5GMOBIX

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

D3.2

Report vehicle development and adaptation for 5G enabled CCAM use cases

Dissemination level	Public (PU)
Work package	WP3: Development, integration and roll-out.
Deliverable number	D3.2
Version	V1.0
Submission date	01/02/2021
Due date	31/12/2020

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

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Editors

Editors in alphabetical order		
Name	Organisation	Email
Hadrian Grille	CTAG	Hadrian.grille@ctag.com

Authors

Authors in alphabetical order		
Partner	Person	Contributed to sections
AALTO	Edward Mutafungwa	3.4.1, 4.5.1, 5.2, 4.4
	Giancarlo Pastor Figueroa	
	Jose Costa Requena	
AIIM	Tijs van der Smagt	5.3.1.1, 5.3.1.2
AToBe	Tiago Dias	3.1.5
CCG	Joel Puga	3.1.5
CTAG	Hadrian Grille	1, 2, 3, 3.1, 3.3, 3.5
	Jose Luís Rodríguez Parajuá	
	Jose Antonio Fernandez Núñez	
	Carlos Rosales Salido	
	Natalia Camba López	
	Daniel Gómez Pérez	
DUT	Yanjun Shi	5.5
FORD OTOSAN	Tahir Sarı	4.1.1, 4.1.3, 2.1, 2.3, 4.2.1, 4.2.3, 4.6.3
IMEC	Seilendria Dima	4.3.1, 4.6.2
Instituto de Telecomunicações	João Almeida	3.1.5
KATECH	Choi You-Jun	5.6
NOKIA	Ignacio Benito Frontelo	3.1.3, 3.2.3, 3.6
SENSIBLE4	Tapio Taipalus	5.2.1, 5.2.2
	Timo Mustonen	
SDIA	Zihui Zhang	3.4.3, 5.5
SISSBV	Victor Ho	5.3.1.1, 5.3.2.2, 5.3.3.2
TNO	Emi Mathews	5.3.3.1
TUB	Sebastian Peters	5.2
	Xuan-Thuy Dang	
TUBITAK	Arda Taha	4.5.3

TU/e	Jos den Ouden Simon Rommel Gijs Dubbelman	2.4, 5.3, 5.3.1.1, 5.3.2.1, 5.3.3.1, 5.3.3.2, 5.3.4, 5.3.5
VEDECOM	Ahmed Soua Alexis Warsemann Guillaume Bresson	3.4.2, 5.4
VICOMTECH	Ángel Martín Gorka Vélez Josu Pérez	2.4, 5.1
VTT	Johan Scholliers	5.3.1.3, 5.3.2.3, 5.3.3.3
WINGS ICT SOLUTIONS	Kostas Trichias Ioannis Dimitriadis Andreas Georgakopoulos Ioannis Prodromos Belikaidis Panagiotis Demestichas	4.1.2, 4.2.2, 4.3.2, 4.5.2, 4.6.1

Control sheet

Version history			
Version	**Date**	**Modified by**	**Summary of changes**
V0.1	29/11/2019	Hadrian Grille (CTAG)	Initial template and structure
V0.2	18/03/2020	Hadrian Grille (CTAG)	Changes after revision
V0.3	19/10/2020	Hadrian Grille (CTAG)	New sub-section division
V0.4	23/10/2020	Hadrian Grille (CTAG)	Added contributions from all sites except korea
V0.5	16/11/2020	Hadrian Grille (CTAG)	Version ready to peer review
V0.6	16/11/2020	Alain Renault (LIST) Kostas Trichias (WINGS)	Sanity check and editing corrections
V0.7	09/12/2020	Hadrian Grille (CTAG)	Add review comments
V0.8	20/01/2021	Hadrian Grille (CTAG)	Added comment from P1 and from peer review.
V0.9	29/01/2020	Hadrian Grille (CTAG), Diana Blanco (CTAG), Carlos Rosales (CTAG)	Added comment from QA review

Peer review		
	Reviewer name	**Date**
Reviewer 1	João Ferreira (CCG)	09/12/2020 (v0.6)
Reviewer 2	Ramsundar Kandasamy (VALEO)	04/12/2020 (v0.6)
Quality reviewer	Céline Décosse (LIST)	25/01/2020(V0.8)

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ABBREVIATIONS

Abbreviation	Definition
AD	Autonomous/Automated Driving
ADAS	Advanced Driver Assistance System
AI	Artificial Intelligence
APM	Authorities and Policy Makers
AV	Automated Vehicle
CV	Connected Vehicle
CAV	Connected and Automated Vehicle
CBC	Cross Border Corridor
CCAM	Cooperative, Connected and Automated Mobility
CAM	Cooperative Awareness Message
CN	China
CoCA	Cooperative Collision Avoidance
CPM	Collective Perception Message
C-ITS	Cellular Intelligent Transport System
C-V2X	Cellular Vehicle to Everything
DE	Germany
DTS	Decoding Time Stamp
EC	European Commission
ES	Spain
EU	European Union
EV	Electronic Vehicle
FI	Finland
FR	France
GA	General Assembly

GDPR	General Data Protection Regulation
GR	Greece
GTP	GPRS Tunnel Protocol
HD	High Definition
HMCU	Hybrid Modular Communication Unit
HW	Hardware
ITS	Intelligent Transport System
Km	Kilometre
KPI	Key Performance Indicator
KR	Korea
LDM	Local Dynamic Map
LiDAR	Light Detection and Ranging
LTE	Long-Term Evolution
MCM	Manoeuvre Coordination Message
MCS	Manoeuvre Coordination Service
MEC	Multi-access/Mobile Edge Computing
MIMO	Multiple-Input and Multiple-Output
mmWave	Millimetre Wave
MNO	Mobile Network Operator
MSG	Message
NSA	Non-Standalone Architecture
NL	Netherlands
OBU	On Board Unit
OEM	Original Equipment Manufacturer
PLMN	Public Land Mobile Network
PT	Portugal

PTS	Presentation Time Stamp
QoS	Quality of Service
RAN	Radio Access Network
RSI	Roadside infrastructure
RSU	Roadside Unit
SA	Standalone Architecture
SAE	Society of Automotive Engineers
SW	Software
SWIS	See-What-I-See
TC	Technology Centre
TR	Turkey
TS	Trial Site
UCC	Use Case Category
UE	User Equipment
US	User Story
VM	Virtual Machine
VRU	Vulnerable Road User
V2I	Vehicle to Infrastructure
V2X	Vehicle to Everything
VW	Volkswagen
Wi-Fi	Wireless Fidelity
WLAN	Wireless Local Area Network
WP	Work Package
WPL	Work Package Leader
X-border	Cross-border
3GPP	The 3rd Generation Partnership Project

5G NR	5G New Radio

EXECUTIVE SUMMARY

This deliverable aims to give a detailed view about what is installed or modified in vehicles' sensors and software and the adaptation of the OBU to the 5G technology, in the context of the 5G-Mobix Project. This document completes the technical descriptions done in D2.4 (1), adding descriptions of the works carried out in vehicles and OBUs to met the UCCs requirements.

First, it presents a summary about the common updates and installations made in all vehicles and OBUs. It also gives a deployment plan on how those activities have been distributed over time. Following, a current integration status of vehicles and OBUs is described, sorted by CBC and TS. Next, a review of the SAE levels applied to the project, determining the maximum level for each vehicle related to the capabilities and UCCs of 5G-MOBIX.

Then, the deliverable is divided in two main parts, a couple of sections dedicated to vehicle integration in the CBCs, with descriptions of the upgrades and installations done in ES-PT CBC and GR-TR CBC, and a third section with the vehicle and 5G OBU integration for each TS. Each of these sections are divided in: Sensors & devices integration, Automated driving functions development, OBU integration, TS contributions, Cyber-security & data privacy and a sub-section with descriptions of the unitary testing at the time of writing. Sub-section 1.4– Structure of the document, a deeper insight of the descriptions is done in each section mentioned above.

Last section is dedicated to present conclusions obtained from the information that also compounds this document.

1. INTRODUCTION

1.1. About 5G-MOBIX

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

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

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

1.2. Purpose of the deliverable

The present document, D3.2 "Vehicle adaptation for CCAM use cases", is the outcome of T3.2 with the same name. This deliverable describes in detail, the SW and HW modules developed in the project's deployment phase, the updates performed in the vehicles and infrastructure as well the integration process; these upgrades are necessary to support the implementation of the UCCs defined in the Project and in the Deliverable D2.1 (2). The CBC descriptions will include a summary of issues and solutions that appear during the integration and development period and if any of these issues are resolved with the collaboration of the TS

1.3. Intended audience

The deliverable D3.2 – Vehicle adaptation for CCAM use cases is a public deliverable and it is addressed to any interested reader. However, it specifically aims at providing the 5G-MOBIX consortium members with an extensive set of how the integration and development of different devices was made in vehicle.

1.4. Structure of the document

The D3.2 document is structured as follows:

- **Section 1, Introduction** briefly describes the 5G-MOBIX project and the purpose of this document together with its intended audience.
- **Section 2, Vehicle integration roadmap& SAE LEVEL,** provides an overview of the required updates in vehicles (Software, sensors and OBU) and a general deployment plan to know when each hardware and software component should be integrated and developed. This section shows the current vehicle and OBU integration status in each CBC and TS and, finally, presents a SAE level review where can be consulted the AD level used by each CAV in the 5G-MOBIX project and the Covid-19 impact on T3.2.
- **Section 3, Vehicle integration of ES-PT CBC,** describes the vehicles integration process for ES-PT CBC, the different TS contribution to this CBC and the results from an early unitary test.
- **Section 4, Vehicle integration of GR-TR CBC,** describes the vehicle integration process for GR-TR CBC, the TS contribution for this CBC and an the results from an early unitary test.
- **Section 5, , TS vehicle integration,** describes the vehicles integration process for each TS and, as in the previous sections, the results of a unit tests done are presented.
- **Section 6** presents the **conclusions**.

1.5. Impact of Covid-19 on T3.2

The global Covid-19 pandemic arose during the execution of T3.2, specifically during Phase 2 of the of the global 5G-MOBIX deployment strategy in which T3.2 focussed on the vehicles and 5G OBU deployment (see Figure 1). The global pandemic resulted in restrictive measures ('lockdowns') being imposed by national governments and/or local or regional authorities, resulting in restrictions to regional, national and global travel, different levels of limitations to access to facilities and/or premised and restrictions to activity in public spaces. While these restrictions and their duration were and are highly country or region dependent and thus affect the work of the consortium partners in T3.2 in different ways, an overall impact of the global Covid-19 pandemic was observed. This impact is largely in the form of delays experienced in a) 5G chipsets delivery b) vehicle integration c) vehicles movement to testing areas due to restrictions to local and national travel and restrictions to activities in public spaces.

The revised 5-phase plan presented in the following section does account for delays due to Covid-19 encountered and foreseen at the time of its definition in mid-2020. Further delays may occur depending on the evolution of the global and national pandemic situations at the CBCs and TSs, especially where collaborative efforts are required for vehicle and 5G OBU integration or testing.

2. VEHICLE INTEGRATION ROAD MAP & SAE LEVEL

The vehicles used for the development of the 5G-MOBIX project need to be updated, i.e. new sensors and devices must be installed, new software must be created and a new OBU with 5G connectivity must be developed to support the use cases defined in the Deliverable D2.1 (1).

The most common changes or updates done in vehicles and their planning are presented, as a summary, in the following two sub-sections.

2.1. Needed upgrades

According to activities registered in ClickUp[1] management tool, the most common updates to develop the UCCs are grouped in the following points:

- **In vehicle equipment**: the vehicles in CBC and TS have had to be updated with new sensors and hardware for AD, new cameras for the remote driving and new devices for multimedia services. All this equipment has been described in D2.4 (2) and the installation process is presented in the current deliverable.
- **5G OBU**: at the beginning of the project, the on-board units did not have 5G connectivity, having to be updated with the new 5G modems, or in some case, creating a new OBU with 5G connectivity.
- **Software components**: to support the new in-vehicle equipment, some new software has been developed. This new software adapts the current version of many components in the CBC and TS to support all new functionalities to carry out the UCs.

[1] https://clickup.com/

2.2. Deployment plan

In D3.1 (3), the 5-Phase Rollout Timeline was presented, where the timeline project is divided in 5 different phases. Each of them is in charge of developing different activities. Figure 1 presents a summary of the 5-Phase plan for T3.2. In Phase 1, all the processes to be developed in Phase 2 were defined. This deliverable D3.2 is part of the Phase 2 - Trial Site and Cross-Border Corridor Deployment & Integration, where the Cross-Border Corridors and the Trial Sites must integrate all equipment, hardware, and software, in their vehicles. Further, the results of Phase 2 will be tested and verified in the following Phases.

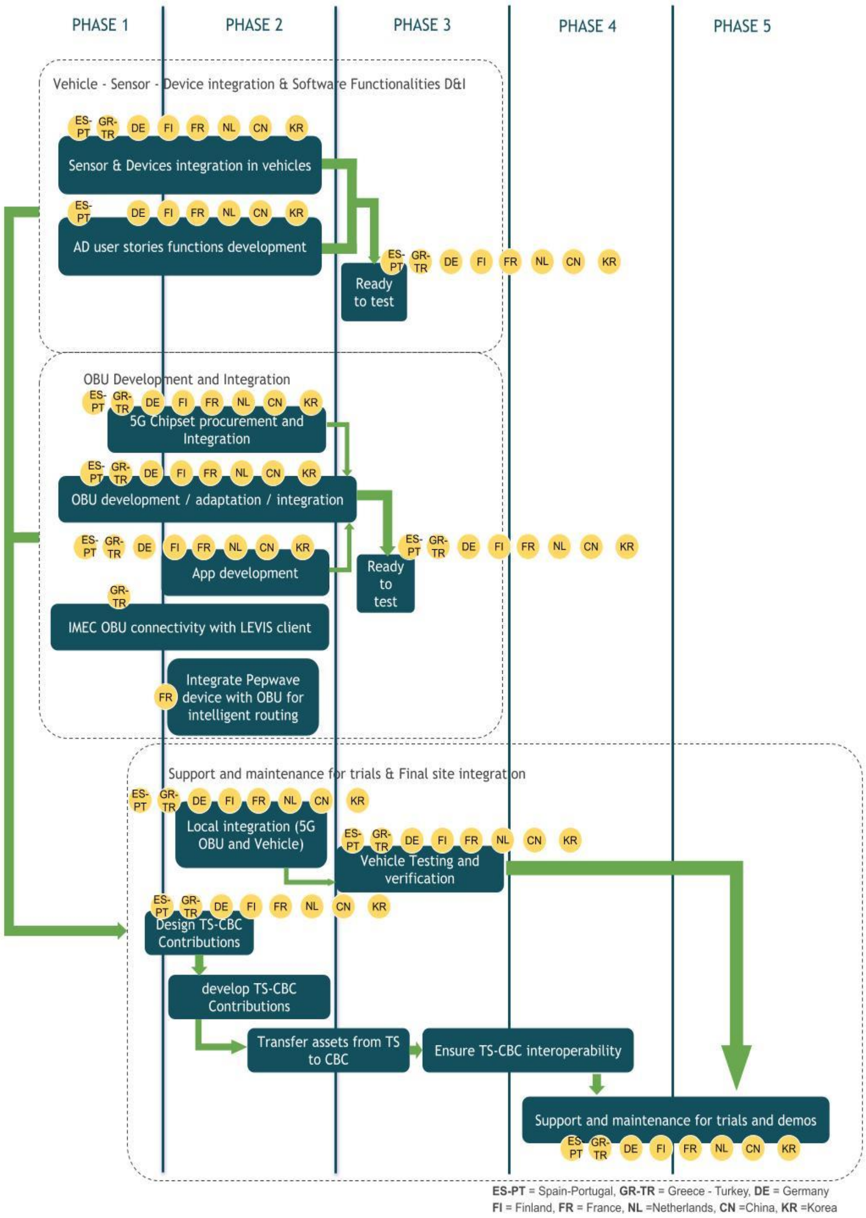


Figure 1: Overall Picture of the 5-Phase Rollout Plan for Vehicle Adaptation

2.3. Current integration status

At the moment to present this deliverable, the current integration status of the vehicles (sensors and other devices) and the OBU is presented in the following Table 1:

Table 1: Vehicle & OBU integration current status

CBC/TS	Ready	Pending	Status & remarks / characteristics
ES-PT	2 Citroën C4 1 Golf 1 Bus ALSA	1 Shuttle 1 PT vehicle	Testing with some of the finished vehicles. The last integrations and tests are being performed on the Shuttle
	6 OBUs	1 OBU (PT)	Integrated. Fully ready, ongoing testing
GR-TR	1 Ford F-MAX	1 Ford F-MAX	1 truck fully ready, ongoing testing. 1 Truck waiting for final component integration
	3 OBUs	-	Fully ready, ongoing testing & integration process
DE	2 Vehicles / 2 OBUs	2 (Valeo Peiker)	Use cases have been tested using two Quectel OBUs. The Valeo Peiker OBUs are already available, ongoing testing.
FI	1 Vehicles / 2 OBUs	1 OBUs	- 1 single-SIM OBU NSA & SA available M24, integration M27 - 1 multi-SIM OBU NSA available M26, integration M27 (to be upgraded to SA) - 1 multi-SIM OBU NSA available M28, integration M29 (to be upgraded to SA)
FR	2 (1 CAV & 1 CV)/ 2 OBUs	2 (Valeo Peiker)	Vehicles and OBUs are completely integrated and ready.
NL	3 CAV. & 1 CV. / 3 OBUs	3 OBUs	2 OBUs (advanced driving - CoCA) have been prepared and sent to NL for further integration testing (January 2021) 1 OBU (remote driving - positioning) is planned to be implemented by end of Q2-2021, ready for first testing.
CN	1 Vehicles	1 OBU	The vehicles will be integrated with the OBUs in May 2021
KR	2 Vehicles / 1 OBUs	1 OBU	The tethering use case is ready (OBU and Veh test in Oct) OBU for remote control use case will be ready in Mar'21.

Total	**17 Vehicles / 19 OBUs**	**3 Vehicles / 11 OBUs**	

As can be seen in the Table 1, the most of the vehicles and 5G OBUs are integrated and assembled, however, some sites with delays in vehicle and OBU integration exits, as shown below:

- In ES-PT CBC the last sensor calibrations and chassis modifications have been done and some test to evaluate the AD functions have also been done. The PT vehicle and OBU are being tested and to some issues are being solved.
- In GR-TR CBC one of the vehicles is waiting for the purchased components to install them in the vehicle.
- A common delay with Valeo Peiker TCU is present in DE, FI and FR. Some alternatives were developed.
- In NL TS, two OBU have been prepared and sent to NL for further integration testing (JAN'21) and other OBU more is planned to be implemented by end of Q2-2021.
- CN and KR TS, have one OBU pending each one.

2.4. SAE level review

In 5G-MOBIX project there are vehicles with a SAE level 4. They are autonomous vehicles, enabled with a 5G OBU. In Table 2 presents a summary of these vehicles, describing the capabilities and the way they are used in the project.. In this table, only CAVs are included.

Table 2: SAE level summary by site

CBC/TS	Type of vehicle	Max. SAE level	SAE level used	Vehicles capabilities	Application in 5G-MOBIX
ES-PT	1 Shuttle EV Bus	4	4	• 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.	• UCC#1 -> User Story: Automated shuttle in cross-border settings: The Shuttle EV Bus use the L4 automated functionalities adding the information get form other actors as VRU, traffic lights,… • User Story: Last Mile EV Automated Shuttle vehicles in Cross Border and urban environment: In this case the Shuttle use the L4 during the test, except to avoid an obstacle placed in the middle of the path it follows, where it uses remote control.
	2 Citroën C4-Picasso	4	3	• 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).	• User Story: Complex Manoeuvres in cross-border settings: In scenarios of Lane merge and automated overtaking these vehicles use the Highway chauffeur L3 functionalities. • UCC#3: Extended Sensors: As in the previous user story, the vehicles use L3 functionalities to detect, in this case, an event not registered on their map and request manual control from the driver.
	1 Volkswagen Golf	4	3	• Autonomous Urban Driving L2. • Highway chauffeur L3 (vehicle following,	• User Story: Complex Maneuvers in cross-border settings: In scenarios of Lane merge and automated overtaking

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

				• 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).	these vehicles use the Highway chauffeur L3 functionalities • UCC#3: Extended Sensors: As in the precious User Story, the vehicles use the L3 functionalities detecting in this case a new event does not registered in their maps and asking take control to the driver
GR-TR	2 FORD-MAX	4	2	• Autonomous Urban Driving L4 • Autonomous Highway Platooning L2+ (Longitudinal and lateral control, no need to human intervention, but only if vehicle move without lane change. Hence vehicle is higher level than L2, but due to lack of autonomous lane change less than L3.) • Automated emergency braking • Path following • Collision detection (Prediction of possible collision). • Lane departure warning • See through • CO_2 emissions and Cargo identification (NFC reader), front ultrasonic sensor • Front radar, camera Precise GNSS positioning (Less than 1 meter)	• User Story: Platooning with See What I See Application settings: In this scenario vehicle will use its Autonomous Highway Platooning L2+, see through, lane departure warning functions. • User Story: Autonomous Truck Routing in Border Crossing: In this scenario, sensors (LIDARs, CCTVs) will be placed around of the facility. When vehicle reach the facility, application will be launched and sensor data placed to facility will be sent to cloud. Meanwhile vehicle will send its precise GNSS position and speed information also to cloud. Cloud will fuse this data and create a path information that will be dynamic and change according to environment. After that path info will be delivered to vehicle. Vehicle will follow this path without any human intervention like an Autonomous Urban Driving L4 vehicle. Use Case: Assisted -zero-touch- truck border-crossing: In

					this use case CO2 emissions, Cargo identification (NFC reader), and front ultrasonic sensors will be used.
DE	1 Volkswagen Passat	4	1	• 360º object detection (four fisheye cameras) • 360º surround view generation • LIDAR (Velodyne32/64) and/or Valeo SCALA/SCALA2	• User Story: EDM-enabled Extended Sensors with surround view generation. • Radars used for reference purposes
	1 Toyota Prius	4	1	• Autonomous driving L4 (longitudinal and lateral control). • 360º object detection (HD cameras and LIDAR) • Driver monitoring (attention, gaze direction, drowsiness) • Collision detection (estimation of collision probability) • 360º surround view generation • Lane departure warning Free space detection	• User Story: EDM-enabled Extended Sensors with surround view generation. • Object detection and risk estimation (collision probability) to assess the need for extended sensors. 360º surround view generation from a remote vehicle's cameras to enhance the perception obtained with on-board sensors.
FI	Renault Twizy (Ava)	4	4	• Autonomous urban driving L4 • HD mapping and localisation • Object detection • Path following • HD Cameras and LiDAR • Remote monitoring and control Road legal in mixed traffic, up to 40km/h.	• User Story: Extended Sensors with redundant edge processing. HD video and LIDAR will be used in UCC3US3. Evaluate the reliability and performance of networking and edge computing. • User Story: Remote driving functionality with increased capability provided by 5G networks will be evaluated in UCC4US2.
FR	Renault ZOE (VEDECOM2)	4	4	• Autonomous urban driving L4 (longitudinal and lateral control). • High-level systems for planning and supervision • Object detection • Path following	• User story: infrastructure-assisted advanced driving (lane change manoeuvre and speed adaptation): The infrastructure assesses the possible collision risk of the AV with another connected vehicle. If the risk is real, MEC sends MCM to the AV to change its lane. The AV,

				• 360° perception • Front and back cameras	upon the reception of the MCM, starts the changing lane manoeuvre and follows the trajectory included in the MCM.
NL	1 VW Touareg (Martti)	4	4	• Automated Valet Parking L4. • Green light optimal speed adaptation. • Object detection • Path following • Collision detection (Prediction of possible collision)	• User Story: Cooperative Collision Avoidance: the vehicle detects collisions based on status data from other vehicles and in-vehicle sensors. The vehicle selects and follows a trajectory based on obstacles detected, initial desired path and data from other vehicles and infrastructure.
	1 Toyota Prius PHV	4	4	• Rebalancing / Valet Parking L4 • Object detection (HD cameras and LIDAR) • Path following • Collision detection • Remote driving	• User Story: using remote driving functionality to take over control of the vehicle over 5G network. Using detection for enhancing remote driving. Since remotely driving, L3 is correct level to be used. • User Story: 2nd vehicle in Cooperative Collision Avoidance user story (with Martti vehicle), using object detection.
	1 Toyota Prius	4	4	• Automated Valet Parking L4 • Object detection • Path following • Collision detection • Remote driving	• User Story: using remote driving functionality to take over control of the vehicle over 5G network. Using detection for enhancing remote driving. Since remotely driving, L3 is correct level to be used.
CN	SDIA	4	4	• Autonomous driving L4 • Collision detection • Path planning • Platoon • Object detection • Remote driving • HD mapping and localisation	• User Story: Cloud-assisted advanced driving: the roadside unit, the remote control centre and the cloud server will monitor and control the autonomous vehicles in real time, to perform tests of vehicles Internet-connected applications, safely and efficiently. • User Story: Cloud-assisted platooning: The autonomous driving vehicle fleet communicates with each other

					through LTE-V at the start. Among them, the leading vehicle includes the platoon control unit (PCU), which coordinates the vehicles in the fleet to ensure a certain safe distance and to drive in a platoon. The leading vehicle communicates with the control centre deployed in a cloud server through V2N to obtain the test scheme and the global path planning. Then it provides the basic planning for the rear vehicle through V2V communication (including chasing, continuous running, acceleration, deceleration, obstacle avoidance, overall acceleration, and deceleration, etc.). The following vehicle also has a certain perception and planning decision-making ability. Besides, LTE-V communication can be replaced by DSRC technology, and comparison between these two methods will be implemented.
KR	Renault XM3 (Arkana)	4	4	• Autonomous urban driving L4 • 360º surround view monitoring • Front, Left, Right and Rear-view monitoring • Lane Departure Warning • Front Collision Warning • Parking Assist • Rear Collision Warning • Short/Long Range Blind Spot Detection • Remote monitoring and control	• User Story: 360º surround view monitoring and Front, Left, Right and Rear-view monitoring system of the remote vehicle is implemented to enhance the perception obtained with on-board sensors such as radar, camera, and ultrasonic sensors. ADAS systems such as lane departure warning, front collision warning, parking assist, rear collision warning and blind spot detection system are also implemented to improve vehicle safety level for remote driving.

3. VEHICLE INTEGRATION OF ES-PT CBC

The ES-PT test and trials will take place using different vehicles depending on the User Stories. The two Citroen C4, Volkswagen Golf and the CTAG Shuttle are vehicles which have autonomous driving capabilities and the PT vehicle and the ALSA Bus does not have those functionalities. Details about equipment installed in those vehicles are available in section 3.1 and details of the developed software functions can be found in section 3.2. Furthermore, the 5G OBU is integrated by CTAG in almost all vehicles besides the equipment aforementioned, to carry out the User Stories. The PT vehicle is the only one which has a different OBU provider, developed by AtoBe, to be used in the User Stories it participates. Table 3 below provides an overview of vehicle related equipment installed for the ES-PT trial, while details regarding their design, development and testing are provided in the following sub-sections.

