and consumed.
URLLC	Yes. uRLLC slices will be used for data sharing between the vehicles and the eRSU.
mMTC	No, the number of vehicles and cameras in a cell for this use case is not enough to require this 5G feature

3.5.4. Use Case 7: SAE L-4 Platooning

3.5.4.1. Motivation

The German trial site is also called "Protocol Road" that leads to the German Parliament and is very often used to drive dignitaries from the airport to the government district. Movement of dignitaries with huge number of vehicles disturbing the normal flow of traffic is a common phenomenon and will also be existing in the autonomous driving era. With the realization of digitized roads, automated & connected vehicles, and talking traffic lights, the efficiency in traffic flow may be achieved alongside road safety. Such vehicle groups pose similar challenges as those highlighted by commonly known platooning use-cases e.g., eMMB relevant, URLLC relevant, seamless MNOs handover, etc. The motivation to execute this use case on the trial site comes from: i) showcasing the autonomously driven protocol vehicles, ii) addressing the platooning challenges for SAE L-4 platoons, iii) studying the need for roadside infrastructure for such platooning, iv) studying the need for sufficient communication coverage, etc. As opposed to typical deployment of the Roadside Units that simply enables the V2X communication, for this use case we rely on the richer roadside unit, that serves as the near edge with additional services for the autonomous driving.

At the trial site, we rely on an extended roadside unit (eRSU), that serves as a near edge with additional services for the autonomous driving. We implement the concept of distributed processing and decision making by contributing with a three-level solution architecture i.e., vehicle level, edge level, and cloud level. At these levels, we create three perceptions namely: Local Dynamic Map, Edge Dynamic Map (created by on-road deployed infrastructure that creates the perception of road segment), and Global Dynamic Map that creates a global perception of the trial sites. These three perception maps interact and populate the LDM by making use of 4G communication technologies, which impose the limitations of delay and bandwidth. With 5G deployed, limitations of the platooning use case will be addressed by: i) availability of greater capacity that allows the population of LDMs of all vehicles with high quality information, ii) flexible control plane that allows efficient execution of network operations, iii) reduced communication delay that enables the real-time information exchange between EDM and LDM, etc. Last but not the least, the use-case scenario aligns well with the cross-border settings.

Contexts of the German trial site will be incorporated in this use-case with full range of complexity relying on 5G infrastructure to provide the required data transmission frequencies, low-latency, trusted, secure and fail-safe data transmission protocols and harmonised data syntax that ensures safe interoperability. This use-case will showcase the roles of 5G services eMMB, URLLC, etc., in providing real-time sensor data and ITS services to automated and connected vehicles:

- Enriching the perception of CCAM by feeding in the data from roadside sensors including: traffic analysis, road-condition, object detection, traffic light, and intelligent street lights etc.,

- Utilizing 5G's access agnostic, virtualized control plane hosted close to the road-side to meet the URLLC requirements of safety-related vehicle-roadside sensor interactions.
- Orchestrating the 5G services near the edge and complementing those with AI approaches to assist lane-keeping / leaving, speed adaptation, and turning decisions of CCAM vehicles.

3.5.4.2. Description

In this use case, a platoon of 3 AVs is operating along a road. The platoon approaches a truck (vehicle B) (see Figure 1). At 500m to a junction, the truck signals its intention to take the right turn and slows down.

A local EDM instance deployed on an eRSU located at the junction, detects the truck's changing velocity and trajectory through learned pattern recognition from local sensor data. It updates the global map and notifies the centralized traffic management & planning applications through eRSU's upstream interfaces.

The platoon leader (vehicle A) detects a potential collision as it approaches the truck and request the EDM from the eRSU. The route planning service in the eRSU detects a possible overtaking manoeuvre due to low traffic ahead and possibly adapted green light phase for extended free flow based on information from traffic management system.

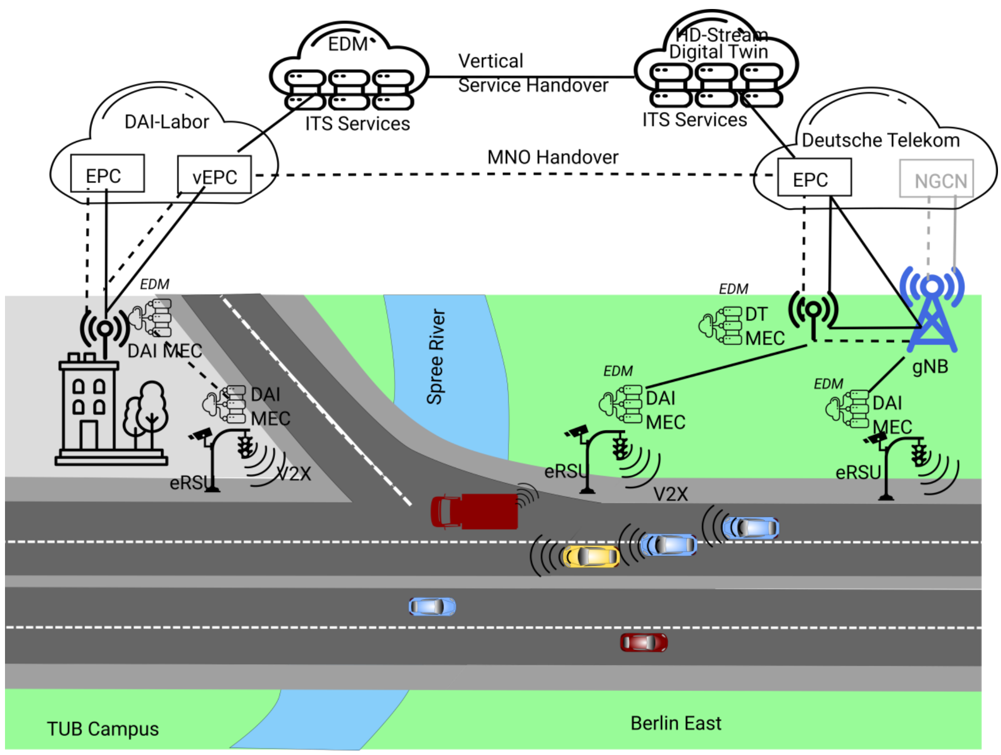

Figure 29 5G supported autonomous overtaking manoeuvre during platooning with MNOs handover

Based on the information provided by the eRSU and its services, the platoon leader initiates an overtaking manoeuvre by communicating context data (location, speed, LDM) to the eRSU. Using the EDM, the route planning service in the eRSU formulates the overtaking manoeuvre and communicates the overtaking plan to the platoon leader.

During the overtaking manoeuvre, the platoon enters the coverage of an eRSU of another provider. This results in eRSU handover with upstream gateway relocation from current MNO's eNB/gNB to new MNO's. In effect, the ITS instances and context on source eRSU must be handed over to the new eRSU. At mobile network level, this handover is carried out with handover protocol between the MNOs' core networks. At application level, resource and service allocation are orchestrated by the centralized ITS service entities, which are made aware of mobile network and MEC provisioning.

Misuse case: Non-cooperating/unconnected vehicle

During the platoon overtaking manoeuvre, the truck driver decided to keep course and started accelerating. Based on the traffic situation, the platoon leader decides to split the last AV from the platoon. As the result, new platoon can adapt to the new situation and accelerate the overtaking process, while the last AV autonomously navigates itself back behind the truck.

Table 26 Overview of Platooning use case

Use Case Short Name	Platooning
Use Case Category	Platooning
Use Case Leader	TUB
Other partners	ALL German partners
Objective	5G supported autonomous overtaking manoeuvre during platooning with MNOs handover.
Actors	Vehicle A (platoon leader), Vehicle B (truck), Vehicle C
Pre-conditions	• Vehicle A, B and C support 5G connectivity • Two eRSUs deployed nearby with EDM generation capability
Use Case flow	1. A platooning AVs group operates normally (3GPP eV2X support) in the reserved bus lane. 2. The truck (vehicle B) signals its intension to turn right at the next junction. 3. The platoon leader request real-time EDM & ITS services and calculate overtaking manoeuvre (3GPP Emergency trajectory alignment & intersection safety information). 4. MNOs and ITS services handover connectivity and application

	context during manoeuvre. 5. The platoon lead coordinates overtaking manoeuvre (3GPP information exchange within platoon & information sharing for high/full automation). 6. Mis-use-case: not connected truck changes course during platoon overtaking → platoon emergency brake & braking.
Post conditions	• Autonomous vehicle platoon completes overtaking manoeuvre. • The potential crash has been avoided in mis-use-case.

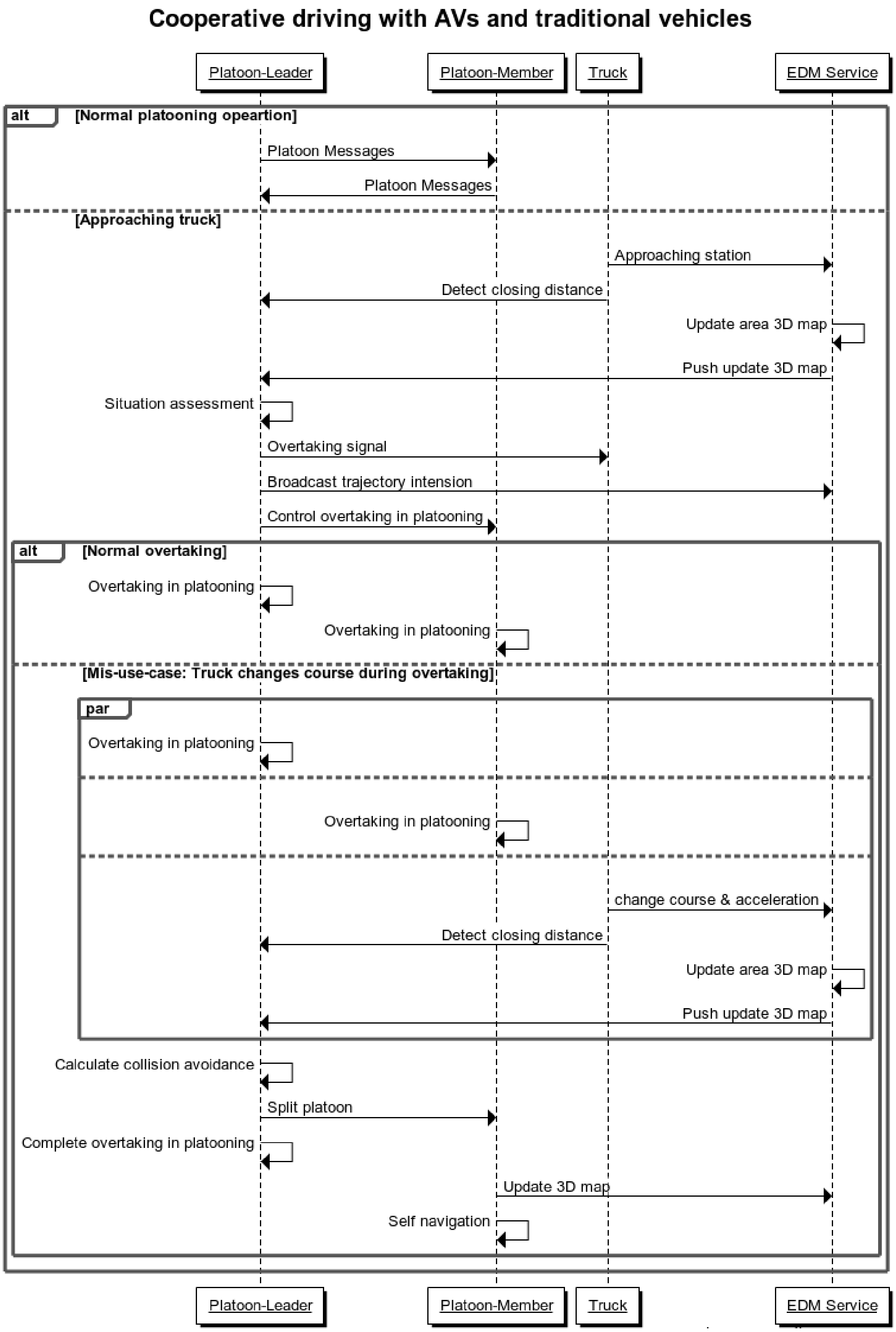

Figure 30 Platooning sequence diagram

3.5.4.3. *Contribution to cross-border corridors*

German trial site has an evolved version of the infrastructure required for cross-border corridor allowing corridor use-cases and beyond to be pre-tested. This is specially demonstrated in this coordinated platooning use case with the involvement of macro and small cells coverage, MEC infrastructure and the co-existence of multiple V2X technologies belonging to multiple SPs (DT, in-house 5G solution). This use case contributes to the GR-TR cross-border corridor. This use case is pretty much in line with the platooning use case of GR-TR corridor. This is to say that the solutions crafted for execution of this use case will to a greater extent simulate the cross-border platooning, specifically the network and service handover between the operators of different countries. It is worth recalling here that the use case aims at solutions for L4-platooning that should complement the solutions of L2+ platooning at GR-TR corridor.

The requirements for road infrastructure and data fusion services to support this use case flow are also similar to the use case "truck platooning with "see-what-I-see" functionality" in TR-GR corridor. At German trial site, the developed IoT-middleware and virtual network orchestration platform allow complex SPs interactions, data access regulation, ePrivacy, net neutrality and licensing schemes, which are not readily available and agreed among EU regulators. Despite the clear objective of the EC policy on CCAM [1] regarding data regulation, implementation and enforcement of the regulation are challenging at international corridors. The trial made possible in German site can provide important insights for the real deployment in the future.

3.5.4.4. *Beyond state of the art*

This use-case showcases the roles of 5G services eMMB, URLLC, etc., in providing real-time sensory data from on-road deployed traffic analysis sensors and ITS services to the vehicles. With the current deployment and concept of Edge Dynamic Map, the use case will allow implementing the platooning use case of L-4 autonomous vehicles. This is to say that through 5G networks will allow the real-time sharing of edge dynamic map with the vehicles. The use case will also study the concept of computation, sensor fusion, decision making at three distributed levels by exploiting the near / far edge of the mobile networks. A distributed middleware platform facilitates the fusion of sensing data for various assisted driving applications. However, current LTE and small-cell based transport networks can provide only limited capability for real-time data communication required to support fully autonomous driving applications. The 5G deployment during 5G-MOBIX project is expected to address QoS limitation of current 4G networks, among others. Additional approaches for intelligent end-to-end orchestration, data fusion and vehicle research will enable the trial and application of SAE L4.

3.5.4.5. 5G services

Table 27 Overview of 5G services to be implemented in the Platooning use case

5G service	Implementation
eMBB	Yes. eMBB slices will be used in this use cases for the transmission of high definition sensing data from street cameras and different types of sensors of the road digitization overlay.
URLLC	Yes. uRLLC slices will be used for the transmission of data from the AVs to the MEC platforms to central cloud for real-time decision making, command and control.
mMTC	Yes. mMTC slices are needed for data transmission from the massive deployment of road side sensors, actuators (e.g. environmental sensors, traffic sensors), and drivers' devices (e.g., smart phones, wearables, etc.).
Other	5G slice management and orchestration of appropriate VNFs are required to realize consistent and efficient operations.

3.5.4.6. References

[1] https://ec.europa.eu/digital-singlemarket/en/cooperative-connected-and-automated-mobility-Europe

[2] https://www.telekom.com/en/media/media-information/archive/5g-rollout-in-germany-523636

3.6. Finnish (FI) Trial Site

3.6.1. Location

Table 28 Finnish location overview

Trial site class	Pre-deployment
Country/Countries	Finland
City/Cities	Espoo

The Finland (Espoo) pre-deployment trial site is located within and around the Otaniemi area of Aalto University. The 5G-MOBIX testbed will build on a legacy of 4G/5G testbeds deployed in the Otaniemi area in past/ongoing national projects. The first of these national projects is the TAKE-5 project (years 2015-2018), which deployed a 4G/5G testbed as part of the planned national 5G Test Network Finland (5GTNF)[3]. The successor of the TAKE-5 project is the national project 5G-FORCE, which from early 2019 will to continue to enhance the Otaniemi testbed as part of an integrated national testbed. This Otaniemi testbed is targeted for testing, piloting and validating a multitude of 5G use cases including smart factories, smart grids and automotive (the latter being relevant for 5G-MOBIX). In summary, 5G-MOBIX anticipates the following value add from the 5G-FORCE project:

- 5G-MOBIX avoids duplication of deploying infrastructure by leveraging as much as possible radio, edge and core network infrastructure deployment by 5G-FORCE;
- 5G-MOBIX utilising additional technical support from 5G-FORCE in terms network configuration, upgrades, fault management etc.;
- 5G-MOBIX obtains channel for collaboration with vendors (e.g. Nokia, Ericsson) and operators within the 5G-FORCE consortium.

[3] http://5gtnf.fi/projects/take-5/

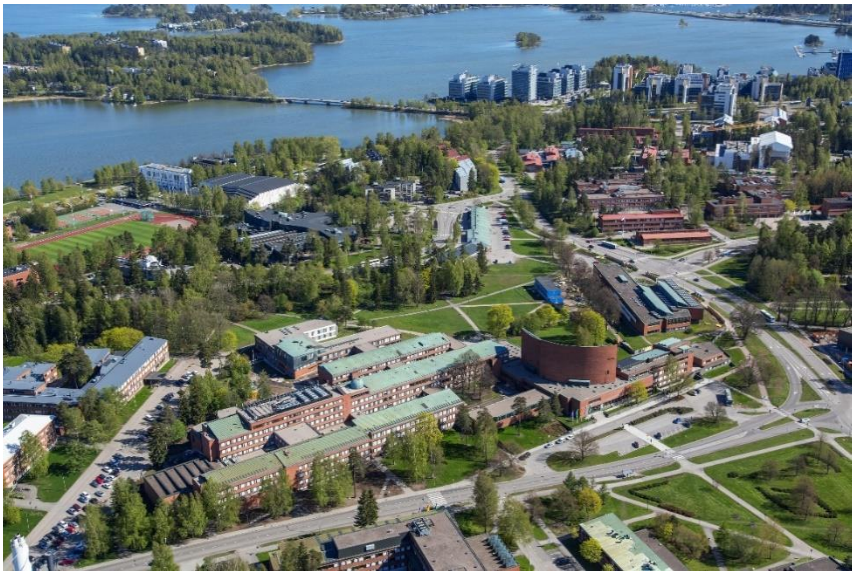

Figure 31 The FINLAND pre-deployment trial site

3.6.2. Local Consortium

The local consortium for the Finland site is shown in the table below. Additionally, the Finnish trial site has previously made contact with key stakeholders who are in the position to provide insights, requirements and other feedback from the two Finnish cross-border corridors (Nordic Way and Aurora) for benefit of the 5G-MOBIX use cases implemented in the Espoo site.

Table 29 Finnish consortium

Role	Partner	Contribution
Full Partner	AALTO	Trial site coordinator, use cases development and testing, 5G infrastructure
Full Partner	SENSIBLE4	L4 vehicles, use cases development and testing
Full Partner	VEDECOM	5G OBU (with chipsets from VALEO)
Advisory Board	TRAFICOM - Finnish Transport and Communications Agency (*merge of FICORA - Finnish Communications Regulatory Authority and FTA - Finnish Transport Agency*)	regulatory of 5G and automated driving

3.6.3. Use Case 8: Video-based Cooperative Perception

3.6.3.1. Motivation

Automated vehicles with cooperative perception functionalities obtain distant information by exchanging data. Some benefits include [S. Kim et al., "*Cooperative perception for autonomous vehicle control on the road: Motivation and experimental results*," IEEE Int. Conf. Intell. Robots Syst., 2013]:

- the sensing area can be extended to the boundary of automated vehicles
- the prices of sensors and radio devices are affordable
- beyond line-of-sight sensing is possible depending on the network connectivity
- traffic flow and safety are improved.

From computing perspective, automated vehicles are supposed to be able to locally handle most data processing tasks, such as real-time lane detection and tracking. However, external computing resources are still needed to support cooperation between automated vehicles and with infrastructures. For example, higher SAE automation levels (L4/L5) inherently demand higher levels of independence hence of situational awareness, which requires cooperative perception based on data from multiple sources including different vehicles and infrastructures. To shorten response delay and to avoid moving tremendous data from the automated vehicle through core network, it is essential to move computational resources closer to where the data is generated. In practice, data can be gathered and processed at edge computing nodes located in wireless access networks. Similar with network connectivity, automated vehicles are expected to connect to at least two edge nodes at the same time to improve reliability and performance through parallel data processing.

Currently automated vehicles are typically attached to a single network. This not only impacts service availability due to lack of fall-back options when connection outage occurs, it also may limit interaction between vehicles and/or roadside infrastructure elements that are connected to different networks. From computing perspective, most computing tasks are handled by automated vehicles or sent to remote cloud for processing. Edge computing services required by higher SAE automation levels have not been well studied.

5G provides ultra-low latency and edge computing capacity which are required by automated driving but not available in 4G networks. The multi-PLMN arrangement may constitute the automated vehicle attachment to a number of possible network combinations. In addition to benefits of improved reliability of connectivity but also provides the opportunity to automated vehicles connected to a home network in a particular location to access enhanced V2X services from a visited network with 5G coverage in that location.

3.6.3.2. Description

In this use case, we take video-based cooperative perception for automated vehicles and evaluate the reliability and performance of networking and edge computing services in x-border scenarios. We will evaluate the functionalities and performance (e.g. processing delay, migration overhead) of an automated vehicle using edge computing for cooperative perception, including auto discovery of edge nodes, adaptive task allocation, and seamless service migration. When a V2N connection is established, the automated vehicle receives the network address of an edge node connected with the same 5G base station. Since an automated vehicle is connected simultaneously to two networks, it is connected by default to two edge nodes at the same time. Data generated by the automated vehicle is forwarded to both edge nodes for processing. When the automated vehicle receives the processing results from one edge node already, it can cancel the task on the other edge node. When the automated vehicle is connected to a different network, services will also migrate to an edge node connected to the newly connected base station.

