Grant Agreement Number: 731993

Project acronym: AUTOPILOT

Project full title: AUTOmated driving Progressed by Internet Of Things

D2.2

ADAPTATION REPORT OF AD FUNCTIONS WITH IoT TECHNOLOGIES

Due delivery date: 30/06/2018

Actual delivery date: 30/06/2018

Organisation name of lead participant for this deliverable: VEDECOM

Project co-funded by the European Commission within Horizon 2020 and managed by the European GNSS Agency (GSA)		
Dissemination level		
PU	Public	X
PP	Restricted to other programme participants (including the GSA)	
RE	Restricted to a group specified by the consortium (including the GSA)	
CO	Confidential , only for members of the consortium (including the GSA)	

Project funded by the European Union's Horizon 2020 Research and Innovation Programme (2014 – 2020)

Document Control Sheet

Deliverable number:	2.2
Deliverable responsible:	VEDECOM
Work package:	2
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Document Revision History			
Version	**Date**	**Modifications Introduced**	
		Modification Reason	**Modified by**
V.01	13/04/2018	First draft	SCHREINER Floriane (VEDECOM)
V.02 – V.06	13/04/2018 - 31/05/2018	Contributions from partners to chapter 5	All prototype leaders
V1	31/05/2018	Version for peer review	SCHREINER Floriane (VEDECOM)
V1.1	15/06/2018	Comments from peer reviewer R. Heras partly integrated	SCHREINER Floriane (VEDECOM)
V1.2	22/06/2018	Comments from peer reviewer A. Petrescu partly integrated	SCHREINER Floriane (VEDECOM)
V1.3	26/06/2018	All comments integrated	SCHREINER Floriane (VEDECOM)
V2.0	27/06/2018	Final version	SCHREINER Floriane (VEDECOM) BENTON, Jonathan (ERTICO)

Abstract
This document presents the vehicle prototypes which are developed, adapted and used within AUTOPILOT. There will be 18 vehicles in total distributed across the pilot sites of Tampere, Versailles, Brainport, Vigo and Livorno. More specifically, this document focuses on the adaptations that have been made on the existing automated driving functions of the different vehicles in order to take into account the Internet of Things technology. This is the final version of deliverable 2.2 *"Adaptation report of AD functions with IoT technologies"*.

Abbreviations and Acronyms

Acronym	Definition
(C-)ACC	(Cooperative) Adaptive Cruise Control
AD	Automated Driving
ADAS	Advanced driver assistance systems
AVP	Automated Valet Parking
CAM	Cooperative Awareness Message
CAN	Controller area network
D	Deliverable
DENM	Decentralised Environmental Notification Message
EC	European Commission
EMC	Electromagnetic compatibility
FMEA	Failure modes and effects analysis
GA	Grant Agreement
GNSS	Global Navigation Satellite System
HMI	Human Machine Interface
IoT	Internet of Things
ITS	Intelligent transport system
LiDAR	Laser Imaging Detection and Ranging
MRM	Minimum risk manoeuver
OBU	On-board unit
PS	Pilot site
RTK	Real-time kinematic
SLAM	Simultaneous Localisation and Mapping
SPaT	Signal Phase and Timing
TCC	Traffic control centre
UWB	Ultra-wide bandwidth
V2X	Vehicle-to-everything
VRU	Vulnerable Road User
WP	Work Package

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Executive Summary

This document is the final version of the public deliverable D2.2. It provides information on the adaptations made to the AD functions of the vehicle prototypes so that they take IoT technology into account.

In particular, in chapter 2, the document describes the expected impacts of the IoT on the different use cases. It then presents, in chapter 3, the vehicle prototypes which are used at the different pilot sites as well as their automated driving functions. Chapter 4 provides a description of the adaptations made to the AD functions in order to connect to the IoT, which is the core topic of the project and this deliverable. The last chapter focuses on the lessons learned and the difficulties that the prototype leaders had to face during the adaptation of the AD functions of their prototypes to the IoT environment.

1 Introduction

1.1 Purpose of Document

This document aims to present the work performed in T2.2 between June 2017 and June 2018. More specifically, the adaptation report of automated driving functions with IoT technologies (D2.2) will present the results of the adaptations that have been made on the existing automated driving functions in order to enable the different use cases of AUTOPILOT project on each pilot site.
This deliverable is a synthesis of the adaptations made on each vehicle to reach the AUTOPILOT objectives. First, the expected impact of the IoT on the use cases will be presented. Second, the current state of the automated driving functions will be described and a description of the adaptations of the automated driving functions with IoT technologies will follow. The last chapter focuses on the difficulties which the prototype leaders encountered by adapting the AD functions of their vehicles so that they are able to take into account the information coming from the IoT.

1.2 Intended audience

The first version of deliverable 2.2 was an internal report, which was delivered in M14. It was addressed to the members of the AUTOPILOT project only and in particular the members involved in WP2. This IR2.2 came along with three other internal reports for WP2: IR2.1, IR2.3 and IR2.4. These internal reports have since been completed.

The final deliverable 2.2 is a public document which will be open to all AUTOPILOT partners, stakeholders of the project, and any other entities interested in the project. Its due date is M18, the same date as for the other WP2 deliverables: D2.1, D2.3 and D2.4.

2 Expected impact of the IoT on the use cases

2.1 Automated Valet Parking

2.1.1 Purpose of the use case

In Autonomous Valet Parking (AVP) the driver is able to leave the car at some predefined drop off location and is able to retrieve the car once s/he needs it back. All the operation of parking, manoeuvring of the car in the parking area, retrieving and possibly other additional services as fuelling or recharging, cleaning or washing will be managed by the parking management system. The AVP use case shows how the service takes advantage of an IoT platform for discovering, booking and retrieving the AVP service, while on the same time the AVP service itself is able to use IoT devices and services in the provision of the service.

The service consists of three different phases as depicted in *"D1.1 Initial Specification of IoT-enabled Autonomous Driving use cases"*.

- The drop off phase is when the driver leaves the car at the predefined location.
- The parking phase is when the vehicle moves in the parking facility and is coordinated by the parking facility to locate the available parking spot and the driving manoeuvre.
- The pickup phase where the vehicle is retrieved from the parking slot and given back to the driver at the pickup location.

2.1.2 State of the art: today's performances of the AD functions, without IoT

AVP is an active area of research and has been demonstrated in different events, as for example in the DARPA Urban Challenge 2007, at ITS World Congress 2013 in Tokyo by Honda, by European co-funded V-Charge (Valet Charge) research project (7FP) in 2015, in 2016 by the EU co-founded AdaptIve[1] Project and by Tesla in an open parking area in 2016. The service is also been deployed in 2017 in multi-storey car park at the Mercedes-Benz Museum in Stuttgart by Daimler and Bosch and one of the application of the EU co-funded L3Pilot Project[2].

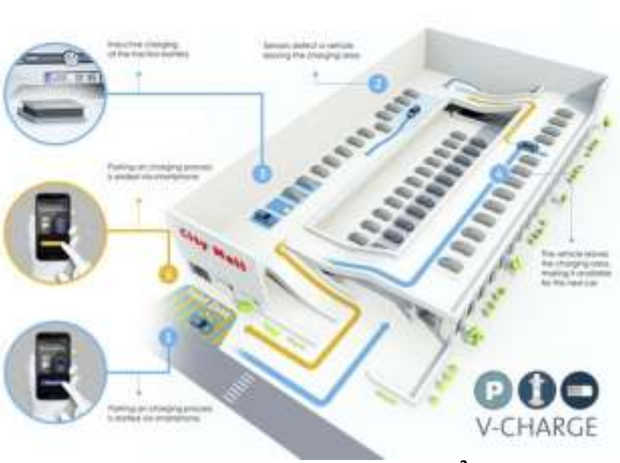

Figure 1 AVP in V-Charge project[3]

[1] https://cordis.europa.eu/project/rcn/191624_en.html
[2] http://l3pilot.eu/
[3] http:/www.greencarcongress.com/2015/07/20150715-vcharge.html

2.1.3 Expected impacts of the IoT

The IoT is expected to contribute in different aspects to the AVP service. On one hand, it helps to the end-user (the driver) to discover and use the service. On the other hand, it helps in developing and deploying the service. For example the service can rely on car-sharing services deployed in the IoT platform. The service can also benefit from smart IoT devices, as for example the camera system that identifies free parking spots or by deploying drones to verify the occupancy of part of the route or the availability of parking spaces. The service could also use motion planning that integrates IoT sensor information as the presence of obstacles connected to the IoT, e.g. pedestrians with enabled IoT devices.

2.2 Highway Pilot

2.2.1 Purpose of the use case

In the Highway Pilot use case, a cloud service merges the sensor measurements from different IoT devices (in particular from vehicles and roadside cameras) in order to locate and characterise road hazards (potholes, bumps, fallen objects, etc.). The goal is then to provide the following vehicles with meaningful warnings and adequate driving recommendations (taken into account by the autonomous/assisted driving functions) to manage the hazards in a safer or more pleasant way. Built upon collective learning of IoTs, this 6th sense anticipation mechanism aims at replicating people's driving experience and road awareness into autonomous vehicles.

2.2.2 State of the art: today's performances of the AD functions, without IoT

Current AD functionalities rely only on the vehicle's own sensors perception of its direct environment. The faster the vehicle goes, the shorter time it has to react to an event or, in the present case, to the presence of a road defect. In addition to the difficulty of perceiving those smaller defects, they are minor and won't seriously impact the vehicle's safety and integrity. It makes no sense for the AD strategy to risk performing critical quick manoeuvres (like steering or braking) in these circumstances. From the point of view of the passengers, the AD strategy just wouldn't have seen that road hazard, which a driver would have intuitively avoided by anticipation and experience.

2.2.3 Expected impacts of the IoT

The collaboration of the IoT, made up by the community of vehicles and their diversity of sensors, will generate much structured data that can be efficiently processed by dedicated cloud services.
It will then be possible to eliminate many unknowns from the vehicles environment and extend the perceived sensing beyond normal range. Hence we expect AD improving from a robotic and carefree AD driving to a more humanised and experienced AD driving.
The impacts will be measured in terms of perceived quality of the ride, travel time, passengers trust towards the vehicle automation, preservation of the vehicle parts, and overall integration of the vehicle as a contributor to the roads infrastructure efficiency.

2.3 Platooning

Platooning is about automatically following another vehicle at a relatively close distance. Driving in a platoon requires vehicles to use inter-vehicle communication to anticipate timely on manoeuvres of other vehicles in the platoon. Communication is necessary, since the other sensors (camera, radar)

do not have a sufficiently fast detection and response time to enable timely automated control. With usage of classical sensors only, problems that typically could arise are either:
1) insufficient time in the case of emergency braking (leading to collisions), or
2) string instability in the platoon.

2.3.1 Purpose of the use case

Several aims and motivations for vehicular platooning exist, such as improvement of traffic throughput and homogeneity, enhancement of traffic safety due to small speed variations and relative low impact velocities in collisions, and reduction of fuel consumption and emissions due to lowering the air drag.

The aim of AUTOPILOT is to demonstrate vehicular platoons consisting of a lead vehicle and one or more highly automated or driverless following vehicles. The following vehicles have automated steering and distance control to the vehicle ahead, and the control is supported by multiple flavours of V2V communication: 802.11 OCB based, as well as by the IoT technologies (LTE+/pre-5G and UWB). Apart from driving in a platoon, forming of the platoon is also part of AUTOPILOT targets. Deploying multiple communication technologies allows both more robust communication, as well as the comparison of quality of services of the deployed technologies.

Two variants of platooning will be deployed and evaluated in AUTOPILOT, see also the pilot site descriptions in D1.1:

- An urban variant to enable car rebalancing of a group of driverless vehicles (up to 4), involving one driver, driving the lead vehicle. The maximum speed considered is 30 km/h. As the first deployment of highly automated driving will likely be on dedicated lanes, the scenario to be implemented in Versailles will start from a car sharing station where the driverless vehicles will have to join the leading vehicle to form a platoon. The platoon will then move to another station, where driverless vehicles will also use automated parking.
- A highway variant in the Brainport, where one or more highly automated vehicles are going to follow a leading vehicle on the highway. Also in this variant, it is considered to use a dedicated lane, i.e. the electronic allowance of the emergency lane is explored. The scenario to be implemented will start from a platooning appointment that has been made and triggering the formation of the platoon. An approaching lead vehicle will pick up the following vehicle, which has just arrived from automated parking. Dynamic pick up of vehicles will be explored, where platoon forming is done while driving. After the platoon is formed, the platoon will drive from the city of Helmond to the city of Eindhoven. On their way, other vehicles may join or leave the platoon dynamically.