Table 3: Vehicle equipment and driving functions utilized in the ES-PT CBC

User Story	Scenario	Vehicles	Sensors	Driving functions
Complex manoeuvres in cross-border settings	Lane merge for automated vehicles Automated Overtaking	Citroen C4 VW Golf	Laser Valeo Scala, Lidar Velodyne, Cameras, GPS Trimble	Highway chauffeur L3 (vehicle following, automated overtaking, highway entry, highway exit and fall-back)
		PT Vehicle	-	-
	VRU cooperation	CTAG Shuttle	Laser Sick, Lidar Velodyne, Cameras and GPS	Autonomous urban driving L4 (longitudinal and lateral control) 360º Object detection (pedestrian, vehicles, bicycles). Route following (HD map information). Automated emergency braking. Collision detection (Prediction of possible collision)."
Complex manoeuvres in cross-border settings	HD maps	Citroen C4 VW Golf	Laser Valeo Scala, Lidar Velodyne, Cameras, GPS Trimble	Highway chauffeur L3 (vehicle following, automated overtaking, highway entry, highway exit and fall-back) Route following (HD map information)."

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

		ALSA Bus	Lidar Velodyne, Cameras, GPS Trimble	-
		PT Vehicle	-	-
Remote Driving across borders	Remote Control	CTAG Shuttle	Laser Sick, Lidar Velodyne, Cameras and GPS	Autonomous urban driving L4 (longitudinal and lateral control) 360º Object detection (pedestrian, vehicles, bicycles). Remote Control."
Public transport with HD media services and video surveillance	-	ALSA Bus	Lidar Velodyne, Cameras, GPS Trimble	-

3.1. Sensors & devices integration

It was necessary to integrate several sensors and devices in the vehicles as described in D2.4 (2). The following Table 4 summarizes all this equipment per vehicle.

Table 4: ES-PT CBC in vehicle equipment

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

LiDAR	Alsa Bus	1	Velodyne	Front	180°	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	1	IDS	Front	60°	-	60m (car) 40 m (ped.)
		2	Laiatech	Roof	-	-	-
	CTAG shuttle	1	FLIR	Front	60°	-	60m (car) 40 m (ped.)
		1	Panasonic	Roof	65°	-	-
		1	Ricoh Theta	Roof	360°	-	-
	Citroen C4	1	Mobileye	Windshield	30°	-	150m (car) 40 m (ped.)
		1	IDS	Front	60°	-	60m (car) 40 m (ped.)
	Volkswagen Golf	1	Mobileye	Windshield	30°	-	150m (car) 40 m (ped.)
		1	Basler	Front	60°	-	60m (car) 40 m (ped.)
GPS	Alsa Bus	1	Trimble	Roof	-	-	-
	CTAG shuttle	1	CTAG	Trunk	-	-	-
	Citroen C4	1	Trimble	Trunk	-	-	-

	Volkswagen Golf	1	Trimble	Trunk	-	-	-
	PT Vehicle	1	Trimble	Roof	-	-	-
Tablets	Alsa Bus	60	-	one per seat	-	-	-
	PT Vehicle	1	-	Dashboard-mounted			
Router 5G	Alsa Bus	1	-	Trunk	-	-	-

In each vehicle, the devices listed above, were installed in different places, depending on the shape of the vehicle, the device features and what was desired to measure. The Installation process, for each vehicle, is described below.

3.1.1. Citroën C4

LiDAR Velodyne VLP16 has been integrated on the roof of the vehicle to have 360° coverage of the objects around the vehicle until a 100-meter radius, which is the maximum specification for this sensor according to the manufacturer. In the framework of this project, it is the main source of information regarding vehicle detection for the ADAS functions involving action upon another vehicle's presence.

Positioning this Velodyne sensor on the roof of the vehicle was meant to respect the vertical field of view of the sensor (+-15º) so that it is placed high enough to avoid occlusions by the own car chassis. The piece to adapt this LiDAR sensor to the rooftop was designed in CTAG.

Valeo Scala-1s are placed on the front and rear bumper of the car, and have a 145º horizontal field of view, so that they will only detect objects ahead of and behind the vehicle within the mentioned region of coverage. Its distance range is much higher (allegedly 200 meters, around 130 meters for cars in practice), so that it enables earlier detections in a high-speed scenario (typically highways). Their integration in the car involved cutting and modifying the bumper pieces.

GPS Trimble is integrated on the trunk of the car and it allows precise positioning of the vehicle. This GPS model has a maximum positioning accuracy of 0.25 m + 1 ppm horizontal and 0.5 m + 1 ppm vertical. The maximum operating limit for vehicle speed is 515 m/sec and 18000m in terms of altitude. The antenna connected to this GPS is located on the roof of the vehicle, avoiding signal loss or attenuation due to vehicle chassis

IDS and Mobileye cameras have been integrated in the front windshield, at the top of it, inside the wipers cleaning zone. In this case, the Mobileye camera is centred and the IDS is besides it, therefore, moved some centimetres from the centre. The two cameras are placed in this position to get always-clean lens (rain, dust) and to get the maximum vision angle.

Figure 2: Overview of the Citroen C4 Picasso with all sensors

Figure 2 is an overview of all sensors installed in these vehicles and to be used in the User Stories. In the above image, the piece designed by CTAG to install the LiDAR and the GPS antenna are also present.

3.1.2. Volkswagen Golf

Velodyne VLP-16, Scala-1s and GPS Trimble are installed following the same rules as in C4 prototype.

As in the C4 prototypes, there are installed two cameras but, for this model, they are a Mobileye and a Basler, both in the windshield. The Mobileye is integrated in the middle of the windshield, at the top of it, while the Basler camera is besides it, but shifted some centimetres. All of them are placed within the angle of action of the wipers

As in the previous sub-section in Figure 3 is showed an overview of how is installed the components in the vehicle.

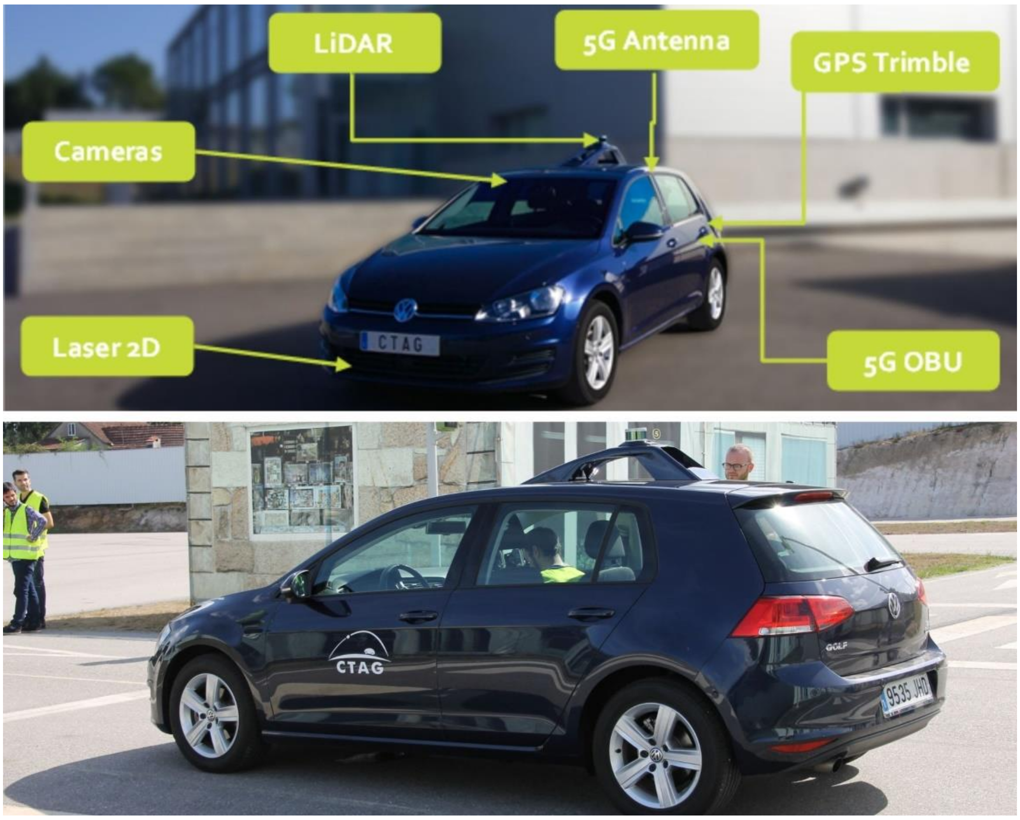


Figure 3: Overview of Volkswagen Golf vehicle with all sensors / components

3.1.3. CTAG Shuttle

The dimensions of this prototype are bigger than in the two aforementioned cars, so the sensors distribution is also notoriously different. An overview of this vehicle is shown in Figure 4

Two LiDAR Velodyne VLP-16s were placed on the rooftop of the shuttle, one on the front end, and the other on the back end. Both sensors were tilted 10º downward in their intended directions of detection (front and rear, respectively). The reason for this applied angle is taking better advantage of the sensing characteristics of the sensor. Due to the reduced speed of the vehicle, Velodyne's range of detection was considered as enough. No Scalas (longer range) were considered as needed.

For the placement of both LiDARs Velodyne the chassis of the shuttle was modified with pieces designed on purpose.

Figure 4: Overview of the Shuttle EV Bus

In this vehicle several cameras were installed. Inside the front window at the top of it and centred was placed one camera model FLIR to get a good view angle of the road to detect objects, traffic signs and lines. To develop the Remote Driving User Story eight cameras, Figure 5, are being placed in different parts of the shuttle.

Figure 5: Remote Driving cameras model

This positioning has been designed to achieve two key factors:

- The camera Lens Field of View, to create a 360º.

- The visual field from the camera to the vehicle perimeter. This is especially important in order to avoid blind spots.

3.1.4. ALSA Bus

In Due to the larger dimensions of the CTAG shuttle compared to the others, the sensors have been placed in different positions. LiDAR Velodyne VLP16 has been integrated on the front of the vehicle to have a larger vision angle at the front of the vehicle, being able to cover the same range as in the previous vehicles (50 meters), but only have this detention in 180º coverage. Trimble GPS unit is integrated on the roof of the bus and it allows centimetre level position accuracy of the vehicle, that is, 0.25 m + 1 ppm horizontal and 0.5 m + 1 ppm vertical.

The IDS camera has been integrated centred at the top of the front , as in previous cases. The other 4K cameras have also placed in the front window; one of them is positioned pointing to the road and another one to the interior of the bus. The Tablets have been placed in the front seat because in this way the user can interact with them easily. The other equipment specified in Table 4 has integrated in one of the trunks available on the bus. Integration of several components can be seen in the following Figure 6.

Figure 6: ALSA Bus integration Overview

3.1.5. PT Connected Vehicle

Despite not being originally present in the initial specifications of the ES-PT CBC, the PT connected vehicle was added to enhance the interoperability tests of 5G communications between the different partners of the project. The PT connected vehicle participates in the "Complex Manoeuvres in Cross-Border Settings user story", namely: Lane Merge, Overtaking and VRU scenarios.

This regular passenger vehicle is not equipped with any automated driving functionalities, being solely retrofitted with a 5G OBU, a dashboard smartphone and a GNSS receiver (Figure 7). The vehicle's OBU integrates a 5G Quectel module for V2N/N2V communications. The smartphone is used to display information to the vehicle's driver and other passengers. The GNSS Trimble is integrated on the roof of the car and it allows accurate geo-localization of the vehicle.

Figure 7: PT Connected Vehicle Architecture

The 5G OBU is also connected to a Time Server machine (Figure 7) with the sole propose of providing a precise source for clock synchronization, using the Pulse Per Second signal available in an independent GNSS receiver. This accurate time synchronization is very important for the logging and evaluation measurements of KPI metrics, such as communications latency in a 5G setup. The Precision Time Protocol (PTP) is used to synchronize the 5G OBU to the Time Server.

The OBU subscribes to the topics of interest in the MEC MQTT broker, namely the ones regarding CAM, DENM and CPM messages, as well as the HD Maps JSON updates. The OBU also publishes CAM messages with vehicle's parameters in the appropriate broker topic. All these messages are forwarded to the V2X App, through a WiFi connection with the OBU also using MQTT protocol. Subsequently the messages are displayed in the smartphone's HMI for driver awareness (Figure 8: (a) lane merge example. (b) Overtaking scenario and (c) HD Maps scenario).

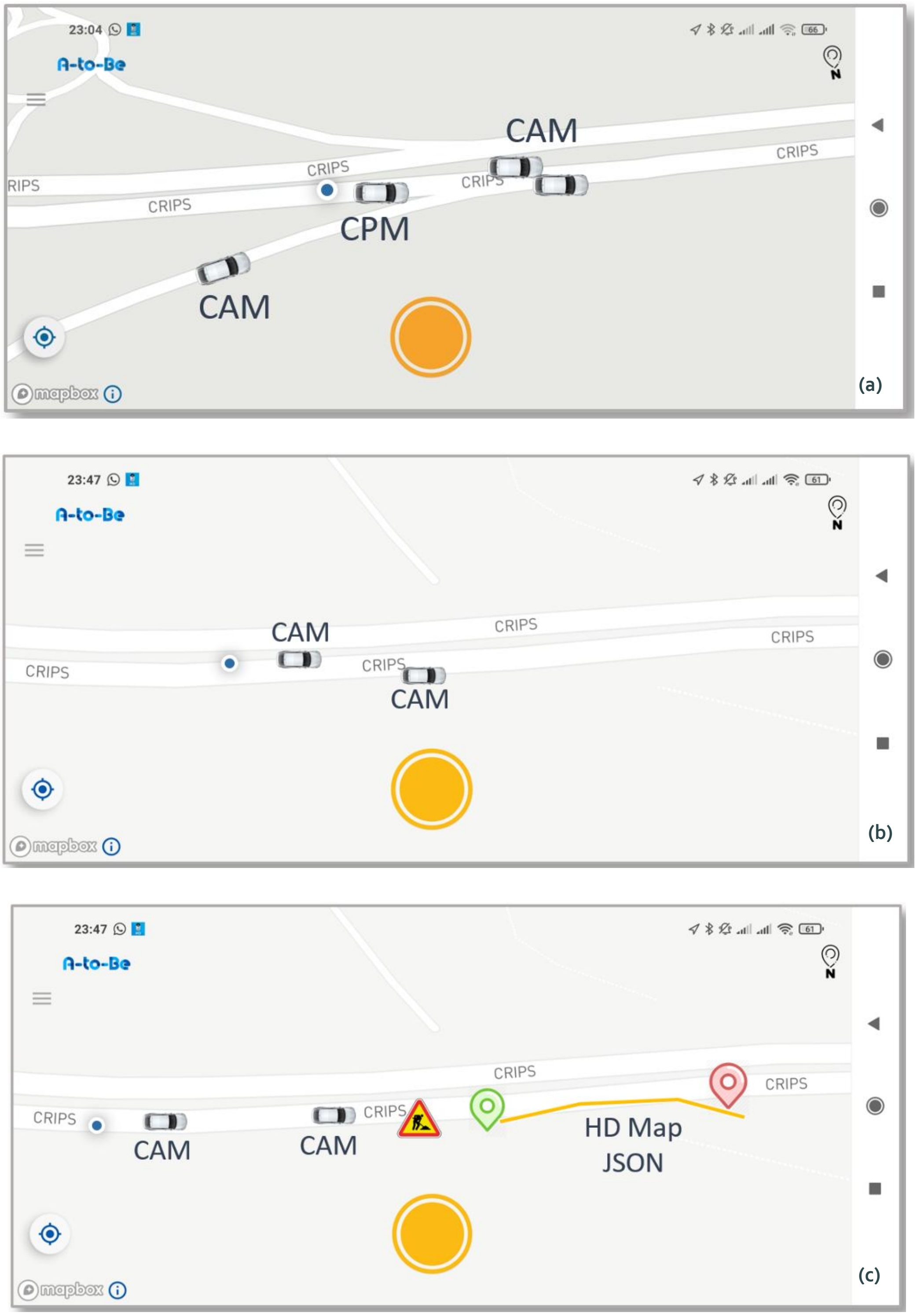


Figure 8: Smartphone Application in the PT Connected Vehicle.

3.2. Automated driving function development

In the following Figure 9 is depicted the high-level software architecture on-board the vehicle, excluding the ALSA bus and the PT vehicle which does not have AD functions:

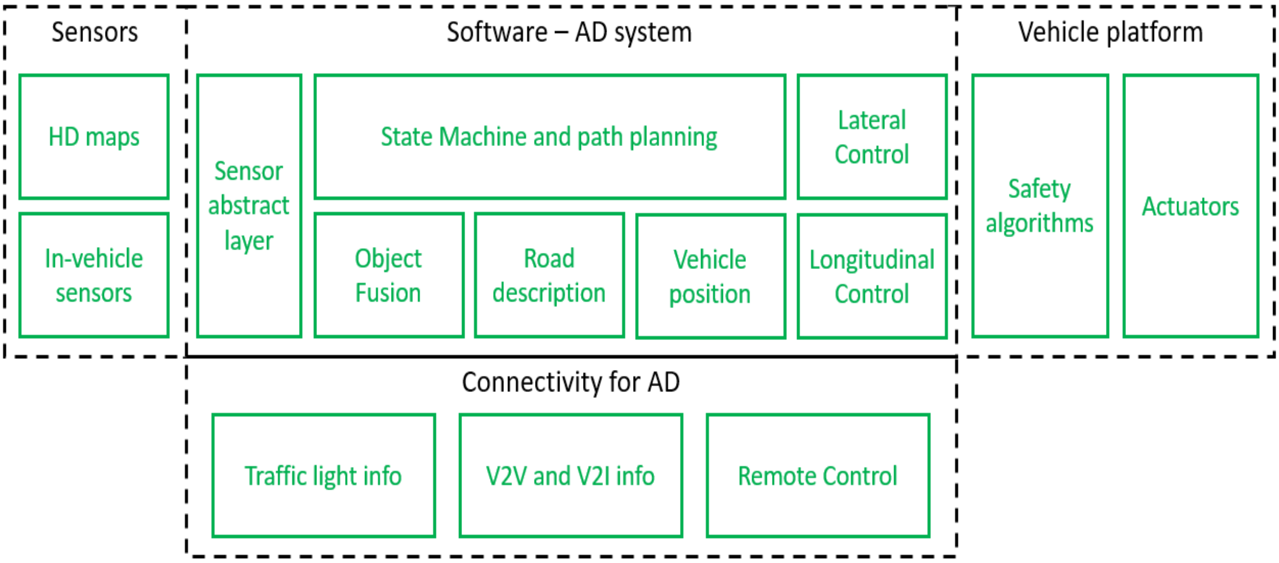


Figure 9: Automated driving high-level software architecture.

As the figure above shows, all software components involved in AD managing functions are divided in 4 big blocks. They are described in detail in D2.4 (1) and of which a summary is given below. Please, note that the 5G OBU is not represented in that scheme because it is described in section 3.3.

- Sensors: This block is related with all software created to retrieve information directly from the sensors.
- AD system: In this block all AD functions are integrated. That is, all algorithm implementations responsible for making appropriate decisions based on the information received, take a roll for one or more of the autonomous operations of the vehicle.
- Vehicle platform: Comprises the software to actuate on the vehicle depending on the information received by the AD functions and the safety algorithms ready to respond if needed.
- Connectivity for AD: This block contains software in charge to receive information from external actors.

The software system presented above is employed to develop the UCC. Different parts of it are involved in each of them, based on the needs to be fulfilled. In order to simplify the current deliverable and having detailed information in D2.4 (1), next sub-sections are a brief description of the UCC and the software parts modified to carry out them.

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

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".

The software development done to carry out all scenarios in this UCC was to adapt the current version of the related automated driving functions, that is, customize the functions to take into account the zones where the user stories will be developed and adding the new information provided by the 5G OBU and the roadside sensors and cameras.

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

This UCC required creating new software components for automated driving functions and modifying the current version of other parts, as explained in the previous paragraph.

New Advanced Driver Assistance Systems Interface Specification (ADASIS 3) [2] was implemented to carry out this UCC. ADASIS is a communication protocol recognized among the main OEMs in the market, created by the alliance between the mapmakers, OEMs and developers to be able to transmit all information available in a digital map abstracting from the format and location of the maps and that all this information can be interpreted by the ADAS system.

Due to this new addition, some AD software modules have been updated to work using it. In addition, AD functions were updated to get information about the new event on the road and to record it, sending this changes to the cloud unit, where this data will be processed to create the new map version that is then downloaded by other vehicles with the new changes.

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

For this UCC a new software was developed in two parts, one in CTAG facilities, where is placed the remote driving cockpit, and the other in the OBU of the shuttle.

The AD functions were adapted to use the commands sent by the cockpit and translate them to be understood by the vehicle's actuators.

In additions to that, a new communication protocol was developed by Nokia. Using the experience of all partners involved in this CCC and after carrying out some internal test with proofs of concepts (PoC), the requirements of this protocol are:

[2] https://adasis.org/

- It should be "Real-Time" meaning that the interval between issuing a command and receiving the acknowledgement of the command should be less than 100ms.
- It should be able to go through all the network topology end to end no matter which type of communications and devices are involved in every piece of the setup.
- It should not carry a big amount of data (e.g., it is not intended to transport video itself, but control commands related to video).
- Commands need to be tagged with unique IDs so that the system is able to detect non acknowledged or late acknowledge commands.
- It should be scalable.

Using the above requirements, a protocol with the following attributes is proposed:

- Periodic messages over the 5G network
- Command (CMD) message
  - From remote control to car
  - Contains: steering angle and target linear velocity + sequence number
- Acknowledgement (ACK) message
  - From car to remote control
  - Contains: actual steering angle, actual linear velocity, (others) + sequence number of CMD
- Periodic message with T = 100 ms
  - If no CMD message is received for 3T = 300 ms, the car stops because disconnection is assumed.
- Wire format to be defined. Initial proposal:
  - Message protocol: UDP
  - Payload: JavaScript Object Notation (JSON)

The mandatory messages for the protocol are:

- CMD (Control Order, only one client is accepted)
- ACK-TELEMETRY (ACKs to Control and Telemetry messages)
- CMD-SUBS-TELEMETRY (Subscription to Telemetry messages, more than one is accepted)
- CMD-SUBS-VIDEO (Subscription to Video feed, more than one is accepted)

Other messages for future versions are:

- CMD-REG (Register in MEC, from old MEC)
- UNSUBS-TELEMETRY (Subscription to Telemetry messages)
- UNSUBS-VIDEO (Subscription to Video feed)
- GET-STATS (Get some statistics)

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

This use case do not necessary requires creating or modifying any AD driving functionality. However new software components were created to use the 4K cameras installed in the ALSA bus and send their information through the 5G network.

3.3. OBU integration

All vehicles present in the ES-PT CBC are equipped with the CTAG 5G OBU (called HMCU) except for the PT vehicle which have a 5G OBU created by PT partners. In the following sub-sections can be checked the information of these two OBU.

3.3.1. CTAG 5G OBU

The OBU used in the ES-PT CBC is the HMCU and its features are described in D2.4 (2) and for 5G-MOBIX project this OBU adds some additional hardware and software features:

- Install 5G chipset
- Adapt functions to send and receive information through that chipset.

The installation process of 5G chipset and the adaptation of the functionalities to use are described in the following paragraphs.

The integration process with the additional 5G modem is depicted in the following Figure 10:

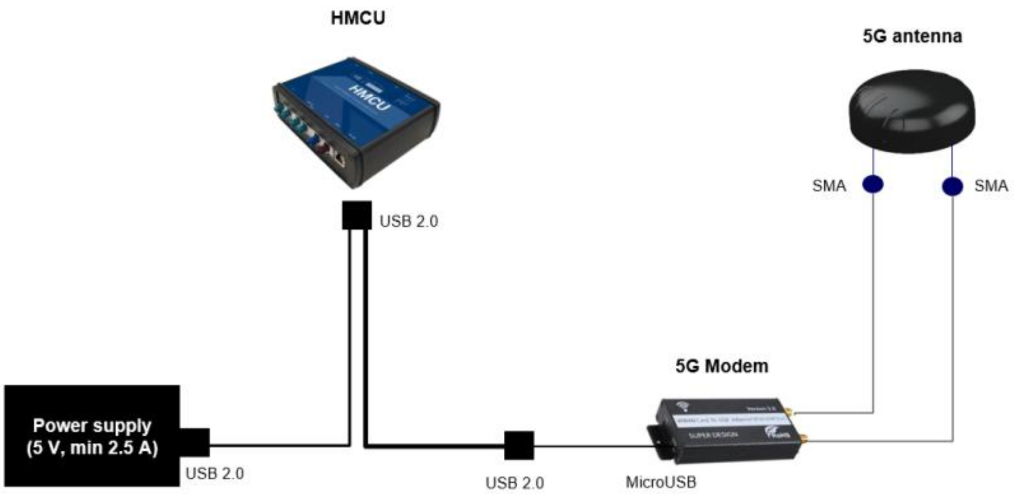


Figure 10: 5G OBU integration scheme

The 5G modem used in this project is the Quectel model 5G RM500Q-GL (Figure 11). It is a 5G Sub-6GHz M.2 Module for IoT applications with 5G (both NSA and SA modes supported) and LTE-A coverage. The use of external e-SIM is supported and it has a multi-constellation GNSS receiver, available for applications requiring fast and accurate fixes in any environment.

Figure 11: 5G Quectel chip 5G RM500Q-GL

The use of an M.2 to USB adapter is required to connect the modem to the external USB port of the OBU. The 5G module consumes more than 500mA (with peaks of about 1000mA), so it is needed to provide an external power source.

The OBU firmware has also been adapted to include the required drivers to use the 5G modem. The Quectel Connect Manager tool is used to manage the connection configuration of the modem.

The 5G antenna is a Poynting PUCK-2 model (Figure 12). It is a 2x2 MIMO omnidirectional antenna that cover the 698 to 3800 MHz band, suitable for automotive use.

Figure 12: 5G Antenna

Even though the 5G module and the 4G module are connected to different ports, they are incompatible since they use different software to manage the internet connection. For this reason, it is necessary to physically disconnect the 4G modem from the OBU's PCI port.

The modem-manager software has also been adapted to manage the 5G modem service, ignoring the 4G modem.

In Figure 13 is shown some steps of the adaptation of the OBU to get 5G connectivity.

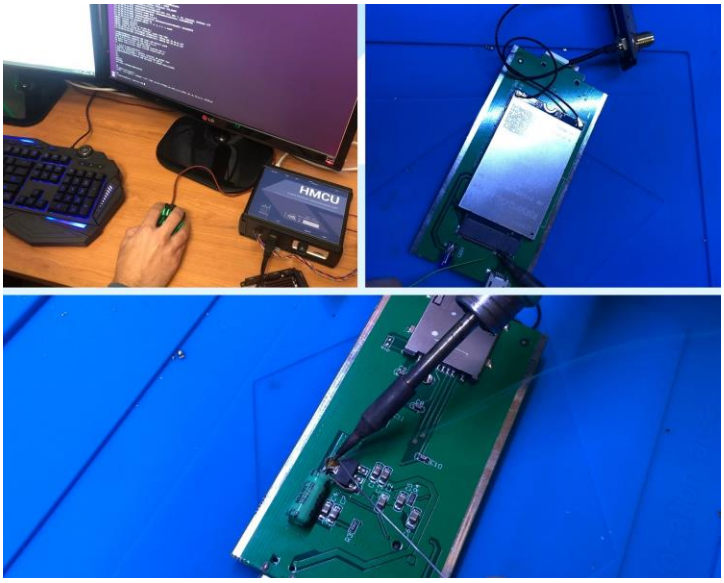


Figure 13: 5G modem integration process

3.3.2. PT OBU

The information of this OBU create in association with the PT vehicle can be found at sub-section 3.1.5.

