5GMOBIX

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

D2.4

Specification of Connected and Automated Vehicles

Dissemination level	Public (PU)
Work package	WP2: Specifications
Deliverable number	D2.4
Version	V1.0
Submission date	31/10/2019
Due date	31/10/2019

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

www.5g-mobix.com

Editors

Editors in alphabetical order		
Name	Organisation	Email
Soua, Ahmed	VEDECOM	ahmed.soua@vededom.fr

Authors

Authors in alphabetical order		
Name	Organisation	Email
ES-PT		
Cabeza, Marcos	CTAG	marcos.cabeza@ctag.com
Cota, Nuno	ISEL	ncota@deetc.isel.pt
Cruz, Nuno	ISEL	ncruz@deetc.isel.ipl.pt
Dafonte, Pablo	CTAG	pablo.dafonte@ctag.com
Datia, Nuno	ISEL	datia@deetc.isel.ipl.pt
Jáuregui, Daniel	CTAG	daniel.jauregui@ctag.com
Martiñán, Daniel	CTAG	daniel.martinan@ctag.com
Mendes, Carlos	ISEL	cmendes@deetc.isel.ipl.pt
Romasanta, Adrian	CTAG	adrian.romasanta@ctag.com
Rosales, Carlos	CTAG	carlos.rosales@ctag.com
Serrador, António	ISEL	aserrador@deetc.isel.ipl.pt
Teixeira, Grazielle	ISEL	gteixeira@deetc.isel.ipl.pt
GR-TR		
Demestichas, Panagiotis	WINGS	pdemest@wings-ict-solutions.eu
Demou, Amalia	WINGS	antemou@wings-ict-solutions.eu
Dimiropoulou, Polyna	WINGS	pdimiropoulou@wings-ict-solutions.eu
Drigopoulou, Ioanna	WINGS	idrigopoulou@wings-ict-solutions.eu
Lannoo, Bart	Imec	bart.lannoo@imec.be
Makantasis, George	WINGS	gmakantasis@wings-ict-solutions.eu
Naudts, Dries	Imec	dries.naudts@imec.be
SARI, Tahir	Ford Otosan	tsari1@ford.com.tr
Trichias, Kostas	WINGS	ktrichias@wings-ict-solutions.eu
Vanneste, Simon	Imec	simon.vanneste@imec.be
DE		
Dang, Xuan-Thuy	TU-Berlin	xuan-thuy.dang@dai-labor.de
Dörsch, Tobias	TU-Berlin	tobias.doersch@dai-labor.de

Khan, Manzoor	TU-Berlin	manzoor-ahmed.khan@dai-labor.de
Martín, Ángel	VICOM	amartin@vicomtech.org
Pelzer, Georg	Valeo	georg.pelzer@valeo.com
Velez, Gorka	VICOM	gvelez@vicomtech.org
FI		
Pastor Figueroa, Giancarlo	AALTO	giancarlo.pastor@aalto.fi
Taipalus, Tapio	Sensible 4	tapio.taipalus@sensible4.fi
FR		
Kalca, Artiol	VEDECOM	Artiol.Kalca@vedecom.Fr
Nicoud, Anne-Charlotte	VEDECOM	anne-charlotte.nicoud@vedecom.fr
Shagdar, Oyunchimeg	VEDECOM	oyunchimeg.shagdar@vedecom.fr
Soua, Ahmed	VEDECOM	ahmed.soua@vedecom.fr
NL		
Belagal, Math Chetan	SISSBV	chetan.belagal_math.ext@siemens.com
Kutila, Matti	VTT	matti.kutila@vtt.fi
Lumiaho, Aki	VTT	aki.lumiaho@vtt.fi
Ouden, Jos den	TUE	j.h.v.d.ouden@tue.nl
Patel, Nandish	TNO	nandish.patel@tno.nl
KR		
Choi, You Jun	KATECH	ychoi@katech.re.kr
CN		
Han, Qiaomei	DUT (DALIAN University of Technology)	hqmdut@163.com
Yanjun, Shi	DUT (DALIAN University of Technology)	syj@ieee.org
Security & Data privacy		
Djibrilla Amadou Kountche	AKKA	djibrilla.amadou-kountche@akka.eu
Marwane EL-Bekri	AKKA	marwane.el-bekri@akka.eu

Control sheet

Version history			
Version	**Date**	**Modified by**	**Summary of changes**
v0.1	06/02/2019	Anne-Charlotte Nicoud (ACN)	Creation of ToC and purpose of the document
v0.2	14/02/2019	Anne-charlotte Nicoud,	Updated and detailed ToC

		Kostas Trichias, Nandish Patel (NP), Tahir Sari (TS)	
v0.3	28/02/2019	Multiple contributors per site	First version of vehicles and OBU descriptions provided by trial sites.
v0.4	14/04/2019	Multiple contributors per site	Final version of sections 2, and 3 s and OBUs that will be used in different cross-border corridors and trial sites
V0.5	22/05/2019	Multiple contributors per site	Description of automated driving functions from trial site leaders and finalized version of section 2. First contributions to section 5 (security and privacy)
V0.6	05/06/2019	Multiple contributors	Final version of section 5. Updated section 2, 3 based on comments from trial site leaders.
V0.7	10/06/2019	Ahmed Soua	Executive summary and conclusion sections writing, formatting and editing review by the editor. Early full draft for PO.
V0.8	14/06/2019	Ahmed Soua	Available version for the Technical review of M9
V0.91	30/07/2019	Oyunchimeg Shagdar	New Table of Contents
V0.92	13/09/2019	Ahmed Soua	First draft of D2.4 with content adaptation to the new structure
V0.93	06/10/2019	Ahmed Soua	Updated section 2, 3, 4 and 5 based on experts' input, CBC/TSs collaboration and complementarity aspects respectively. Document ready for internal review
V1.0	28/10/2019	Ahmed Soua, Sébastien Faye	Quality check, final version of D2.4

Peer review		
	Reviewer name	**Date**
Reviewer 1	Lozano, José Santa (UMU)	15/10/2019
Reviewer 2	Fidalgo, David (AEVAC)	15/10/2019
Reviewer 3	Sivrikaya, Fikret, Sahinel, Doruk (GTARC)	15/10/2019
Reviewer 4	Oscar Castañeda (DEKRA)	15/10/2019

Legal disclaimer

Table of contents

List of figures

List of tables

ABBREVIATIONS

Abbreviation	Definition
CBC	Cross Border Corridor
TS	Trial Site
CCAM	Cooperative, Connected and Automated Mobility
UCC	Use Case Category
US	User Story
DoA	Description of Action
EC	European Commission
GA	General Assembly
TS	Trial Site
TSL	Trial Site Leader
WP	Work Package
WPL	Work Package Leader
X-border	Cross-border
CAN	Controlled Area Network
Wi-Fi	Wireless Fidelity
HMI	Human Machine Interface
OBU	On-Board Unit
FOV	Field of View
FLIR	Forward-looking infrared
ECU	Electronic Control Unit
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
LTE	Long Term Evolution
EV	Electric Vehicle

GPU	Graphics Processing Unit
V2V	Vehicle-to-Vehicle
I2V	Infrastructure-to-Vehicle
V2X	Vehicle-to-Everything
C-V2X	Cellular V2X
PC5	LTE-V2X for sidelink communication
CAV	Connected and Autonomous Vehicle
HD	High Definition
HW	Hardware
ITS	Intelligent transport system
MEC	Multi-access/Mobile Edge Computing
SIM	Subscriber Identity Module
SW	Software
SAE	Society of Automation Engineers
RTK	Real Time Kinematic
LDM	Local Dynamic Map
AD	Autonomous Driving
MAP	mapDATA
ACC	Adaptive Cruise Control
CACC	Cooperative Adaptive Cruise Control
5G NR	5G New Radio
5G PPP	5G Infrastructure Public Private Partnership
AV	Automated Vehicle
BS	Base Station
CAD	Connected and Automated Driving
CAM	Cooperative Awareness Message

eRSU	Evolved RSU
EDM	Edge Dynamic Map
RAN	Radio Access Network

EXECUTIVE SUMMARY

This document is deliverable D2.4 "Specification of connected and automated vehicles". This deliverable aims to provide a detailed specification of the 5G -augmented vehicles that will be used in Cross Border Corridors (CBC) and Trial Sites (TS) within 5G-MOBIX project. This specification's study spans from automated driving control functions to on-boards units (OBU), 5G chipsets, automatic control and computing resources and needs that will be considered during 5G-MOBIX project. In addition, in this deliverable, an analysis of the regulation x-border issues has been carried out and a set of possible solutions have been proposed by trial sites and cross border corridors. This approach aims to define the targeted components and functionality selections per corridor to tackle the issues. Moreover, as cyber-security risks represent a main challenge for 5G-enbaled vehicles, this deliverable highlights the possible measures to ensure cyber-security, data protection and compliance to the applicable data privacy regulations of "5G-augmented" CCAM vehicles. All the efforts mentioned above aim at enabling and ensuring the successful operation of even the most challenging CCAM use case categories and related user stories.

The outline of the document is the following:

- **Section 1 introduces** 5G-MOBIX project and the scope of this deliverable.
- **Section 2** highlights the main **regulatory issues** related to crossing the border from the vehicle perspective and provides the respective solutions.
- **Section 3 & 4** give an **overview** of the **vehicles used in the ES-PT and GR-TR** corridors respectively by describing the different vehicle architectures. In addition, for each UC category, **tangible contributions from trial sites** to a specific cross-border site are provided.
- **Section 5** highlights the **different the use case categories** that will be **addressed locally** at each trial site and **presents the extended evaluation scenarios** specific for a TS to support the CBC sites.
- **Section 6 specifies** the **security and privacy framework to support CCAM**, with the corresponding requirements from the **vehicle perspective**.
- **Section 7 concludes** the deliverable.

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 urban 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 case categories. The matching of these latter 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, D2.4 "Specification of connected and automated vehicles", is delivered as part of WP2 and presents a detailed specification of the different components of the 5G-augmented vehicles that will be used in each Cross-Border Corridor (CBC) as well as the specific technological contributions of each of the Trial Sites (TS) to the CBCs from the vehicle perspective. The overall vehicle architecture requirements that the two CBC will use to support the successful operation of the defined 5G-MOBIX CCAM Use Case Categories (UCC) is also presented, along with the vehicle architecture deployed at the TS for extended evaluations.

The present deliverable has been feed by contributions already made in deliverables:

- D2.1 [1] : 5G-enabled CCAM use cases specifications: defines the 5G-MOBIX use case categories as well as user stories and proposes and initial set of Key Performance Indicators (KPIs).
- D2.2 [2] "5G architecture and technologies for CCAM specifications". This deliverable describes the reference 5G architecture and the dedicated 5G technologies relating to the deployment of advanced CCAM use case categories and user stories.
- D2.3 [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 case categories and user stories.

Using this input, the use case requirement analysis in term of vehicle regulation is focused at cross-border operation per CBC (Section 2). Based on this requirements analysis, alongside with the use case category needs description, we present afterwards the required modifications and implementation that shall be carried out at the vehicles level in both ES-PT and GR-TR corridors. This deliverable also provides, in Section 5, an overview of the extended evaluations that will take place at the TSs since certain types of testes are difficult to implement at actual borders with the natural aim to enhance and complement the results of the trials performed at the CBC.

This deliverable will be used by WP3 as a "blueprint" and a baseline for the development and roll-out of the 5G-MOBIX's 5G augmented autonomous vehicles (to be tested in the various CBCs and TSs), while it will also serve as detailed documentation of the deployed 5G vehicles for any interested stakeholder.

The purpose of this document is to specify the vehicles augmented with 5G used in every cross-border corridor and trial site in order to perform CCAM use case categories as defined in D2.1. It includes all aspects related to the vehicles or on-board systems, such as:

- **Regulation requirements of automated vehicles for cross-border operation**: This section highlights the main regulatory issues that an automated vehicle may encounter when crossing the border, and the respective solutions.
- **Global description of the vehicles in each cross-border corridor:** The description depicts the vehicle architecture in terms of software, hardware and automated functions (type, quantity, level of automation, on-board sensors, architecture). In addition, for each UC category, tangible contributions from trial sites to a specific cross-border site are provided.
- **Extended evaluation section:** This section provides further details on different the issues that will be addressed locally at each trial site and hence extending the evaluation of the cross-border user stories by providing further pre-testing capability, consultancy, etc.
- **Cyber security:** Specification of on-board measures taken to guarantee cyber security.
- **Appendixes:** This section describes:
  - **Automated Functions augmented with 5G**: description of how the use of 5G impacts the automated driving functions of the vehicles and specification of the 5G augmented functionalities.
  - **On-Board units augmented with 5G**: hardware and software specification, including 5G chipsets.

1.3. Intended audience

The dissemination level of D2.4 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 cross-border corridors and trial sites leaders.

Beyond 5G-MOBIX partners, this deliverable should guide other stakeholders to envision the required vehicles components and automated functions to realise a specific CCAM application. We make this deliverable public because it has an interest for CCAM and 5G research beyond the 5G-MOBIX sphere.

2. REGULATION REQUIREMENTS OF AUTOMATED VEHICLES FOR CROSS-BORDER OPERATION

This section aims to describe the requirements of automated vehicles in terms of regulations to enable cross-border operation. To do so, the approach is to identify the possible regulation issues that may encounter an automated vehicle when crossing the border and then propose the corresponding solutions. In the following, we give an overview of the different vehicles used in the trial sites and the cross-border corridors. Afterwards, we detail the different regulation challenges for cross border operation followed by the proposed solutions that can be implemented during 5G-MOBIX. Before that, we give an overview of the different use case categories and user stories that will be implemented in 5G-MOBIX.

2.1. 5G-MOBIX Use Case Categories and User Stories

Here we provide a brief overview of the cross-border corridors and trial sites of 5G-MOBIX, together with the planned user stories at each site. We use the common 3GPP use case categories in 3GPP TS 22.186 R16 [4], and Table 1, courtesy of D2.1 [1], classifies the user stories specified for each corridor and trial site under the use case categories.

Table 1: 5G-MOBIX User Story – Use Case Category Classification in D2.1 [2]

Trial site	Advanced Driving	Vehicles Platooning	Extended Sensors	Remote Driving	Vehicle QoS Support
ES-PT	Complex manoeuvres in cross-border settings		Complex manoeuvres in cross-border settings	Automated shuttle remote driving across borders	Public transport with HD media services and video surveillance
	Automated shuttle remote driving across borders		Public transport with HD media services and video surveillance		
GR-TR		Platooning with "see what I see" functionality in cross-border settings	Extended sensors for assisted cross-border crossing		
			Platooning with "see what I see" functionality in cross-border settings		
DE		eRSU-assisted platooning	EDM-enabled extended sensors with surround view generation		
FI			Extended sensors with redundant Edge processing	Remote driving in a redundant network environment	
FR	Infrastructure-				QoS adaptation for

	assisted advanced driving				security check in hybrid V2X environment
NL	Cooperative Collision Avoidance		Extended sensors with CPM messages	Remote driving using 5G positioning	
CN	Cloud-assisted advanced driving	Cloud-assisted platooning		Remote driving with data ownership focus	
KR				Remote driving using mmWave communication	Tethering via Vehicle using mmWave communication

2.2. Global description of automated vehicles

To enable 5G CCAM use cases in the 5G-MOBIX project, different types of vehicles are used in each trial site. In total 21 vehicles are planned to be used. The Table 2 below gives an overview of them per trial site and cross-border corridor.

Table 2: Overview of the different vehicles used in cross-border corridors and trial sites

CBC/TS	Number of vehicles	Type of vehicle	Level of automation	Responsible partner
Spain-Portugal	6	1 Bus with Premium services 1 Shuttle EV Bus 3 Citroën C4-Picasso 1 Volkswagen Golf	1 4 4 4	ALSA CTAG CTAG CTAG
Greece-Turkey	2	2 FORD-MAX	4	FORD
Germany	4	1 Volkswagen Tiguan 2 Volkswagen Passat 1 Toyota Prius	4 4 4	TUB VALEO VICOMTECH
Finland	2	Renault Twizy (Juto and Ava)	4	Sensible 4
France	2	Renault ZOE (VEDECOM2) Renault Twizy (VFLEX)	4 4	VEDECOM
Netherlands	3	1 Citroen C4 (Marylin) 1 Toyota Prius PHV 1 Toyota Prius	4 4 4	VTT TUE SISSBV
China	1	SDIA	4	SINOTRUK

				SDIA
South Korea	1	Renault QM6	4	KATECH

2.3. Regulation issues

Automated driving technology will completely transform urban mobility. Driverless vehicles will help smooth traffic flow and reduce congestion by automating transportation across ever-advancing telecommunications networks. Nevertheless, effective policies and regulations for managing the mainstream adoption of self-driving cars remain a complicated challenge. To fill this gap, in 5G-MOBIX, some of the regulation issues for cross-border use cases are studied and respective solutions are provided.

In the following, we highlight several cross-border related regulation issues that will be handled during 5G-MOBIX project. For each issue, both a description and potential solutions are provided.

2.3.1. Autonomous vehicle regulation compliance

The major difference between conventional automotive technologies and autonomous vehicle (AV) technologies is that these latter perceive and make decisions based on the environment outside the vehicle. An environment that cannot be controlled and changes significantly in terms of traffic on the road, vulnerable road users, static objects, the quality of the road, road elements such as lane markings and signs and weather and illumination levels. Thus, it is clear that performance standards for autonomous driving technologies must specify entire range of conditions in which the vehicle might operate

Issue Title	**Autonomous vehicle regulation compliance**	**Issue ID**	**RC1**
Description	• There are no national or international regulations specified for the roads and the corresponding autonomous vehicles moving on these roads. • Different vehicles will have different safety distance levels for emergency braking situations. In case of handing over the control of the driving from vehicle to driver, there should be standardized driver warning systems. • Neighbouring countries can have different driving regulations. A situation where a connected and automated vehicle (CAV) has been homologated for the source country but not for the destination country can happen. As an example, an Autonomous vehicle A has successfully passed the minimum tests required to drive in autonomous mode in country A, but it has not passed the tests on country B, or the tests are different in both countries; and therefore, autonomous vehicle A is not authorized to be driven in autonomous mode in country B. These tests ensure that the AV is safe on that country, e.g. it takes into account the local laws, it has installed the maps for the route, etc.		

Consequences & impact	• Lack of regulations may affect the vehicular hardware selection and its specifications; hence, compliance to several different systems of different brands can be costly from the perspective of OEMs. • In case of doing any CCAM application for the worst-case scenario, there would be a trade-off between security and efficiency of each application (e.g. for the platooning case, increasing safe distance level may result in decrease in fuel efficiency). • Driver may not understand the warning due to hand over process and may not act as s/he should, thus unwanted results may occur. • A vehicle sold in country A can drive autonomously in that country but not in country B. If no preventive measures are taken, the vehicle might enter into country B driving in autonomous mode and therefore break the laws of country B and become a potential safety risk.
Proposed Solutions	• There should be a regulation in terms of hardware specifications and capabilities. • By using a standardized software algorithm, an adaptive behaviour in each CCAM application can be defined for each vehicle according to their capabilities and status. • Driving license trainings can be rearranged according to SAE levels of autonomy of the vehicles and also for specific applications such as platooning. • Use geo-fencing or GPS to restrict the operation of the vehicle in autonomous mode to the areas where it is legally approved. In case the destination of the travel is an area outside of the approved domain the vehicle shall ask the user to take control and then deactivate its autonomous driving or even perform a safe stop autonomously. Preventing autonomous mode to be activated based on geo-referenced position. Ask the driver to take back the control of the car before entering another country (and have a fallback strategy if driver does not resume driving). • Seek approval of the AV to be driven in public roads in advance. May require technical inspection or self-verification.
Progressed solutions	• The vehicle hardware, software, algorithms, applications and connectivity incompatibility are major issues during testing, verification and evaluation of the work done in CBCs and other contributing test sites. For the full European deployment there needs to be several EU-wide decisions and actions in place prior to entering into EU operations of Cooperative Connected and Automated Vehicles. Even for the CBC and TS operations, these aspects are extremely challenging to overcome due to different approaches of involved OEMs', suppliers' and operators' choices based on pre-commercial solutions. However, several steps will be taken in order to enable testing between various CBC's and TS's.

2.3.2. Road & traffic regulation compliance

Issue Title	Road & traffic regulation compliance	Issue ID	RC2
Description	• Neighbouring countries can have different traffic rules. This means, the AV software needs to be adapted to the target location, so that it knows how to behave to respect local traffic law. • Even for the same country the rules might vary depending on the type of road, e.g., speed limit or overtaking behaviour on urban vs. highway. In addition, roadside units of a specific region may need to supply different message types that may not be understandable by the foreign vehicles. •		
Consequences & impact	• The vehicle might break the law if this has not been taken into account in the design of the algorithm • Vehicle moves above the legal speed limit or even in reverse direction and might cause a danger on traffic. • The autonomous driving might be restricted to certain road types, e.g., highway chauffeur • Lack of understanding in safety related messages might cause danger on traffic. • In regions where mostly high-level AD exists, pedestrians tend to expect the vehicle will have the automated braking feature and it will automatically stop when it perceives a pedestrian. Thus, the general level of pedestrian care may decline as people become accustomed to this common safety feature. In case vehicles do not stop in the same way in a different region, fatal accidents could emerge.		
Proposed Solutions	• The legislation of the destination markets shall be well known by developers so that the AD algorithm might adapt its behaviour depending on the vehicle location. This adaptation can be done in several forms: • Create HD maps that takes into account all countries where the vehicle will be allowed to drive and store not only the road but also all the traffic signs. Add the information about the type of road (urban, highway, etc.) to the onboard map database so that the vehicle does not depend on the road code to determine the road type. • Traffic management centre and RSU at the border shall inform vehicles that they pass/enter to another country and also inform them about the traffic rules. Autonomy of vehicle can be changed accordingly. • The AV shall check its current location before AD can be activated to ensure it is prepared to drive autonomously on that location and type of road. • When a destination is entered, the AV shall check if it is prepared to drive autonomously on that location and, if not prepared, it should warn the user and perform a safe stop before passing the border if needed.		

	• Administrations may concur on common international level traffic legislations and laws, in order to standardise the traffic rules. • Traffic management centre and RSU at the border shall inform vehicles that it passes/entering to another country and also inform about traffic rules. Autonomy of the vehicle can be changed accordingly.
Progressed solutions	• Due to different homologation requirements of CAV, it requires significant efforts to have a CAV approved for public roads operation in highly automated mode in several countries, even if the CAV has been approved for public roads operation in its native country.

2.3.3. Sensor compliance

Issue Title	Sensor compliance	Issue ID	RC3
Description	• AD vehicles usually are equipped with Radar and Lidar sensors. The allowed frequencies and wavelengths that this kind of devices use to send/receive pulses might vary from one country to another according to the national radiofrequency spectrum		
Consequences & impact	• If the vehicle drives on a different country, it shall not use sensors that work in frequencies that are not allocated for that kind of application. This might cause that the vehicle cannot drive in autonomous driving mode if it can not diagnose this or otherwise the owner of the vehicle could be fined if this is not diagnosed.		
Proposed Solutions	• Radiofrequency spectrum harmonization between different countries to ensure that there are no differences when switching between borders • If possible, the design of the vehicle can be made with different kind of sensors so that even in the event of disabling one of them it could still be operated in autonomous driving mode using the other sensor. If this is not possible, then restrict the autonomous driving functionality to the countries where these sensors can be used and ensure they are not used after passing through the border.		

2.3.4. Geo-dependant spectrum

Issue Title	Geo-dependant spectrum	Issue ID	RC4
Description	• Neighbouring countries can have different radiofrequency spectrum. The AV usually relies on the availability of a wireless connection to receive V2X messages or download updates on the map. If this connection is not available some of the functions of the AV might be unavailable.		

Consequences & impact	• If the frequency used by the onboard connectivity systems is not available on the destination country, then connectivity functions might become unavailable. • If the vehicle depends on the availability that functions to send/receive critical data for performing autonomous driving, then AD might not be available in the new country. • The AV might break the law if it emits data on an unauthorized frequency.
Proposed Solutions	• If possible, the vehicle will be designed to use different frequencies or connectivity technologies and dynamically adapt the used frequency based on location. • If this is not possible, then restrict the autonomous driving functionality to the countries where there are compatible frequencies and ensure that these frequencies are not used after passing through the border. Accept certain delay off rollout across countries.

2.3.5. Law enforcement interaction

Issue Title	Law enforcement interaction	Issue ID	RL1
Description	• The rapid deployment of autonomous vehicle technology will undoubtedly have a significant impact on public safety services, including law enforcement agencies. In fact, AV's will reshape the nature of the interactions concerning police authorities. Police officers and other law enforcement authorities must be able to interact with AVs on the road. To do this, new police interaction protocols have to be designed to communicate with AVs. As an example, a police officer may need to stop an AV for a security check, and to do that it has to send a stop request to the vehicle.		
Consequences & impact	• In case of suspicious AV and if police is not able to stop the vehicle, a potential danger can be present in the road, or threat the lives of people (kidnaping, terrorism, etc.).		
Proposed Solutions	• A common message sets/protocols dedicated to police interactions shall be standardised by the European Level (and even in international level).		

2.3.6. Neutrality regulation

Issue Title	Neutrality regulation	Issue ID	RN1
Description	• The roaming PLMN does not allow prioritizing the data connection for the vehicle over the other users based on the network neutrality law in this country. But the home PLMN allows it in a way which is compliant with the regulation.		

Consequences & impact	• No priority will be set when the vehicle roams out of its home country. A connection interruption while network is congested may happen.
Proposed Solutions	• Try to find a common implementation mechanism compliant with the laws of all countries

3. VEHICLE SPECIFICATION OF SPAIN – PORTUGAL CBC

3.1. Deployed vehicles architecture

In total, six vehicles will be used on the Spain-Portugal (ES-PT) corridor for 5G-MOBIX use cases. These vehicles are categorized into two types: passenger buses and passenger car.

- Passenger buses
  - 1 bus with Premium services, provided by ALSA
  - 1 Shuttle EV bus, provided by CTAG
- Passenger cars
  - 3 Citroën C4 Picasso, provided by CTAG
  - 1 Volkswagen Golf, provided by CTAG

The use of these prototypes in the different Use case Categories (UCC), User Stories (US) and scenarios is shown in Table 3.

Table 3: Overview of the repartition of ES-PT vehicles within implemented user stories and scenarios

UCC	User Story	Scenario	Vehicles
UCC#1: Advanced Driving	**Complex Manoeuvres in Cross-Border Settings:**	SC1: Lane Merge for Automated Vehicles	3 Citroën C4 Picasso 1 Volkswagen Golf
		SC2: Automated Overtaking	3 Citroën C4 Picasso 1 Volkswagen Golf
	Automated shuttle in Cross Border settings	SC1: Cooperative Automated Operation (VRU)	1 Shuttle EV bus
UCC#3: Extended Sensors	**Complex Manoeuvres in Cross-Border Settings**	**SC 3. HD Maps**: Public transportation	1 bus with Premium services
		SC3. HD Maps: Private Automated Vehicles	3 Citroën C4 Picasso 1 Volkswagen Golf
UCC#4: Remote Driving	**Automated Shuttle in cross-border settings**	SC2: remote control	1 Shuttle EV bus
UCC#5: Vehicle Quality of Service Support	**Public transport with HD Media services and video surveillance**	SC1: Streaming of 4K camera	1 bus with Premium services
		SC2: User access to high definition multimedia content	1 bus with Premium services

3.1.1. Software and hardware architecture

The six automated driving prototypes from the Spanish-Portuguese corridor (Shuttle, bus n, Golf and 3 C4 Picasso) follow a similar architecture, of which some particularities will be explained in the next sections. All of them are conventional vehicles that have been equipped with a constellation of sensors providing an adequate knowledge of the environment and allowing the test of the vehicle in different scenarios (Urban, highway, rural and parking) in several SAE levels. Furthermore, these in-vehicle sensors are from different technologies which adds robustness to the system especially in bad weather conditions.

Apart from the sensors, the prototype was equipped with some different systems aiming at enhancing the performance of the perception algorithms, such as:

- Map Unit: It provides detailed information about the road characteristics (number of lanes, speed limits, signals, road boundaries ...) with centimetre precision. It also can be updated in "real time".
- DGPS+IMU: They represent the positioning system with accelerometer and magnetometer information, as well as RTK GPS with differential correction.
- Connectivity Unit: It is a device with the capacity of receiving information from outside the vehicle using different technologies (C-V2X, LTE PC5)

The information provided by the sensors and the units are received by the Rapid Prototyping platforms with the perception function and control algorithms.

First, the data is fused in order to define the static and dynamic objects in the environment (speed, position, heading, etc.), position of the vehicle as better as possible (longitudinal and lateral) and describe the road in as much detail as possible.

Then, the function algorithms which define the behaviour of the vehicle in every moment and the path to follow are executed. Once the desired behaviour has been defined, the relevant information (acceleration and steering wheel angle) is sent to the control layer so that it can be commanded to the actuators. In addition to the autonomous driving prototypes, ALSA bus is equipped to different sensors and platforms in order to provide some advanced functions in multimedia or connectivity services.

In **Table 4**, we depict the different components of the vehicle that will be used in the ES-PT corridor.

Table 4: Different components of the vehicles used in the ES-PT corridor

Sensor	Vehicle Type	Units	Type	Car position	Horizontal field of view	Vertical field of view	Range
2D Laser	Alsa Bus	3	Sick	Front and lateral	180°	0°	10m
	CTAG shuttle	3	Sick	Front and lateral	180°	0°	10m
	Citroen C4	2	Valeo ScaLa	Front and rear bumper	145°	3,2° (4 layers)	200m

	Volkswagen Golf	2	Valeo ScaLa	Front and rear bumper	145°	3,2° (4 layers)	200m
3D Laser	Alsa Bus	2	Velodyne	Roof	360°	30°	6m-100m
	CTAG shuttle	2	Velodyne	Roof	360°	30°	6m-100m
	Citroen C4	1	Velodyne	Roof	360°	30°	6m-100m
	Volkswagen Golf	1	Velodyne	Roof	360°	30°	6m-100m
Cameras	Alsa Bus	3	IDS	Front and lateral	60°	-	60m (car) 40 m (ped.)
	CTAG shuttle	3	IDS	Front and lateral	60°	-	60m (car) 40 m (ped.)
	Citroen C4	2	Mobileye	Windshield	30°	-	150m (car) 40 m (ped.)
	Volkswagen Golf	2	Mobileye	Windshield	30°	-	150m (car) 40 m (ped.)
GPS	Alsa Bus	1	Trimble	Trunk			
	CTAG shuttle	1	Trimble	Trunk			
	Citroen C4	1	Trimble	Trunk			
	Volkswagen Golf	1	Trimble	Trunk			

ALSA Bus

The first vehicle provided in Spain-Portugal corridor is the ALSA Bus with Premium services (see **Figure 1**). The main characteristics of this vehicle are in the following:

- Interior and exterior cameras
- Communication unit developed by CTAG
- Currently legal and in service between the cities of Porto and Vigo

Figure 1: Overview of ALSA bus

CTAG Shuttle EV Bus

CTAG Shuttle EV Bus, illustrated in **Figure 2**, is the second vehicle used in 5G-MOBIX in the Spain-Portugal corridor. It is completely developed by CTAG, and has the following specifications:

- Disabled passenger friendly.
- Maximum speed of 40 km/h.
- Battery autonomy for 8 hours.
- Real-time remote management from control centre.
- Connectivity unit (4G/LTE, ITS-G5, 5G).
- C2X services (GLOSA, hazards, traffic jam, accident, emergency vehicles, ...).
- Intelligent routing services.
- Free Wi-Fi for users.
- Multimedia route services.
- Dimensions: 5200mm (L) x 2770mm (H).

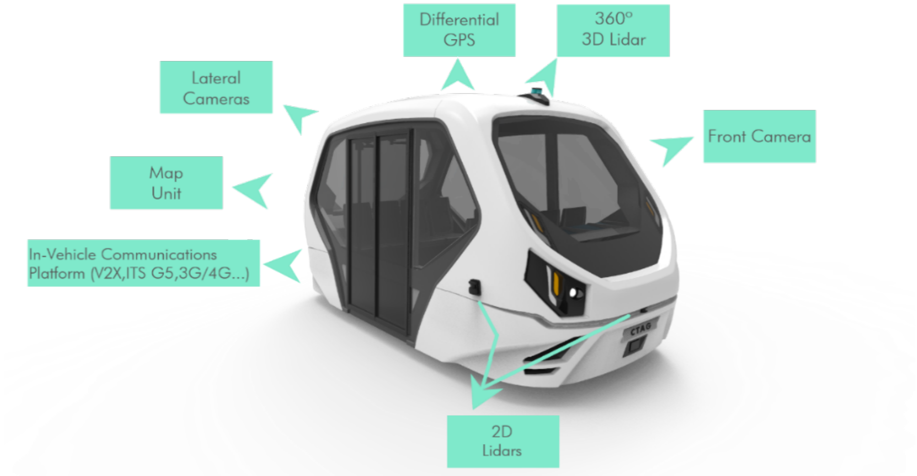

Figure 2: Overview of the Shuttle EV Bus

Citroën C4 Picasso

CTAG also provides three C4-Picasso automated vehicles (depicted in **Figure 3**), with the following characteristics:

- SAE L4 automated driving functions.
- Communications unit developed by CTAG.
- Sensors: Lidars 2D and 3D, cameras, radars, map unit, DGPS and IMU.

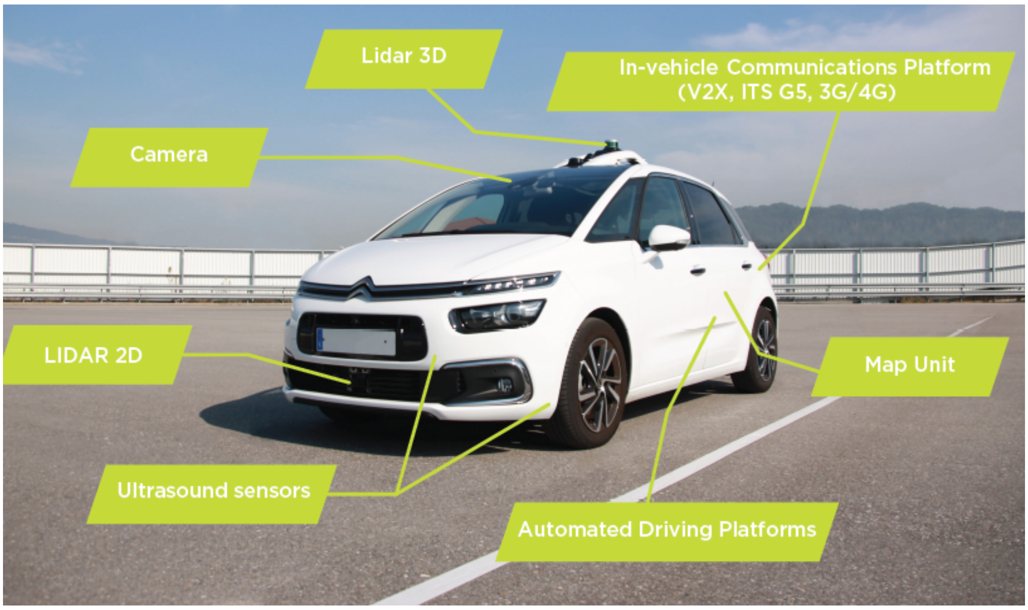

Figure 3: Overview of the Citroen C4 Picasso

Volkswagen Golf

The automated vehicle from Volkswagen Golf, as illustrated in **Figure 4**, has the following characteristics:

- Volkswagen Golf, SAE L4.
- Communications unit developed by CTAG.
- Sensors: Lidars 2D and 3D, cameras, radars, map unit, DGPS+IMU.