2.3.2 State of the art: today’s performances of the AD functions, without IoT

Typically, the state-of-the-art AD platooning function consists of the following sub functions:

- Longitudinal vehicle control:
  C-ACC (Cooperative Adaptive Cruise Control), which is an extension of ACC (Adaptive Cruise Control). In addition to the feedback loop used in the ACC, which typically uses radar measurements to derive the range to the vehicle in front, the preceding vehicle's acceleration is used in a feedforward loop. In current state-of-the-art solutions, the preceding vehicle's acceleration is obtained from V2V communication using ITS-G5.
- Lateral vehicle control:
  Functionality which enables the following vehicle to follow the preceding vehicle by steering. Fundamentally two methods exist:
  - Path following: the control objective is to steer the vehicle as such that it follows a pre-defined path. To achieve this two things are required:

- a path;
- localisation of the vehicle with respect to the path.

The path to follow can have different origins, but it is in essence not depending on the leading vehicle's position. The most common method is to use an Automated Lane Keeping functionality, which keeps the vehicle laterally in the lane in which it is driving. Typically the path to follow (lane centre line) and localisation with respect to this path are obtained using camera line information. Other solutions exist as well to obtain the path, e.g. using map data (HD maps, GPS trace). In these cases also a suitable localisation technique is required.

- Lateral vehicle following: the control objective is to steer the vehicle in order to follow the motion ('path') of the preceding vehicle, e.g. by following its tail observed from camera/radar measurements. The essential difference with regard to the above-described path following method is that the lateral control of the vehicle is solely depending on the observed motion of the preceding vehicle. On the one hand, this means that no information about the road (e.g. lines) or from a map is required. On the other hand, the (controlled) lateral position of the vehicles in the platoon is fully dependent on each other, possibly causing the following vehicles exceeding road/lane boundaries due to accumulating position errors without having notice of this.

It is essential to note that regarding the lateral control functionality, the targeted level of automation plays a major role. All of the above-described methods have their shortcomings, which might be acceptable for driver assistance systems, but not for SAE level 3 and higher systems. It is generally believed that a fusion of the different techniques can provide the required reliability.

- Platoon management:
  With C-ACC and automated steering, vehicles can automatically follow each other. However when only having this functionality, the vehicles are not aware of being a platoon, i.e. they only know that they are following a preceding vehicle. The awareness of being a platoon is obtained from sharing information, think of who is leading, who is following, the number of vehicles in the platoon, request handling for engaging or disengaging from a platoon, etc. The largest benefit of this awareness of being in a platoon is that it enhances the tactical decision making, e.g. by avoiding unintended platoon breakups. State of the art is that the AD vehicles have an on-board 'platoon management' function (software) for this task and V2V communication using ITS-G5 for exchanging the required platoon state information. Further, state of the art is that this platoon state information is not exchanged outside of the platoon.
- Safety features:
  In state-of-the art platooning applications, drivers in the following vehicles monitor the driving environment and are expected to take control in case something goes wrong, e.g. actuator/sensor/communication failure, environmental perception shortcomings, etc. Although the driver is supported by technology for assisting and warning him, and the system is developed for minimum driver interactions, the technology is not yet at the level required for taking over the dynamic driving task (i.e. driver does not act and decide anymore), as is required for automated driving systems (i.e. SAE level 3 and higher).

2.3.3 Expected impacts of the IoT

Below the expected impacts are categorised:

Organisation of platoons:

- IoT will enable integration of platooning in a mobility service concept;
- IoT will facilitate finding other vehicles as members for platooning;

- IoT will extend the distance at which vehicles initiate towards platooning.

The impact on the AD functions is that algorithms must be developed and implemented that allow scheduling, organising and formation of platoons.

Decision making:

By receiving traffic intent and interference information that cannot be sensed by vehicle sensors, IoT will allow a better anticipation on legacy traffic evolution, traffic lights, etc.

The impact on the AD functions is that an algorithm must be in place that interprets the received information and translates it into mainly tactical decisions, e.g. desired speed for passing a traffic light without platoon break-up.

Communication options and cost:

- IoT may enhance the suitable options for communication technologies by which platooning can be realised;
- IoT may provide lower cost solutions for communication and positioning than possible until now.

Quality of service:

- IoT may provide additional positioning-information and -quality of service, and provide sensor fusion algorithms with more input data yielding far more robust positioning enhancing stability and comfort of the driving (platooning) experience;
- IoT may enable higher quality of service for platooning (e.g. robustness), especially when redundant communication can be implemented (preferably in a low cost way).

Enhancing safety:

IoT will contribute to reach a higher level of automation by enhancing safety as result of redundant sensor information and communication channels, e.g.:

- HD maps might be used to improve localisation. Key element for map usage is that the map must be up to date. IoT will enable streaming of the most recent map to the vehicles.
- Hybrid communication, i.e. combining different communication technologies (802.11 OCB/ITS-G5 and the IoT technologies UWB and (Pre-) LTE-V (Pre-5G)) via a fusion algorithm, can improve the performance and robustness of the communication. Besides that, novel IoT communication technologies might provide redundant sensor information such as position and distance.
- The performance of RTK (real-time kinematics) GPS positioning solutions can be improved by communicating corrections over the internet from NTRIP (Networked Transport of RTCM via Internet Protocol) base stations instead of using the traditional radio communication. In this way, the radio communication limitations can be overcome, e.g. blocking of signals by buildings, trees, etc. and the limited distance over which the radio signals can travel.
- Direct communication between the lead vehicle and the traffic lights controller, or between the lead vehicle and the traffic enforcement devices (speed-cam that enforces red light crossing), will help a longer platoon of vehicles to safely cross complex intersections.

2.4 Urban Driving

2.4.1 Purpose of the use case

Driving autonomously in city centres can be one of the most challenging functions the automated cars have to face, due to the complexity of the environment and its dynamic behaviour. So, it is easy to understand that in-vehicle sensors will not be enough to cope with all the possible use cases in such an environment. Adding new sources of information like those provided by IoT services, will be of great value.

In the automated urban driving use cases for AUTOPILOT some typical situations in urban scenarios will be tested. The prototypes will face VRUs which appear suddenly in situations with bad visibility, unexpected roadworks, accidents or traffic jams and they will have to adapt their speed to the traffic lights. It is expected that the prototypes reduce their speed and even break in a safe way. All of these use cases will be clearly enhanced with the aid of the IoT services.

2.4.2 State of the art: today's performances of the AD functions, without IoT

Until now there have been some tests of automated driving cars in urban scenarios, which added more complexity and difficulties for the automated vehicles than on highways. Companies like Google, Delphi, Waymo, Yandex, Uber, Tesla or Ford have tested their automated prototypes in city centres. Their strategy was to integrate as many sensors as possible in the vehicles (cameras, radars, 2D and 3D LiDARs, ultrasonic sensors, high definition maps…) in order to get a 360° view and not miss anything. However, the installation of this amount of sensors is not going to be feasible in commercial cars, so another solution must be adopted.

2.4.3 Expected impacts of the IoT

Connectivity and, therefore, IoT services can provide more useful information than the one received by in-vehicle sensors. One of the biggest challenges autonomous cars have to face in urban scenarios, are the number of unexpected events which may occur suddenly. IoT services can give information about the infrastructure (traffic lights, cameras, traffic management centres…), VRUs and other vehicles, with enough time to be prepared once they interfere with the vehicle. For automated cars this information will increase and improve their electronic horizon and therefore automated driving urban functions will be more efficient and safer.

2.5 Overview of the use cases in each pilot site

The following table gives an overview of the use cases implemented in each pilot site:

Use cases	Tampere	Versailles	Livorno	Brainport	Vigo	Daejeon
Automated valet parking	X			X	X	
Highway Pilot			X	X		
Platooning		X		X		
Urban Driving	X	X	X	X	X	X
Car Sharing		X		X		

Figure 2 Use cases implemented on the pilot sites

3 Description of the vehicle prototypes

Chapter 4.1 describes the prototypes at high level: type of vehicle, number and type of sensors, in-vehicle architecture.

3.1 Overview

The table below aims to give an overview of the vehicles used on each pilot site: numbers and types of vehicles with the responsible partner.

Table 1: Overview of the AUTOPILOT prototypes

Pilot Site	Prototype leader	Number of vehicles	Prototypes description
Tampere	VTT	2	• Citroën C4 • Volkswagen Touareg
Versailles	VED	3	• VFLEX (on a Renault Twizy base)
Livorno	CRF/AVR	2	• Jeep Renegade (AD + connected/CRF+FCA)
Brainport	TNO/Tass TU/e VCDA DLR	9	• TNO/Tass: 3 Toyota Prius • TU/e: 1 Toyota Prius and 3 VFLEX • VCDA: 1 Volkswagen Tiguan 2 • DLR: 1 VW e-Golf 'FASCar-E'
Vigo	CTAG	3	• 2 PSA C4 Picasso • 1 CTAG C4 Picasso

The vehicle used on the Korean PS in Daejeon is a Hyundai vehicle used only for safety warnings to a human driver. Therefore it is not described in this report.

The vehicles from NEVS and TomTom do not appear in this report either for the following reasons:

- TomTom's mobile mapping van is not intended for self-driving functions but only to develop localisation.
- Regarding NEVS, the automated driving functions for platooning in Brainport are developed in the Prius vehicles and then transferred to the NEVS vehicles.
- Neither of them have PMs in T2.2.

3.2 Tampere: VTT prototype

VTT will provide two automated vehicles for piloting activities in AUTOPILOT:

Table 2: Finnish prototypes / VTT

Pilot Site	Owner of the prototype	Number of prototypes	Type	Use case
Tampere	VTT	1	Citroën C4, 'Marilyn 2.0'	AVP / Urban driving
	VTT	1	Volkswagen Touareg, 'Martti'	AVP / Urban driving
	Total	2		

The first prototype is Marilyn 2.0, a Citroën C4, which has been updated for automated driving, by installing electric actuators for control of throttle, steering wheel and brake (Figure 3 below). It is equipped with advanced sensor technology, software solutions and automated driving functions. The vehicle has been modified for automated driving. The following sensors have been installed at the front of the vehicle:

- SICK HD laser scanners (110°/6.4°, range: 120 m)
- Bosch LLR2 77 GHz long range radar (16°/4°, range: 200 m)
- FLIR AX8 thermal cameras 80x60, 7.5 -13 µm (48°/37°, range ~30 m)
- IDS HDR stereo camera system.
- Continental SRR 20X Short range radars (150°/12°, 50 m)
- DGNSS (GPS, Glonass) for positioning
- Vehicle CAN-bus connection for reading data from the vehicle.
- XSENS AHRS unit
- ITS-G5 and cellular LTE communication devices.

At the rear of the vehicle, the following sensors are installed:

- ibeo LUX Laserscanner
- Continental SRR 20X Short range radar

Figure 3: Sensors installed in the Finnish automated vehicle prototype

The second Finnish prototype is Martti, a modified Volkswagen Touareg (Figure 4). The vehicle contains a similar sensor set and the same software as Marilyn 2.0. The following sensors have been installed at the front of the vehicle:

- 3 SICK laser scanners, from which 1 HD LiDAR (110°/6.4°, range: 120 m)

- Continental SRR 20X Short range radars (150°/12°, 50 m)
- Vislab 3DV-E stereo camera
- DGNSS (GPS, Glonass) for positioning
- Vehicle CAN-bus connection for reading data from the vehicle.
- ITS-G5 and cellular LTE communication devices.

Figure 4: Sensor kit installed in VTT's pilot vehicle Martti

Figure 5 below shows the draft in-vehicle architecture of the prototype. DDS (Data Distribution Service) is used for the communication between the different components.