3.4. TS contributions to ES-PT vehicles / OBU

3.4.1. FI collaboration Contribution implementation

FI TS contribution to the ES-PT CBC is to test a handover scenario between two PLMNs. This contribution, alongside with the FR TS, will elaborate a benchmark on possible seamless handover approaches to transit from 5G to 4G/5G/sat networks.

The FI TS is testing two units of a new 5G multi-SIM OBU solution, based on Sierra modems, which is in development phase. The OBU is able to switch over up to four 5G NSA networks, but it will be tested over just two networks in the ES-PT CBC, both in NSA mode. Furthermore, in the FI trial site, the OBU will be tested in SA mode, pending upgrades by H1 2021. The criterion to switch over multiple networks is primarily based on fixed connectivity metrics (basically, signal strength), but the OBU allows to introduce different criteria. The OBU includes a configuration and management platform which will be deployed in the 5G test bed of the FI TS. The OBU also includes an optional VPN service.

The initial benchmarking between the FI and FR multi-PLMN solutions will be done in the FI TS, using the FI remote driving UCC. This benchmarking trial will allow the solution developers to have empirical evidence on the performance between the two solutions under similar road and network conditions, when running similar remote driving traffic flows and experiencing similar transitions (e.g., handover, induced network failure etc.). Moreover, the benchmarking will provide useful insights prior to redeployment and testing of the solutions in realistic cross-border environments.

3.4.2. FR Contribution implementation

FR TS is bringing the following two contributions to ES-PT CBC

- Seamless handover using multi-SIM solutions
- 5G connected vehicle for benchmarking and inter-operability tests

3.4.2.1. Seamless handover using multi-SIM solution

This contribution provides the implementation of seamless handover between available technologies at the corridor: 5G to 5G, 5G to 4G or 4G to 5G using a dual-SIM solution.

FR TS will use an intelligent router solution, connected to its OBU, which allows the UE to keep multi-SIM connections with PLMNs ensuring continuity with the application end-point (in the cloud or in the MEC). Based on continuous monitoring of available networks (4G, 5G) and their quality, the intelligent router selects and connects to two PLMNs. Specifically, the first 5G interface will stay connected to the available PLMN while the second one will be in monitoring mode, scanning for secondary connection, and when it sees a secondary stable connection, it will connect the second interface to the secondary PLMN. At the reception, a software module, so-called aggregator, aggregates data transmitted over the different

PLMNs and provides the aggregated data to the target application. An overview of this solutions can be checked in Figure 14

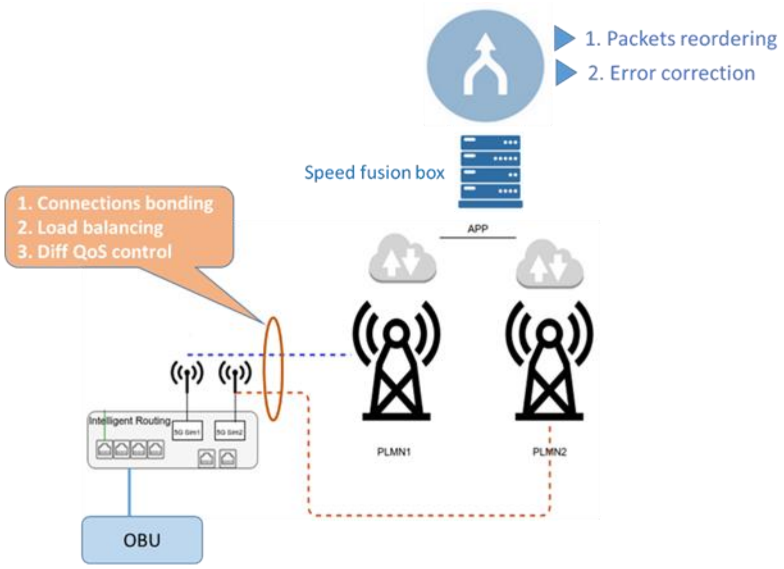


Figure 14: multi-SIM solution for seamless handover using Pepwave device

Agnostic tests will be carried out to evaluate the performances of the contributions. In this scheme, the connected vehicle will be equipped with a 5G OBU and intelligent router. The vehicle will communicate with a destination node (e.g., ITS centre) in the cloud, where the aggregator module, which provides flow aggregation and error correction functionalities.

At the CBC, the FR TS dual-stack OBU, the intelligent router will be integrated in the FR TS connected vehicle, and the proposed seamless handover solution will be tested under the CBC multi-PLMN scenario, and compared against the ES-PT single-SIM solution.

3.4.2.2. 5G connected vehicle for benchmarking and inter-operability tests

The second contribution of the FR TS is bringing a connected vehicle to the ES-PT corridor to interoperate with the other "local" vehicles. Targeting the user stories developed in the ES-PT corridor: US1 of Advanced Driving category (Complex manoeuvres in cross-border settings) we test inter-operability between the FR TS vehicle and ES-PT vehicles/network. Different communication flows will be tested during these benchmarks including CAMs and CPMs.

3.4.3. CN Contribution implementation

CN TS contribution to the ES-PT CBC is to test the coordinated driving and remote driving scenario between autonomous vehicles and pedestrians to keep safety. This contribution, along with the CN TS, enables road safety and traffic efficiency services.

To do so, CN is trying to enable the vehicle to assess the probability of an accident better and coordinate the exchange of information and safety information, sensor data, braking and acceleration command lists, horizontal and vertical control in the application of road traffic flow through V2X communication.

Moreover, CN TS will consider the pedestrians who are highly injurious, disabled, or even fatal when a traffic accident occurs. In this case, CN will upgrade the intersection safety information system, which consists of road radar, traffic signals, LDM servers, and RSUs.

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

What's more, CN TS will contribute as follows:

- Make a seamless connection between 4G and 5G networks to ensure network connectivity in areas not covered by 5G.
- Make data type processing and conversion of MEC when the network is transferred from 5G to 4G.
- Make collaborative interaction between MEC and CBC.
- Make backup and management of data in CBC's cloud systems.

Therefore, the CN site will test scenes like a bridge, long steep slope, ramp, toll station, and other places. At these scenes overtaking is not allowed by some safety regulations. It is difficult to place enough road infrastructures because of the harsh environment with little room. When a platoon runs on the bridge or long steep slope, it is more important for each vehicle to receive information on dangerous situations.

Also, platooning with remote driving is complementary from a single-vehicle with remote driving. Not only will the head of the platoon be controlled, the rest of the vehicles will be monitored.

3.5. Cyber-security & data privacy

For the cyber-security and data privacy aspect, and due to the different needs of the UCC, several solutions have been used. In the following sub-sections they are listed by UCC and in D2.4 (1) is available more information.

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

The communication between vehicles and infrastructure is protected by a secured MQTT service. This service is installed in each OBU unit as a MQTT client where is available a TLS layer. This implementation is also available on the server, that's it, a MQTT server with a TLS layer.

The OBU creates a unique private key and is sent to the registration server. After that the OBU requests a JWT (Json Web Token) to the server and it returns the JWT and the Geoserver address where the OBU must establish the communication to. Finally, the OBU subscribe to the topics of the specified Geoserver.

In that way, the communication between all actors is secured and they can exchange ITS messages.

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

The files exchanged between remote actors are secured with the Secure File Transfer Protocol (SFTP). This protocol allows the transfer of encrypted data between two hosts using Secure Shell (SSH), with the help of a user and a password to upload and download the files.

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

For carry out this UCC, a VPN has been implemented using OpenVPN, therefore, the exchange of information between the control centre and the Shuttle is encrypted end-to-end. Provisioning of certificates for such network is done manually during the configuration phase.

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

In this case, the video streaming access and application is protected with a user/password registration.

3.6. Early testing results

All components, hardware and software, were tested individually to check their good operation, showing their results in the D3.5 (4).

Tests were made to check potential video transmission issues for remote driving and here are presented some result of these tests and the way how the testing were done.

Test development

The first integration setup was built with the following two components (Figure 15):

- Camera kit:
  - One Front Camera PTZ for exterior, for **front view (Panasonic WV-X6531n)**
  - One 360 Camera for exterior, for **360 view (Ricoh Theta V**)
- Communication Box
  - One **small OBU for testing** connectivity built on a **raspberry Pi**, VPN to MEC tests
  - One **Smartphone with GPS** and connectivity to NSA 3.x in the n78 5G band

Figure 15: Vehicle equipment Installation

Before placing the two cameras in the vehicle we had studied several options to understand the quality of the view from both cameras. The two main factors to consider were:

- The camera Lens Field of View: that was [16:9 mode] Horizontal: 2.1 ° (TELE) – 65 ° (WIDE) for the Front View Camera, while for the 360 Camera it was 360º.
- The visual field from the camera to the car perimeter. This measure is very relevant because objects may be outside the field of view due to the position of the camera and, therefore, are not visible.

The 5G radio node is located at about 1.4 Km from the test zone even do not have direct view from the tower antenna. The gain of the antenna for the automotive modem will be critical to have additional dB in the uplink and in the downlink to improve the coverage and the performance of the connectivity.

The roof of the vehicle has a better point of sight for the antennas and there is less car components that can decrease the received signal. The communication devices were placed in a white box on the roof of vehicle.

During the test some issues with its solutions were found, and they are presented in the following paragraphs.

Radio power in the border by Telefónica

Telefónica has deployed 5G nodes in available sites for 4G, so the antennas location is fixed and, unfortunately, the distance to the border is not optimal, about 1400 meters **¡Error! No se encuentra el origen de la referencia.**, so, the impact of this for the cameras is that the video is uploaded at lower speeds, and the required minimum bandwidth was lost many times. This long-distance impacts on downlink capacity, but it is even more remarkable in the uplink. In fact, the 5G NSA 3.x in 3,5 GHz is deployed in TDD with 4:1, so the bandwidth available for uplink is very restrictive. The measures described in this section were obtained with a very preliminary version of the radio software. In newer versions (release 5G19A) throughput behaviour is improved, especially in the upload section.

Figure 16: Line of Sight of Telefónica Antenna

The proposed solution was to place the smartphone in the roof of the vehicle as it is shown in the main picture. The camera sensors have been configured to encode video at a maximum of 3 Mbps in AVC, using variable bitrate. In order to have a real correlation of video and bandwidth, these tests are UDP video feeds in the uplink, so the bandwidth limitation in the captured video can be captured and analysed.

Video Traffic test

Video was uploaded in UDP, so one missing UDP packet has an impact on quality. At these bitrates, missing an UDP packet of 150 bytes has a ¼ probability of visual impact, but as many UDP packets can be lost, the impact in the quality of the video is very high. In Figure 17 can be seen how the video quality is good at the Portuguese side of the bridge:

Figure 17: Inside the Bridge Video Capture

However, as the vehicle is driven to the Spanish side of the bridge, the radio signal gets weaker and some packets are lost with an initial small impact on the video frames (Figure 18).

Figure 18: Inside the Bridge Video Degradation I

The solution in the border of the bridge, where the quality of the 5G Telefónica network is very limited, is that NOS will deploy a radio antenna just in the border of the bridge, so it is expected that in case the quality in Telefónica network is not good, the vehicle can switch to the NOS network in the area. The other solution is to decrease the required camera bitrate in order to deliver the video without loss of packets. If the video is LOW LATENCY VIDEO, the delivery of UDP is almost mandatory to save time in the video delivery. There are other retransmission techniques for UDP reliable traffic, but these options increase the frames latency, so are not considered by now. Other option is to deliver video using TCP but, in this case, there is a relevant impact on delay. The most efficient method is UDP delivery.

Missing coverage with metallic trucks overtaking

During the recordings in the highway, when a big truck with metallic load overtook the vehicle, some video effect was perceived due to some missing UDP packets. This spurious lack of radio quality shows that having only one radio feed from one single site in the motorway makes the real-time video feed extremely vulnerable to clean radio links to the automotive antenna.

The solution to provide continuous video feed will be always to have more than one site connected to the car with carrier aggregation.

Speed impact on the video quality

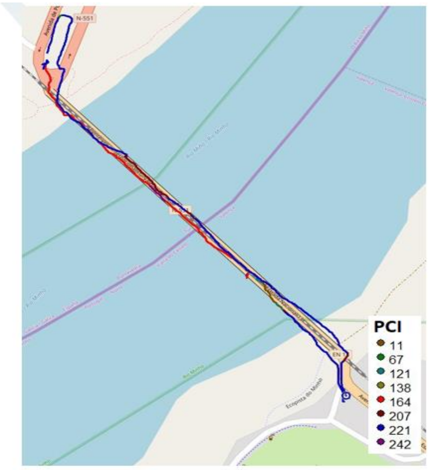
The cameras have been fine-tuned to provide good video quality in interiors and exteriors, but when the camera is mounted in the vehicle, and it starts to move, the video quality was degraded. As the video has been tuned to low latency configuration, the video quality when moving is worse than in still positions. The low latency configuration of the camera requires not using B frames in order to save PTS/DTS times and keep the video latency under minimum values. Not using B frames means using more bits to encode the frames only with I frames and P frames, which are the type of frames that need more bits. So, when the video images are constantly changing, like in moving scenarios, the video is degraded as it is spending much more bits per frame than in regular video coding.

The solution for this is to only use Low Latency Video in video configuration that requires Low Latency like remote driving control. In the case of remote driving, it is recommended to use as much as possible bandwidth in order to guarantee the required minimum video quality. In the areas where remote driving is required, it is better to have a very good uplink channel.

Loosing minimal radio signal many times in the bridge

In the bridge area, and sometimes in other areas with low quality coverage has been observed that the 4G carrier is constantly leaping from side to side, causing additional throughput degradation. Some of the 4G carriers are located at very long distances, providing very low uplink throughputs. In Figure 19, we can see that the 4G node changed 8 times, some of these times the nodes did not have 5G carrier signal capacity. The 4G nodes that have direct view at very long distance are covering the old bridge area, and if the nearest node is out of sight then are used by the smartphone. Therefore, there are some issues: there is not 5G coverage, the 4G node has not capacity and the performance of the uplink channel to nodes located at almost 6 Km in the 2600 MHz band is extremely low.

The solution is to use a non-commercial PLMN SIM that is only associated to the 4G nodes where we have 5G capacity. Other option is to control in the automotive modem when the modem must handover from a 4G node to a different node, avoiding Ping-Pong cases.



PCI	Band	Location	Distance to old bridge (Km)
11	LTE 2600 (Band 7)	As Bornetas	1,42
67	LTE 1800 (Band 3)	San Julian EB	5,86
121	LTE 2600 (Band 7)	Salceda-Soutelo	5,34
138	LTE 2600 (Band 7)	San Julian EB	5,86
164	LTE 1800 (Band 3)	Tui Centro	1,23
207	LTE 1800 (Band 3)	Salceda-Soutelo	5,34
221	LTE 1800 (Band 3)	Tui Centro	1,23
242	LTE 2100 (Band 1)	Salceda-Soutelo	5,34

Site with 5G available
Site with 5G unavailable

5GMOBIX
NOKIA Bell Labs

Figure 19: Antenna Position Analysis

VR360 view for outside view of the car may not be enough

The 360 camera in the top of the car provides a very good view of the area around the vehicle, but shows some disadvantages like missing lot of bits in the top and the bottom view (in the top the sky is visible, while in the bottom the vehicle roof is shown), and also there is not a clean view of the perimeter of the vehicle. Therefore, the 360 camera is nice to have a broad view, but in some cases where the bandwidth is critical, or the remote vehicle driving perimeter view is mandatory, this is not the best approach. In the following 360 photograms (Figure 20 and Figure 21), we have the 360 view, in red colour the areas of no interest for the remote driving case.

Figure 20: 360 Video Sectors Optimization

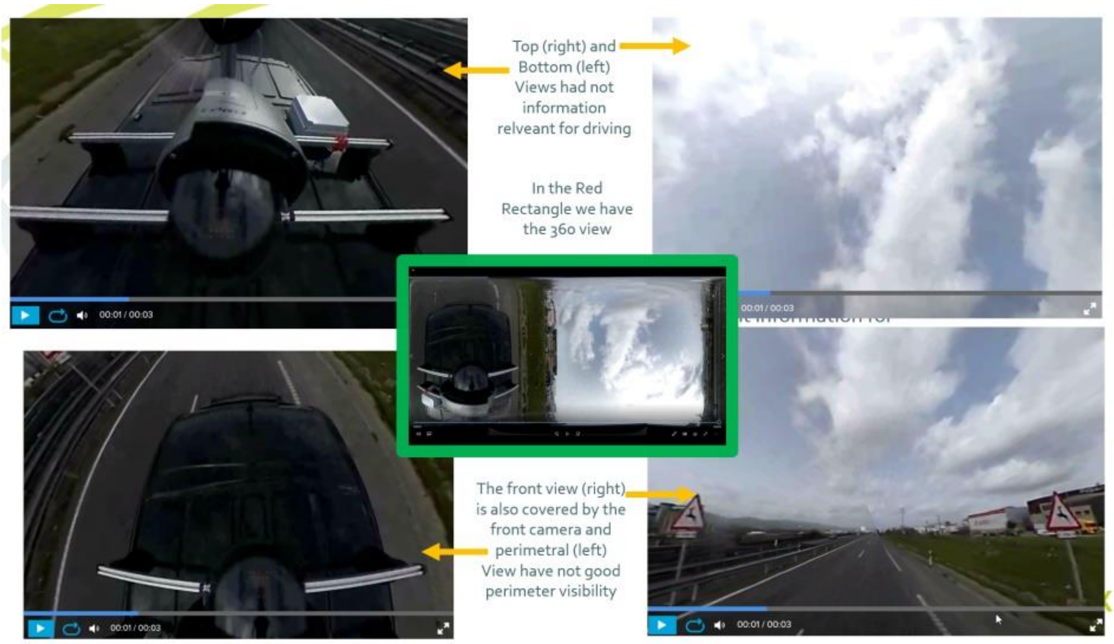


Figure 21: Non 360 Cameras Optimization

The Solution to optimize the information per pixel and then the bandwidth for the uplink is to place several cameras without 360 view that can include more relevant information of the perimeter of the vehicle. These cameras could have smaller resolution in order to consume less bandwidth, and optionally, depending on the car manoeuvre, the bitrate of the perimeter cameras may be increased when needed.

4. VEHICLE INTEGRATION OF GR-TR CBC

The GR-TR trials will take place using a FORD truck with autonomous driving/platooning capabilities. Details of FORD Truck can be found in section 4.2. In order to realize all three User Stories of the GR-TR corridor, different OBUs and automated driving functionalities have been developed by the GR-TR partners, while different sets of onboard (and road-side) sensors are also utilized. The developed OBUs and sensors have been integrated with the FORD truck in order to allow the various functionalities of the GR-TR User Stories. Table 5 below provides an overview of the various vehicle related equipment developed for the GR-TR trial, while details regarding their design, development and testing are provided in the following sub-sections. It has to be noted that different RSI, road-side sensors and applications have also been developed for each of the User stories, but they are presented in deliverable D3.4 (5). of 5G-MOBIX.

Table 5: Overview of OBUs, driving functions and sensors utilized in the GR-TR CBC

User Story (US)	US Lead partner	On-Board Unit	Sensors	Driving function
Platooning with "see what I see" functionality	FORD/ICCS	IMEC OBU	RTK-GNSS, Camera, Radar, Webcam	Platoon Manoeuvres(Join, Dissolve, Merge, Split, Maintain)
Extended sensors for assisted border-crossing	WINGS	WINGS OBU	Proximity, CO_2, NFC, GPS	Customs agent protection (autonomous braking, Threat assessment of incoming trucks)
Truck routing in customs site	TUBITAK	IMEC OBU	CCTVs, VLP-16 Lidar	X-ray Inspection, Autonomous Path Following

4.1. Sensors & devices integration

4.1.1. Platooning with "see-what-I-see" equipment & sensors

In this project, two FORD F-MAX trucks will be used. These trucks will be equipped with front radar and front camera for object detection, electronic steering wheel controller, RTK-GNSS for cm precise positioning, rapid prototyping unit for vehicle autonomous controller (dSpace MicroAutoBox II), and IMEC/WINGS on-board unit for connectivity.

Additionally, LEVIS clients (for video encoding, decoding) and one 4K camera (only for front vehicle) will be used for "See What I See" video streaming application. High level vehicle architecture can be seen on Figure 22 below.

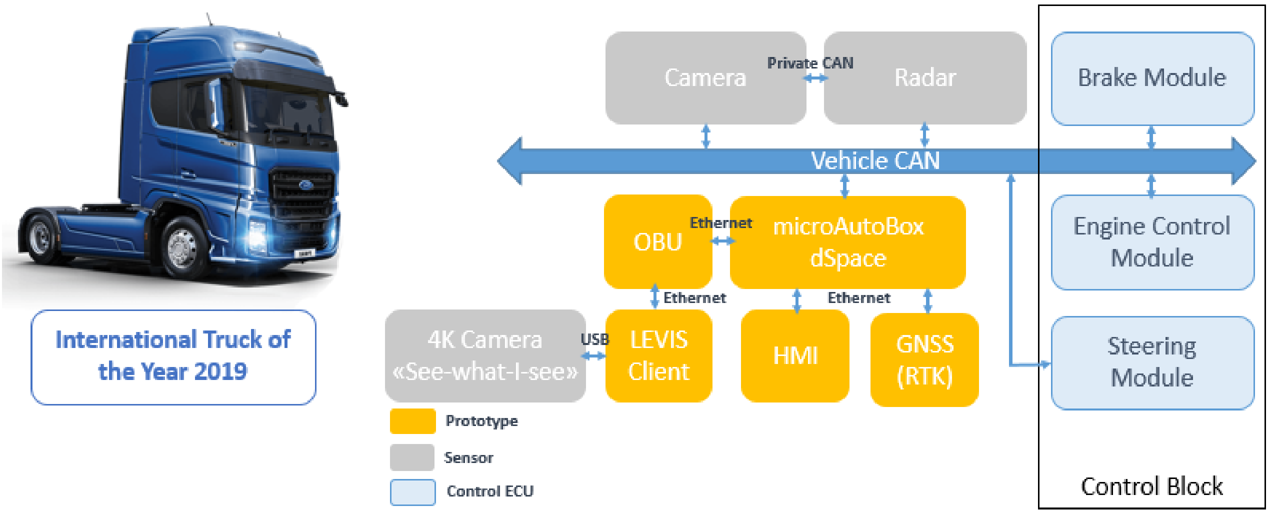


Figure 22: High Level Hardware Architecture of F-MAX Trucks

FORD OTOSAN works on vehicle controller algorithms and for this purpose dSpace MicroAutoBox II (MABX) module is used. MABX is a fast prototyping module. Algorithms are developed first on MATLAB and after that, they are integrated into MABX module. For this project dSpace MicroAutoBox II[3], DS1401/1513 will be used. Picture of the module can be seen on Figure 23 below.

Figure 23: dSpace MicroAutoBox II – 1401/1513

[3] https://www.dspace.com/shared/data/pdf/2020/dSPACE-MicroAutoBoxII_Product-Brochure_2020-02_EN.pdf

To accomplish platooning, radar, camera and GNSS information is the required sensor suits. This sensor suits provide perception and with the help of this perception vehicle controllers are manipulated with software. For radar, Continental ARS408[4] is used. Figure 24 of the radar can be seen below.

Figure 24: Continental ARS408 Radar

As camera suit, Mobileye 630 Series[5] is used. Picture of the sensor can be seen below (Figure 25). More detail is also can be found in product website:

Figure 25: Mobileye 630 Series Camera

4.1.2. Assisted "zero-touch" border crossing equipment & sensors

In order to realize the "Assisted zero-touch border-crossing" user story at the GR-TR the following equipment will be deployed by WINGS inside the FORD truck.

[4] https://conti-engineering.com/components/ars-408/

[5] https://www.mobileye.com/us/fleets/products/mobileye-6-collision-avoidance-system/

- 1 integrated portable OBU to be installed in the FORD Truck (connection with the truck's ECU to receive data regarding speed, revs, etc.). See Section 4.3.2 for detailed information on the WINGS OBU
- Multiple sensors connected via cable to the OBU measuring a multitude of metrics from the cargo haul and around the truck, namely:

  - ***CO2 sensor***: For CO2 level measurements, the CCS811 sensor from Adafruit is used. The sensor's output range is [400 – 8192] ppm. A connection to the OBU is established through the I2c protocol.
  - ***Proximity sensor***: The Lidar lite v3HP is attached in the middle of the front bumper of the vehicle and it measures the distance from the vehicle in front, or a possible obstacle/human. The sensor has a range of [0.05m – 40m], operates at 5V DC power supply, it can sample faster at rates greater than 1kHz (necessary for the URLLC functionality of VRU protection) and still possesses an accuracy of +/-2.5cm at >2m. The sensor is housed in a durable, IPX7-rated housing that makes it water resistant. A connection to the OBU is established through the I2c protocol.
  - ***NFC (reader & tags)***: The ACR122U NFC Reader is a PC-linked contactless smart card reader/writer based on 13.56 MHz Contactless (RFID) Technology. Compliant with the ISO/IEC18092 standard for Near Field Communication (NFC), it supports both MIFARE and ISO 14443 A and B cards and tags. Every time that a cargo NFC tag is scanned, its ID is added on a list of ID's of contained cargo. Each ID is removed from the list when the corresponding cargo is exported. A connection to the OBU is established via a USB port
  - ***GPS (GNSS) module***: Global Navigation Satellite System (GNSS) services are provided by the SIM7600 with the following specifications:
    - Receiver type: 16-channel, C/A code
    - Sensitivity: Tracking: -159 dBm (GPS) / -158 dBm (GLONASS) / TBD (BD), Cold starts: -148 dBm
    - Time-To-First-Fix (open air): Cold starts: <35s, Hot starts: <1s
    - Accuracy: Position: <2.5 m CEP

As the GPS positioning accuracy obtained by the on-board GNSS module is not fine-grained enough to support the customs agent protection scenario, WINGS has implemented a two-factor positioning verification system, in order to the customs agent's safety (VRU protection). The distance between the incoming trucks and all customs agents are constantly calculated based on their GPS signals. If that distance is decreasing, indicating that a truck is coming closer to an agent, then the readings of the on-board proximity sensor are also consulted. If both the calculated distance based on GPS and the proximity sensor readings indicate that a collision among the truck and a custom agent is imminent, then an autonomous braking instruction is issued to the truck, which immediately brakes to avoid the accident. URLLC communication is necessary for the transmission of GPS and proximity sensor measurements, as well as for the transmission of the braking command to the truck.