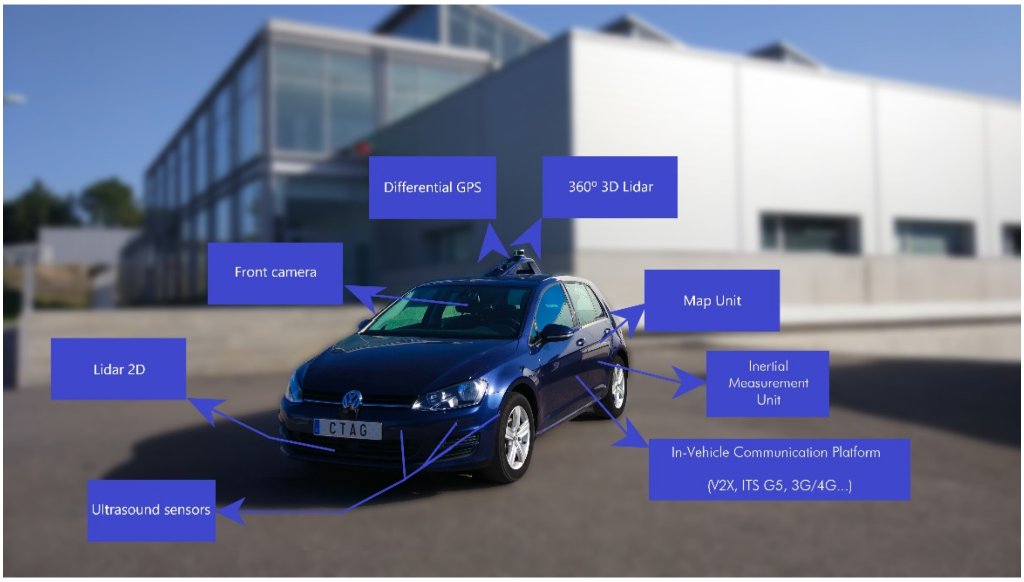

Figure 4: Overview of Volkswagen Golf vehicle

3.1.2. Automated driving functions

In the following, we detail the different automated driving functions in each of the vehicles that will be used in the trials of the ES-PT corridor.

ALSA Bus

The ALSA Bus with Premium services has the following components to enable the automated driving functions:

- Lane control system.
- Distance control system.
- Reversing camera.

CTAG Shuttle

The automated driving functions of the Shuttle EV Bus, provided by CTAG, are depicted in the following:

- Autonomous urban driving L4 (longitudinal and lateral control)
- 360º Object detection (pedestrian, vehicles, bicycles).
- Route following (HD map information).
- Green light optimal speed adaptation.
- Automated emergency braking.
- Collision detection (Prediction of possible collision).
- Remote Control.

Figure 5 describes the high-level SW architecture onboard the vehicle.

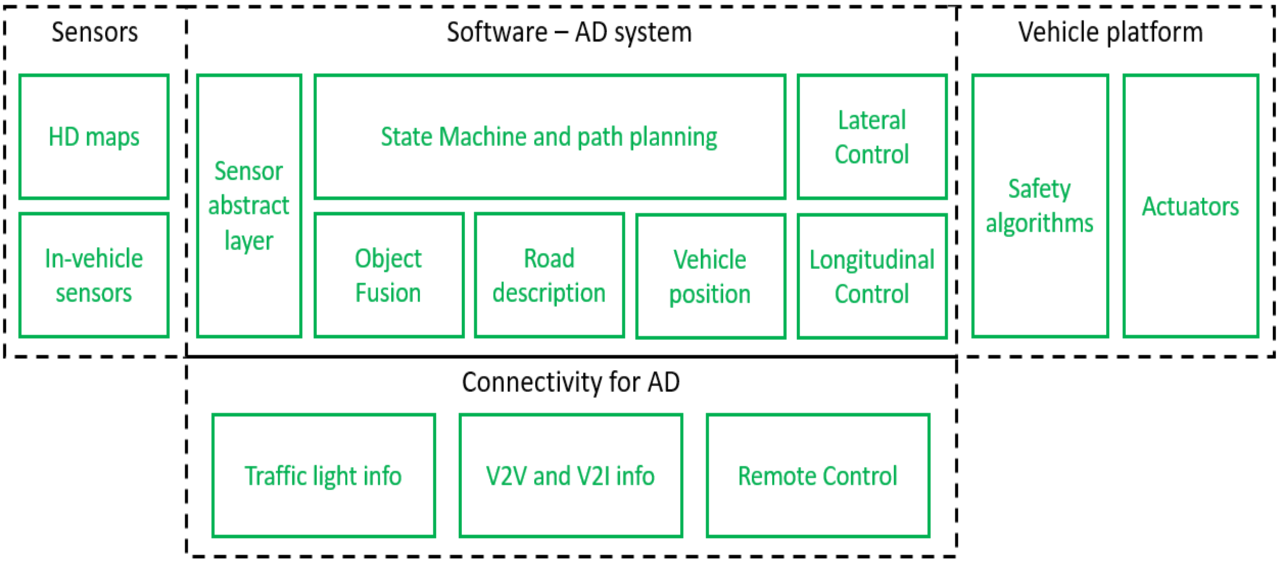

Figure 5: Automated driving functions of the Shuttle EV Bus

C4 Picasso

The CTAG c4 Picasso Autonomous vehicle has the following automated driving functions:

- Autonomous Urban Driving L2.
- Highway chauffeur L3 (vehicle following, automated overtaking, highway entry, highway exit and fall-back)
- Automated Valet Parking L4.
- Green light optimal speed adaptation.
- 360º Object detection (pedestrian, vehicles, bicycles).
- Route following (HD map information).
- Bus stop function (Bus stop detection, opening and closing doors automatically).
- Automated emergency braking.
- Collision detection (Prediction of possible collision).

The diagram of **Figure 6** describes the high-level SW architecture onboard the vehicle.

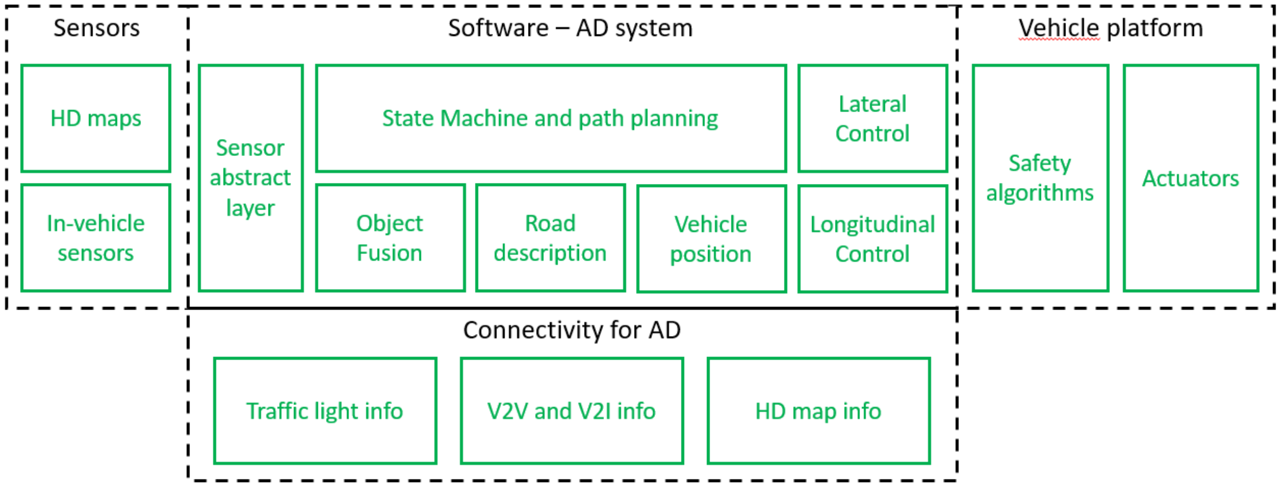

Figure 6: Automated driving functions of the Citroen C4 Picasso

Volkswagen Golf

The CTAG Volkswagen Golf Autonomous vehicle has the following automated driving functions:

- Autonomous urban driving L2.
- Highway chauffeur L3 (vehicle following, automated overtaking, highway entry, highway exit and fall-back)
- Automated Valet Parking L4.
- Green light optimal speed adaptation.
- 360º object detection (pedestrian, vehicles, bicycles).
- Route following (HD map information).
- Bus stop function (Bus stop detection, opening and closing doors automatically).
- Automated emergency braking.
- Collision detection (Prediction of possible collision).

Figure 7 below describes the high-level SW architecture onboard the vehicle.

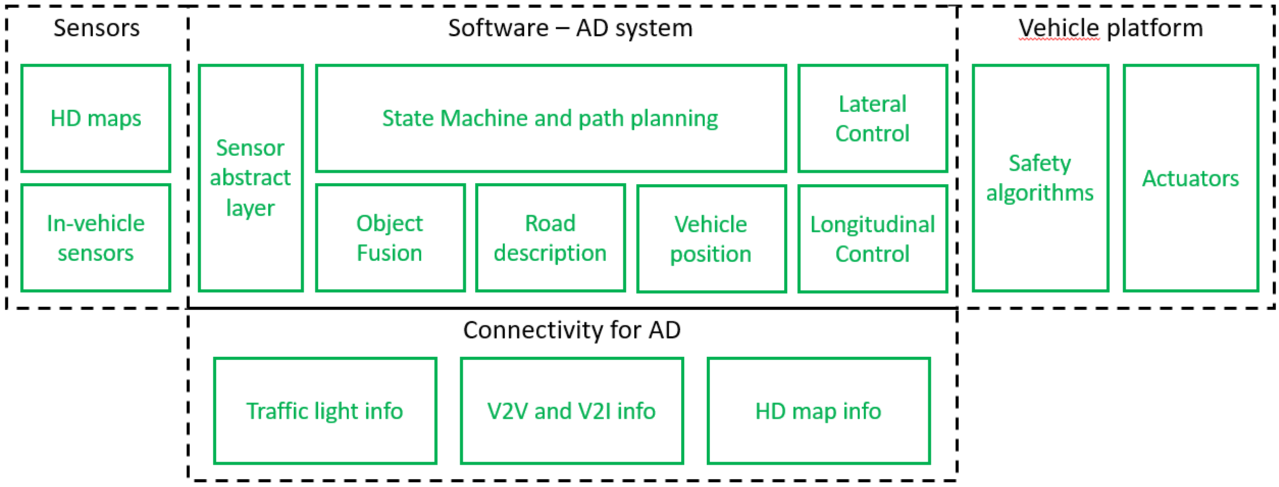

Figure 7: Automated driving functions of the Volkswagen Golf vehicle

3.2. UCC#1: Advanced Driving at the ES-PT CBC

3.2.1. Description of the use case category

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".

3.2.2. Requirements on vehicle architecture for advanced driving

In order to fulfil the requirements related to Advanced Driving functions, all the prototypes involved in the EP-PT cross-border were integrated with an OBU with 5G Capabilities which will provide information of other actors of the environment in a very short period of time which on-board sensors cannot detect.

3.2.3. Vehicle automated driving functions for advanced driving

Inside the ES-PT cross-border corridor two different user stories will be executed related to the advanced Driving use case category: "Interurban complex scenarios for private automated vehicle", has two different scenarios, and "Last Mile EV Automated Shuttle vehicles in Cross Border and urban environment"; All of these scenarios showcase the advantages offered by the 5G connectivity to the automated driving vehicles (private and public).

User Story: Complex Maneuvers in cross-border settings

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. The vehicles used are the 3 C4 Picasso and the VW Golf.

This user story consists of two different scenarios where connectivity will support automated manoeuvres:

- Scenario 1: Lane merge for automated vehicles.
- Scenario 2: Automated Overtaking.

In these scenarios, the object fusion model of the vehicle receives additional information provided by communication technologies which will drastically improve and complement the information provided by its sensor constellation. The purpose of these scenarios is to extend the 360º perception layer of the automated vehicle by integrating communication capabilities in the different vehicles 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., and receive information from the road-side infrastructure, helping automated vehicle to understand the current situation and thus take the best decision of how to proceed with the manoeuvre.

User Story: Automated shuttle in cross-border settings

The vehicle involved in this user story is the shuttle EV Bus. This vehicle will receive information from traffic lights and from other actors (like a VRU). Information provided by the 5G OBU will enhance the behaviour of the fusion algorithm in two main aspects. Firstly, connectivity OBU works as another sensor (with high reliability and accuracy) and its detections can be merged with the ones provided by on-board sensor like lidars and cameras. In addition, the field view of connectivity covers more distance than on-board sensors, which is even more important in urban scenarios where there are many blind spots and sensor occlusions.

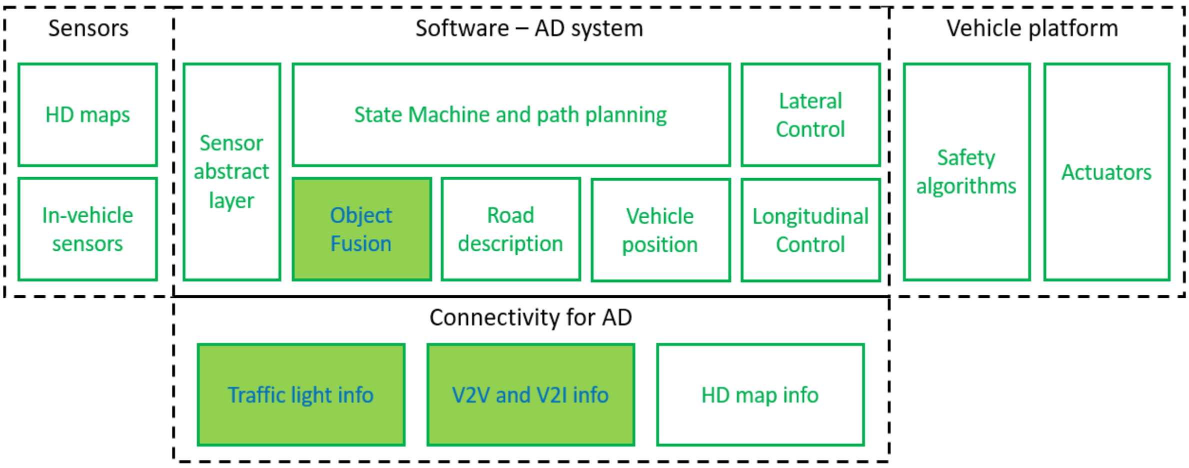

Figure 8: ES-PT vehicles AD function development to support AD Use Case Category

The integration of the OBU with 5G capabilities implies a considerable enhancement in the environment understanding and allows the achievement of complex and challenging use cases for advanced driving functions, necessary for a SAE L4 AD vehicle. The above functionalities are depicted in **Figure 8**.

3.2.4. Portfolio of transferable assets

In this section, an overview of the tangible assets that can be transferred to ES-PT CBC is provided for each trial site contributing to the AD use case category. Table 5 illustrates these contributions.

Table 5: Assets to be transferred to the ES-PT corridor for AD UCC

TSs contributing	FI	FR	NL
List of assets to be transferred to the ES-PT corridor	• FI trial site will coordinate with FR to provide an alternative approach for supporting simultaneous attachment to multiple PLMNs. Together with the FR trial site, they will provide a benchmark framework on seamless handover mechanism	• FR trial site will bring a connected vehicle to the ES-PT corridor to interoperate with the other "local" vehicles. The interoperability will be in receiving CPM and CAMs sent eventually by surrounding cars. Furthermore, the French car will participate in the user stories developed in the ES-PT corridor. • FR Vehicle's OBU will test a different handover scenario using two PLMNs. A soft handover (connection with two SIM cards) experiment will be carried out in order to compare it with other implementations with only on SIM card using home routed or local breakout (NL side). • Alongside with the FI trial site, FR site will elaborate a benchmark on possible seamless handover approaches to transit from 5G, to 4G/5G networks.	• NL trial site will bring OBUs and MEC components. The idea is that the foreign OBU will receive CPM messages from roadside infrastructure and start advanced driving maneuver like a change lane, etc. On the other hand, a human driver proceeds with the maneuver and everything is logged so that it can be compared afterwards.

3.3. UCC#3: Extended Sensors at the ES-PT Cross-Border

3.3.1. Description of the use case category

According to 3GPP TS 22.186 R16, Extended Sensors enables 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.

3.3.2. Requirements on vehicle architecture for extended sensors

Private automated vehicles and a public transport bus are used for the implementation of user stories in the Extended Sensors use case category. For both cases, the vehicle architecture has been modified in order to fulfil the use case category requirements.

Public transport bus (HD Maps)

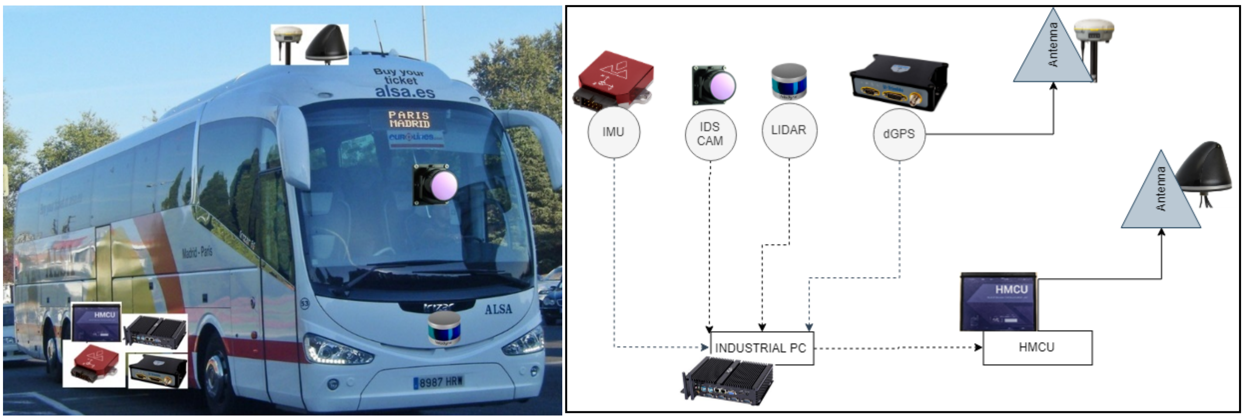

Figure 9: Alsa bus architecture for Extended Sensors Category

For the Alsa bus, a constellation of sensors and platforms has been defined aiming at allowing the uploading of detailed enough road characteristics detailed enough to create a high definition map in the server:

- Lidar and Camera: Provides detailed raw data of the road (lanes, speed limits, tips of lines).
- DGPS and IMU: Vehicles position and synchronisation of all the systems.
- Industrial PC and 5G OBU (HMCU): Store, prepare and upload the data to ITS server.

These elements are reported in Figure 9 above.

Private automated vehicles (HD Maps)

The vehicle prototypes already have integrated sensors which are able to collect detailed data of the road, and positioning algorithms which can localize the vehicle with high accuracy. Because of this, it is only necessary to integrate an industrial PC and 5G OBU to send all the data collected to the ITS centre.

Furthermore, these vehicles have to be prepared to receive the updated map, so that the 5G OBU will receive the new database from the ITS server and forward it to the Map Unit of the vehicle. This platform has to be modified in order to received updated databases and use them to maintain the automated driving mode in the prototypes.

3.3.3. Vehicle automated driving functions for extended sensors

User stories related with Extended Sensors use case category in the ES-PT CBC are related to the logging, cloud processing and updating of High Definition map data for autonomous vehicles. The HD-Map unit of the vehicle is updated with the information provided by the ITS-centre about the changes in the map (road geometry, speed limits, available lanes, etc.).

Furthermore, the information transfer can also work in the opposite way. For example, when the "Road description module" detects that the information provided by in-vehicle sensors does not match with the data that it has stored in the HD map units, this new information is sent to the ITS-Centre in order to be stored and shared with other vehicles. The mentioned modifications are presented in Figure 10.

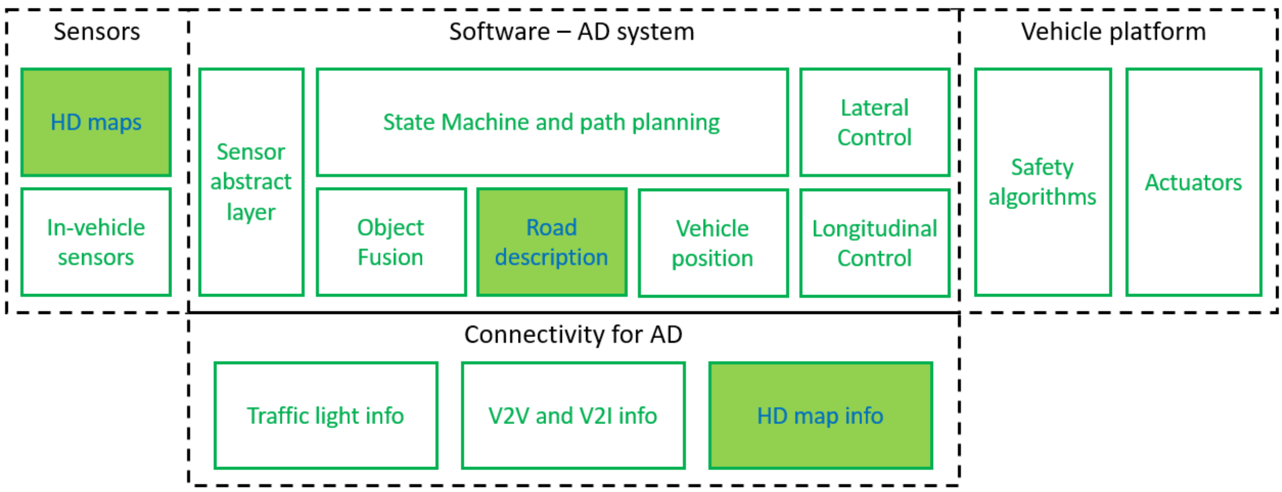

Figure 10: ES-PT vehicles AD function development to support HD Maps use case

3.3.4. Portfolio of transferable assets

In this section, the different tangible contributions of the trial sites implementing user stories in Extended Sensors use case category are provided in Table 6.

Table 6: Assets to be transferred to the ES-PT corridor for Extended Sensors UCC

TSs contributing	DE	FR	NL
List of assets to be transferred to the ES-PT corridor	• DE TS will bring two SAE-L4 vehicles to ES-PT corridor. LDM maps application is installed with the OBUs allowing benchmarking with ES-PT HD-maps support CCAM operations in the same scenarios. The V2X based realization of extended sensors with eRSU infrastructure provides an alternative solution to evaluation ES-PT CCAM infrastructure.	• FR trial site will bring a connected vehicle to the ES-PT corridor to interoperate with other "local" vehicles. The interoperability will be in receiving CPM and CAMs sent eventually by surrounding cars. Furthermore, the French car will participate in the user stories developed in the ES-PT corridor.	• NL trial site will bring OBUs and MEC components. The idea is that the foreign OBU will receive CPM messages from roadside infrastructure.

3.4. UCC#4: Remote Driving at the ES-PT CBC

3.4.1. Description of the use case category

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".

3.4.2. Requirements on vehicle architecture for remote driving

A remote-control system provided by Nokia is installed in the EV Automated shuttle (see **Figure 11**), which contains two cameras understanding of the situation and what is happening inside the vehicle, and a unit in charge of sending the rotation and acceleration instructions. The 5G OBU is this time even more important since the information sent by the control centre is critical as it commands the behaviour of the vehicle.

Figure 11: EV shuttle architecture for Remote Driving Category

3.4.3. Vehicle automated driving functions for remote driving

User Story: Last Mile EV Automated Shuttle vehicles in Cross Border and urban environment

The Last Mile EV Automated shuttle is a driverless vehicle, which means when there is a situation that the vehicle cannot solve by itself, remote control is necessary to be remotely controlled to save the situation. In this User Story, the shuttle is going to find an obstacle in its path that is blocking the original route. An operator will be alarmed, and he/she will be able to remotely take the control of the vehicle in order to handle the new route. Once the vehicle is in remote control, the information received by the operator concerning the situation (position and environment) is provided by the cameras installed. The operator will send movement requests directly to the actuator of the shuttle bypassing the AD controls system. Main AD functions required for this user story are illustrated in Figure 12.

.

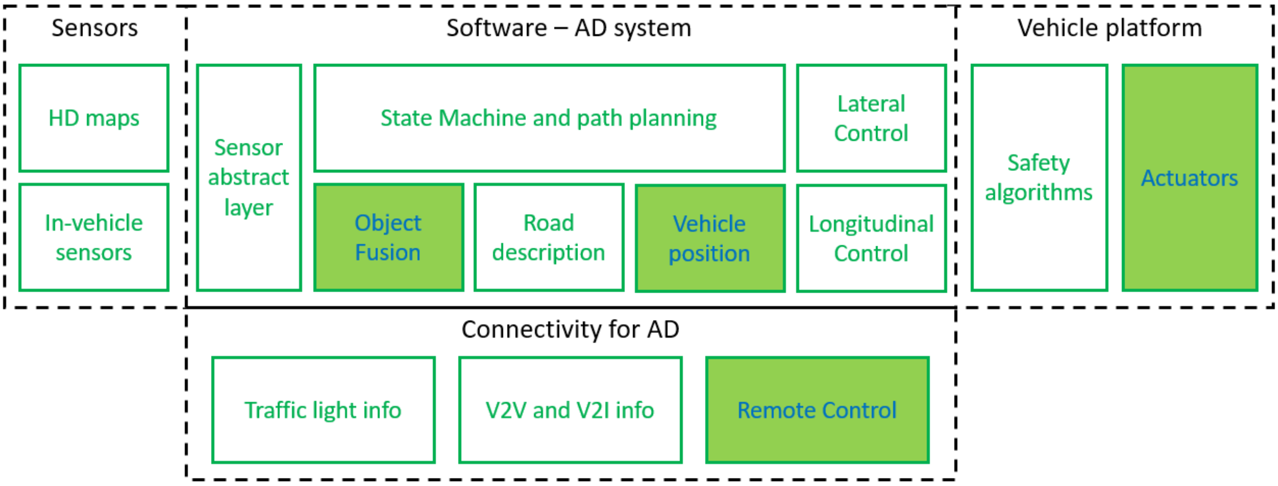

Figure 12: ES-PT vehicles AD function development to support Last Mile EV Automated Shuttle

3.4.4. Portfolio of transferable assets

In the following, the different concrete contributions of the trial sites implementing user stories in Remote Driving use case category are provided in Table 7.

Table 7: Assets to be transferred to the ES-PT corridor for Remote Driving UCC

TSs contributing	FI	KR
List of assets to be transferred to the ES-PT corridor	• FI will coordinate with FR to provide an alternative 2 PLMN possible implementation so that together with FR they will be able to test different scenarios in the CBC (5G-4G transitions, for instance). FR Vehicle's OBU will test a different handover scenario using two PLMNs – a soft handover (connection with two SIM cards) experiment to compare with the other implementations with only on SIM card using home routed or local breakout, for instance.	• Test results and insights from mmWave V2I communication implementation. •

3.5. UCC#5: Vehicle Quality of Service Support at the ES-PT Cross-Border

3.5.1. Description of the use case category

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 the behaviour to 3GPP system's conditions. The benefits of this use case group are offerings of smoother user experience of service".

3.5.2. Requirements on vehicle architecture for Quality of Service support

One public transport bus running between Vigo and Porto will be equipped with a number of units which allow the deployment of two systems that will increase the quality of service for users and control centre:

- Two Xiaomi Cameras: These cameras will be integrated in the front windshield of the bus. One of them will record video from the inside and the other will record video from the outside of the bus. Recorded video will be uploaded in real time to the Alsa ITS control centre in order to monitor what is happening in the interior and in the surroundings of the bus.
- Tablets with multimedia content: It is expected to integrate one tablet per seat. All of them are expected to receive multimedia content in HD at the same time. All this information will come through a single 5G router, in order to show the 5G capacities for bandwidth.

The above identified components are depicted in Figure 13.

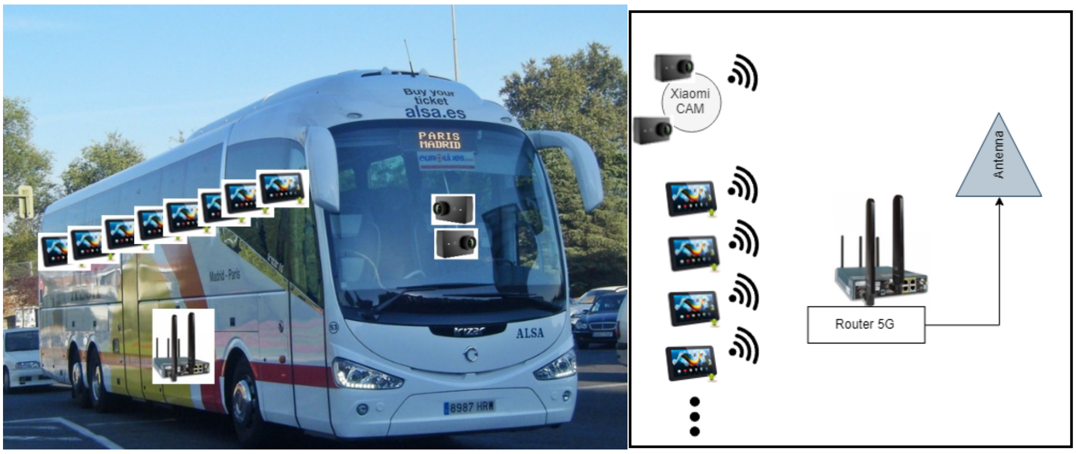

Figure 13: Alsa bus architecture for Quality of Service (QoS) support Category

3.5.3. Vehicle automated driving functions for Quality of Service support

<u>User Story: Interurban scenario for public transport</u>

The Alsa bus involved in this user story will provide real time connected services to the public transport fleet that connects the cities of Vigo and Porto. In ES-PT CBC two different services will be deployed:

- **Streaming of 4K camera** and in-vehicle sensors data to the ALSA control centre. This 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.
- User access to **high definition multimedia content** with great quality of service. One tablet per seat will be able to provide time multimedia content in HD at the same, and everything coming from a single router installed on the bus.

3.5.4. Portfolio of transferable assets

In Table 8, a highlight about the different contributions of the trial sites implementing user stories in Vehicle QoS Support use case category are provided.

Table 8: Assets to be transferred to the ES-PT corridor for Vehicle QoS support UCC

TSs contributing	FR	KR
List of assets to be transferred to the ES-PT corridor	• FR trial site, by bringing its connected vehicle to the ES-PT corridor and will carry out a seamless handover pre-test on the vehicle side (5G to 4G, 4G to 5G, 5G to 5G, 5G to satellite, etc.) with data in both DL and UL.	• Technical report evaluating the feasibility of mmWave-band V2I/N communications after testing a variety of onboard mobile services will be shared.

4. VEHICLE SPECIFICATION OF GREECE – TURKEY CBC

4.1. Deployed vehicles architecture

4.1.1. Software and hardware architecture

To enable 5G CCAM use cases (platooning and truck routing), two SAE L2 F-MAX tractors will be used on the Greece-Turkey (GR-TR) corridor, as depicted in **Figure 14**. Both vehicles are equipped with communication capabilities allowing them to communicate with the network, infrastructure and other vehicles. In this manner, overall autonomy of the process will be SAE L4 with help of sensors located at the testbed.

Figure 14: Overview of vehicle used in the GR-TR CBC

F-MAX trucks are produced in Ford Otosan Inonu Plant that is located in Eskisehir, Turkey. Trucks are selected as International Truck of The Year in 2019 and they have 500ps engine power, 2500Nm torque with automatic transmission as standard. Additionally, the truck cabin interior height is 2160mm.
F-MAX is equipped with Adaptive Cruise Control, Advanced Emergency Brake System, Lane Departure Warning System, Predictive Cruise Control, ESP and ASR features. The general architecture of F-MAX tractors is highlighted in Figure 15. It is worth noting that the MicroAutoBox development is under Ford Otosan responsibility, while OBU is developed by IMEC. FMAX tractors will have radars, cameras, Lidar and on-board units for C-V2X communication.

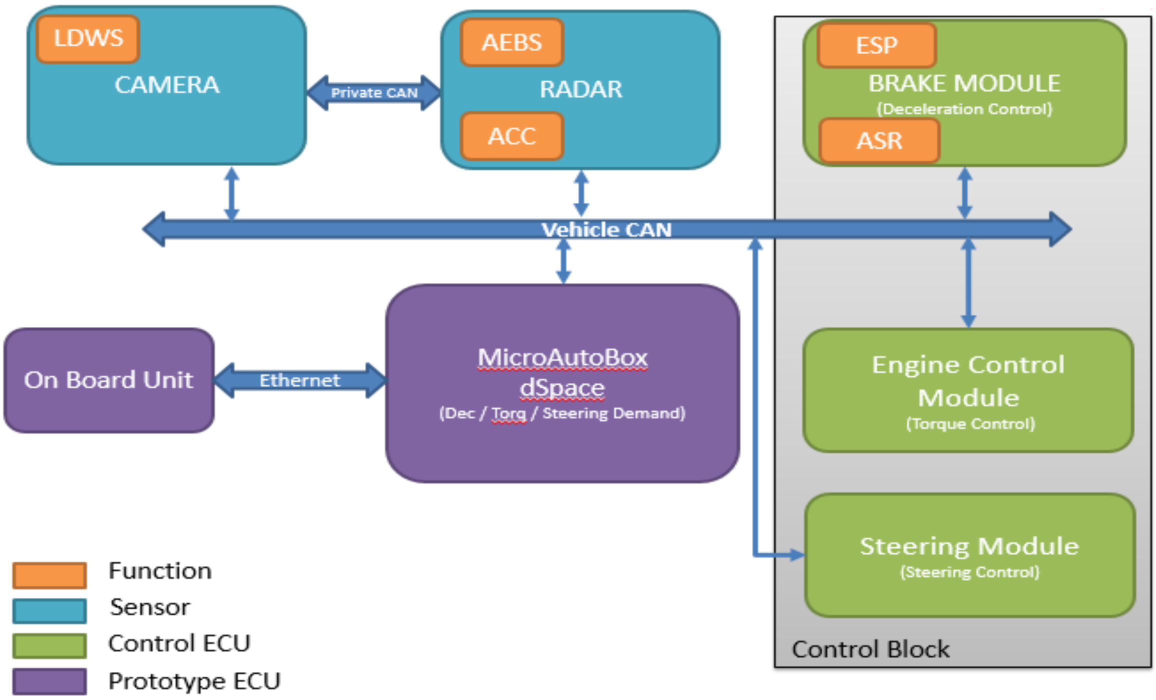

Figure 15: General architecture of F-MAX tractors

4.1.2. Automated driving functions

F-MAX trucks originally have advanced emergency braking, lane departure warning and adaptive cruise control systems. Ford Otosan R&D team will add also C-V2x connectivity feature to vehicles so that they will be used in trials.