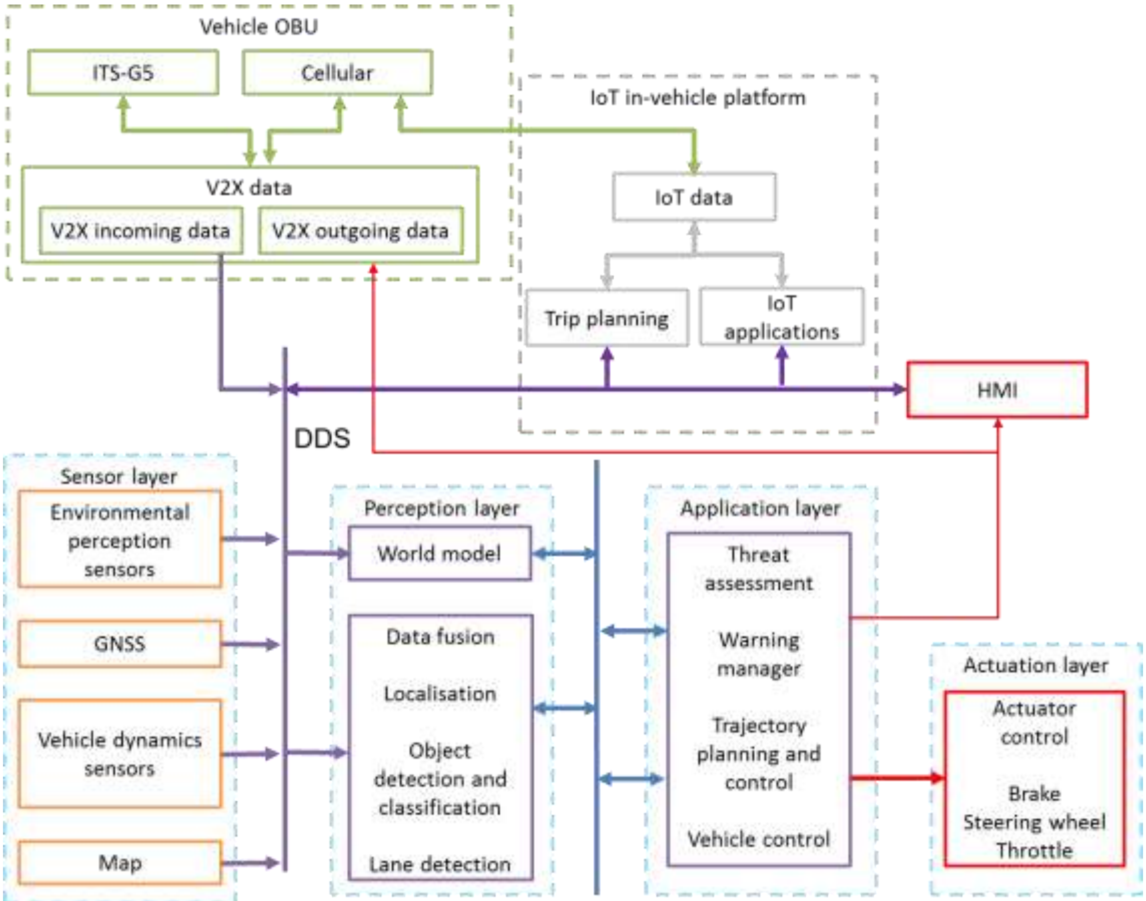

Figure 5: In-vehicle architecture of the Finnish prototypes

The architecture consists of the following layers:

- **Sensor layer**: environmental perception, location and vehicle dynamics sensors, and static maps.
- **Perception layer**: Data fusion of the different sensors, in order to localise the vehicle, to detect the lane, to detect and classify objects, to provide a detailed view of the objects around the vehicle and for planning the route to the destination.
- **Application layer**: Assessment of threats, warning manager (prioritisation, timing and modality of the warnings), trajectory planning and control, and control of the vehicle.
- **Actuation layer**: control of the different actuators, and control of the HMI.
- **Communication system** takes care of all communication of the vehicle, including ITS-G5 and cellular communications, and potential other communication methods. Communication includes V2X messages, complying with ETSI (CAM [5], DENM [6]) and IoT data. In order to ensure low latency, incoming V2X vehicles are directly made available in DDS, and V2X messages (CAM, DENM) transmitted to other vehicles.
- The **IoT in-vehicle platform** manages the IoT services:
    - urban driving support:
        - traffic light support (in case the message is not delivered in SPaT format)
        - traffic information on potential disruptions.
    - automated valet parking
        - control of the vehicle: setting destination (parking place), allowing to start, support during parking (e.g. improved location)

The following use cases will be demonstrated in Finland TS in Tampere:

- Urban driving: intersection support. Traffic signal data will be in real time collected from the traffic signal control system. Potential conflicts, observed by traffic cameras, will be transmitted to the vehicles.
- Automated valet parking: traffic cameras installed at the parking lot will assist the vehicle in the parking manoeuver.

3.3 Versailles: VEDECOM prototype

VEDECOM will provide 3 automated vehicles for piloting activities in AUTOPILOT:

Table 3: French prototypes / VED

Pilot Site	Owner of the prototype	Number of prototypes	Type	Use case
Versailles	VED	3	VFLEX (=Renault Twizy)	Urban driving, platooning, car sharing
	Total	3		

VEDECOM is going to develop 3 (VFLEX prototypes) for the French PS. A VFLEX is a prototype with automated driving functions made from a Renault Twizy which has been modified in order to perform Autonomous Driving uses cases.

Figure 6: Image of a French prototype

Thanks to VEDECOM's collaboration with Renault, the Twizy has been transformed in an open robotic platform (with an open access to the CAN bus of the vehicle). On top of that, the VFLEX is equipped with:

- CONTINENTAL radar ARS 408
- CONTINENTAL stereo camera
- Camera provided by TU Eindhoven
- VALEO ultrasonic belt (360° perception system)
- GNSS/RTK localisation with SBG inertial sensor

Figure 7: Overview of VEDECOM's prototype's sensors

The in-vehicle IoT platform (hardware and software) is guaranteed by CEA. The basic functions such as steering, breaking, throttling as well as the automation system, the handling of vulnerable road users and the generation of the trajectory are managed by VEDECOM. The software of the perception camera is going to be provided by TU Eindhoven.

The functional architecture of the VFLEX is described in the figure hereafter. This diagram shows the interactions internal to the vehicle. Data exchange between the vehicle and its environment is not represented here.

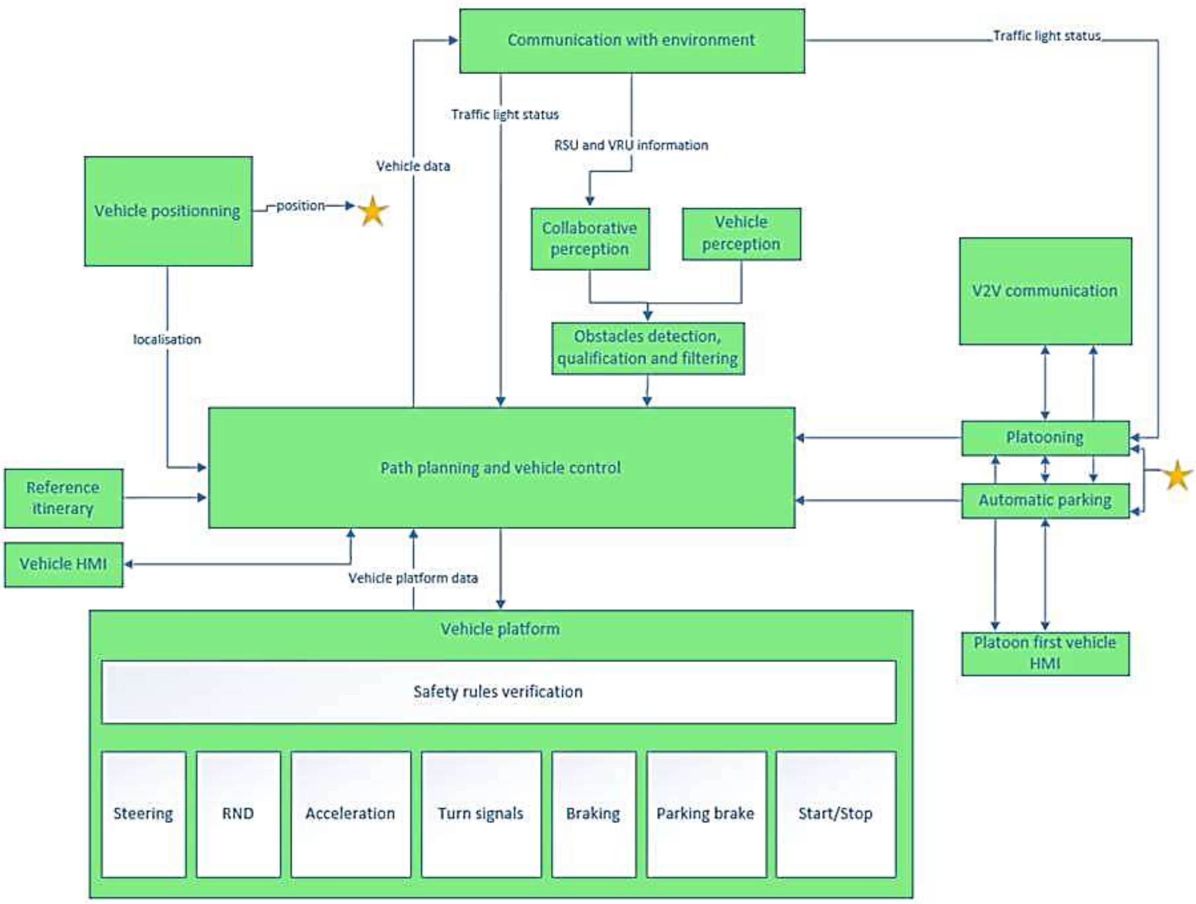

Figure 8: Functional architecture scheme of French prototypes

The main functions selected for French prototypes in 'autonomous driving' mode are:

- Follow a predefined itinerary
- Track and keep the driving lane
- Respect the road rules (stop at red light, stay below maximum speed, stop at stop signs etc.)
- Avoid obstacles (adapt speed, stop or change lane)

The main functions in 'platooning' mode are:

- Change direction by following the vehicle in front
- Stay at close distance to the vehicle in front

The main functions in 'automated parking manoeuvres' mode are:

- Exit a parking place
- Position behind a predefined vehicle
- Park in a specific parking spot

In order to achieve these functions, the system is going to have the following technical functions:

- Detect, qualify and filter obstacles (using direct or collaborative perception)
- Identify road rules (speed limit, traffic light state, stop signs, …)
- See road surface markings
- Locate the vehicle position
- Save a reference itinerary
- Start the vehicle (manually or wirelessly)
- Switch between the 4 driving modes: manual, autonomous, parking manoeuvres, platooning
- Change the vehicle direction

- Start the vehicle movement
- Accelerate the vehicle
- Regulate the vehicle movement at a constant speed
- Decelerate the vehicle (braking)
- Stop the vehicle
- Shut down the vehicle and activate parking brake
- Give signals (braking light, turn signals, horn…)
- Acquire driver's commands and inform the driver (HMI)
- Communicate with the environment (with traffic lights, road users etc.)
- Communicate with other vehicles

3.4 Livorno: CRF/AVR prototype

On the Italian PS, a fleet of 7 vehicles is planned to be operational for the piloting activities. Among these 7 vehicles, there will be:

- Connected prototypes (two provided by CRF and three by AVR):

The vehicles are equipped with a communication platform that provides both ETSI ITS G5 bidirectional communication and LTE connectivity. They are also equipped with some sensors to get information from the environment and with an on board unit that elaborates the collected information to give warning notifications to the driver or to broadcast aggregated information to the other road users.

- Connected and automated prototype (two provided by CRF):

The two connected and automated prototypes are equipped with the same kind of devices as the vehicles described above. Some modules are added onto the prototype in order to enable automated driving functionalities. The outputs of these devices permit the control of the actuators (breaking and steering system, adaptive cruise control) that manages the vehicle behaviour.

Figure 9: Jeep Renegade, vehicle model used on the Italian PS (source: Jeep official website)

Table 4: Italian prototypes / CRF-AVR

Pilot Site	Owner of the prototype	Number of prototypes	Type	Use case
Livorno	CRF	2	Jeep Renegade – connected + AD	Highway pilot / Urban driving
	Total	2*		

*The other 5 vehicles are not listed in the table as they are connected, but not automated.

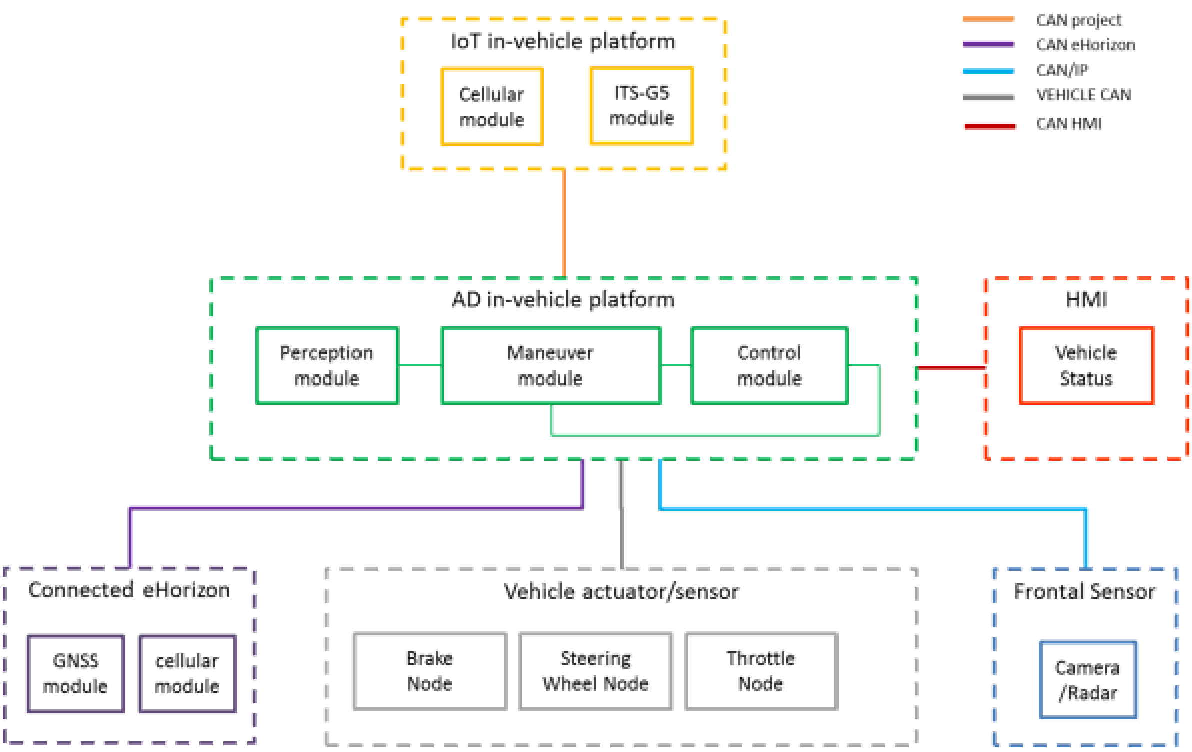

Figure 10: Generic in-vehicle architecture of the Italian AD prototypes

The architecture of the Italian AD prototypes consists of the following layers:

IoT in-vehicle platform:
This block enables the ITS-G5 and oneM2M (cloud) communication between vehicle and infrastructure. Moreover, it cares the IoT in-vehicle applications and devices.