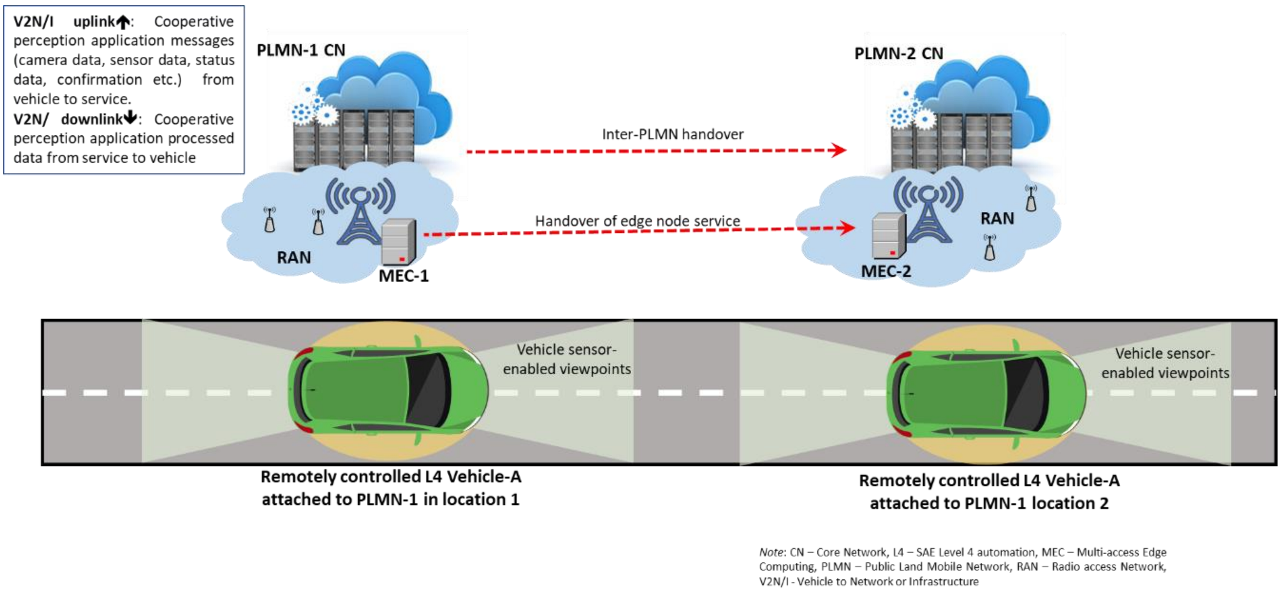

Figure 32 Cooperative perception

Table 30 Overview of Cooperative perception use case

Use Case ID	Cooperative perception
Use Case Category	Extended sensors
Use Case Leader	AALTO
Other partners	SENSIBLE4, VEDECOM

Objective	To increase the safety and independence of automated vehicles.
Actors	Automated vehicle, home PLMN operator, visited PLMN operator(s), Edge nodes
Pre-conditions	Automated vehicle is able to attach to/roam between all PLMNs/MECs considered in the multi-PLMN/MEC scenario
Use Case flow	1. Automated vehicle starts journey with separate V2N connections to both PLMN1 / MEC1 and PLMN2 / MEC2 2. A V2X application run by the automated vehicle selects V2N with best QoS 3. - The V2X application run by the automated vehicle swaps the V2N connection when QoS of current connection drops below secondary V2N connection
Post conditions	Vehicle has received updated perception from edge computing service

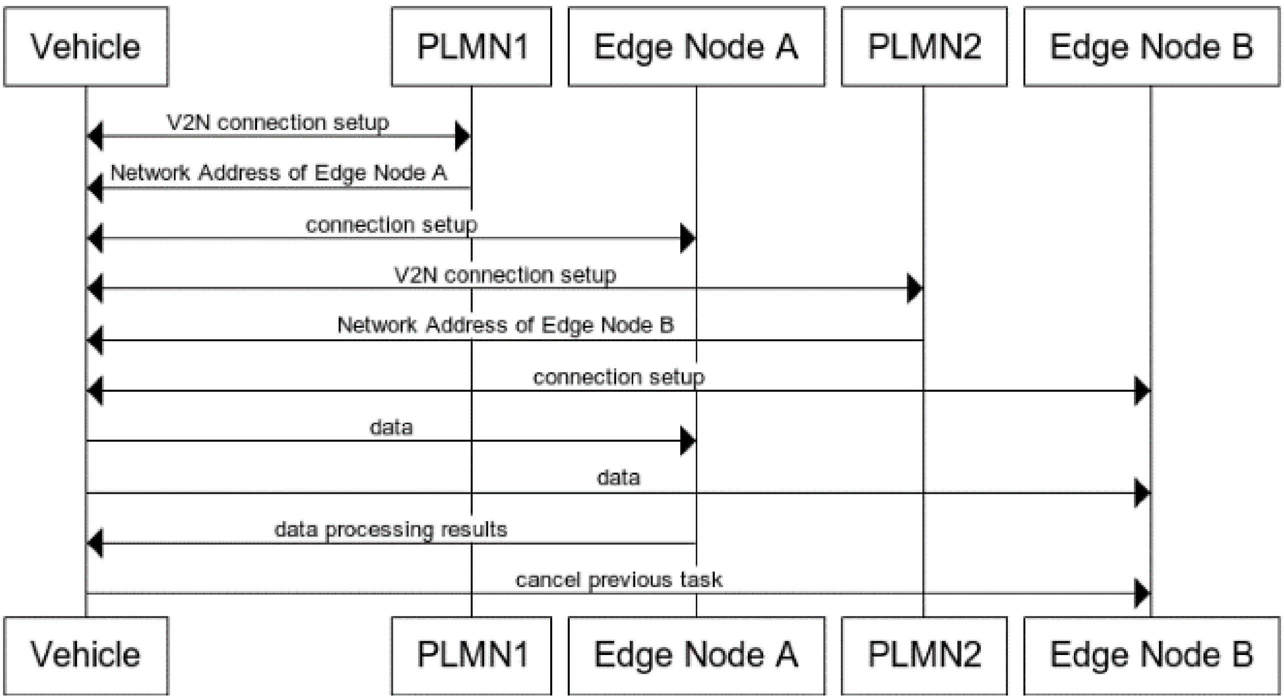

Figure 33 PLMN/MEC migration sequence diagram

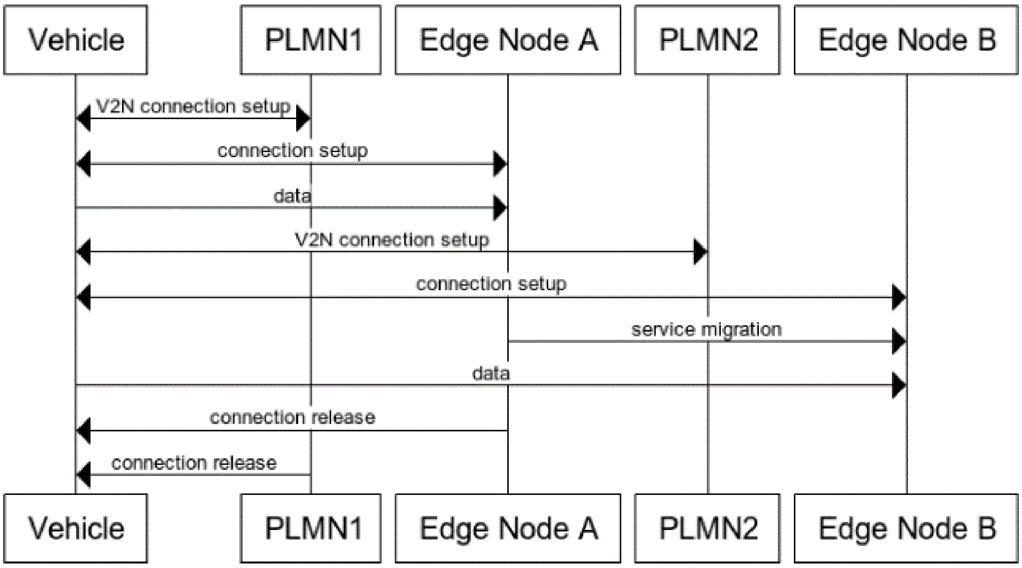

Figure 34 PLMN/MEC migration sequence diagram

3.6.3.3. Contribution to cross-border corridors

In the cross-border use case there will be a scenario of automated vehicles offloading (critical) tasks from one edge node to another one. To that end, the Espoo pre-deployment trial site provides an opportunity to test these "multi-edge" scenarios with higher level of experimentation that may not always be feasible in the real networks of the two cross-border sites. Being fully software-based enables rapid, flexible testing of new ideas at all layers on the automated driving stack. Additionally, this makes it suitable for virtualization using edge nodes or container approaches.

3.6.3.4. Beyond state of the art

Based on the 5GCAR project, the availability of computing capabilities at the edge of the network, is critical to support [automated] vehicles use cases. Specifically, when an [automated] vehicle is predicted to hand over from a base station connected to one MEC server to a new base station connected to a different MEC server, the pending jobs are pre-emptively transferred to the new one, with the purpose of minimizing any job interruption caused by the handover. The introduction of these 5G-based V2X applications, particularly those with URLLC service demands, creates then a need for the reliability and latency impact on a V2I connection to be minimal when the automated vehicle roams from one edge node to another (in both national roaming and cross-border scenarios). Furthermore, there is need to evaluate how V2X applications will benefit by the V2I connections having the redundancy of being attached simultaneously to two or more edge nodes. This includes scenarios whereby the data from the automated vehicle is processed simultaneously through multiple edge nodes or when the connection for the processing task is switched form one edge node to another (in a typical national or international roaming scenario). This 5G-MOBIX use-case provides an opportunity to study the new possibilities and challenges offered by edge nodes architecture in the context of V2I for automated vehicles.

Additional experimentation at AALTO will leverage the ARF software-defined radio platform to study the challenges and new possibilities offered by cloud-RAN architecture in the context of V2I. In this 5G-based cell-free architecture, multiple multi-antenna RSUs are controlled by a common gNB. The cell-free architecture allows for implementation of mobility management solutions for seamless handover of a V2I connection from one RSU to another as the vehicle traverses the road. Furthermore, the ARF software-based implementation allows for cellular/application co-deployment on edge computing infrastructure by placing a mobile edge-cloud instance alongside the ARF gNB controller to provide low-latency decision-making capability.

3.6.3.5. 5G services

Table 31 Overview of 5G services to be implemented in the Cooperative perception use case

5G service	Implementation
eMBB	Yes, HD video uptake from automated vehicles and infrastructure to PLMN/MEC.
URLLC	Yes, HD video processing in the PLMN/MEC to automated vehicles and infrastructure.
mMTC	No
Other	No

3.6.4. Use case 9: Remote driving

3.6.4.1. Motivation

Remote driving of a high automation (SAE L4) vehicle occurs when the vehicle is remotely controlled, by a human operator, and in some cases a cloud-based application within the domain of a Remote Operations Centre [3GPP TR22.886]. A number of business-, socially- or safety-inspired scenarios may motivate remote driving of L4 autonomous vehicles [5Americas 2018][4]. These include:

- Facilitating cloud-driven autonomous shuttles or public transportation services with predefined routes and stops;
- Providing remote driving services for individuals who are unable or unlicensed to drive (e.g. youth, elderly, disabled persons etc.);
- Providing a fall-back driving solution for autonomous vehicles which have encountered unfamiliar navigation environments or developed some faults;
- Providing a solution for autonomous vehicle fleet owners to remotely-control their assets (e.g. delivering/retrieving rental vehicles to/from customers, moving trucks between different delivery drop-off points etc.)

In a typical remote driving scenario, the remote human operators would utilise live data feeds from vehicular sensors (LIDAR, radar, camera, etc.) to formulate and send back commands for controlling the vehicle in a more reliable manner over a V2N connection between an L4 vehicle and a Remote Operations Centre. The reliability and effectiveness of the commands from a remote human operator of an L4 vehicle is contingent on the quality and timeliness of the data received from the vehicle's sensor feeds. Therefore, any significant constraints or disruptions in the sensor data transfer would not be tolerable in a remote driving scenario. For instance, limits on the uplink throughput in a V2N connection would limit sensor data feeds in terms of achievable resolution, frame (or refresh) rates and compression applied (contributing compression latency). These throughput limits become more severe in road environments with multiple autonomous vehicles contenting the same mobile network resources for V2N communications. The constraints in achievable uplink throughput and area capacity in legacy 4G networks would make wide-scale adoption of the solution challenging.

The increased availability of 5G connectivity will alleviate the aforementioned throughput constraints and reduce latency, as well as, providing additional benefits of security, service discovery and so on. These improvements are an enabler higher-resolution sensor data feeds (and possibly more feeds) from vehicle to human operator in Remote Operations Centre.

[4] 5G Americas white paper, "Cellular V2X Communications Towards 5G", March 2018.

3.6.4.2. Description

The remote driving of an L4 vehicle is enabled by a V2N connection between the vehicular Onboard Unit (OBU) and a remote server hosting V2N applications, in this case the remote driving application used by the remote human operator. The V2N connection transfers the sensor data feed (high resolution perception data) from the vehicle to the remote human operator (in the uplink direction). The sensor data provides the human operator a "driver's view" for that particular vehicle and allows the human operator to send appropriate command messages (e.g. command trajectories) back to the L4 vehicle (in the downlink direction).

The remote control/driving of vehicle presents stringent requirements on connection between the vehicle and the Command and Control Center. These requirements include the need to ensure that human operator always maintains connectivity to the vehicle they control, the latency minimized to ensure timeliness of the downlink control messages from the human operator; and the uplink capacity is guaranteed for the transmission of the sensor data feeds from the vehicle. The whole control loop needs to kept tight. The accumulated delay from: sensor reading, sensor data processing, uplink, data visualization, manual control, control signal reading, downlink, and control signal processing to control has to be kept low for direct control (depending on speed and dynamics of the vehicle). Furthermore, the vehicle should be aware of any latency issues, so that the operational speed could be adjusted accordingly.

Remote driving (and other V2X use cases) will occur in multi-operator scenarios in legacy 4G [3GPP TR 36.885][5] and future 5G [3GPP 38.885][6] contexts, whereby, the L4 vehicle trajectory is an areas covered by multiple public land mobile networks (PLMNs) or transitions between two PLMN coverage areas. Therefore, the remote driving use case considers two possible scenarios depending the PLMN used for the realizing the V2N connection.

Remote driving in a multi-PLMN scenario (Scenario 1): The remote driving use case also underlines safety aspects and need for the L4 vehicle to maintain reliable/uninterrupted V2N connectivity. In practice, a vehicle's home PLMN (original serving network) may have locations with poor or non-existent coverage, or then experience V2N connection degradation or failure due to overloading, network failure etc. To guarantee availability V2N connectivity for critical L4 vehicle services (such as, remote driving), the possibility of the vehicle to seamlessly switch to (or simultaneously utilise) a visited PLMN ensures safer operation of the vehicle regardless of instantaneous network conditions. Figure 35 illustrates this scenario, whereby, an L4 Vehicle-A has PLMN-1 as the Home PLMN and also an attachment to a Visited PLMN (PLMN-2) as a redundancy option (e.g. in case of loss of PLMN-1 connection).

[5] 3GPP TR 36.885, "Study on LTE-based V2X Services" June, 2016
[6] 3GPP TR 38.885, "NR; Study on Vehicle-to-Everything" March, 2018

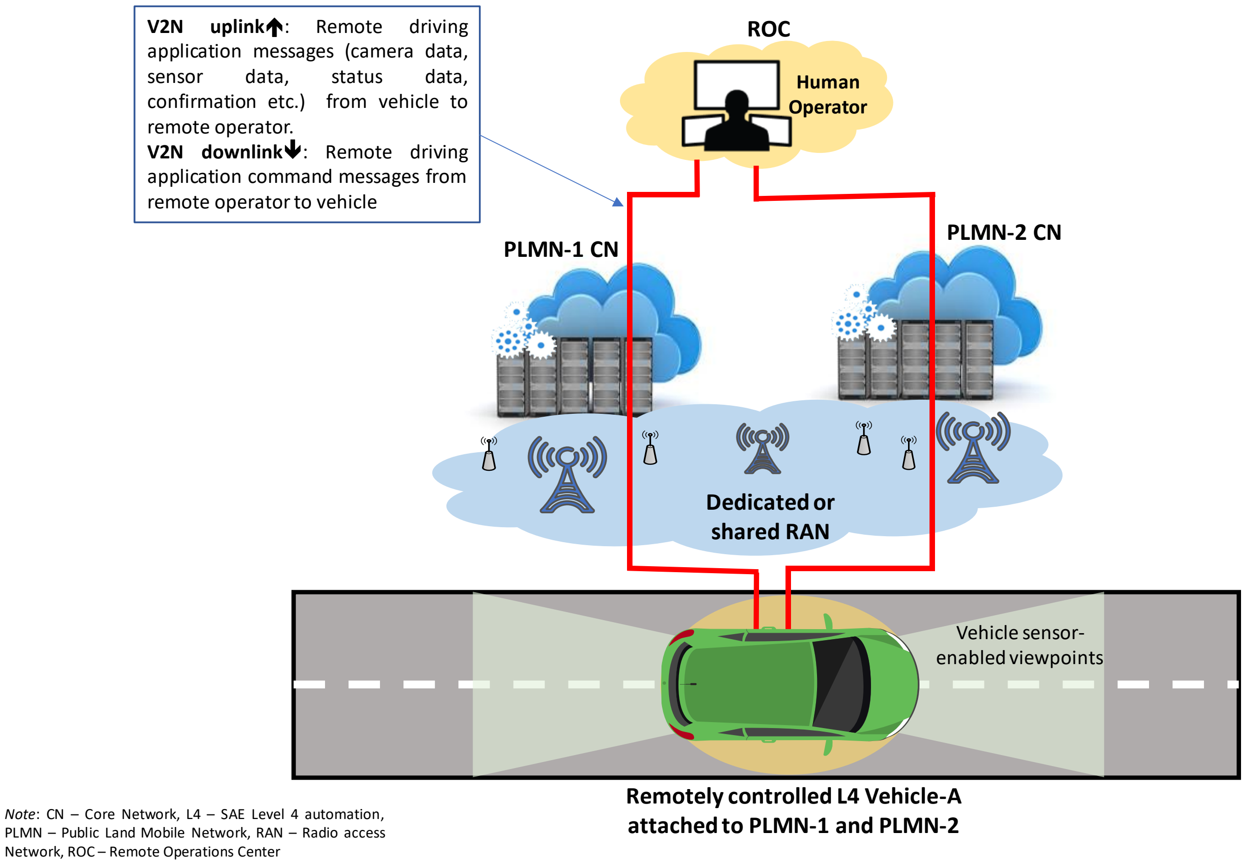

Figure 35 High-level illustration of the remote driving use case (multi-PLMN scenario)

Remote driving in an inter-PLMN scenario (Scenario 2): In this scenario, a remotely controlled L4 vehicle trajectory goes beyond the coverage area of the Home PLMN, necessitating the roaming and reattachment of the vehicle to a Visited PLMN. Figure 36 below, illustrates this scenario, whereby, an L4 Vehicle-A has PLMN-1 as the Home PLMN at a given location-1, the vehicle moves to a location-2 which is covered by a Visited PLMN (PLMN-2), resulting in an inter-PLMN handover (roaming) scenario. In the case that location-1 to location-2 transitions are in cross-border areas (international roaming), it may be accompanied by handover of the L4 vehicle control from one Remote Operations Centre to another (depending on remote driving service arrangement, country regulations etc.).

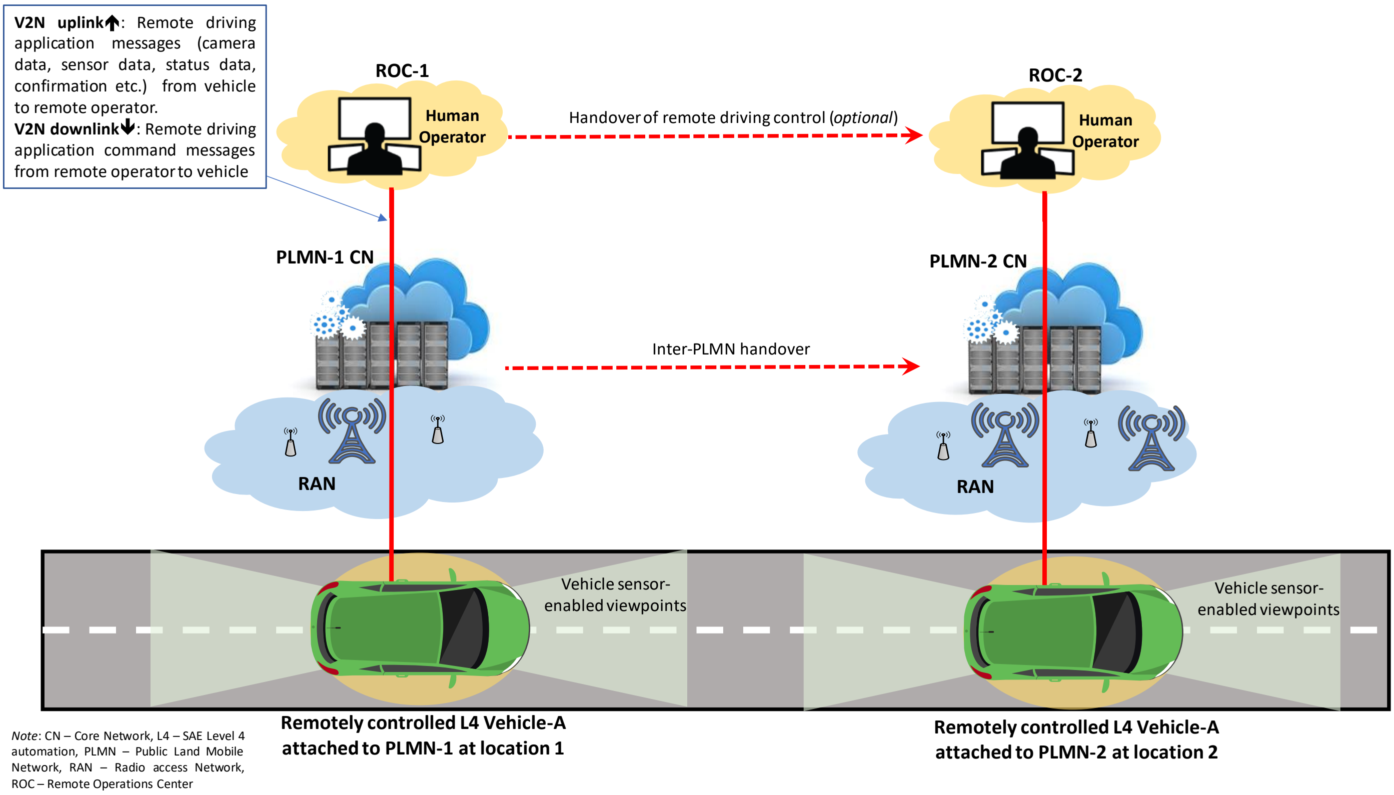

Figure 36 High-level illustration of the remote driving use case (inter-PLMN scenario)

Table 32 Overview of remote driving use case

Use Case Short Name	Remote driving
Use Case Category	Remote Driving
Use Case Leader	Sensible 4
Other partners	AALTO, VEDECOM
Objective	Human operator leverages remote sensor data feed to control/drive autonomous vehicle.
Actors	L4 Vehicle, Human Operator, Home PLMN operator, Visited PLMN operator, V2X Application Server
Pre-conditions	• Vehicle is equipped with sensors to ensure human operator has acceptable view to execute particular control function • Vehicle supports remote driving application • Vehicle able to attach to all PLMNs considered in the scenario

Use Case flow	<u>Scenario 1</u> 1. Vehicle attaches to both PLMN-1 and PLMN-2, with PLMN-1 the primary connection 2. Vehicle triggers request for remote driving operation 3. Vehicle sends sensor data feeds to remote human operator 4. Remote human operator sends command message to Vehicle 5. Vehicle executes control/drive manoeuvre according to command message 6. Vehicle losses connection to PLMN-1 and uses PLMN-2 as primary connection 7. Remote driving data and command exchanges between vehicle and human operator continues via PLMN-2 <u>Scenario 2</u> 1. Vehicle attaches to PLMN-1 2. Vehicle triggers request for remote driving operation 3. Vehicle sends sensor data feeds to remote human operator 4. Remote human operator sends command message to Vehicle 5. Vehicle executes control/drive manoeuvre according to command message 6. Vehicle leaves PLMN-1 coverage area and attaches to PLMN-2 7. Remote driving data and command exchanges between vehicle and human operator continues via PLMN-2
Post conditions	• Remote driving service terminated when no further support or control from remote human operator is needed

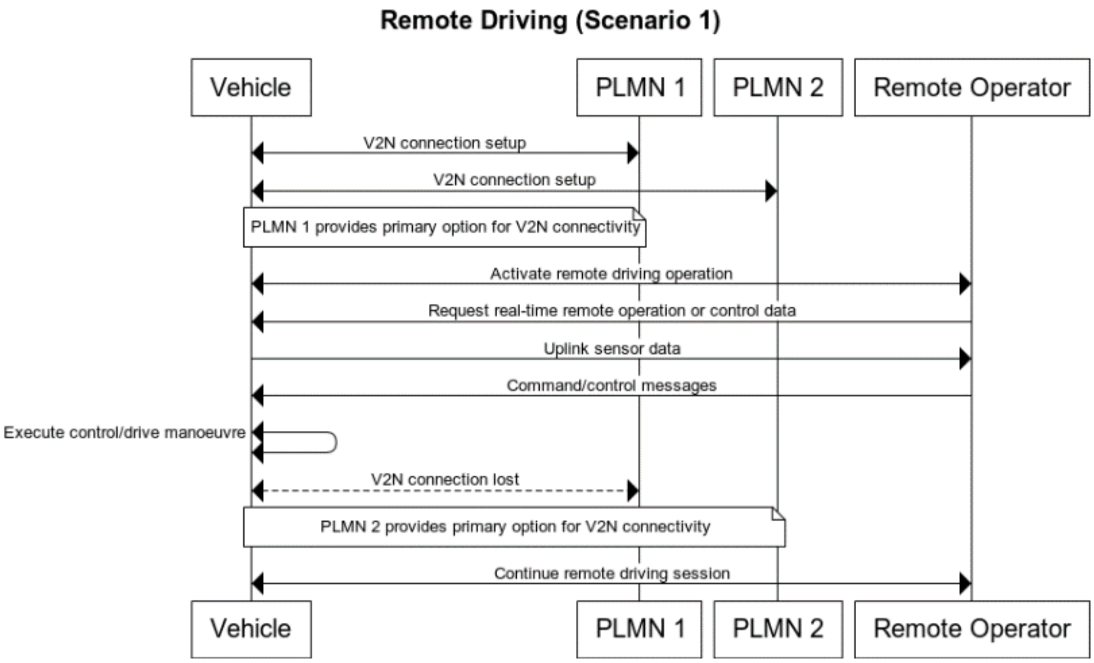

Figure 37 Sequence diagram for remote driving use case (scenario 1)