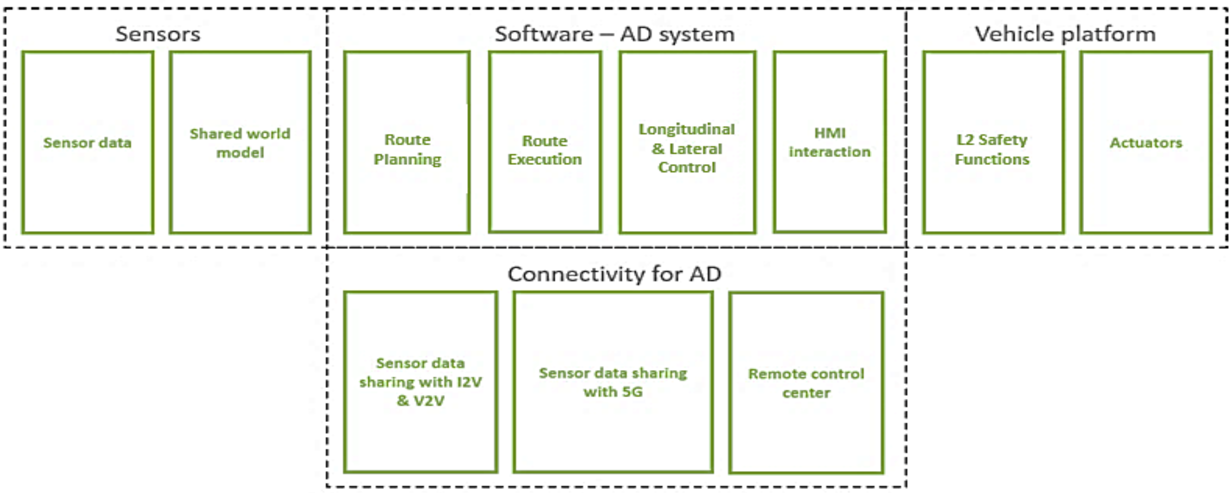

Figure 16: Automated driving functions of the F-MAX

With the help of the connectivity, trucks will be autonomously routed in a controlled area. Automated driving functions of the F-MAX can be seen on Figure 16.

4.2. UCC#3: Extended Sensors at the GR-TR CBC

4.2.1. Description of the use case category

The description of this use case category has already been provided in section 3.3.1.

4.2.2. Requirements on vehicle architecture for extended sensors

To enable this use case category, GR-TR platform shall be able to collect a large amount of data, both from the road side unit as well as from on-board sensors mounted in the vehicles (trucks). To do so, a functionality of data collection inside the vehicle shall be implemented. The connectivity to the data collection platform shall be ensured to efficiently deliver the data.

4.2.3. Vehicle automated driving functions for extended sensors

The "assisted truck border-crossing & increased cooperative awareness" use case to be executed in the GR-TR corridor will be realized through the upgrade and use of the WINGS's cloud platform, STARLIT (Smart living platform powered by ArtIficial intelligence & robust iot connectivity) [5], which will provide the assisted driving functionality necessary for the completion of the trial. This functionality will be enabled by the collection of a large amount of data, both from the road side unit as well as from on-board sensors mounted in the vehicles (trucks). The additional functionality offered by the STARLIT platform is based on intelligent heterogeneous data processing and concerns reduced times for customs inspections (even reaching the ideal scenario of "zero-touch" inspection), improved decision making by the customs officers and even increased safety and security of all customs personnel, by providing autonomous driving instructions to the trucks. The exact use case flow has been described in detail in D2.1, while the STARLIT architecture and its functionality has been described in detail in D2.3. In this section, we describe the vehicle (truck) on-board sensors which feed data to the STARLIT platform and enable its intelligent functionality.

In the context of a demonstration scenario relevant to this use case, the vehicle (truck) is expected to be equipped with a number of devices so that it is characterised as capable of automated, assisted border crossing even down to the level of a "zero-touch" border crossing.

Besides the basic vehicle measurements which will become available through its OBU (speed, heading, coordinates, etc.), we envision mainly two types of control regarding its cargo relevant to (a) checks on the type and quantity of the products being transferred and whether these are consistent with the vehicle's manifest, and (b) the illegal presence of humans or animals (smuggling). Regarding the former, the foreseen equipment aiding these checks comprises NFC-enabled devices that are scanned by an NFC reader so as to identify product type and quantity, whereas regarding smuggling, we envision the deployment of thermal cameras and CO2 sensors that are both capable of detecting human or animal presence. All this information is aggregated by a gateway located inside the truck and it is transmitted wirelessly to the vehicle's OBU that in turn sends them to WINGS STARLIT platform. This system will be deployed at a MEC server or a cloud-based environment, through the 5G network for processing. Once the processing results are available, they are sent from STARLIT to the inspection center of the corresponding country.

Figure 17 below depicts these different changes in the concerned vehicle.

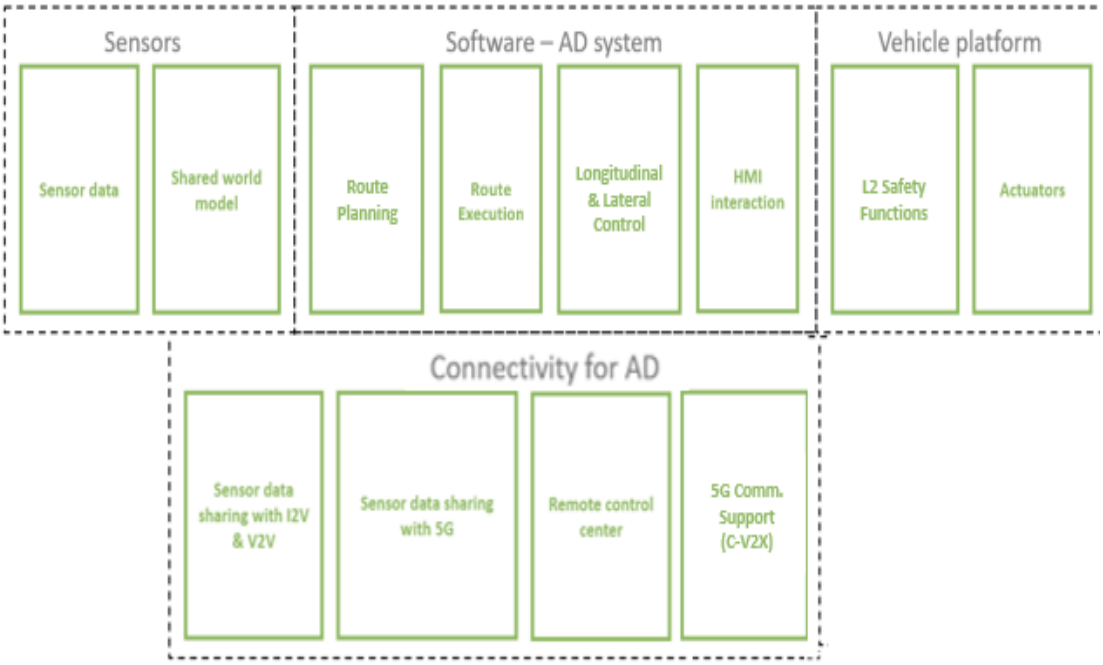

Figure 17: GR-TR CBC vehicle AD function development to support Assisted Truck Border-Crossing & Increased Cooperative Awareness use case

4.2.4. Portfolio of transferable assets

In Table 9, we provide an overview of the possible tangible assets that both DE and FI trial sites will provide to the GR-TR corridor to enable user stories of extended sensors category.

Table 9: Assets to be transferred to the GR-TR CBC for Extended Sensors UCC

TSs contributing	DE	FI
List of assets to be transferred to the GR-TR corridor	• Onboard computer vision LDM and EDM software for enhanced AVs perceptions based on V2X communication. (Deplending on the level of support at CBC)	• The LEVIS (Live strEaming VehIcle System) platform from AALTO is used to obtain HD video streams (with location tags) from vehicle(s) and relaying it authorized subscribers of the stream. The LEVIS-Client application is deployed in the vehicle on a single-board computer (e.g. Raspberry-Pi) to gain access to the vehicle's camera(s). It provides users with services including Live Streaming, Local Recording and Uploading Recorded Streams.The LEVIS-Server (web platform) offers a secure platform that enables only authenticated subscribers to access the different streams for watching and enables streams' owners to manage their streams. would allow the remote operator to have further understanding of the triggering events.

4.3. UCC#4: Vehicle Platooning at the GR-TR CBC

4.3.1. Description of the use case category

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.

4.3.2. Requirements of vehicle architecture for vehicle platooning

To enable see-what-I-see capability, the platoon leader vehicle has to be able to share sensors data and camera video streams. To do so, a data sharing through 5G, or C-V2X shall be enabled. Furthermore, an application capable of sending compressed (with H.265/HVEC codec standard) 4K video stream is required. This video encoding shall be able to take into account the quality of the link used for transmissions.

4.3.3. Vehicle automated driving functions for vehicle platooning

User Story: Truck platooning with "see-what-I-see" functionality

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, two or more vehicles on the move will decide to form a platoon. In the platoon, while one of the vehicles takes 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 can take a rest and let the platoon leader take control of their movement.

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.

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.

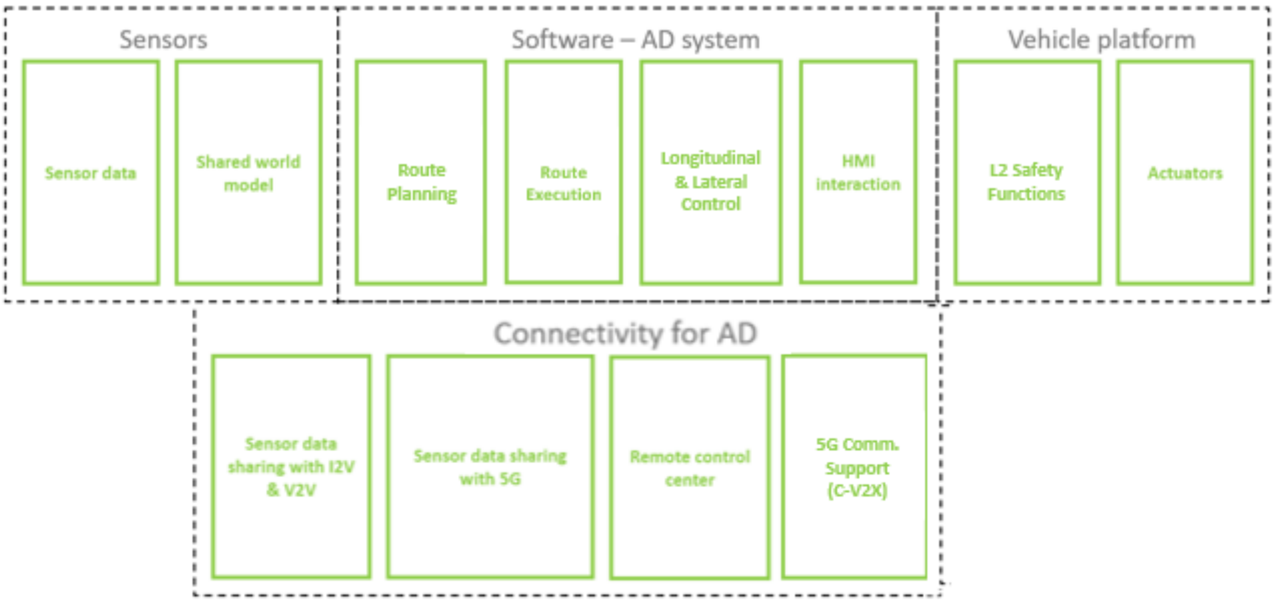

Figure 18: GR-TR CBC vehicle AD function development to support Truck platooning with "see-what-I-see" functionality use case

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.

The above required automated function to enable the user story are illustrated in Figure 18.

4.3.4. Portfolio of transferable assets

TS contributing	DE	Fi, FR, NL	CN
List of assets to be transferred to the GR-TR corridor	• Generation of 360° surround views (still under discussions) • LDM/EDM	• Encoding and Decoding Functionality for Video Streaming Application	• Feedbacks on 5G-capable test vehicles for testing platooning

below summarize the different contributions of trial sites to the GR-TR corridor for the vehicle platooning UCC.

Table 10: Assets to be transferred to the GR-TR CBC for Vehicle Platooning UCC

TS contributing	DE	Fi, FR, NL	CN
List of assets to be transferred to the GR-TR corridor	• Generation of 360° surround views (still under discussions) • LDM/EDM	• Encoding and Decoding Functionality for Video Streaming Application	• Feedbacks on 5G-capable test vehicles for testing platooning

5. EXTENDED EVALUATIONS

5.1. UCC#1 Advanced Driving - Extended Evaluations

This section aims to highlight the unique issues addressed locally in each trial site, and the complementarity aspects in their user stories, within extended sensors use case category, compared to cross-border corridors. Trials sites will be evaluating different architectures, solutions from a vehicle perspective, that can help by providing consultancy, pre-testing, and additional evaluations. Obviously, these contributions are difficult to be brought to the cross-border corridors, and therefore they are addressed locally.

5.1.1. Complementarity & added value to CBC trials

Automotive connectivity is a critical element for advanced driving use case stories because it will allow vehicles to exchange information and to talk to the infrastructure. Trial sites will be testing different connectivity solutions for the same issues addressed in CBCs. In the following, complementarity features will be described for each trial site.

Complementarity & added value from FR trial site

To this end, the FR trial site, developing infrastructure based advanced driving user story, will test an OBU-based seamless handover technique (5G, PC5, 4G, satellite link) which operates by monitoring the link quality and application requirements. On the other hand, the ES-PT corridor will implement a roaming approach between two 5G networks. Thus, the FR site approach will provide insights on different handover scenario using two PLMNs when 5G network is not available at a cross-border situation. In addition, the FR site will integrate different ETS V2X services/messages, which have already been developed in previous projects, to carry out advanced driving manoeuvres. MCM and CPM messages from the vehicle perspective, will be a key element developed in this context. Hence, AVs will exchange MCM messages (V2V communication) to negotiate a safe lane change maneuver.

Complementarity & added value from NL trial site

NL trial site will focus mainly on precision collision risk detection and calculation. The approach is to use direct V2V communication by utilizing LTE/5G-NR sidelink or ITS-G5. An MCM approach will be also tested in the NL site for advanced maneuvers. In addition, they will test a seamless handover approach between two independent and different supplier 5G NWs only.

Complementarity & added value from CN trial site

On the other hand, for advanced driving, CN trial site will add value to CBC trials with collision avoidance and lane changing manoeuvres. This value will be implemented by our coordinated overtaking. For instance, vehicle A receives the overtaking order or detects the obstacles. And then vehicle A sends the overtaking or obstacle information to Vehicle B, which sends back instant information, including vehicle position, speed, course angle, etc. While RSUs receives the information, they fuse them to send to a cloud server. Thus, Cloud server decides its actions according to the information and carries out corresponding path planning.

5.1.2. Additional facilities for UCC#1 evaluation

Additional facilities at FR trial site

The FR site is going to carry out an OBU-based seamless handover when testing lane change manoeuvre. The goal is to test different soft handover scenarios (4G, 5G, satellite communication). This will be done through the use of a 5G OBU connected to an external modem for 4G connection, and also a satellite communication device. The FR site will be unique to test the use of satellite communication link during advanced driving manoeuvres. This is not feasible to test in the ES-PT corridor since they lack this kind of technology. However, this soft handover benchmark will provide the ES-PT corridor with useful insights on the performances of the switching mechanism from 5G to other technologies such 5G, and 4G.

Additional facilities at NL trial site

In the NL trial site, an in-vehicle manoeuvring calculation will be carried out to enable advanced driving manoeuvres. This will be coupled by a MEC computing to help in this procedure. Since the ES-PT corridor is mainly focusing on the vehicle side, the NL trials will give insights on the added values of using infrastructure, and also on how their different on-vehicle calculation mechanism can improve the efficiency of advanced manoeuvre compared to the one developed in the ES-PT corridor.

Additional facilities at CN trial site

Collision avoidance tests will be conducted at the CN test site, where OBU and MEC will be used to test the switch between 4G and 5G. The purpose is to test how to implement the internal running switch in a timely manner.

5.2. UCC#2 Vehicle Platooning - Extended Evaluations

5.2.1. Complementarity & added value to CBC trials

Complementarity & added value from DE trial site

The DE trial site is developing the only user story of this category with a V2V platooning message pipeline and an intensive MEC processing for EDM generation including an RSU-driven approach. On the other hand, the user story at GR-TR delivers 4K video streams from the platoon leader to members over 5G network and streaming service/server. Going beyond, DE will develop a different type of solutions by pipelining vehicle data among vehicles and mainly relying on C-V2X and RSUs infrastructure for data communication and processing.

Complementarity & added value from CN trial site

For vehicle platooning, CN trial site will add value to CBC trials with different 5G coverage and multi C-V2X scenario. Within the 5G coverage with multiple areas, the first vehicle in the fleet is controlled by the control centre via 5G. The following vehicles are connected to the first car via V2V under 5G. The control centre sends information to the first vehicle, including driving routes, control commands, etc. The first vehicle in the fleet uploads sensor information (V2C) (including video, radar, etc.) to the control centre, as well as vehicle condition information. The first vehicle in the fleet sends command information (V2V) to the following vehicles (including driving route, driving information, vehicle status, etc.). The following vehicles send condition information (V2V) to the first vehicle.

For multi C-V2X scenario, vehicle moves from area 1 covered by 5G to area 2 covered by LTE-V2X without 5G, which enables remote driving to achieve cross-network handover.

5.2.2. Additional facilities for UCC#2 evaluation

Additional facilities at CN trial site

In the CN trial site, a platooning test will be carried out, in which OBU and MEC will be used to test the transition from 5G to 4G. The purpose is to test how to timely achieve inter-RAN handover.

Additional facilities at DE trial site

DE TS offers 4km test road for the trial of vehicle platooning operations in a long distance. The extensive deployment of eRSUs and road sensors allows highest level of AV perception to be realized and tested. The AV OBUs mainly rely on 5G based V2X communication to exchange data with eRSUs. This unique deployment allows DE TS to investigate flexible communication and application dynamics at mobile access network and to provide alternative solution to handle mobility and service continuity.

5.3. UCC#3 Extended Sensors - Extended Evaluations

5.3.1. Complementarity & added value to CBC trials

Complementarity & added value from DE trial site

The DE trial site will focus on the fusion of video stream from multiple AVs to generate a 360° surround view and it will mainly rely on C-V2X and RSUs for data communications and processing. This constitutes a different approach compared to the one developed in the GR-TR corridor, and then will offer useful feedbacks to cross-border partners. Specifically, the improved environment awareness provided to AVs by

LDM software installed on OBU and EDM on eRSU allows CCAM operations to be carried out by the vehicles, in contrast to the centralized waypoints and operation planning on cloud platform, which is then communicated to AVs. With the added intelligence, the AV platforms are expected to react with AD events in real-time. However, the 5G communication infrastructure is also required to support such dynamics in access network with more advanced features. Thus, the DE TS deployment enables alternative solutions to extended sensor scenarios to be evaluated for benchmarking with CBC implementation. Additionally, the focus on access network components helps in identifying new requirements and extensions for 5G infrastructure to support CCAM use case categories.

Complementarity & added value from FI trial site

In the FI trial site, to enable the extended sensors user story, a device sending video upstream to a video processing/aggregation service will be carried out. The device will register to a different PLMN and will get assigned a new video processing/aggregation service with a different MEC server.

Complementarity & added value from NL trial site

The NL trial site will carry out tests of performances continuity with handover between different PLMNs. CPM implementation on the vehicle side will be also tested, which can provide a different benchmark compared to cross-border tests.

5.3.2. Additional facilities for UCC#3 evaluation

Additional facilities at DE trial site

Beside the additional facilities described above, an extensive deployment of AVs and road side sensors is available at the DE TS. The road-side sensors, e.g., traffic analysis, road condition, environment, cameras, etc, allow a detailed HD maps of the driving environment to be realized. Similarly, on vehicle sensor platform, e.g., lidar, radar, cameras, etc, helps realized high level of vehicle perception. Such extensive deployment also places high requirement on computing and communication infrastructures, which requires novel approaches to be realized for increased efficiency and flexibility. Cloud and edge computing infrastructures are autonomously managed by an orchestration platform, which takes in account real-time application QoS requirements and traffic loads. Various 5G network functions are investigated and extensions to their APIs are realized for increased network performance supporting CCAM scenarios.

5.4. UCC#4 Remote Driving - Extended Evaluations

5.4.1. Complementarity & added value to CBC trials

Complementarity & added value from FI trial site

ES-PT corridor focus has been on roaming between two PLMNs (inter-PLMN, rather than multi-PLMN scenario), but there is noted interest to evaluate multi-PLMN approach in areas with overlapping x-border network coverage. The redundant multi-PLMN approach is an original feature of Finland trial site.

Complementarity & added value from NL trial site

The NL trial site will carry out a test localization of vehicles over 5G and test different frequency bands: i.e., 3.5 GHz and 26 GHz. The use of a localization algorithm that is able to switch between both in an optimal way (also on more commonly available frequency bands) is found feasible since it will offer more flexibility for the vehicle side

Complementarity & added value from CN trial site

The CN will carry out a multi C-V2X scenario in which a vehicle will move from an area covered by 5G to another area covered by LTE-V. This will enable remote driving to be tested in cross-network handover. This scenario will complement the scenario on GR-TR corridor. A data adjustment will be also implemented in uplink and downlink based on the quality of service of the network.

Complementarity & added value from KR trial site

The use case in the KR trial site aims to validate the feasibility of remote driving system based on mmWave-band V2I communication. Since mmWave frequency is higher than the 5G frequency in the GR-TR corridor, it is expected that its performance will be far superior to the other existing remote-control user stories in terms of data rate and latency.

In addition, the user story implemented in KR trial site is focusing on four real time video streams (front, left side, right side, and rear) require high data rate uplink communication supporting system bandwidth up to 1GHz. In order to provide stable high data rate uplink wireless connectivity, mmWave band V2I communication will be implemented. Only KR partners are developing remote vehicle user story based on 5G NR-based V2I/N system operating at a mmWave band (22~23.6 GHz).

5.4.2. Additional facilities for UCC#4 evaluation

Additional facilities at CN trial site

OBU and MEC will be used to switch between 4G and 5G networks during remote driving tests at high-speed intersections at the CN trial site. When the 5G network connection is interrupted, whether the connection can be switched in time and connected to the available 4G network is crucial for remote driving technology.

5.5. UCC#5 Vehicle Quality of Service Support - Extended Evaluations

5.5.1. Complementarity & added value to CBC trials

Complementarity & added value from FR trial site

FR site is the unique site considering coverage gap and hybrid network connectivity (4G/5G/Sat) when developing its user story belonging to Vehicle QoS support UC category. It is developing an intelligent network selection procedure and data adaptation when network conditions change. FR site considers that a normal cross-border scenario will suffer from a network coverage gap when the vehicle is crossing the border. For this, FR site will use different generation of cellular networks (5G, 4G) and satellite communications.

A data adaptation will be carried out during seamless handover in order to maintain the QoS of user story. In addition, the FR site will test a law enforcement scenario where the police authority will send a stop request to the AV when this latter is detected to be suspicious.

Complementarity & added value from KR trial site

The user story in the KR trial site is focused on providing high data rate WiFi service inside a vehicle including public transportation like a bus. In order to support such in-vehicle wireless connectivity, mobile backhaul link between base stations installed along the road and onboard terminals deployed at a vehicle will be implemented and tested.

In addition, a broadband onboard connectivity is enabled by mmWave-band 5G NR V2I/N communications supporting system bandwidth of up to 1 GHz. While the user story at the ES-PT CBC uses a 5G NR band at 3.6 GHz, the Korean user story aims to validate the feasibility of the mmWave-band V2I/N communications by showcasing a variety of onboard mobile services and its performance far superior to the other existing V2X communications in terms of data rate and latency.

5.5.2. Additional facilities for UCC#5 evaluation

Additional facilities at FR trial site

The French trial site will use satellite communication as the unique site in 5G-MOBIX project to test seamless handover between different technologies (5G, 4G, sat comm). As the ES-PT corridor is not considering this communication vector during their test, the use of satellite technology in the FR site will enrich this benchmark of testing and can give more insights on the advantages of such technology.

6. CYBER SECURITY & DATA PRIVACY ASPECTS

Connected and automated vehicles are today the targets of various attacks that threaten the security, safety and privacy of passengers and other citizens. These threats might have huge impacts on manufacturers and might result in a bad reputation for a research project such as 5G-MOBIX.

The protection of connected and automated vehicles depends on the protection of all the systems involved (vehicles' components, cloud infrastructure, 5G network, other networks, etc.). Each of these systems has been addressed in the following deliverables:

- D2.1 presents the overview of security and privacy issues in 5G-MOBIX
- D2.2 presents cybersecurity and data privacy aspects related to 5G technologies and networks used in the project
- D2.3 presents the overall cybersecurity and data privacy aspects related to CCAM.

This chapter studies the challenges residing mostly in the security of the connected and automated vehicles, where security mechanisms should be implemented in spite of the several kinds of limitations due to the very large number of interfaces to secure which might lead to conflicts between security requirements and safety requirements, planning and cost issues.

The augmented vehicles used in 5G-MOBIX, as described in previous sections, integrate IoT components to bring added-value services to drivers and passengers. These components communicate with each other and with the outside world of the vehicle (other vehicles, 5G network, etc.). This chapter summarizes the components of the vehicles used in 5G-MOBIX trial sites as well as the corresponding threats, risks, mitigation factors and possible security measures to implement.

Also, good practices, intended for the trial sites, that ensure the security of the connected vehicle against cyber threats are presented, with the particularity that connected vehicles security shall also guarantee safety. These good practices are listed as follow: Policy and standards, organizational measures, and security functions.

The impact of attacks on the vehicles, described in this deliverable, used could have far-reaching consequences in terms of safety. The risks to the driver, their passengers and other users of the road during the trials should be managed by each trial site.

6.1. Threats and risk related to connected and automated vehicles

The following figure provides an overview of the general components of connected and automated vehicles used in 5G-MOBIX.

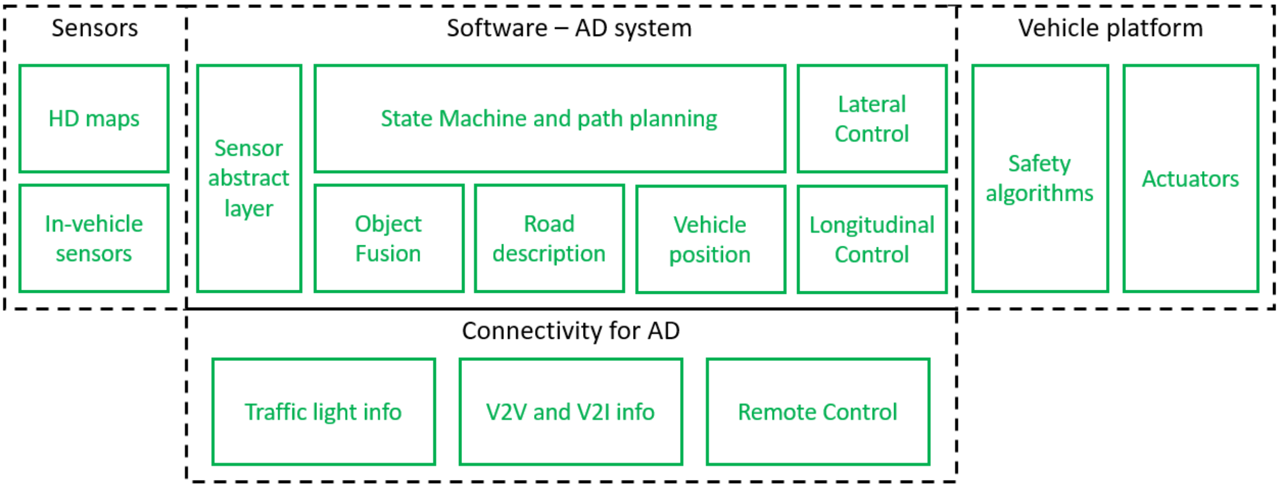

Figure 19: Connected and automated vehicles' components

Each of the components listed above belongs to the typical architecture parts of smart cars. Moreover in Table 11, each of these parts are described and illustrated by providing the equivalent components in vehicles used in the different trial sites of 5G-MOBIX project [25].

Table 11: The parts of a connected vehicles mapped with 5G-MOBIX vehicles.

Parts[1]	Description	Equivalent on 5G-MOBIX Vehicles
Powertrain control	This domain is in charge of the chain between the energy source of the car and its transformation into propulsion.	Sensors, Vehicle platform, Software-AD system
Chassis control.	This domain is in charge of the control of the vehicle frame with regard to its environment	Sensors, Vehicle platform, Software-AD system
Body control.	The body control is in charge of the body, which means most of the time the passenger's compartment and trunk.	Sensors, Vehicle platform, Software-AD system
Infotainment control.	This domain is generally separated from the remainder of the body. It includes navigation services, communications (telephone,	-

[1] https://www.enisa.europa.eu/publications/cyber-security-and-resilience-of-smart-cars/at_download/fullReport

	etc.) as well as entertainment services (head unit audio/video).	
Communication control.	This domain, contrary to the previous ones, is not a subnetwork, but more frequently a set of communication features offered by a Telematics control unit (TCU), acting as a gateway.	Connectivity for AD.
Diagnostic and maintenance systems.	Diagnostic and maintenance systems are external systems interfaced with the car through a dedicated port. Aftermarket dongles are also included in this category, since they use the same interfaces. It should however be noted that they do not necessarily provide maintenance or diagnostic features	Sensors, Vehicle platform, Software-AD system.

After listing the different components of 5G-MOBIX vehicles in Table 11, the table below presents the different threats available on the connected and automated vehicle.

Table 12: Different threats facing the connected and automated vehicle

Category	Threat	Description	Assets affected
Physical	• Side channel, fault injection, glitching, access to HW debug ports.	• Physical threats arise from a well-identified attack vector and they might lead to various type of risk suck us: tampering with the ECUs or TCUs (to recover keys or access physical debug interfaces) using the device electro-magnetic emanations or power usage to leak information (side-channel); use light, power or other mean to alter	• ECU and sensors (privileged debug interfaces of the ECUs causing cascading impact on all assets).

		the device behaviour and ultimately gain access to protected data.	
Unintentional damages (accidental)	• Erroneous administration of devices and systems. • Lack of awareness • Inadequate design and planning or lack of adaption.	• Trial sites must be aware of the importance of data privacy and security by adopting a security by design approach and following a strict policy for managing the ICT infrastructure.	• All assets.
Disasters and Outages	• Network outages.	• Many designs relying too much on connectivity expose the vehicle to potential issues in case of outages. ENISA recommends that the vehicles be designed to offer a usable degraded mode of operation in case of outage.	• All assets.
Damage / Loss	• Loss of information in the cloud.	• Sensitive data may be lost due to attacks when stored by third party CSPs.	• Sensitive data stored by CSPs
	• Loss (of integrity) of sensitive information.	• The integrity of sensitive data can be lost due to wear and tear, failures and or malfunctions.	• All assets.
	• Information leakage.	• Private and sensitive data may be leaked when the driver/owner of the car change.	• Private data transmitted over subnetworks .
Failures / Malfunctions	• Failures or disruptions of the power / main supply.	• See Network outage.	• All assets.
	• Software bugs.	• The presence of software bugs is a basis for potential exploitable vulnerabilities	• All assets
	• Failure or disruption of communication link.	• See Disasters and Outages - Network outage.	• All assets.

Eavesdropping / Interception / Hijacking	• Man in the middle / session hijacking.	• Seen the large set of interfaces, there are many incentives for an attacker to impersonate a distant user. •	• All assets.
	• Network reconnaissance and information gathering.	• Information on car networks can be obtained in many ways.	• Wireless external communication networks or subnetworks.
	• Replay of the messages.	• Attackers may have access to a wide range of critical commands if the internal networks are not protected.	• Sensitive data transmitted on subnetworks
	• Repudiation of actions.	• Data related to the car usage can be compromised if the liability of the driver is engaged.	• Data related to powertrain control, chassis control or infotainment control.
Nefarious Activity / Abuse	• Denial of service.	• A denial of service can be triggered on internal network by flooding a CAN bus, or by provoking faults on an ECU via a malicious payload. The potential impact of such an attack depends on the targeted ECU but may lead to unexpected behaviours from driving systems.	• All assets.
	• Manipulation of hardware, software and information.	• Changing or reconfiguring the firmware of a component may endanger the vehicle manoeuvre.	• All assets

	• Unauthorized access to information system network.	• A remote attacker can take the control of an ECU and take the control of a car by sending driving-related commands.	• All assets.
	• Compromising confidential information.	• Attackers may deliberately compromise private data or sensitive data such as keys.	• All assets.
	• Unauthorized use of administration of devices & systems,	• A user may try to access unauthorized functions in order to bypass the normal functioning of the vehicle.	• All assets.
	• Identity fraud.	• The simplest case of identity fraud is the cloning of a key fob.	• All assets.
	• Abuse of authorization, abuse of information leakage.	• A disgruntled employee (backend services, garage) may use their authorizations to perform malicious actions. A slightly different scenario would be for an infotainment application to abuse its authorizations.	• All assets.
	• Malicious software activity.	• Malicious software may provide an attack vector to get in the driving system of the vehicle.	• All assets
	• Remote activity (execution).	• All external interfaces may be subject of a remote code execution which may result an access to the driving system of the vehicle.	• All assets
Advanced Persistent Threats	• One or many combined attacks (listed above) used to inflict considerable damage to an Information System or alternate stealthy its normal functioning.	• Smart cars are exposed to Advanced Persistent Threats where the attackers can move laterally into multiple systems. This risk is also relevant for infrastructures. Such attacks typically use several types of methods and entry points.	• All assets

Most of these threats could be exploited to conduct several attacks [6] such as remote attacks, persistent vehicle alteration, theft and surveillance, while the last one remains one of the highest importance threats. There are essentially two kinds of plausible surveillance scenarios:

- Targeted surveillance, where a single individual is tracked using a vulnerability in its vehicle systems.

- Mass surveillance, where a large number of individuals are tracked through some common vulnerability.

An alternative to both scenarios consists in performing surveillance only on cloud-stored data, instead of focusing on vehicles. For more information see [7].

6.2. Recommendations for computer security

Figure 20 depicts a schematic view of the security module in an ITS-Station and the protected interfaces to interact with it, according to ETSI TS 102 940 V1.1.1. Inside the ITS-S, only a secure processing engine – the cryptographic module – must access the keys. Other modules and applications should solely deal with key handles. The cryptographic functions and key storage must be restricted to a secure module deployed in tamper resistant hardware, protecting the key material and offering cryptographic operations as services to all other applications. Well-defined interfaces should be specified to separate applications from the cryptographic module, in order to avoid unsolicited interaction.