AD in-vehicle platform:
This block enables for the equipped vehicles the autonomous driving. The inputs are the signals coming from vehicle sensors, IoT cloud, and human driver. Based on this information it decides which manoeuvre has to be performed. The outputs are the signals for the vehicle actuators and the information to human driver through the HMI.

Vehicle actuator/sensor:
This block performs the actuation of the commands coming from the AD in-vehicle platform and gives feedback on current status of the sensors.

Connected eHorizon:
The role of this block is to predict the most probable path that the vehicle will perform given the current position and updated information on traffic, road blocks, etc. coming from the cloud.

Frontal sensor:
The role of this block is to give information of the external world in front of the vehicle. The result is forwarded to AD in-vehicle platform for the perception and scenario construction.

HMI:
This block informs the human driver about the AD in-vehicle system status.

The architecture of the Italian connected prototypes consists of a subset of the previous blocks:

- IoT in-vehicle platform
- HMI (optional)

3.5 Brainport prototypes

All vehicles used in the Brainport (TNO, TUE, VALEO, DLR) have the same in-vehicle high level architecture. It is shown in the scheme below:

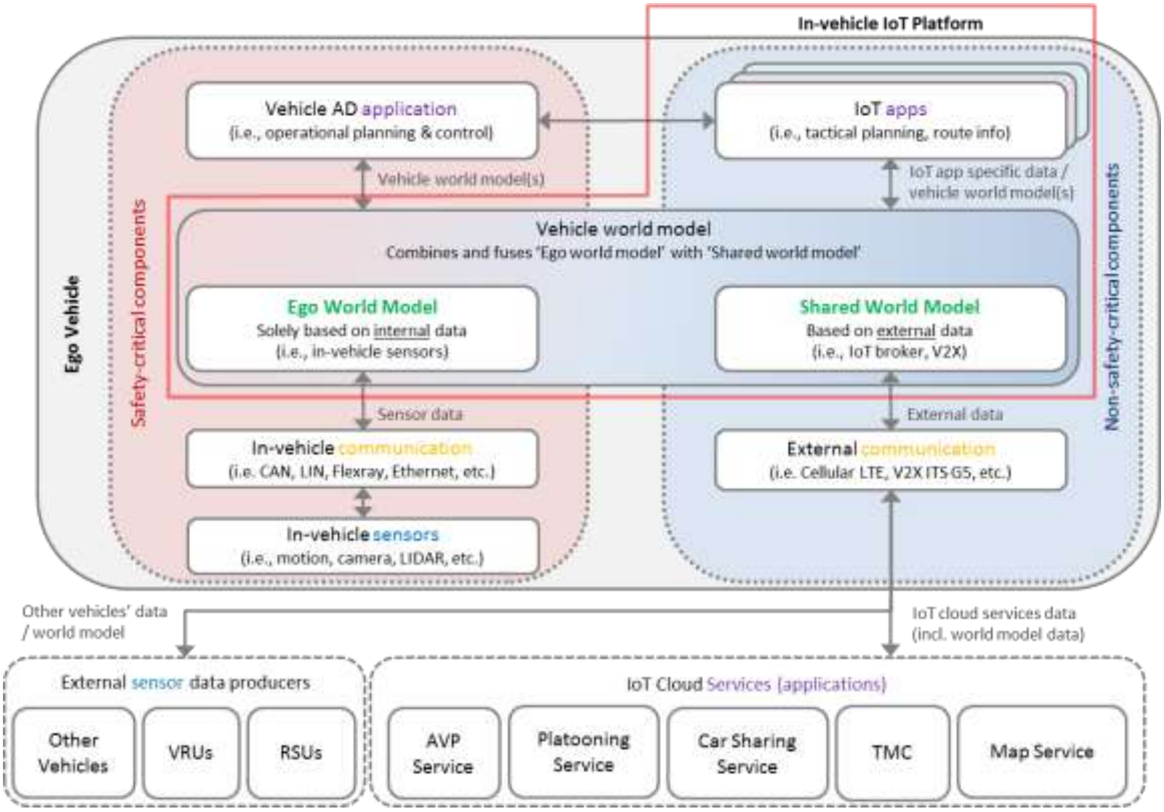

Figure 11: Brainport in-vehicle high level architecture

Table 5: Dutch prototypes / TNO

Pilot Site	Owner of the prototype	Number of prototypes	Type	Use case
Brainport	TNO	3	Toyota Prius	1 vehicle used for AVP and all 3 vehicles used for platooning.
	TU/e	1	Toyota Prius	Urban driving
	TU/e	3	VFLEX (=Renault Twizy basis)	
	Valeo	1	Volkswagen Tiguan 2	Highway pilot (obstacle detection and road surface scanning)
	DLR	1	Volkswagen e-Golf 'FASCar-E'	Automated valet parking
	Total	9		

3.6 Brainport: TNO prototype

TNO will present three modified Toyota Prius equipped with additional sensors to support automated driving functions for piloting activities in AUTOPILOT:

Figure 12: TNO's prototype

The general vehicle architecture of hardware components is shown in the figure below:

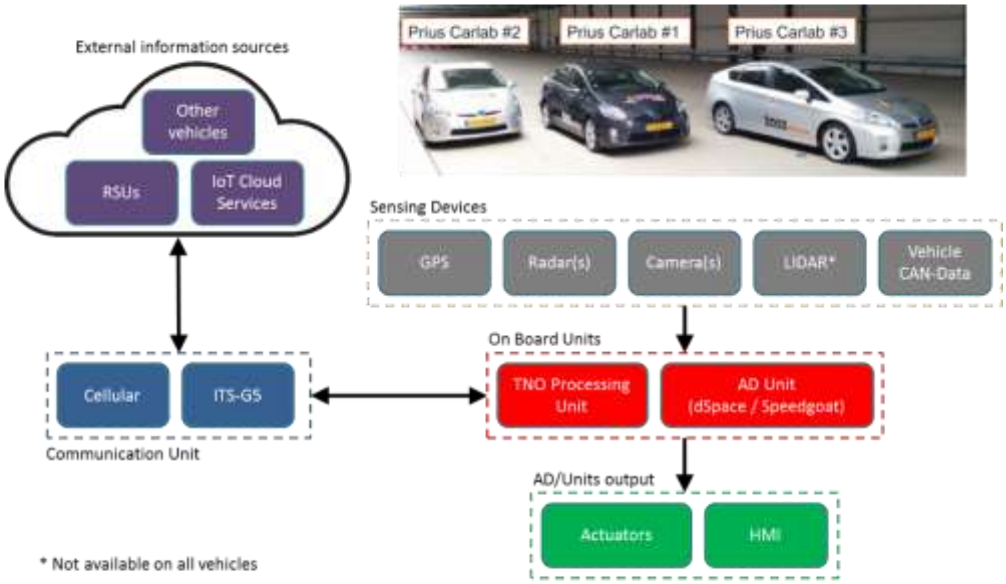

Figure 13: TNO's vehicle architecture

The vehicle architecture is organised in the following component groups:

Communication unit: device that processes network data coming from two interfaces:

- Cellular: Cellular interface LTE (-V2X) to Tx/Rx information from IoT cloud services.
- ITS-G5: Wireless communication module based on ITS-G5 technology to communicate with vehicles in the neighbourhood and with the road infrastructure (roadside units).

Sensing devices:

- GPS module: It estimates the position of the vehicle (latitude, longitude, heading, speed). RTK-GPS might be used to enhance the positioning precision.
- Radar(s): Radars generate point cloud data of the environment that can be used for tasks such as localisation and object detection.
- LiDAR *: LiDAR will be optionally used to generate precise point cloud data of the environment that can be used for tasks such as localisation.
- Camera(s): (Stereo-) camera(s) are used to get images of the environment that can be used for tasks such as object classification and scene understanding.

- Vehicle CAN data: It provides data from sensing devices installed in the normal production vehicle as odometers, accelerometers, information on the vehicle state, etc.

On board units:

- TNO processing unit: It processes and fuses data coming from sensors and from the communication unit to create 'world model' data that it is needed internally by vehicle components such as the path planner. Also, it shares the world model data with external entities via the communication unit.
- AD Unit: It is the component responsible for control related functions that will send commands to actuators in the vehicle.

AD/Units outputs:

- Actuators: components that act on the commands determined by the AD Unit to control basic vehicle functions such as steering, braking and acceleration.
- HMI: shows data currently being processed in the on board units.

The TNO Toyota Prius vehicles will be connected to a stream service for HD map delivery developed by TomTom. Further, the additional RTK-GPS localisation system will receive correction signals from an NTRIP (Networked Transport of RTCM via Internet Protocol) service

3.7 Brainport: TU/e prototype

TU/e will provide four automated vehicles for piloting activities in AUTOPILOT: 1 Prius and 3 VFLEX.

TU/e will start with using two different vehicles: a Toyota Prius and a VFLEX from VEDECOM for implementation and execution in the Brainport TU/e Car Rebalancing (Urban Driving) use case. Both vehicles have a basic Automated Driving functionality which can be controlled from a real time target (AD unit), but differ partially in sensory input.

Figure 14: TU/e's prototype Toyota Prius

For the first implementation phase the Prius is going to be used. For the final use case pilot testing, TU/e plans to equip 3 VEDECOM vehicles in total (as described in 4.1.3) to demonstrate the rebalancing use case on TU/e campus.

Figure 15: VEDECOM's prototype VFLEX also used by TU/e

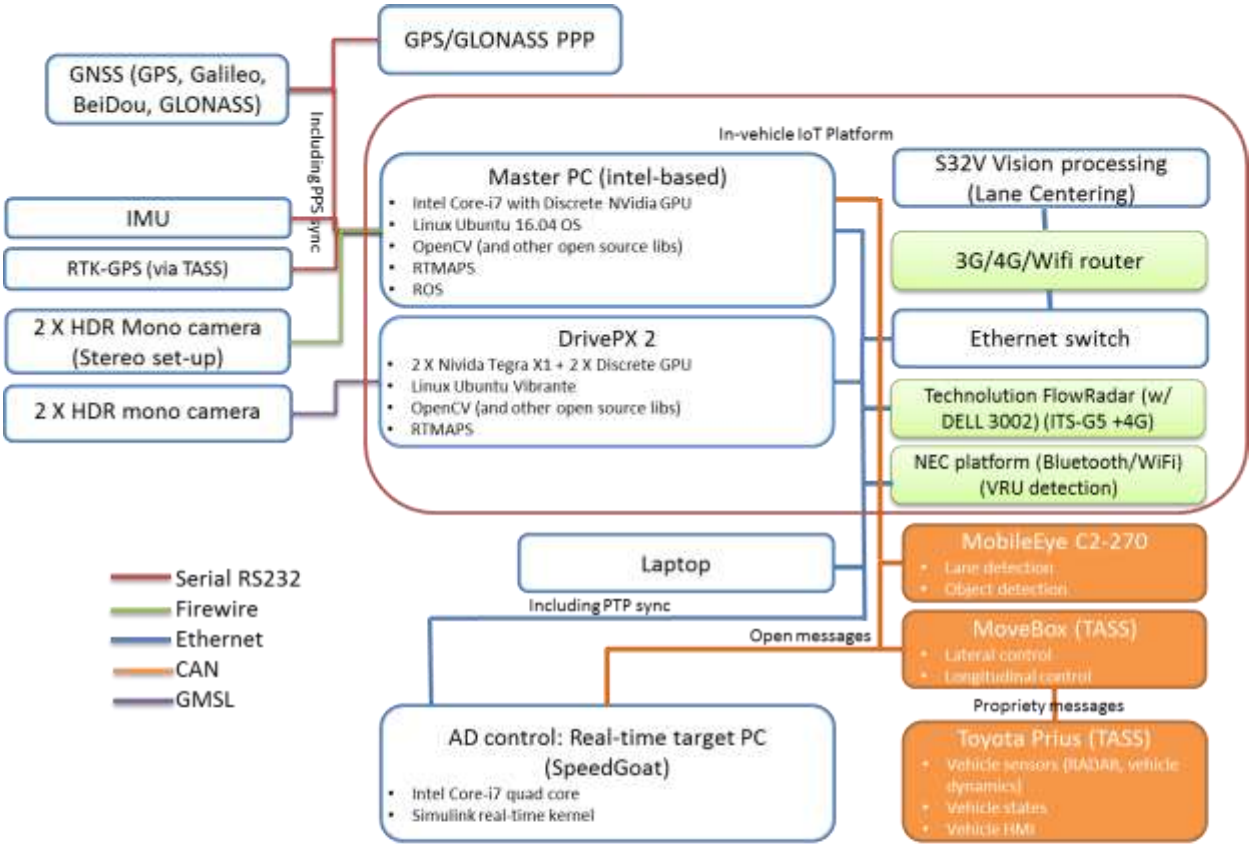

Figure 16: TU/e's prototype hardware architecture

3.8 Brainport VALEO prototype

Valeo will provide one automated vehicle for piloting activities in AUTOPILOT. It comes equipped with an Adaptative Cruise Control (ACC) and a Side Assist for Traffic Jam. This specific model was selected because of its generic MQB platform[4] developed by Volkswagen, which Valeo has experienced in upgrading to AD level. The vehicle will be equipped with the additional sensors and platform needed to conduct the obstacles detection and the road surface scanning that power the use case.