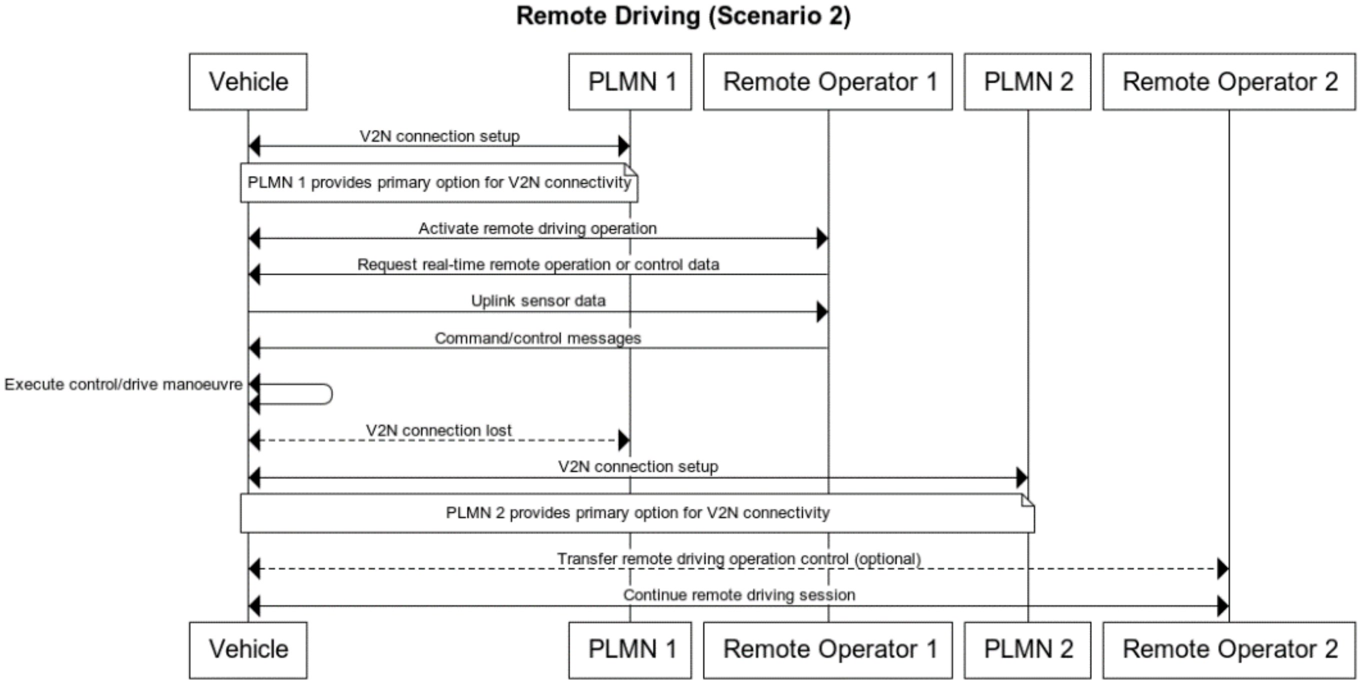

Figure 38 Sequence diagram for remote driving use case (scenario 2)

3.6.4.3. *Contribution to cross-border corridors*

The ES-PT cross-border site includes a use case involving the remote control of an electric vehicle (EV) automated shuttle buses running between two cross-border towns. To that end, this remote driving use case in Espoo site will provide an opportunity to test common and additional features not considered in the ES-PT remote control use case.

3.6.4.4. *Beyond state of the art*

The continuity of the remote driving sessions within or across multiple PLMN environments creates a number of interesting challenges, particularly environments with different mobile technologies (4G and 5G). Some of these challenges of maintaining the service in across different systems or operator domains are also highlighted by projects, such as, 5GCAR[7], and the 5G Automotive Association (5GAA)[8]. Different approaches will be explored further in the Espoo trial site to provide further experimental insights on the implementation barriers and potential solutions.

[7] 5GCAR Delivarable D4.1, "Initial design of 5G V2X system level architecture and security framework," April 2018 https://5gcar.eu/wp-content/uploads/2018/08/5GCAR_D3.1_v1.0.pdf

[8] 5GAA white paper, "Cellular V2X Conclusions based on Evaluation of Available Architectural Options" March 2019

3.6.4.5. 5G services

5G service	Implementation
eMBB	Yes. Providing high capacity connectivity also in the uplink direction to relax constraints on sensor data feeds.
URLLC	Yes. Reliable and low latency for whole remote driving control loop
mMTC	No
Other	No

Table 33: Overview of 5G services to be implemented in the Remote Driving use case

3.7. French (FR)Trial Site

3.7.1. Location

Table 34 French location overview

Trial site class	Local site
Country/Countries	France
City/Cities	Saclay & Satory & Linas-Montlhéry

VEDECOM is going to use two types of trial sites: the first one of VEDECOM's test and demo sites situated between the campus of Paris-Saclay University (Polytechnique) and the train station Massy-Palaiseau. The second test site will be Satory and the UTAC CERAM closed test sites located in the suburb of Paris. The first is composed of urban and semi-rural roads (both separated lanes and open road are available), and the second is a closed site composed of 12 Km of different type of roads (highway, urban, rural, parking and braking circuits) and associated facilities. 5G equipment is being installed in the course of 2019 and will be available for 5G-MOBIX.

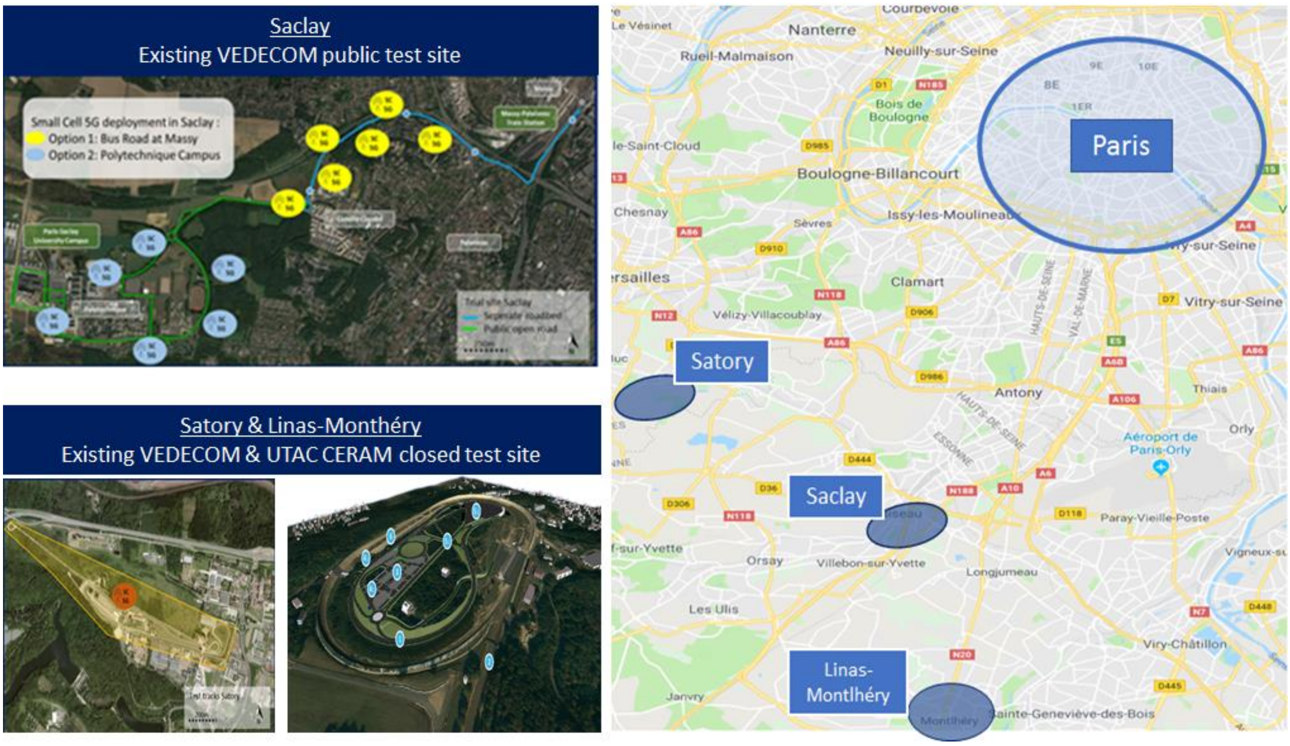

Figure 39: French trial sites

The site of Saclay is being equipped with 5G network infrastructure provide by NOKIA. Several small cells will be placed along the testing area. Open road facility at Saclay will allow us to pre- test our proposed uses cases.

The closed site of Satory is composed of closed roads (private test tracks). The second closed site of UTAC CERAM autodrome is situated at Linas-Montlhéry

As illustrated by the Figure 40 below, the trial site at Linas-Monthéry provides a variety of road configurations and presents a complete road infrastructure circuit to efficiently test the proposed use cases: from highways with three lane, 2.2 Km of length and high permitted velocity to urban circuit with traffic lights and parking area.

For the telecommunication side, the circuit is being equipped with 5G network infrastructure. This latter will be available by September 2019 and provided by both Orange and Bouygues Telecom operators. This will allow us to test roaming operations during use cases. Moreover, the site is already equipped with C-V2X RSUs, located at each 200m of the highway circuit.

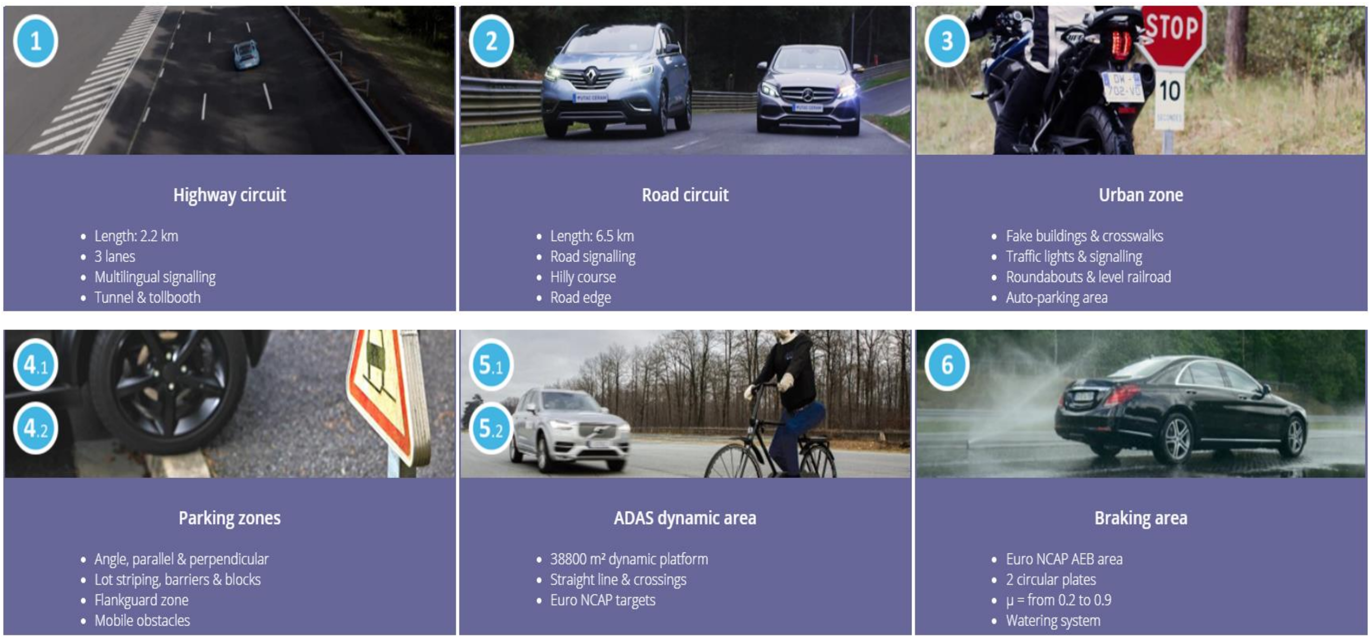

Figure 40 Road infrastructures and facilities provided by UTAC CERAM test site

3.7.2. Local Consortium

Table 35 French consortium

Role	Partner	Contribution
Full Partner	VEDECOM	Trial site coordinator use case development and testing, vehicles provider (incl. OBU),
Full Partner	AKKA	MEC and Fog computing solutions for network performance optimization (especially for latency-sensitive applications)
Subcontracting	VALEO	5G OBU chipsets (modems/5G cards)
Other	NOKIA	5G Infrastructure at SACLAY
Other	BOUYUGUE and ORANGE	5G network at Linas-Montlhéry
Other	La Croix	C-V2X infrastructure at Linas-Montlhéry
Other	UTAC CERAM	Closed site and necessary logistics of Linas-Montlhéry

3.7.3. Use Case 10: Automated Overtaking

3.7.3.1. *Motivation*

Investigating advanced vehicle control and safety systems has become the key development within C-ITS research fields and the automotive industry. The ultimate purpose of such investigation is to implement various types of driving-assistance systems, providing an opportunity to relieve the driver from driving fatigue and the monotonous routines of driving tasks. Among these tasks, lane-change manoeuvres are used as primitives for performing complex operations such as avoiding obstacles or overtaking vehicles ahead. Overtaking manoeuvre may cause numerous fatal crashes because of the unsafe diversion space from the original lane, poor visibility when passing a vehicle, or erroneous judgment in returning to the lane.

Hence, the ultimate goal of the automated overtaking use case is to guarantee the safety of the driver as well as other vehicles when performing such an action. Performing such manoeuvres safely will require cooperation among vehicles as well as infrastructure (in case of a temporary work zone for example), to create the necessary gap to allow the overtaking vehicle to quickly merge onto the lane corresponding to its direction of travel in time to avoid a collision with an oncoming vehicle and obstacle.

Fully-automated vehicles will need to perform overtake manoeuvre on two-way roads. Such a manoeuvre may be dangerous as a quickly approaching oncoming vehicle may be out-of-range of vehicle sensors. Performing such manoeuvres safely will require cooperation among vehicles on multiple lanes, to create the necessary gap to allow the overtaking vehicle to quickly merge onto the lane corresponding to its direction of travel in time to avoid a collision with an oncoming vehicle.
In addition, in the case of a temporary work zone present in the highway, cooperation between infrastructure and automated vehicle is needed to enhance its local perception through exchanging road sensors data.

By using 5G, vehicles and infrastructure are able to exchange raw data with the automated vehicle with very high reliability (URLLC), which is not feasible with previous generation mobile networks, in order to avoid hazardous situations. The use of MEC technology allows local data analysis for faster decisions. MEC requires massive amount of data (eMBB) to be collected and dynamic map layers require low latencies (URLLC) to keep the database up-to-date. Moreover, URLCC service is required when the automated vehicle (vehicle ahead) will communicate with the connected one (vehicle behind coming in the same direction) to negotiate the lane change manoeuvre. Specifically, the system will showcase the added value of using 5G services like eMBB and URLCC technologies for automated overtaking manoeuvre.

3.7.3.2. *Description*

A safe overtaking manoeuvre entails a construction zone ahead or a stopped vehicle, on a two-way lane. The most critical factors of overtaking manoeuvres comprise the following: a safe distance to the work zone or the stopped vehicle to be overtaken when initiating the overtaking operation, a safe gap to the connected vehicle behind coming in the same direction, but on a different lane, and a safe return to the original lane. Consequently, such a system requires the capability to manage the speed and steering in a coordinated manner, thereby minimizing collision risk with neighbouring vehicles.

Information provided by roadside sensors (such as cameras, lidar) with efficient timing and content will improve the vehicle perception and can be seen as additional sensors. The raw data will be treated in vicinity of the road entities, i.e. in the MEC, to be quickly processed and the risk analysis will be shared with vehicles.

MEC information is given to the automated vehicle in time, so it can start its overtaking manoeuvre. The automated vehicle will start a lane change manoeuvre negotiation with the connected vehicle behind coming in the same direction. To ensure safe and efficient lane change, exchange of trajectory plans between vehicles is necessary. Involved vehicles will exchange their intended trajectories to coordinate their lateral (steering) and longitudinal controls (acceleration/deceleration) to ensure a smooth manoeuvre. Such a communication should be very rapid and reliable to guarantee the safety of both vehicles.

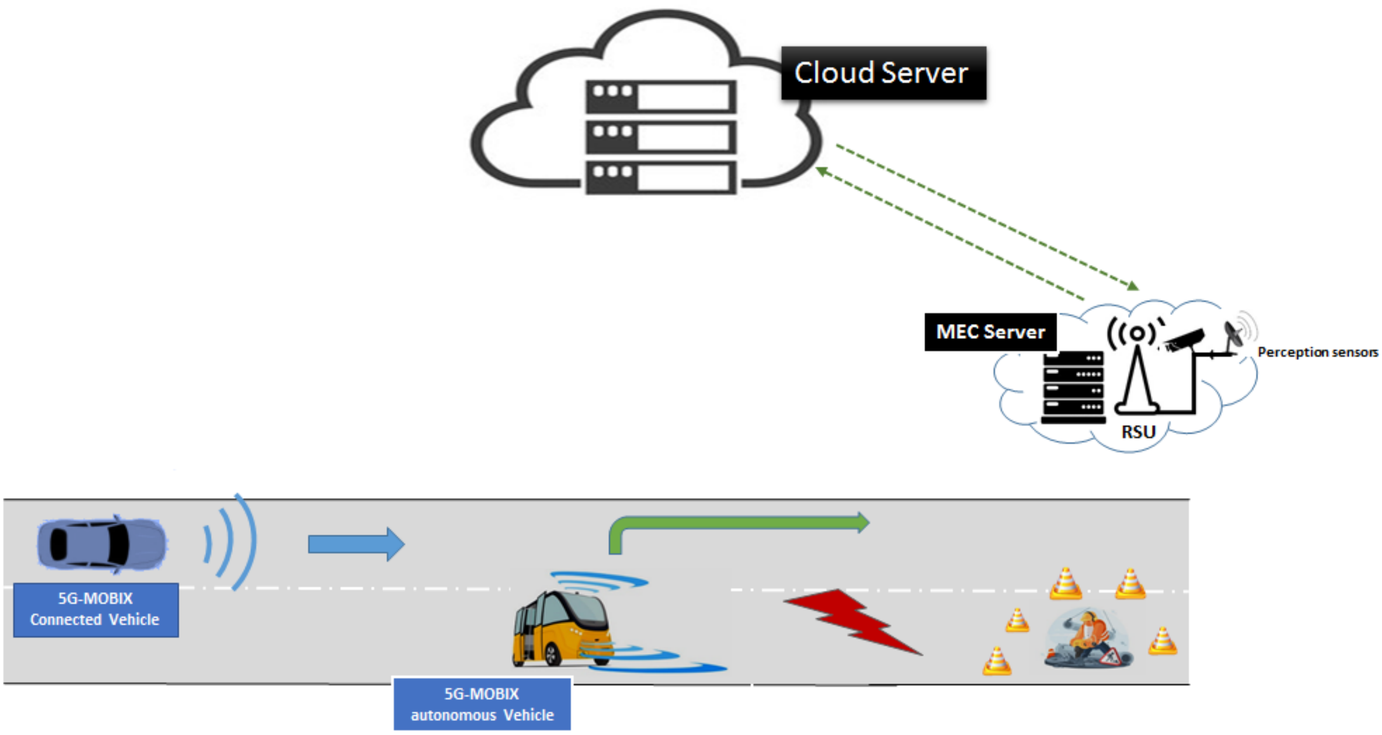

Figure 41 Example of the automated overtaking use case from the FR corridor.

Table 36 Overview of automated overtaking use case at the French site

Use Case Short Name	Automated Overtaking
Use Case Category	Advanced Driving
Use Case Leader	VEDECOM
Other partners	Nokia, AKKA, VALEO, La Croix, Bouygues, Orange, UTAC/CERAM
Objective	Improve safety of automated driving manoeuvres by coordinating driving trajectories
Actors	Vehicle A, Vehicle B,
Pre-conditions	• Vehicle A is a connected vehicle and potentially automated • Vehicle B is an automated vehicle • Vehicles A, and B support message exchange over 5G networks. • A work zone (or a stationary vehicle) is located at the same line of the automated vehicle B
Use Case flow	1. Road infrastructures (sensors, cameras, lidars) installed at the work zone send their raw data to the local MEC server. 2. MEC treats received data (fusion, risk analysis) and sends information to the approaching vehicle B 3. When Vehicle B receives the information from the MEC server, it detects the need for a lane change and requests a safety distance creation. 4. Vehicle A confirms the creation of the required safety distance 5. Vehicle B is informed of the creation of required safety lateral distance 6. Vehicle B moves into the selected lane by continually transmitting periodically its trajectory plan to vehicle A over 5G. 7. The trajectory plan is updated based on the evolution of the manoeuvre and the locations of Vehicle A
Post conditions	• Vehicles B performs safely the lane change with the cooperation of Vehicle A

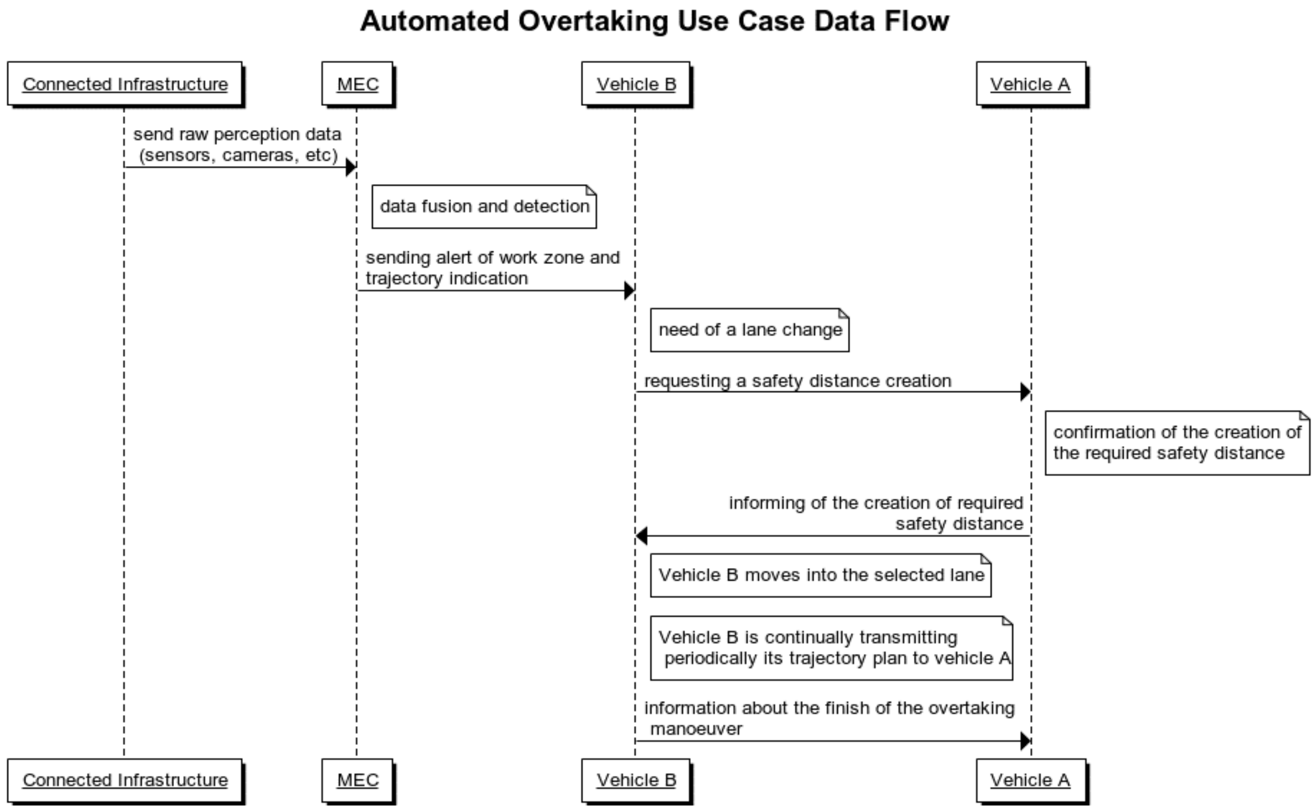

Figure 42 Automated Overtaking sequence diagram

The work zone can be replaced by a stationary vehicle on the highway. In this case, the vehicle will use V2V communications to alert other approaching vehicles about its presence, and thus to take the required manoeuvres.