4.1.3. Truck routing in customs site equipment & sensors

In addition to the sensors and devices described in the sub-section 4.1.1.for Autonomous Truck Routing Application at Ipsala Border Area, precise positioning is needed to follow paths that are will be sent by TÜBİTAK cloud. Precise positioning will be accomplished by using Oxts RT-3000 v2 (Figure 26) and with and NTRIP (Network Transport of RTCM data over IP) connectivity. NTRIP Server will be provided by TUSAGA-Aktif[6] and NTRIP Client will be Lefebure[7] open source software. With this setup, we have accomplished 9cm precise positioning information and that can be seen on the Figure 27 below:

Figure 26: Oxts RT-3000 v2 for RTK-GNSS precise Positioning

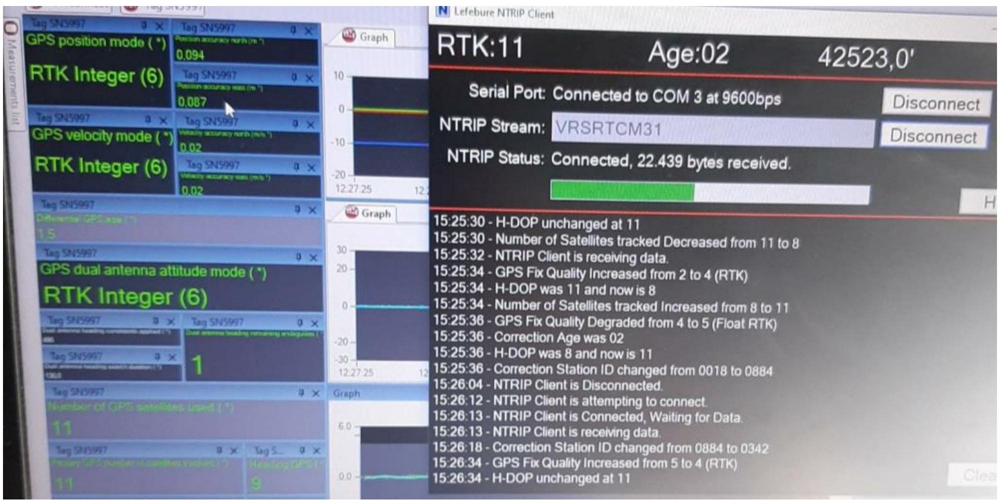


Figure 27: Lefebure Client and Oxts RT 3000v2 position information

6 https://www.harita.gov.tr/english/u-13-turkish-national-permanent-rtk-network--cors-tr-tusaga-aktif-.html
7 http://lefebure.com/software/ntripclient/

4.2. Automated driving function development

4.2.1. Platooning with "see-what-I-see" functionality

As mentioned in sub-section 4.1.1 FORD OTOSAN also works on vehicle controller algorithms and they are mainly listed below:

- Platooning controller algorithms (e.g. join, split, merge, maintain, dissolve etc.)
- Radar – Camera multi object tracking algorithm for perception
- Waypoint tracking algorithm for Autonomous Truck Routing Application.
- CAN (Controlled Area Network) to Ethernet and Ethernet to CAN message gateway algorithms

Algorithms are developed first on MATLAB and after that, they are integrated into MABX module. Main development blocks that are accomplished on MATLAB – Simulink and integrated into MABX can be seen on Figure 28 below:

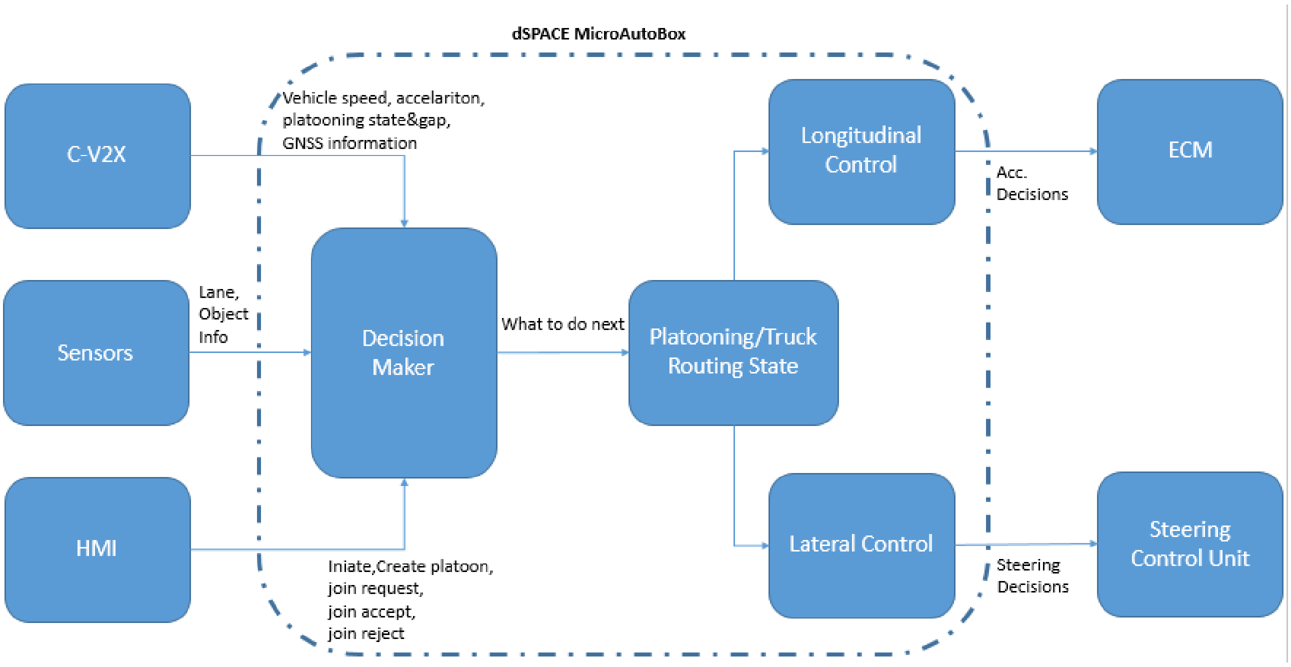


Figure 28: MATLAB – Simulink Development Blocks

Decision Maker gathers sensor, C-V2X data and HMI input and decided to control vehicle for either Platooning application or Autonomous Truck Routing application. After that decision is made, required longitudinal and lateral controller algorithms that are developed by FORD OTOSAN take action to drive vehicle autonomously. ECM (Engine Control Unit) is manipulated for acceleration/deceleration and Steering Control Unit is manipulated for directional decisions.

4.2.2. Assisted "zero-touch" border crossing functionality

The full functionality of the WINGS Assisted "zero-touch" border-crossing platform is described in deliverable D3.4 (5), where the 5G-MOBIX application are presented, however we will point out in this section the autonomous driving functionality enabled by the WINGS platform and OBU. Based on the information transmitted by the integrated sensors through the WINGS OBU two different autonomous driving functionalities are enabled:

1. ***Autonomous braking for customs agent's protection***: Upon the detection of a customs agent in close proximity to the truck (based on GPS distance + proximity sensor reading) an autonomous braking order is issued from the WINGS platform and the FORD truck immediately breaks to avoid the accident in the customs area.
2. ***Autonomous driving to the appropriate inspection lane***: Based on the input collected by the on-board and road-side sensors the WINGS platform performs a threat assessment classification for each incoming truck. Based on the outcome of this threat assessment trucks are expected to go through a more rigorous manual inspection by customs agents (high risk assessment), a more light-weight inspection (medium risk assessment) or even no further inspection (low risk assessment – zero-touch border crossing case). Depending on the outcome the truck is instructed to autonomously drive to the respective lane within the customs. This functionality is enabled by the *truck routing in customs site* User Story.

4.2.3. Truck routing in customs site functionality

The algorithms implemented for this Use case are listed in sub-section 4.2.1.

4.3. OBU integration

In the GR-TR CBC two partners develop their own OBUs. Each of these OBU is employed in different use cases as can be seen in Table 5 and in the following sub-sections is done a description for all features of these OBUs.

4.3.1. IMEC OBU

4.3.1.1. 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 29 below.

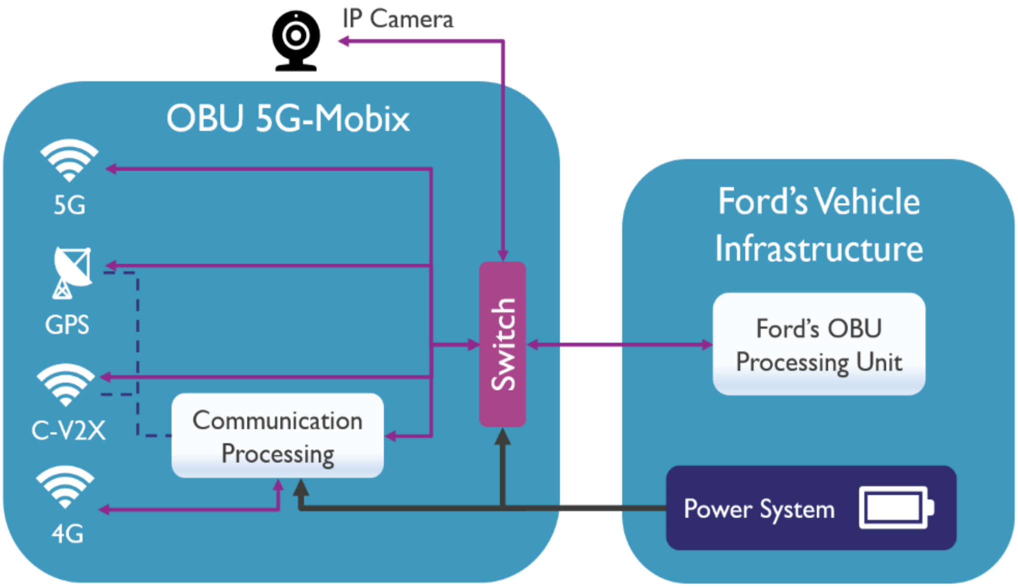


Figure 29: OBU Overview

4.3.1.2. *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 have to 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 enables 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 and ZeroMQ. The goal of DUST is to provide an interface between the messaging protocols and the applications. The developers can 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. These data structures can be extended without losing backwards compatibility between the software components which allows the OBU to be extended as needed without the need of upgrading every software component in the system. This feature will enable us to integrate the FORD OBU by only writing a bridge between the required data structures and the OBU software.

4.3.1.3. *OBU Hardware Architecture*

The OBU contains all communication hardware, V2X processing hardware and sensor processing hardware. Figure 30 below shows the roof unit 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.

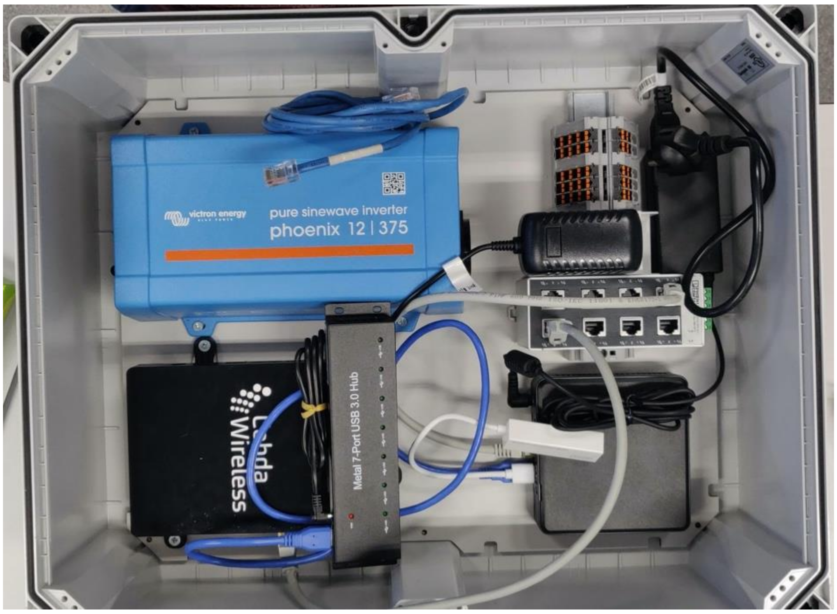


Figure 30: Inside the OBU

Figure 31 below shows the main OBU unit from the outside. The heart of the unit is the Intel NUC processing unit which will implement the V2X stack and communicate with the OBU within the vehicle.

Figure 31: OBU Ports

The OBU unit is supposed to be installed inside the vehicle. All Antennas of the 5G module and CV2X have standard SMA connections and can be installed outside the vehicle. All antennas have magnetic mounts making it easy to use them in any vehicle. The 4G modem is powered by PoE and is should also be installed outside the vehicle.

The OBU unit requires 12V DC input and an Ethernet connection to the vehicle unit to operate correctly. The following Figure 32 contains a list of all the hardware of the unit and their specifications.

Figure 32: Front View of the OBU

The OBU unit contains the following list of components:

- V2X processing unit: NUC7iDNKE
- Phoenix gigabit switch 8x 1Gbit/s ports
- C-V2X: Cohda MK6C
- 4G module: Mikrotik wAP LTE kit
- GPS module: Navilock NL-8012U GPS
- 5G modem: Quectel RM500Q
- PHOENIX 12/375 VE.Direct – Schuko
- 2X DIN power plug SN312

4.3.2. WINGS OBU

The WINGS On-Board Unit (OBU) is designed to collect and send real time vehicle information. As a computation platform, the raspberry pi 3 is used with a Quectel RM500Q chipset attached providing 5G connectivity as well as a SIM7600 modem, providing 2G (GPRS)/3G/4G connectivity. The OBU may also work over Wi-Fi connectivity that is build-in the raspberry pi. Power supply is provided form the connected vehicle's battery, through the On-Board Diagnostics (OBD) port connection. There is a capability for secondary power supply from AC voltage (220 V). Once powered up, the OBU starts transmitting data with a refresh rate starting from 1 second.

There is a multitude of onboard sensors with wired connections to the OBU, that provide CO_2, GPS, proximity, acceleration and ECU data. A mini buzzer is used as an alarm indication to inform the vehicle's driver that an obstacle has been detected. The NFC scanner attached, is used for cargo monitoring. The exact specifications of the onboard sensors are provided below. Figure 33 below depicts the design of the WINGS OBU and its external connectivity to sensors, while Figure 34 shows a picture of the actual implemented WINGS OBU and its connected sensors.

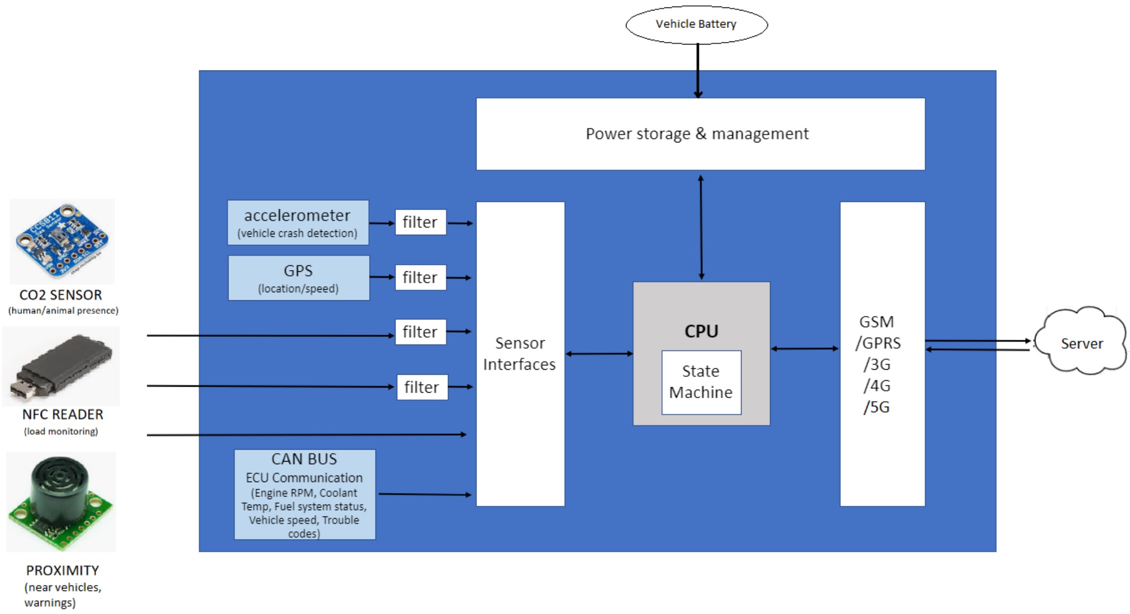


Figure 33: WINGS OBU Diagram

Figure 34: WINGS OBU (with integrated 5G chipset) & connected on-board sensors

4.4. TS contributions to GR-TR vehicles / OBU

4.4.1. FI Contribution implementation

LEVIS application is a platform that enables cloud-based video streaming between two vehicles as part of the of the See What I See (SWIS) user story at GR-TR (described further in D3.4 (5)). In order to achieve low latency streaming we would need to keep the encoding process, which is the most time-consuming process in the whole pipeline, as low as possible. To this aim, we need to leverage hardware capabilities as they are deemed to be more efficient and reliable than software encoders. To do so, we have used the Jetson Xavier[8] [2] that is powerful enough and GPU-capable. This resulted in a faster processing time, hence lower latency. The deployment of a separate hardware consisting of Single Onboard Computer (SOC), which is the Jetson Xavier, for taking care of the streaming task avoids consuming from the vehicle's resources, which can be critical, and makes the development, testing and deployment much easier. The powering of the Jetson Xavier will be done using its original adapter directly from the vehicle at 19.0V. A converter might be used for this purpose. At the time of writing the selection of the touch screen products to be used in the two vehicles had yet to be completed.

As to the camera used during development and tests, we have used Logitech BRIO USB webcam[9]. The use of a USB webcam makes the deployment more flexible and much easier, notably when using it on board of a vehicle where the driver of the truck driver wants to move it to capture better view. The devices used for the live streaming are depicted in Figure 35.

Figure 35: Jetson Xavier and Logitech USB camera used for the live streaming.

[8] NVIDIA Corporation, "Jetson AGX Xavier Developer Kit," [Online]. Available: https://developer.nvidia.com/embedded/jetson-agx-xavier-developer-kit. [Accessed 30 10 2020].
[8] Logitech, "BRIO ULTRA HD PRO WEBCAM," [Online]. Available: https://www.logitech.com/en-us/product/brio. [Accessed 30 10 2020].
[9] Logitech, "BRIO ULTRA HD PRO WEBCAM," [Online]. Available: https://www.logitech.com/en-us/product/brio. [Accessed 30 10 2020].

4.5. Cyber-security & data privacy

4.5.1. Platooning with "see-what-I-see" equipment & sensors

As to the security aspect in SWIS user story, the access to the web platform that allows the leader and follower drivers requires user authentication. So, only users having approved accounts can log in and then exchange messages (request live stream, accept/reject request, start live stream, stop live stream, etc.). We can also add an additional security measure consisting of IP whitelisting to limit the access from a specific subnet (192.168.0.0/16). To do that, we need to know the subnet of network we will be using. Assisted "zero-touch" border crossing equipment & sensors

In order to guarantee the security and privacy of the drivers, customs agents and all platform users, WINGS has implemented two layers of security on its application layer, targeting user authentication, and sensor data encryption. Besides that, all transmitted information over the 5G network enjoy the inherent security offered by the 3GPP security and authentication mechanisms.

More specifically WINGS has implemented a user authentication mechanism, to guarantee that only authorized personnel may access and use the "Assisted border-crossing" platform and equipment, and to filter the amount and type of information provided to the user depending on their role and authorization level. This means that customs agents enjoy access to much richer information regarding incoming trucks, the status of the system, sensitive information such as license plates etc., while drivers only receive a restricted amount of information that will help them navigate through the customs and align with the commands of the customs authorities. Figure 36 depicts the user authentication, log-in and registration screen used for the Assisted "Zero-touch" border-crossing US.

Figure 36: WINGS User authentication & registration mechanism for the "Assisted border crossing" US

Moreover, all messages to and from the OBU, meaning all sensor readings, driving instructions and camera footage are encrypted at the source and decrypted at the destination to offer an additional layer of security, as some of these information (e.g. license plate, truck location) is sensitive and access should only be provided to authorized personnel. All messages are encrypted/decrypted using the AES-128 protocol, which is a well-established encryption mechanism. Figure 37 depicts how the WINGS OBU is integrated with the IMEC OBU and in extension with the FORD Truck, as well as how the various measurements and communication to and from the OBU is encrypted to provide an additional layer of security.

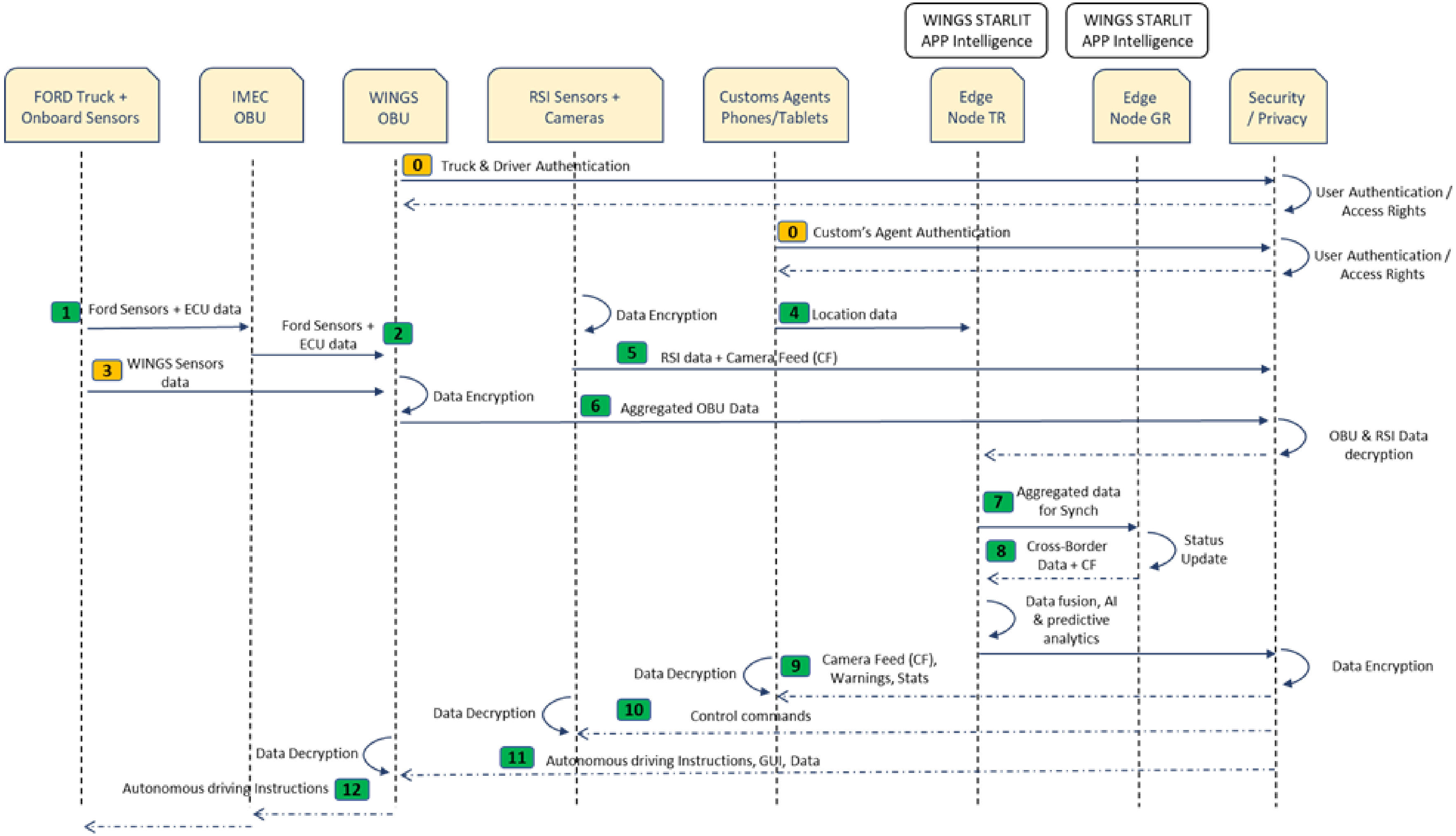


Figure 37: Assisted "zero-touch" border-crossing – Integration & security/privacy oriented UML diagram

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

4.5.2. Truck routing in customs site equipment & sensors

TUBITAK Cloud is located in a secure area and only authorized users can access the building. Cloud tenant's private networks are isolated with different VLANs. There is a firewall located between the cloud and the internet. Openstack Security groups are used tenant's inbound and outbound access as additional security layer. B3LAB Cloud is based on IaaS (infrastructure as a service) model, so tenants are responsible for application and other security. Also whitelisting is required in order to send messages to virtual machines. For this user story OBU and RSUs will be added to whitelist and incoming messages from them to cloud will be forwarded to Truck Routing Application Server. Figure 38 depicts TUBITAK Cloud infrastructure.

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

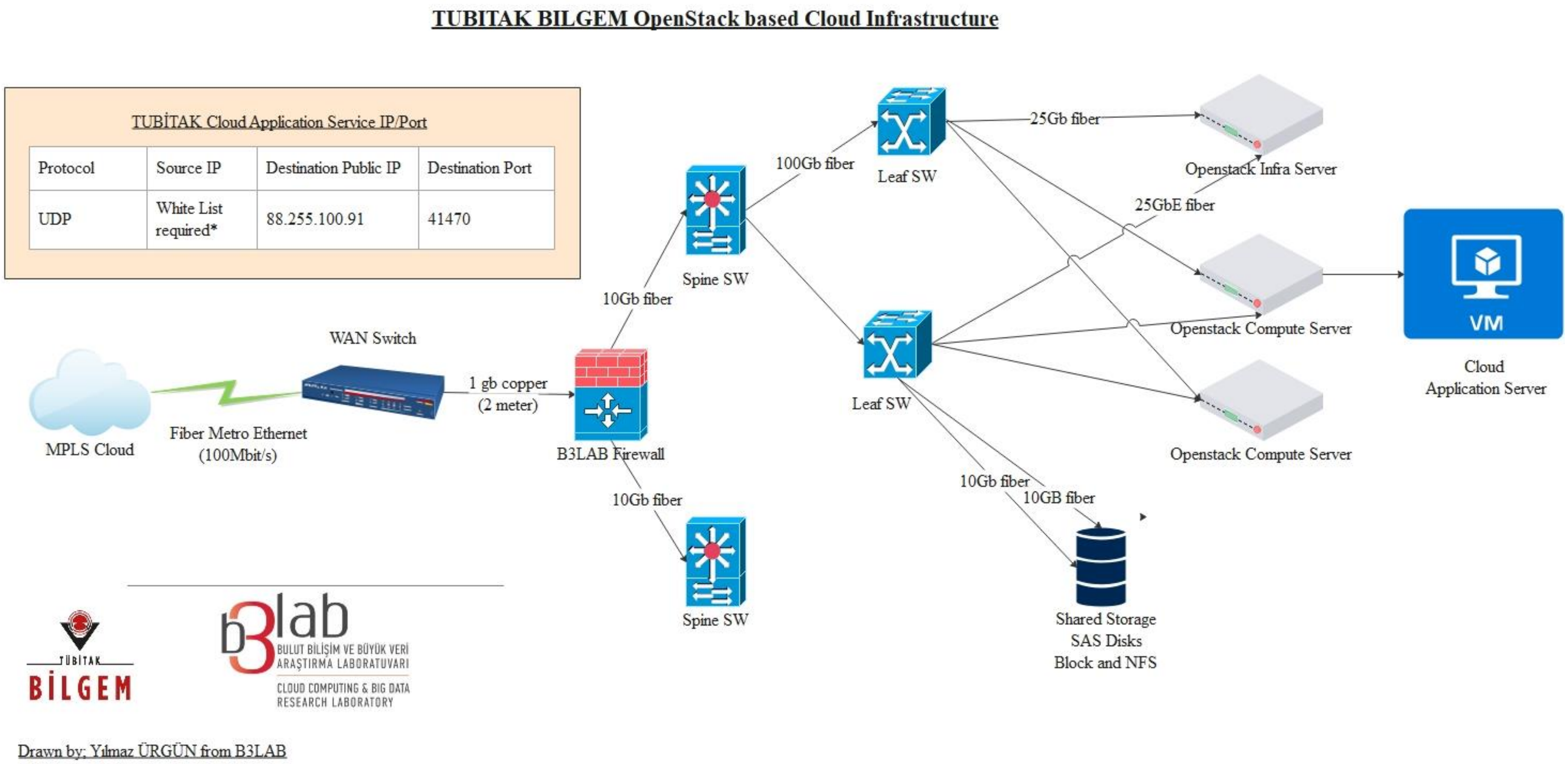


Figure 38: TUBITAK Cloud infrastructure

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

4.6. Early testing results

In this section several test results are presented, done to ensure the good operation of some systems.