Figure 17: Valeo's prototype

[4] https://en.wikipedia.org/wiki/Volkswagen_Group_MQB_platform

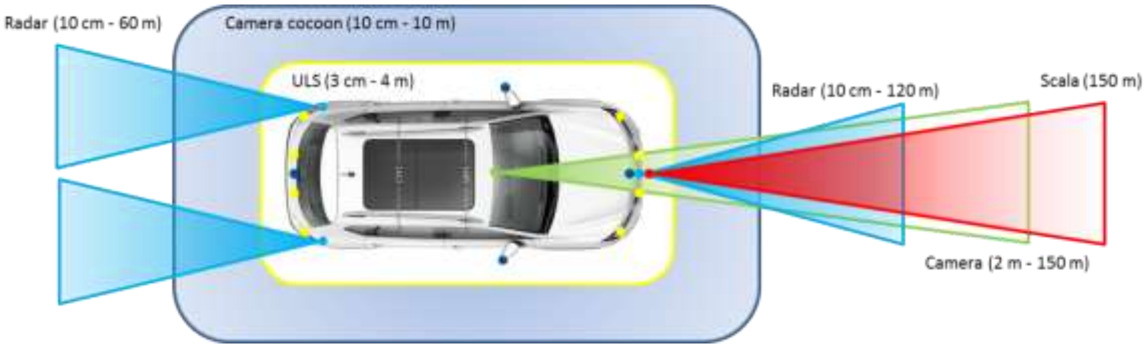

Figure 18: Sensors of Valeo's prototype

The simplified functional blocks view below illustrates how in-car IoT devices (aka sensors) and the ACC/AD control system connect to the Valeo smart platform (our in-vehicle IoT platform). It is worth pinpointing that the ACC/AD control system keeps its direct link to sensors and functions, without critically relying on the added link to the Valeo smart platform. Also, this added link goes both ways: information of the ACC/AD control system could (and will) be retrieved in the Valeo smart platform.

As such, the developments supporting the use case can be considered as an add-on module, whose information will serve as complementary aid to the functionality of the ACC/AD control system. This aid will be mediated by a secure agent that will pass on suggested new speed limit, increased safety distance. Ultimately the ACC/AD control system shall preserve its isolated integrity and sole action on actuators.

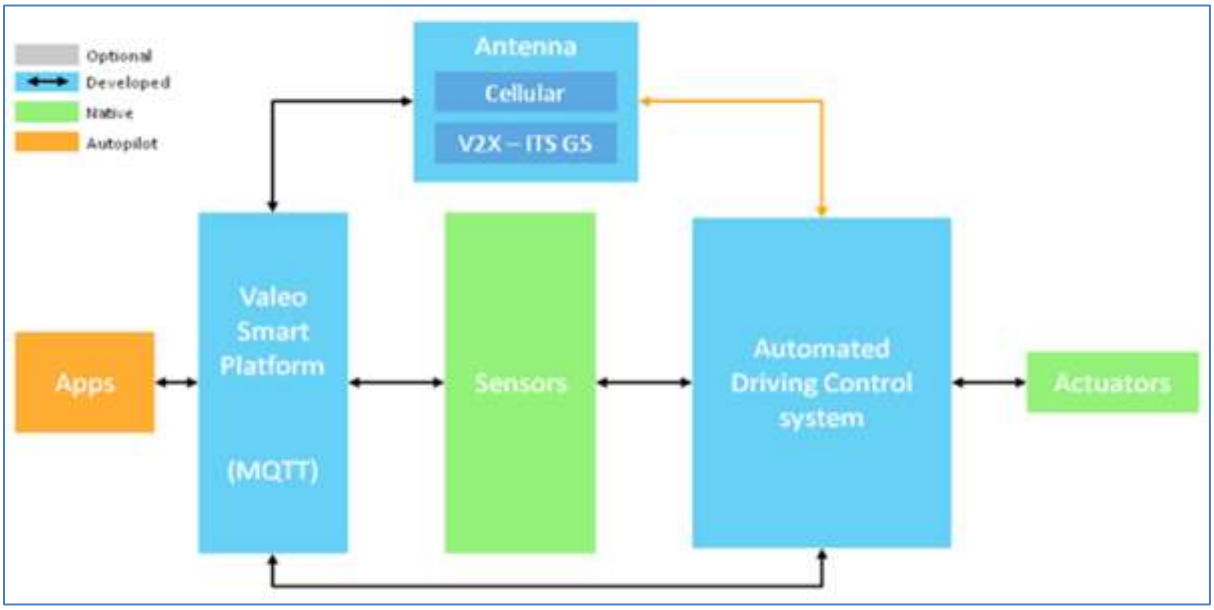

Figure 19: Functional view of the Valeo prototype

The functional blocks can be further described:
Apps: most important for the use case, we will mention:

- a specific HMI application that shall relay alerts/driving instructions about road hazards
- a bridge with the embedded HD-maps solution
- a near real-time module that will perform the road scanning
- a service that will package relevant sensors data for upload whenever peculiar events are observed (which may be later be analysed and confirmed as actual hazards)
- a service that will manage broadcasting alerts in case of critical/serious obstacles observation

Valeo Smart Platform:

- a MQTT broker that handles subscriptions and messages across all the components

- note that actual video and LiDAR streams will be controlled via messages through this broker but carried through direct links not appearing on the diagram

Sensors: includes LiDAR (Valeo Scala), front camera, radar, ultrasound, cocoon cameras, CAN, GNS, etc.

Antenna: manufactured by Valeo, this integrated antenna will handle both ITS-G5 communication (for time critical messages) and 4G cellular communication (most of the time, in particular for data upload)

ACC/AD control system

- VW system including lane detection, trajectory, pedestrian detection, mission planning, object detection, traffic signs detection
- an additional secure agent will mediate extra external information to these.

Actuators: components controlling steering, speed, braking

3.9 Brainport: DLR prototype

DLR will provide one automated vehicle for piloting activities in AUTOPILOT: a Volkswagen FASCar-E.

Figure 20: DLR prototype vehicle *"FASCar-E"*

The FASCar-E[5] is an electric 7th generation Volkswagen Golf. It is equipped with a 115-hp electric motor. Taking into account all the build in technology, its range is approximately 130 km (80 miles). Its main goal is to conduct research in the field of automation in public urban scenarios. The vehicle in its series-production state does not support any interventions into lateral or longitudinal controls except for the driver's actuators. Therefore, the vehicle had to be modified to enable access to the CAN bus. Longitudinal control is realised by rerouting the signals of the adaptive cruise control (ACC). The lateral control accesses the active park assist system. The use of OEM systems was particularly important in order to receive homologation for public roads. Furthermore, additional sensors and communication devices were equipped to improve positioning and environmental perception. For environment recognition and vehicle localisation FASCar®-E is equipped with four laser scanners and three long range radars which are mounted in front and rear bumpers of the vehicle (see Figure 21), as well as an inertial measurement unit (IMU) with GPS aiding. A C2X-System is used for vehicle-to-infrastructure and vehicle-to-vehicle communication

[5] DLR Institute of Transportation Systems. (2017). Experimental vehicles FASCar®-II and FASCar®-E, Journal of large-scale research facilities, 3, A111. http://dx.doi.org/10.17815/jlsrf-3-147

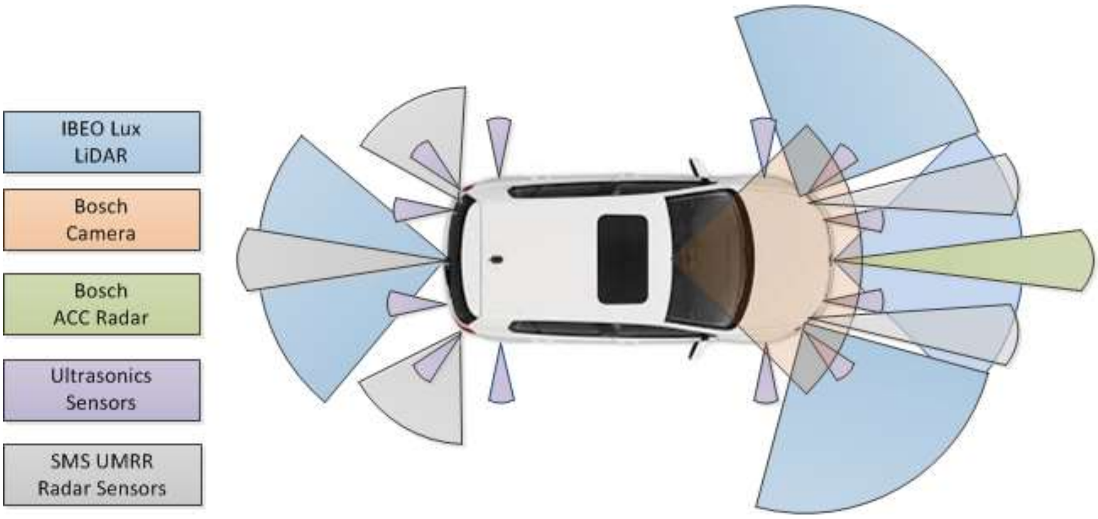

Figure 21: Radar and optical sensors of DLR's prototype

Error! Reference source not found.22 shows an outline of the vehicle architecture. Components to be adapted or implemented in AUTOPILOT are coloured green. The vehicle as a whole will act as an IoT device which connects to the AUTOPILOT IoT platform over cellular network. The necessary interfaces are provided by the IoT gateway. Based on the IoT information the sensor fusion will enhance the world model based solely on the vehicle's own sensors to a shared world model. The automated driving functions will be adapted to benefit from the additional information gained.