3.7.3.3. Contribution to cross-border corridors

Automated overtaking manoeuvre use case at the French site will enable L4 automated driving. To this end, when the automated driving system is enabled, the automated vehicle will start performing the lane change manoeuvre without any intervention from the driver. This is done using the perception and communication capabilities of the concerned vehicle as well as the cooperation between vehicles and road infrastructures.

Although being a local trial site, the French site has a similar infrastructure required for cross-border corridor allowing corridor use-cases and beyond to be tested. This is demonstrated in this use case with the involvement of multi 5G network operators, and the presence of highway demonstrations facilities at the closed site of UTAC/CERAM to emulate a highway cross-border situation.

To emulate a handover scheme at a cross-border trial site, this use case will benefit from a multi telecom operators' platform at UTAC/CERAM facility to perform a network continuity test when switching from Orange Network to Bouygues during the overtaking manoeuvre since the autonomous vehicle is monitored remotely from the control centre. The remote driving use case (second use case at the French site) will showcase the service continuity when the control centre takes over the control of the automate vehicle.

In addition, the present use case contributes to the development of the automated use case in the ES-PT cross-border corridor as it can serve as pre-test deployment. Moreover, the implementation of the use case at the French site targets a complementary situation of the one developed at the ES-PT cross-border corridor. In fact, it handles a different situation not covered by the ES-PT cross border corridor, where the automated vehicle will have to perform a change lane because of the presence of a temporary obstacle on the highway (work zone, accident zone, etc).

The present use case also contributes to the development of the "Assisted truck border-crossing & increased driver awareness" of the GR-TR cross-border corridor, serving as pre-test scenario for heterogenous data collection, fusion and data analysis at the Edge of the network (MEC).

3.7.3.4. *Beyond state of the art*

Current 4G technology cannot offer the required performances needed for the present use case since it needs low latency communications with high reliability between vehicles. In this case, 5G is needed since the bandwidth and latency provided by the network allow for the creation of network slicing and provide a better QoS for safety critical applications. URLLC will be used for low latency exchange between vehicles and infrastructures while eMBB will be used for the 5G positioning system and data sharing when changing the lane and then maintaining a safe distance from the connected vehicle behind

3.7.3.5. *5G services*

Table 37 Overview of 5G services to be implemented in the Automated Overtaking use case

5G service	Implementation
eMBB	Yes. To exchange raw sensors data between vehicles and infrastructure
URLLC	Yes. Low latency data exchange between vehicles
mMTC	No

3.7.4. Use Case 11: Remote Driving

3.7.4.1. *Motivation*

Remote driving is the simplest answer of managing the automated vehicle (AV) internal defect. The objective is to permit to an external operator (in the control centre) to drive the vehicle to a safe area. The motivation is not saving the vehicle but saving the people inside it. The remote operation can both be local where the operator is located close to the machine but not in visible range. It can also be global where communication needs to be relayed via the Internet or by a satellite link. Different kinds of autonomous tasks can be used by the operator at this level.

A key element in teleoperating vehicles is providing the operator with a sense of presence or awareness of that environment. Traditionally, a video feed is used to provide information to the operator. This video feed, usually from an on-board, front-mounted camera, provides visually rich information of the environment.

Remote driving needs strong video streaming with low latency and the transmitted control actions need to experience low latency as well. For these 3 reasons, we need to validate that the 5G network performs well enough to permit this fall-back use-case.

3.7.4.2. *Description*

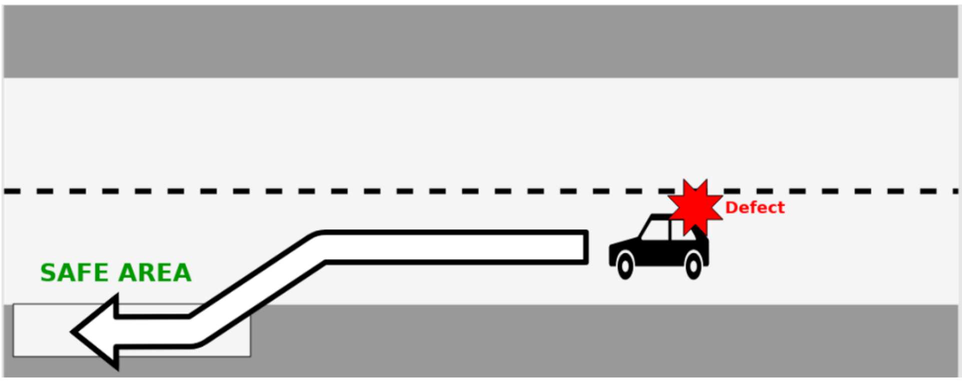

Figure 43 Remote driving Use case from the FR corridor

The present use case deals with a situation where the autonomous vehicle faces a sensor failure during its trip on the highway (a troll station can be investigated also). Thus, the operator shall take control of the vehicle to drive it to a safe area located in the far-right side of the highway. Afterwards, the human intervention can be made to repair the failed sensor.

This use case is carried out at UTAC/CERAM closed site where it will be tested on a highway circuit. A multi 5G telecom operator at the site (Orange and Bouygues) will allow to perform both service and network continuity when the autonomous vehicle changes the network during its manoeuvre and a second operator takes the vehicle control. The existence of a troll station allows us to investigate to perform remote driving when the AV is crossing the troll area.

Table 38 Overview of Remote Driving use case at the French site

Use Case Short Name	Remote driving
Use Case Category	Remote driving
Use Case Leader	VEDECOM
Other partners	Nokia, AKKA, VALEO, Bouygues Telecom, Orange, La Croix , UTAC/CERAM
Objective	Improve safety of remote driving by using direct control of the vehicle
Actors	Vehicle A, Remote operator
Pre-conditions	• Vehicle A is stopped on the road • Vehicle A is not able to enable the automated mode (defect on device, flat tire ...)
Use Case flow	1. The vehicle requests a remote operator intervention. 2. The operator analyses the situation and drives the vehicle from the control centre. 3. The operator moves the vehicle with direct driving instructions with limited speed 4. the monitoring is based on live video stream from the camera installed on the vehicle. It can be enhanced by sensors installed on the roadside 5. The operator drives the vehicle to a safe area to allow a human intervention. 6. The AV is stopped 7. The operator stays in survey of this AV (if some users are inside).
Post conditions	• The passengers are in a safe area and wait • The vehicle waits for human intervention to fix the sensor failure

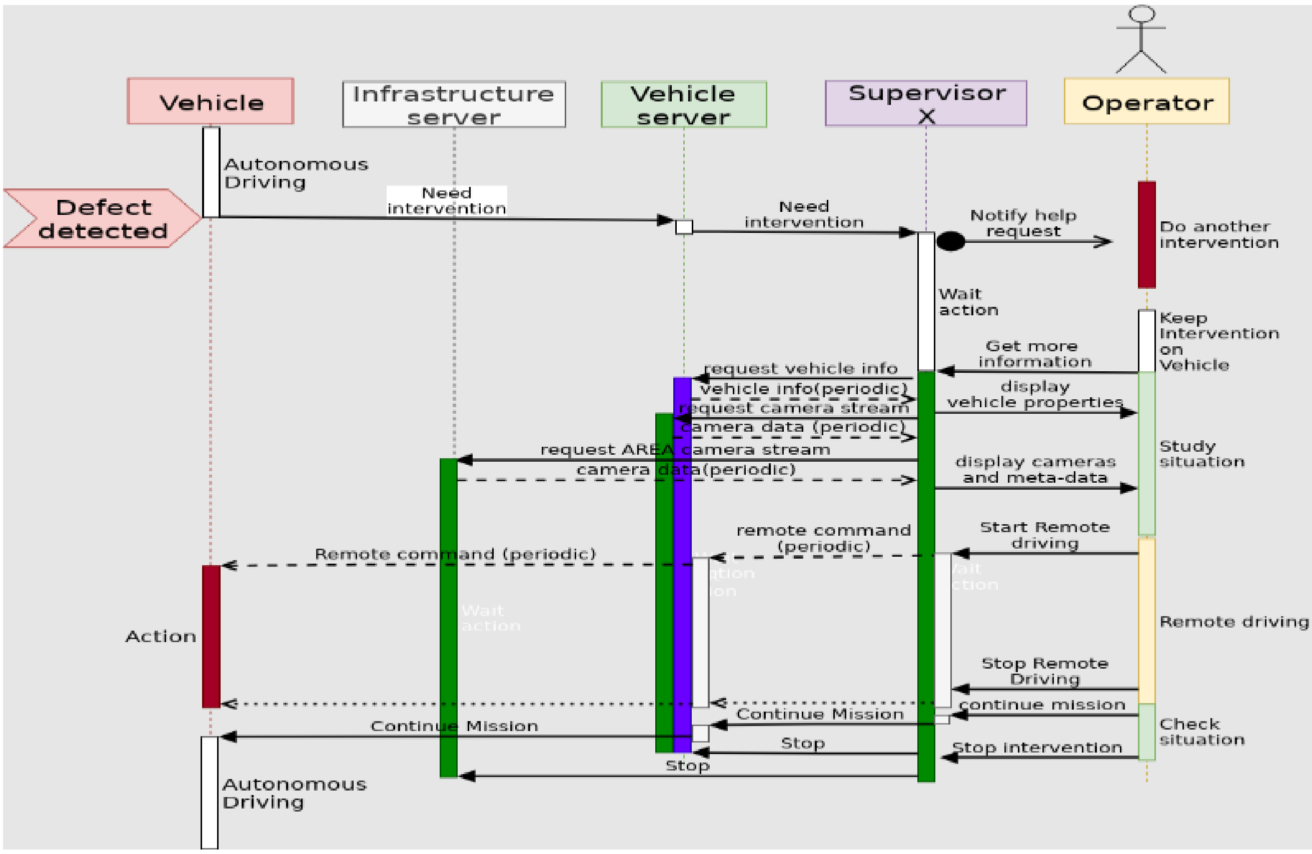

Figure 44 Remote Driving sequence diagram

3.7.4.3. Contribution to cross-border corridors

The present use case contributes to the development of the remote driving use case at the ES-PT cross-border corridor by serving as a pre-test for a non-implemented situation. In fact, the situation where a perception sensor is down is not covered by the ES-PT site.

Compared to local sites implementations (NL, FI), the present use case will perform precise localization techniques and implement both service and network continuity during the remote driving operation. This will be done through testing the use case at UTAC/CERAM closed site with the presence of two telecom operators.

3.7.4.4. Beyond state of the art

Taking control of the autonomous vehicle and driving it to a safe zone will require a high bandwidth to be able to monitor the vehicle moves through high quality video streaming with low latency. 4G is not able to handle these requirements, and then 5G is needed since the bandwidth and latency provided by the network allow for the creation of network slicing and provide a better QoS for safety critical applications.

3.7.4.5. 5G services

Table 39 Overview of 5G services to be implemented in the Remote Driving use case

5G service	Implementation
eMBB	Yes. To exchange raw sensors data between vehicles, infrastructure and pedestrians
URLLC	Yes. Low latency exchange between road entities
mMTC	No

3.8. Dutch (NL) Trial site

3.8.1. Location

Table 40 Dutch location overview

Trial site class	Corridor / Local site
Country/Countries	The Netherlands
City/Cities	Eindhoven, Helmond

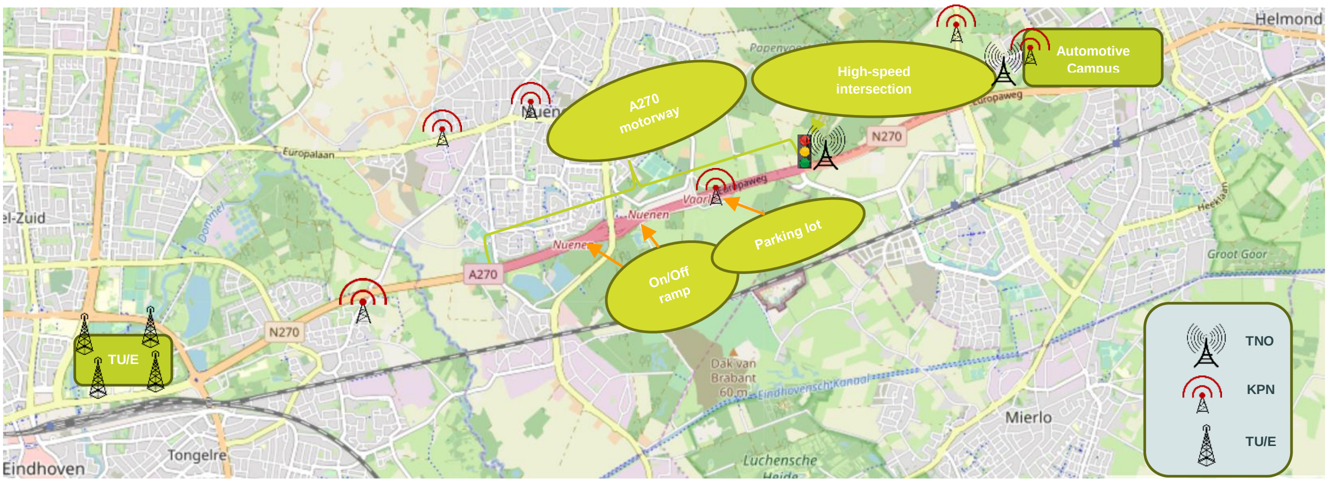

Figure 45 NL trial site

The NL trial considered is located at the motorway A270/N270 connecting the cities of Eindhoven and Helmond in the Netherlands which has road exemptions to support automated driving in mixed traffic conditions. Trials start at Technical University of Eindhoven campus in Eindhoven. AD vehicles drive towards the Automotive campus in Helmond covering road distance of approximately 10 km, of which 6km is a high speed (100 kmph speed limit) road segment on A270/N270. 5G networks are provided by three partners namely KPN, TNO, TU/e. Commercial 5G network with 6 gNBs from KPN will serve along the trial site. 5G small cells provided by TU/e will cover university campus, Eindhoven and a 5G research network with two gNBs along the trial site closer to the Automotive Campus, Helmond will be provided by TNO. These three 5G networks will provide a multi-Public Land Mobile Network (PLMN) environment for testing services in a cross-border setup. Additional road side units such as fixed camera every 100m and ITS-G5 units every 500 m in the A270/N270 segment and intelligent traffic light controllers along the route with their C-ITS services makes the trial site an ideal location for testing and evaluation.

AD vehicles will be provided by four 5G-Mobix partners, namely VTT, TU/e, SYSSBV and TNO. The vehicles capable of ITS-G5 and 4G communication will be upgraded to 5G C-V2X communication capabilities. In-vehicle platforms and services will be developed and tested locally in the campuses of respective participating member states (i.e. the Netherlands and Finland) and will be brought to trial site for evaluation.

3.8.2. Local Consortium

Table 41 Dutch consortium

Role	Partner	Contribution
Full partner	HELMOND	Support services
Full partner	KPN	5G provider
Full partner	TNO	Trial-site leader,5G provider, AD vehicle, Application developer
Full partner	TU/E	5G provider, AD vehicle, Application developer
Full partner	SISSBV	AD vehicle, Application developer
Full partner	VTT	AD vehicle, Application developer

3.8.3. Use Case 1: Cooperative Collision Avoidance

Cooperative Collision Avoidance: CoCA is a safety-critical service where communication between vehicles and vehicles and infrastructure are used for Collision Avoidance. 5G technologies provide the required low latency communications environment that is a prerequisite for any safety-critical ITS system or service. Connected and Automated Vehicles (CAV) and intelligent infrastructure solutions together are capable to provide technical and communications support for CoCA.

CoCA will be activated when there is a potential traffic violation, which is assessed considering the traffic light status, and status of existing C-ITS services (to make note that these are operational services that cannot be deactivated). The triggering of the CoCa application is very time critical, and it needs to intervene in time to initiate evasive action. For that purpose, the speeds and position of approach vehicles towards the intersection need also to be assessed with great precision. The 5G technology in conjunction with road-side systems will also allow for improved assessment of the vehicle trajectories at the intersection. The ego vehicle must be able to utilise both its own trajectory and timing data as well as the alter vehicles' precise location and intended direction and speed to avoid colliding with each other.

3.8.3.1. Cooperative Collision Avoidance (CoCA) Use case description

This 5G-MOBIX Service will take place at an Intelligent Intersection of the A270 Motorway - N270 Highway between Eindhoven and Helmond (NL). This site has been used for several tests and trials on Automated Driving and/or C-ITC. In 5G-Mobix the current facilities to support CCAM will be upgraded to work on a 5G mobile connectivity platform.

CoCA targets to solve a challenging traffic situation on the motorway/highway environment. The Vehicle A ('ego vehicle', a foreign registered vehicle driving on the Dutch motorway/highway network) will make itself 'visible' and known to other traffic participants and to the infrastructure for Edge Computing through C-ITS messaging via 5G networks, and Cellular V2X (C-V2X) communication i.e. either LTE-based or 5G NR-based V2X. The Vehicle B ('alter vehicle', a Dutch registered vehicle) will submit similar information of its presence, speed and direction of movement to 'ego vehicle' and infrastructure as described above. Hence the 'Edge Cloud' infrastructure facilities can perform calculations and offload from the vehicles to the infrastructure and then return the suggested manoeuvring messages.

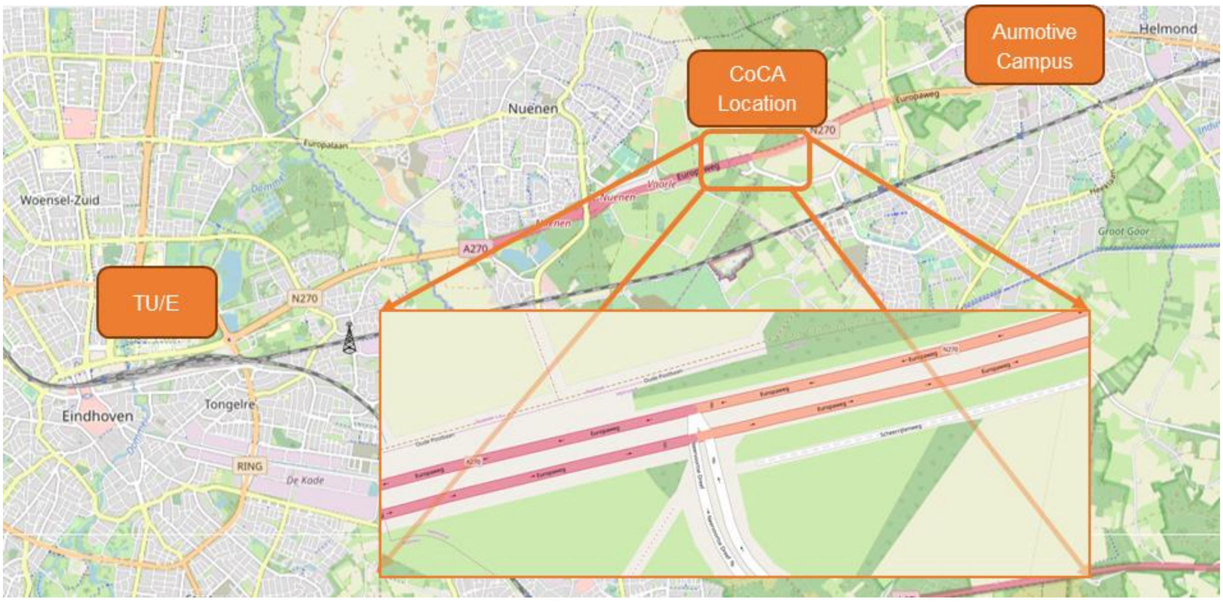

Figure 46 Location of the intelligent intersection on the A270-N270 motorway/highway between cities of Eindhoven and Helmond

At the intersection of A270-N270 roads, the most critical path for cooperative automated driving is the left turn over the direct traffic flow that has a right-of-way for driving in highly automated mode through the intersection. The ego vehicle that is approaching the intersection must be able to clear itself safely across the motorway/highway lanes to join the main traffic flow. When deemed necessary, the ego vehicle need to safely stop autonomously before crossing the motorway/highway and start driving only when its calculated trajectory path is safe and clear for autonomous manoeuvring. For this purpose, the ego vehicle must be able to utilise both its own trajectory and timing data and information from the road side sensors as well as the alter vehicle's precise location, intended direction and speed to avoid collision.

The target in 5G-Mobix is time-critical message exchange between CAVs using 5G technologies. These technologies include:

- C-V2X based on LTE or 5G NR for direct communication between vehicles and 5G networks
- 5G NR enabled base stations (gNB)
- 5G core technologies like Edge Computing ('Edge Cloud ') and Slicing
- Ultra-Reliable Low Latency Communication (uRLLC) to support time-critical communication.

Currently the CAVs are capable to support direct communication between vehicles via ITS-G5 based solutions and/or 4G network-based communication for C-ITS message exchange. The ultimate solution is to use hybrid in-vehicle communication units that can communicate both directly between vehicles and over the network using 5G NR-V2X.

Table 42 Overall description of the Cooperative Collision Avoidance Service at the highway intersection

Use Case Short Name	Cooperative Collision Avoidance
Use Case Category	Advanced Driving
Use Case Leader	VTT
Other partners	TNO, KPN, SISSBV
Objective	High bandwidth, low latency data exchange for safety-critical application of Cooperative Collision Avoidance at the highway intelligent intersection
Actors	CAV vehicles, 5G operators, roadside sensors
Pre-conditions	• Vehicles A and B support message exchange via 3GPP V2X communication. • Vehicles A and B support basis for V2X safety application (CAM, DENM etc.) so they already know their relative positions. • With relative positions, Vehicles A and B can operate CoCA application
Use Case flow	1. Vehicle A is a foreign registered CAV, and Vehicle B is a Dutch registered CAV 2. Vehicle A or B detects the risk of collision. 3. V2X application of vehicle A detects a risk of collision. Vehicle A's application exchanges CoCA related messages (trajectories, sensor data, brake commands etc.) via 3GPP V2X communication service. 4. Vehicle B confirm on application layer to vehicle A the coordinated manoeuvre for CoCA by transmitting messages via 3GPP communication service
Post conditions	• Vehicles A and B perform coordinated manoeuvre

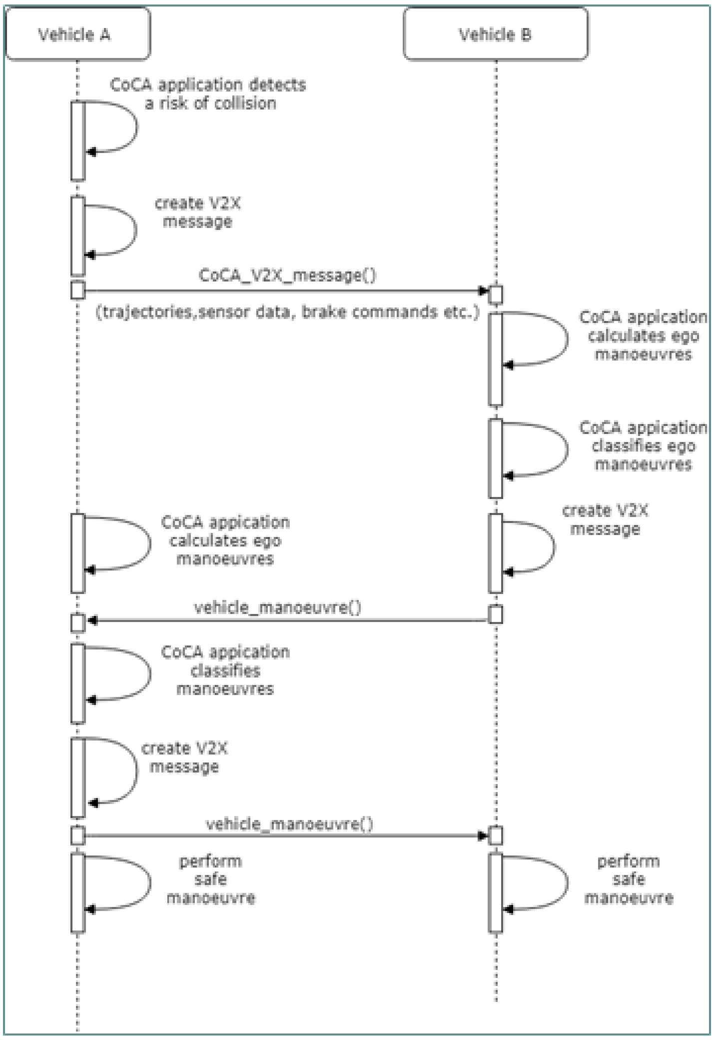

Figure 47 Sequence diagram of Cooperative Collision Avoidance use case

3.8.3.2. Beyond state of the art

The ultimate target of the project is deploying the services and applications functionalities over 5G Network. 5G is needed due to the limitations of LTE technology regarding the bandwidth and latency. Also, 5G allow for the creation of network slicing and provide a better QoS for safety-critical applications.