4.6.1. WINGS OBU testing

The first version of the WINGS OBU that has been developed was tested over a 5G-NSA testbed provided by Ericsson GR, which is available at COSMOTE premises in Athens. This 5G testbed (which was developed as part of the ICT-17-2018 project 5G-EVE) is identical to the one that is deployed at the GR-TR borders, allowing for accurate testing before taking the implementations to the borders.

The WINGS OBU was brought to the COSMOTE facilities where the 5G testbed resides, in order to test its connectivity and attachment to the 5G network, to troubleshoot any potential issues and to provide a first sense of the performance that can be expected by the 5G Ericsson network in terms of throughput and latency. The achieved performance was also tested over the locally available WiFi connection in order to compare the performance with the 5G network. Figure 39 depicts the WINGS OBU and the Quectel testing board at the COMOSTE facilities where the Ericsson 5G testbed resides, during testing.

More specifically the following early tests took place during the test session at the COSMOTE facilities which took place on the 30th of October 2020:

- OBU connection to the 5G network and confirmation of attachment to the 5G-NSA network (success)
- Confirmation of communication (data exchange) between the WINGS OBU and the WINGS remote server, over the 5G network (success)
- Early performance measurements over the 5G testbed targeting the following KPIs: Throughput, E2E latency (success)
- Performance comparison between the 5G testbed and WiFi, based on the WINGS OBU transmitted data (success)

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

Figure 39: WINGS OBU & testing board under test in COMOSTE premises, Athens

4.6.1.1. Early test performance

After the successful attachment to the Ericsson 5G-NSA testbed a couple of throughput tests were performed in order to observe the achieved throughput. When the 5G SIM card was inserted in a commercial 5G phone available for testing a DL Throughput of 1.2 Gbps was achieved over the 5G testbed. When the 5G SIM card was inserted in the WINGS OBU a max DL throughput of370 Mbps was observed. This is due to the HW restrictions introduced by the Raspberry Pi and its interfaces, which is used as the main CPU of the WINGS OBU. The Raspberry Pi has a HW maximum cap of 400 Mbps on its interfaces, hence the restriction in DL speed originated from the Raspberry Pi, and not the 5G network. Still this is considered a very successful test, as the achieved throughput of 370 Mbps is more than enough for the purpose of the WINGS "Assisted "zero-touch" Truck Border-Crossing" Use case, and much more than the WiFi achieved throughput which was below 100 Mbps. Figure 40 depicts the actual throughput logged by the WINGS OBU during testing.

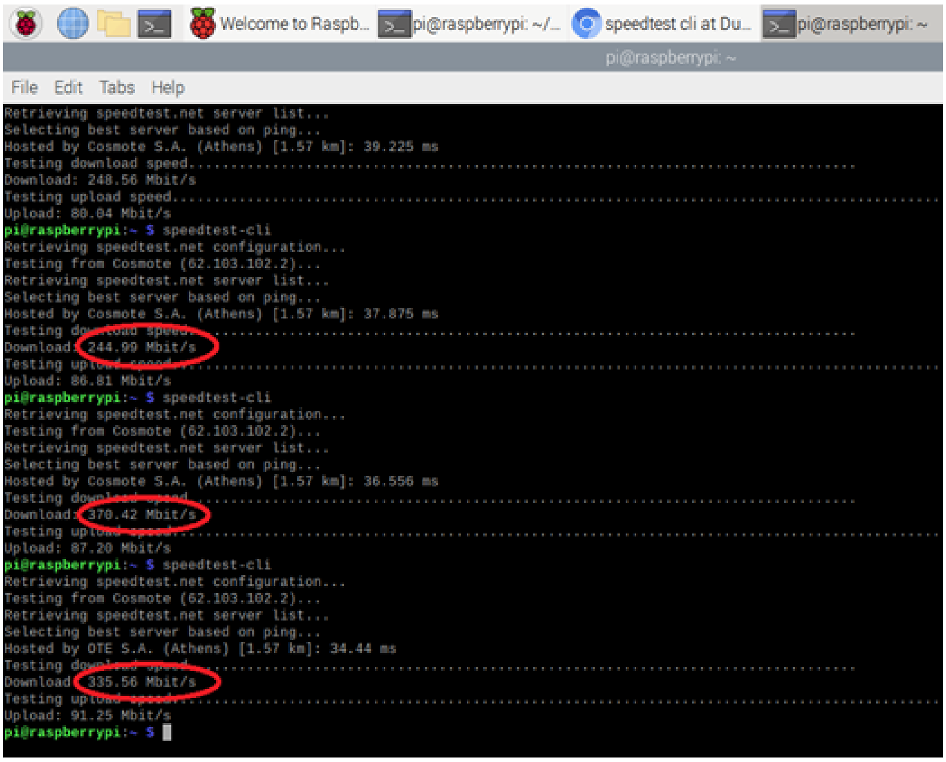


Figure 40: Throughput test via the WINGS OBU

Regarding latency, three different measurement sessions were performed, with transmissions from the WINGS OBU, of the actual data that will be transmitted for the execution of the Assisted Truck Border-Crossing use case. The first two sessions were performed over the 5G network while the 3rdsession was performed over the WiFi network. The detailed measurements for all three sessions are presented in Figure 41 while the average experienced E2E latency per session were:

- Average E2E latency – 1st 5G session = **63.79 ms**
- Average E2E latency – 2nd 5G session = **60.52 ms**
- Average E2E latency – WiFi session = **155.9 ms**

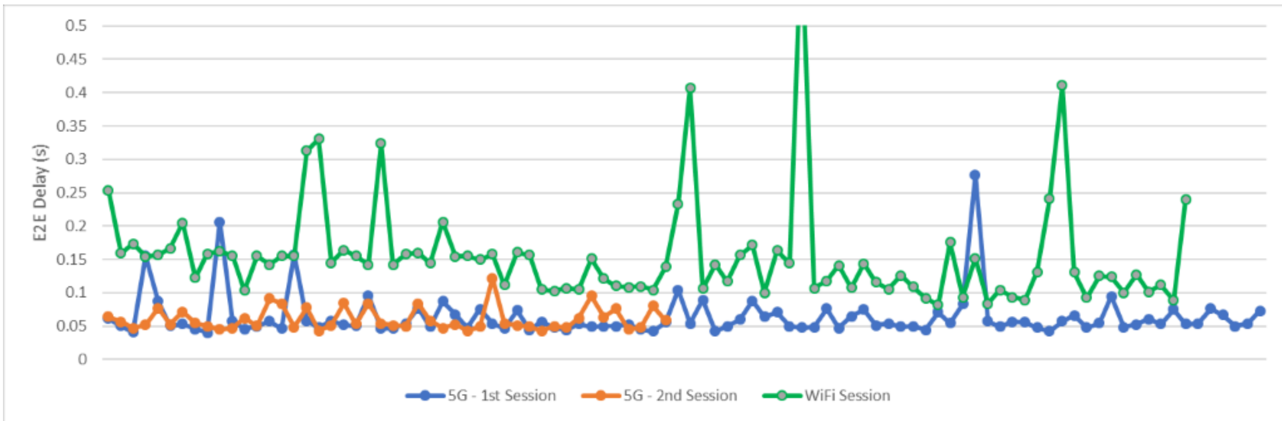


Figure 41: Measured E2E latency of the WINGS OBU transmissions

The reported latency contains the server processing time as well as the round-trip time a transmission from the OBU to the WINGS server and the reception of the relevant ACK and instructions from the server. It is clear that the performance is significantly improved when using the 5G connectivity compared to the WIFi.

The early test session proved very useful, as initially the WINGS OBU could not attach to the Ericsson 5G network. It required intense troubleshooting and a 5G chipset firmware update in order to fix the issues (with support from Quectel). After the necessary updates the WINGS OBU successfully attached to the Ericsson 5G network and performed as reported above. As the 5G network that Ericsson has deployed at the GR-TR follows the exact same specifications and configuration as the 5G testbed located at COSMOTE facilities in Athens (where the test session took place), it is expected that a similar performance of the WINGS OBU will be observed at the GR-TR borders. A more complete testing session will be performed at the Athens based 5G testbed, in order to obtain more useful data and to fine tune the configuration of the WINGS OBU to achieve maximum performance.

4.6.2. IMEC OBU Testing

After completing the assembly of the two OBUs that will be integrated to the FORD trucks, IMEC performed a series of tests in its premises to ensure their expected correct operation. In that direction and as a first step, IMEC firstly tested each component of each OBU individually.

IMEC firstly ensured that each individual component can be remotely accessible and are correctly interconnected through the switch (Phoenix gigabit switch). At the processing unit side (NUC7iDNKE), IMEC installed the Ubuntu 18.04 operating system and all the required software that will be used to further build the necessary functionality for each use case within the GR-TR test site. Then, the GPS module (Navilock NL-8012U) that will be used for time synchronization with the other ITS stations (e.g.OBUs and RSUs) has been tested. Concerning the 4G (Mikrotik wAP LTE kit) and 5G (Quectel RM500Q) modems, the wireless interfaces have been configured and it has been verified that the modems can be connected to the network. Due to the lack of a 5G network in Belgium during the testing period, the 5G modems have been tested only on a 4G network. The 5G connectivity will be tested in FORD's and Turkcell's premisses, when the OBUs arrive in Turkey. Additionally, the 5G modems have been updated to the latest firmware version provided by Quectel. Regarding the C-V2X PC5 modules (Cohda MK6c), they have been updated to the latest firmware version provided by Cohda and they have been configured to communicate with the processing units of the OBUs. Moreover, it has been verified that the integrated GPS of each C-V2X PC5 module works as expected and that it can get a GPS fix. Finally, IMEC tested the correct operation of the short-range wireless communication link over PC5.

Afterwards, the operation of the OBUs as a whole and the end-to-end communication between the two OBUs have been tested and verified (Figure 42). To this end, IMEC used custom testing tools installed in each processing unit to transmit standardized V2X messages between the two OBUs wirelessly via both short-range C-V2X PC5 and long-range C-V2X Uu links. Once again, at this stage for the long-range communication only the 4G link has been tested since a 5G network was not available in Belgium yet. An end-to-end test over 5G will take place in Turkey when the OBUs arrive and become remotely accessible.

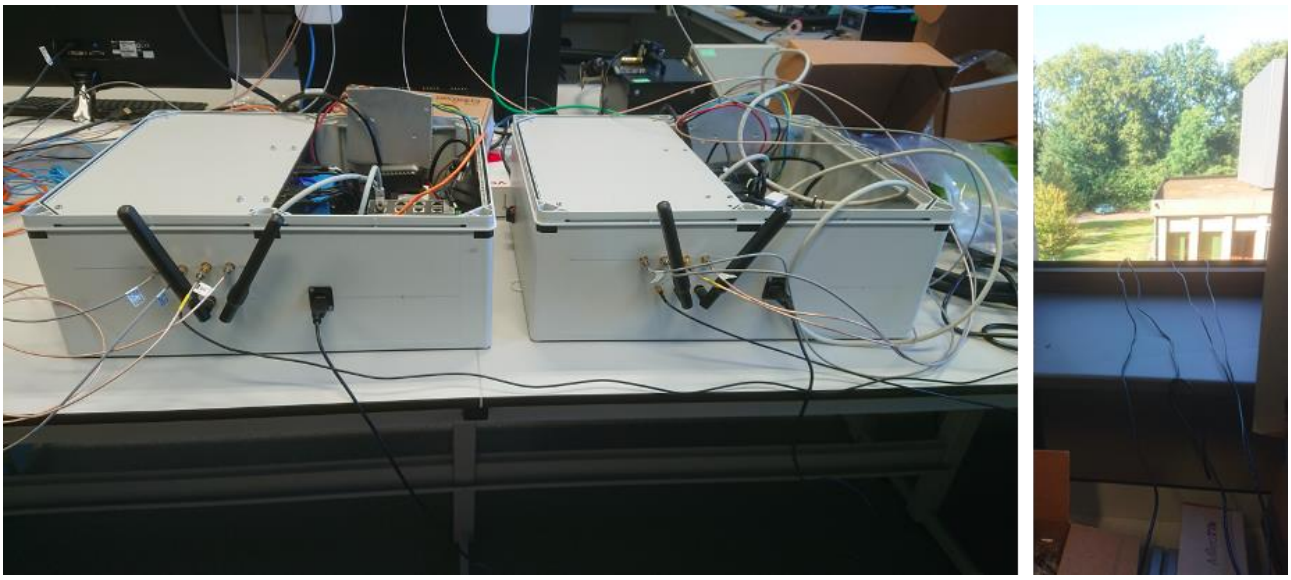
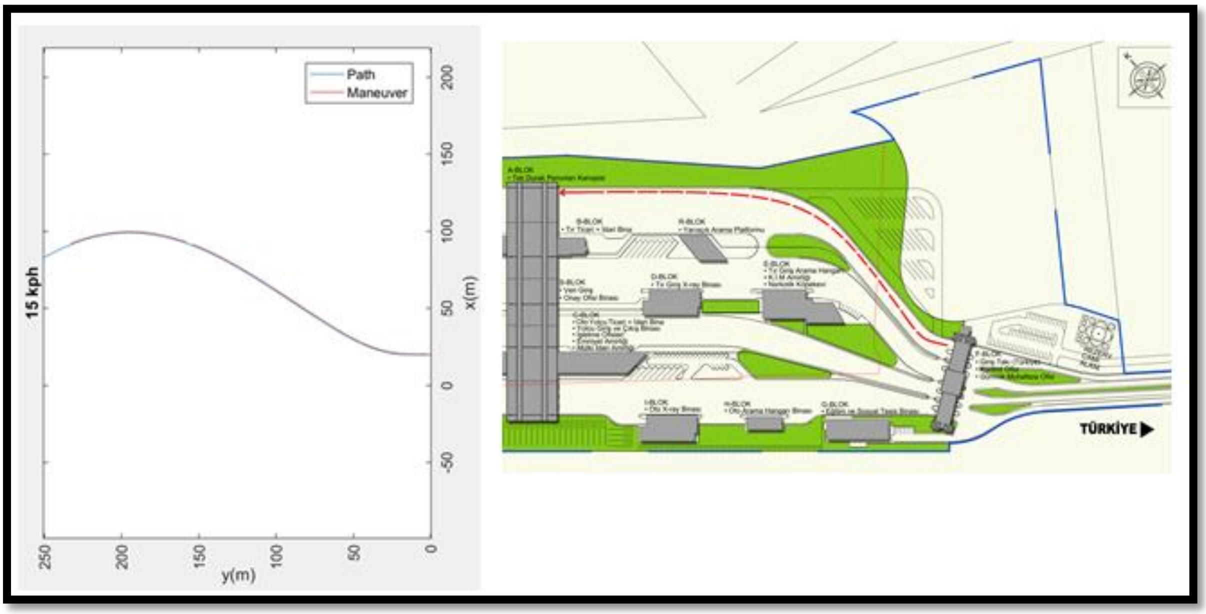


Figure 42: shows the two IMEC OBUs being evaluated and the cables of the GPS devices that are located outdoors

4.6.3. Trunk routing in customs site

Early phase tests of "path following" algorithm that will be used in truck routing in customs site application has been completed. To accomplish this test, path input that normally will come from Tübitak cloud is fed by our Matlab Simulink model and observed whether controller path follow performance. Fed path contains 500 elements and each element contains required x,y coordinates and speed information. Path information will change dynamically in the future according to cloud directives.

Planned path is shown in **¡Error! No se encuentra el origen de la referencia.** on the right side as red marked on Ipsala Border Gate map and actual followed path is shown at the same figure on the left side. Tests were conducted with various speed range between 5 to 25km/h and at the all test cases, path is



followed successfully.

Figure 43: Truck Routing Path Following Test Results

5. TS VEHICLE INTEGRATION

5.1. DE Setup

VICOMTECH will use one prototype of automated vehicle for 5G-MOBIX called CarLOTA, as depicted in Figure 44.

Figure 44: VICOM test vehicle

CarLOTA is a prototype of automated vehicle built from a Toyota Prius platform. CARlota prototype ships the following sub-systems necessary to L4 functionalities of automated driving:

- *The sensing system.* This system uses onboard sensors for perception.
- *Computer Vision-driven perception*. This system integrates collaborative perception, forwards obstacle detection, driver attention and fatigue behaviour monitor, road signs interpretation and lateral and lane detection systems.
- *Vehicle platform*. This system is based on vehicle platform CAN to control the actuators of the vehicle.
- *HMI*. The user can visualize all the perception events identified by the system. The HMI is also able to display the system status to the user for maintenance. Specifically, CarLOTA ships two different HMIs specialized in inside as can be checked in Figure 45 (information displayed over real-time raw sensors) and outside perception (information displayed over navigation maps):

Figure 45: Car inside view & Navigation view

CARlota already ships GPS sensors, processing units, communication interfaces and OBU. Furthermore, in order to ensure a consistent ecosystem with VALEO's vehicles to focus on communication perspectives of Extended Sensors, the main adaptations on setup pivot around these items:

1. Embody VALEO's cameras.

2. Perform Calibration and record geometry setup to facilitate the appropriate and coherent integration of external data flows in the sensor-equipped environment from onboard systems.

3. Expand network interfaces with 5G-ready modems compatible with target bands.

4. Aggregate IoT-based edge-empowered discovery capabilities to get accurate and wider awareness of surrounding sensor flows exploiting.

5. Integrate standard WebRTC stack to RTMaps libraries to allow industry-level workflow.

VALEO will use a VW Passat Variant (B8) modified for sensor technology and ADAS functionality testing. The vehicle is shown in Figure 46.

Figure 46: VALEO test vehicle, B8

In autonomous mode the Valeo Cruise4U system (SAE L2-L4) takes over full longitudinal and lateral control (steering wheel, break, accelerator) as well as indicators, gear shift etc. The car will be driven by a professional test driver who can override the system's execution and take over the control at any time. In manual mode, the driving experience and configuration corresponds to that of a VW Passat production vehicle. Therefore, it is road-legal and insured in Germany. Further details are described in the following sections.

5.1.1. Sensors & devices integration

CARlota vehicle from VICOMTECH has added 4 cameras from VALEO to cover 360º around the vehicle (Figure 47).

Figure 47: VALEO's Camera

In order to appropriately install the cameras a deep calibration setup has been carried out following the instructions, guidelines and methodology created by VALEO.

The following pictures (Figure 48) depict the necessary setup and the markers employed to fully characterise the geometry and alignment of the cameras.

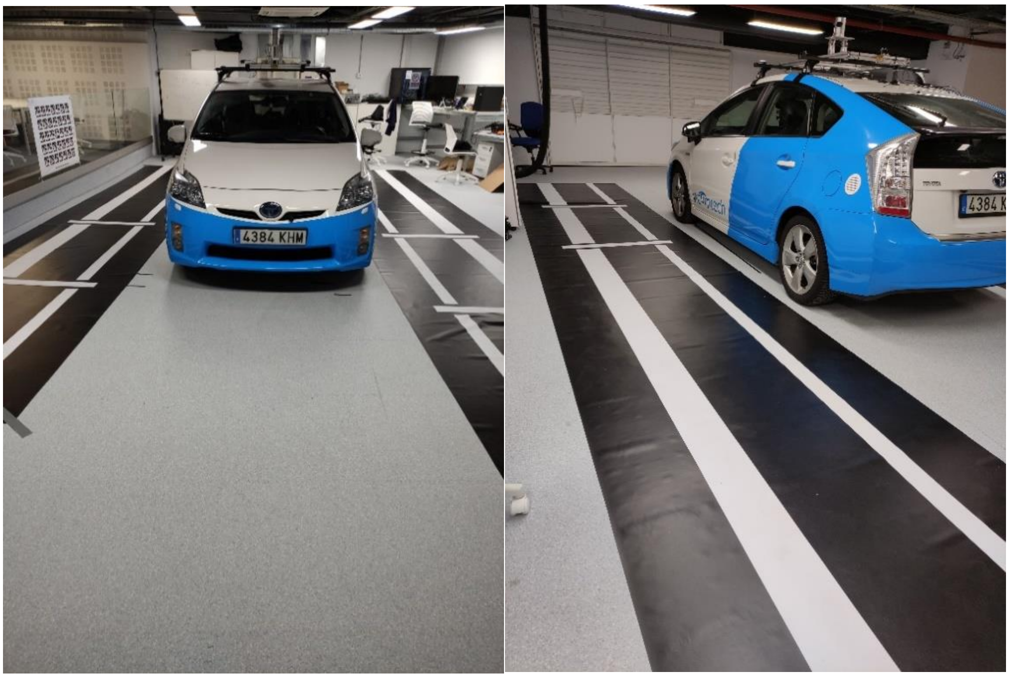


Figure 48: Calibration setup for the cameras

The surround view camera system (Figure 49) consists of four fisheye cameras with large FOV (Field-Of-View): one in the front, one camera at the rear, and two cameras on each of the side mirrors. We also use an additional fisheye camera in the front (see the left photograph) for reference purposes, not related to surround view generation. The cameras have a resolution of 1280x800 pixels and provide images at a

frame rate of 30 Hz.

Figure 49: Surround View camera system on Valeo's VW Passat

In the process of 360° surround view generation, the computer vision algorithms generate a coherent image stitching from the four calibrated fish-eye cameras. The implementation is realized as a RTMaps diagram. The Valeo vehicle is equipped with a NEOUSYS Nuvo-7160GC[10] computer with GPU to provide the required computing power. Each of the surround view cameras is connected to this computer using automotive Ethernet (BroadR Reach). Example frames for the raw images of all four fish-eye cameras are shown in Figure 50

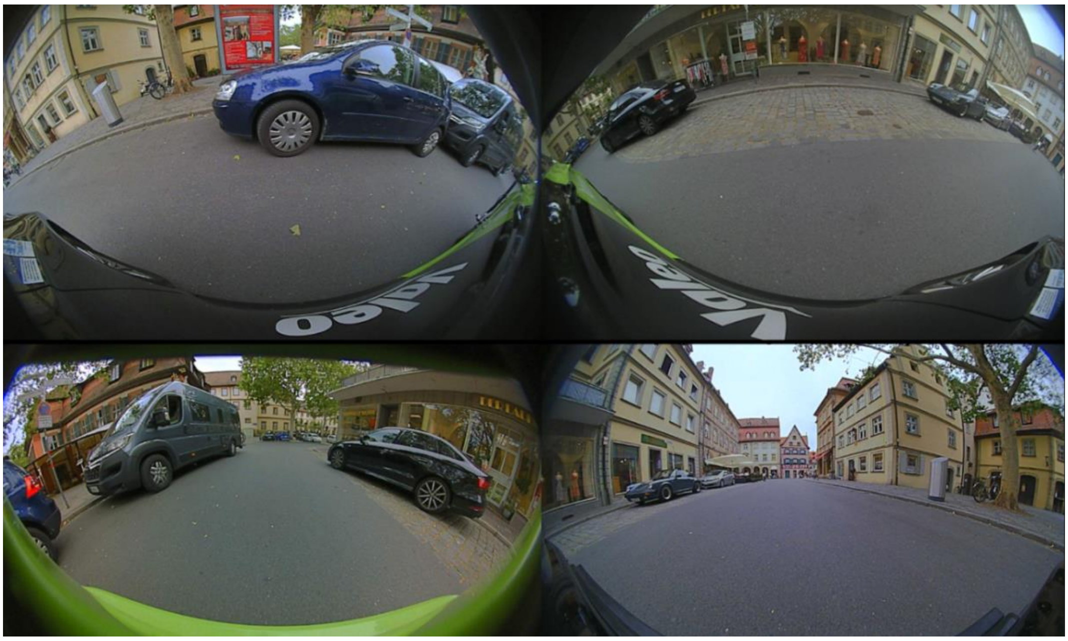


Figure 50: Raw images of fish-eye cameras. From top-left to bottom-right: right, left, rear, and front.

[10] link to NEOSYS website

5.1.2. Automated driving function development

In both vehicles, from VICOMTECH and VALEO, the Automated driving function enhanced is intrinsically linked to the Computer Vision-driven perception and the HMIs, bringing a see-through-like vision to the surround view.

To launch the Discovery Service and automatically perform a surround view with extended sensors creating a video stream session, we have added a manual HMI component.

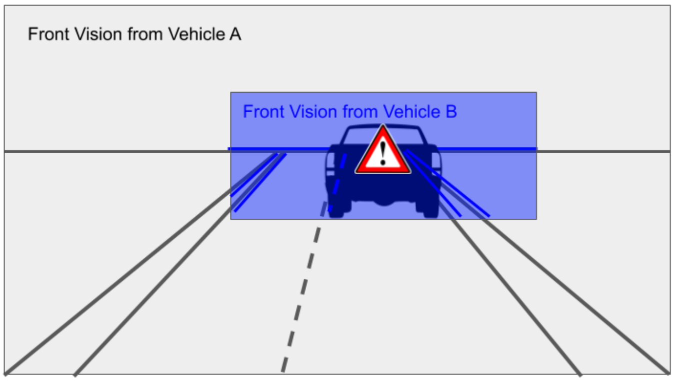


Figure 51: Vehicle's A Line-of-Sight is blocked and extended sensors' data widens the Field of View

Once this situation is identified, the driver can ask for a surround sensor covering the blocked Field of View Figure 51.