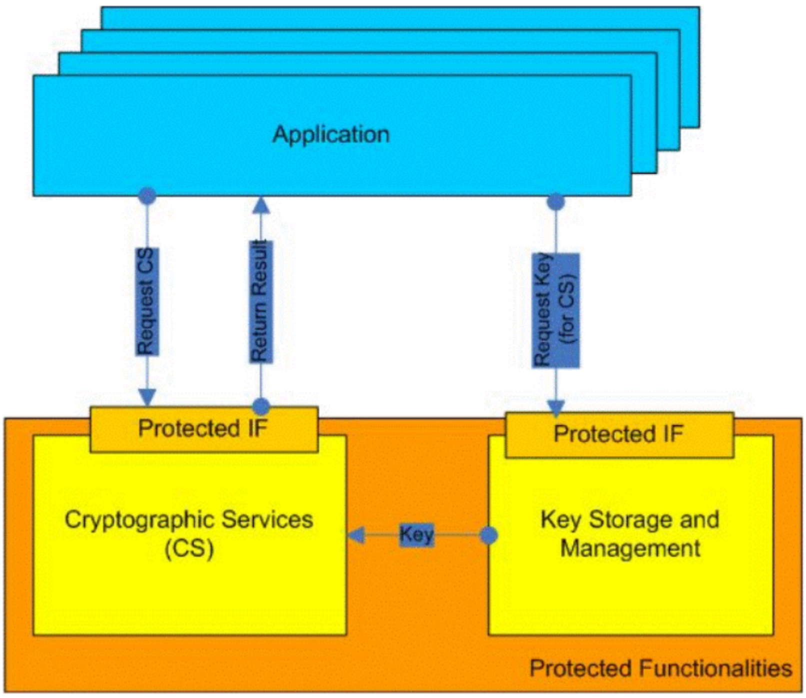

Figure 20:Secure module access in an ITS-S [8]

6.3. Security good practices for 5G-MOBIX vehicles

The good practices presented in this section are to be considered with the security requirements set in the deliverables D2.2 and D2.3.

6.3.1. 5G security modules

The following security requirements can be listed in the scope of CCAM communications:

- Message Authentication and Integrity: V2X messages must be protected from any alteration and the sender must be authenticated.
- Message Non-Repudiation: The sender cannot deny having sent a given message (related to Message Authentication).
- Entity Authentication: Once it receives an unmodified message, the receiver has the proof of liveness of the sender.
- Access Control: A set of policies which defines which entity is allowed to do what in the network (e.g. which types of messages can be inserted in the network).
- Message Confidentiality: Content of the message is kept secret from those nodes that are not authorized to access it.
- Privacy and Anonymity: It must be difficult for an observer to learn if a node performed or will perform in a specific action in the future (assuming that the node actually performs the action).
- Availability: The security infrastructure (e.g. protocols + services) should implement specific protocols to be fault-tolerant to benign or malicious faults.
- Liability Identification: In case of malicious action/behaviour, it must be possible to recover the identity of the malicious actor/entity.

Based on ISO/IEC 15408-2, ETSI TS 102 941 identifies four key attributes that relate to ITS privacy:

- Anonymity: alone is insufficient for protection of an ITS user's privacy.
- Pseudonymity: ensures that an ITS-S may use a resource or service without disclosing its identity but can still be accountable for that use.
- Unlinkability: Service providers cannot link different transactions by the same user even if he/she uses the same credentials, unless he/she uses the same pseudonym.
- Unobservability: Even if the credential issuer and service providers collude, they cannot track the use of a credential back to the user identity.
- Unlikability and Unobservability ensure that an ITS-S may make multiple uses of resources or services without others being able to link them together.

6.3.2. Policy and standards

Table 13 highlights some standards about good practices.

Table 13: Policy and standard good practices

CATEGORY	Description
Policy and standards	**GP1 – Adherence to regulation**. Each trial site should, as a first step, adhere to regulation related to security and privacy.

	GP2 – Liability. The liability issues should to be addressed in the context of national legislation and case law. Where gaps are identified in national legislation, these should be addressed.
	GP3 – Traceability. Each trial sites should ensure that appropriate technical measures (e.g. logging, distinct authentication, transparency provided through OEM/Tier sites concerning each particular car/component, integration with type approval authorities and monitoring agencies) exist allowing for tracing liability between actors.

6.3.3. Organizational measures

Table 14 below highlights the different organizational measures and good practices required to enable CCAM from the vehicle perspective.

Table 14: Organizational measures good practices

CATEGORY	GOOD PRACTICES
Organizational measures	**GP12 - Check the security assumptions regularly during life-time.** The devices and services made assumptions to ensure that the security requirements are sufficient (limitations in the usage of the vehicle, assumed properties of the environment, assumed properties of cryptographic properties). Each trial site and users should check regularly that these assumptions are still valid.
	GP13 - Protect the software update mechanism. Each trial site should protect the updates (typically via encryption and digital signature) and protect the application of an update in the vehicle. Eventually, the update server and infrastructure (Including diagnostic tools) should also be protected.
	GP14 - Raise user awareness. Each trial site should explain users what actions can contribute to mitigate potential threats, especially how to securely use interfaced systems such as a smartphone. In the other side, a car owner often does not know what was changed in his car. OEM shall support users by setting up issue-tracking sites where users can track changes of their cars and report problems.

6.3.4. Technical measures

Table 15 displays technical measures and good practices.

Table 15: Technical measures good practices

CATEGORY	GOOD PRACTICES
Security functions – Security audit	**GP16 – Users should be informed of security events**. HW and embedded systems should provide clear error data that can be leveraged upon by the SW vendors. The user must be informed in case of security errors, updates or compromised data in a device or service they use.
Security functions – Communications protection	**GP20 - Protect remote monitoring and administration interfaces.** Each trial site should protect all monitoring and administration interfaces by mutual authentication and access control mechanisms.
Security functions - cryptography	**GP23 - Consider using dedicated, and independently audited, hardware security modules.** The standard for independent assessment of security HW should be either FIPS 140-2, or a Common Criteria certification following relevant Protection Profiles. If needed, consider getting advice from security experts or your national cybersecurity agency.
	GP24 - Cryptographic keys should be securely managed, which means securely generated, distributed (or provisioned), used, stored, and deleted (including revocation). Manufacturers, as well as Tier-1/Tier-2 and aftermarket Trial sites should consider very carefully the revocation mechanisms associated with their components, especially for OTA provisioning or key management.
Security functions – User data protection	**GP25 - Identify personal data.** Each trial should identify all data relating to an identified or identifiable person. In the case of smart cars, this may especially include location-based data. Consider getting advice from your national data protection agency.
	GP29 - Define measures to ensure secure deletion of user data in case of a change of ownership. More generally, a secure factory-reset of the firmware and configuration should be available on the vehicle.
Security functions - Identification, authentication, authorization	**GP34 - Enforce session management policies to avoid session hijacking.**
	GP35 - Provide the user with mechanisms to securely erase its private data. For client information in remote infrastructures such as cloud services, data sanitization must be in place. For user data present on vehicles, secure deletion of encryption keys may provide enough protection, assuming that data is encrypted in conditions that guarantee long-term confidentiality.
Security functions – self-protection	**GP36 - Define a consistent policy for self-protection.** Each trial site should challenge every security function of their design, consider how they could be bypassed or weakened, and eventually implement self-protection measures.
	GP37 – Implement Hardware self-protection. Each trial site should define measures to protect hardware against physical attacks or observation. This includes tamper evidence or tampers resistance and secures design measures.

	GP38 – Implement Software self-protection. Each trial site should define measures to protect existing security functions, typically by validating inputs and outputs, or by separating the capacities of the different software components (levels of trust, virtualization...).
	GP40 – Perform Hardening. Each trial site should actively reduce the attack surface of the product or device. This includes removing or disabling unused services or interfaces (especially debug interfaces), providing secure configuration by default, as well as integrating malware protection. Some actors may consider intrusion detection systems for internal subnetworks (for example CAN bus monitoring), although this study will not conclude on the merits of these solutions.
	GP41 – Isolate components Each trial site should reduce the capacity for attackers to jump from a component to another, either by a physical disconnection or by using gateways.

6.4. Security good practices implemented per trial site

In Table 16 below, we present the security good practices that will be implemented in each trial site.

Table 16: Security good practices implemented per trial site

Trial Site			NL	SP-PR	GR-TK	DE	FR-FN	CN	KR
		Requirements	To be Implemented by the trial site						
Policy And Standards		GP01 – Adherence to regulation	☒	☒	☒	☒	☒	☒	☐
		GP02 – Liability	☒	☒	☒	☒	☒	☒	☒
		GP03 – Traceability	☒	☒	☒	☒	☒	☒	☒
Organizational Measures	Security until the End-Of-Life	GP12 - Check the security assumptions regularly during lifetime.	☒	☐	☒	☒	☒	☒	☒
		GP13- Protect the software updates mechanism.	☒	☐	☒	☒	☒	☒	☒
		GP14 - Raise user awareness.	☒	☒	☒	☒	☒	☒	☐
		GP15 - Provide end-to-end protection in confidentiality and integrity	☒	☒	☒	☒	☒	☒	☐
		GP16 - Mitigate vulnerabilities or limitations of standard security library.	☒	☒	☒	☒	☐	☒	☒
		GP19 - Consider denial of service as a usual threat to communication Infrastructures.	☐	☐	☒	☒	☒	☒	☐
		GP20 - Protect remote monitoring and administration interfaces.	☐	☒	☒	☒	☒	☒	☐
		GP30 - Use mutual-factor authentication for remote communication.	☒	☒	☒	☒	☒	☒	☐
		GP31 - Use multi-factor authentication for user authentication.	☒	☐	☒	☐	☐	☐	☐
		GP32- Implement access control measures to separate the privileges of different users and the privileges of different applications as well as to ensure traceability of access and modifications.	☒	☒	☒	☒	☒	☒	☐

		GP33 - Allow and encourage the use of strong passwords.	☒	☒	☒	☒	☒	☒	☒
Technical	Communication Protection	GP34 - Enforce session management policies to avoid session hijacking.	☒	☐	☒	☒	☒	☒	☐
		GP35 - Provide the user with mechanisms to securely erase their private data.	☐	☐	☒	☒	☒	☒	☐
		GP15 - Security events must be securely logged	☒	☐	☒	☒	☒	☒	☒
		GP16 – Users must be informed of security events.	☒	☐	☒	☒	☒	☒	☒
	Identification, Authentication, Authorization	GP36 - Define a consistent policy for self-protection.	☒	☒	☒	☒	☐	☒	☒
		GP37– Implement Hardware self-protection.	☒	☐	☒	☒	☒	☒	☒
		GP38 – Implement Software self-protection.	☒	☒	☒	☒	☒	☒	☒
		GP39 – Protect Non-user data.	☒	☒	☒	☒	☒	☒	☒
		GP40 – Perform Hardening.	☒	☐	☒	☒	☐	☒	☒
		GP41 – Isolate components.	☒	☒	☒	☒	☒	☒	☒
	Security Audit	GP21 - Do not create proprietary cryptographic schemes but use state-of the-art standards instead.	☐	☒	☐	☒	☒	☒	☐
		GP22 - Rely on an expert in cryptography.	☐	☐	☒	☒	☐	☒	☐
	Self-Protection	GP23 - Consider using dedicated, and independently audited, hardware security modules.	☐	☒	☒	☐	☐	☐	☐
		GP24 - Cryptographic keys should be securely managed.	☐	☒	☒	☒	☒	☒	☐
		GP25 - Identify personal data.	☒	☒	☒	☒	☐	☒	☒
		GP26 - Implement transparency measures.	☒	☐	☒	☒	☒	☒	☒
		GP27 - Design the product/service with legitimate purpose and proportionality in mind.	☒	☒	☒	☒	☐	☒	☒
		GP28 - Define access control, anonymity and unlinkability measures to enforce the protection	☒	☒	☒	☒	☐	☒	☒

		of private data.							
	Cryptography	GP29 - Define measures to ensure secure deletion of user data in case of a change of ownership.	☒	☐	☒	☒	☒	☒	☐

7. CONCLUSION

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.

The document 5G-MOBIX D2.1 presents a detailed description of the 5G-MOBIX user stories that will be implemented in the different cross border corridors and trial sites. The user stories are classified into five use case 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. In addition, D2.1 describes the classification into categories of different issues present at the cross-border areas when operating advanced CCAM applications.

This document D2.4 describes the 5G augmented automated driving functions of different vehicles used for each cross-border corridor and trial site. The descriptions scope comprises the on-board units, (and 5G chipset), automatic control functions, as well as the required sensors, and cyber-security. As such, several OEMs and multiple 5G-chipset providers will be involved during 5G-MOBIX project to enable and showcase CCAM use cases. This also requires several augmentations in the different AD and sensing components of autonomous vehicles.

Furthermore, for each cross-border corridor, detailed description of local sites concrete contributions from a vehicle perspective are highlighted. These contributions depict the different tangible assets that will be provided by local trial sites to both cross-border corridors.

This deliverable has also carried out a detailed study of the different extended evaluations of cross-border user stories at the different trial sites. These extended evaluations present the different issues that will be addressed in trial sites and not in cross-border corridors.

A special attention has been given to measures to ensure cyber-security, data protection and compliance to the applicable data privacy regulations in Section 6.

All these elements are described and specified 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.

REFERENCES

[1] "5G-MOBIX Deliverable D2.1, "5G-enabled CCAM use cases specifications", April 2019".

[2] "[2] 5G-MOBIX Deliverable D2.3, "Specification of roadside and cloud infrastructure and applications to support CCAM", July 2019.".

[3] "5G-MOBIX Deliverable D2.4, "Specification of Connected and Automated Vehicles", July 2019.".

[4] "5G; Service requirements for enhanced V2X scenarios (3GPP TS 22.186 version 15.3.0 Release 15), July 2018".

[5] "https://www.wings-ict-solutions.eu/assisted-living-smart-home".

[6] "Autopilot projetc, D1.9 Initial Specification of Security and Privacy for IoT- Enhanced AD".

[7] "ENISA, Cloud Security Guide for SMEs".

[8] "ETSI TS 102 940 V1.1.1, Intelligent Transport Systems (ITS); Security; TS communications security architecture and security management".

[9] "3GPP TS 22.185: Service requirements for V2X services.".

[10] "RAZA, Salman, WANG, Shangguang, AHMED, Manzoor, et al. A Survey on Vehicular Edge Computing: Architecture, Applications, Technical Issues, and Future Directions. Wireless Communications and Mobile Computing, 2019, vol. 2019".

[11] "Rappaport, T. S., Xing, Y., MacCartney, G. R., Molisch, A. F., Mellios, E., & Zhang, J. (2017). Overview of millimeter wave communications for fifth-generation (5G) wireless networks—with a focus on propagation models. IEEE Transactions on Antennas and Pr".

[12] "P. Popovski, K. F. Trillinsgaard, O. Simeone and G. Durisi, "5G Wireless Network Slicing for eMBB, URLLC, and mMTC: A Communication-Theoretic View"".

[13] "https://www.oracle.com/technetwork/java/javase/downloads/jdk11-downloads-5066655.html".

[14] "https://www.osgi.org/developer/architecture/".

[15] "Intelligent Transport Systems (ITS),Vehicular Communications: GeoNetworking;Part 1: Requirements. ETSI".

[16] "mqtt.org/".

[17] "ZeroMQ," [Online]. Available: https://zeromq.org.

[18] "3GPP Work Item RP-190766: 5G V2X with NR sidelink".

[19] "https://www.auto-talks.com/product/secton".

[20] "https://www.5g-mobix.com," [Online]. Available: https://www.5g-mobix.com.

[21] "https://github.com/alexvoronov/geonetworking/blob/master/HARDWARE.md".

[22] "ETSI EN 302 663: Intelligent Transport Systems (ITS); Access layer specification for Intelligent Transport Systems operating in the 5 GHz frequency band.".

[23] "ETSI Multi-acccess edge computing main web page: https://www.etsi.org/technologies/multi-

access-edge-computing”.

[24] “ZigBee Document 053474r06, Version 1.0, ZigBee Specification. Zigbee Alliance. 2004.”.

[25] “http://www.linuxembedded.fr/2017/12/introduction-a-lora/”.

[26] “Kurawar, Arwa; Koul, Ayushi; Patil, Viki Tukaram (August 2014). "Survey of Bluetooth and Applications". International Journal of Advanced Research in Computer Engineering & Technology. 3: 2832–2837”.

[27] “https://www.cisco.com/web/TH/assets/docs/seminar/200903_Night_Academy_3_1_WLAN_Introduction.pdf”.

[28] “https://www.autosar.org/”.

[29] “ETSI EN 302 636-3 V1.2.1 (2014-12) Intelligent Transport Systems (ITS); Vehicular Communications; GeoNetworking; Part 3: Network Architecture”.

1. ANNEX A: DEPLOYED VEHICLES AT TRIAL SITES

1.1. A.1 Vehicles in trial site Germany

1.1.1. A.1.1 TUB vehicle

TUB will use one vehicle (VW Tiguan Allspace - 2018) within 5G-Mobix.

Figure 21: Overview of TUB test vehicle

Overall Description

TUB prototype of automated vehicle is based on the VW Tiguan Allspace platform as illustrated in Figure 21.The vehicle's factory configuration supports up to SAE-L3 operations, e.g., park assist, traffic jam assist, traffic jam chauffeur, highway chauffeur.

The vehicle is extended with additional technologies enabling SAE-L4 capabilities:

- Advanced sensor stack for 360º perception with combination of Radars, 3D lidars, surround view cameras, IR.
- OBU platform with computing, C2X, positioning, and mobile broadband communication capabilities.
- Software platform for network management, perception (LDM), analytics with programming interface to vehicle (steering ACC/EPS, data-busses CAN/Flexray).
- User-interfaces (e.g. convenient eth/power for laptop, tablet, displays).

Sensors platform for extended vehicle perception required by CCAM operations are highlighted below in Table 17 :

Table 17: Sensors platform for extended vehicle perception of the TUB vehicle

Type	Model	Units	Data
Lidar	• Ibeo Scala B3 Lidars	4	• Embedded Feature-Based Object Tracking and Classification • Infrared Laser (905 nm) (Eye Safety) • Horizontal Field-of-View of 145° • Horizontal Resolution of 0.25° • Vertical Field-of-View of 3.2° • 4 Vertical Layers of 0.8° each • Data Refresh Time of 40/80 ms • Distance Resolution <0.1 m • Typical Range 150 m (Passenger Car) • Power Consumption <7 W • CAN Interface for vehicle data and Ethernet interface • Package Size: 105 x 60 x 100 mm
Radar	• 2 x Delphi ESR 2.5 24VDC • 4 x Delphi SRR2		• For ACC
Stereo camera	• front camera	1	• 1000 view, used by Traffic sign recognition
Area view camera	• Surrounding (VW original)	4	• short range surrounding view/modelling
Inertial Measurement Unit	• XSense IMU	1	• Gyroscope, acceleration sensor for validation
GPS	• uBlox EVK-M8L	1	• GPS Positioning

1.1.2. A.1.2 Valeo vehicle

Valeo will use two vehicles (VW Passat B8) within 5G-Mobix as illustrated in Figure 22.

Figure 22: Overview of VALEO test vehicles

Overall description

The Valeo test cars are two VW Passat modified for sensor technology and ADAS functionality testing.

- Both vehicles are equipped with a variety of Valeo sensor systems as depicted by Table 18.

Table 18: Sensors and HW platform overview of VALEO vehicle

Type of Sensor	Units	Model	Characteristics
Radar	4		
Camera	6		• 4, 360° surround view 1, Front camera 1, Front reference camera
Ultra sound	12		• GNSSS RTK
Lidar	7	• 6, VALEO SCALA 1, Velodyne	• HDL64, HDL32
Driver camera	1		• Driver monitoring camera
Localisation	1	• iMAR	• Reference localisation module

Each vehicle is equipped with three Spectra Powerbox PCs (one with a GPU) to provide the required computing power. In addition, in one car a National Instruments PXIe 1085 Chassis for multi-sensor raw data recording is installed. Valeo Peiker Communication Modules will be implemented in the vehicles within this project to provide 5G connectivity. The following Figure 23 shows the hardware architecture of the two test vehicles.

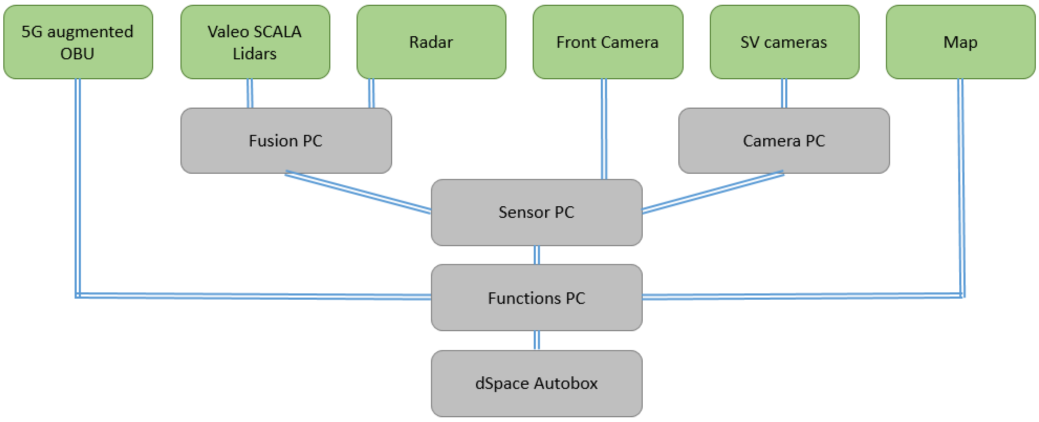

Figure 23: Overview of the HW architecture of VALEO vehicles

1.1.3. A.1.3 VICOM vehicle

VICOMTECH will use one prototype of automated vehicle for 5G-MOBIX called CarLOTA, as depicted in Figure 24.

Figure 24: VICOM test vehicle

Overall description of CarLOTA

CarLOTA is a prototype of automated vehicle built from a Toyota Prius platform. This vehicle has two driving modes:

- Standard manual driving
- Level 4 self-driving mode prototype

In manual driving mode, the performance of the vehicle remains the same as the original Toyota Prius. In self-driving mode, the vehicle integrates several technologies to ensure level 4 automation (see on-board technologies section) operating through an open access to the CAN bus of the vehicle:

- 360º perception around the vehicle using 1 lidar, 1 radar 9 mono cameras and 1 stereo camera
- Localisation systems with GNSS/GPS/RTK and inertial sensors
- Automated driving functions
- Connectivity platform (OBU)

The overall hardware and software components equipped on the vehicle are depicted below in Figure 25.

Figure 25: Overview of the HW and SW architecture of VICOM test vehicle

Table 19 compiles all these components in a more detailed manner.

Table 19: Overview of sensor components of the VICOM test vehicle

Type	Model	Units	Data
Lidar	• Velodyne HDL-32	1	• Position accuracy: ± 2 cm • Distance range: 80m-100m • Data: ~1.39 Million Points per Second • Angular range Horizontal: 360° • Angular range Vertical: +10° to -30°
Stereo camera	• Firefly FFMV-03M2C-CS	1	• Throughput: 752 x 480 @ 60fps
Mono camera	• Sekonix GMSL	9	
Depth IR camera	• Intel RealSense D435		• Angular range (Horizontal × Vertical × Diagonal): 69.4° x 42.5° x 77° • Throughput: 1280 x 720 @ 90 fps • Distance range: 0.3m - 10m
Lidar	• Velodyne HDL 32	1	• ± 2 cm accuracy. • 32 channels. • 80-100 m range. • 360º Horizontal FOV • +10º to -30º Vertical FOV
GNSS receiver	• U-Blox EVK-M8T 1 Hertz	1	
Inertial	• XSens MTi-200 IMU	1	• Latency < 2 ms • Angular range 450°/s • Acceleration range 200m/s2
DGPS	• OXTS xNAV550 DGPS with internal IMU for Ground truth	1	• Position accuracy: 1.6 m CEP SPS, 0.4 m DGPS, 0.02 m RTK • Velocity accuracy: 0.1 km/h RMS • Angular range: 300°/s • Acceleration range: 5g

Onboard	• Move Box: Vehicle ECU data reader and actuator	1	

1.2. A.2 Vehicles in Trial Site Finland

Overall description

Sensible 4 provides two autonomous vehicles (AV) for the Finnish trial site. The AV is based on Renault's electric vehicle with model named Twizy. Sensible 4 has altered them to drive-by-wire systems and equipped the vehicle with sensors and computing units for AD.

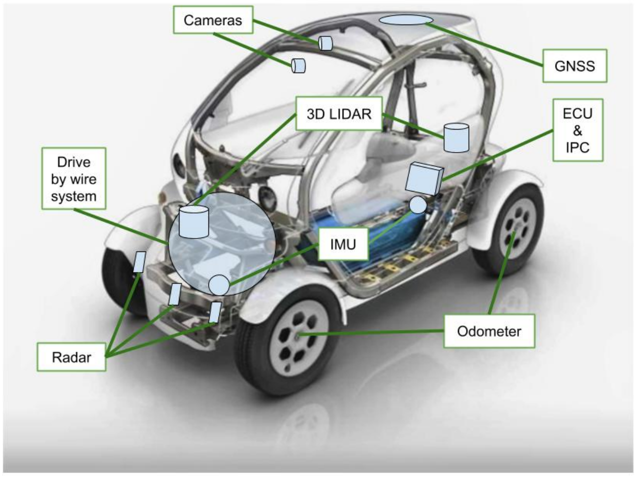

Figure 26: Placement of automation components in vehicle used in the Finnish corridor

- The navigation sensor set is depicted in Table 20.

Table 20: Sensors and HW platforms overview of Sensible4 vehicle

Type of Sensor	Units	Characteristics
Radar	3	
Camera	2	• 2 colour cameras 1 thermal camera
GNSS	1	• GNSSS RTK
Lidar	2	• 3D Lidar
Inertial	2	• IMU
Odometer	4	• Wheel odometer
Steering sensor	2	• Steering angle sensor

Sensible 4 is developing autonomous shuttle bus services and these presented AVs emulate the operations of the shuttle bus. This means that the AVs can be loaded remotely with different routes for the vehicles to follow autonomously while avoiding obstacles along the path. These AVs can also be operated manually using the original conventional driving with the steering wheel or remotely over the wireless connection. The AD operation can be initiated locally, on board the vehicle, or remotely. The conventional manual controls on board can override the AD functions.

1.3. A.3 Vehicles in Trial Site France

VEDECOM will use two prototypes of automated vehicles for 5G-MOBIX:

- 1 Renault ZOE called VEDECOM2
- 1 Renault Twizy called VFLEX

Figure 27: Overview of French test vehicles

1.3.1. A.3.1 Renault Zoe vehicle

Overall description

VEDECOM2 is a prototype of automated vehicle built from a Renault ZOE platform. This vehicle has two driving modes:

- Standard manual driving
- Level 4 self-driving mode prototype

In manual driving mode, the performances of the vehicle remain the same as the original ZOE. In self-driving mode, the vehicle integrates several technologies to ensure level 4 automation, as depicted by the following table.

Table 21: Sensors and HW platform overview of Renault Zoe vehicle

Type of Sensor	Units	Model	Characteristics
Radar	1	• ARS 408	• 0.20 ...250 m far range,
Lidar	5	• Velodyne	• 360° perception
Camera	2	• Stereo camera	• Front and back cameras
GNSS	1	• Geoflex	• RTK GPS receiver
Fusion	1	• IBEO	• Fusion box
Communication	1	• YogoKu	• OBU ITS-G5
Ethernet switch	1		
PC	3	• 1 Nexcom 1 Nexcom 1 dSPACE	• PC Camera Perception PC

The overall functional architecture of the vehicle is described below:

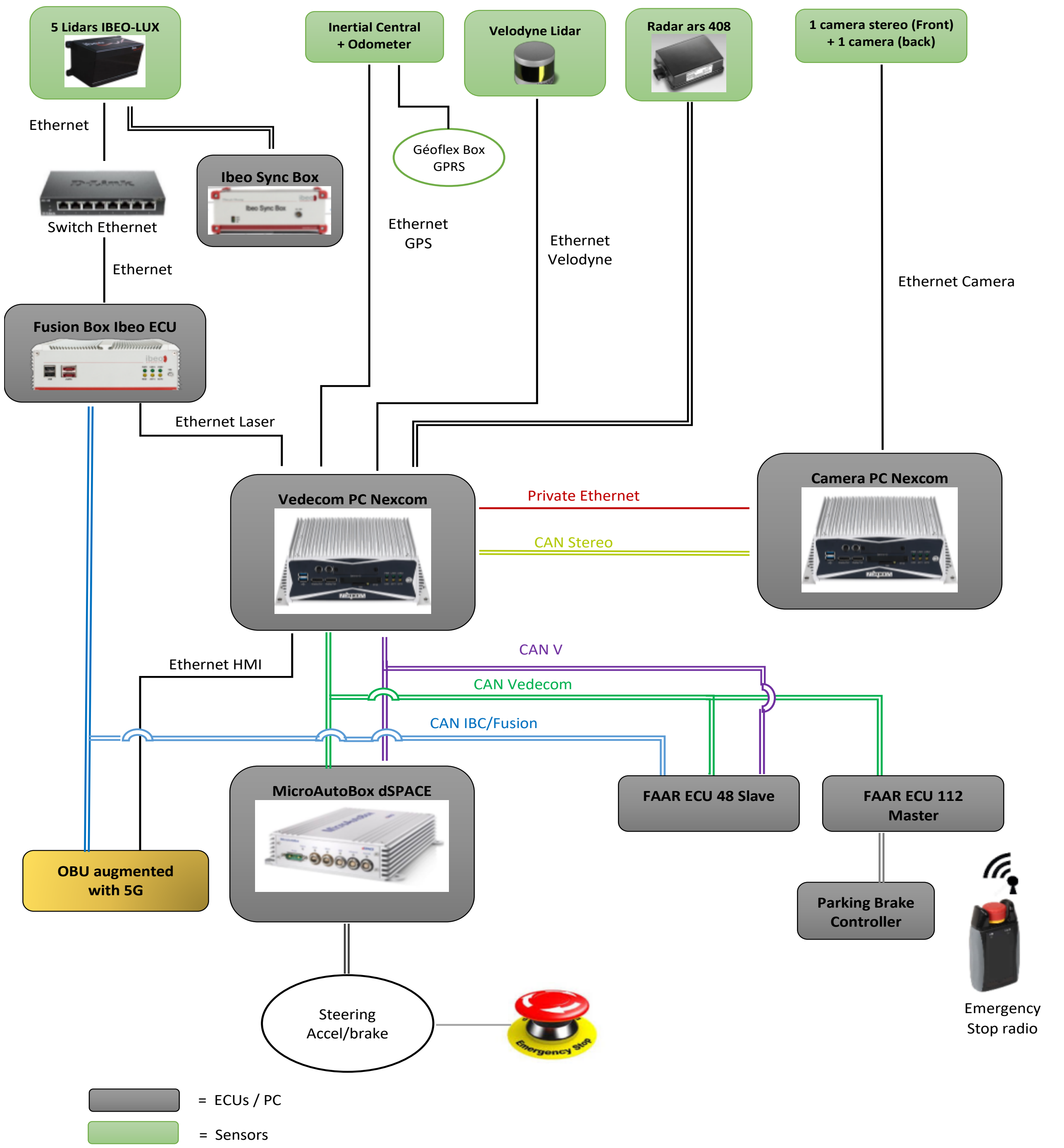

Figure 28: Overall functional architecture of Renault Zoe vehicle

1.3.2. A.3.2 VFLEX vehicle

Overall description

The second vehicle used by VEDECOM during 5G-MOBIX is based on a Renault Twizy. Thanks to VEDECOM's collaboration with Renault, the Twizy has been transformed in an open robotic platform (with an open access to the CAN bus of the vehicle). On top of that, the VFLEX is equipped with different sensors as described in Table 22.

Table 22: Sensors and HW platform overview of VFLEX vehicle

Type of Sensor	Units	Model	Characteristics
Radar	1	• CONTINENTAL	• ARS 408
Camera	1	• CONTINENTAL	• Stereo camera
GNSS	1		• RTK GPS receiver
Intertial	1	• SBG	
ABS	1	• CONTINENTAL	• ABS MK 100

This vehicle will be mostly used has a connected vehicle in order to share information gathered with its own sensors to the ZOE.

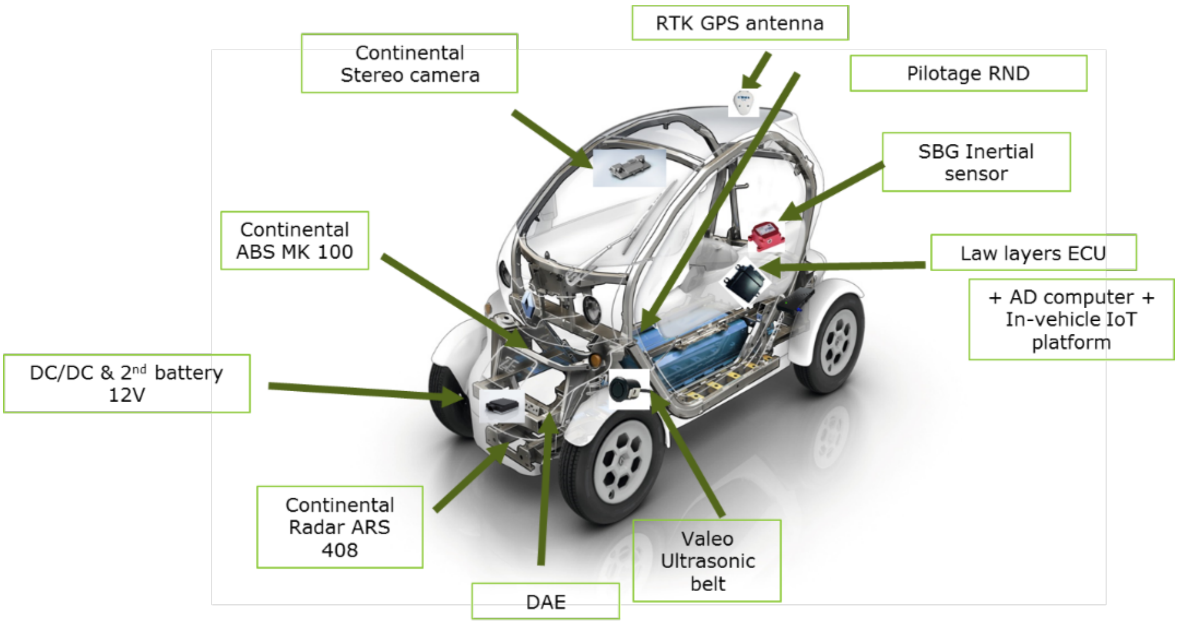

Figure 29: Overview of Renault VFLEX test vehicle

1.4. A.4 Vehicles in Trial Site Netherlands

The 5G augmented vehicles used in the Netherland trial site are provided by VTT, TU/e, TNO and SISSBV. In total, 3 automated vehicles with self-driving capabilities and 1 or 2 vehicles only with connectivity are deployed to test and implement the proposed use cases.