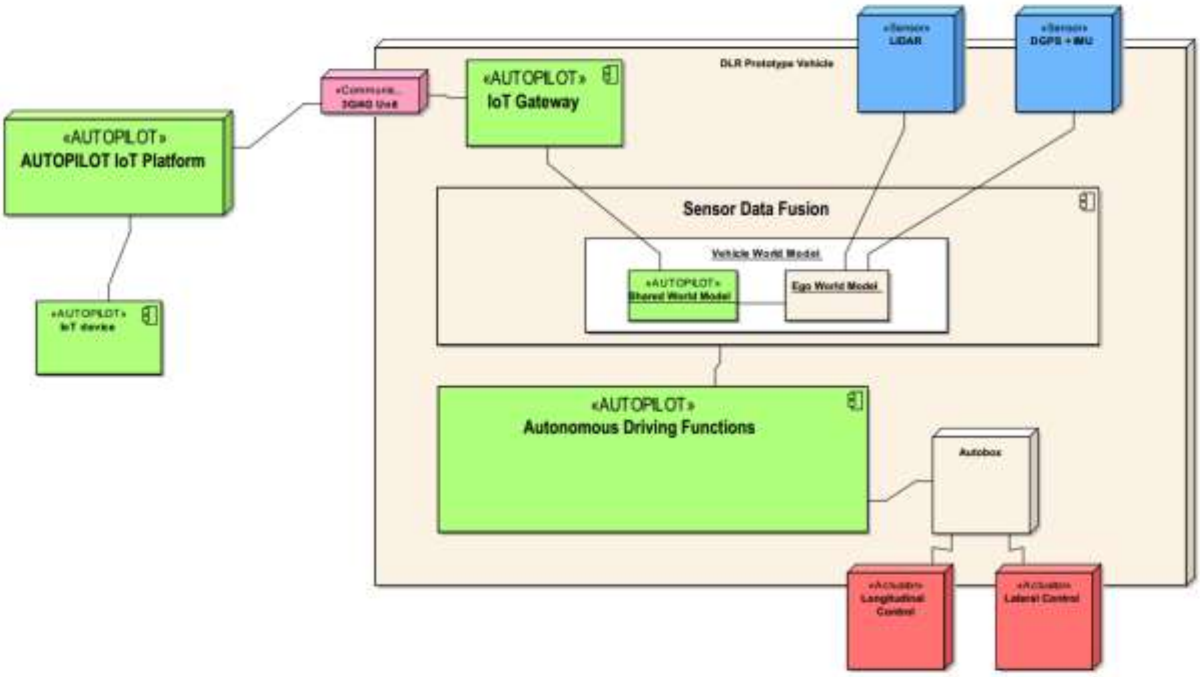

Figure 22: In-vehicle architecture of DLR's prototype

3.10 Vigo: CTAG prototype

CTAG will provide 3 automated vehicles for the Spanish piloting activities of AUTOPILOT:

Table 6: Spanish prototypes / CTAG

Pilot Site	Owner of the prototype	Number of prototypes	Type	Use case
Vigo	CTAG	1	PSA C4 Picasso	AVP, Urban driving
	PSA	2	PSA C4 Picasso	
	Total	3		

All the vehicles will be delivered with an IoT vehicle platform and the necessary automatic driving functions to support the use cases deployed in Vigo:

- Urban driving: in this use case the prototype will be able to adapt the speed according to the status and remaining time to change of traffic lights and will react in advance to potential warnings received by IoT Sensing about hazards provided by TMC or other vehicles (pedestrian, accident, road works…)
- Valet parking: in this use case the prototype will establish a connection with the parking infrastructure through the IoT in-vehicle platforms and will have access to information from parking cameras and sensors together with parking mapping and instructions (such as 'free lane: you can leave parking space') according to internal traffic.

The following sensors have been installed into the vehicle:

- Corner medium range radars (150° and 80m)
- 1 camera at the front (60° and 50m)
- 1 2D LiDAR sensor at the front (135° and 200m)
- 1 3D LiDAR sensor on the top (360° and 100m)
- 12 Ultrasound sensors (120° and 3m)

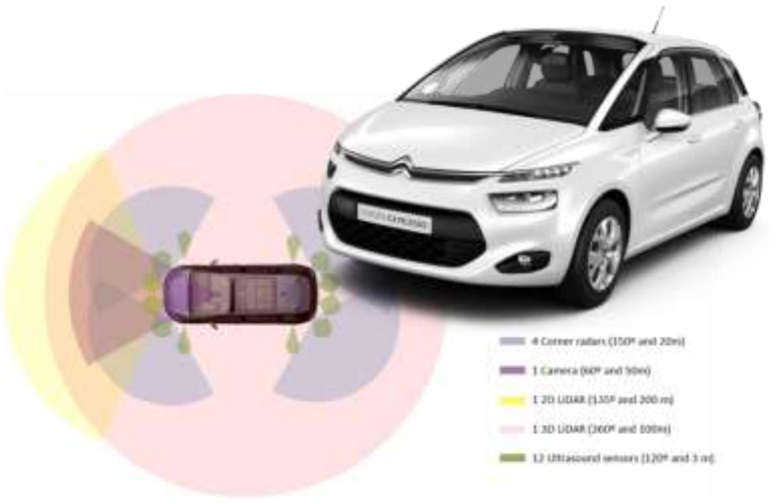

Figure 23: Sensor configuration on the CTAG prototype

The in-vehicle architecture of the Spanish prototypes is described in the figure below. The components in grey are the existing ones in the current AD architecture and the orange components (cf. *"current OBU + IoT in-vehicle platform"*, *"IoT sensors/devices"*) are the new ones related to the IoT-enhancement.

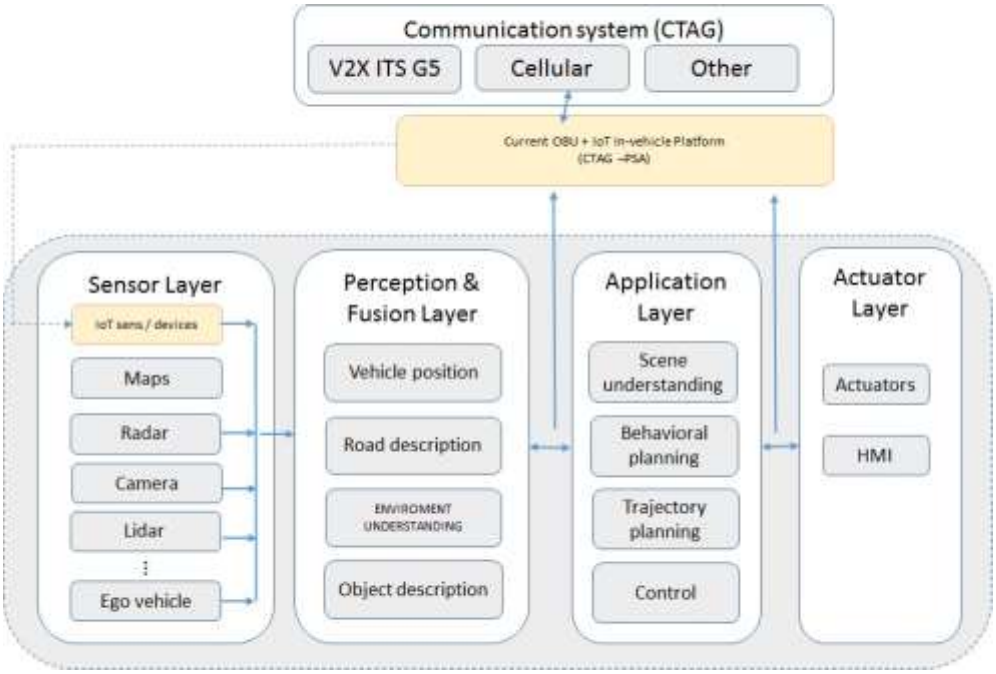

Figure 24: Global in-vehicle architecture of the Spanish prototypes

The different components of the architecture are described hereafter:

- Communication system: is the component responsible for the V2X communication using 802.11-OCB, cellular communication and all other that could be necessary during the project.
- IoT in-vehicle platform: is the responsible to convert the vehicle in a Thing in the IoT environment with the capacity to be a data provider or data consumer. Using IoT in-vehicle platform the vehicle can communicate directly to other *"Things"* in his environment, as it does using V2X communication, or all those other sources/consumers of data can be made available via IoT.
- Sensor layer is comprised of the physical and virtual sensors. For some of those sensors, a pre-processing algorithm is implemented. For LiDAR and camera data a clustering and tracking algorithm are applied to obtain a list of objects with certain level of confidence for further fusion.
- Perception and Fusion Layer is responsible for the selection of data from different types of sensors exploiting the better of each one. With this information, the logic Layer is implemented with fusion algorithms, in order to construct the environment perception.
- Application layer: in this layer with the information provided by the previous layer of the environment and the positioning of the vehicle, the behaviour of the vehicle it is decided, the path which is going to be followed and the control of the different actuators (engine, break and steering wheel).
- Actuator layer: is comprised of the actuators like engine or break and the HMI systems like head display, instrument cluster or head unit.

4 Automated driving functions of the vehicle prototypes

Chapter 4 describes the automated driving functions of the vehicle prototypes and is structured per pilot site. Each section is then split in two sub-sections:

1. The *existing automated driving functions* of each prototype are described before they have been adapted to perform the AUTOPILOT use cases.
2. The *adaptations made to the automated driving functions* in order to take into account the new sources of information coming from the IoT technologies, are presented.

4.1 Tampere: VTT prototype

4.1.1 Existing AD functions

In AUTOPILOT, the automated driving prototypes are used for the urban driving (intersection support) and AVP functions. The following functions are in the vehicle prior to the adaptations for the AUTOPILOT project:

World model
The information coming from the vehicle sensors and status data from other vehicles, transmitted as CAM V2X messages, are fused.

Path planning
The vehicle path is currently based on previous measurements of the vehicle path. The vehicle path can also be calculated off-line, and downloaded to the vehicle.

Longitudinal and lateral control of the vehicle
The longitudinal and lateral control is based on the planned path and the vehicle's location. Based on the vehicle's current position and velocity, as well as potential objects on the vehicle's path, the vehicle's target speed and heading are calculated. Based on this information, brake, throttle and steering wheel are controlled.

HMI
The vehicle is equipped with a simple HMI, which can show the projected path of the vehicle, the position of the vehicle and other objects on the path.

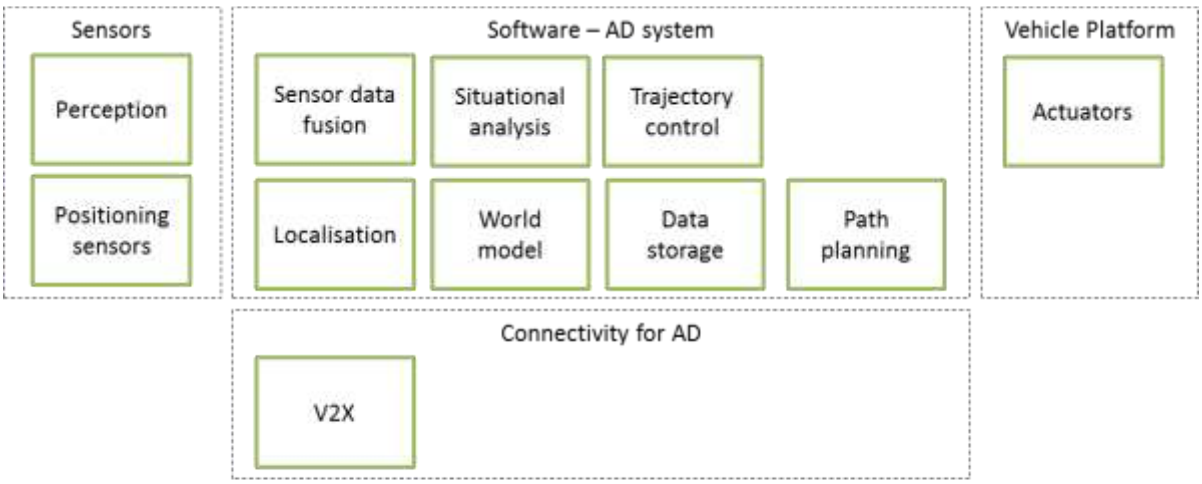

Figure 25: AD functions of the Finnish prototype

4.1.2 Adaptation of AD functions

In the Finnish pilot two use cases will be piloted: automated valet parking and urban driving.

In both use cases, the vehicle path will be updated based on information on objects provided by traffic cameras. The traffic camera will identify objects in the field of view of the camera, and publish the information to the IoT platform, which will forward it to subscribers to the information (like the vehicles).

In the urban driving use case, the vehicle will also receive information from traffic lights. Traffic light status information will be received from the traffic light provider.

For automated valet parking the vehicle had to be adapted, in order to be able to drive safely backwards. The following changes were made to the vehicle:

- Adding the possibility for the vehicle to drive backwards, and to start moving without the driver. An actuator was added to control the gear lever, and functionalities for trajectory control while driving backwards were implemented.
- Adding sensors to the rear of the vehicle, in order to detect obstacles during backwards manoeuvring, and to the side of the vehicle, in order to avoid collisions with other parked vehicles during the parking manoeuver.