Figure 52: Ask for Extended Sensors and monitor Communications status

Once the systems establish a session (Figure 52), the surround view with extended sensors is ready and displayed (Figure 53).

Figure 53: Surround View from VALEO with a recording from San Sebastian

5.1.3. OBU integration

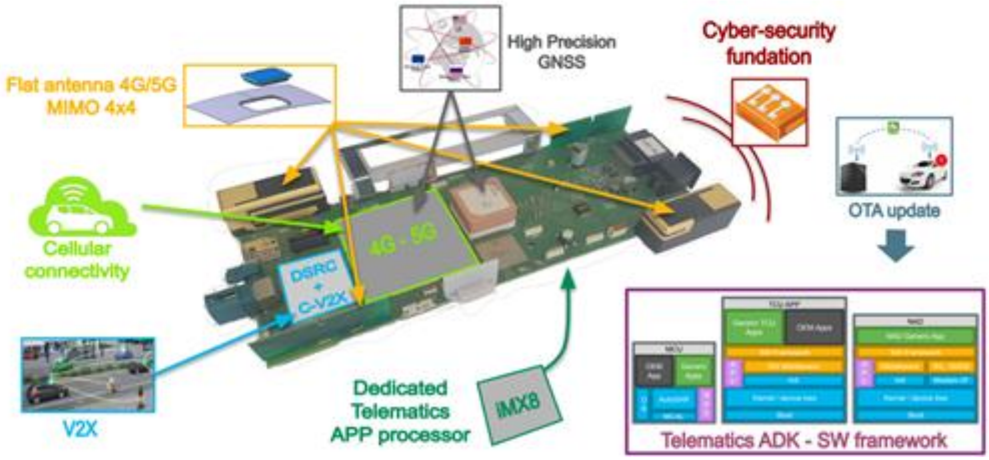


Figure 54: Technologies of Vulcano TCU

The Vulcano 5G modem (Figure 54) is integrated in a Passat Variant (B8) of Valeo. The modem is a trunk variant, which means that the modem itself is located in the trunk of the vehicle, and the minimum of four antennas are mounted on the roof of the vehicle. The connection from the host PC to the TCU can be established via Ethernet or via USB. To use the Modem via Ethernet an additional Technica Media converter is required in between to convert standard Ethernet from the PC to BroadR-Reach of the TCU. If the TCU is connected via USB, it is detected as external modem, which works with USB sharing of the mobile connection. Functions like DSRC may not be possible with this connection. Vulcano 5G in the EU version is able to communicate in the following frequencies:

- 2G: GSM900 / DCS1800. 3G: B1, B3, B8
- 4G FDD: B1, B3, B5, B7, B8, B18, B19, B20, B26, B28, B32. 4G TDD: B34, B38, B39, B40, B41, B42
- 5G (Sub-6GHz): n41, n77, n78, n79

The current version 1 of the peiker Vulcano 5G TCU does not support all required network frequencies in SA/NSA mode to demonstrate national roaming in the DE TS UCCs. The envisioned solution is to piggyback an external modem (Figure 55) to the Vulcano TCU to bridge the connectivity gap. The external modem is equipped with the Quectel modem RG500Q in the version "commercial sample 2". The two modems will monitor the signal strengths in their respective band and coordinate the handover if required.

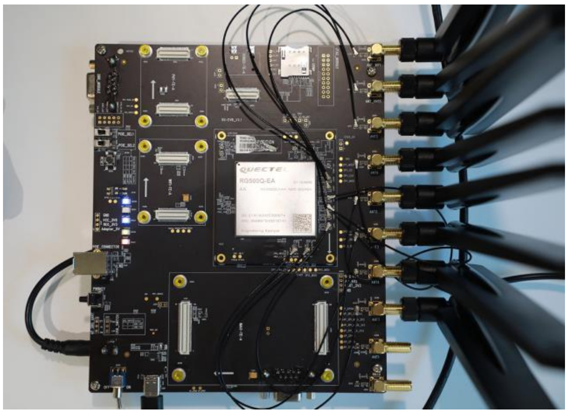


Figure 55: External supplement modem

In Valeo's VW Passat test vehicle, the TCU is mounted along with the data acquisition and processing units in the trunk (black/blue box in below Figure 56). The antenna array is fixed to a rack that is mounted on the vehicles roof.

Figure 56: Integration of the OBU and antenna system on Valeo's VW Passat

CARlota includes two different 5G Modems to the OBU, Quectel RMU500-EK and Quectel RG500Q-EA CS2 which are interfaced and powered though USB cable. The RG500Q-EA CS2 model is fully compatible with the Deutsche Telecom SA band n1 to be used at Berlin with the Quectel RMU500-EK is compatible with commercial NSA n77 and n78. Both would allow a quick national roaming shifting the traffic gateway through one or another modem.

In order to get them working the vendors supplies a driver for Linux and Windows systems. In fact, the drivers for Linux are available from the standard Kernel 5.4.20.

Concerning WebRTC stack, the benefits brought includes:

- Designed for delivering Video and Audio streams and data channels
- The QoS of the streams is monitored and reported
- Secure and private by design including end-to-end encryption with certificates handshake

- Ready to cross NATs and firewalls thanks to ICE protocol
- Performs low-latency with real-time protocols

Furthermore, different systems have been embodied in RTMAPS modules as can be seen in Figure 57, employing specific industry/standard protocols:

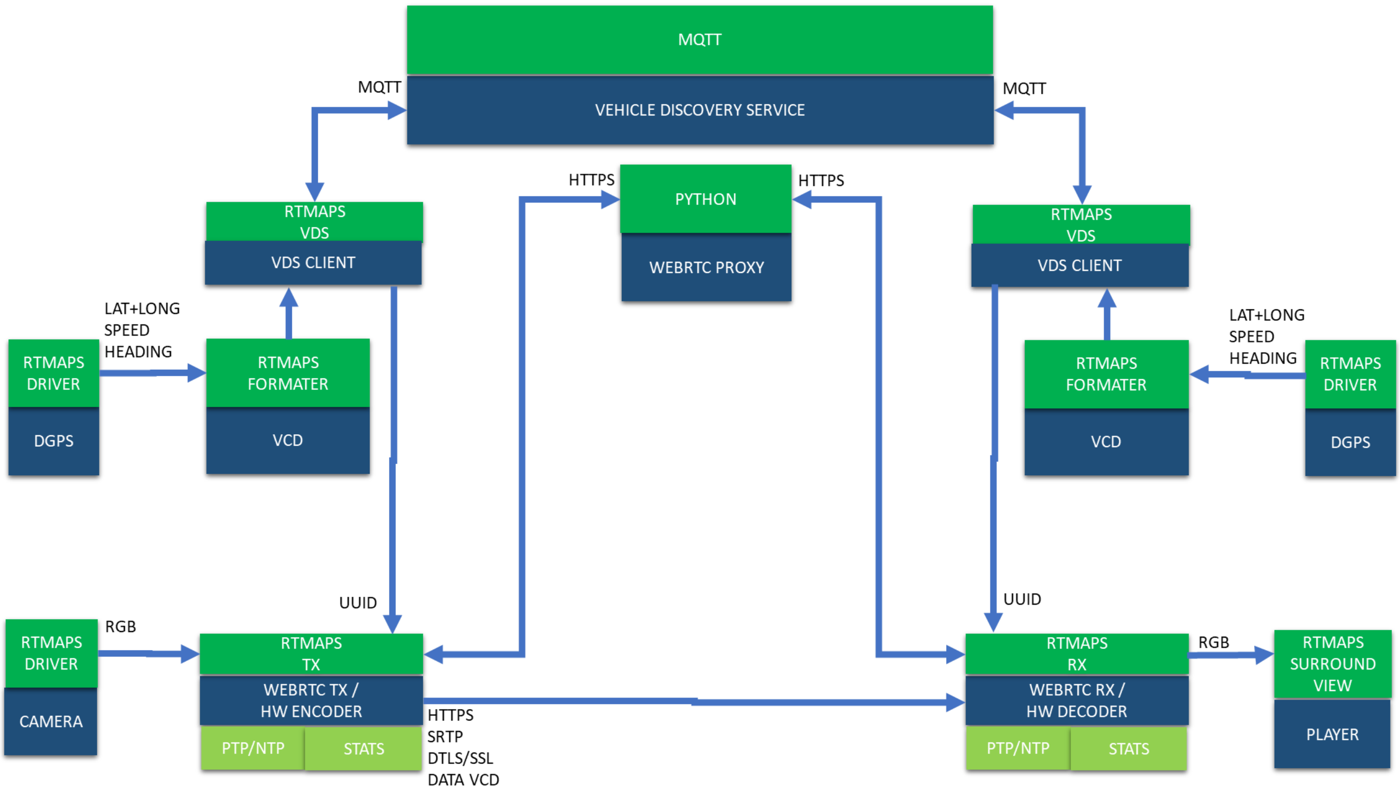


Figure 57: RTMAPS Pipeline in the cars (Transmitter and Receiver) connected to Systems deployed in the Edge

Furthermore, we plan to move from VCD format to standard CPM messages to provide presence and position awareness to Vehicle Discovery Service.

5.1.4. Cyber-security & data privacy

Concerning cyber-security and data-privacy, these aspects have been foundational for the selection of the appropriate technology to deploy and use.

Thus, for the Vehicle Discovery Client a MQTT Mosquitto client using the PAHO library enabling SSL certificate and alternatively using user and password credentials for access control.

Concerning the Sensor streams, WebRTC communications employs HTTPS communications for signalling where TLS is employed for certificates handshake among participants and SSL is employed to encrypt all the communications and data flows. The complete stack is depicted in Figure 58:

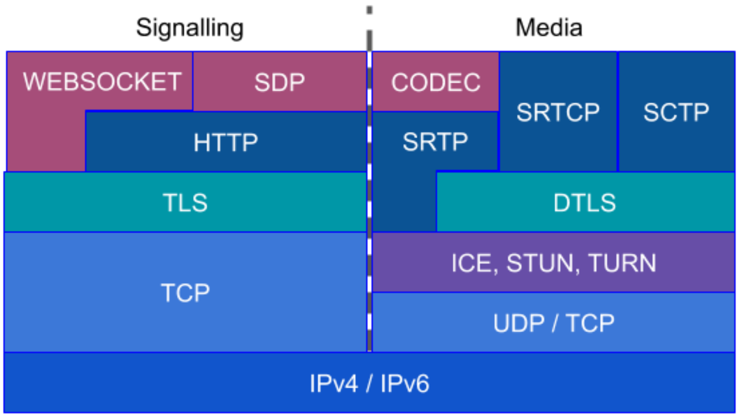


Figure 58: WebRTC communications stack including standard security protocols

5.1.5. Early testing results

Four different tests have been done, where the proximity of the two vehicles/systems participating in the Extended Sensors user story, the MEC distance and the communications technology changes according to the available setup in the experimentation area.

- Zero-distance (=0m): When everything is installed locally, all the network is LAN based and wireless communications impact is zero. This ideal context provides:
  - end-to-end latency under 80ms, mainly from encoding/decoding buffering, encryption/decryption and RTP pipelining
  - start time under 1 sec mainly for the negotiation and handshake
- Local-distance (~20m): Employing 5G testbed from Vicomtech 5GNSA, the MEC at Berlin (~2000km away from both sides). Here the achieved performance is:
  - end to end latency was under 120ms, as just the signalling traffic is gatewayed by the MEC at Berlin

  - start time ~16 secs, as several messages are exchanged and latency is accumulated for a set of messages

- Mid-distance (~200Km): Using commercial networks (Orange and Vodafone), the MEC in the middle (~100Km away from both sides) with an hybrid 5GNSA and LTE. Here the achieved performance is:

  - end to end latency was under 500ms
  - start time ~2 secs, as several messages are exchanged and latency is accumulated for a set of messages

- Long-distance (~2000km): Using commercial networks (Vodafone and Deutsche Telekom), the MEC at Berlin (~2000km away from one side and ~100km away from the peer) with an hybrid 5GNSA and LTE. Here the achieved performance is:

  - end to end latency was under 1s, as all the traffic is gatewayed by the MEC at Berlin
  - start time ~16 secs, as several messages are exchanged and latency is accumulated for a set of messages

The first results also show:

- Unsteady behaviour of Quectel Modem in terms of bandwidth and connection to LTE or 5G NSA.
- A 15fps performance of Surround View for unoptimized RTMAPS SW where HW-acceleration is not employed yet.

5.2. FI Setup

5.2.1. Sensors & devices integration

The FI TS vehicle provided by SENSIBLE4 will be equipped with the following sensors listed in Table 6 and described in D2.4(1)The sensors utilised in the user stories testing are Lidar and (HD) camera. The vehicle is also equipped with other sensors that are utilised in the autonomous driving operations. Their data remains in the vehicle side, and is not transferred to the remote operating centre.**Table 6: FI vehicle equipment**

Type of Sensor	Units	Characteristics	Additional info
Lidar	2	3D lidar	Velodyne VLP-16 360° perception 3D lidar
Camera	2	Colour camera	Front and back cameras
Radar	3	GPR	Bosch GPR 1.0
GNSS	1	GNSSS RTK	
Inertial	2	IMU	
Odometer	4	Wheel odometer	
Steering sensor	2	Steering angle sensor	
PC	1	PC	Navigation PC for data processing
Communication	1	OBU	single-SIM and multi-SIM, both operating in NSA and SA modes

The integration of all sensors is completed. These sensors will be used depending on the user stories' need; mainly HD video camera and LIDAR. Furthermore, the vehicle at SENSIBLE4 is road legal and has been used for demonstrations and testing on open roads in Finland. The vehicle counts with a navigation PC on-board which will be configured to use the 5G multi-SIM OBU for network connection. SENSIBLE4 vehicle is showed in Figure 59.

Figure 59: SENSIBLE4 vehicle

5.2.2. Automated driving function development

To carry out the trials for the FI TS user stories, the automated driving functions have been adapted according to the illustrations below.

5.2.2.1. 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 60.

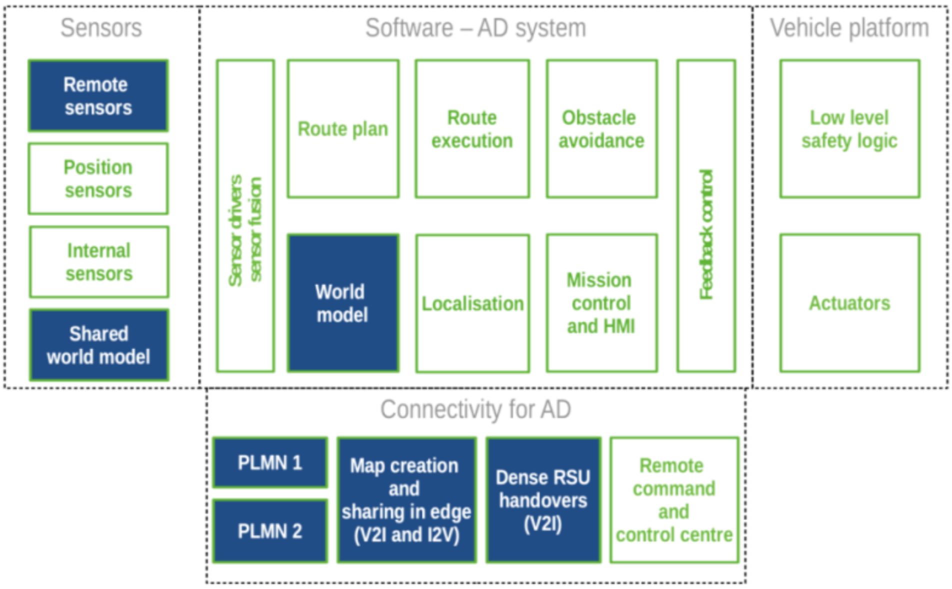


Figure 60: Automated driving functions overview US#1

5.2.2.2. User Story #2: Remote driving

Remote driving is a demanding task for connectivity. The situational awareness of a multitude of sensors needs to be transferred to the remote operating centre (ROC). The remote operator needs situational sensor data updates from the vehicle to be brought in quickly, despite even long periods of inactivity. Then, control commands need to be sent swiftly from the ROC to the vehicle. 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 Figure 61 shows the adaptions of the AD system SW to utilize the benefits of 5G communication.

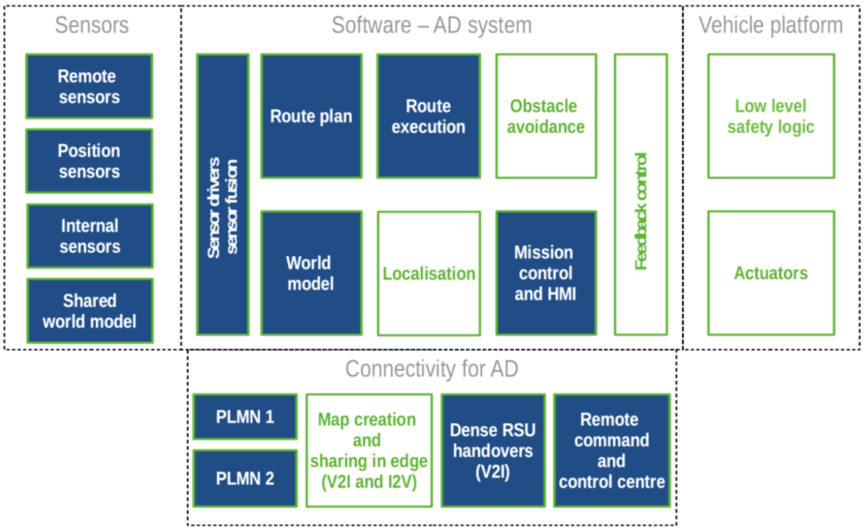


Figure 61: Automated driving functions overview US #2

The Remote command and control centre (RCC) module currently show both camera feeds from the vehicle, as well as car sensor data (GPS position). These feeds are transferred from the vehicle to Remote Control Server via 4G/5G (OBU, base stations), which is then connected to Remote Control Centre where Remote Operator can view the feeds and provide commands to the vehicle. The goal is also to increase the data feed sources to increase the situational awareness of the remote operator.

5.2.3. Cyber-security & data privacy

Data privacy will be covered at the AALTO Data Centre which follows GDPR guidelines.

On cyber-security at the vehicle side, the communication between ROC and vehicles are done inside a VPN. All the communication inside the VPN is encrypted. To get access to the VPN the client needs a signed by a Certificate Authority (CA). The signing is done by Sensible 4 and keys are given to the needed clients. The key allows one client to connect the VPN and have one static IP on the network. In case of a key get breached, the current key can be easily excluded. All client-to-client communication is forbidden inside the VPN, so all the communication must be coming through the ROC (which acts as a VPN server). Also, all the communication to the public IP of the ROC is blocked by a firewall, which allows only establishing the VPN connection to it. To avoid direct connection to the vehicles, they do not have a static public IP and all the communication should come from inside the VPN. Also, all the direct connection from public IP has been blocked out

5.2.4. Early testing results

The Quectel modems (5GRM500Q) were able to successfully connect to the 5G AALTO testbed (Figure 62), both in NSA and SA modes. The following are the steps:

- Install Quectel drivers in Linux to be able to access the Quectel modems using AT commands.
- Configure the Quectel modems to initiate PDU session (IP based) and setup connection with gNB in SA mode.
- Basic connectivity tested, i.e. ICMP messages were successful.

Figure 62: Early testing of Quectel modems.

In addition, the FI site will utilize 2 multi-SIM OBUs, operating in NSA and SA mode (SA upgrade by Q1 2021). This is one of the CBC contributions by the FI TS. This multi-SIM OBU is based on SIERRA modems (EM9191). The OBU can operate in both simultaneous (connected to 2 PLMNs) or selective modes (selecting 1 PLMN at the time). Below, in Figure 63, the multi-SIM OBU and modem used.

Figure 63: The FI 5G multi-SIM OBU (router and modem).

5.3. NL Setup

5.3.1. Sensors & devices integration

To carry out the User Stories testing and trialling, the NL TS vehicles are being equipped by the following sensors, as can be seen in Table 7. Three vehicles are developed in NL TS and used in different user stories:

Table 7: Vehicles used in NL TS for different user stories and vehicles, Connected Vehicle (CV) and Connected Autonomous Vehicles (CAV)

User Story		TNO	SISSBV	TU/e-AIIM	VTT
	Type of vehicle:	CV	CAV	CAV	CAV
Extended Sensors		x (lead) – *no additional sensors*	x		
Remote Driving			x	X (lead)	
Advanced Driving (CoCA)				x - no additional sensors	x (lead) no additional sensors

The TNO vehicle is a Connected Vehicle (CV) only, so it is equipped with additional communication (and no automated driving functions). Therefore, it will not be described in this section 5.1.3 further.

5.3.1.1. TU/e-AIIM vehicle

TU/e provides and uses one automated vehicle and uses this in 2 user stories: Remote Driving and Advanced Driving (CoCA user story, led by VTT). The vehicle is a 2018 Prius PHV (Figure 64), which is equipped with sensors, connectivity and hardware to support CCAM functionalities.

Figure 64: Sensor setup of TU/e-AIIM vehicle during January 2020 KPN 5G FieldLab event in Helmond, The Netherlands, demonstrating the Remote Driving user story

This vehicle is currently being built and will be based on a previous research vehicle (which was based on a Toyota Prius 2010 model, like 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 8:

Table 8: Sensors and HW platforms overview of TU/e vehicle for use in Remote Driving and Advanced Driving User Stories

Sensor	Number	Type	Car position	Horizontal field of view	Vertical field of view	Range
3D LIDAR	1	Ouster	Roof	360°	40°	~ 150m
Remote Driving cameras	4	Mono-camera	Roof	120°	-	~40 m (ped.)
RTK-GPS (incl. FOG-IMU)	1	Advanced Navigation	Trunk	-	-	-
Communication unit	1	5G modem (KPN)	Trunk	-	-	-
Ethernet switch	1	10Gbit	Trunk	-	-	-
Computing units	2	- nVIDIA DrivePX2 - carPC	Trunk	-	-	-

For the 5G-MOBIX Remote Driving user story, the vehicle has been extended with a 360° camera set-up. Currently it is further extended with mmWave antennas for the 5G positioning tests.

The integration of these sensors is done with the collaboration of the connectivity and vehicle automation teams in order to offer the required interfaces to let all these sensors communicate with the 5G-OBU. As these vehicles have been already used for demonstrations in other projects, all sensors are already in place in the vehicles. Interfaces with the 5G-OBU and the internal PC are also defined in order to provide a harmonize the data format and facilitate integration. This communication interface is now validated and tested.

5.3.1.2. SISSBV vehicle

Siemens provides one connected automated vehicle for user stories Remote Driving and Extended sensors. This vehicle is a Toyota Prius (model XW30), shown it in Figure 65, which has been altered to fit the requirements for automated and connected driving. The Prius is used as a research and development platform for automated driving technology within Siemens. While the vehicle is outfitted with numerous equipment, only a subset is used for the 5G-Mobix user stories. The following Table 9 states the equipment that will be used in the vehicle for 5G-Mobix:

Table 9: Sensors and HW platforms overview of the Siemens vehicle for use in Remote Driving and Extended Sensor User Stories

Sensor	Number	Type	Car position	Horizontal field of view	Vertical field of view	Range
Remote Driving cameras	4	Mono-camera	Roof	120°	-	~40 m (ped.)
GPS (incl IMU and RTK)	1	– Ublox Lane Accurate Navigation – NTRIP receiver	Trunk	-	-	-
Communication unit	1	– 5G modem (KPN) – Cohda MK5	Trunk	-	-	-
Hardware						
Ethernet switch	1	Gigabit	Trunk	-	-	-
HMI	1	Touchscreen	Dashboard	-	-	-
Computing units	2	- NVIDIA DrivePX2 - Custom PC	Trunk	-	-	-
CAN Router	1	CAN bus router	Trunk	-	-	-

All equipment listed is used to enable the connected driving with 5G-OBU. The Custom PC provides the interfaces for logging and facilitates any data stream from other sensors.

Figure 65: Sensor setup of the Siemens vehicle during January 2020 KPN 5G FieldLab event in Helmond, The Netherlands, demonstrating the Remote Driving user story

5.3.1.3. *VTT vehicle*

The Automated Vehicles team has a set of research prototype vehicles. For the 5G-MOBIX trials the Martti vehicle, which is a VW Touareg which has been modified for automated driving, is used. The vehicle is equipped with a set of environmental perception sensors, such as radar and laser scanners (Table 10). The vehicle architecture is based on DDS (Data Distribution Service), through which the data of the sensors and the information received through 5G is made available to the other vehicle modules, such as trajectory planning and actuator activation. The 5G-MOBIX project uses the set of sensors, which have previously been integrated in the vehicle.

Table 10: 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	1	• dynniq V2X	• Trunk			

Communication		ITS G5				
GNSS	1	• ublox RTK-GPS	• Trunk			
Inertia	1	• IMU	• Roof			
Antennas	4	• GNSS Receivers	• Roof			

Additionally, a research connected motorcycle "Jarno", a modified KTM motorcycle, which is equipped with 5G OBU, will be used for testing the CoCa user story in Tampere. In the following Figure 66 can be checked and overview of the two VTT vehicles

Figure 66: VTT research prototype vehicles Martti and motorcycle Jarno

5.3.2. Automated driving function development

In NL Trial site, the 3 CAV are being set up as described in section 5.1.3. The motorcycle "Jarno" is a CV and for this reason is not include in current section.

5.3.2.1. TU/e-AIIM vehicle

The TU/e vehicle is being used in the Remote Driving & Advanced Driving user stories on NL site Use Case. The Remote Driving User Story focuses on the function to stream video data from the vehicle to a remote station. Additionally, this vehicle will also be used, for testing 5G mmWave localisation. Since this was a new vehicle only parts of the former TU/e test platform (Prius 2010) could be exchanged to this new platform. Some parts were completely redesigned, especially the low-level safety for remote control, and the sensor setup rooftop. This change in rooftop design, provides a more flexible set-up for environmental perception sensor testing and antenna integration and can change and be extended. In the architecture this reflected that the function localisation, sensor fusion, obstacle qualification and filtering and world model had to be adapted.

By adding a 5G NR enabled mmWave localization, the sensor fusion module and world model is being updated now (not yet finished to enable the 5G localisation function. Since the video stream and the localisation function operate on different 5G bands, two separate modules are integrated to support this. Currently the module for remote driving is integrated, the module for localization is still in development. In Figure 67 is shown the AD function development to support remote driving User Story.