1.4.1. A.4.1 TU/e vehicle

Overall description

TU/e provides and uses one automated vehicle: a 2018 Prius PHV, which is equipped with sensors, connectivity and hardware to support CCAM functionalities.

Figure 30: Overview of TU/e Vehicle

This vehicle is currently being built and will be based on a previous research vehicle (which was based on a Toyota Prius 2010 model, similar to the SISSBV vehicle). We intend to extend the sensor set for 5G-MOBIX. The vehicle will be equipped with the following sensors and hardware depicted in Table 23:

Table 23: Sensors and HW platforms overview of TU/e vehicle

Sensor	Number	Type	Car position	Horizontal field of view	Vertical field of view	Range
3D LIDAR	1	Robosense	Roof	360°	40°	up to 200m
Camera	1	Stereo camera	Windshield	60°	-	~100m (car) ~40 m (ped.)
RTK-GPS (incl. FOG-IMU)	1	Advanced Navigation	Trunk			

Communication unit	1	ITS-G5 & LTE	Trunk			
Ethernet switch	1	10Gbit	Trunk			

For the 5G-MOBIX Remote Driving use case, the vehicle will be extended with a 360° camera set-up, to create the 3D bird's eye view.

Based upon additional requirements the following sensors are available, to extend the sensor set with:

- 2 x Velodyne LIDAR sensor (16 lines)
- 1 x uBLOX F9P and/or M7P
- 1 x Xsens IMU
- 5x radar (NXP radar cocoon) (depending on another project progress).

1.4.2. A.4.2 SISSBV vehicle

Overall description

SISSBV will utilize Prius vehicle to enable 5G MOBIX use cases. This vehicle is equipped with various sensors, hardware and communication modules to support various CCAM functionalities as depicted by Figure 31.

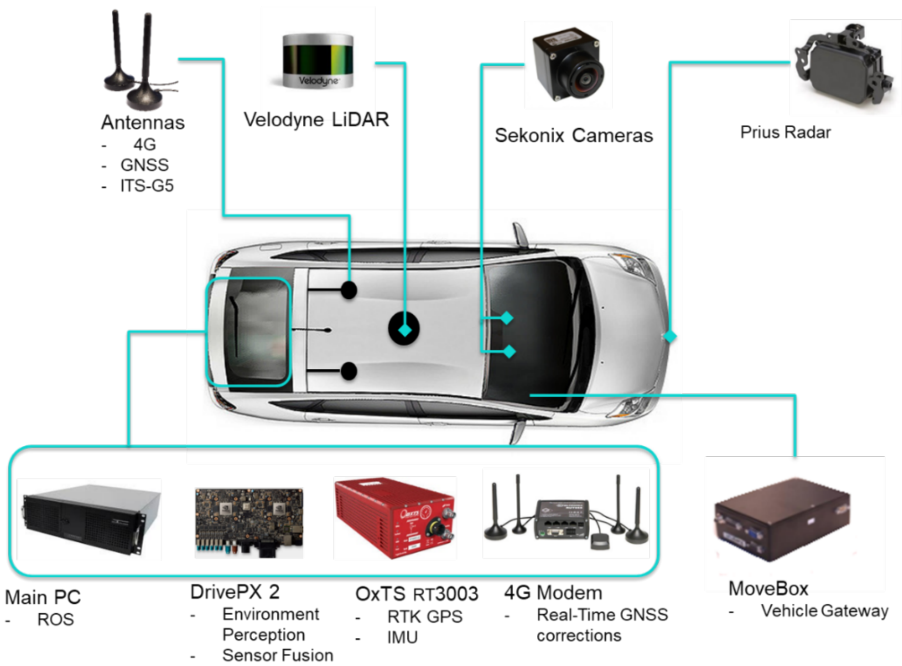

Figure 31: Overview of the SISSBV vehicle

Sensors and hardware components of the vehicle are illustrated in Table 24.

Table 24: Sensors and HW platforms overview of SISSBV vehicle

Type of Sensor	Units	Model	Characteristics
RADAR	1	• Prius	
Perception sensor	1	• MobilEye sensor	
MoveBox	1		
Camera	1		• Webcams
GNSS	1 1	• OXTS U-Blox F9	• High accuracy positioning
LIDAR	1	• Velodyne	• 16 layers
Camera	2	• Sekonix Camera	• Onsemi AR0231 image sensor
PC	1		• High performance PC
IA	1	• NVIDIA	• DrivePX2
Communication interfaces	2		• ITS-G5 and 4G
HMI	4		• For development
Ethernet switch	1		
Wi-Fi AP	1		
CAN interface	1		

•

The following figure shows the hardware architecture of the SISSBV vehicle.

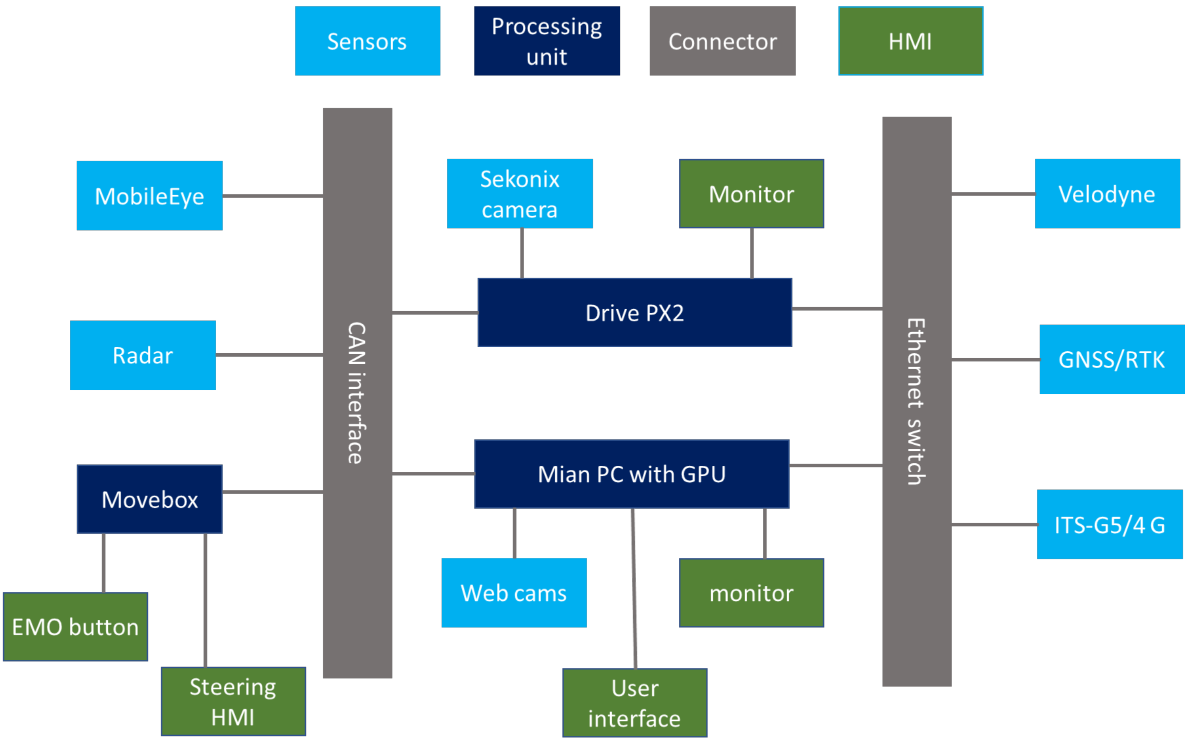

Figure 32: Hardware architecture of the SISSBV vehicle

1.4.3. A.4.3 VTT vehicle

Overall description

VTT is providing a connected autonomous vehicle to enable 5G CCAM use cases. The test vehicle is equipped with retrofitted parts for having steering, acceleration, braking and gear box controls and actuators. The car has modern sensors installed and on-board communication devices for ITS G5 and cellular LTE/Pre-5G environment. The vehicle body is VW Touareg and it has been registered as a special passenger car.
The car itself has been equipped with multiple Lidars for environment perception in front up to 150 m. Two ECUs are dedicated for processing LiDAR, camera and radar data. Besides, one ECU is engaged with taking care position and heading of the vehicle while driving (see Figure 33 and Figure 34).

The car has two communication units and antennas. The first one is ITS G5 unit compatible for communicating with traffic lights. The second one is a Pre-5G device which is going to be updated to real 5G compatible device for doing C-V2X PC5 [9] based trials.

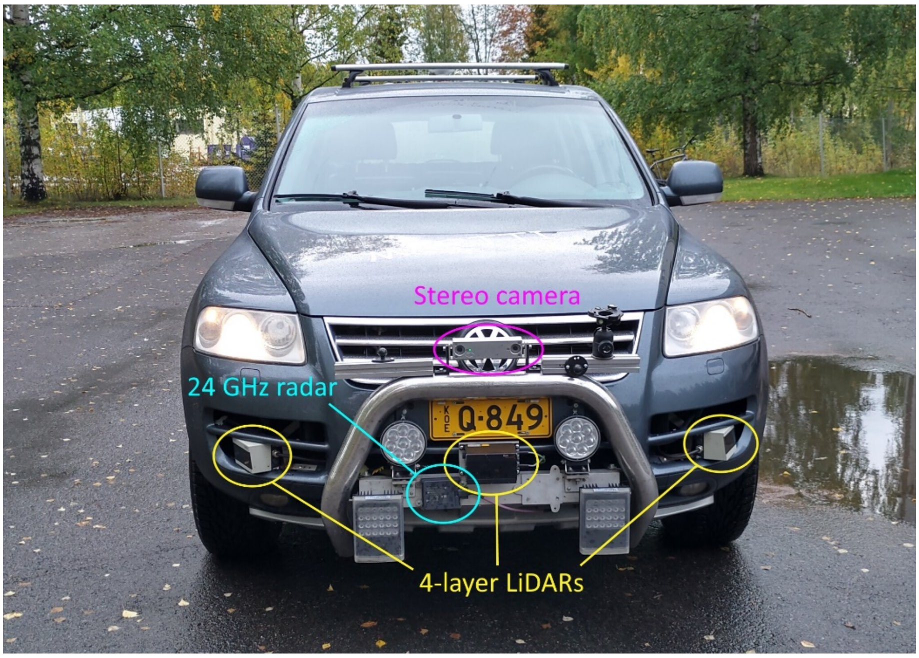

Figure 33: The VTT's demo vehicle Marilyn in front

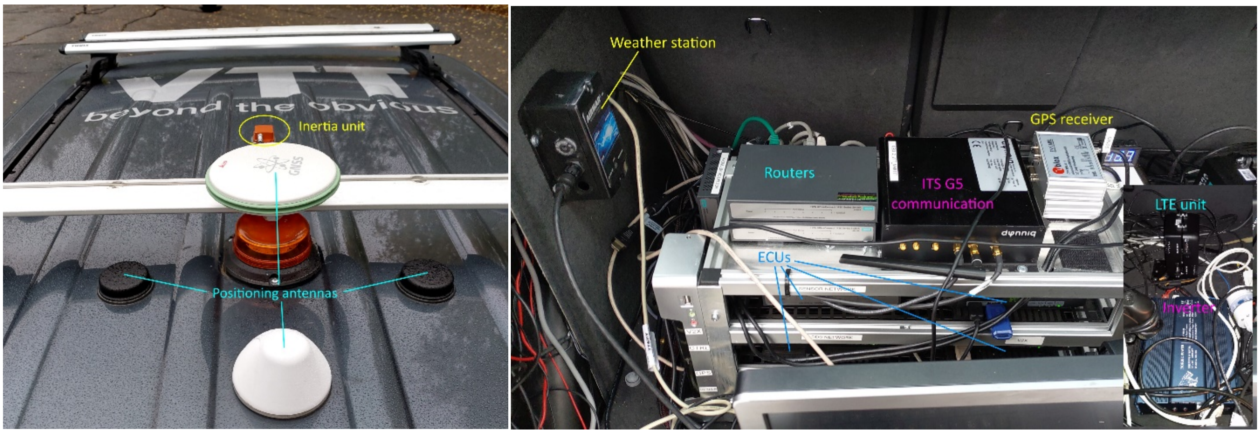

Figure 34: The VTT's demo vehicle Marilyn in back and the computing units

The table below highlights the different elements embedded in the vehicle system:

Table 25: Overview of hardware components of the VTT Martti

Sensor	Number	Type	Car position	Horizontal field of view	Vertical field of view	Range
3D LiDAR	3	• 1 x ibeo Lux • 2 x Sick	• Front	110 °	3,2 °	up to 200 m
Radar	1	• Conti SRR 208	• Front	150 °	12 °	< 50 m
Camera	1	• Stereo	• Front			
Weather station	1	• Airmar	• Trunk			
Hybrid Communication	1	• Intrinsyc C-V2X hybrid LTE & ITS G5	• Trunk			
Mobile Communication	1	• 4G/LTE Communication	• Trunk			
Wireless Communication	1	• dynniq V2X ITS G5	• Trunk			
GNSS	1	• ublox RTK-GPS	• Trunk			
Inertia	1	• IMU	• Roof			
Antennas	4	• GNSS Receivers	• Roof			

1.5. A.5 Vehicles in Trial Site China

Chinese trial site will use SDIA vehicle to carry out trials. In the following, we detail the main characteristics of this car.

Figure 35: overview of SDIA vehicle

Overall description

- Here are the main components for SDIA vehicle: Image sensor: number of dedicated image sensors for monocular camera warning: 1 pc;
- Millimeter wave radar: front millimeter wave radar, number of 76 GHz radar: 1;
- Integrated navigation: MEMS gyroscope, MEMS accelerometer, GNSS satellite navigation system, supporting local GPS base station, the horizontal differential positioning accuracy of 2cm. Quantity: 1;
- 3GPP network module, quantity: 1 host, 1 slave. ZIGBEE short-range communication module, the number: 1 host, 1 slave;
- High-performance computer (built-in Kithara real-time kernel and development environment), Quantity: 2;
- Ultrasonic radar sensor: quantity 8;
- Brake actuator: no need to change the structure, based on the original brake, steering, and accelerator pedal actuator, communication mode CAN;
- Main controller: Cortex-A9, CAN (2ch), ETH, Python language, etc.

Perception Environment system of SDIA

The environment perception is mainly machine vision, radar, V2X and other environmental perception theory, algorithm verification, environmental simulation test. The modelling and simulation analysis, hardware theory research and various environmental sensing technologies aim to provide a basis for intelligent network vehicles research. The research mainly adds actuators to complete the power, braking, steering control and other functions of the vehicle.

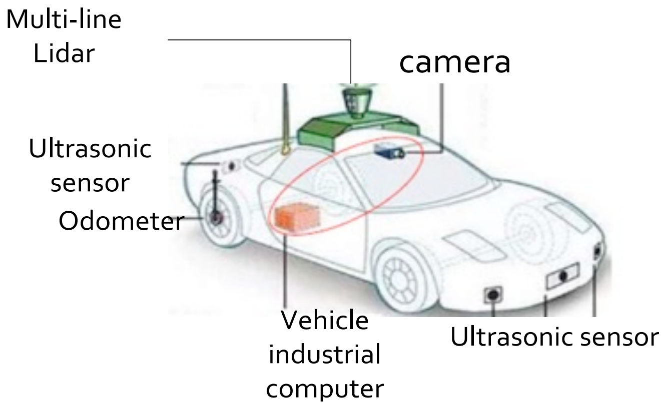

Figure 36: Perception Environment of SDIA vehicle

1.6. A.6 Vehicles in Trial Site South Korea

Overall description

KATECH will provide one automated vehicle (Renault QM6) which is equipped with sensors and 5G connectivity for supporting two use cases (remote driving and tethering).

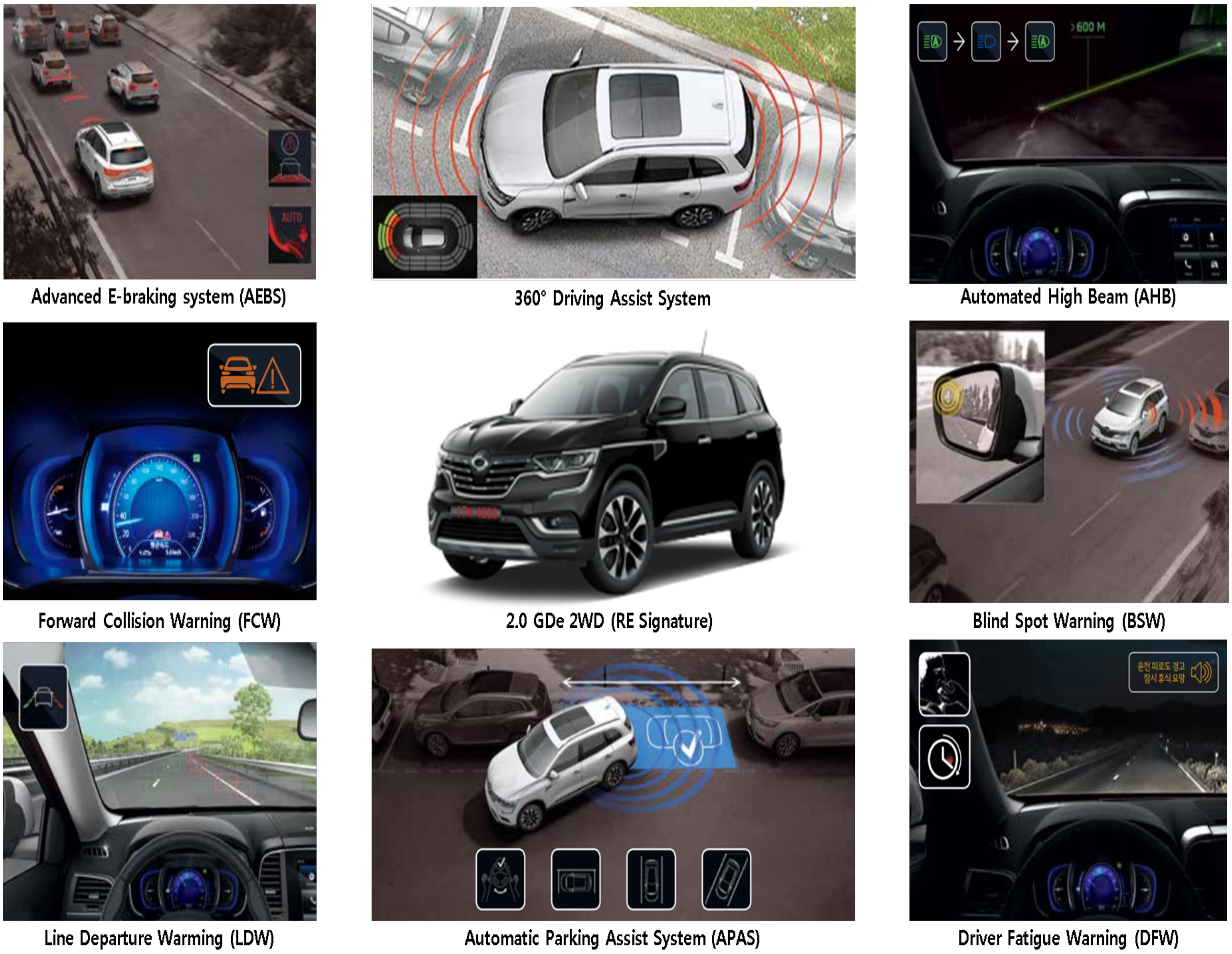

Figure 37: Overview of KATECH Vehicle

The vehicle is equipped with ADAS (advanced driving assist systems) functions as follows:

- Advanced E-braking System
- 360° Driving Assist System
- Automated High Beam
- Forward Collision Warning
- Blind Spot Warning
- Line Departure Warning
- Automatic Parking Assist System
- Driver Fatigue Warning

In addition, the vehicle is equipped with the following sensors and hardware components.

Table 26: Sensors and HW platform overview of Renault QM6 vehicle

Type of Sensor	Units	Characteristics
Ultrasonic sensors	6	
Camera	4	• Front, Rear, Left, Right
GNSS	1	• DGPS
HMI	2	• 2 HMIs foe development
CAN	1	• Vehicle CAN interface
Communication interfaces	3	• 1 WAVE communication • 4G interface • 5G interface

2. ANNEX B: 5G AUGMENTED AUTOMATED DRIVING FUNCTIONS

This section aims to described how the automated driving functions are impacted by the use of 5G in order to execute 5G-MOBIX use cases.

2.1. B.1 Trial Site Germany

2.1.1. B.1.1 User Story #1: Cooperative perception with HD maps and surround view

To carry out the user story "cooperative perception with HD maps and surround view", three vehicles will be used in the German trial site.

As such, TUB's vehicle has been already tested on the German Trial site for a use-case similar to user story#7. However, only 4G and DSRC / ITS G5 communication has been used.

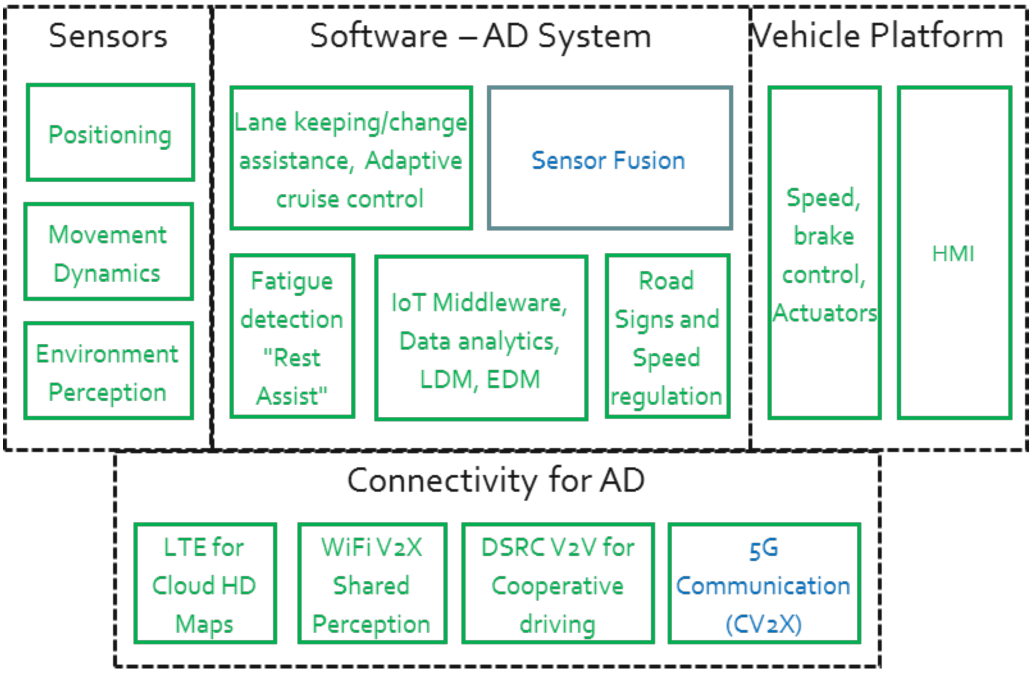

Figure 38: TUB vehicle AD function development to support cooperative perception with HD Maps user story

TUB vehicle must be extended with a 5G on-board unit to fulfil the user stories' communication requirements. The vehicles must also be extended with software to process and fuse sensor data of its own sensors and that of other vehicles. Furthermore, the vehicle platform does not support sending raw data streams to other vehicles other than through the mobile network over LTE. To allow the vehicle to exchange environment information directly with other vehicles, CV2X communication capabilities must be implemented as well. These extensions are reflected in Figure 39.

For VALEO vehicle, the modules incorporating the vehicle's localisation in the LDM will be altered that way that they can retrieve updates of from an eRSU in form of an Edge Dynamic Map (EDM) [10]. These updates are received by a module for Map Sharing connected to the Localisation & Map module. The Message exchange must be able to understand and send messages, which trigger the update or exchange of LDM data.

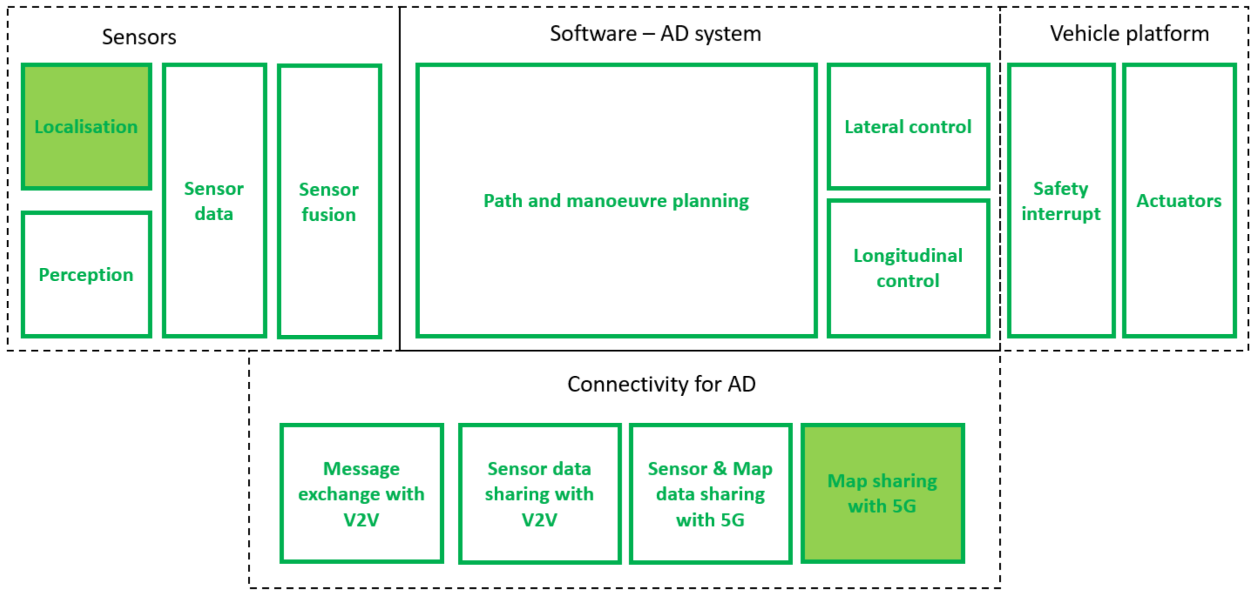

Figure 39: VALEO vehicle AD function development to support cooperative perception with HD Maps use case

To implement the second part of User Story #1, which is the exchange of sensor raw data, a module within the connectivity branch is needed which handles the exchange of data retrieved from the Sensor interfaces. In addition, received data must be handled and sent to the Sensor fusion module where the enhanced Surround view is modelled. In order to trigger this exchange messages must be exchanged in between the vehicles. The Sensor Fusion module itself will be altered to not only cope with the vehicle's own sensor data but to incorporate data from external sensors, for example received from another vehicle via V2V communication channels. However, due to the modular structure there is no need to manipulate other parts of the vehicle's software architecture.

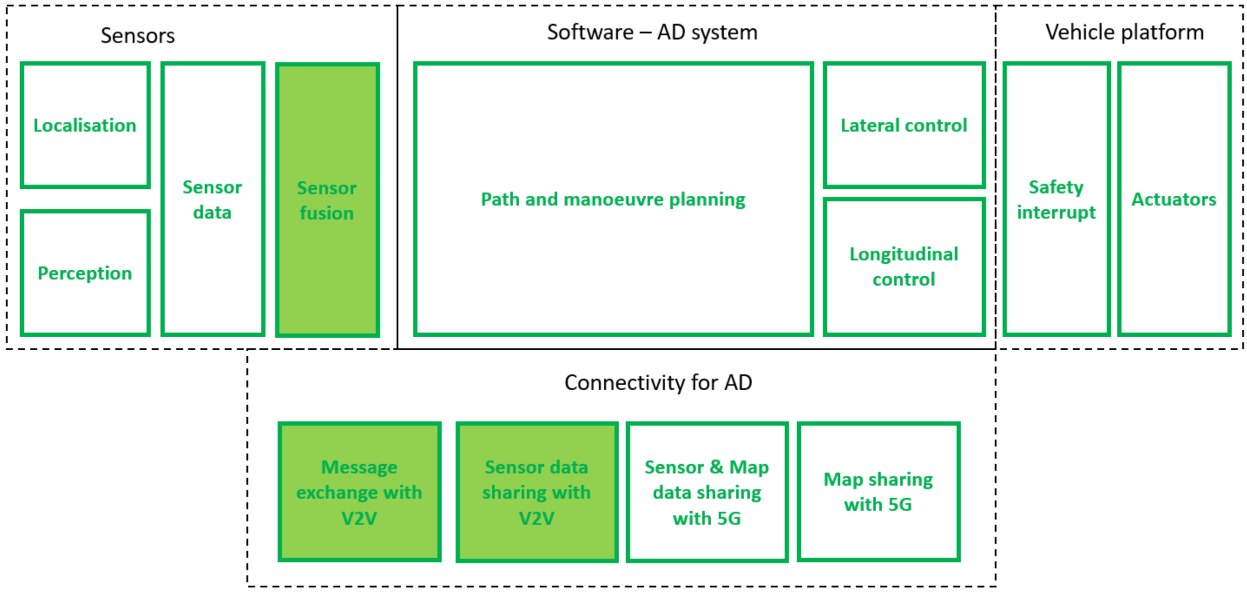

Figure 40: VALEO vehicle platform extension to support Use Case, part 2

Regarding the third vehicle provided by VICOMTECH, CatLOTA, would be evolved in terms of more demanding and powerful computer vision systems able to understand more complex situations like the one described in "Cooperative perception with HD maps and surround view" where the fusion of onboard sensors and LDM with surrounding RSU and vehicles cameras and EDMs is possible to arrive on time and synchronously thanks to URLLC capacity of 5G networks.

Specifically, the realisation of this use case will need the participation of onboard sensors (self-localization and environment perception) and HD maps and that will be sent to the MEC system which would allow a zero latency and transparent handshake between surrounding vehicles and publishes available data streams to complement onboard perceptions. This incoming data can feed some AD functions such as the composition of a 360º view from a collaborative perception, the identification of ahead risks or obstacles and the guide and support of overtake manoeuvres.

To this end, the collaborative perception system would be able to identify relevant sensors from the surrounding ones selecting the sensor feeds on the path of the movement, based on the EDM information. Then, the obstacles and leading perception system needs to be prepared to be able to add new data from external sensor streams that are instantly accessed. This system would exploit the new information beyond the onboard sensors to update the lateral and longitudinal path planning.

All these AD functions trigger renders at vehicle HMI and actively actuate on the vehicle dynamics accordingly, when necessary. These data are sent from the vehicle to the infrastructure using LTE, ITS-G5, WiFi or 5G ProSe depending on the connectivity interface of the interlocutor of the vehicle and the required KPIs of the exchanged data volume and latency sensitivity.

LDM needs to extend its functionality to ROI extraction and EDM fusion. Trajectory prediction, risk estimation and planning modules need to be adapted to meet the needs of the demonstrators. The collaborative perception module will be specifically designed and implemented for 5G-MOBIX and will be an important added value for the AD system. The car connectivity will be extended for 5G capabilities following the 5G-MOBIX approach. Finally, the vehicle HMI and actuators will be updated according the necessities of the demonstrators. All these updates are reflected in Figure 41.

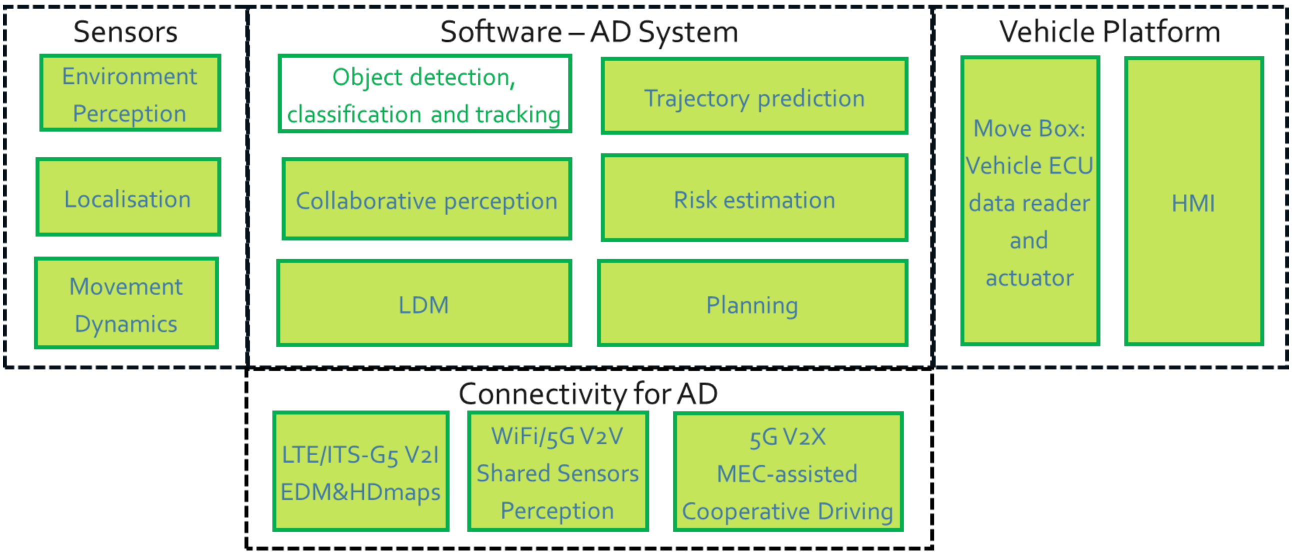

Figure 41: Automated driving functions of VICOM test vehicle

2.1.2. B.1.2 User Story #2: Platooning

Use Case 7 - SAE L-4 Platooning requires both V2V and V2I communication and cooperative manoeuvring capabilities.

For this goal, with the exception of CV2X & 5G communication, TUB's vehicle is already able to execute this manoeuvre. These extensions are reflected in

Figure 42.