MEC will be used to orchestrate the communications, applications and functionalities of CoCA.

URLLC will be used for low latency data exchange between vehicles and infrastructures while eMBB will be used for the 5G positioning system and data sharing.

Figure 48 Sequence diagram of Cooperative Collision Avoidance service

3.8.3.3. Contribution to cross-border corridors

This use case contains CAVs from different countries and three different 5G network operators. The two CAVs from two Member States performing CoCA supports a direct cross-border corridor situation. The presence of three independent 5G operators opens an evident situation of cross-border corridor interoperability. This use case has several similarities with a cross-border corridor as indicated above. This is highly applicable for a pre-test for such environment. The present use case will be difficult to test in the 5G-MOBIX cross-border corridors due to the requirement of vehicles from two different Member States.

3.8.3.4. 5G services

Table 43 Overview of 5G services to be implemented in the CoCA use case

5G service	Implementation
eMBB	Yes, to exchange raw sensors data between vehicles and infrastructure
URLLC	Yes, low latency exchange between road entities
mMTC	No, the density considered is lower to require this service

3.8.4. Use Case 2: L4 automated vehicle tele-operation and tele-monitoring services

3.8.4.1. Motivation

At border crossings on the outline of European Union, manual inspection of automated vehicle is still required even when vehicles become L4 automated. The customs can assign an inspection bay to these L4 automated vehicles and the vehicle should be able to be manoeuvred itself in that spot.

Current similar services (applied in different areas) rely on either fully equipping the vehicle with multiple sensors or using sensors in the infrastructure to locate the vehicle. In both cases, these services are in a controlled environment, with mainly no other traffic involved.

This requires a high level of autonomy and decision making from the L4 vehicle. In the current state of art this is L4 is not yet fully possible, so therefore a simple solution is to have a remote operator take over control in case the vehicle is unable to manoeuvre further (because of i.e. an unexpected roadblock, error in the vehicle system, or because of customs regulations where there is a need for further manual inspection and the vehicle needs to be controlled by the customs).

To manoeuvre a vehicle, sensor data from multiple vehicle sensors (cameras, LIDAR, radar) should stream their information in real time (synchronised and with low latency) to the operator and at the same time have low latency in the control task (manoeuvring the vehicle in real time). Using current communication technologies, the bandwidth is not enough to support the exchange of for example raw video data between vehicles.

5G technology can be aiding in improving bandwidth, latency limitations and reliability for manoeuvring a vehicle automatically into an inspection bay (in a slot assigned by border control remotely/via 5G and local edge computing) as well as using localization (of the car in surroundings by the car, plus potentially of the car by the infrastructure) for monitoring actions of the autonomous car by the border agents.

3.8.4.2. Description

In situation where the AD vehicle is unable to automatically drive further (due to a failure or unexpected driving condition), a remote operator takes over control of the vehicle and drives it to a point where AD can be resumed. As an example, this can be in situations like border control, construction zones and inclement weather. To tele-operate a vehicle, the data from multiple sensors should stream their information (synchronised and with low latency to the operator and at the same time have low latency in the control task of manoeuvring the vehicle in real time.

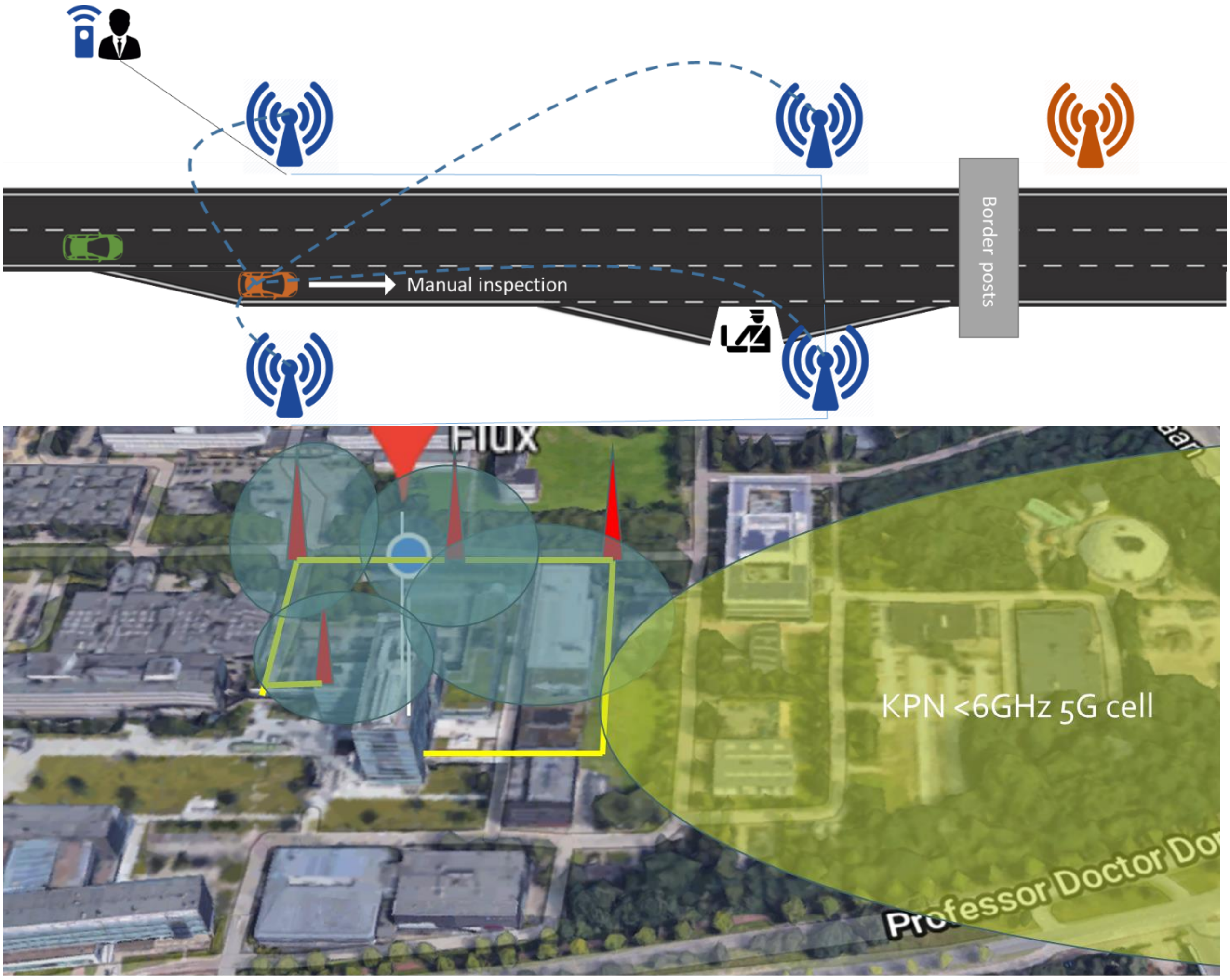

Figure 49 Example of how tele-operation with mm-wave localization (with multiple mm-wave base stations in blue) could be implemented on cross border sites (top) and TU/e site with multiple mm-wave base stations (in red) for testing with adjacent KPN network for handover (bottom).

One example for tele-operation is when an AD vehicle is automatically manoeuvred to a bay/slot assigned by border control remotely/via 5G and local edge computing for monitoring actions of the autonomous car by the border agents. For automated manoeuvring in a complex border-post environment, precise localization (of the car in surroundings by the car, plus potentially of the car by the infrastructure) is needed. In the NL trial, tele-operation will be tested by driving the vehicle from the emergency lane to an assigned slot on a rest area along the A270. However, testing of localization services will be carried out at the TU/e campus as it needs special infrastructure, e.g. fibre optical backbone and multiple 5G small cells, available at the TU/e campus for high accuracy localisation services and low latency. New 5G technology based on adaptation and integration of 5G beam steering and MIMO will be used for localization and positioning. The 5G (mm-wave) based location can serve as a redundant localization system and useful in scenarios such as border customs control with gates with a roof covering.

Table 44 Overview of Remote driving use case

Use Case Short Name	Remote driving
Use Case Category	Remote driving
Use Case Leader	TUE
Other partners	TNO, KPN
Objective	In case of failure of the AD system, remote take over can aid in the manoeuvring of the L4 automated vehicle
Actors	Vehicle (A), Operator (B), Tele-monitoring network (C)
Pre-conditions	• Vehicle is automated driving at L4 (ODD) • Vehicle is not able to continue due to defect, or an unknown road block.
Use Case flow	1. Vehicle detects obstacle or error 2. The vehicle requests remote operator intervention 3. The operator analyses the situation and decides to drive the vehicle from the control center. 4. The operator can move the vehicle with a limited maximum speed (because of safety). 5. The operator drives the vehicle to a predefined emergency lane or to the customs inspection bay.
Post conditions	• Vehicle is operational again and operator hands over control to vehicle again • The passenger/driver is informed, or customs are informed to start inspection

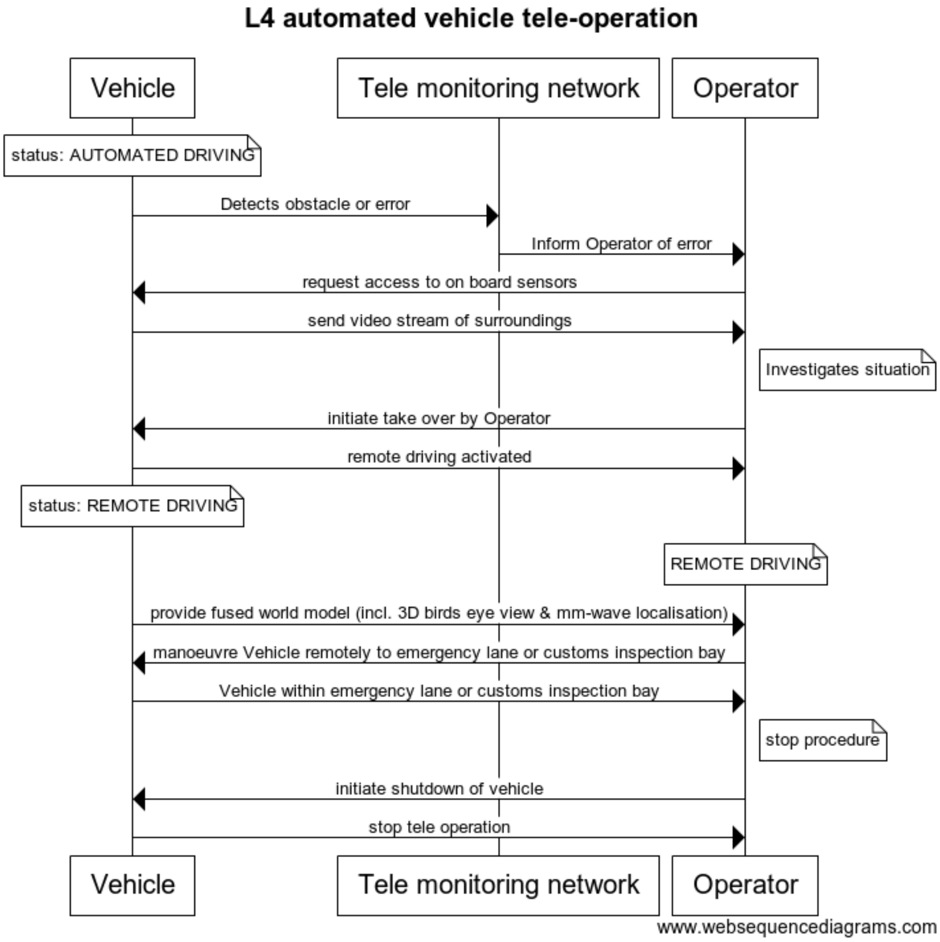

Figure 50 Remote driving sequence diagram

3.8.4.3. Contribution to cross-border corridors

TU/e intents use to new 5G technology by adaptation and integration of 5G beam steering and MIMO technology for localization and positioning. This technology will be deployed and tested first on the TU/e campus, where we are able to deploy several 5G small cells easily to test the functionality. Adding 5G high precision localization to the existing set of internal localization sensors (like GPS, LIDAR, camera, RADAR) of the Highly Automated Driving (HAD) vehicle will enable redundancy in localization of the vehicle and therefore enable further deployment of L4 automated vehicles more rapidly.

It has therefore the potential to solve the problem, where the required localization accuracy of AD vehicles is higher (because of the higher complexity of the traffic situation with intersections and other traffic participants) beyond only that of motorways.

Specifically, in GR-TR, the border customs control has multiple gates with a roof covering the customs patrol. This makes localisation using typically GPS for autonomous vehicles difficult and requires additional redundant technologies like vehicle sensor localisation (i.e. SLAM) or using 5G localisation (mm-wave).

Handover between dedicated local network (of the border agency, country A) and short-distance 'neutral' network (in 'no-mans-land' between border posts) and another local network (of border agency, country B) can be simulated at the NL Trial site.

3.8.4.4. Beyond state of the art

Using 5G technology we aim to:

- Improve localisation of AD vehicle and add redundancy to existing sensor set using 5G mm-wave technology.
- Using the 3D bird's eye view of vehicle sensors with AI enabled by 5G to the operator to perform safe tele-operation.

This technology can also be applied into the collective perception of environment and CoCA use cases of the NL Trial Site.

3.8.4.5. 5G services

Table 45 Overview of 5G services to be implemented in the Remote driving use case

5G service	Implementation
eMBB	Yes, for sending video streams for remote driving
URLLC	Yes, for precise localization and remote driving
mMTC	No, the density considered is lower to require this service

3.8.5. Use Case 3: Collective perception of environment

3.8.5.1. Motivation

In this use case, highlighting the theme of international travel, we consider SAE Level 4 automated driving (AD) in the motorway A270/N270 connecting the cities of Eindhoven and Helmond in the Netherlands. The ego vehicle starts from the Automotive campus and drives autonomously towards the Technical University of Eindhoven campus, successively crossing borders of different 5G networks (i.e. multi-Public Land Mobile Network (PLMN) provided by three partners (KPN, TNO, TU/e). This use case resembles and includes several aspects of a cross-border scenario: AD vehicles are provided by partners from different countries (The Netherlands and Finland), namely VTT, TU/e, SISSBV and TNO and are tested in a multi-PLMN scenario.

To address challenges of this international travel theme, *collective perception of environment* (CPE) is an important technology for L4 AD. Traditionally, a vehicle makes use of on-board sensors to create a perception of the environment. However, on-board sensors have their own limitations in terms of field-of-view in addition to the challenges posed by weather conditions, blind spots and far ahead road and traffic conditions. In this use case, vehicles and road side unit (RSU) exchange information in real time to enhance their perception of the environment. CPE can improve the safety of AD vehicles and traffic flow by providing better anticipation, which in turn increases energy efficiency and reduces the carbon footprint. CPE can aid in the coordinated control of vehicles as in cooperative collision avoidance or cooperative manoeuvre such as lane change, merge and diverge. By connecting to existing C-ITS and traffic management road-side information systems, and by exploiting sources from legacy traffic that are available in the cellular network, it can further improve the traffic flow. 5G technologies play the crucial role of enabling the exchange of high frequent messages (e.g., Collective Perception Message (CPM)) and high-resolution perception data such as camera, LIDAR, occupancy grid and/or detailed planned trajectory in real-time, which requires high bandwidth and low latency communication.

3.8.5.2. Description

The objective of this use case is to enhance the environmental perception of vehicles by enabling the real-time data exchange between vehicles and RSU. AD vehicles with Level 4 capability require predictive information of environment sufficiently ahead in time. AD vehicles are equipped with on-board sensors, however, with limited range to detect objects and obstacles. CPE extends this range by providing perception of areas not visible to the vehicle sensors due to curves, corners or obstacles in the roads. AD vehicles equipped with 5G technology could share raw sensor data from cameras, LIDAR, etc. or share pre-processed data such as dynamic objects and planned trajectories as the Collective Perception Message (CPM). Additionally, other driving condition data such as weather situation and traffic information can be shared. gNodeB can act as a hub to relay pre-processed data in low resolution or raw data in high resolution, or (in case of MEC) combined data from different vehicles. Exchanging high resolution perception data in real-time requires high bandwidth and low latency communication as promised by 5G (eMBB, uRLLC).

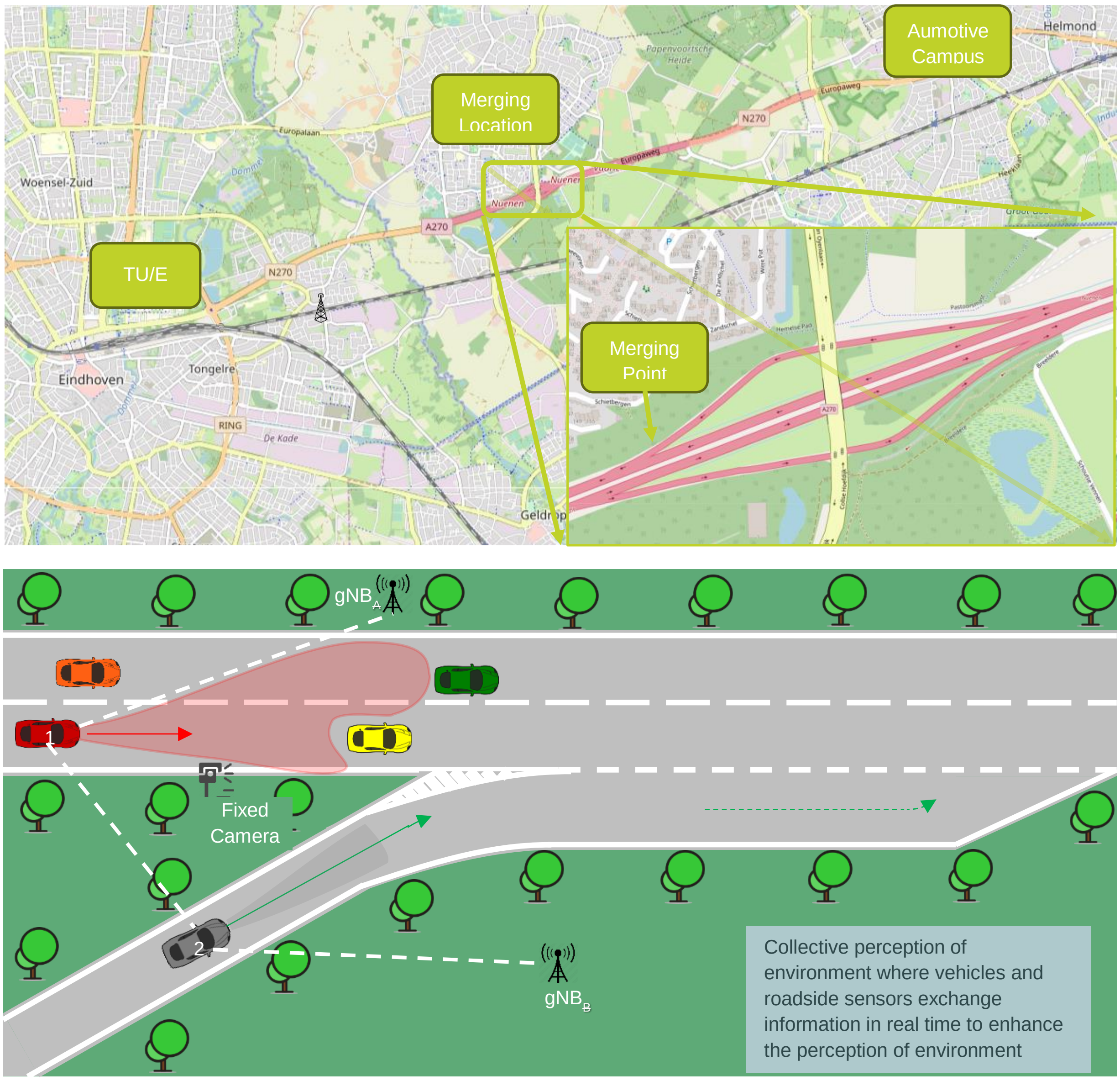

Figure 51 Collective Perception of Environment in cooperative merging example

In the NL trial, CPE will be evaluated in a cooperative merging scenario at the on-ramp from Nuenen to A270 motorway on the route from Helmond to Eindhoven. Traffic information from the roadside sensors (fixed cameras from SISSBV) will be utilized for a safe merging scenario. There are two autonomous connected vehicles in this scenario. The first vehicle is driving from Helmond on A270 and arriving close to the on-ramp from Nuenen while the second vehicle is driving from Nuenen and is arriving close to the ramp to finally merge in the A270. The second vehicle has no information about the traffic situation on the A270 due to its limited field-of-view. The vehicles are connected to two different networks; namely KPN and TNO. Both vehicles send requests to their respective gNodeBs to obtain each other's environmental information. Collective Perception Service aggregates CPM messages from vehicles and roadside sensors. The gNodeBs send aggregated CPM messages from the Collective Perception Service to the vehicles. Both vehicles will therefore be aware of each other's presence and anticipate on it accordingly. When in proximity vehicles also receive CPM messages over C-V2V. Upon request, vehicles can ask for more detailed data about a region, by exchanging pre-processed or raw sensor. The second vehicle can now evaluate and determine its merging possibilities in real time considering safety and traffic situation. When the second vehicle is on the on-ramp, it sends its decision to the first vehicle to make it aware about its merging action. Hence, a safe and efficient merging manoeuvre can be achieved using CPE and exploiting the capabilities of 5G.

Table 46 Overview of use case "Cooperative perception of environment"

Use Case Short Name	Collective perception
Use Case Category	Extended sensors
Use Case Leader	TNO
Other partners	SISSBV, KPN
Objective	Collective perception of environment where vehicles, roadside sensors and gNodeB exchange information in real time to enhance the perception of environment
Actors	AD_Vehicle_1, AD_Vehicle_2, roadside cameras, gNodeBs, 5G operators
Pre-conditions	• AD_Vehicle_1 and AD_Vehicle_2 are equipped with sensors (cameras, lidar, GNSS, odometry, etc.) • AD_Vehicle_1 and AD_Vehicle_2 are equipped with C-V2X and high bandwidth 5G communication
Use Case flow	1. AD_Vehicle_1 is driving on A270 and arriving close to the on-ramp from Nuenen and AD_Vehicle_2 is driving from Neunen and arriving close to the on-ramp to finally merge on to A270; but they cannot see each other due to the restricted field of view of the sensors. 2. AD_Vehicle_1 and AD_Vehicle_2 send request to their respective gNodeBs to extend their field of view. 3. Collective Perception Service aggregates CPMs from vehicles and roadside sensors 4. gNodeBs fetch aggregated CPMs from Collective Perception Service and send them to AD_Vehicle_1 and AD_Vehicle_2 5. AD_Vehicle_2 determines the traffic situation of A270 and checks

	the merging possibilities considering safety and traffic flow. 6. AD_Vehicle_1 and AD_Vehicle_2 when in range exchange CPM messages over C-V2V. 7. If necessary, AD_Vehicle_1 and AD_Vehicle_2 exchange sensor data (e.g. HD video). 8. AD_Vehicle_2 is on the on-ramp and sends its decision to merge to AD_Vehicle_1. 9. CPE is used for safe and efficient lane merging and finally AD_Vehicle_2 successfully merges on the A270 with AD_Vehicle_1.
Post conditions	• AD_Vehicle_2 merges successfully on the A270 with AD_Vehicle_1. Due to limitation of AD_Vehicle_2's field of view during the merging, enhanced perception of environment is provided for a safe and efficient merging.