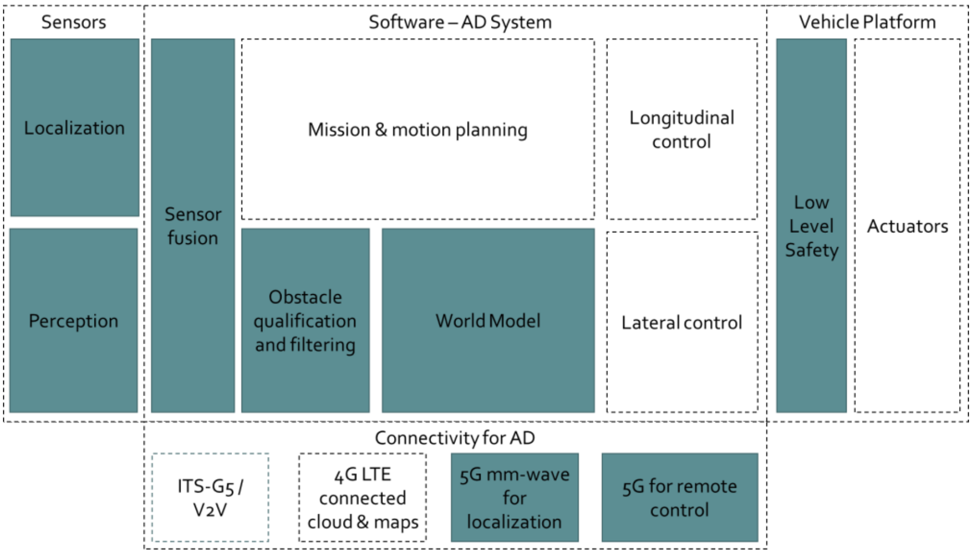


Figure 67: TU/e vehicle AD function development to support Remote Driving User Story

5.3.2.2. SISSBV vehicle

The Siemens vehicle uses a similar set-up as the TU/e-AIIM (sub-section 5.3.2.1) and therefore similar function had to be adapted for the SISSBV vehicle in the remote driving user story, mainly focusing on Perception, 5G for remote control and low-level safety.

5.3.2.3. VTT vehicle

The VTT research prototype vehicle Martti is used for the Cooperative Collision Avoidance (CoCA) User Story. CoCA uses the Manoeuvre Coordination Service (MCS) for negotiation between the vehicle and infrastructure.
The following adaptations were made to the vehicle software:

- MCS (Maneuver Coordination Service): generation of planned (collision-free) trajectory and desired (intended manoeuvre) trajectory, and interpretation of the message
- Sensor fusion: fusion of the sensor own data and the information coming from MCS from other vehicles
- Obstacle qualification and world model: integration of the information from MCS
- Mission and motion planning: evaluation of the advices and maneuver suggestions from other vehicles. Selection between planned and desired trajectory.

An overview of modified modules is shown in Figure 68.

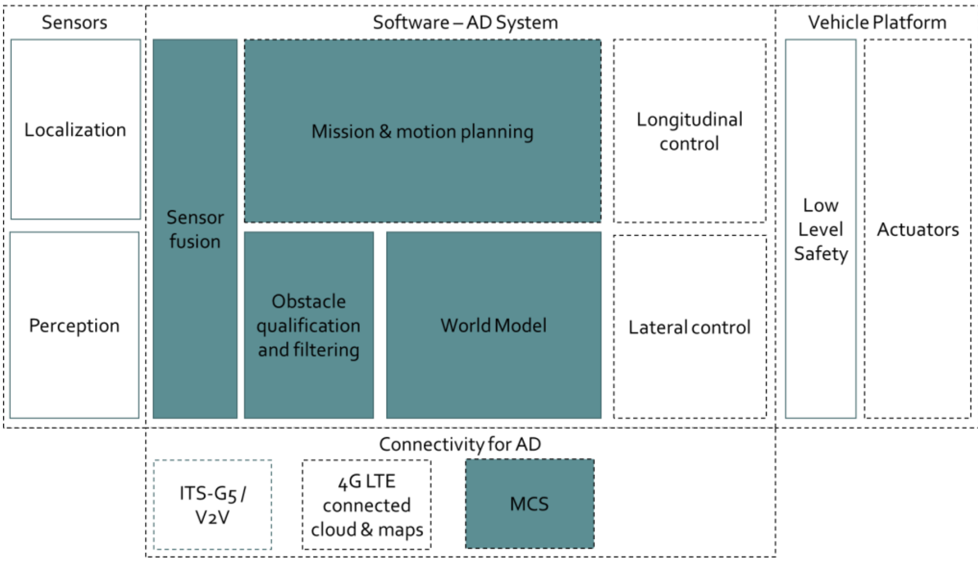


Figure 68: VTT vehicle AD function development to support CoCA User Story

5.3.3. OBU integration

In NL Trial Site, TNO is actively working on developing a 5G based OBU. Other partners use KPN provided 5G modems to integrate into their vehicle compute modules.

5.3.3.1. TNO 5G OBU

TNO has developed an OBU with integrated 5G capabilities. This OBU will be placed in TNO's vehicle alongside with a smartphone for HMI functionalities, see Figure 69:

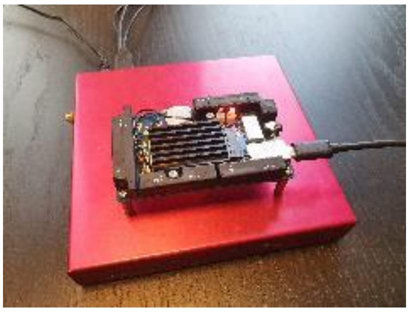


Figure 69: TNO 5G OBU

The OBU's internal 5G modem is based on the SDX55 (LE1.2 Baseline) chipset from Qualcomm. The OBU hosts an ITS software stack which will be used to support the Extended Sensors use case, this stack will be coupled with a smartphone, over WiFi, which will function as an HMI for the driver. The stack supports sending CAM messages as well as generating merging advices for the driver/CAD vehicle based on the combination of incoming CPM and CAM messages

5.3.3.2. TU/e-AIIM vehicle & SISSBV

In the TU/e-AIIM vehicle as well as the SISSBV vehicle, the main vehicle PC is connected to the CAN-bus of the vehicles for data from the vehicle ECU. Both vehicles use a DrivePX2 with 4 cameras for the remote driving functionality, which in its turn is connected using UDP to the vehicle PC.

For the remote driving function, TU/e-AIIM and SISSBV vehicles both use a KPN provided 5G modem from Ericsson, see Figure 70:

Figure 70: (left) TU/e-AIIM vehicle showing integrated OBU with 5G modem; (right) SISSBV vehicle showing integrated OBU with 5G modem.

For the Advanced Driving user storey, VTT is developing a 5G based OBU that will be integrated with the TU/e-AIIM vehicle (see sub-section 0)

For the 5G positioning using mmWave, TU/e is developing its own OBU for testing on the TU/e network.

In all cases, a 10Gbit Ethernet switch is integrated into the TU/e-AIIM vehicle for integration with each of the communication modules. These can and will be interchanged between tests, in order to prevent any unintended interference on antenna frequencies or on power supply during testing.

5.3.3.3. *VTT vehicle*

The VTT OBU consists of a PC, connected to a 5G modem. The OBU, integrated in the vehicle, is shown in Figure 71. VTT has developed also a version of the on-board unit, which will be placed in other vehicles during the 5G-MOBIX tests, such as TU/e connected vehicle for CoCA tests in Helmond, VTT's motorcycle in Tampere and in CTAG's vehicles for the Cross-border contribution of the Dutch test site (overtaking maneuver with MCS).

The on-board unit uses a 5G-modem from Huawei in Tampere, which will be replaced with Ericsson modem for the tests in Helmond, and has additional a GNSS receiver, and is connected to a PC. Both the 5G modem and the PC get power from the vehicle's auxiliary power outlet.

The on-board unit will transmit and receive MCM (Maneuver Coordination Messages). Trajectories are calculated based on previous recorded vehicle paths. Potential warnings are shown on the PC display.

Figure 71: VTT OBU integrated in the trunk of the prototype vehicle Martti

5.3.4. Cyber-security & data privacy

The information exchange between all actors in this UC is secured to ensure it integrity. In case of the Remote Driving user story, security is ensured by the use of certificates: both the remote stations (both of TU/e and SISSBV's) as well as both vehicles (also TU/e-AIIM and SISSBV) use certificates and are required to connect to a central gateway. The remote driver at the remote station logs in using user name and password and selects which vehicle to connect to. Once the connection is made, the video stream and control commands are directly linked between remote station and vehicle, ensuring a direct link and minimizing security risks.

5.3.5. Early testing results

For the remote driving user story, early tests took place in January 2020, testing both the SISSBV and TU/e remote station and SISSBV and TU/e vehicle on the KPN network and showcasing this in a demo during the KPN 5G FieldLab event in Helmond. During the PO review on 3 December, KPN, TU/e, SISSBV, AIIM and associate partner Roboauto, showed a working demo, using 1 remote station and 2 vehicles over the KPN 5G SA network, proving the remote driving function to be working as expected and integration of the OBU in the vehicles to be ready. A video recording can be found on the 5G-MOBIX website[11], showing the results. See also Figure 72(upper left: SISSBV vehicle (inside), upper right: TU/e-AIIM vehicle (inside, being remotely driven); lower left: TU/e-AIIM vehicle (outside); lower right: SISSBV remote station):

Figure 72: Screenshot of TU/e-AIIM and SISSBV vehicles remotely driven over KPN 5G SA network during PO review 3 December 2020

[11] https://5g-mobix.com/hub/5g-mobix-demo-remote-driving

5.4. FR Setup

5.4.1. Sensors & devices integration

To carry out the user stories testing and trialling, the FR TS vehicle will be equipped by the following sensors (Table 11), as described in D2.4 (2)

Table 11: Overview devices integrate in FR 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	VEDECOM OBUS (SIMcom shipset) VALEO OBU	5G -OBU
Ethernet switch	1		
PC	3	1 Nexcom 1 Nexcom 1 dSPACE	PC Camera Perception PC

The vehicle integration is completed and is done with the collaboration of the connectivity and vehicle automation teams in order to offer the required interfaces to let all these sensors communicate with the 5G-OBU. Interfaces with the 5G-OBU and the internal PC are also defined in order to provide a harmonized data format and to facilitate integration. This communication interface is now validated and tested. In the Figure 73 and Figure 74 below, we depict the sensors integration architecture inside the Zoe vehicle.

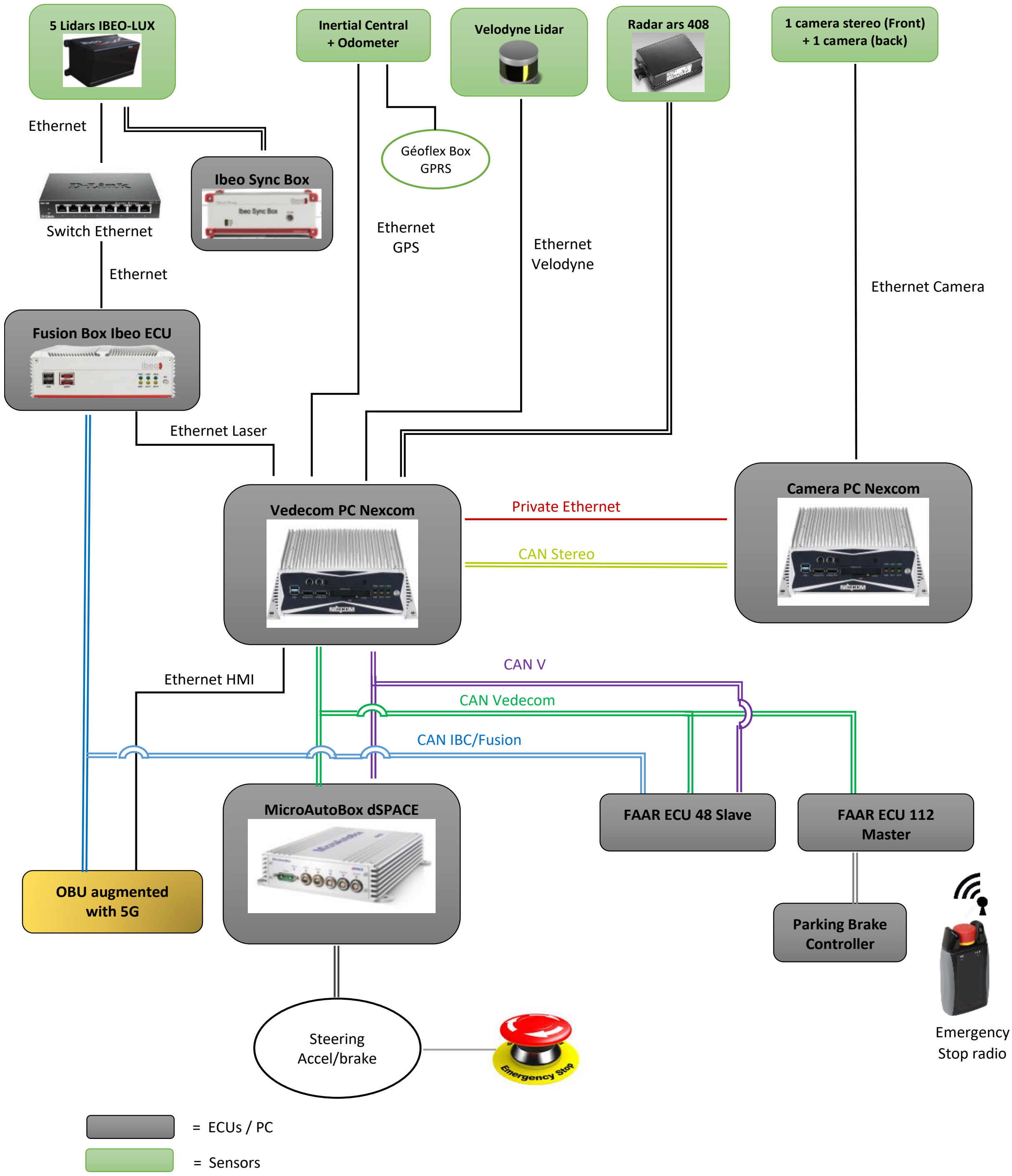


Figure 73: FR TS Vehicle Zoe: Sensors integration

Figure 74: distribution of the devices in the vehicle

5.4.2. Automated driving function development

To carry out the trials for the user story infrastructure-assisted advanced driving, automated driving functions had to be adapted to support the introduction of 5G technology and also the information that will come from the infrastructure to extend its perception or also requesting advanced manoeuvre.

To this end, the module related to lateral path planning is adapted to be able to receive requests for lane change manoeuvre from an external entity (infrastructure) and execute the command if possible, taking into account its own environment of perception.

Another module was introduced which will offer the connection with the 5G-OBU; this module is an evolution of the 4G module already in place. This module will offer the required interfaces and APIs to communicate with the 5G-OBU.

An overview of AD modules can be consulted in Figure 75.

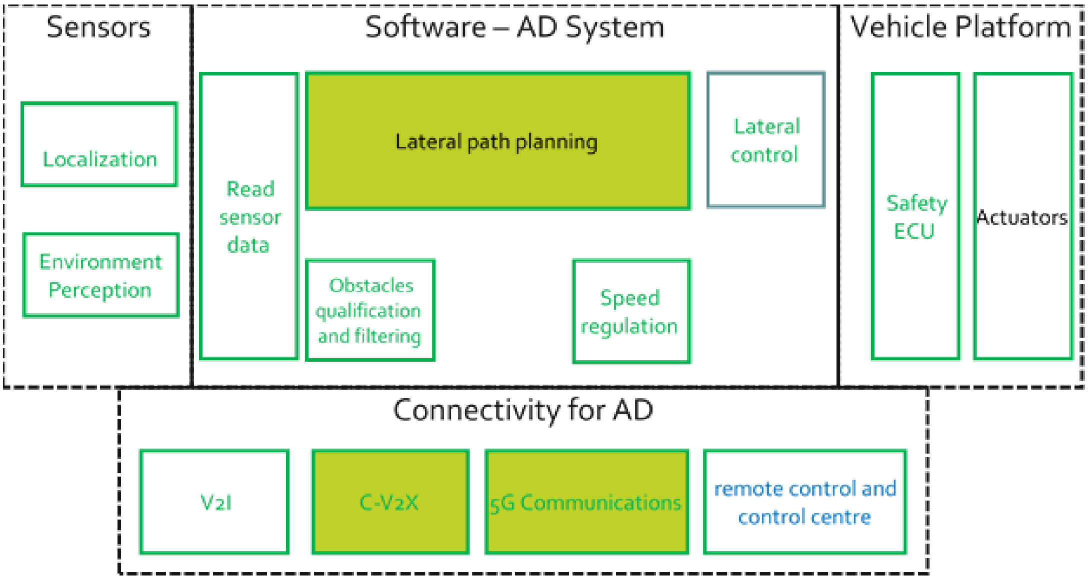


Figure 75: Automated driving functions overview

5.4.3. OBU integration

5.4.3.1. FR communication unit set up

FR TS will use 2 types of OBUs:

- VEDECOM made 5G OBUs: based on SimCOM modems. These 2 OBUs are ready already tested with 5G network of Bouygues.
- 3x VALEO 5G OBUs: based on Qualcomm chipsets. These OBUs are still on the delivery process and not yet received by the FR TS.

The 2 5G modems (SimCom8200), presented in Figure 76, allow the communication box to be attached at 2 different MNO at once and to be connected on the best vector of communication.

The SIM8200-M2 series is the Multi-Band 5G NR/LTE-FDD/LTE-TDD/HSPA+ module which supports R15 5G NSA/SA up to 4Gbps data transfer. It has strong extension capability with rich interfaces including UART, PCIe, USB3.1, GPIO etc. The module provides much flexibility and ease of integration for customer's application.

The SIM8200-M2 series adopts M.2 form factor, TYPE 3052-S3-B. AT commands of SIM8200-M2 series are compatible with SIM7912G/SIM8300G-M2 series modules. This also minimizes the investments of customers and enables a short time-to-market.

It is designed for applications that need high throughput data communication in a variety of radio propagation conditions. Due to the unique combination of performance, security and flexibility, this module is ideally suited for many applications.

Figure 76: SIM8200-M2 5G modem

In the following Figure 77, we highlight the use of M.2 to mPCIe adapter in order to connect the 5G modem to the OBU board.

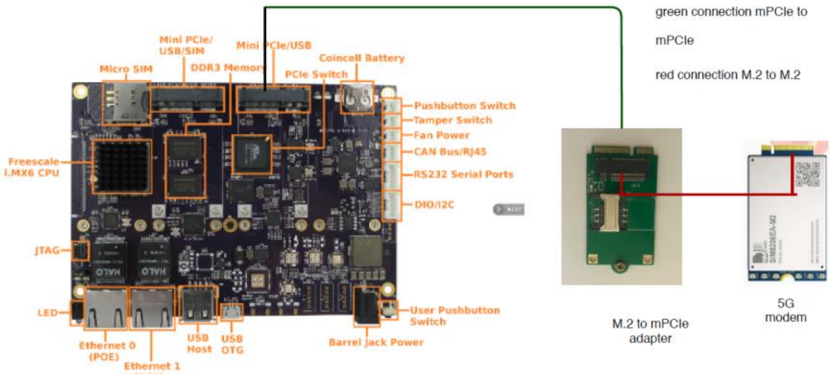


Figure 77: SimCOM 8200 connection to the board using M.2 to mPCIe adpater

5.4.3.2. 5G OBU Board

One of the gigabit Ethernet interfaces will be used to connect to the Pepwave device which will handle the intelligent routing. This device will monitor all means of communication and will decide for the handover between technologies like 5G to 5G or 5G to satellite. The other Gigabit Ethernet port will be connected to the internal PC which will be in charge of handling the sensors in the vehicle.

In the following Table 12, we describe the different components on the 5G-BOX at its current phase, including the 4G, 5G and 11 p technologies.

Table 12: Components on the 5G BOX

Technology	Driver modification	Kernel modification	Recognized on the OBU	Connectivity	Tests
4G	Yes	Yes	Yes	Yes	done
5G (1st modem)	Yes	Yes	Yes	Yes	done
5G (2nd modem)	Yes	Yes	Yes	Yes	To start
11p	Yes	Yes	Yes	Yes	done

The Figure 78, highlights the different components of the board. The components are the following:

- (1) Bougyes sim card,
- (2) 4G modem,
- (3) 4G antennas connected to the modem,
- (4) Ethernet cable connected to PC, using the OBU as a gateway,
- (5) Jtag connector to flash image from PC to board and connect to board also

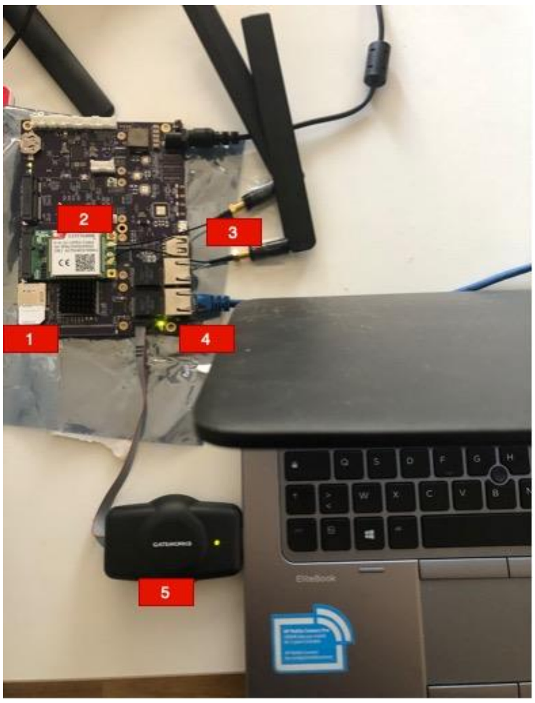


Figure 78: VEDECOM 5G OBU components.

5.4.3.3. *Pepwave device integration*

In the FR-TS, a Commercial Off the Shelf (COTS) routing device equipped with mode switching and RAT bonding capabilities, will be integrated with the OBU. The OBU is connected through the router's LAN interface and the router is configured with two wide area network (WAN) interfaces, one dedicated to terrestrial 5G connectivity and another to satellite Low Earth Orbit (LEO) connectivity as illustrated in Figure 79.

To terminate the VPN connection, another intelligent router is required at the server site, where the CCAM application is installed. In this example, the server site (application platform) is located at Catapult's 5G step out centre facility, in Oxfordshire, UK. A similar configuration will be followed for the deployment on the FR-TS

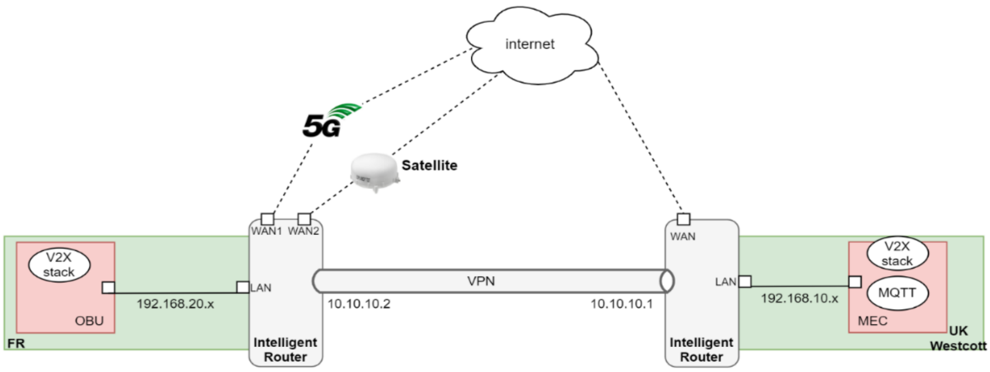


Figure 79: FR TS Pepwave device integration

5.4.4. Cyber-security & data privacy

As securing the communication between the vehicle and the central system is a priority for the FR TS, VEDECOM has chosen to combine MQTT technology and authentication mechanism to provide autonomous vehicle with a high level of security when exchanging information with the MEC or supervision centre. This mechanism is illustrated through Figure 80.

Hence, in this scheme The MQTT broker Mosquitto supports an authentication mechanism based on usernames & passwords. These credentials are sent with the CONNECT message from the vehicles. Mosquitto allows the authentication of both publishers and subscribers, and then authorize routing of messages. The Authentication module provides the 3 functions used by Mosquitto, authenticateWithCredentials, authorizePublish and authorizeSubscribe.

- broker Root certificat (CA certificat)

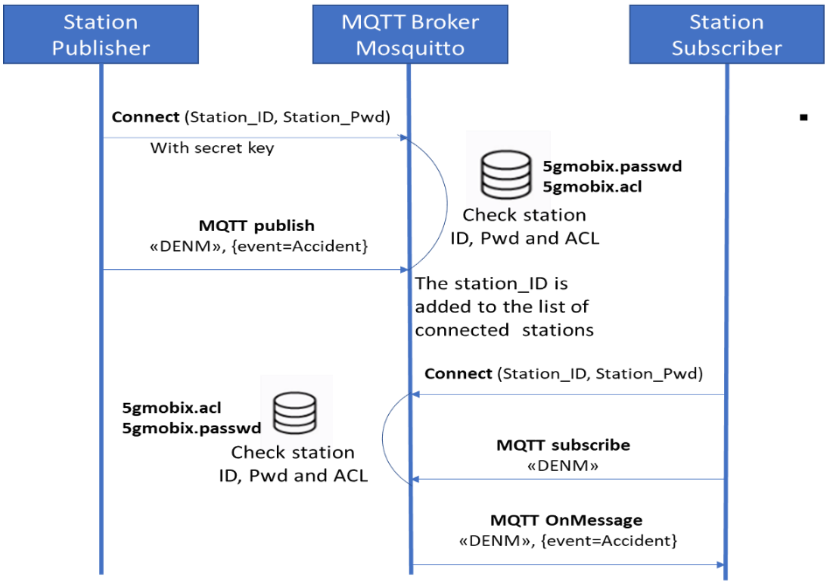


Figure 80: MQTT Authentication sequence using usernames, passwords and certificates

Each time a publisher or a subscriber send a CONNECT message to the broker the authenticate function is called. Station profile also has property topics (ACL). This is an array with all topics this particular device is allowed to.

The authorizePublish and authorizeSubscribe functions simply check that a particular requested topic is present in this ACL.

5.4.5. Early testing results

Two validation phases are considered in the following: laboratory validation and closed-circuit validation.

5.4.5.1. Laboratory validation

The objective of this step is to approve the output of the system before testing it on a closed circuit or on an open road.

5G connectivity:

As the two 5G OBU made by VEDECOM were ready by the end of September, VEDECOM has carried out a first testing session with Bouygues 5G network in lab conditions. The main goal of this test was to see if the 5G connectivity will work as it's the first time FR TS will test its OBU. Hence, the 5G connectivity test was successful and the board got connected right on the start-up is illustrated by Figure 81.