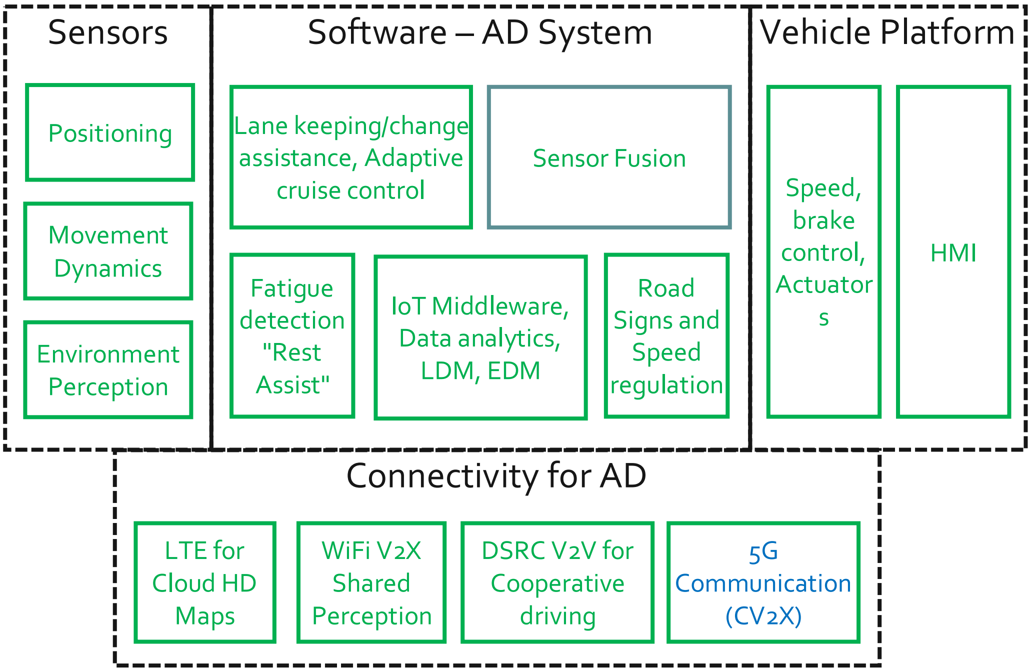

Figure 42: TUB vehicle platform extension to support platooning use case

To implement the platooning Use Case within the Valeo vehicle's similar requirements to the Map Exchange modules are given as in Use Case 1. Here the aim is of course to integrate those functionalities in one architecture, which can handle all scenarios in Berlin Trail Site. However, in this Use Case more (especially time-) critical requirements are laid down in the exchange of V2V based Messages where for platooning low latency is crucial. Additionally, to the adaptions required for Use Case 1, the Path and Manoeuvre planning has to augmented to a platooning mode, where the vehicle can interpret driving intentions and commands from a platoon-leader or distribute those in case it is the leader itself. All these required changes are depicted in Figure 43

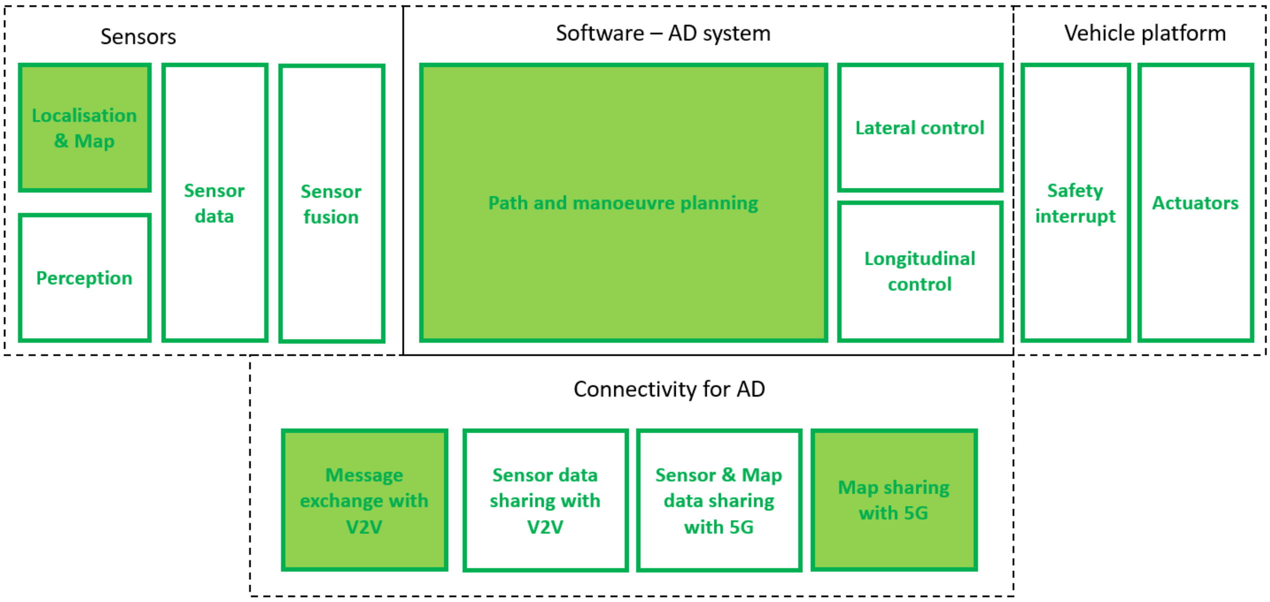

Figure 43: VALEO vehicle platform extension to support Use Case 7

2.2. B.2 Trial Site Finland

In the trial site Finland two use cases are conducted. Both of the use cases involve session handover from one PLMN to the other. Described in the following is how 5G-MOBIX affects the development of the automated driving functions in the use cases.

2.2.1. B.2.1 User Story #1: Video-based cooperative perception

In traffic, the situations change fast and thus all perception related processing is time and place critical. We need to develop methods to ensure the correctness of the temporal and spatial relation of the sensor information. This work is then towards the Remote sensors, Shared world model, and World model component implementations. Naturally, whole processing chain from raw data producer to the data end user has to be streamlined and fast enough to be useful. This affects the connectivity components of the system. Furthermore, reliability or trust for the information coming from and going to the infrastructure has to be ensured and developed. These augmentations are illustrated in Figure 44.

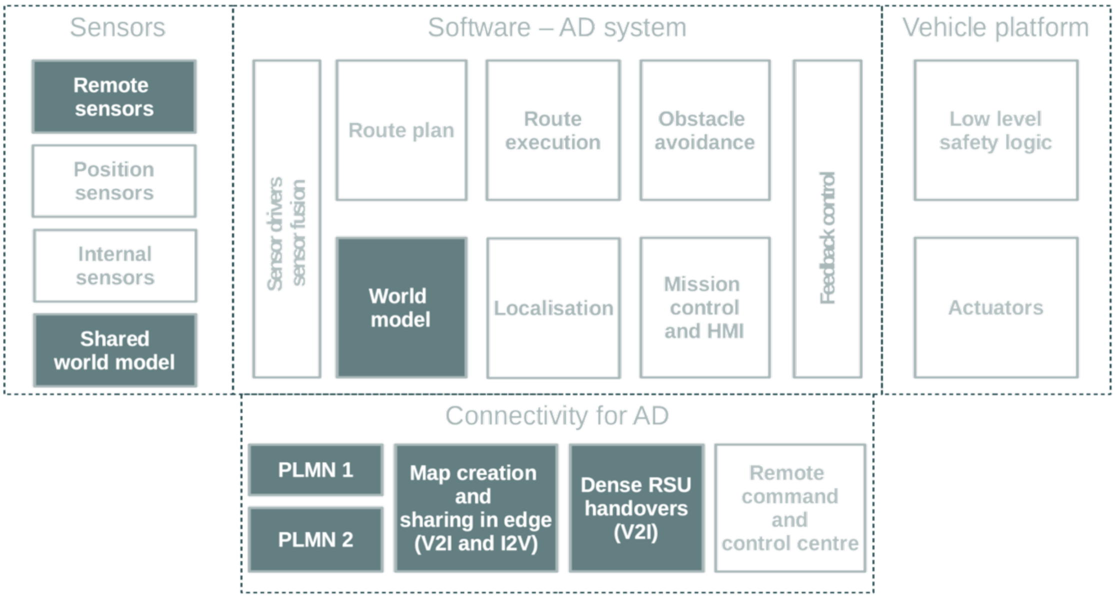

Figure 44: Finnish vehicle AD function development to support cooperative perception use case

This means also that the service discovery needs to be implemented and improved to the level that data producer and consumer find each other before they are too far apart for relevant information.

2.2.2. B2.2. User Story #2: Remote Driving

Remote driving is very demanding task for the connectivity. The situational awareness from multitude of data rich sensor needs to be transferred to the remote location. The remote operator needs to be brought quickly up the current moment despite even long periods of inactivity. Control commands need to be sent swiftly to make the whole chain from the data acquisition to actuators moving. The temporal length of this chain needs not only to be fast but also monitored and known.

In addition, situational awareness requires development of the sensors, their drivers, and data buffering to support the visualization of the data and its temporal aspects at the Remote command and control centre. Regarding the connectivity functions, these latter need to develop the seamless handovers. The AD system SW has to be adapted to utilise the benefits of 5G communication. All these adaptations are illustrated in Figure 45.

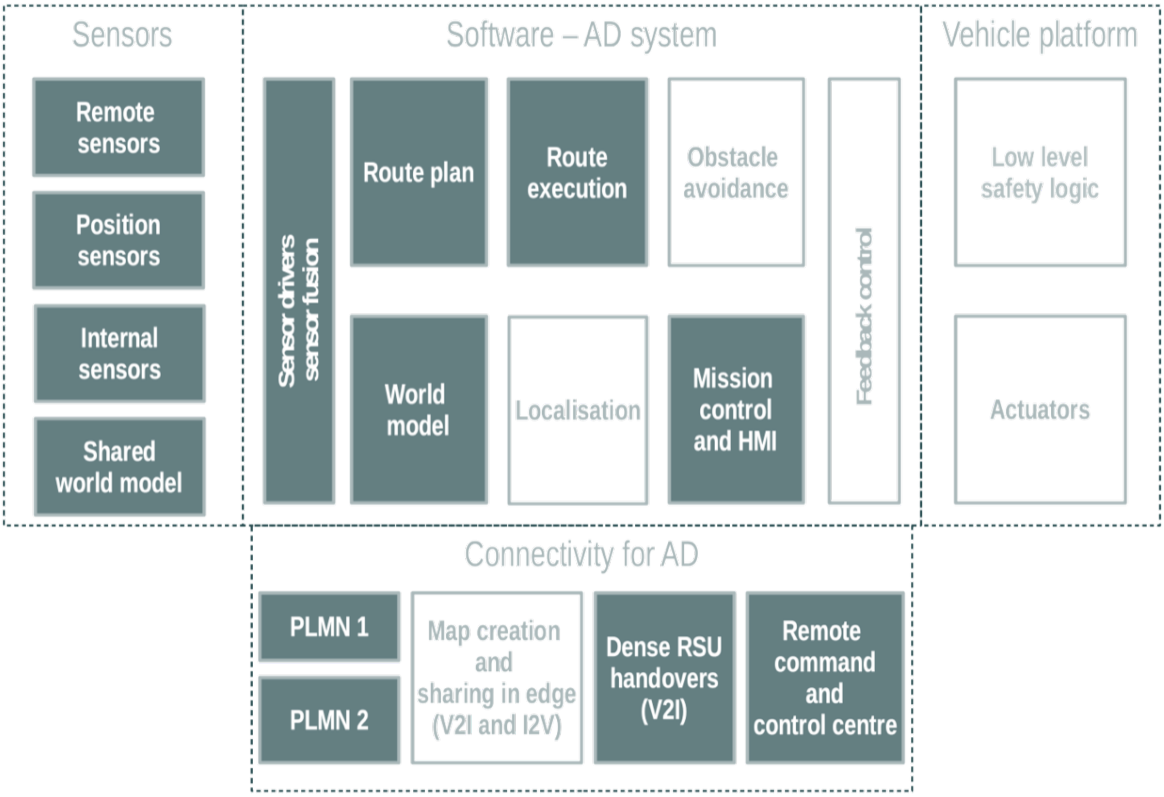

Figure 45: Finnish vehicle AD function development to support remote driving use case

2.3. B.3 Trial Site France

2.3.1. B.3.1 User Story #1: Infrastructure assisted advanced driving

In order to perform this use case, the functions highlighted in Figure 46 have to be adapted:

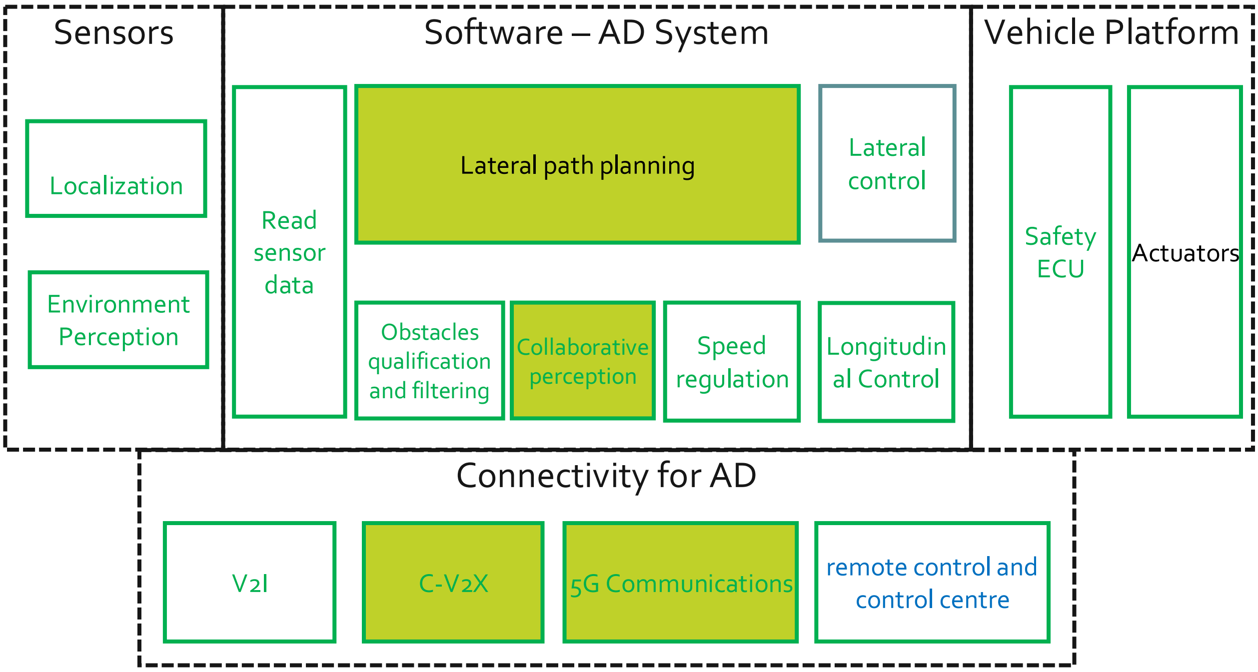

Figure 46: VEDECOM vehicle platform extension to support Use Automated Overtaking use case

Currently, Reanult Zoe and VFLEX vehicles are equipped with ITS-G5 and 4G technologies. In the 5G-MOBIX scope the communication device is changed to C-V2X devices and 5G NR.

The C-V2X devices support direct PC5 based communication between two cars or between car and local digital infrastructure. The 5G chipset will enhance the communication capacities of the two vehicles by introducing its capabilities to handle higher throughput and lower delays. Furthermore, for this use case, the infrastructure will be a crucial component since it will help to enhance the perception of vehicles. Thus, the collaborative perception component shall be adapted and augmented to support the new changes made in the communication part.

2.3.2. B.3.2 User Story #2: QoS adaptation for security check in hybrid V2X environment

In order to perform this use case, the following highlighted functions have to be adapted:

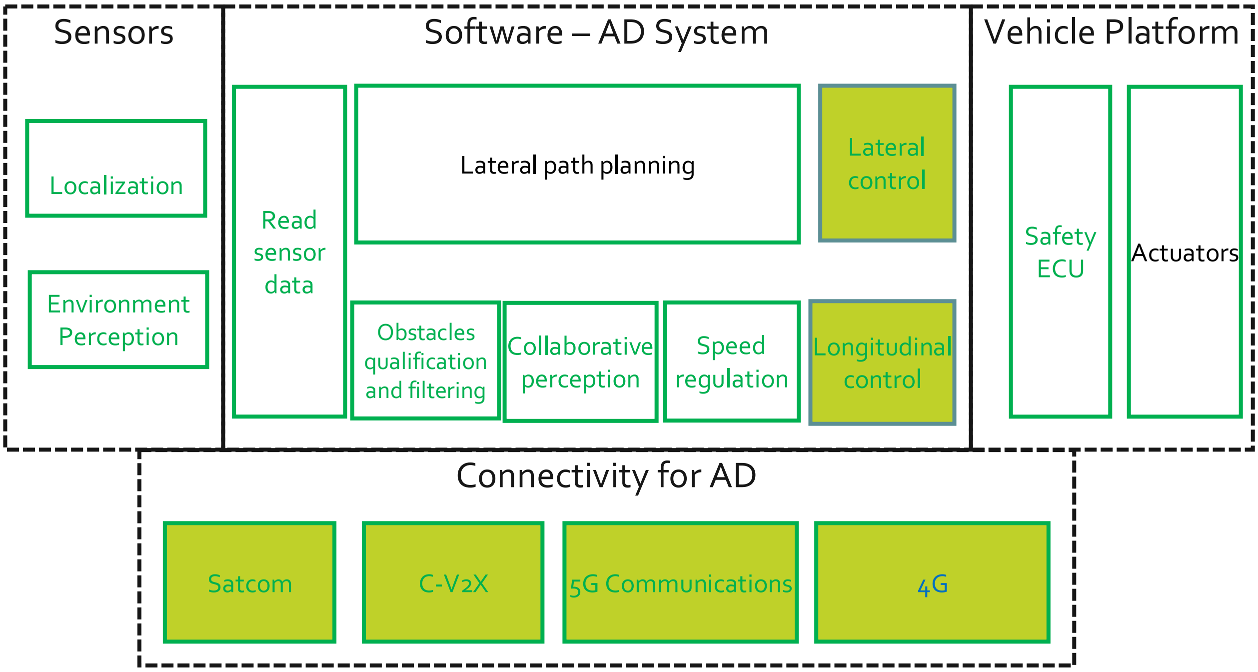

Figure 47: VEDECOM vehicle platform extension to support Use Remote driving

To perform the use case QoS adaptation for security check, an intelligent soft handover will be carried out in the vehicle in order to use the available technologies (4G, 5G, Satellite communication) when there is a gap in the 5G coverage. In fact, this use case is very demanding in terms of uplink connectivity in order to be able to send live video from the car. When the communication link is changed to a lower bandwidth capacity, a data adaptation mechanism has to be fulfilled (adjust data type, data rate, etc). In addition, remote commands need to be sent with high reliability and very short latency. This new integration will be added to the vehicles by integrating a 5G chipset inside.

Furthermore, position accuracy must be adapted to the new feature provided by 5G; Thus, several adaptations need to be added to the longitudinal and lateral control functions of the different vehicles used for 5G-MOBIX.

2.4. B.4 Trial Site Netherlands

In the Dutch trial the following use cases will be executed to showcase the impact of 5G communication technologies on automated driving functions:

2.4.1. B4.1 User Story #1: Cooperative collision avoidance

VTT's pilot vehicle is equipped with the LTE and ITS G5 communication devices and they are able to exchange MAP messages in C-ITS format. In the 5G-MOBIX scope the communication device is changed to C-V2X devices. The C-V2X devices support direct PC5 based communication between two cars or between car and local digital infrastructure. Due to communication channel change the sensor data fusion level is changed to support the broadband message including partly raw LiDAR data also in the Netherlands trial site.

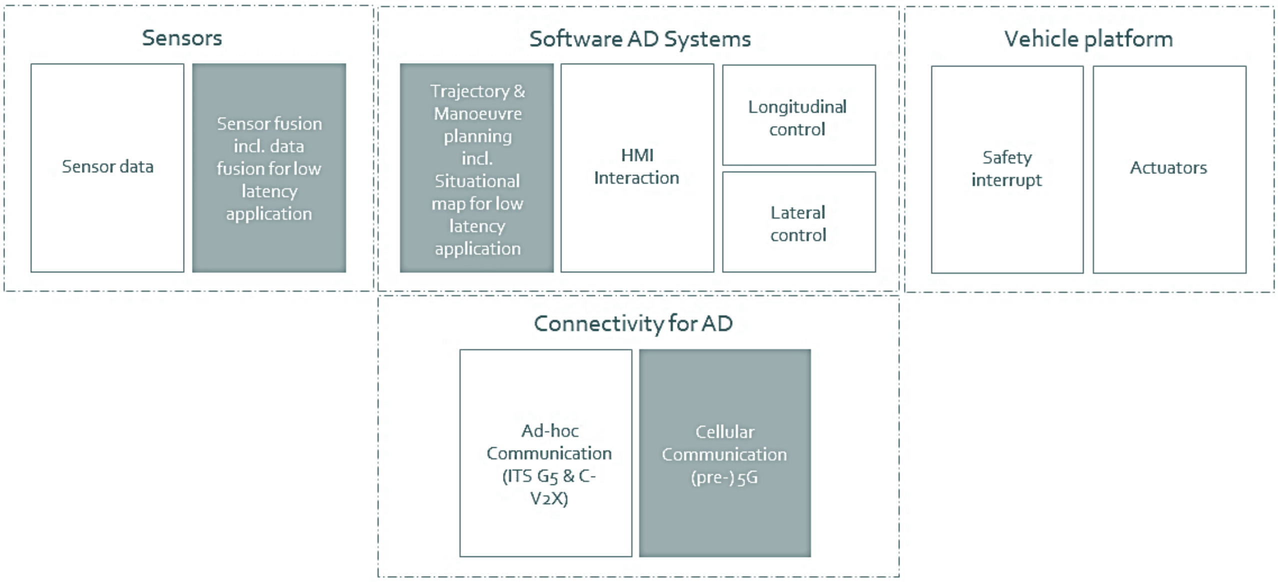

Figure 48: VTT's demo vehicle AD function development to support cooperative collision avoidance use case

2.4.2. B4.2 User Story #2: L4 automated vehicle tele-operation and tele-monitoring services

SISSBV vehicles are involved in L4 automated vehicle tele-operation and tele-monitoring services NL site Use Case. To perform these proposed Use Case the different modules in the SISSBV automated driving platform have to be enhanced to cope with additional 5G augmented driving functionalities. The "L4 automated vehicle tele-operation and tele-monitoring services", requires sensor data to be streamed in real time to the operator and at the same time have the operator control vehicle in real time. The sensor and control task impose very low latency, high bandwidth and high reliability requirements. 5G technology can be aiding in improving bandwidth, latency and reliability limitations for tele-operations. Thus, further enhancements of cellular communication modules in the car are necessary. The lateral and longitudinal controllers need to be modified to make the vehicle capable of responding to the operator request. Furthermore, effective sharing of sensor data is necessary to enhance the visualization of the operator. The required enhancements are highlighted in Figure 49.

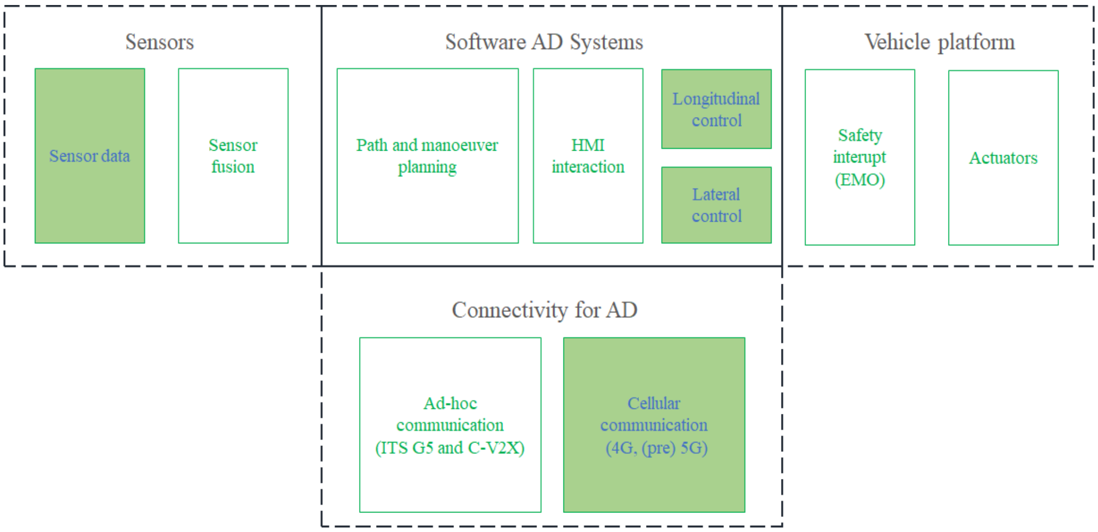

Figure 49: SISSBV vehicle AD function development to support Teleoperation use case

The TU/e vehicle is going to be used in the L4 automated vehicle tele-operation and tele-monitoring services NL site Use Case. Additionally, to what is described above with SISSBV, this vehicle will also be used, with mm wave localisation. Also, this is a new vehicle only parts of the former existing platform (Prius 2010) can be exchanged to this new platform, but some part needs to be redesigned (especially the low-level safety for remote control) The environmental sensor set-up will change and be extended, causing the function localisation, sensor fusion, obstacle qualification and filtering and world model to be adapted.

With respect to the SISSBV vehicle, additional sensor fusion needs to be taken into account for mm wave localisation function, by adding a 5G NR enabled mm wave localization. Remote control function needs to be added and some additional adaptations to the existing 4G LTE system

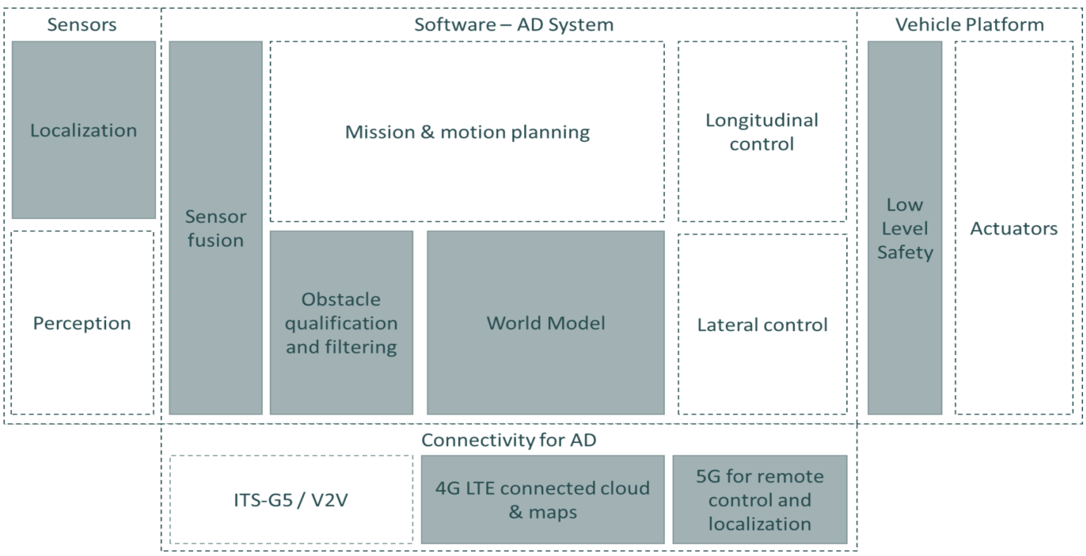

Figure 50: TU/e vehicle AD function development to support teleoperation use case

2.4.3. B4.3 User Story #3: Collective perception of environment

The “Collective Perception of Environment” use-case exchanges real time sensor information between two vehicles and road side infrastructure available as cameras to create an enhanced perception of the environment for the vehicle on-ramp for a merging scenario. This has an impact on the sensor data and sensor fusion functions for both vehicles, one driving on the highway and second driving on-ramp attempting to merge the highway. The exchange of information takes place using a collective perception message (CPM) which tests the important properties of 5G technology like low latency and high bandwidth requirements. The vehicles will also be equipped with current state of the art LTE and ITS-G5 communication devices. These aspects will have an impact on the connectivity functions of both vehicles. Finally, the enhanced perception for the vehicle on-ramp will have an impact on its planning and decision function to perform a safe an efficient merging on the highway. The impact and required enhancements for TNO’s vehicle to demonstrate this use case are highlighted in blue in the figure below:

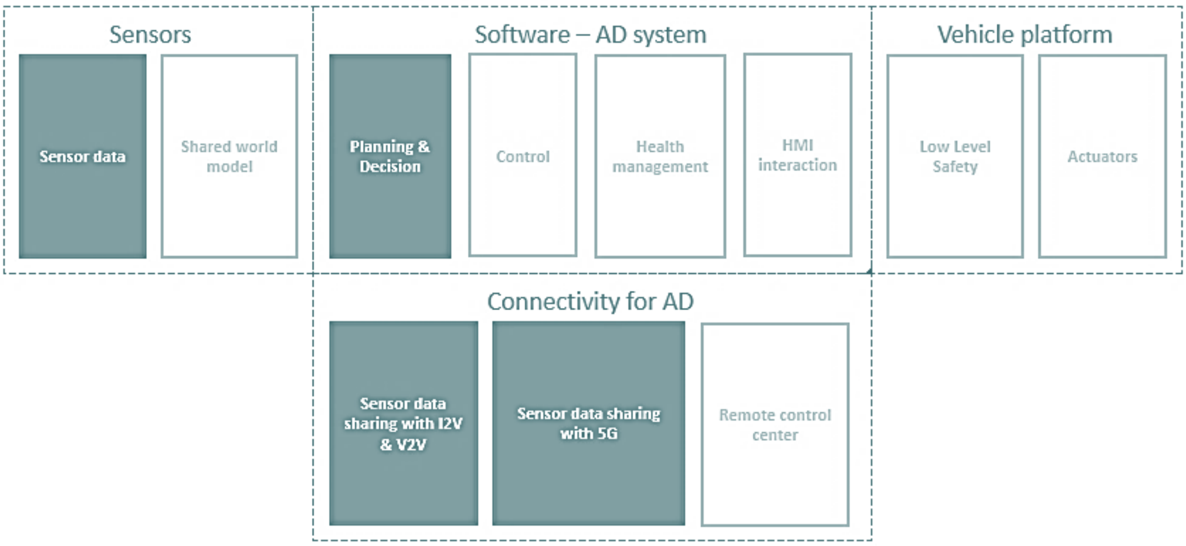

Figure 51: TNO’s vehicle AD function development to support collective perception of environment use case

SISSBV vehicles are also involved in Collective perception of environment NL site Use Cases. To perform these proposed Use Cases the different modules in the SISSBV automated driving platform have to be enhanced to cope with additional 5G augmented driving functionalities. The “Collective perception of environment”, exchanges real time sensor information between vehicles and road side infrastructure such as cameras to create a better perception of the environment for the vehicle. These exchanges impose very low latency and high bandwidth requirements, which can be provided by 5G technology. The vehicles should be able to gather this sensor information from both vehicles and infrastructure thus enhancement of both cellular and ad-hoc communication of SISSBV is necessary. Furthermore, vehicles should be capable of fusing sensor data to enhance the perception, hence, further development of sensor fusion functions in vehicle is necessary.

2.5. B.5 Trial Site China

2.5.1. B5.1 User Story #1: Road safety and traffic efficiency services

-

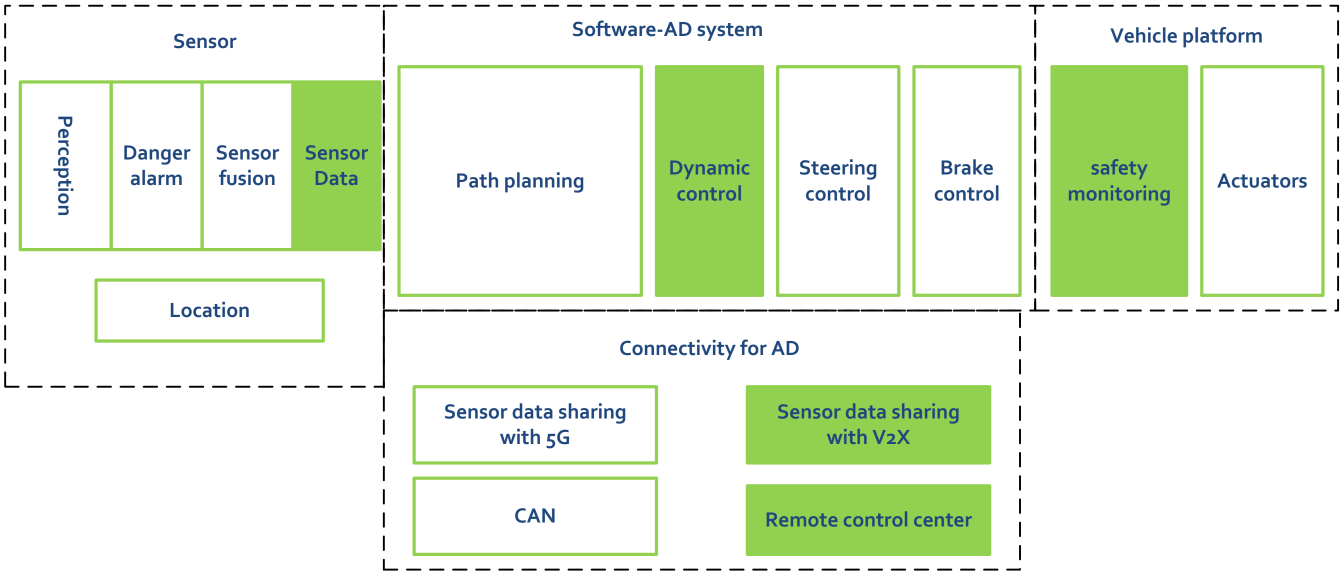

Figure 52: China vehicle platform extension to support Road safety use case

- The SDIA Vehicle collect sensor data and contact with each other by V2X Communication.
- Vehicles monitor the road safety and dynamic control its motion.

2.5.2. B5.2 User Story #2: Automated driving

This user case will employ SDIA for Automated driving (Coordinated overtaking and collision avoidance and Remote Manoeuvre).

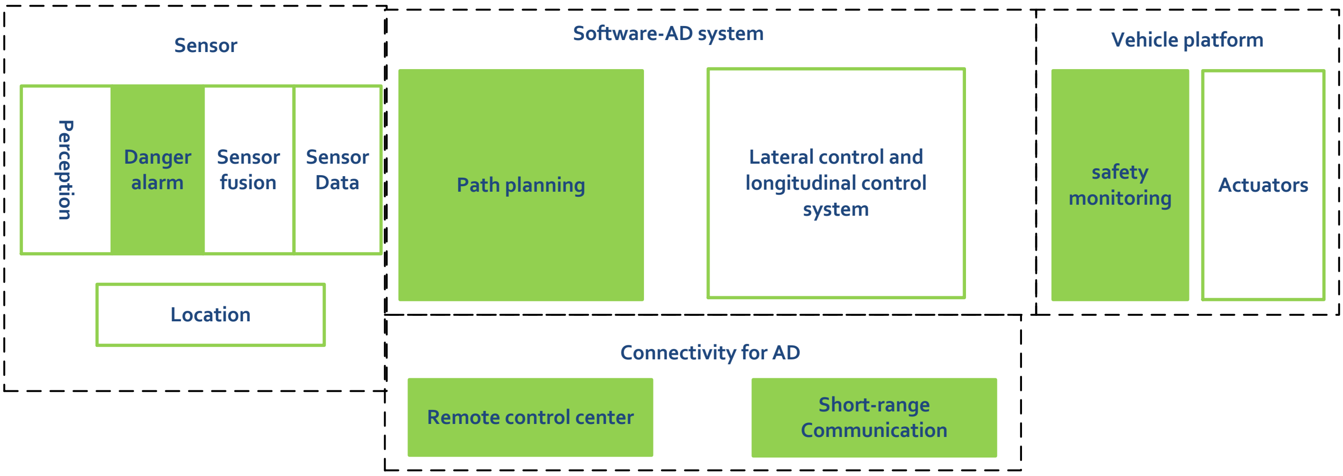

Figure 53: SDIA Chinese vehicle platform extension to support automated driving use case

- Vehicles contact with each other by Short-range Communication.
- Vehicles monitor the road status and alarm dangerous situation and send the information to the remote centre.