In order to allow the automated valet parking and urban driving use cases, the following functions have to be modified:

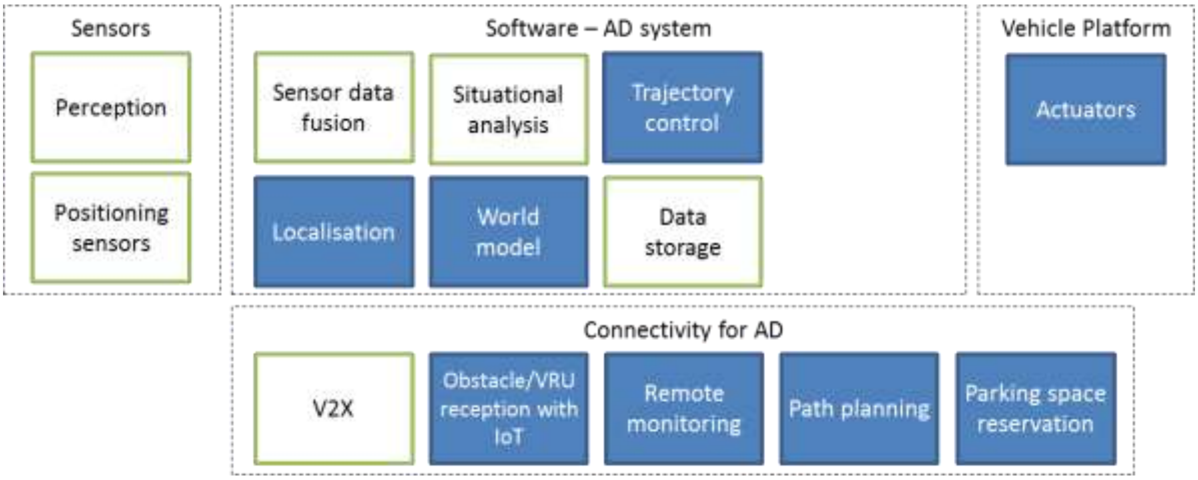

Figure 26: Adapted AD functions of the Finnish prototype with IoT

- <u>World model</u>: the information on objects coming from the traffic cameras have to be integrated in the World model. In addition, the status of the traffic lights has to be integrated for the longitudinal control of the vehicle.
- <u>Path planning</u>: for the automated valet parking, the plan can be transmitted as IoT data from outside the vehicle.
  - For automated valet parking, algorithms for path planning for parking, including reaction on objects have to be developed.
  - For the urban driving pilot, algorithms have to be included for giving way to VRUs, i.e. the vehicle should stop before the crossway until the VRU has passed. For the pilot, the VRU can be informed through a string of LEDs which is attached to the front of the vehicle.
- <u>Vehicle positioning</u>: The position of the vehicle can be improved through use of the UWB technology. This has been demonstrated by VTT using technology from HERE. The HERE

indoor-positioning system uses a network of beacons installed in the parking place, and one (or two) UWB-receivers at the vehicle. The beacons at the vehicle calculate the position of the vehicle from the signals transmitted by the UWB beacons installed at the parking place.

- Longitudinal and lateral control: In addition to forward longitudinal control, the vehicle also has to be able to drive backwards during parking, and be able to avoid obstacles during the parking manoeuver.
- Reservation of the parking place: The vehicle reserves a parking place from the reservation system, which is developed in the 'Transforming Transport' project.
- Implementing unmanned mode:
    - This includes connection to a monitoring centre. For this purpose, video is transmitted to a monitoring centre.
    - It also includes starting the vehicle to drive to the parking place when the driver has left the vehicle
    - In case of an emergency, the monitoring centre sends a message to the vehicle forcing it to stop.

4.2 Versailles: VEDECOM prototype

4.2.1 Existing AD functions

In AUTOPILOT, the automated driving prototypes are used in 3 use cases: urban driving, platooning and car sharing. These are high level use cases for which the vehicles need to have both longitudinal and lateral automation, i.e. accelerating/braking and steering. In the vehicle these functions are realised by using several other lower level automated driving functions:
World model and vehicle sensors
Here all information obtained from both in-vehicle sensors and V2X communication is collected and processed.

HMI
The user can activate or turn off the automated driving mode through the HMI installed in the dashboard of the vehicle. The HMI is also able to display the system information to the user.

Longitudinal control of the vehicle
In the urban driving use case, the longitudinal control is set according to the itinerary and the vehicle's location. In the platooning use case, the speed is computed based on the information of the vehicle ahead (detected by the sensors or with V2V communication). In all use cases, longitudinal control is also set based on the collision avoidance functionality.

Lateral control of the vehicle
The vehicles have an automated steering function. A lateral controller generates a steering angle set point for the steering system low-level controls. Different functionalities exist depending on the use case:

- Automated lane keeping: camera line information is used to steer the vehicle in the lane;
- Vehicle following: tail of preceding vehicle is followed;
- Path following: following a pre-determined path, e.g. RTK-GPS waypoints

The AD functions of the VEDECOM prototype are described in the following scheme:

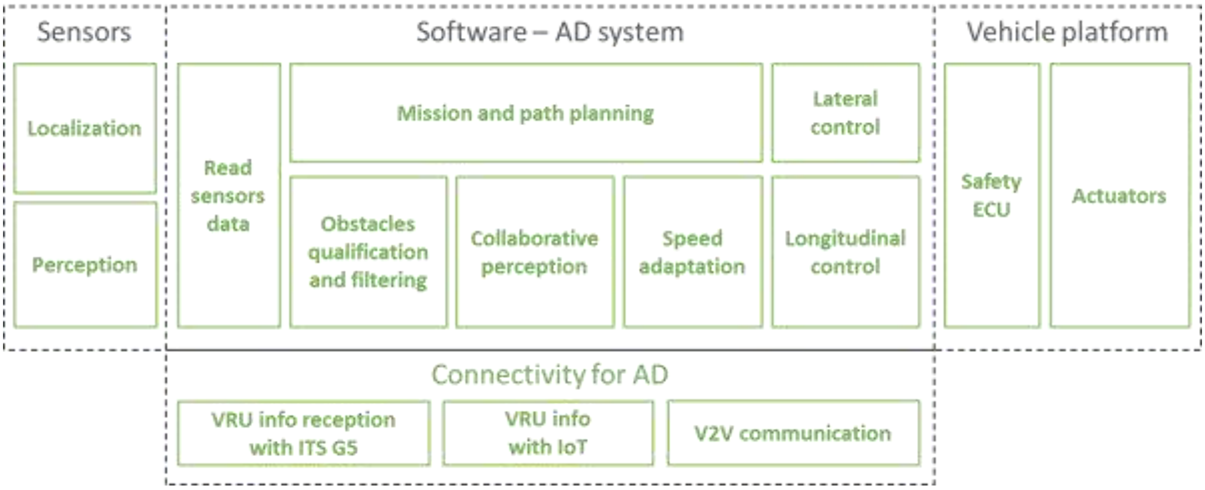

Figure 27: AD functions of the French prototype

4.2.2 Adaptation of AD functions

The French PS counts three use cases, car sharing, urban driving and platooning, but only two of them, urban driving and platooning, are relevant to mention in this chapter. Indeed, the automated driving functions of the prototypes performing these two use cases have to be adapted in order to take into account the IoT.

The following questions illustrate the added value of IoT:

- Urban driving (collaborative perception):
    - To what extent can the IoT improve the communication with the traffic lights? (IoT considered as accelerating AD – see table 1 of WP4.1 internal report)
    - To what extent can the IoT help to widen the vehicles perception / detect VRU? (IoT considered as enhancing AD – see table 1 of WP4.1 internal report)

- Platooning:
    - To what extent can the IoT improve the communication with the traffic lights and help receiving traffic information? (IoT considered as enhancing AD – see table 1 of WP4.1 internal report)
    - To what extent can the IoT contribute to improve the performance of the platooning system (plan a mission efficiently; manage crossroads, minimise the distance between the vehicles forming the platoon?) (IoT considered as enhancing AD)

In order to perform these two uses cases, the functions highlighted in blue in the scheme below have been modified in order to integrate new inputs coming from the IoT.

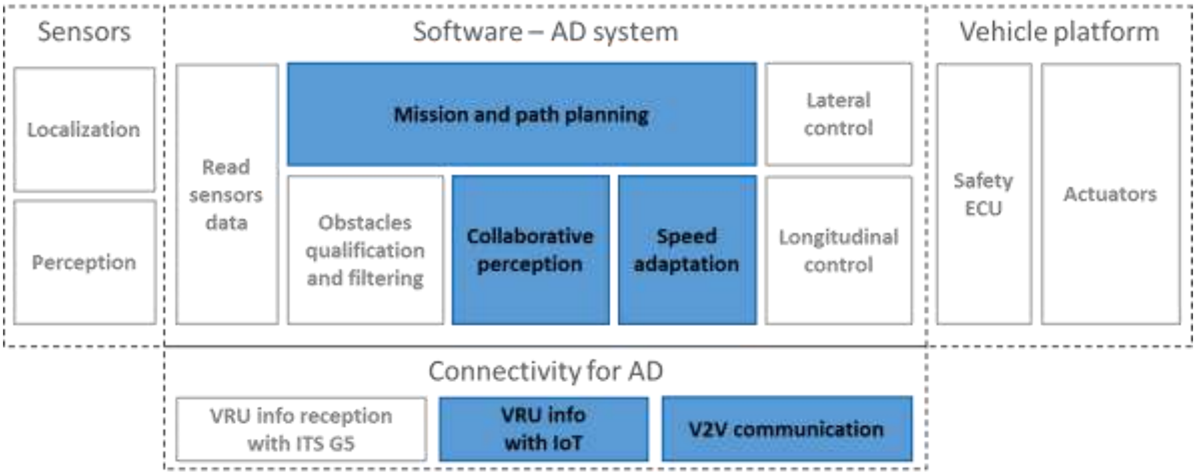

Figure 28: Adapted AD functions of the French prototype with IoT

Note to the reader: The developments related to the platooning use case are still ongoing in M18 (date of the submission of this deliverable), as this use case will be performed on the French PS from M24 onwards.

4.2.2.1 Urban driving / collaborative perception

The collaborative perception relies on the exchange of information between all road users in order to increase the capacity of perception of a single road user (vehicle and vulnerable road user). In particular, the safety of VRUs is improved through collaborative perception because the vehicles and the VRUs are both informed of a critical situation. In order to propose this new service, it uses direct communication (ITS-G5, WLAN…) as well as cellular communication for exchanging data with the IoT Cloud as illustrated in Figure 29: Collaborative perception.

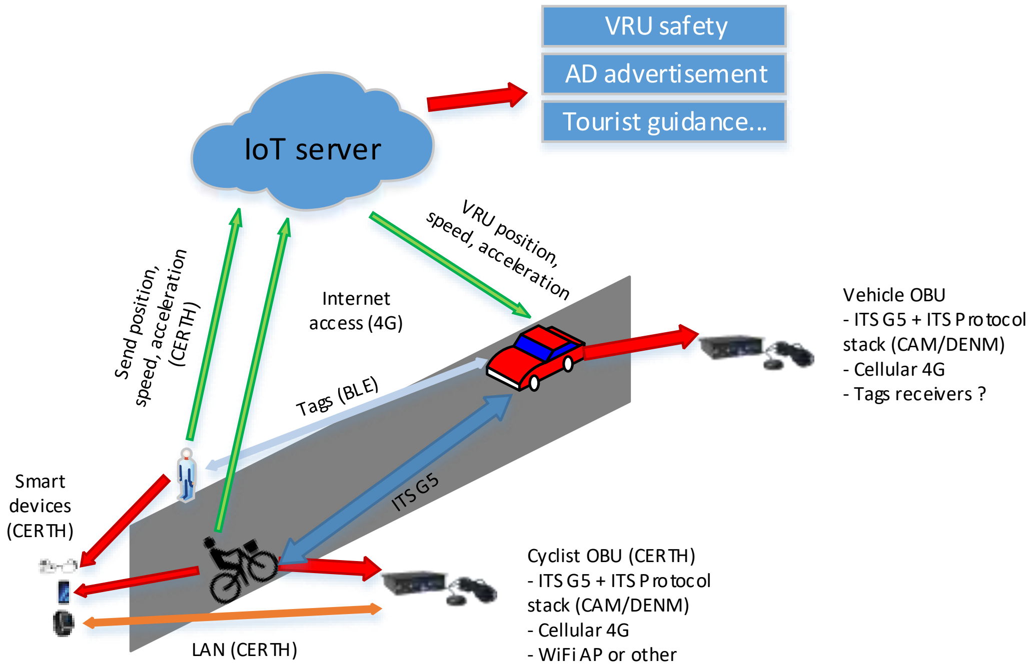

Figure 29: Collaborative perception

Within the AD system of the vehicle, the collaborative perception is in charge of fusing the information obtained from the local embedded sensors via a local perception module and the information obtained from the V2X communication using cooperative awareness messages (CAM) and data concerning vulnerable road users available at the IoT platform. Figure 30: Functional description of the collaborative perception system of the French prototypesbelow shows the different functions of the collaborative perception module installed in the vehicle.