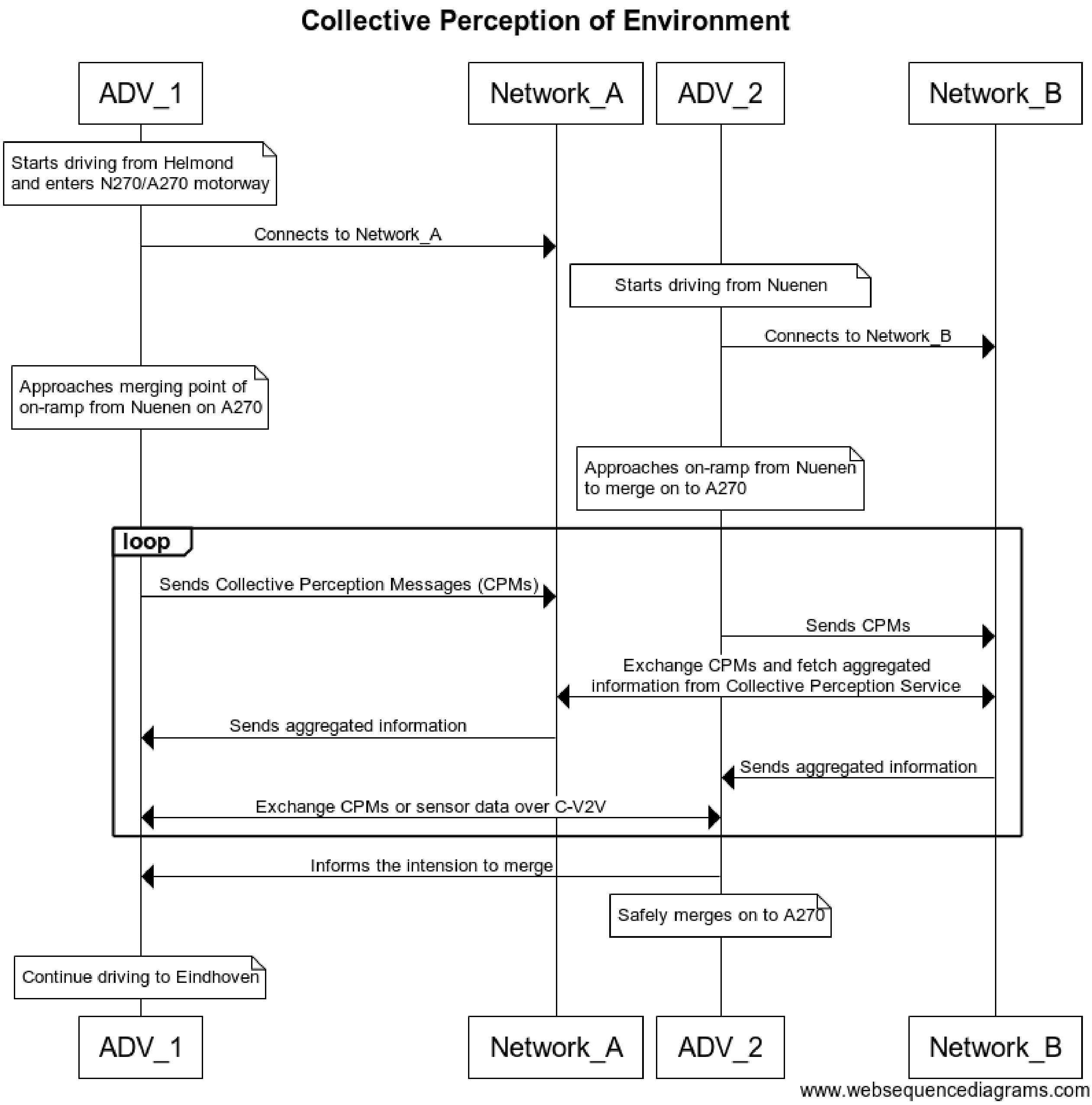

Figure 52 Sequence diagram - Collective Perception of Environment in cooperative merging

3.8.5.3. Contribution to cross-border corridors

This use case complements the "Assisted truck border crossing & increased cooperative awareness "functionality deployed in the Greece-Turkey cross-border corridor in the following aspect:

- Making use of a structured CPM to exchange relevant data between the vehicles in real time. The enhanced perception of environment extending the field of view of a merging vehicle by exploiting 5G technologies and ultimately help in decision making for a safe and efficient merging.

Moreover, in the German trial site, a "Cooperative perception with HD maps and surround view" use case, where cooperative perception will be evaluated for three vehicles to successfully perform a lane change and overtake the obstacle is mentioned and in the Finnish trial site a "Video-based cooperative perception" use case with focus on edge computing services in x-border scenarios is mentioned. In this use case we are targeting a different merging scenario of on-ramp from Nuenen to A270 performing a cooperative merging. An enhanced field of view for a completely different merging scenario together with a safe and efficient merging are added values. Moreover, the successively crossing borders of different 5G networks provided by 5G-MOBIX partners resembles several aspects of a cross-border scenario.

3.8.5.4. Beyond state of the art

The current AD vehicle capabilities are limited by the field of view of the on-board sensors and not so promising communication technologies for safety critical situations. The CPE technology in this use case extends the field of view of a merging vehicle thus provide better options in decision making for a safe and efficient merging. To complement CPE the 5G network capabilities such as high bandwidth, reliable and low latency communication are exploited.

- MEC will be used to orchestrate the communications, applications and functionalities of CPE.
- URLLC will be targeted for low latency V2X data exchange.
- eMBB will be used for high bandwidth communications such as raw data sharing and CPM

3.8.5.5. 5G services

Table 47 Overview of 5G services to be implemented in the Collective perception use case

5G service	Implementation
eMBB	Yes, in CPE for CPM or raw sensors data exchange (e.g. HD video sharing)
URLLC	Yes, for safety critical message exchange of CPE
mMTC	No, the density considered is lower to require this service
Other	Inter-PMLN operation with use of MEC and slicing concepts

3.9. Chinese (CN) Trial Site

3.9.1. Location

Table 48 Chinese location overview

Trial site class	Pre-deployment
Country/Countries	China
City/Cities	Jinan

The Jinan urban trial site is located in Shandong Academy of Sciences, which is the north-western part of Shandong province, about 400 kilometres south of the national capital of Beijing. Jinan city is the capital of Shandong province in Eastern China. The area of present-day Jinan has played an important role in the history of the region from the earliest beginnings of civilization and has evolved into a major national administrative, economic, and transportation hub. The local traffic condition is ideal for evaluation of 5G-MOBIX CCAM, where Jinan city is one of the most congested cities in China.

Figure 53 The China pre-deployment trial site.

3.9.2. Local Consortium

The local consortium for the China site is shown in the table below.

Table 49 Chinese consortium

Role	Partner	Contribution
Full Partner	DUT(DALIAN)	Trial site leader, technology integrator
Full Partner	Institute of Automation, Shandong Academy of Sciences (SDIA)	Vehicle provider, Use case leader
Full Partner	China Academy of Telecommunications Technology (Datang Telecom Group)	5G technology provider
Full Partner	Intelligent Networking Group, China National Heavy Duty Truck	Vehicle provider
Full Partner	Dalian Dazzlee Technology Co. Ltd	Vehicle application developer
Full Partner	Qilu Transportation Information Group	Site builder, network provider
Associate partner	China Unicom Jinan Company	MNO, network provider
Associate partner	Zhongxing Telecommunication Equipment Corporation(ZTE)	5G technology provider
Advisory Board	City of Jinan	Authorizations to roads and feedback in view of CCAM and 5G in China, invitation to dissemination events
	Shandong Academy of Sciences	
	China National Heavy Duty Truck Group	

3.9.3. Use Case 15: Automated driving (Coordinated overtaking and collision avoidance + Remote Manoeuvre)

3.9.3.1. Motivation

In our automated driving, we mainly consider coordinating overtaking and collision avoidance, and change driving mode, which are key enabling techniques for road safety and traffic efficiency services.

This case tries to enable the vehicle to assess the probability of an accident better and coordinate the exchange of information in addition to safety information, sensor data, braking and acceleration command lists, horizontal and vertical control in the application of road traffic flow through V2X communication.

Current V2X technology employs either DSRC or 4G LTE. Both are not the perfect solution to meet the requirements of most V2X scenarios concerning road safety, traffic efficiency, and infotainment.

The 5G network plays an important role in achieving communication between User Equipment (UE), supporting message exchange with ultra-high data throughput and ultra-low latency. Less than 10 ms latency is an important index for regular manoeuvre coordination within the time limit. UEs' message exchange shall be ultra-reliable. 99.99 % reliability for safety coordinated driving manoeuvre.

3.9.3.2. Description

The autonomous vehicle is equipped with advanced on-board sensors, controllers, actuators and other devices. It integrates modern communication and network technology to realize intelligent information exchange and sharing between the vehicle and X (vehicle, road, human, cloud, etc.) and has functioned such as complex environment perception, intelligent decision-making, and collaborative control. In our China site, the roadside unit, remote control centre and cloud server will monitor and control the autonomous vehicles in real time, to realize the various testes of Internet-connected applications of vehicles safely and efficiently.

Coordinated overtaking and collision avoidance scenario (Scenario 1): Figure 1 shows high-level scenario illustration of coordinating overtaking and collision avoidance, where Vehicle A and Vehicle B are both running in a straight line along the right lane. Vehicle B is traveling at a constant speed in front of Vehicle A, and both vehicles keep a small distance. In the beginning, the remote control centre (MEC) issues the overtaking order to vehicle A through the RSU. After receiving the order, Vehicle A sends the overtaking information to Vehicle B through V2V communication and receive the real-time information from Vehicle B via V2V, which includes the position, speed and heading angle of the vehicle. Thus, Vehicle A makes an automatic decision according to the information of Vehicle B. The process is also illustrated in Figure 3 with a sequence diagram.

The decision-making of Vehicle A is detailed as follows: First, it will change to the left lane; then it will accelerate to overtake according to the speed of Vehicle B. Finally it can change lane back to the right lane, and send its information to Vehicle B. In this way, these two cars complete overtaking operation. In this process, Vehicle A exchanges messages related to CoCA (Coordinated collision avoidance) through the 3GPP V2X communication service, while other vehicles transmit messages through the 3GPP communication service as well, finally they will achieve coordinated manoeuvring.

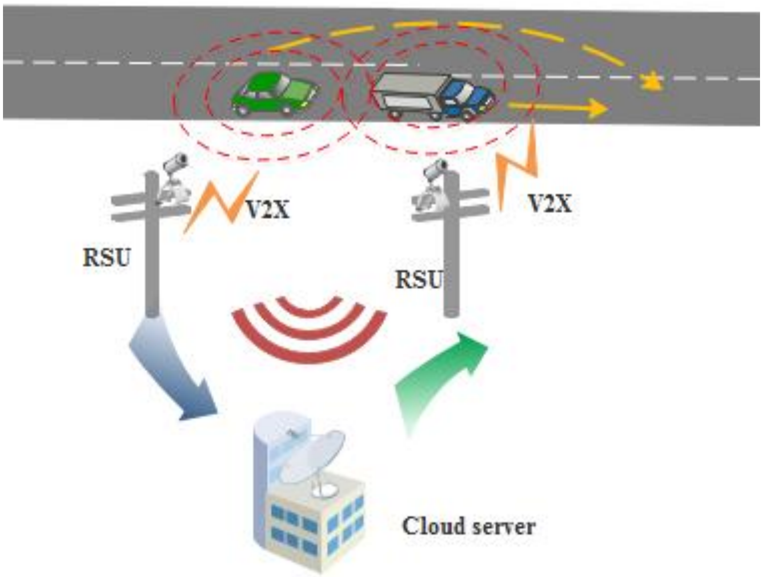

Figure 54 High-level illustration of the use case 1(Scenario 1)

Remote Manoeuver scenario (Scenario 2): In the China test site, the control center plays an important role to remotely control the autonomous subject vehicle (Vehicle A), autonomous test vehicle (Vehicle B) and Pedestrian C to complete the networking performance testes of connected vehicles. Figure 2 show these main actors in high-level illustration of remote maneuver. And the corresponding sequence diagram is illustrated in Figure 35. Here are the detailed steps: The control center first plans the scheme and then sends the global path information to Vehicle B through RSU. During the experiment, subject vehicle A communicates with RSU via V2I and with test vehicle B via V2V. After obtaining real-time information, local path planning will be carried out to complete the plan. After the test, Vehicle A notifies the control center and uploads various data to the cloud server.

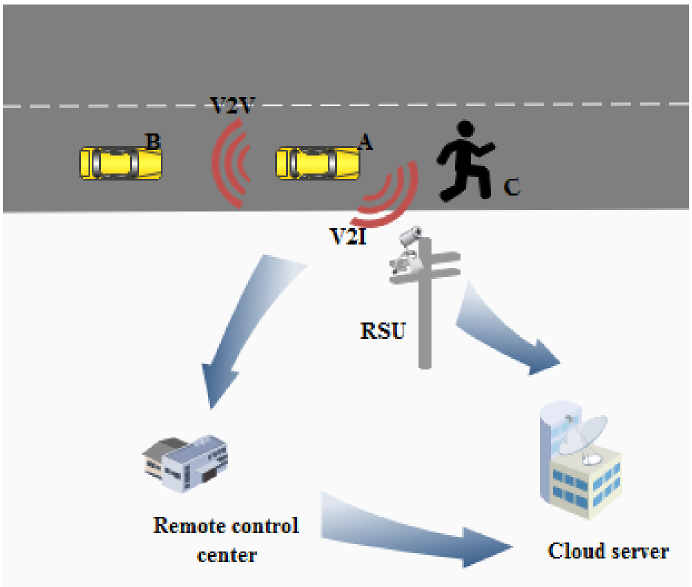

Figure 55 High-level illustration of remote maneuver

Table 50 Overview of Advanced driving with remote driving use case

Use Case Short Name	Advanced driving with remote driving
Use Case Category	Advanced Driving, Remote Driving
Use Case Leader	DUT(DALIAN)
Other partners	SDIA (SHANDONG), CNHTC, DDET ,QILUTIG
Objective	To achieve coordinated driving between autonomous vehicles
Actors	Vehicles A and B, RSU, ME
Pre-conditions	Vehicles A and B support message exchange via 3GPP V2X communication.
Use Case flow	<u>Scenario 1</u> Vehicle A receives the overtaking order or detects the obstacles 1. Vehicle A sends the overtaking or obstacle information to Vehicle B 2. Vehicle B sends back instant information, including vehicle position, speed, course angle, etc. 3. RSU receives the information, fuse them to send to a cloud server 4. Cloud server decides according to the information and carries out corresponding path planning. <u>Scenario 2</u>

	1. Control center monitors the status of the autonomous driving Vehicle A 2. Vehicle A sends various states through the RSU and cloud servers 3. Control center receives Vehicle A's information 4. Control center determines whether vehicle A continues to run automatically or the control center takes over it remotely 5. Control center operates Vehicle A remotely.
Postconditions	Vehicles A and B perform the coordinated maneuver.

Table 51:

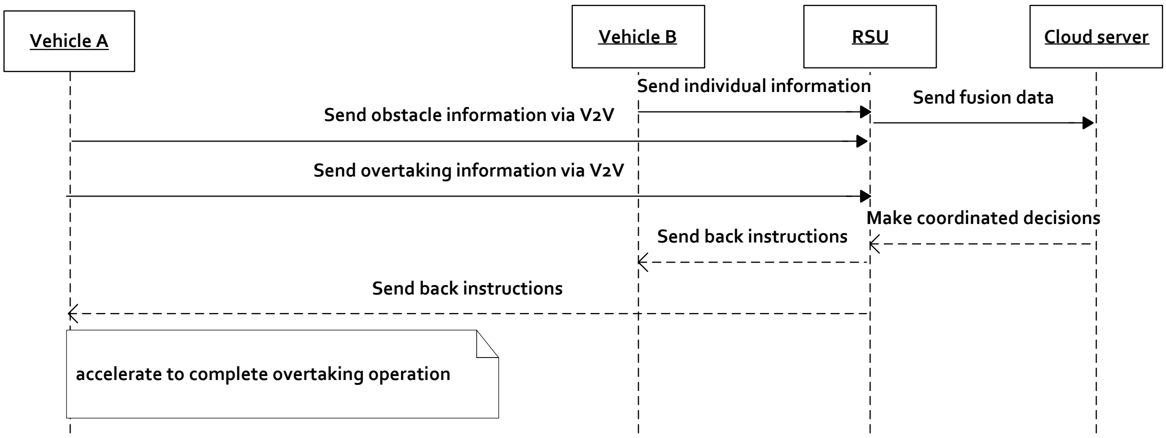

Figure 56 Sequence diagram of Advanced driving with remote driving use case (scenario 1)

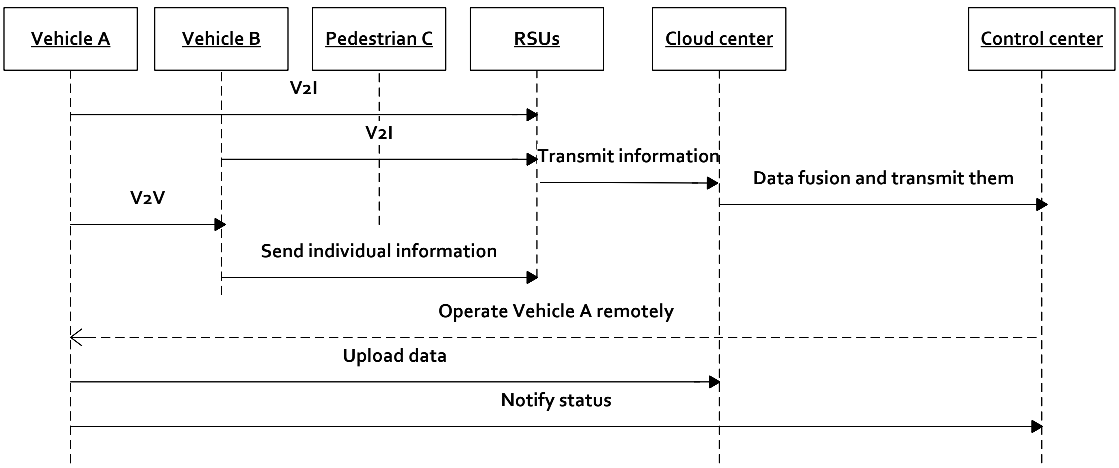

Figure 57 Sequence diagram of Advanced driving with remote driving use case (scenario 2)

3.9.3.3. Contribution to cross-border corridors

Collaborative vehicle driving can effectively reduce the complexity of road traffic control and management, reduce environmental pollution and ensure road traffic safety at the same time. The present use case is feasible to test in the 5G-MOBIX cross-border corridors (ES-PT), so it is tested at a local site first. Besides, our remote and cloud centre have very high performances, such as HD Map, path planning and real-time decision making, which may be the most different from other sites. We also have two MNO partners, so we will compare their devices in the same case and try to find which one is more suitable for ours.

3.9.3.4. *Beyond state of the art*

Our current L3 vehicles employed DSRC V2X solutions. The 5G-MOBIX technology deployed in this use case has long coverage range, ultra-low latency, and ultra-reliable reliability, and will enable L4 Autonomous Driving.

3.9.3.5. *5G services*

Table 52 Overview of 5G services to be implemented in the Advanced driving with remote driving use case

5G service	Implementation
eMBB	Yes. The remote center can receive HD videos and take control of the vehicles.
URLLC	Yes. The collected data should be delivered by ultra-low latency and high reliable communication in case of emergency.
mMTC	No.

3.9.4. Use Case 16: Road safety and traffic efficiency services

3.9.4.1. Motivation

The complexities of urban road traffic flow bring the strong randomness of pedestrian distribution, and the movement state of the pedestrian is more time-varying than that of cars. As one of the main road traffic participants, pedestrians are highly injurious, disabled or even fatal when a traffic accident occurs, so our road safety and traffic efficiency services will mainly care pedestrians.

In this case, we will upgrade the intersection safety information system, which consists of road radar, traffic signals, and LDM servers and RSUs. Based on them, our purpose is to detect pedestrians and avoid accidents.

At this stage, V2X road safety services are applied to traffic systems through roadside units (RSUs). RSUs generate and distribute traffic safety-related messages for road safety and deliver them to vehicles equipped with onboard units (OBUs). In this case, safety information at the intersection involves precise digital map, traffic signal information, pedestrian and vehicles' moving status information and location information, which is generally expressed in LDM (Local Dynamic Map) . The 3GPP system will support an average of 0.5 Mbps in downlink and 50 Mbps in uplink. An RSU will communicate with up to 200 UEs supporting a V2X application. Also RSU will support 50 packet transmissions per a second with an average message size 450 bytes.

3.9.4.2. Description

Travel through the intersection (Scenario 1): Figure 58 shows a high-level illustration of travel through the intersection. An autonomous Vehicle A passes through the intersection, and the control center remotely controls an autonomous test vehicle (Vehicle B) and a mobile pedestrian C. Vehicle A notifies the control center when it arrives at the intersection. Vehicle B and Pedestrian C also reach the adjacent intersection. As shown in the Figure, Vehicle A aims to turn right at the intersection. Vehicle B and A go straight through the intersection, at the same time Pedestrian C crosses the road. During the test, Vehicle A notifies the RSU and obtains the information of traffic lights and Pedestrian C through LDM, and obtains the information of Vehicle B through V2V communication. In this way, Vehicle A can avoid collision with Vehicle B and Pedestrian C. The case can test the performance of the vehicle network in vehicle-road cooperation and vehicle-vehicle communication. The related sequence diagram is shown in Figure 3.

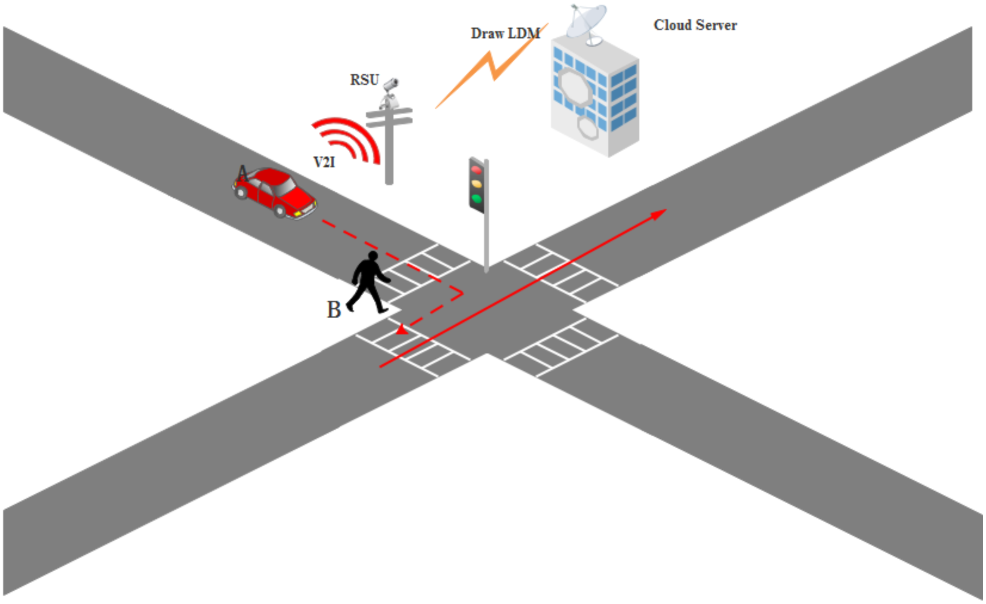

Figure 58 High-level illustration of the Road safety and traffic efficiency use case (Scenario 1)

Vehicle Platooning (Scenario 2): Figure 59 illustrates that autonomous driving vehicle fleet communicates with each other through LTE-V at the start. Among them, the leading vehicle (Vehicle A) includes the platoon control unit (PCU), which coordinates the vehicles in the fleet to ensure a certain safe distance and to drive in a platoon. The leading vehicle communicates with the control center through V2I to obtain the test scheme and the global path planning. Then it provides the basic planning for the rear vehicle through V2V communication (including chasing, continuous running, acceleration, deceleration, obstacle avoidance, overall acceleration, and deceleration, etc.). The following vehicle also has a certain perception and planning decision-making ability. Besides, LTE-V communication can be replaced by DSRC technology, and comparison between these two methods will be implemented. The steps of this scenario are shown in Figure 4.