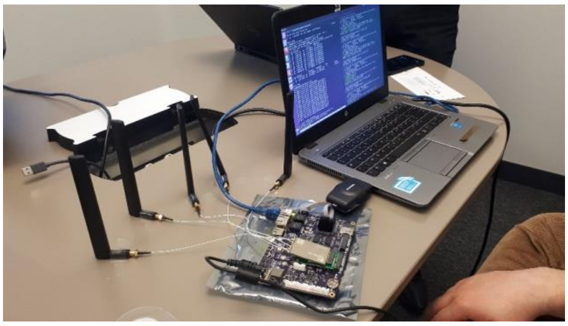


Figure 81: VEDECOM 5G OBU testing with Bouygues 5G network

During these tests, we managed also to test the latency, throughput and other parameters related to the modem and operator as illustrated by Figure 82.

```
+CGPS: 0
at+cpsi?
+CPSI: LTE,Online,208-20,0x76E9,129550855,482,EUTRAN-BAND20,6200,3,3,-63,-706,-472,19
+CPSI: NOT IN EN-DC CONNECTED MODE

OK
at+cpsi?
+CPSI: LTE,Online,208-20,0x76E9,129550852,482,EUTRAN-BAND7,3175,4,4,-65,-864,-611,24
+CPSI: NR5G,480,650592,-11,-68,22.0
```

Figure 82: VEDECOM 5G OBU: modem and operator parameters measurement

The results of throughput in DL and UL were unsatisfactory as depicted by Figure 83.

```
root@OpenWrt:/# iperf3 -c bouygues.iperf.fr -p 5200
Connecting to host bouygues.iperf.fr, port 5200
[  4] local 10.51.149.189 port 36382 connected to 89.84.1.222 port 5200
[ ID] Interval           Transfer     Bandwidth       Retr  Cwnd
[  4]   0.00-1.00   sec  5.02 MBytes  42.1 Mbits/sec    1    197 KBytes
[  4]   1.00-2.00   sec  5.09 MBytes  42.7 Mbits/sec    0    214 KBytes
[  4]   2.00-3.00   sec  5.00 MBytes  41.9 Mbits/sec    0    230 KBytes
[  4]   3.00-4.00   sec  5.30 MBytes  44.4 Mbits/sec    0    246 KBytes
[  4]   4.00-5.00   sec  5.06 MBytes  42.5 Mbits/sec    0    259 KBytes
[  4]   5.00-6.00   sec  4.70 MBytes  39.5 Mbits/sec    0    279 KBytes
[  4]   6.00-7.00   sec  4.90 MBytes  41.1 Mbits/sec    0    339 KBytes
[  4]   7.00-8.00   sec  5.45 MBytes  45.7 Mbits/sec    0    418 KBytes
[  4]   8.00-9.00   sec  5.19 MBytes  43.6 Mbits/sec    0    511 KBytes
[  4]   9.00-10.00  sec  5.50 MBytes  46.1 Mbits/sec    0    649 KBytes
```

Figure 83: Measured Throughput within Bouygues 5G network

In fact, the DL throughput calculated was equal to 35 Mbps. On the other side the UL throughput was equal to 45 Mbps. Using a 5G phone provided by Bouygues, the DL throughput of the 5G phone was equal to 600 Mbps.

An investigation was carried out to figure out why the throughput measured by the 5G-OBU is lower than expected. The results have confirmed that the use of M.2 to MPCIe adapter is behind the throughput decrease. In fact, the OBU without the adapter with a mPCIe 2.0 interface can achieve up to 5Gbps but when the adapter is installed it limits the throughput to 4.8 Mbps which converts to roughly ~ 60 Mbits/s.

Additional testing has been carried out to investigate the latency measurements. The latency calculated using the ping command has led to the following result: **10 ms (one way).**

C-ITS modules

In the following Table 13 and Table 14, the different conducted tests to validate the OBU C-ITS modules are presented

Table 13: Test result for C-ITS modules

Environment: **VEDECOM Laboratory**		
Components: **OBU C-ITS module**		
TEST ID	**TEST PURPOSE**	**RESULT**
OBU-CAM01	Test that the **OBU CA Server** is able to generate and broadcast CAM .	Validated
OBU-CAM02	Test that the **OBU CA Client** is able to receive CAM	Validated
OBU-MCM01	Test that the **OBU MC Client** is able to receive MCM messages without trajectory guidance	Validated
OBU-MCM02	Test that the **OBU MC Client** is able to receive MCM messages with trajectory guidance container. The message is relevant i.e., the vehicle is the destination of the trajectory guidance.	Validated
OBU-CPM01	Test that the **OBU CP Server** is able to generate and transmit CPM messages.	Validated

OBU-CPM02	Test that the **OBU CP Client** is able to receive CPM messages sent by a MEC.	Validated
OBU-CPM03	Test that the **OBU CP Client** is able to receive CPM messages sent by a vehicle.	Validated
OBU-MAP01	Test that the **OBU MAP Client** is able to receive MAP msg.	Validated

Perception modules

Table 14: Test result for perception modules

Environment: **VEDECOM Laboratory**		
Components: **Vehicle perception module**		
TEST ID	**TEST PURPOSE**	**RESULT**
OBU-PER-L01	Test that the **OBU Local perception module** is able to detect a vehicle driving in a targeted lane.	Validated
OBU-PER-A01	Test that the **OBU Fusion module** is able to provide a list of objects when no V2X communication exists.	Validated
OBU-PER-A02	Test that the **OBU Fusion module** is able to provide a list of objects when no local perception exists	Validated
OBU-PER-A03	Test that the **OBU Fusion module** is able to add an object detected by the local perception system to its list of objects when no V2X communication data exists	Validated
OBU-PER-A04	Test that the **OBU Fusion module** is able to add an object to its list of objects based on CAM data when no local perception information is available	Validated
OBU-PER-A05	Test that the **OBU Fusion module** is able to associate a CAM Data with an existing object that has been detected by the local perception	Validated

5.4.5.2. *Field test results*

Tests have been carried out in story site to test different functionality related to the OBU (connectivity+ perception).

As it is shown in the Figure 84, as the AV was heading towards the intersection, the MEC has assessed that there is a potential collision risk with the basic vehicle, and then an MCM message was sent to the AV. In the right screen of the figure, the OBU is receiving an MCM with the required information regarding the lane change manoeuvre and with also the required speed. The reception of MCM message was then validated in field test conditions.

Figure 84: MCM reception inside the AV

5.5. CN Setup

5.5.1. Sensors & devices integration

The CN TS vehicle will be equipped with the sensors described in D2.4(1)Table 15 for testing the user stories.

Table 15: Devices integrated in CN vehicle

Type of Sensor	Units	Characteristics	Additional info
Camera	1	Monocular camera	Dedicated image sensors
Radar	1	mmWave radar	Front mmWave radar of 76 GHz
Lidar	1	Multi-line lidar	
Navigation	1	Integrated navigation	MEMS gyroscope and GNSS navigation
Computer	2	High-performance computer	built-in Kithara real-time kernel
Brake actuator	1	Communication mode CAN	based on the original brake
Radar sensor	8	Ultrasonic radar sensor	
Controller	1	Main controller	Cortex-A9, CAN (2ch), ETH
Communication	1	3GPP network module	ZIGBEE short-range module

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

5.5.2. Automated driving function development

The Cloud-assisted advanced driving functions have been adapted according to the illustrations below for testing the user stories.

5.5.2.1. User Story #1: Cloud-assisted advanced driving

In this case, we employ the SDIA vehicle to test the scenario, shown in Figure 85.

Figure 85: CN vehicle

Due to the fast-change situations on the road, all perception-related processing of vehicles is time-critical, which have the following functions:

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

Also, another module was introduced which will offer the connection with the 5G-OBU; this module is an evolution of the 4G module already in place. This module will offer the required interfaces and APIs to communicate with the 5G-OBU.

In Figure 86 can be checked and overview of AD functions for CN vehicle

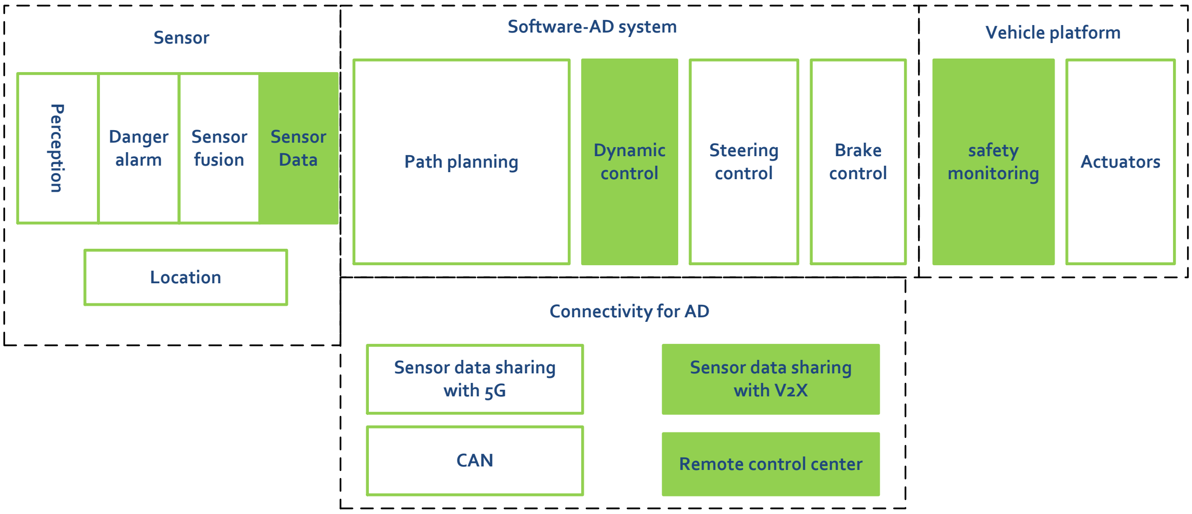


Figure 86: Automated driving functions overview

5.5.2.2. *User Story #2: Cloud-assisted platooning*

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

5.5.2.3. *User Story #3: Remote driving with data ownership focus*

Remote driving is a very demanding task for connectivity. The situational awareness from a 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. Therefore, the flow of the user story is as follow in Figure 87:

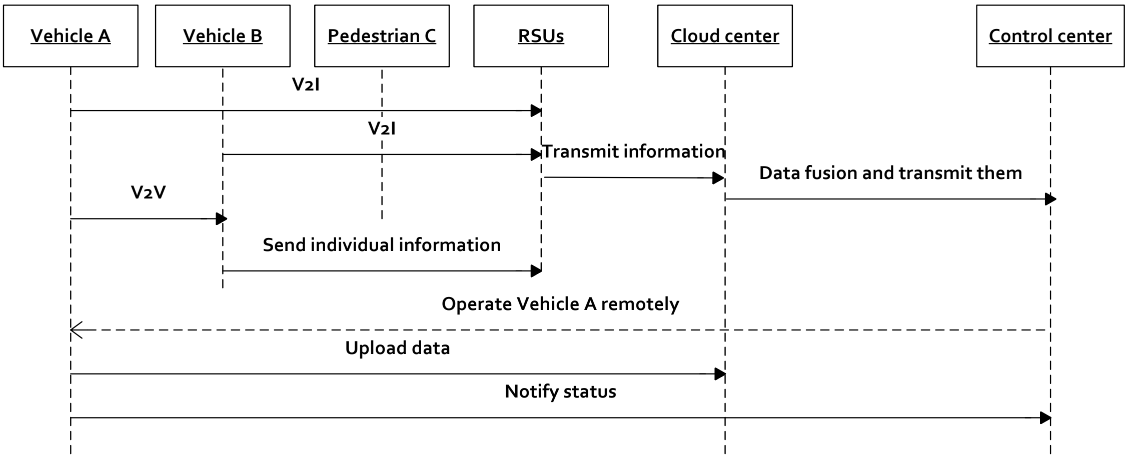


Figure 87: UC messages flow

We tested the remote driving scenario and achieved phased results. The following Figure 88 shows the control terminal is remotely controlling the vehicle during the remote driving test.

Figure 88: Remote driving control terminal

5.5.3. OBU integration

We used the SIM8200EA-M2 to establish communication between the test vehicle and the system. The SIM8200EA-M2 is a multi-band 5G NR/LTE-FDD/LTE-TDD/HSPA+ module solution that supports R15 5G NSA/SA data transmission to 4.0 Gbps. The module had powerful expansion capabilities and rich interfaces, including PCIe, USB3.1, GPIO, etc. Simultaneously, the module could provide a range of spectrum to help us test even more complex communication scenarios in the future, whose spectrum is shown in Table 16.

Table 16: spectrum supported by SIM8200EA-M2

5G NR	**n1,n2,n3,n5,n7,n8,n12,n20,n25,n28,n40,n41,n66,n71,n77,n78,n79**
LTE-TDD	B1/B2/B3/B4/B5/B7/B8/B12/B13/B14/B17/B18/B19/B20/B25/B26/B28/B29/B30/B32/B66/B71
LTE-FDD	B34/B38/B39/B40/B41/B42/B43/B48
WCDMA	B1/B2/B3/B4/B5/B8

In Figure 89 the SIM8200EA-M2 can be seen.

Figure 89: SIM8200EA-M2

We deployed the module on our tested vehicle, provided by CHNTC. We have also connected the SIM8200EA-M2 and OBU to supply Uu connection for V2I and V2V (Figure 90).

Figure 90: OBU equipment in vehicle

5.5.4. Cyber-security & data privacy

In the CN TS, security is ensured by the Certificate Authority (CA) for three user stories. Firstly, the vehicle applies to a trusted CA for access to the MEC server and cloud. In this access, SDIA or CNHTC completes the signature, and the key is provided to the required client for secure storage time. Secondly, the vehicle uses its corresponding private key to sign and send the data and select a pseudonym to send it out together when the vehicle needs to send a message. Moreover, the vehicle from a nearby RSU will collect RSU signature timestamp information and communicate with a timestamp sequence as its identification information to ensure vehicle location safety. The receiving party by the CA public key certificate validation received a pseudonym to verify the source's legitimacy. Data privacy is covered by the Data Centre of SDHS or SDIA, which will follow data privacy guidelines such as GDPR guidelines.

5.5.5. Early testing results

The early tests consist on simple connectivity tests, see Figure 91. And the two 5G OBU made by Cohda were ready by the end of September. The main goal of this test was to see if the connectivity would work. Hence, the connectivity test was successful and the board was connected right on the start-up!

Figure 91: Early test of Cohda OBU

We also test the Device to Device Connection:

- Two set are used, one of them is configured as Main device and the other one is set as From device. The MAC address must be different.
- Main device: Input: bt_mast.sh init "02 44 32 AA 47 61"
- From device: input: bt_slave.sh init "01 44 32 AA 47 61"
- The result is shown in Figure 92

```
root@imx8qxpmek:~# bt_master.sh init "02 44 32 AA 47 61"
!!Load Bluetooth firmware!!
---> setup hci device
hciconfig hci0 up
---> Set test BD address
hcitool cmd 0x3f 0x000b 01 02 06 02 44 32 AA 47 61
< HCI Command: ogf 0x3f, ocf 0x000b, plen 9
  01 02 06 02 44 32 AA 47 61
> HCI Event: 0xff plen 10
  0B 01 02 06 02 44 32 AA 47 61
---> set hci device is piscan
hciconfig hci0 piscan
---> Show hci device information
hciconfig hci0
hci0:   Type: Primary  Bus: UART
        BD Address: 61:47:AA:32:44:02  ACL MTU: 1024:7  SCO MTU: 60:8
        UP RUNNING PSCAN ISCAN
        RX bytes:2096 acl:0 sco:0 events:119 errors:0
        TX bytes:2017 acl:0 sco:0 commands:119 errors:0
```

Figure 92: Device to Device Connection Test

5.6. KR Setup

5.6.1. Sensors & devices integration

To carry out the user stories (mmWave -based remote control) testing and trialling, the KR TS vehicle equips with the following sensors and communication devices as can be consulted in Table 17.

Table 17: vehicle equipment overview

Type of Sensor	Units	Characteristics	Additional info
Radar	1	Front Radar	Valeo, 77GHz (70m~
	2	Left/Right Side Radar	Valeo, 24GHz
Ultrasonic	8	Front / Rear Ultrasonic Sensor	Valeo, 50kHz
Camera	4	HD camera	- Front, Left/Right and rear cameras
	4	HD Camera	- Around view camera(Front, Left/Right and rear) for 360 deg camera
	3	HD Camera	Front and rear scene recording Driver recording scene camera
GNSS	1	DGPS	less than 10cm
Speed Sensor	1	Vehicle Speed	N/A
	1	Displayed Speed(Cluster)	
Steering sensor	1	Steering angle sensor	N/A
V2X	5	802.11p	- 4 V2X module for 4 single camera(Front, Left/Right and Rear) - 1 V2X module for around view camera
HMI	1	Android	CAN, Automotive Ethernet
Controller	1	RCV controller	CAN, Automotive Ethernet
Communication	5	OBU	mmWave

KATECH provides the test vehicle, XM3 by Renault Samsung Motors, which is used for a remote-controlled vehicle use case. The test vehicle equips various long and short-range sensors to detect obstacles around the test vehicle and has a mmWave -based communication module to communicate with a remote site. Especially, the test vehicle equips 8 HD cameras (4 sets of cameras for a real-time video stream of the front, left/right, and rear side video, and another 4 sets of cameras for a real-time video stream of around view). CAN communication is mainly used to share most of the sensor measurement and vehicle-related data and automotive Ethernet is used for video data. The mmWave based on-board unit provides reliable connection to remote site

5.6.2. Automated driving function development

To carry out the trials for the KR TS user stories, the automated driving functions have been adapted. The vehicle fully supports not only lateral and longitudinal control but also transmission control to support remote driving. The test vehicle shares its each front, left and right, and rear video information and also its surrounding view video information with remote site based on mmWave communication. Lane recognition result that is detected by one of the front cameras is shared with remote server through mmWave communication link also. Radar and ultrasonic sensors are mounted to support collision avoidance function. Front radar detects front obstacles such as vehicle, two-wheel bike, and pedestrian within 170m, 150m and 70m, respectively. Ultrasonic sensor is mounted front and rear bumper and its obstacle detection range is maximum 120cm. Obstacle detection results also transmit to remote server via mmWave communication. The following Figure 93 shows the software architecture for the vehicle:

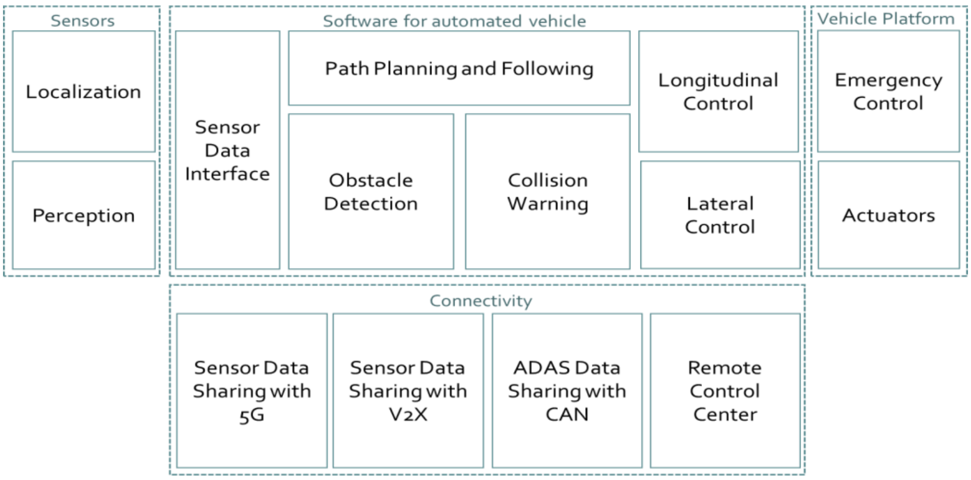


Figure 93: Automated driving functions of the KATECH vehicle

5.6.3. OBU integration

The mmWave -based OBU, also called User Equipment (UE), is installed in the test vehicle (Figure 94). The control plane (CP) and User plane (UP) protocols has been integrated across L1, L2, and L3 functions as depicted in Figure 95.

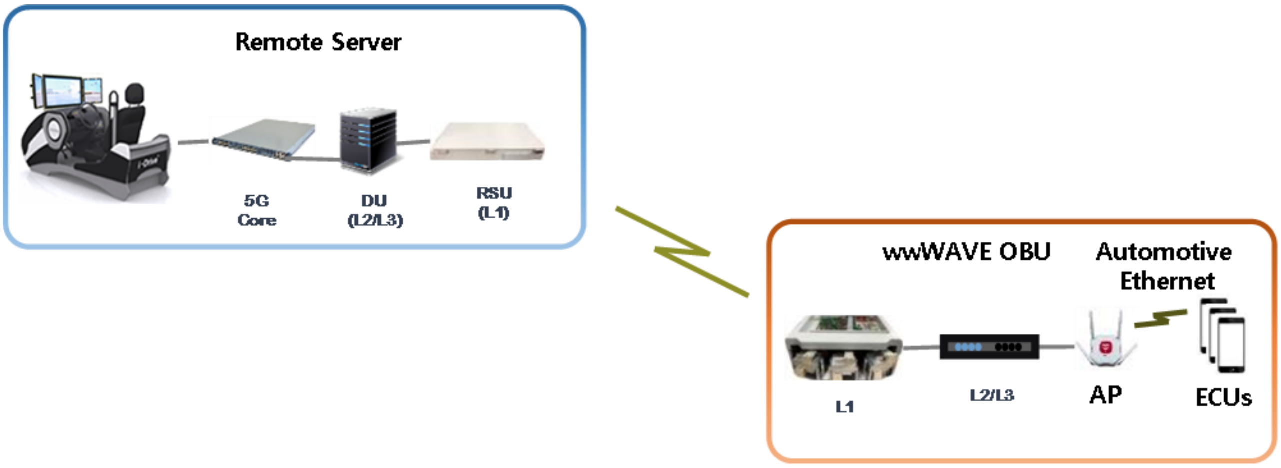


Figure 94: Testbed implementation for integrated road infrastructure

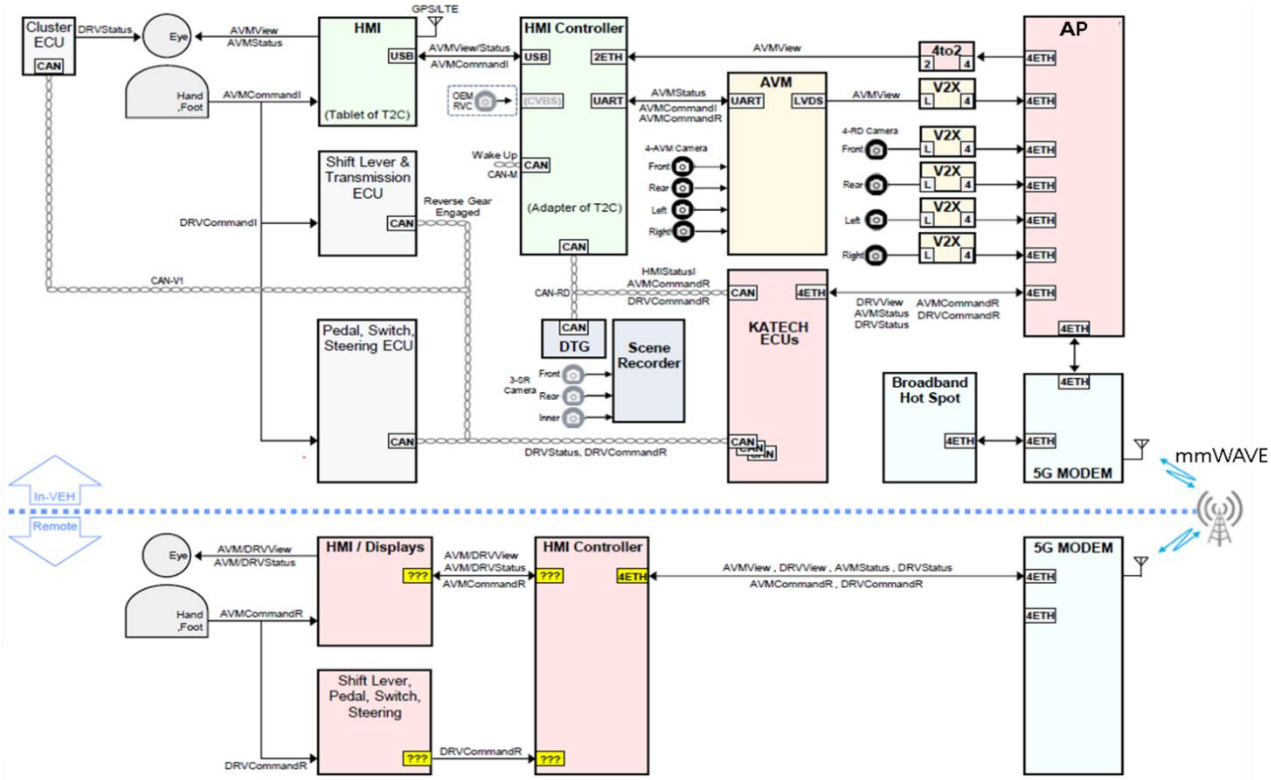


Figure 95: OBU integration with test vehicle

5.6.4. Cyber-security & data privacy

In KR TS, all the data is secured by security protocol (NAS and GTP tunnel). NAS protocol is applied to communication between mmWave units and base stations. GTP tunnel protocol is applied to communication between 5G core network and base station.

5.6.5. Early testing results

The early tests consist on simple connectivity tests as shown in Figure 96.

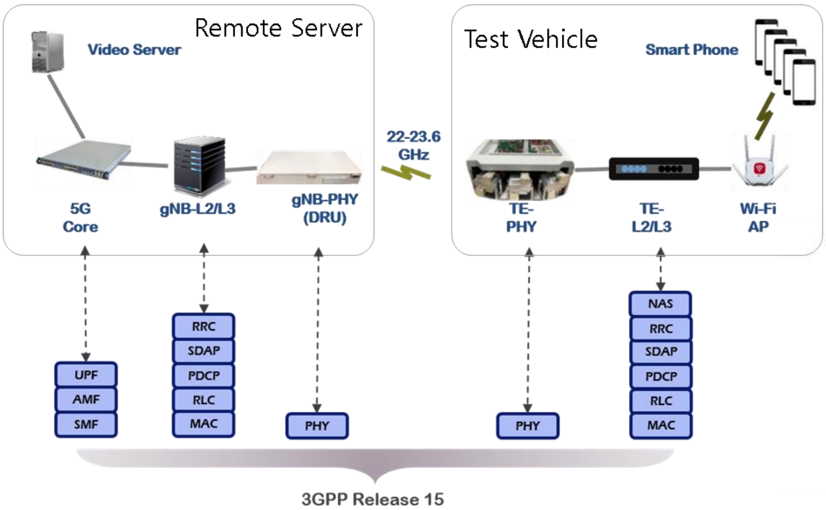


Figure 96: Test configuration

- Video server is connected to 5G core and share video file to test vehicle
- User connects to the video server with his/or her smart phone that is connected with AP in the test vehicle.
- User watching video, that is, downloading from video server in the remote site.
- Test results show that 3G bps @ downlink and 200Mbps @ uplink during the PHY to PHY test.

The developed mmWave modem in the test vehicle was able to successfully connect to the mmWave network.

6. CONCLUSION

This deliverable aimed at providing a view of integrations and modifications done in vehicles and OBUs, The cyber-security methods used and the first early unitary tests done by the partners to ensure the good operation of some components.

Following the specifications done in D2.4 (1) all partners have performed the integrations and modification during this Phase 2 to carry out the verification tests and the TS collaborations. These works enhance the vehicles in each site developing new functionalities and preparing those vehicles to get data from 5G connectivity and carry out the UCC described in D2.1 (2).

To get the 5G connectivity, all sites work together to search the 5G-modems or 5G OBU. These chipsets and OBUs have suffered delays due to Coronavirus, but sites worked in parallel developing the functions to integrate them in those OBU.

Currently the most part of sites have done some individual test and they are preparing for the verification phase.

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