2.6. B.6 Trial Site South Korea

2.6.1. B.6.1 User Story #1: Remote Driving

KATECH's automated vehicle is equipped with the WAVE, 4G/LTE, and 5G communication devices as a V2I communication device (or OBU) and is equipped CAN communication as an in-vehicle network interface. Since low latency (up to 4ms) and high reliability are essential KPIs (Key Performance Index) between automated vehicle and remote-control centre for satisfying remote driving use case, 5G device supports direct communication between vehicle and remote-control centre (local digital infrastructure) with mm WAVE. ADAS (Advance Driver Assist System) information such as BSD (Blind Spot Warning), LDW (Lane Departure Warning), and FCW (Forward Collision Warning) will be accessed by in-vehicle network (or CAN communication) and will be shared with remote control centre with remote control centre. Network slicing technology will be implemented to ensure real time streaming of sensor, video, and control data in the core network layer. The lateral and longitudinal controller will be utilized to make the automated vehicle capable of responding to the request of remote site operator.

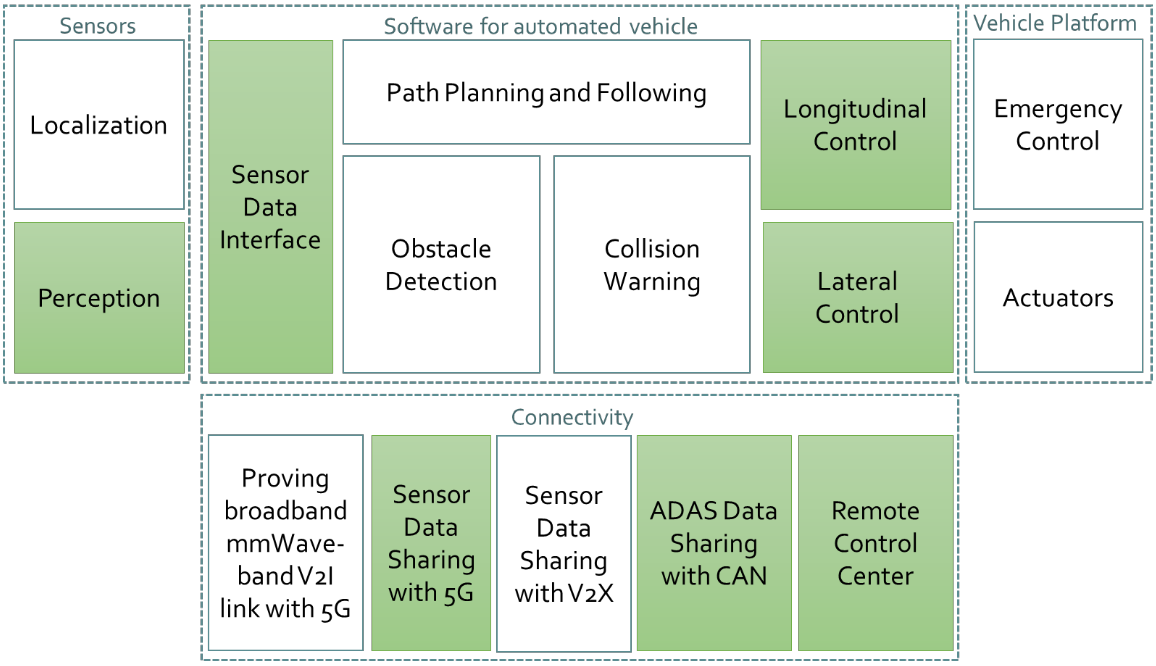

Figure 54: KATECH vehicle platform extension to support remote driving use case

2.6.2. B6.2 User Story #2: Tethering

KATECH's automated vehicle is equipped with the WAVE, 4G/LTE, and 5G communication devices as a V2I communication device (or OBU). Since management of wide mmWave [11] spectrum bandwidth reaching 1GHz and robust mobility supporting algorithms with very low interruption time down to 2ms are essential KPIs (Key Performance Index). Therefore eMBB (Enhance Mobile BroadBand) [12] technology base on mmWave will be implemented to provide moving vehicles with a broadband mmWave-band V2I link that allows onboard passengers to experience high-quality connectivity to the Internet.

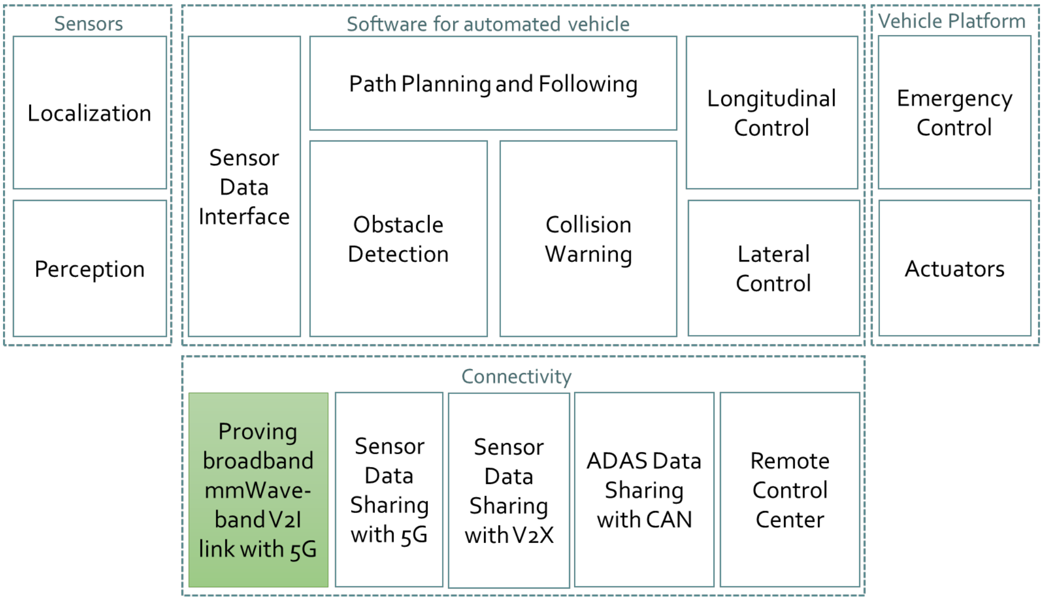

Figure 55: KATECH vehicle platform extension to support tethering use case

3. ANNEX C: 5G AUGMENTED ON-BOARD UNITS

This section aims to give a complete description of the On-Board-Units augmented with 5G used on each cross-border corridor and local trials.

3.1. C.1 Overview

In total 20 different OBUs are used within 5G-MOBIX. The table below gives a summary per local trials and cross-border corridors:

Table 27: Overview of different OBUs used in each corridor and trial site

Trial	Number of OBU	Type of OBU	5G chipset	Responsible partner
Spain-Portugal	1 OBU per vehicle **6 OBUs in total**	Developed by CTAG Developed by ISEL	Provided by Qualcomm Provided by Qualcomm	CTAG ISEL
Greece-Turkey	1 per vehicle **3OBUs in total**	Developed by IMEC	Provided by Qualcomm	IMEC
Germany	1 per vehicle (1xTUB, 2xVALEO, 1xVICOM) **4 OBUs in total**	Developed by TUB Developed by VALEO Developed by VICOM	Provided by Qualcomm Provided by Qualcomm Provided by Qualcomm	TUB VALEO VICOM
France	1 per vehicle **2 OBUs in total**	Developed by VEDECOM	Provided by Valeo (subcontracting)	VEDECOM
Finland	1 per vehicle **2 OBUs in total**	Developed by VEDECOM	Provided by Valeo (subcontracting)	VEDECOM
Netherlands	1 per vehicle (1x TU/e 1x SISSBV 1xVTT) **3 OBUs in total**		Provided by Qualcomm	
China	1 per vehicle	Datang	Datang	SINOTRUCK

	1 in total			SDIA
South Korea	1 OBU **1 in total**	Developed by KATECH	Developed by ETRI	ETRI

3.2. C.2 OBU on Spain-Portugal CBC

3.2.1. C.2.1 CTAG OBU

Specifications

The first OBU used in the Spanish-Portuguese cross-border site is from CTAG. In the following, we present an overview of its hardware components.

Table 28: HW components for the CTAG OBU

Functionality	Device	Units
Computation	IMX-6 Quad CoreRAM: 4GB DDR3	1
Memory	Internal NAND: 8GB Internal FLASH (up to 32GB).	
GPS	D-GPS (1 or 10Hz optional)	1
Connectivity: V2V/V2X + 4G LTE	Cellular Channel (3G/4G/LTE/LTE-V2X/5G	1
Connectivity ITS-G5	ITS-G5 (802.11p) Channel	1
Connectivity: Wi-Fi	WIFI: 802.11n & Bluetooth 4.0	1
Connectivity: CAN	CAN Channel	2
Connectivity: Ethernet	Ethernet 100/1000 Automotive Ethernet	1 1

5G Connectivity	Qualcomm modem and antenna	1
Other characteristics	• 12/24V. • Dimensions: 150x110x50 mm • Weight: 365 gr. g (w/o antennas) • 16750-2 & 4 compliant (electric B-code and climatic D-code loads) • Heat generation: 45ºC • KL15 to select Power Mode (Operational or Sleep). • 2 x USB 2.0 (Host & OTG) • CAN & Cellular wakeup capability	

The main functionalities/capabilities of CTAG OBU are highlighted below:

- Possibility to modular different configuration for Cellular, 802.11p and D-GPS, according to specific needs.
- Possibility to deploy cooperative services for the different communication technologies
- Possibility to deploy Infotainment & Telematic services
- Possibility to deploy AD services
- Possibility to deploy IoT services

Main Interfaces

Vehicle connectivity:

- 2 CAN HS interfaces: to provide a vehicle link up to 2 CAN networks (ISO 11898-2 and -5) are available. They allow the connectivity with the vehicle for data acquisition (status, actuators, etc...) and also to connect with the HMI elements (Instrument Cluster, buttons) in order to interact with the driver.
- Automotive Ethernet: to provide a connectivity with other ECUs inside the vehicle, and the exchange of vehicle data.

Software components

The On-Board Unit relies on a Custom Linux distribution that can be customized for different purposes. Applications are developed under JAVA [13] and the OSGI Framework [14], allowing a very flexible environment for the implementation and development of different solutions.

ITS Stack has been developed following ETSI Standard for the Geonetworking [15] and Application layers, complying with the latest versions of the defined standard.

OSGI provides the possibility of creating new Bundles that can use the ITS Stack or the other connectivity functionalities enhancing the flexibility of the unit.

Hardware components

- Storage
  - Internal Flash Memory (up to 32GB)
  - External USB memory stick could be added
- Power Supply
  - Power input range: 8-36V
  - Wake-up via CAN, Cellular or KL15
  - Low power consumption operation mode (sleep mode)(less than 2mA), wake-up via CAN, cellular or KL15
- Housing
  - Bola Alubos anodized aluminium
  - Automotive TE Connectivity MQS connector to power supply and vehicle connectivity.
  - Customized cabling on demand.
  - Dimensions: 150x110x50 mm
  - Weight: 365 gr (w/o antennas)

3.2.2. C2.2 QoS Probe OBU

To assess the 5G Quality of Service (QoS) supported from the vehicle perspective, an 5G QoS OBU Probe will be developed. The main goal is to measure 5G performance technical KPI (defined in D2.5) at RF front-end adding network KPI using an API available in the core network.

QoS Probe OBU Functional Architecture

The functional architecture of the 5G QoS probe, as depicted in Figure 56, contains the following components:

- The Man Machine Interface (MMI) present information to the operator about the state of the probe and its main components, using a LED interface, and to accept control instructions;
- The Repository includes the necessary interfaces and services to support the data storage management.
- Remote Server Connection allows connecting periodically, or on request to a server to send and receive data, via 3 G / 4 G modem. Using these RANs, the 5G performance is not disturbed by this KPI data flow
- QoS Test Manager is responsible to execute active and passive tests, producing network data via 5G modem measurements, to support the KPI calculation. All tests will be georeferenced using a navigation module.

- QoS Test Manager that will execute active and passive tests to produce network KPIs, via 5G modem measurements. All tests will be georeferenced using the navigation layer modules.
- OBU Core that will manage the system configuration, alarms and the tests scheduling.

The CAN-bus interface allows the capture of contextual information. Besides the enrichment of the RF data, contextual vehicle information is needed to assure the proper KPI computation that are velocity depend. Contextual information is also needed to support 5G traffic sessions repetitions design and 5G traffic generation during network stress tests.

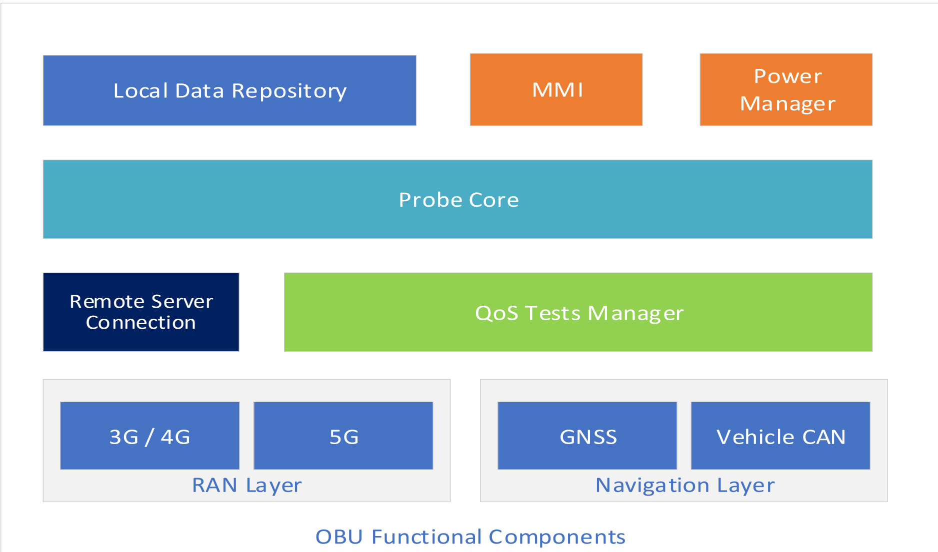

Figure 56: QoS Probe OBU functional components

QoS Probe OBU Hardware architecture

The QoS OBU hardware architecture contains the following components:

- A Global Navigation Satellite System (GNSS) interface that will provide geo-spatial positioning.
- A CAN BUS interface that will provide vehicle information.
- A 5G Modem with MIMO capabilities, with a number of antennas dependent on the available modem.
- Power Manager will monitor the ignition shutdown in order to softly shutdown the probe.
- Probe Main Board controls all OBU components, communication interfaces. Supports all functions necessary for technical KPI extraction.

The following figure provides the 5G QoS probe prototype enclosure aspect, front and back:

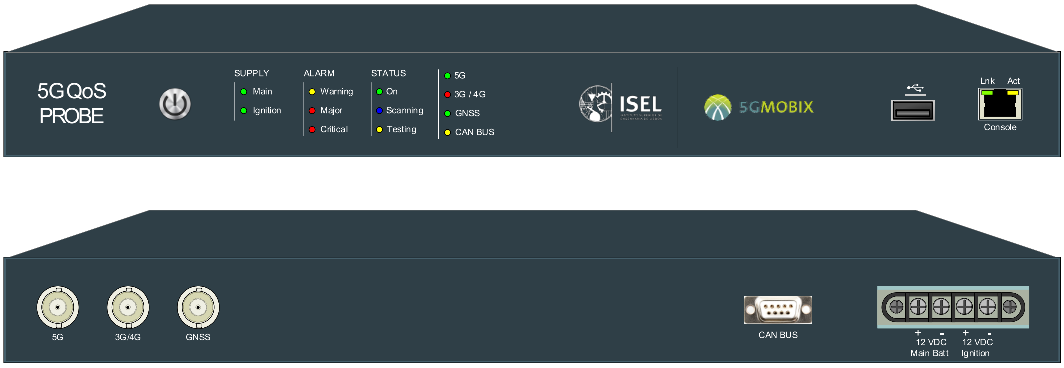

Figure 57: QoS Probe OBU hardware design

In the front side we can see the status of different OBU critical internal systems and cellular interfaces using status LED, OBU console access plug it is also visible. The 5G modem will be installed internally and respective external connections to antennas will be available on the prototype back side. The CAN bus and external power supply connections are also available in the OBU back side.

3.3. C.3 OBU on Greece-Turkey CBC

OBU System Architecture

The OBU architecture is split into two separate OBU units. The first OBU unit will be provided by Ford Otosan. This OBU will control the vehicle and process the sensor information. The second OBU unit is installed on the roof of the vehicle and is only connected to the vehicle OBU with an Ethernet connection, power connection and camera connection (depending on the camera setup used in the vehicle). The OBU will contain all the V2X communication hardware and the processing units of sensors that are mounted on top of the vehicle. The two OBU units and their components are shown in Figure 58.

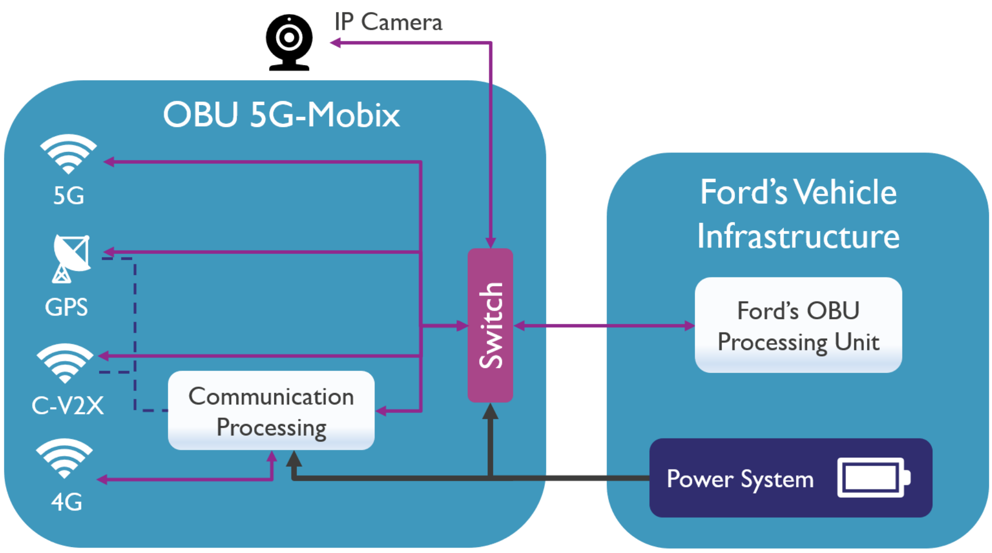

Figure 58: GR-TR OBU System Architecture

OBU Software Architecture

The software architecture of the OBU is based on event streaming architecture. This architecture is chosen to split the software into modular software components that can be run on different processing platforms to reduce the load on the main processing unit. This allows us to create sensor connection platforms that can interact with an individual sensor and output a standardised message that can be used in the entire system. This design allows us to create strong interfaces between the sensors and high-level software components. When we must change a sensor or a V2X component we can implement new software components to connect the new sensors and new V2X components to these interfaces. This allows us to create high level applications while allowing flexibility in the low-level components.

Imec's Distributed Uniform Streaming (DUST)-framework will be used to send the messages between the different software components. DUST is built on top of traditional messaging protocols like MQTT [16] and ZeroMQ [17] . The goal of DUST is to provide an interface between the messaging protocols and the applications. This allows the developers to switch to a different messaging protocol without changing the application. This can be required because every messaging protocol has its advantages and disadvantages. The messages in DUST are defined with google protocol buffers. These data structures are used to create the interfaces between the software components that are used in the OBU.

OBU Hardware Architecture

The roof unit contains all communication hardware, V2X processing hardware and sensor processing hardware. Figure 59 shows the OBU prototype with all the hardware installed. The centre of the roof unit is the Intel NUC processing unit which will implement the V2X stack and communicate with the OBU within the vehicle. The OBU can access the functionally of the roof unit with the interfaces of imec's DUST framework as discussed in the software architecture.

Figure 59: Roof Unit Prototype

The roof unit requires three voltages to operate correctly (12V DC, 230V AC) and an Ethernet connection to the vehicle unit. The following table list all the specifications of the hardware that is used in the OBU.

Specifications	
V2X processing unit: NUC7iDNKE	• I7-8650U Processor • 8GB system memory • 120GB SSD
Phoenix gigabit switch	• 8 port • 1 Gb/s
ITS-G5: Cohda Wireless OBU 	• Cohda MK5 OBU • Mobilemark MGW-303 antenna • two 5.9GHz antennas for DSCR with an active GNSS antenna

C-V2X: Qualcomm C-V2X Development Platform

	• MDM9150 module with 5.9 GHz RF Front End (RFFE) –B47 and B46D
	• Qualcomm® Snapdragon™Application Processor module
	  ◦ The QTI CV2X platform software development kit (SDK) on APQ8096 provides an interface to the CV2X radio/QDR/CAN
	  ◦ Savari software to support the ETSI ITS stack
	• Mobilemark MGW-412 (LTE, 2xWiFi, GPS) antenna
	  ◦ GPS Multiband Mag-Mount Antenna

4G module: Mikrotik wAP LTE kit	• LTE Category 4 (150Mbps downlink, 50Mbps uplink) • Internal WWAN antennas with support for optional TS9 external antennas

	

3.4. C.4 OBU in Germany Trial Site

3.4.1. C.4.1 VALEO OBU

The OBU used at the German trial site is a Valeo prototyping system that integrates a superset of features usually available on mass-market automotive telematics control units (TCUs). We will introduce the system architecture in section 1.2.1, while describing the SW framework in section 1.2.2 and concluding the chapter with further details on the deployed hardware in section 1.2.3.

OBU system architecture

The OBU system architecture is shown in Figure 60.

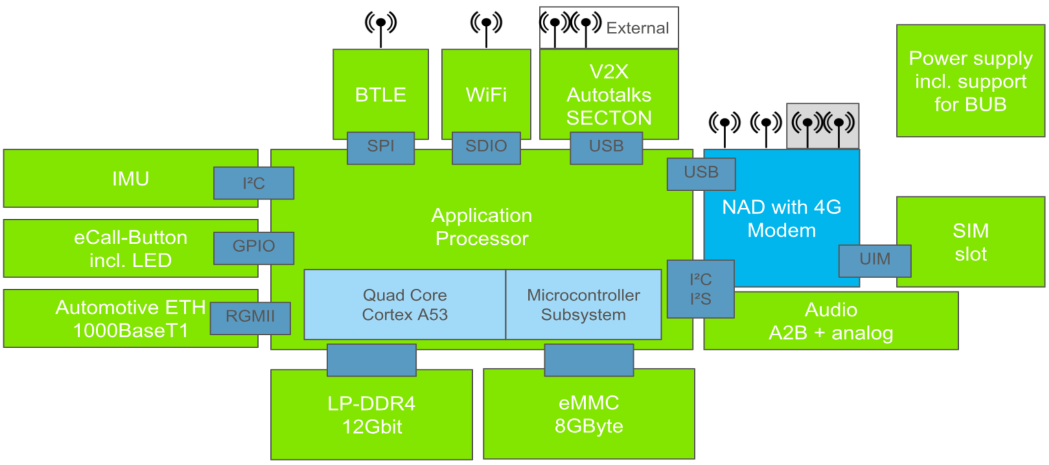

Figure 60: System architecture of OBU for German trial site

The system is based on a slim modem architecture around a central system on chip hosting a quad-core A53 application processor and an additional microcontroller subsystem that may support CAN or other interfaces but will not be used in the context of MOBIX.

The second main component is the Network Access Device (NAD) hosting the 4G LTE modem. It will be replaced in a latter phase of the project with a NAD hosting a 5G NR [18] capable modem. In addition to the modem chipset the NAD hosts its own flash and RAM but also power management, radio frequency frontend and a less powerful application processor that can be used for less complex telematics applications or delay-sensitive tasks such as control of voice data processing within the NAD.

Most of the components are connected to the central application processor that also runs the main Linux software framework as described in the following section.

In the following, we describe the remaining system components as shown in the above figure:

- LP-DDR4 RAM and eMMC flash memories are basic requirements for an OBU to operate in standalone mode.
- The automotive ETH interface is the main interface the OBU uses to communicate with the remaining vehicle. The system at hand supports the latest IEEE standard 1000BaseT1.
- Since eCall functionality is an important feature of typical TCUs in vehicles the prototyping OBU also supports dedicated hardware interfaces to connect and diagnose, e.g., an eCall button that the car passengers could press in case of emergency. However, no use of these features is foreseen for MOBIX.
- The IMU (Inertial Measurement Unit) provides accelerometer and gyroscope sensors enabling to track parts of the movement of the vehicle. It enables improved dead reckoning for positioning solutions.
- A dedicated BTLE chipset is also part of the OBU.
- Same goes for a WiFi chipset that, e.g, enables sharing the cellular connectivity with car passengers via a hotspot functionality. It will also be useful during testing and system optimization.

Another important part of the system is the V2X solution. It is based on an Autotalks SECTON chipset [19] that supports both major V2X radio standards, namely IEEE 802.11p/DSRC and 3GPP C-V2X (Rel. 14). Via software changes the system can be configured to run either one of the standards.

OBU software

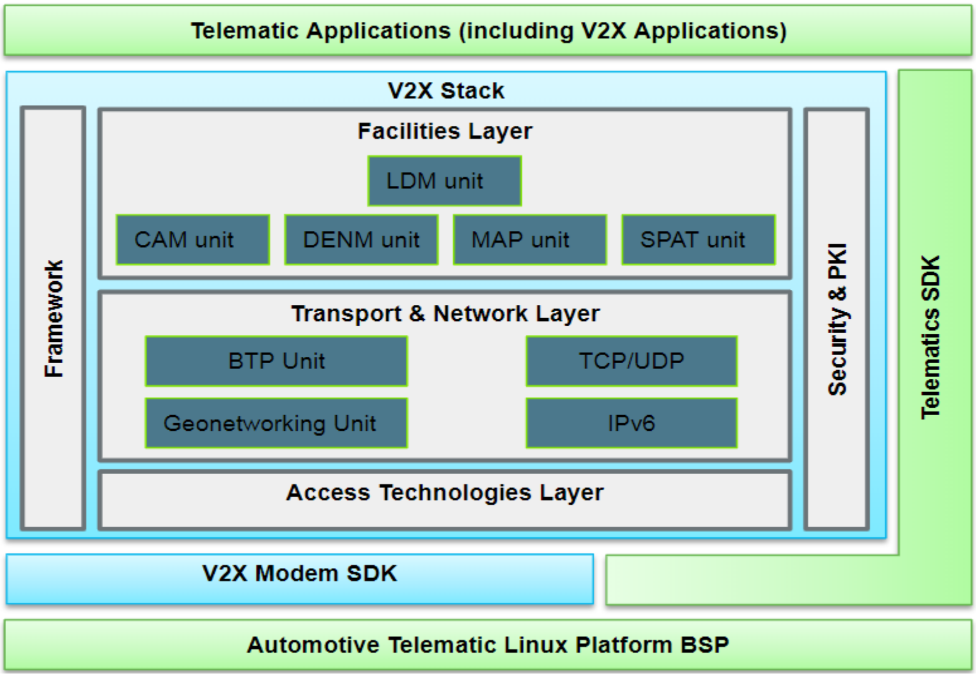

Figure 61: OBU software architecture for the German trial site

Hardware and variants:

The OBU is available in two groups of variants. The major difference between the two groups is the installation space in the vehicle. The device can be installed in the roof of the vehicle providing integrated antennas for multiple wireless technologies. The other group of variants can be installed in multiple different installation spaces, i.e., the trunk of the vehicle, since it relies on external antennas and provides SMA-connectors to connect to the external antennas. However, some antennas such as WiFi and Bluetooth are still integrated such that an installation close to the passenger compartment will ensure stable communication links for these technologies.

Inside each group of variants, the difference between the devices is the frequency band configuration of the NAD (network access device), i.e., the support for different frequency bands used in different geographical areas of the world. The device has been designed for automotive use and since cars rarely travel between continents and tailoring the band configuration for the area of use saves significant cost there are in total four different variants: Europe (EU), North America (NA), China (CHN), and Rest of World (RoW). The latter covers countries that have specific band support needs such as Japan and cannot be supported properly with the other three variants.

The table below lists antennas across all supported wireless technologies, and which are internal or external for the different variants:

Table 29: Overview of different supported wireless antennas of VALEO vehicle

Antenna	Roof variants	Trunk variants
Cellular: MIMO1-MIMO4	Internal	External via SMA-connectors
GNSS	Internal	External via SMA-connector
WiFi	Internal	Internal
Bluetooth	Internal	Internal
Remote Keyless Entry	Internal	Internal
V2X (DSRC/C-V2X)	External via 4-times FAKRA connector	External via 4-times FAKRA connector
SDARS	Internal (signal will be forwarded to remaining signal via 4-times FAKRA connector)	N/A

The V2X antennas will always have to be installed externally since the high frequency of 5.9GHz and the low angle to the communication peers prevents sufficient performance for internal antennas.

3.4.2. C.4.2 VICOM OBU

OBU system architecture

The following diagram depicts the connection interfaces of CarLOTA's OBU.

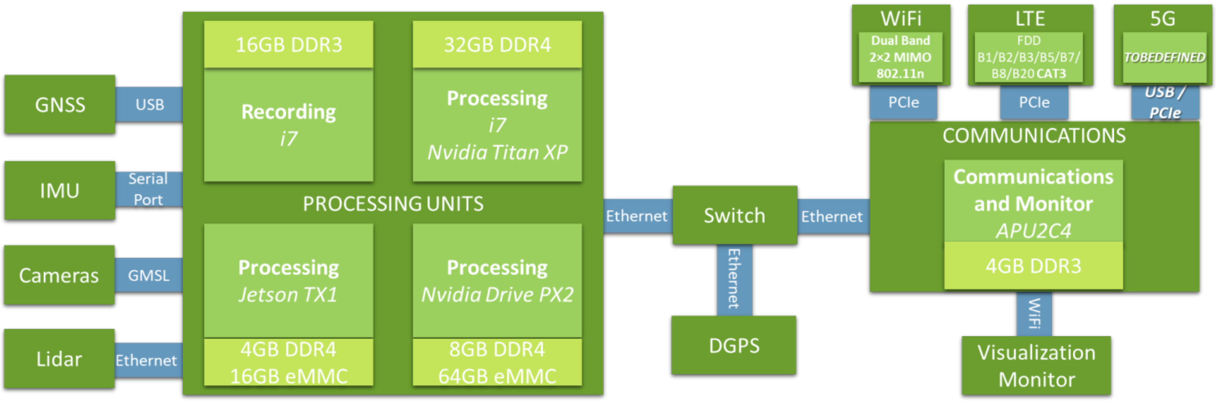

Figure 62:System architecture of VICOM's OBU for German trial area

The system ships 4 different processing units for different sensors and AD functions. The second main component is the communications equipment mounting the 4G LTE and the WiFi modem. It will be extended in a latter phase of the project with a 5G capable modem.

OBU Software

For the CarLOTA vehicle the OBU include the following SW libraries pipelined to support AD functions provided by Viulib SDK developed by Vicomtech.

Figure 63 depicts the SW stack at CarLOTA's OBU.

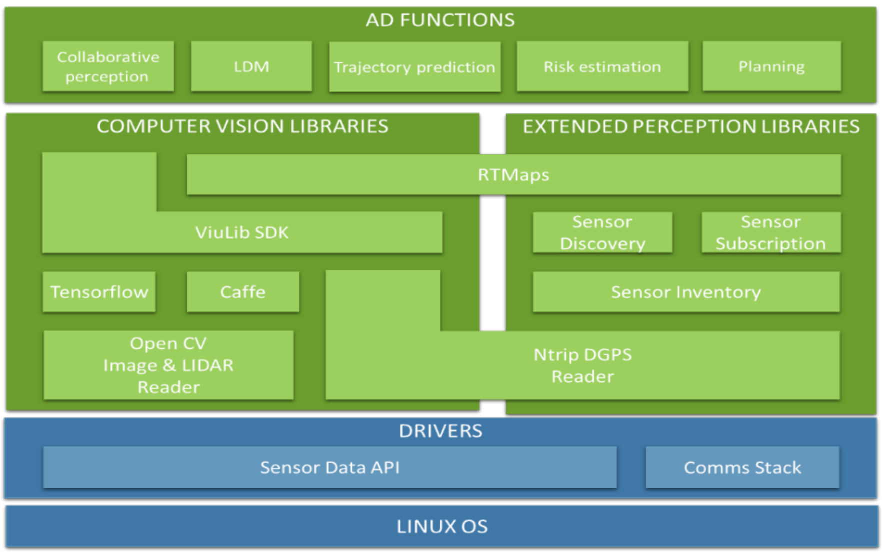

Figure 63: SW architecture of VICOM's OBU for German trial area

The different AD functions are based on HD maps built by means of RT Maps [20] suite and Viulib features. For the sensor sharing the geolocation and the support from the network edge is exploited to discover available sensors and to subscribe their flows instantly. Different sensor drivers and libraries allow to setup and read data from them. This manner the different components and libraries provide the extended perception functionalities to expand AD functions from onboard sensors to external sensors.

OBU hardware

For the Carlota vehicle, the OBU include the following HW components.

Table 30: HW components for the VICOM OBU

Functionality	Device	Details
Recording	• ACO-6000 embedded PC	• intel i7-6700TE and 16GB RAM
Processing	• Intel I7 7700k with	• Nvidia Titan XP and 32GB RAM
Processing	• Nvidia Jetson Tx1	• 4 GB DDR4, 16 GB eMMC, WiFi and BT Ready
Processing	• Nvidia Drive PX2	• 1x Tegra X2 (Parker) + 1x Pascal GPU 8 GB DDR4, 64 GB eMMC
LTE+WiFi Communications	• APU.2C4	• 4GB quad core, WLE200NX miniPCIe wifi Huawei ME909u-521 LTE miniPCIe + OpenWrt OS
Switch	• Netgear GS108E-300PES	
5G Modem	• To be defined	

3.4.3. C.4.3 TUB OBU

This section describes OBU system of TUB used in German trial site.

OBU system architecture

TUB's OBU system is the result of extending the existing Tiguan Allspace platform with hardware and software components to support SAE L-4 functionalities. General component architecture of TUB's OBU system design and connectivity is depicted in the following diagram.