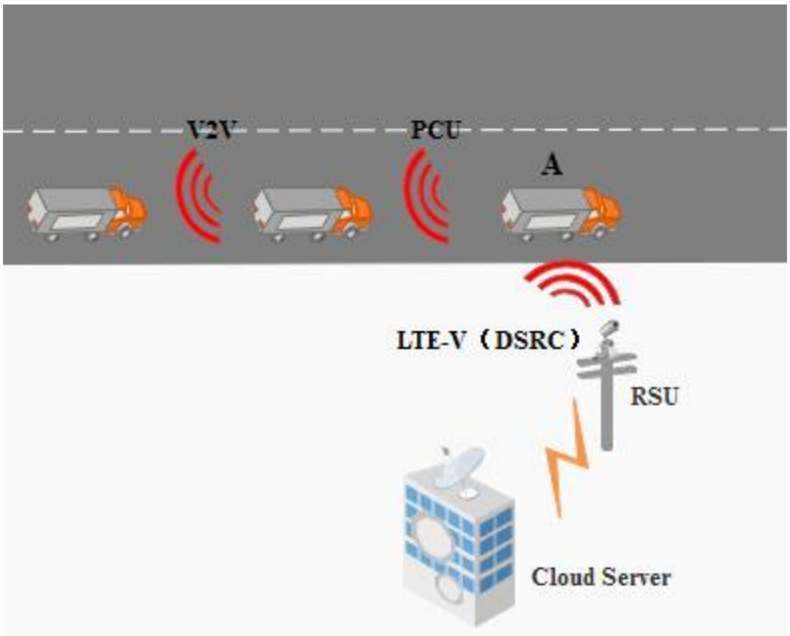

Figure 59 High-level illustration of the Road safety and traffic efficiency use case (Scenario 2)

Table 53 Overview of Road safety and traffic efficiency use case

Use Case Short Name	Road safety and traffic efficiency
Use Case Category	Extended Sensors, Vehicles Platooning
Use Case Leader	DUT(DALIAN)
Other partners	SDIA(SHANDONG),CNHTC,DDET ,QILUTIG
Objective	Vehicle A detects Pedestrian B and avoids it.
Actors	Vehicle A, Pedestrian B, RSU, LDM server
Pre-conditions	• The road radar or cameras are installed at the intersection, and they will detect the movement of the vehicle and the pedestrians • The RSU will receive the location and movement information on the vehicle and pedestrian and traffic signal information, generate LDM information
Use Case flow	Scenario 1 1. RSU detects that Vehicle A, Vehicle B, and Pedestrian C 2. RSU draws LDM and generates traffic safety-related messages to the cloud server 3. Cloud server operates MEC and makes decisions for vehicles 4. Vehicle A and B replan their paths to avoid Pedestrian C

	Scenario 2 1. Vehicle A communicate with others through LET-V(DSRC) 2. Vehicle A sends messages to RSU 3. RSU delivered data to cloud center 4. Center makes a decision back to RSU, and then it delivers them back to Vehicle A. 5. Vehicle A translates messages to its following vehicles via V2V.
Post conditions	• UE will generate vehicle control information for the autonomous vehicle • The autonomous vehicle will avoid the collision by vehicles or pedestrians

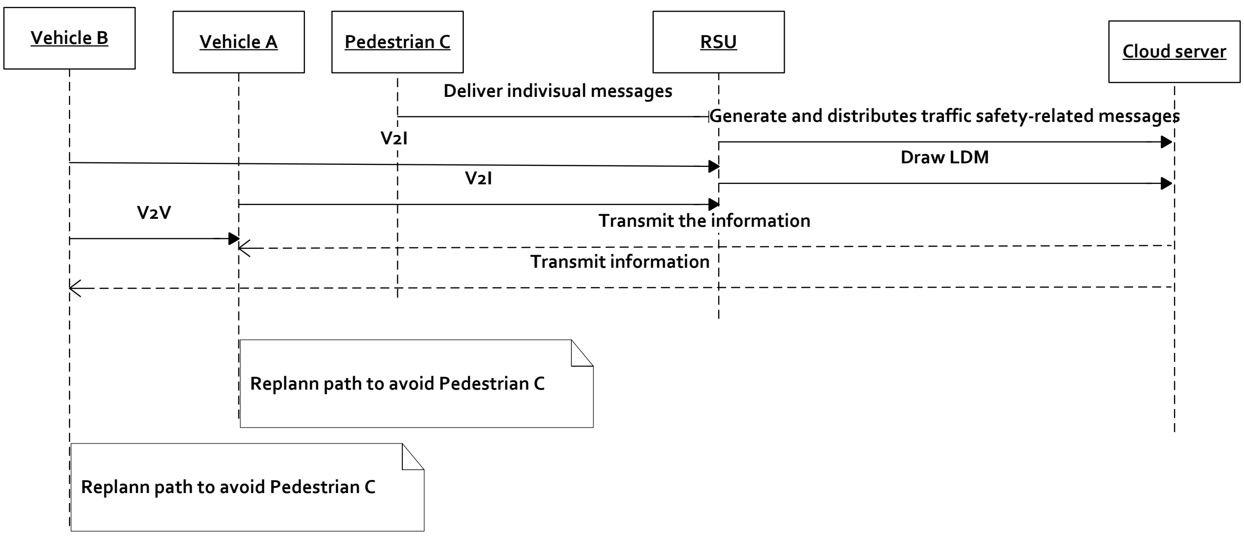

Figure 60 Sequence diagram of use case 2(Scenario 1)

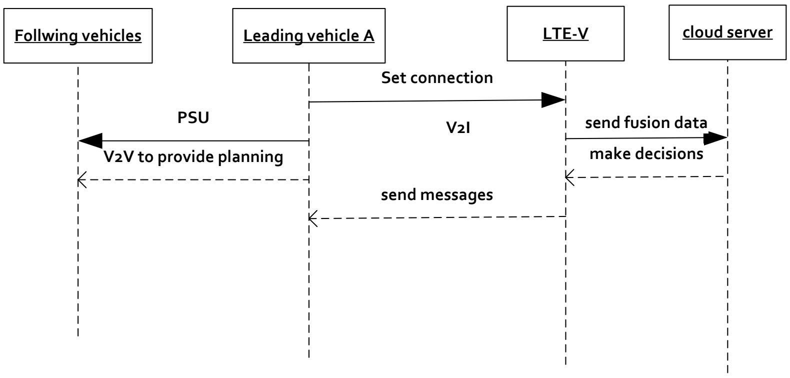

Figure 61 Sequence diagram of use case 2 (Scenario 2)

3.9.4.3. Contribution to cross-border corridors

The present use case can serve as a pre-test in China test site. The present use case is feasible to test at our local site. The present use case hopes to avoid the potential risks of human-vehicle conflicts which are common situations in cross-border corridors. Our cloud centre has very high performances, such as HD Map, path planning and real-time decision making, which may be the most difference from other sites. We also have two MNO partners, so we will compare their devices in the same case and try to find which one is more suitable for ours.

3.9.4.4. Beyond state of the art

The previous warning method of avoiding accidents is mainly based on vehicle technology, such as image sensor, radar to check the location information of pedestrians, to avoid human-vehicle collisions. The 5G V2X deployed in our use case considers the urban traffic environment where always exist pedestrians beyond the scope of sensor detection, and thus it is possible to avoid the potential risks of human -vehicle conflict.

3.9.4.5. 5G services

Table 54 Overview of 5G services to be implemented in the Road safety and traffic efficiency use case

5G service	Implementation
eMBB	Yes. Our remote center needs to monitor the whole process by HD videos collected from on board cameras.
URLLC	Yes. The data must be delivered by ultra-low latency and high reliable communication in case of emergency
mMTC	Yes. Much equipment is deployed in this use case, which means the data size is really large.

3.10. Korean (KR) Trial Site

3.10.1. Location

Table 55 Korean location overview

Trial site class	Pre-deployment
Country/Countries	Korea
City/Cities	Yeonggwang

An urban-type-proving ground located in Yeonggwang, Korea, will be provided by KATECH and will be constructed by end of 2019. It consists of various type of test roads such intersection, pebble road, test hills, circle road with real time monitoring system based on V2X network such as mmWave-band 5G NR, Wi-Fi, WAVE, NFV and etc. The proving ground is designed to test various functions for connected and automated vehicle such as blocking GPS signal, providing moving hotspot (or tethering), traffic light control, and collision avoidance at the cross-section areas. The 5G infrastructures within this trial site are facilitated by another national project (years 2018 – 2022). The national project includes mobile network provider (KMW, Korea Micro Wave), Korean operator (SKT) which will cooperate with 5G-MOBIX Korean partners internally. The Younggwang proving ground will be targeted to be become local testbed to pilot and to validate the not only Korean use cases, but also to be open proving ground used in all the national and international project.

Figure 62 The Korea pre-deployment urban type trial site.

3.10.2. Local Consortium

Table 56 Korean consortium

Role	Partner	Contribution
Full Partner	KATECH	- Trial site coordinator - Providing trial site and trial execution. - Remote driving (5.4 eV2X support for remote driving)
Full Partner	ETRI	- 5G NR, OBU provider - Broadband in-vehicle hotspot (5.18 Tethering via Vehicle)
Full Partner	SnetICT	- 5G OBU and core network provider
Associated Partner	Renault	- Vehicle provider (OEM)

3.10.3. Use Case 17: Tethering via Vehicle

3.10.3.1. Motivation

Due to the provision of highly developed networks corresponding to ever-increasing demands of getting connection to the Internet even in vehicles, people can enjoy variety of Internet services on the move. In-vehicle users may connect to the Internet with a help of appropriate mobility supporting networks such as existing 3G and 4G networks. Furthermore, the in-vehicle network access through a relay node that is deployed in the vehicle can provide some technical advantages that direct connections between UEs and base stations do not have (see below for the details). Since the relay node in the vehicle can provide tethering to passengers or nearby pedestrians owning Wi-Fi devices, they are able to experience bigger and safer data pipelines with the network's evolution towards 5G. Improved connectivity can be used for a better entertainment experience, such as high-definition 360 live streaming and virtual reality online gaming services. However, we cannot imagine this advanced experience without a high level of autonomous driving because drivers are easily distracted by immersive services. Therefore, high-level autonomous driving will promote the entertainment services in connected vehicles, and vice versa.

Technically, providing hundreds of Mbps data rate for every data hungry passengers in expressway buses is a specific goal. Considering, for example, 10 active users per bus and 10 buses per cell, those amount to total 10 Gbps of cell throughput. Therefore, this service will be a good practice of 5G eMBB (Enhanced Mobile Broadband) scenarios requesting very high data rates and low latencies. Since that service also needs mobility support over bus speed of around 100 km/h, methods for high spectral efficiency such as 256QAM or spatial multiplexing are largely limited. Therefore, to achieve the very high throughput, handling of very wide spectrum, i.e., mmWave, is inevitable.

The challenging aspects are as follows:

- Management of wide mmWave spectrum bandwidth reaching 1 GHz
- Robust mobility supporting algorithms with very low interruption time down to 2 ms
- Multiple beam management securing high reliability and availability for end users

3.10.3.2. Description

Tethering via Vehicle use case enables in-vehicle UEs and pedestrian UEs to access the network with the help of a vehicle relay which is deployed at a vehicle. For in-vehicle UEs, through Tethering via Vehicle use case, it is possible to avoid high penetration loss occurring from the metallic vehicle surface, thereby achieving more reliable wireless connectivity as well as reduced UE power consumption. The in-vehicle UEs are also benefited from the minimized handover operations. Only the vehicle relays involve in the handover operations. For pedestrian UEs, Tethering via Vehicle use case enables more reliable connectivity, increased throughput and reduced UE power consumption since it reduces the communication range of the pedestrian UEs.

As a deployment scenario for Tethering via Vehicle use case, a vehicle relay can have the Internet connectivity to the network through a base station (BS) including macrocell BS, microcell BS, and BS-type road side unit (RSU). Another UE such as UE-type RSU can also provide the Internet connectivity to the network. Non-terrestrial links such as satellite BS, satellite relay, and high-altitude platform (HAP) can also be used to provide the Internet connectivity to the network.

Tethering via Vehicle use case generally supports eMBB-type services such as web surfing, FTP, and video streaming. Hence, it intrinsically requires high data throughput up to several Gbps. In order to satisfy such very high throughput, large bandwidth is necessary which is quite difficult in lower frequency bands below 6 GHz. Therefore, mmWave frequency band should be employed to support such high throughput and to satisfy the Tethering via Vehicle use case.

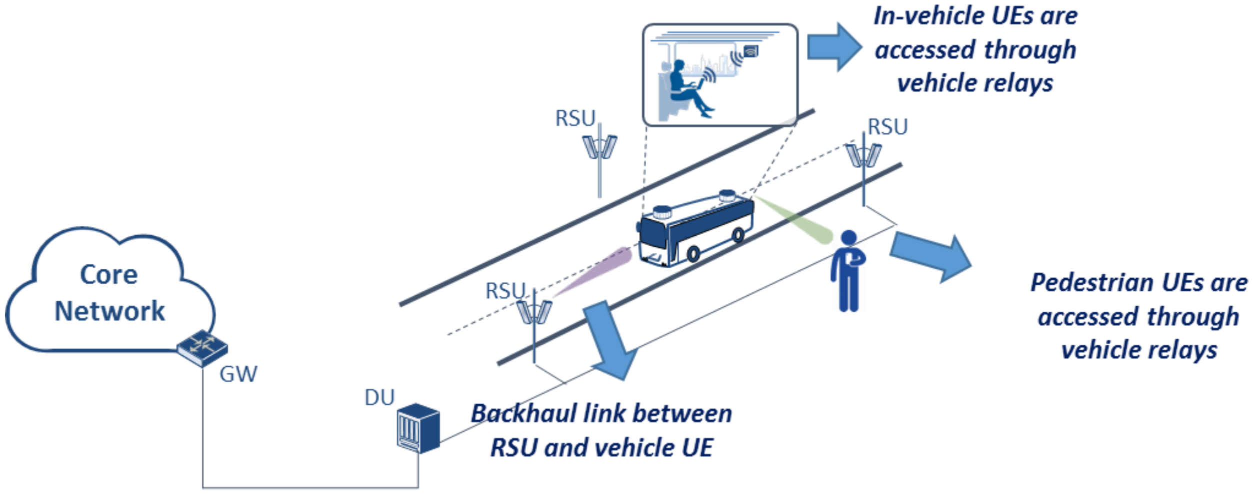

Figure 63 example of the Tethering via Vehicle use case from the KR local test bed.

Table 57 Overview of Tethering via vehicle use case

Use Case Short Name	Tethering via Vehicle
Use Case Category	Vehicle Quality of Service Support
Use Case Leader	ETRI
Other partners	KATECH, SNetICT
Objective	Providing reliable and high-throughput Internet access to in-vehicle UEs and pedestrian UEs

Actors	Vehicle A, Occupant A, Network
Pre-conditions	• Vehicle A is V2X capable and is equipped with E-UTRAN access capability. • Occupant A has a mobile device that is V2X capable.
Use Case flow	1. When Occupant A is riding in Vehicle A, their handset obtains access to the network via Vehicle A. 2. Vehicle A relays the communication between Occupant A and the Network using its own network access 3. When Occupant A parks Vehicle A to go for a quick shop nearby the communication between Occupant A and the Network continues via Vehicle A, as long as passenger A is in range of V2P communication.
Post conditions	Occupant A's handset saved battery power and potentially obtained higher throughput due to gaining network access via Vehicle A's network connectivity.

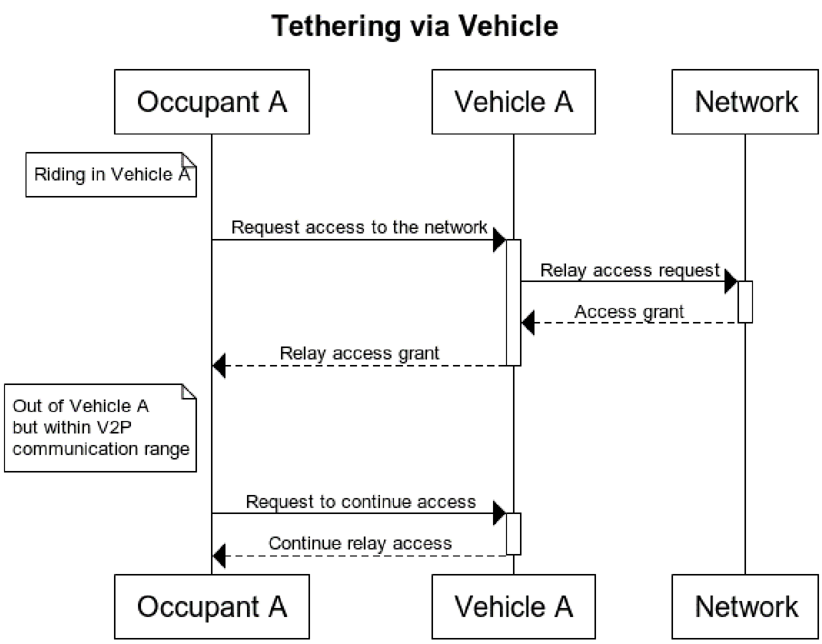

Figure 64 Tethering via vehicle sequence diagram

3.10.3.3. *Contribution to cross-border corridors*

- The use case is similar to use cases in the ES-PT cross-border corridor (real time 4K video streaming and services for users), so it serves as a pre-test.
- The use case is not convenient to test in the 5G-MOBIX cross-border corridors since it is planned to be tested using a prototype system operating at the local unlicensed band called FACS (Flexible Access Common Spectrum in Korea, 22~23.6GHz) allocated by the Korean government. For this reason, it will be tested at a local site.
- The present use case completes the set of use cases tested in cross-border corridors with
    - a use case that targets broadband in-vehicle hotspot allowing onbroad passengers to connect the Internet for free, which is a common situation in cross-border corridors and is not covered in the cross-border use cases.
    - A prototype system of mmWave-band 3GPP 5G NR V2I communications that introduce key enabling technologies capable of overcoming various technical challenges caused by using mmWave and supporting high mobility.
    - The use case will be tested at South Korea test site, which offers urban type proving ground located in Yeonggwang area (300m x 300m.

3.10.3.4. *Beyond state of the art*

Recently, with the proliferation of mobile devices and the emergence of a wide range of broadband applications (e.g., video on demand, virtual reality (VR), augmented reality (AR)), traffic demand for users on the move has been growing rapidly. However, the existing cellular systems including Long Term Evolution (LTE)/LTE-Advanced (LTE-A) are unable to offer wireless connectivity to vehicles that enables such services since these systems were primarily designed for low-mobility environments. For this reason, 5G-MOBIX will contribute to developing a mmWave-band 3GPP 5G NR V2I system with the following key enabling technologies to solve the technical challenges encountered in mmWave-band vehicular communications.

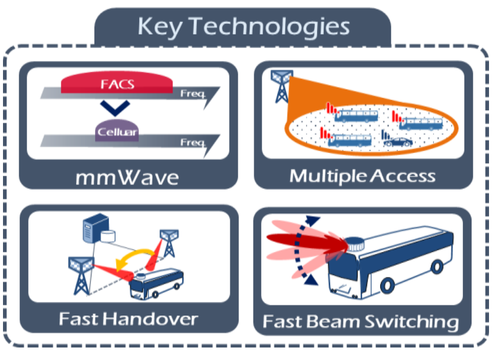

Figure 65 Key Technologies of Tethering via vehicle use case

- mmWave-based vehicular communications: by taking advantage of a vast amount of spectrum underutilized, mmWave enables high data rate transmission
- Multiple access: a technology that allows multiple vehicles in a cell covered by a BS to simultaneously receive MWB links for broadband Wi-Fi services. In addition, by effectively scheduling radio resources to vehicles in the coverage, multiple access technique is able to offer increased system throughput.
- Fast handover: a key technology to provide seamless handover to minimize the communication interruption time when a vehicle crosses cell edge.
- Fast beam switching: a technology to combat unexpected signal blockage and increase received signal quality.

3.10.3.5. 5G services

Table 58 Overview of 5G services to be implemented in the Tethering via Vehicle use case

5G service	Implementation
eMBB	Yes. To provide moving vehicles with a broadband mmWave-band V2I link that allows onboard passengers to experience high-quality connectivity to the Internet
URLLC	No
mMTC	No
Other	No

3.10.4. Use Case 18: Remote Driving

3.10.4.1. Motivation

While automated driving vehicle needs a lot of sensors and algorithms such as obstacle detection and avoidance, remote driving can with human operator should be realized using less of them. A main objective of the remote driving is to control or to driving automated vehicle remotely when the automated vehicle is mal-functioned or driver in the vehicle is in accident such as heart attack. Since the remote driving vehicle is able to share the real time live video stream not only around the vehicle but also inside the vehicle, driver or passengers in the remote-controlled vehicle should be safer during the driving to their final destination.

Technically, remote driving has to be provided multiple up-link video streaming with ultra-low latency and down-link control signal with low latency at the same time. Therefore, 5G key technologies such as eMBB (Enhanced Mobile Broadband), URLLC (Ultra-Reliable Low Latency Communication) should be developed and be validated to realizes this use case.

The challenging aspects are as follows:

- 1Mbps downlink data rate and 200Mbps uplink data rate
- 4k video stream is up to 100 Mbps
- Four live video streams (front, rear, left and right sides) are delivered to a remote driver
- User-plane latency is up to 4 ms

3.10.4.2. Description

Remote driving use case enables remote operator to access the right of control in case of automated vehicle in under malfunction or driver is in accident. The most important factors for realizing remote driving should comprise the following: Ensuring enough field of view and high definition of view for front camera, ultra-low latency to sharing live video stream between vehicle equipped cameras and remote site, and reliable connectivity to control remote driving vehicle in remote site. Consequently, remote driving vehicle needs to be shared not only driving information like speed, position, and videos (front, right and left side, and rear), but also vehicle status information like steering angle, gear position, throttle pedal position, and fuel consumption with remote operator. The driving and status information provided by the remote driving vehicle should be transmitted to the human operator at the remote site with ultra-low latency. In order to sharing high definition live video stream data with remote site in real-time, very high up-link data rate should be required and it will be realised by 5G network. At the same time, the control data to driving remote vehicle should be generated by human operator at the remote site and be streamed to the remote driving vehicle through down-link with low latency.

An emergency stop function of the remote driving vehicle should be enabled automatically when the connectivity is unstable between remote driving vehicle and remote site, thereby achieving more reliable and robust safety.

As a deployment scenario for remote driving use case, remote driving vehicle has a connectivity to the 5G network through a base station (BS) including microcell BS, and BS-type road side unit (RSU). In-vehicle UE that is equipped in the remote driving vehicle will provide the connectivity to the 5G network by connected with RSU.

The remote driving use case generally supports eMBB 5G-service to stream raw sensor and high definition video data from remote driving vehicle to remote site. Hence, it intrinsically requires high data throughput up to several Gbps. It also supports URLLC 5G-service to exchange safety critical message.