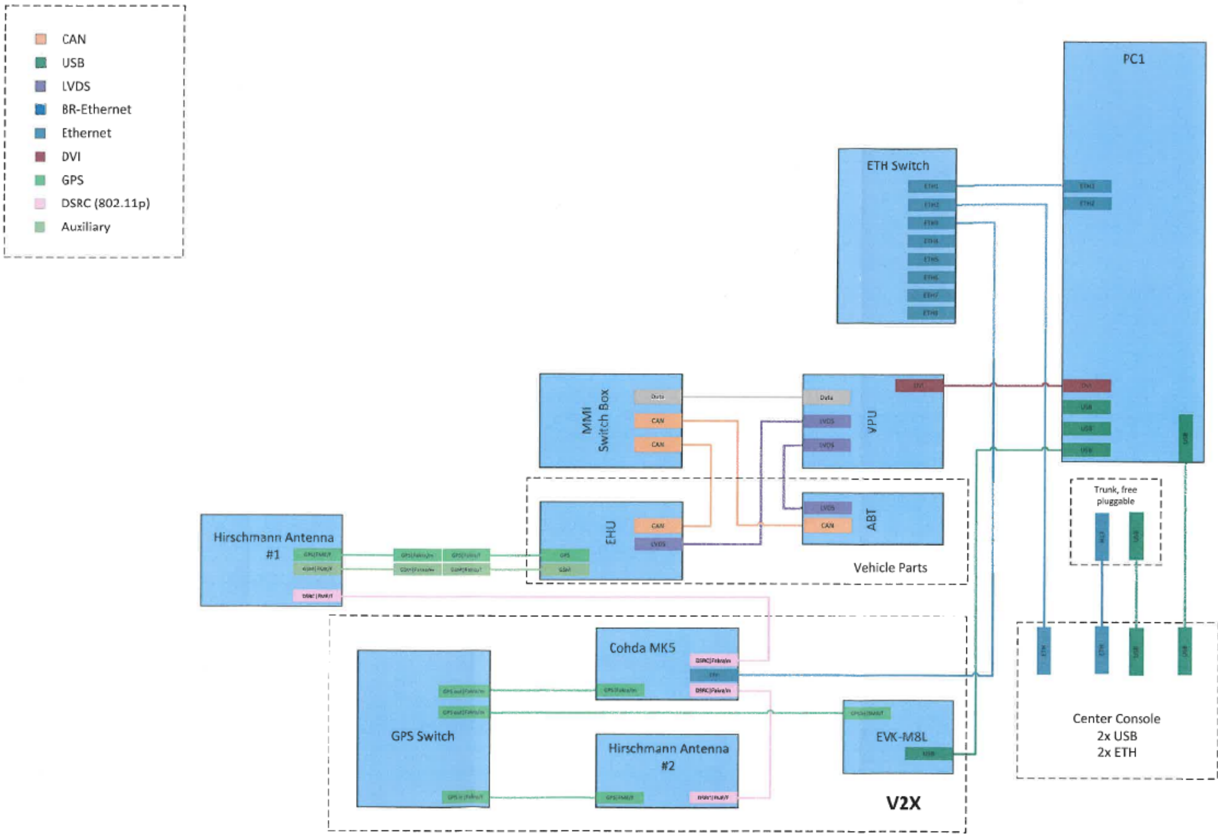

Figure 64: Connection plan for on-board components

The OBU components enabling SAE L-4 are listed in the following table.

Table 31: TUB OBU components enabling SAE L-4

Functionality	Device Model	Units	Description
Compute	• Spectra Powerbox 1295 (PC1)	1	• Computer for on-board computation. • Mini-PC, Bare, i7-5850EQ, 8GB, 128GB SSD, PCIe16. • Ubuntu 16.04
Network: V2V/V2X	• Cohda MK5 OBU	1	• V2V/V2X DSRC based communication with dual IEEE 802.11p radio, integrated GNSS. • Cohda SDK

Mobile Broadband	• Ericsson Business Mobile Networks BV F3507g Mobile Broadband Module	1	• 4G communication
Mobile Broadband	• Huawei Technologies Co., Ltd. Modem/Networkcard	1	• 4G communication
Network: WiFi	• "Nao" Wifi-Stick		• WiFi communication
Network: Antenna	• Hirschmann CGW 70 26 59 S/FME/3.0 (2x)	2	• LTE und GPS Antenas
Energy	• MRS CAN Gateway Modul	1	• Energy control and management for additional on-board devices
Network: Switch	• Spectra NS-208G CR Switch	1	• Network switch for vehicle internal communication
Multimedia	• BFFT IPU / VPU	1	• Image adaptation for on-board display
Multimedia	• BFFT MMI-Switchbox	1	• Multimedia switch for on-board display

OBU software system

TUB' OBU software stack is depicted in

Figure 65.

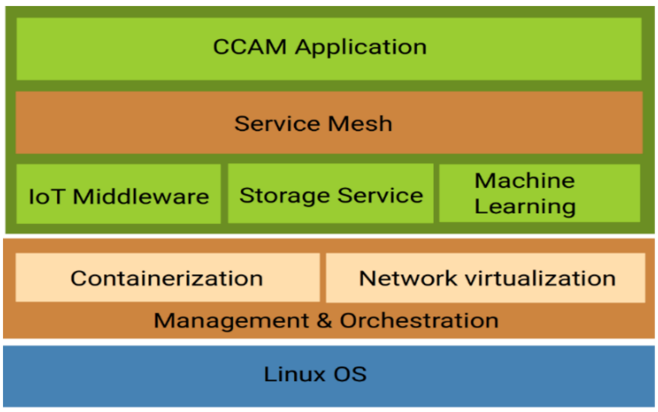

Figure 65: TUB's OBU software stack

OBU hardware architecture

The following picture depicts the hardware integration of TUB’OBU in the autonomous vehicle.

Figure 66: TUB's OBU installation on AV

- **On-board computing**

The OBU’s computing capability is provided by an off-the-shelf mini computer platform. A hardened and customized Ubuntu linux is installed as operating system with features required for operating on vehicle, e.g., energy, persistence storage, life cycle management. In addition, a container-based virtualization and a network management layer allows the platform to serve as a mobile edge host for the flexible deployment of CCAM services.

- **V2V/V2X communication**

The OBU is equipped with multiple short-range communication interfaces enabling efficient data communication for different CCAM application requirements. DSRC interface provides low latency, low bandwidth and short-range communication with other AVs and road infrastructure for coordinated driving, emergency communication. Additional WiFi interface provides higher bandwidth and coverage for more demanding applications, e.g., HD-Maps, EDM, etc.

- **Mobile broadband**

Mobile broadband interfaces provide reliable connectivity with cloud based and edge platforms using 4G/5G technologies.

- **Energy management**

The power management is designed to power up the measurement equipment and to protect the vehicle battery against unintended discharge. The power management provides a vehicle-integrated power supply and an emergency shutdown. There are implemented features to control the power up and shutdown sequences which depend on vehicle and battery conditions.

Development & testing consoles

The console provides peripheral interface for connecting development and testing devices. These include an ethernet port, a USB port, an emergency switch and a key switch for measurement equipment.

3.5. C.5 OBU in France & Finland trial sites

OBU system architecture

In the following, we present a high-level overview of the VALEO's OBU (see Figure 67) provided for the French & Finnish site.

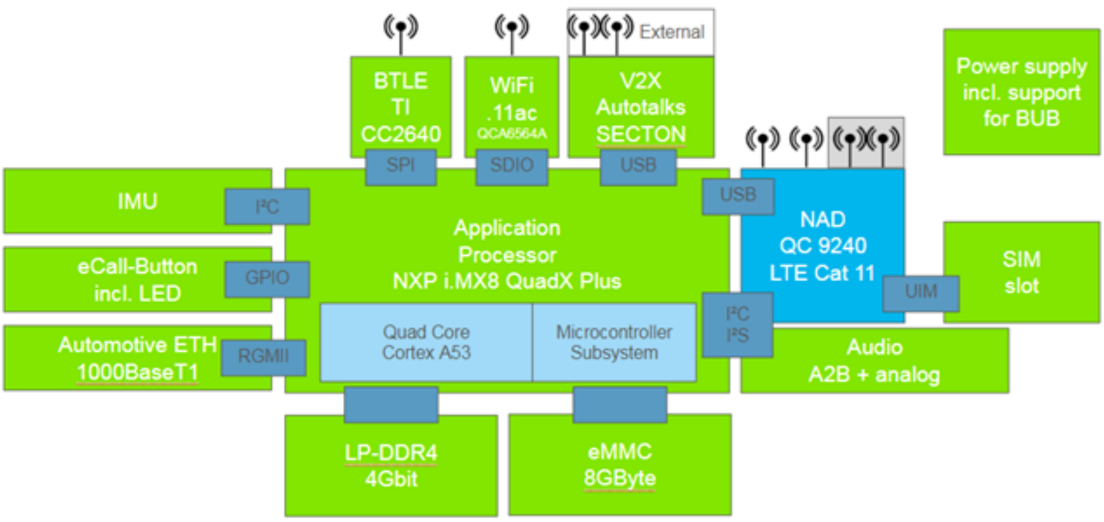

Figure 67: High level architecture of VALEO's OBU in the French trial site

The main OBU characteristics are depicted in the following table.

Table 32: FR & FI OBU main hardware components

Functionality	Device	Units

Computation	• NXP i.MX8 with Optional external MCU	1
GPS	• D-GPS (1 or 10Hz optional)	1

Connectivity: V2V/V2X + 4G LTE	• NAD Qualcomm 9240
	  • LTE Category 11 modem
	  • PCB prepared for larger 5G NAD
		1

Connectivity ITS-G5	• DSRC & C-V2X	1
Connectivity: Wi-Fi	• WIFI: 802.11n & Bluetooth 4.0	1
Connectivity: CAN	• CAN Channel	1
Connectivity: Ethernet	• 1Gbps Automotive Ethernet	1
Connectivity 5G	• Qualcomm SA515m	1
Antennas	• 4x4 MIMO cellular • GNSS • V2X antennas • SDARS, BLE, WiFi, RKE	
Other characteristics	• Digital (A2B) and analog audio • Thermal dissipation & shielding concepts • Back-up Battery mounting concept • Small size (220x145mm)	

For 5G-MOBIX project, the 4G and 5G cellular communication technologies are implemented and delivered in a three-step ("delivery-1", "delivery-2" and "delivery-3" hereafter) process.
The goal behind this multiple delivery is to carry over as much as possible but further improve platform maturity. The new delivery will include also new features, mainly around 5G chipset

- NAD upgrade to 5G NR (based on Qualcomm SA515m)
- Different application processor derivate (i.MX8DX, more cost-optimized to match telematics)
- High precision GNSS (as part of 5G modem chipset)

VALEO's OBU software architecture

In

Figure 68, we present the software architecture of VALEO OBU.

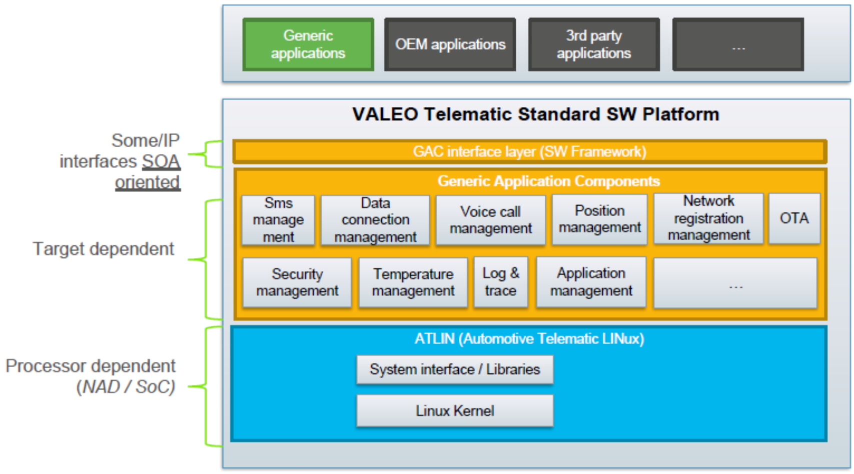

Figure 68: VALEO's OBU Software architecture in the French trial site

Automotive Telematic Linux Platform

The Automotive Telematic Linux Platform is the base layer. It comprises of standard/openly available Linux operating system. Linux 4.14.62 (built using Yocto 2.5 "Sumo"), AUTOSAR version 4.2.2, and other middleware and framework to support the general and OEM specific telematics (including V2X) applications running on the application layer.

Telematics SDK

The telematics SDK is the enabler for all the features of the OBU. The functionalities are exposed through the northbound APIs to the application layer. Using the software drivers, it manages and communicates with the underlying hardware using the OS layer below.

Application module

The application module will implement the applications needed for testing the use cases. These applications will be developed by VEDECOM but will utilize the functionalities exposed by the telematic SDK layer provided by VALEO

VALEO's OBU hardware architecture

Since the OBU will be installed inside the car, we opted to have the Trunk version of the hardware provide by VALEO. This variant can be installed in multiple different installation spaces, i.e., the trunk of the vehicle, since it relies on external antennas and provides SMA-connectors to connect to the external antennas. However, some antennas such as WiFi and Bluetooth are still integrated such that an installation close to the passenger compartment will ensure stable communication links for these technologies.

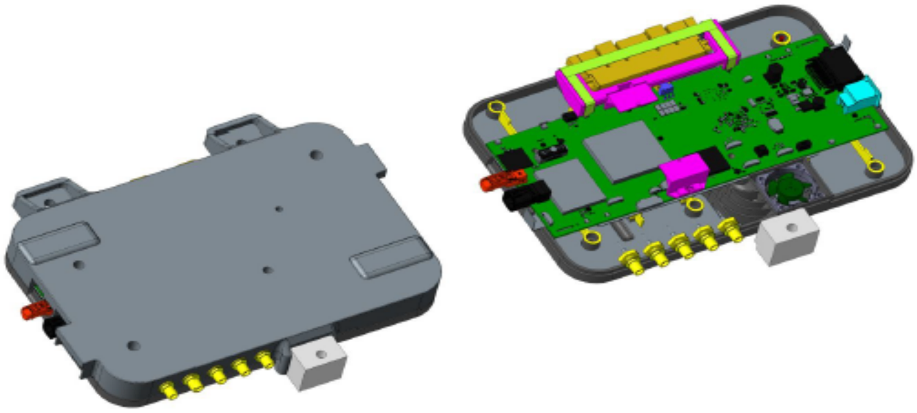

Figure 69: VALEO's OBU Hardware design in the French trial site

3.6. C.6 OBU in Netherlands Trial Site

The partners involved in the Dutch trail will use an identical hardware and software stack for the OBU (communication unit) capable of establishing a connection to a 5G network via 5G modem. The following sub-section describes each partner’s overall OBU system architecture and descriptions of hardware and software stack for the OBU.

In case of the NL Trial, the OBU will first be based on existing OBU with 4G LTE and ITS-G5 capabilities, which will later be extended with 5G chipsets or replaced by the VALEO OBU as described in sections below.

VTT is using an OBU based on Intrinsyc device platform with Qualcomm Cellular Vehicle-to-Everything (C-V2X) development platform.

OBU system architecture

The OBU is designed such that it can accommodate and extend functionalities for SAE-L4 automated driving. The following are the functionalities offered by different components of the OBU that SISSBV, TNO and TU/e use initially.

The overall vehicle OBU architecture for SISSBV, TU/e and TNO (TNO only for a connect, non-automated vehicle) are similar.

TU/e intends to extend this OBU (or the VALEO OBU depending on requirements, functionality and lead time) with mm-wave specific antenna and radio hardware.

Table 33: Connectivity components of the VTT Martti

Functionality	Device	Units	Description
Computation	• APQ8096AU module	1	• To connect the radio modules with on-board functionalities
Connectivity: 4G LTE	• Intrinsyc Development platform, and • dynnic communication device	1 + 1	• To extend the vehicle's connectivity
Connectivity: ITS-G5	• Intirinsyc Development platform, and LTE units	1 + 1	• To extend the vehicle's connectivity and for remote access
Connectivity: 5G	• TBD	1	• To extend vehicle's connectivity to 5G infrastructure
Connectivity: Antenna		4	• ITS-G5 & LTE functional antenna

OBU hardware components

In the Dutch trial site, the hardware for the communication unit is mainly based on a motherboard from PC Engines (see Figure 70). For the 5G-Mobix project the mother board APU 2D4 is selected. This mother board has an AMD Embedded GX-412TC CPU with 4 cores and 4GB DDR3-1333 DRAM. For storage the board has the following options: Slot for m-SATA, SD-card slot, SATA connector or USB. The board is powered by 12V DC and consumes around 6 till 12 Watts. For wired networking the board has three Gigabit Ethernet ports. Further the board has support for a DB9 serial port, 2x USB 3.0, 2x USB 2.0, LED status indicators, 2 miniPCI Express sockets (one with SIM socket), GPIO header. The board is passively cooled by the enclosure that is connected via a heat sink to the CPU.

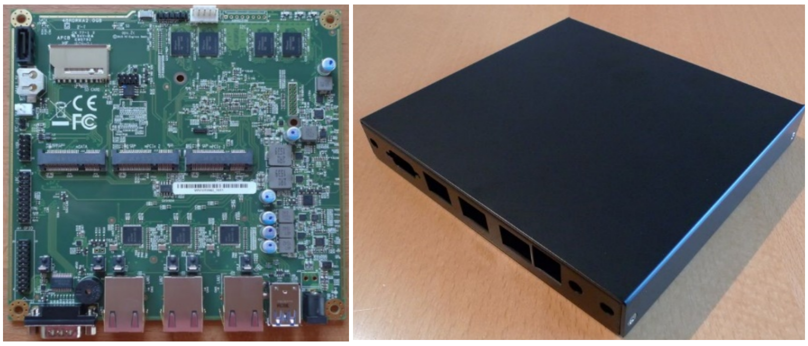

Figure 70: Left PC Engine Motherboard, right Black enclosure of the motherboard

The setup in 5G-mobix includes a SSD for storage on the APU mother board. One miniPCI Express socket is used for an ITS-G5/WiFi-p module, the Compex WLE200NX is selected for this.

VTT use Intrinsyc Development platform's OBU with Qualcomm Cellular Vehicle-to-Everything (C-V2X) development platform, as illustrated by Figure 71. This device is aimed at collision avoidance and value-added services. CV2X will enable vehicles to communicate critical messages with everything around them, including other vehicles and infrastructure. The major features of Intrinsyc device include CV2X 3GPP single channel radio, 2.4 GHz WiFi 802.11n connectivity, GNSS supporting 10 Hz augmented location fixes and HSM for storing private keys and signing the ITS messages.

Figure 71: Intrinsyc development platform of the VTT Martti

OBU software architecture

The software on the APU is running on a Linux operating system. The Linux distribution used on the APU is Debian. The WiFi module drivers need to be adapted in order to support the 802.11p protocol [21]. Then main software is developed in Java and consist out of 2 parts. Part one is the ROS (Robot Operating System) part that takes care of communicating with other computers over the in-car LAN. Part two is the BTP/geo-networking stack that handles the ITS-G5 geo-networking and communication. The software stack is partly based on open source software and partly on TNO developed closed source code. The stack also includes the C-ITS Security stack (ITS PKI) based on ETSI 103097 v1.2.1 and is successfully tested during PKI Security Testfest in Reims, April 2018. The ITS-G5 messages are put in UDP payloads that are converted to raw Ethernet messages that are then broadcasted over the 802.11p protocol via the WiFi module. The clock of the APU is synced with GPSD that is consuming the NMEA strings and PPS signal from the GPS module. The hardware clock of the APU has therefore been synchronized with microsecond accuracy with GPS time.

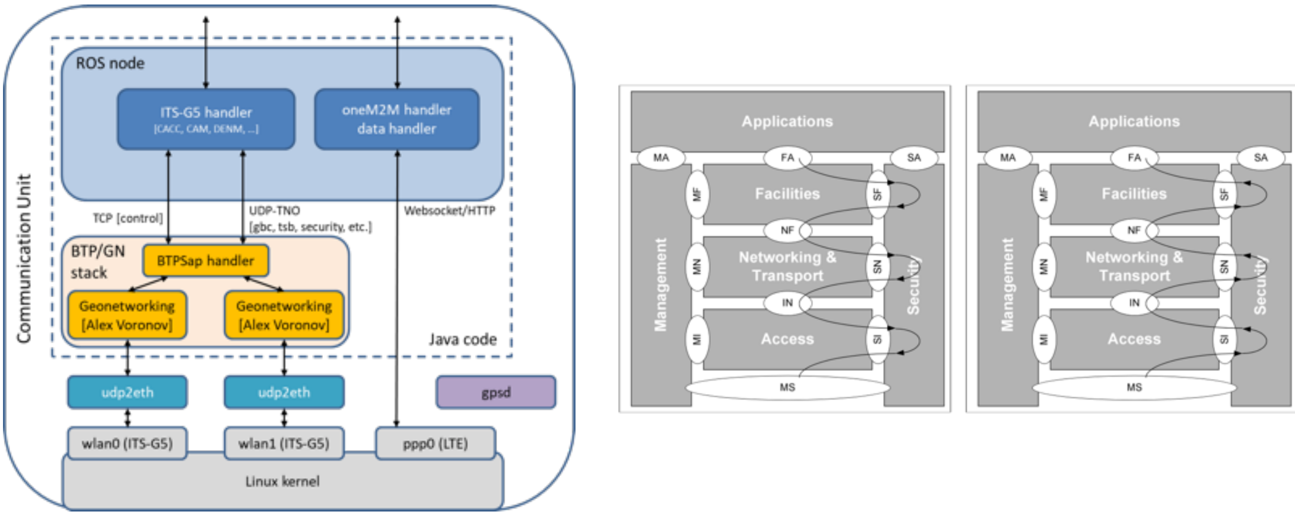

Figure 72: Software architecture overview of the OBU

3.7. C.7 OBU in China Trial Site

The OBU in the China site will be provided by Datang. Datang also provide the protocol stack and the SDK tools needed for development, which supports both cellular and pass-through modes for rich Telematics and V2X applications. The OBU features includes: (1) supports both cellular and pass-through modes for rich Telematics and V2X applications; (2) equipped with 7-inch screen, using Datang self-developed chip, built-in 4-core A7 processor, support for Linux/Android operating system, can run third-party applications directly; (3) support CAN / serial / RJ45 / USB interface, easy to interface with third-party equipment and testing.

OBU Architecture

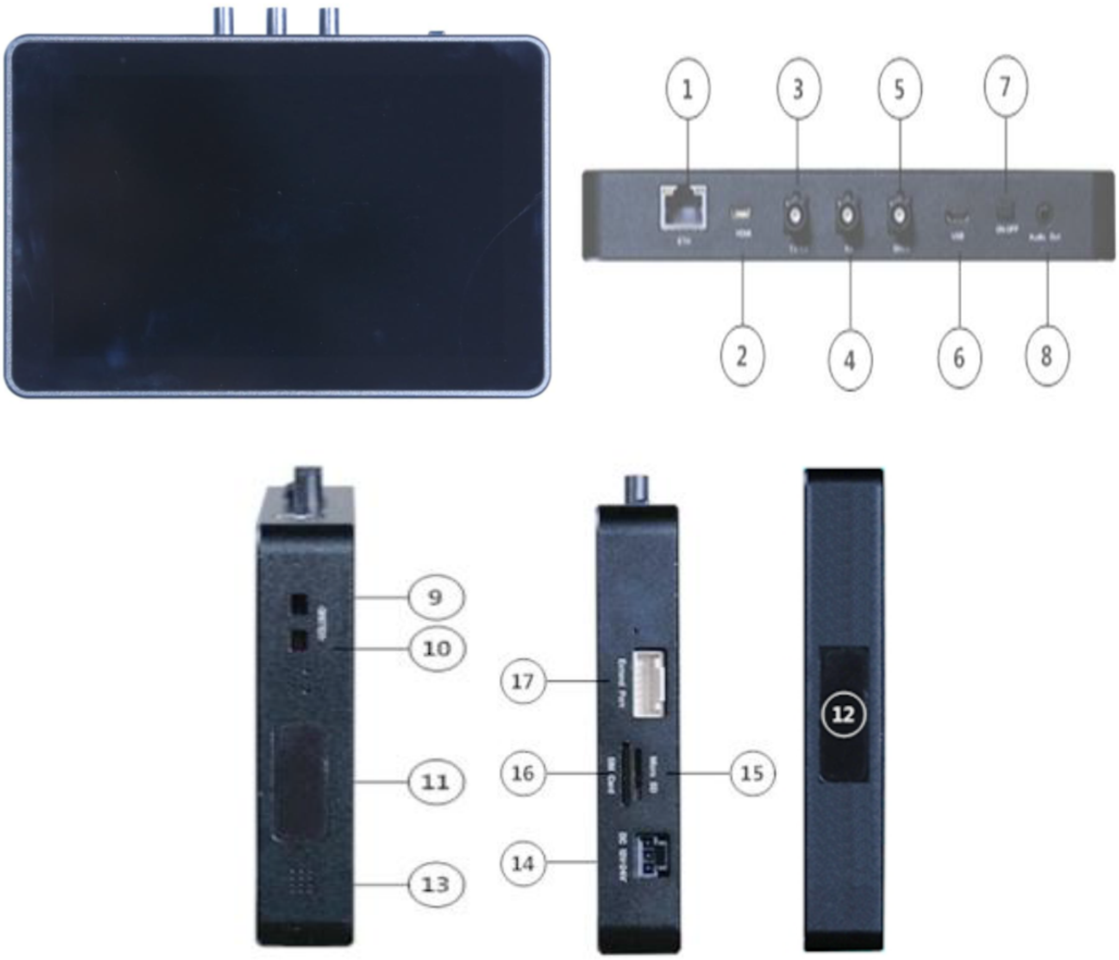

Figure 73: On Board Unit DTVL 3000 OBU

OBU Product Features

The different characteristics of the OBU used in the Chinese trial site are highlighted in the following table.

Table 34: ONU product features in China trial site

Product Features	Description
Physical characteristics	• Size: 185*124*23mm `Weight (without antenna): 0.75kg
Communication system	• TD-LTE • LTE-V2X PC5 mode4 • WIFI protocol 802.11 bgn • Bluetooth 4.0 • GPS/BeiDou
Communication indicator	• Working frequency band: 5855~5925MHz adjustable • Working bandwidth: 10MHz/20MHz • Transmit power: up to 23dBm • Channel: 1 transmit 2 receive • Number of antennas: 2
Voltage	• 9 V to 36 V (typically 12V/15V/24V)
Machine power consumption	• OBU: 12W • RSU: 10.5W
Operating system	• OBU：Android 4.4.4， Linux Kernel 3.10 • RSU：Linux Kernel 3.10

OBU Operating mode

The OBU has two operating mode (see figure below): (1) LTE-V-Cell, which provides large bandwidth and large coverage communication transmission support to meet Telematics communication requirements; (2) LTE-V-Direct, which provide low-latency, highly reliable communication services to meet road safety and traffic efficiency applications.

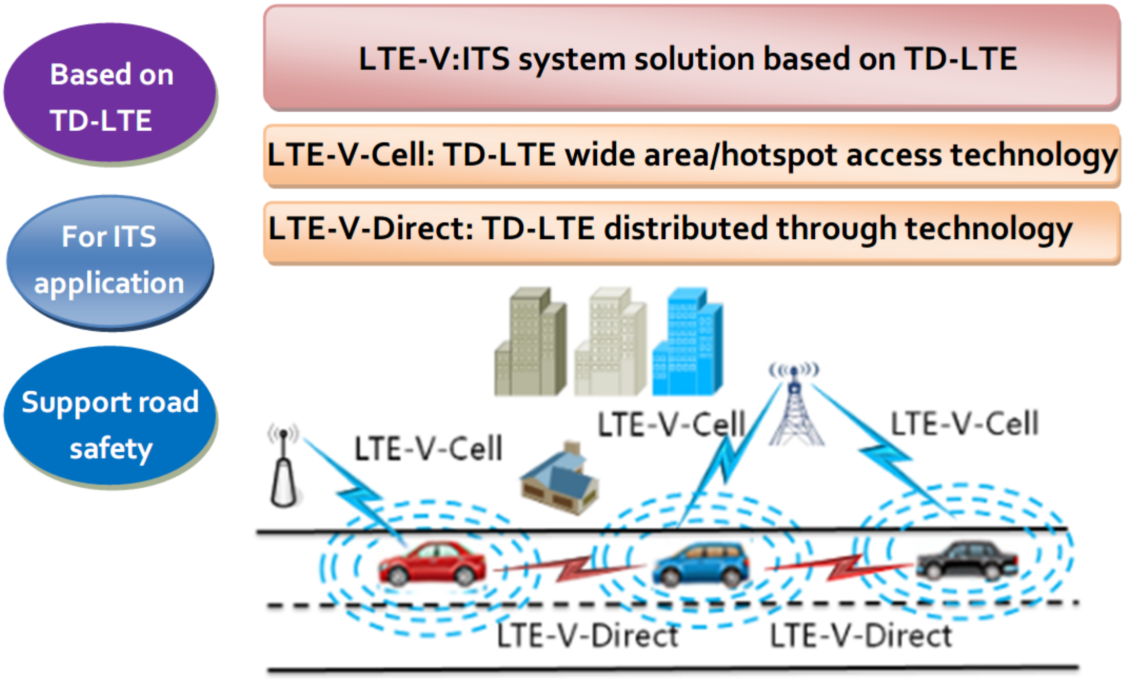

Figure 74: CN trial site OBU operating modes

3.8. C.8 OBU in South Korea Trial Site

OBU system architecture

KATECH's OBU system is modified platform of the existing Renault's QM6 with hardware and software to supporting remote driving system. The OBU is consisted of mainly 5 parts: remote driving (RD) control ECU, Lateral control ECU, Longitudinal control ECU, T2C adapter, and around view monitoring (AVM) ECU. The AVM ECU receives four camera inputs (left, right, front, and rear) and shares it with not only the remote server through 5G modem but also T2C+ adapter. The RD control ECU receives lateral and longitudinal control signal form remote server through 5G modem and sends control commands to the lateral and longitudinal control ECU through CAN. The T2C+ adapter monitors all RD status and command information and displays it on T2C module. T2C module get input from users such as driving mode change, HAVC, etc. and shares that information to the RD or remote side operator via CAN and 5G Modem. BCM ECU interfaces all the ADAS ECUs that is already implemented in the test vehicle and shares results of the ADAS through CAN network. High-level architecture of KATECH's OBU is shown in following figure.

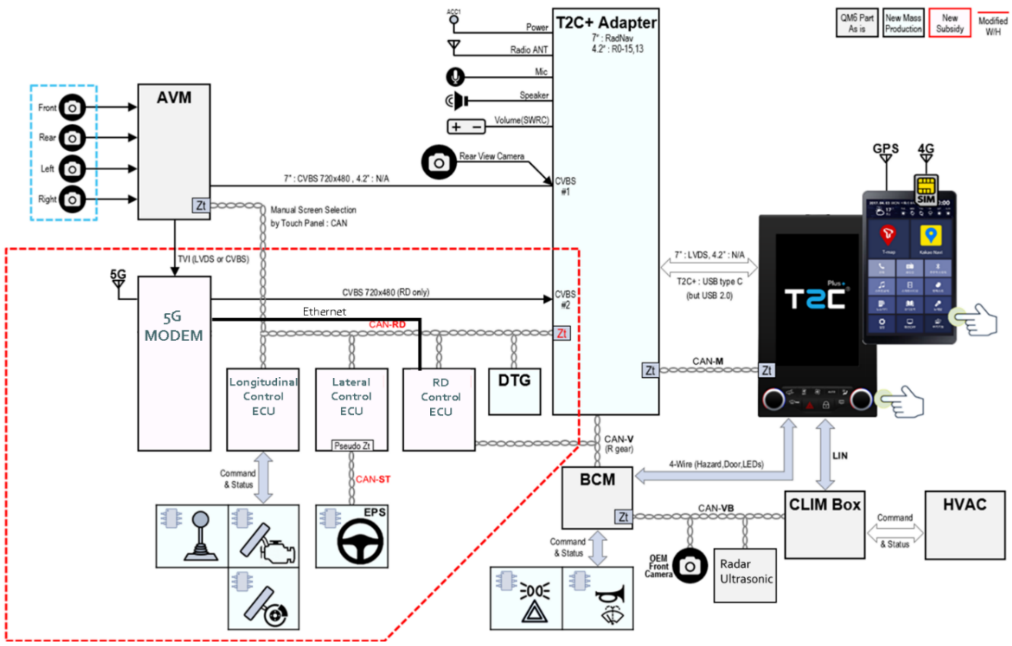

Figure 75 High-level architecture of KATECH's OBU in the Korea trial site

OBU software architecture

The software architecture of the KR OBU is depicted in Figure 76. In the following, we describe the different software components.

Application layer

The application module consists of three parts: Remote drive (RD) controller, emergency manager, and ADAS manager. Major functionalities of application modules are summarized as follows:

- Remote driving vehicle controller
  - Lateral and longitudinal control (steering, transmission, acceleration, and deceleration)
  - Broadcast the vehicle status
- OTA (Over the Air) manager
  - Logging status data from the RD system
- Emergency manager
  - Emergency management
  - RD system diagnostic information monitoring
- ADAS manager
  - Advanced E-breaking system interface
  - Forward collision warning interface
  - Lane departure warning interface
  - Blind spot warning interface

- Driver fatigue warning interface
  - Automatic parking assist system interface
  - 360° driving assist system interface
  - Automated high beam interface
- Log & trace
  - Log messages from the system
  - Send the messages to an external client
  - Store the messages for a delayed analysis
- Diagnosis
  - Retrieve diagnosis data from the TCU
  - Gateway for vehicle diagnosis requests

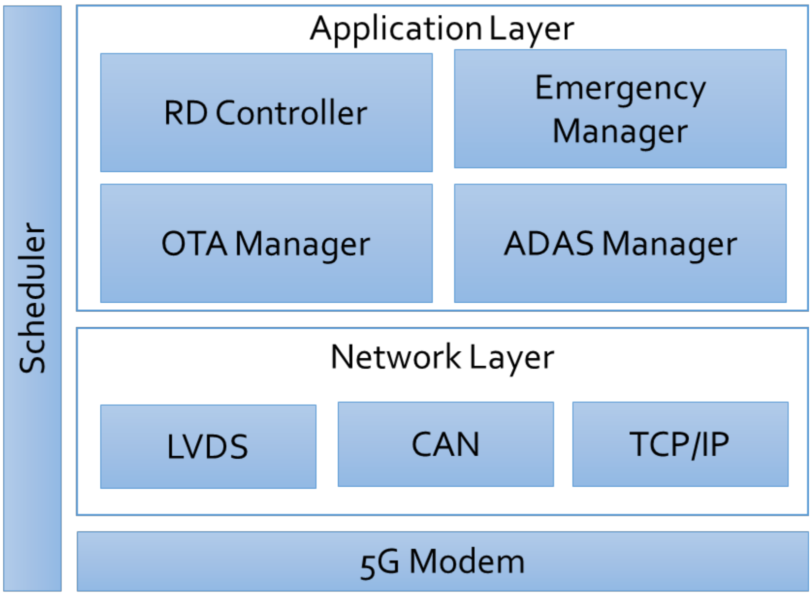

Figure 76: KATECH's OBU software architecture in the Korea trial site

Network layer

The network layer manages all communication links between vehicle and remote centre. The LVDS module provides access functionality to the cameras and CAN module enables accessibility to the in-vehicle network, and the TCP/IP is used to access 5G modem.