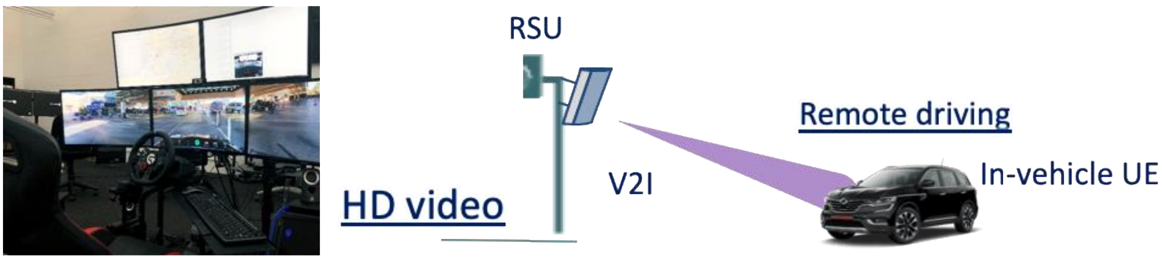

Figure 66 Remote driving use case from the Korea local test site

Table 59 Overview of use case for remote driving

Use Case Short Name	Remote driving
Use Case Category	Remote Driving
Use Case Leader	KATECH
Other partners	Renault Samsung Motors (RSM), ETRI, SNetICT
Objective	Providing reliable and safe control of the remote driving by high-throughput data sharing between remote driving vehicle and remote site operator
Actors	Remote Driving Vehicle (RDV), Driver, Remote Operator
Pre-conditions	Vehicle is parked or stopped on the road with stable 5G-connectivity to remote site

Use Case flow	1. The driver in the remote driving vehicle (RDV) requests a remote operation to the remote operator. 2. The remote operator checks the status of the RDV (speed, video, state of fuel, automated vehicle controller, and so on) and decide to activate remote driving function from the remote site. 3. The remote operator starts to control or to drive the RDV with limited speed. 4. The remote operator drives the RDV to a safe area. 5. When the RDV is parked, the remote operator checks status of the RDV.
Post conditions	The RDV is parked in a safe area.

3.10.4.3. *Contribution to cross-border corridors*

- The use case is similar to use cases in the ES-PT cross-border corridor, so it serves as a pre-test.
- Especially, the Korea trial site should be focused on the RDV system based on real-time high definition multi-video live streams (1 front, left and right side, and rear) to ensure the safety of the RDV.
- The use case is hard to test in real road situation because of possibility of the car accident or occurring traffic congestion during the test, therefore it is tested at a local site
- Test results and scenario will be shared with cross-border so that it will help to minimize trial and error of the ES-PT cross-border corridor.
- The present use case completes the set of use cases tested in cross-border corridors with
    - A prototype system of mmWave-band 3GPP 5G NR V2I communications that introduce key enabling technologies capable of overcoming various technical challenges caused by using mmWave and supporting high mobility.
    - The use case will be tested at South Korea test site, which offers urban type proving ground located in Yeonggwang area (300m x 300m).

3.10.4.4. *Beyond state of the art*

RDV should be realised by supporting 2 key technologies; real-time high definition live video stream and ultra-low latency. However, the existing cellular systems represented by Long Term Evolution (LTE)/LTE-Advanced (LTE-A) and dedicated private V2X communication systems are not able to offer wireless connectivity to RDV that enables such services since these systems were primarily designed for low-mobility environments. Therefore, in 5G-MOBIX, Korean trial site will contribute to developing a mmWave-band 3GPP 5G NR V2I system focusing on eMBB and URLLC technologies to solve the technical challenges encountered in mmWave-band vehicular communications.

3.10.4.5. 5G services

Table 60 Overview of 5G services to be implemented in the use case

5G service	Implementation
eMBB	Yes. To provide moving vehicles with a broadband mmWave-band V2I link that allows RDV to share raw sensor data and high definition video steam with remote site
URLLC	Yes. Mission critical data exchange with low latency up and down link access between RDV and remote site.
mMTC	No

4. 5G-MOBIX USE CASES OVERVIEW

This section presents an overview of the use cases including different maps and graphs to underline the complementarity and the representation of the 5G-MOBIX use cases.

The different use cases have been classified to check the contribution from several use cases to common categories. The following table shows the first iteration of this classification. It can be noticed that some use cases fall into two categories, as they have elements of both categories. The use cases planned at cross-border corridors cover all categories. The use cases planned at local trial sites contribute mostly to the first four categories, as it is believed that they are the main enablers of CCAM .

Table 61 5G-MOBIX Use Case classification (first iteration)

Trial site	Advanced Driving	Vehicles Platooning	Extended Sensors	Remote Driving	Vehicle QoS Support
ES-PT	UC1 (Interurban complex scenarios) UC3 (Last Mile Automated Shuttle)			UC3 (Last Mile Automated Shuttle)	UC2 (Interurban public transport)
GR-TK		UC4 (Truck platooning with "see what I see")	UC4 (Truck platooning with "see what I see") UC5 (Assisted border crossing)		
DE		UC7 (Platooning)	UC6 (Cooperative perception)		
FI			UC8 (Cooperative perception)	UC9 (Remote driving)	
FR	UC10 (Automated Overtaking)			UC11 (Remote driving)	
NL	UC12 (Cooperative Collision Avoidance)		UC14 (Collective perception)	UC13 (Remote driving)	
CN	UC15 (Advanced driving with remote driving)	UC16 (Road safety and traffic efficiency)	UC16 (Road safety and traffic efficiency)	UC15 (Advanced driving with remote driving)	
KR				UC18 (Remote driving)	UC17 (Tethering via Vehicle)

In the Figure 67 we have refined the classification, and we have assigned a single category to each use case based on the main focus of the use case. The figure depicts the different use cases around the 5 selected categories. Here, the Remote Driving, Advanced Driving and Extended Sensors categories host most of use cases, but 5G-MOBIX use case ecosystem represents each of the identified categories. In this graph the outer bold italic use cases are promoted by cross border trial sites. The dark grey use cases come from European trial sites and the light grey from China and Korea.

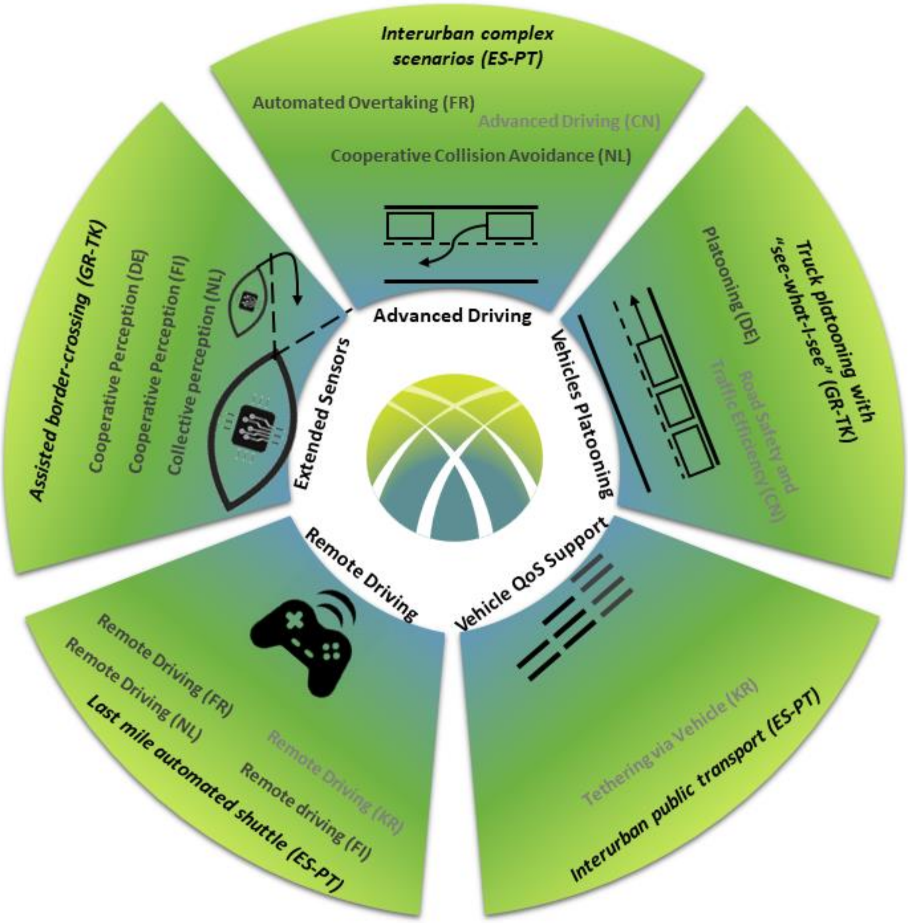

Figure 67 Set of Use Cases in 5G-MOBIX around 3GPPP Categories for Release 16.

The set of use case categories are presented in summary below:

1. Advanced Driving enables semi-automated or fully-automated driving for coordinating vehicle trajectory or maneuvers based on data sensors shared from surrounding RSU or vehicles.
2. Vehicles Platooning enables several vehicles to dynamically form a group travelling together allowing a short distance between the members.

3. Extended Sensors enables the live exchange of raw or processed data gathered through local sensors among vehicles, RSUs and servers for an enhanced perception beyond onboard sensors.

4. Vehicle Quality of Service Support enables smooth user experience of application with timely notifications of expected or estimated change of quality of service before actual change occur.

5. Remote Driving enables a driver or application to operate a vehicle remotely.

All the considered use cases will be deployed, tested and validated in specific trial sites. Thus, the use cases geographically distributed over the European trial sites are depicted in the Figure 68. Here, the variety of use cases in each trial site is evident, identifying different use cases with different categories to be demonstrated.

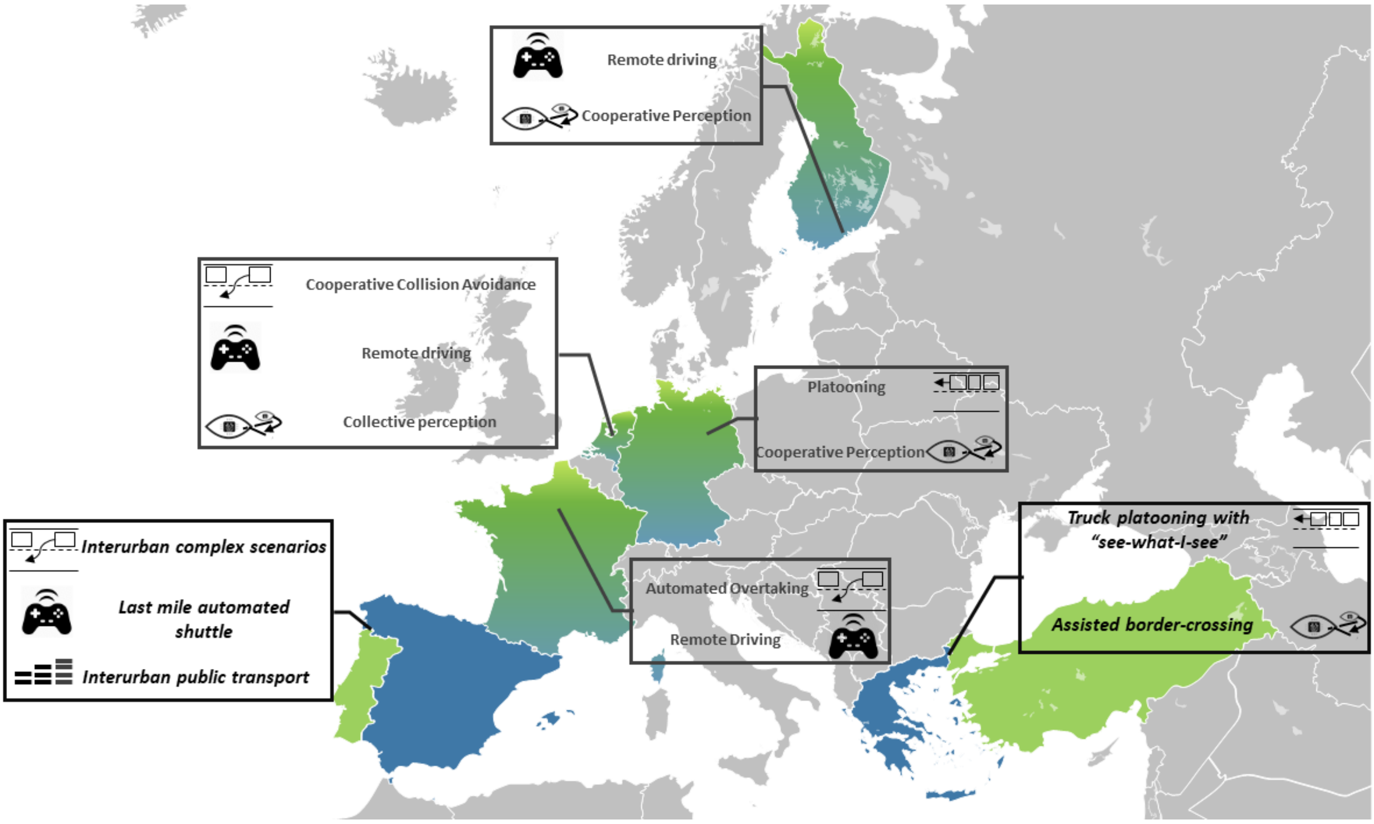

Figure 68 Set of Use Cases in 5G-MOBIX mapped to European trial sites

The same concept is depicted in the following figure for the Asian trial sites. Even if there are only two trial sites, the diversity of use case categories is clear.

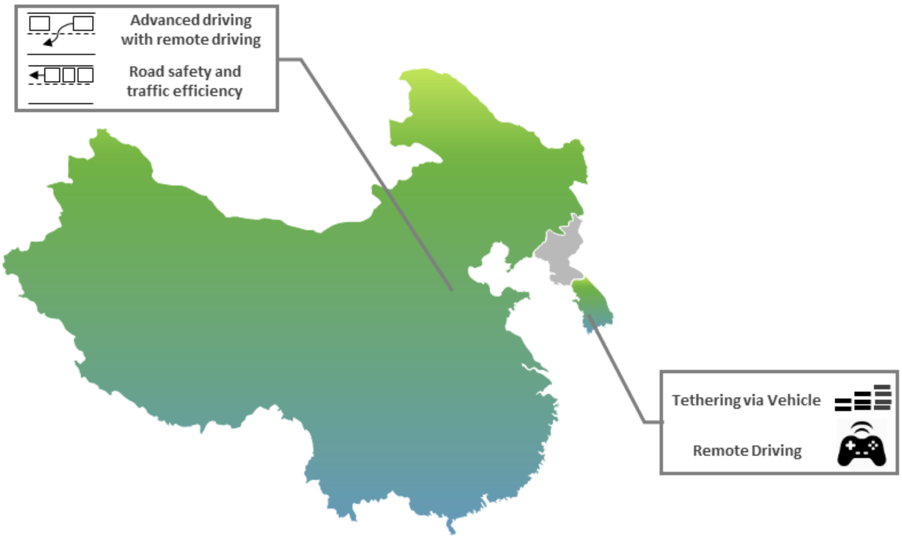

Figure 69 Set of Use Cases in 5G-MOBIX mapped to Asian trial sites

In order to underline the synergies of use cases contributed to 5G-MOBIX cross border sites the Figure 70 depicts target Autonomous Driving situations, functions or techniques and 5G technical components exercised that would add value or complement the test and validation of use cases done in each cross-border site. The contribution of each use case in a trial site to a use case in a cross-border site can be related to specific 5G feature or component, or an Autonomous Driving function which can be applied to the cross-border use case adding a beneficial technique or technology.

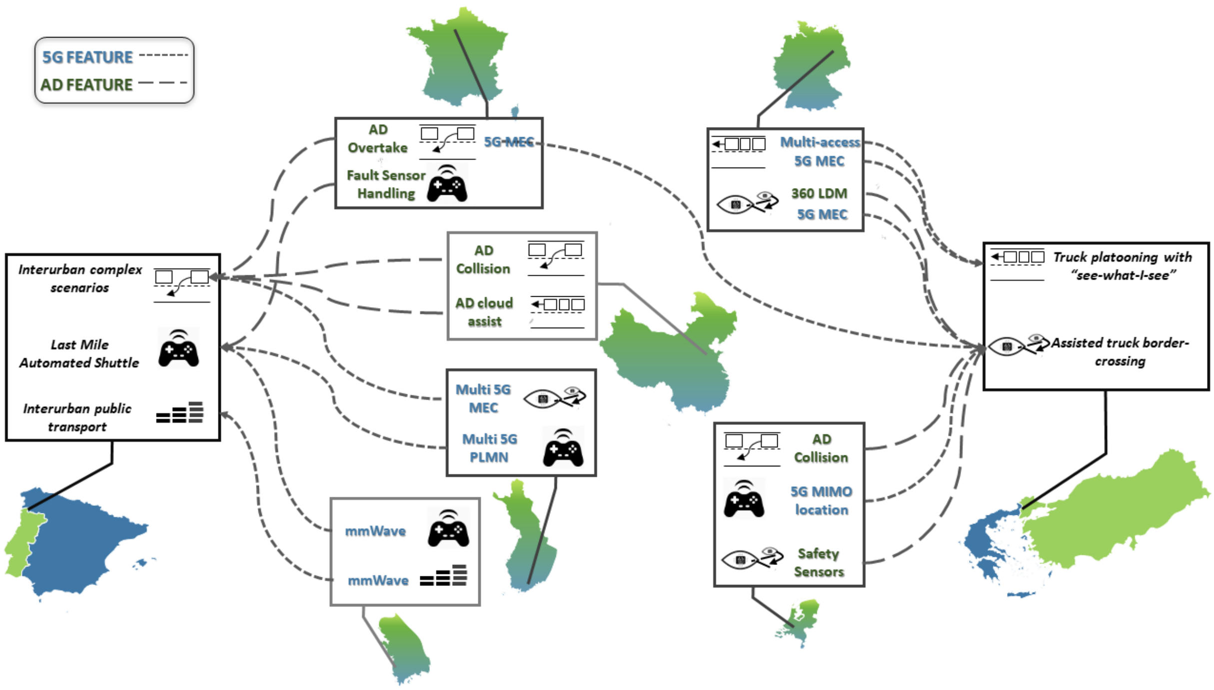

Figure 70 Complementarity of Use Cases in 5G-MOBIX mapped to cross border trial sites

An important aspect that can be concluded from the Figure 70 is that features designed for a category is also applicable in a cross-border use case from another category. This is visually depicted in the Figure 71. Here we can see how some use cases in a category extends their coverage to cross border use cases of another category.

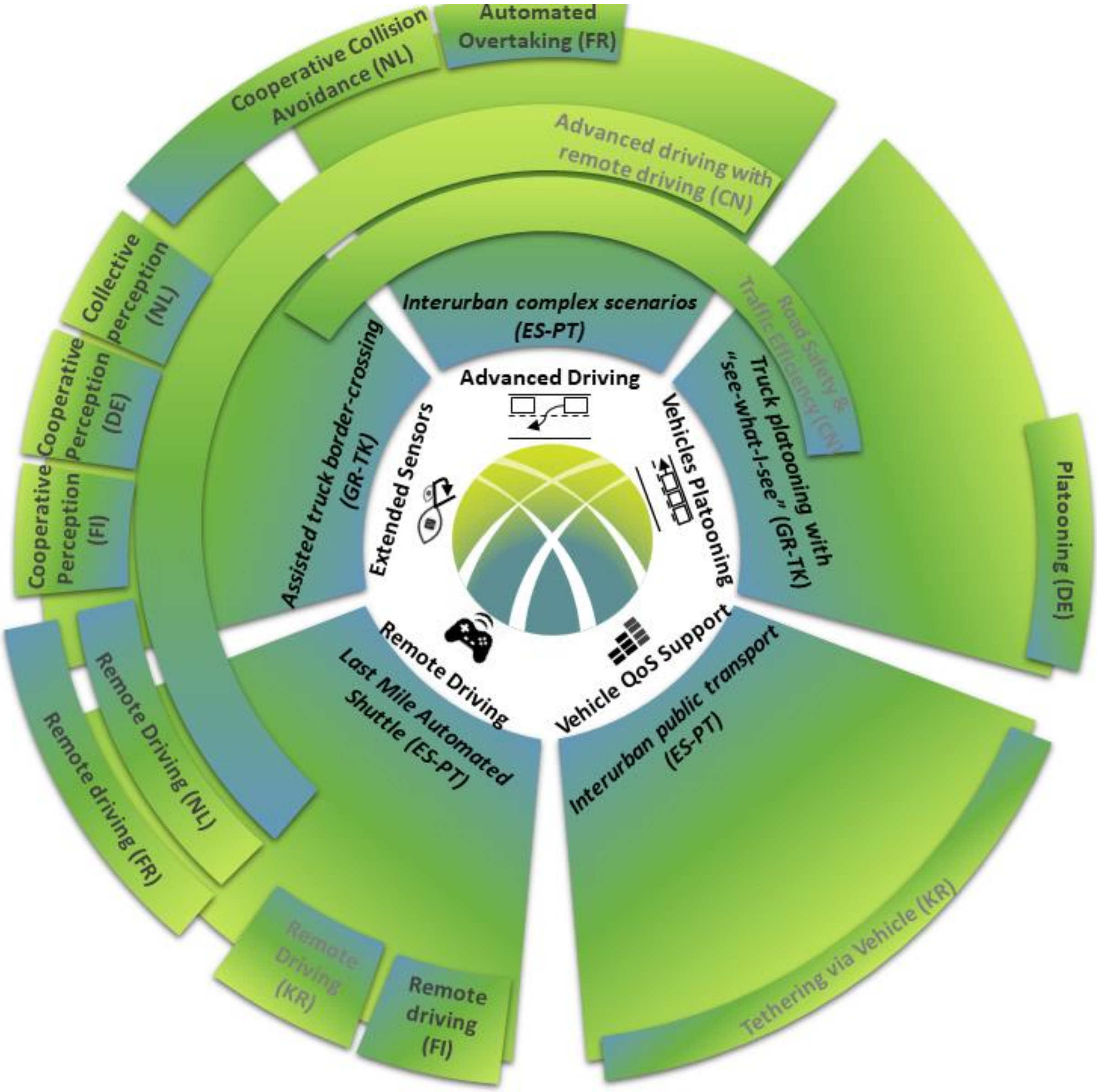

Figure 71 Set of Use Cases in 5G-MOBIX with features applicable in other 3GPPP Categories for Release 16

5. CONCLUSIONS

Europe set ambitious objectives for 5G deployment in the 5G Action Plan from 2016 as well as for pan-European 5G Corridors for Connected and Automated Mobility (CAM) in the 3rd Mobility Package from 2018. This year, on February 7, the European Commission held a workshop with all stakeholders interested in the deployment of 5G networks along roads to kick off the definition of a European 5G Strategic Deployment Agenda (SDA) for Connected and Automated Mobility. 5G-MOBIX is fuelled by all these initiatives and committed to deploy and test use cases that will contribute to the success of these initiatives.

This document presents the resulting 5G-MOBIX use cases after a throughout review of the use cases included in the proposal. The use cases were rearranged and refined to be completely aligned with European Commission's vision of 5G cross-border corridors. The Spain-Portugal corridor connecting Vigo and Porto, and the Greece-Turkey corridor located in the South-Eastern borders of Europe are the two flagship cross-border corridors of 5G-MOBIX. In addition, there are six trial sites located inland in France, Germany, Netherlands, Finland, China and South Korea.

The use cases planned at the local sites contribute to the 5G cross-border corridor roadmap in diverse aspects and all of them complement the set of use cases to be deployed in 5G-MOBIX cross-border corridors. In some cases, they target a common situation in cross-border corridors that is not fully covered in the 5G-MOBIX cross-border use cases. In other cases, they plan a different implementation of a cross-border use case which is also interesting to test from the business or technological point of view. Sometimes, the implementation of a use case variant is simply not feasible in a real cross-border corridor and needs to be implemented in a more controlled environment present at a local site. And in general, testing different implementations of the same use case category (e.g. remote driving) in different driving environments is very valuable. One of the biggest challenges of Autonomous Driving is clearly the validation of the system as it requires to cover a vast amount of driving situations. "Collecting" kilometres and edges cases is key for the success of CCAM and 5G-MOBIX is also aligned with this.

It is also important to highlight the participation of two non-European countries, China and South Korea, that enrich the consortium and further enhance the alignment of views on 5G. Options for jointly drafting white papers and positions about cross-border corridor use cases resulting from 5G-MOBIX are envisaged.

To sum up, this document describes the planned 5G-MOBIX use cases which are classified into five categories (Advanced Driving, Vehicles Platooning, Extended Sensors, Remote Driving and Vehicle QoS Support) and distributed among eight trial sites. All of them are designed to be meaningful in a cross-border corridor context and aim to contribute to Europe's ambition to lead in large-scale testing and early deployment of 5G infrastructure, enabling connected and automated mobility.