From the lists of detected object given by the local perception and the V2X communication system, **a cooperative fusion function is introduced** to:

- Construct an augmented perception of the local environment surrounding the vehicle, particularly, to handle the uncertainties due to occluded zones and to improve the precision of the information obtained from the multiple sources (local perception and V2X communication)
- Ensure consistent information and prevent from failing of the local perception system and/or the V2X communication system

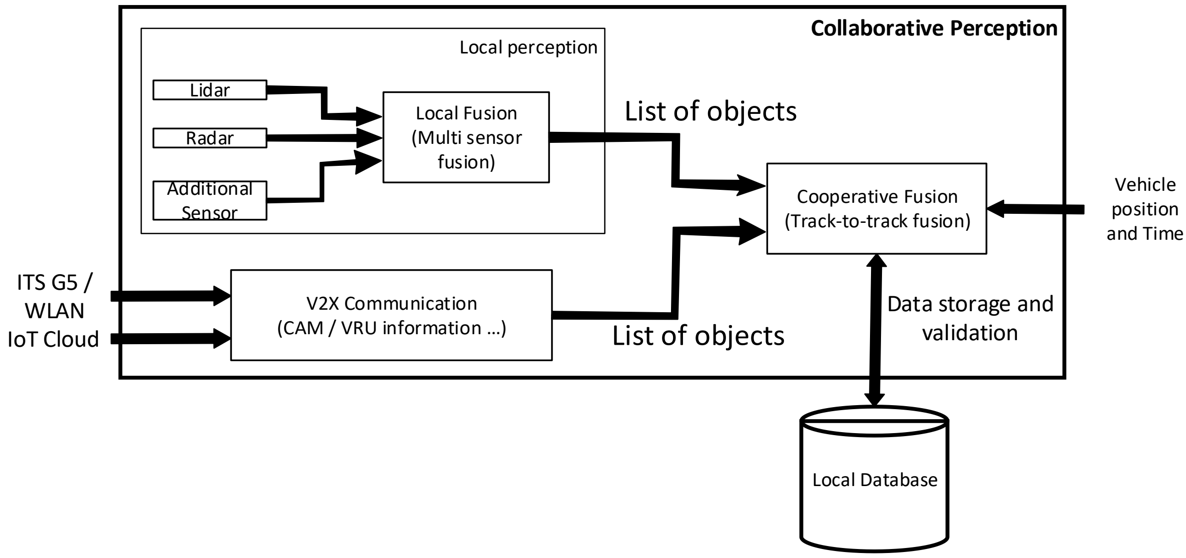

Figure 30: Functional description of the collaborative perception system of the French prototypes

Finally, the list of objects obtained from the cooperative fusion function is stored in a local database that should be accessible in real time. In such a way, a supervision system can subscribe to the local database in order to be provided with the list of objects located in the extended environment of the ego vehicle. In order to install the cooperative fusion, it is required for every information source (local perception or V2X communication) to provide:

- An identification about the type of information source
- A description of the observation zone (size, shape, position of the zone)
- A list of object detected inside the observation zone.

The type of every object (dynamic object, navigation lane…) is initially provided and every object is then described by its specific characteristics (position, speed, object class…). In addition, confidence values have to be given for every detected object.

4.2.2.2 Platooning

The platooning consists of creating convoys of virtually linked vehicles which travel along the same path and act as one unit. These vehicles follow one another with small headway-vehicle spacing. The first vehicle, called *"leader"*, can be driven in manual or autonomous mode (but will only be driven in manual mode for the platooning). In addition, it transmits the required information to the other vehicles of the platoon, called *"followers"*, so they can follow it in autonomous mode. The autonomous vehicles move with the same speed as the leader and they keep a predefined distance between each other.

The urban platooning use case is considered, for the French PS, as a part of the fleet rebalancing between car sharing stations. The detailed information about this use case can be found in the deliverable 1.1. Anyway, the platooning component implies several automated driving functions such as path planning, speed adaptation, longitudinal and lateral controllers.

Including IoT in the development of automated driving functions for urban platooning will allow to:

- Plan a mission efficiently
- Ensure the integrity of the platoon while crossing crossroads controlled by traffic lights
- Enhance the lead vehicle path estimation

However, in order to set up a safe urban platooning, the automated driving functions must be adapted to achieve the following components:

<u>Platoon formation and mission planning</u>

Platoon formation and mission planning are key for the use case and consists of the following functionalities:

- Planning the rebalancing mission by determining the car sharing station of departure as well as that of the arrival and reserving the dedicated parking lots in the destination station.
- Identifying the vehicles that will constitute the convoy according to their states like their availability or the loading rate of their batteries.
- Defining the roles of each vehicle in the platoon (lead/following vehicle), and the order of the following vehicles in the convoy taking into account their position in the departure station and their parking lots at the destination.

These functionalities will be developed in a dedicated server and the data exchanged with various vehicles belonging to the platoon as well as the human operator will be done by the means of the IoT platform.

<u>Decision making assistant for crossing intersections</u>

During the evolution of the platoon throughout its itinerary, it will be going to cross different crossroads (controlled by traffic lights). According to the itinerary of the platoon, we distinguish two types of configuration for crossroads controllers by traffic lights:

- Complex configuration: it is a crossroad in which the traffic light cycle does not allow a priority passage of the convoy (Figure 31)

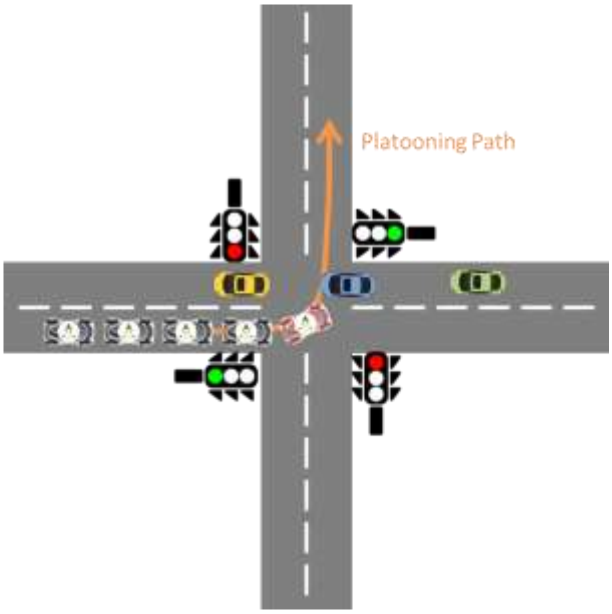

Figure 31: Complex configuration of crossroad controlled by traffic light

- Simple configuration: it is a crossroad in which the traffic light cycle is favourable to give a priority passage of the convoy (Figure 32)

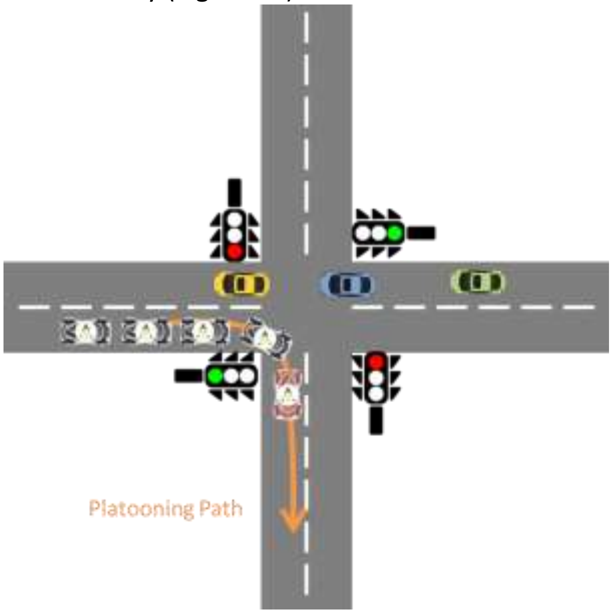

Figure 32: Simple configuration of crossroad controlled by traffic light

Hence, appropriate functional components have to be developed in order to provide a high level decision that handles the previous two configurations. In the first case, the lead vehicle will request the traffic light controller to change the traffic light cycle so that the priority of the passage of the platoon is ensured. While for the simple configuration, the lead vehicle will adapt its dynamics in such a manner to guarantee a non-separation of the platoon and to minimise the waiting time at a red traffic light. So, the decision making functionality will provide a recommended speed to the operator so that the previous constraints are guaranteed.
For both cases, a communication between the lead vehicle and the traffic light controller is required. Thus, the IoT solutions will be explored in order to facilitate data exchange needed for decision making.

<u>Localisation and lead vehicle path estimation</u>

The localisation is an essential component in platooning system. In fact, it provides required information allowing the vehicles in the convoy to stay in line. Moreover, it can be used to give redundant information such as inter-distance between vehicles.
In general, the path following approach depends on the environment in which the platoon has to manoeuvre. For example, the centre of lane is used as a reference path when the platoon is evolving on highways. In this case, the information needed for path following is the estimation of the centre of lane and the position of the vehicle with respect to this reference. This information can be acquired by a vision system or magnetic beacons.
However, for the French PS, the platoon is brought to manoeuvre in an urban environment. Hence, a path generation algorithm representing the lead vehicle path has to be developed. In order to achieve this requirement, we explore the possibility to use a localisation system based on a Real Time Kinematic Global Positioning System (RTK-GPS). In fact the traditional RTK-GPS requires a base station receiver which transmits correction signals to vehicles via radio modem. This way, each vehicle can calculate its position with a high precision (with an error of 5 centimetres). For the French PS, the correction signals are transmitted over internet using the NTRIP protocol as defined in RTCM 10403.3, differential GNSS Services – Version 3 (October 7, 2016).

4.3 Livorno: CRF/AVR prototype

4.3.1 Existing AD functions

In AUTOPILOT, the automated driving prototypes are used for the hazard avoidance and speed adaptations coming from the traffic management centre (highway pilot) and for the urban driving.

World model
Useful information coming from vehicle sensors and V2X information are integrated to perform AD functions.

HMI
The aim for the HMI function is to inform the driver on vehicles, the environment and the status control of autonomous driving.

Longitudinal control of the vehicle
Depending on the user input, vehicle status, environmental perception and V2X and cloud communication, the manoeuvre module decides which action the vehicle has to perform (e.g. decelerate/brake to follow a target speed). The control module sends commands to the actuators and gives feedback on their status to the manoeuvre module.

Lateral control of the vehicle
Depending on the vehicle status, environmental perception, V2X and cloud communication, the manoeuvre module decides if it has to keep the vehicle in the actual lane or perform a smooth lane change, automatically actuating on the steering system.

Path planning
The most probable path can be calculated by the connected e-Horizon module according to maps data updated from the cloud.

The AD functions of CRF prototypes are described in the following scheme:

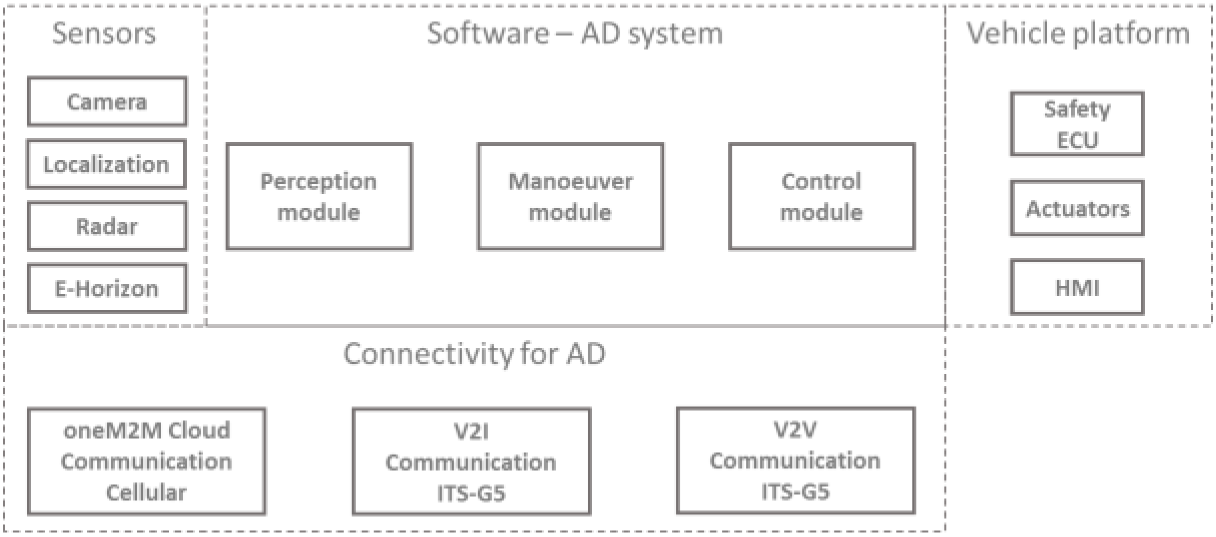

Figure 33: AD functions of the Italian prototype

4.3.2 Adaptation of AD functions

The Italian PS is composed of urban and interurban areas, in which different use cases will be tested. The whole vehicle fleet is composed of seven prototypes: two CRF connected and AD prototypes, integrating AD functions and five connected prototypes (two from CRF and three from AVR), equipped with advanced communication capabilities.
The goal of the following use cases is to demonstrate that IoT can support autonomous driving, providing useful information that can improve the AD functions.

4.3.2.1 Highway pilot

Hazard avoidance along the highway: speed adaptation. Information coming from the IoT (other vehicles, infrastructure and cloud) can be used for warning AD vehicles in advance of dangerous situations as slippery road conditions. On the basis of this information, fused with other sensors' data, the AD functions keep the vehicle in the actual lane and autonomously adapt the vehicle speed to the traffic and road conditions for preventive safety.

Roadway works with TCC in the loop. Information coming from the IoT (other vehicles, infrastructure and cloud) can be used for informing AD vehicles in advance on the presence of a closed lane due to roadworks. The AD system fuses this information with other sensors' data and it plans and actuates a control strategy for keeping the vehicle inside the lane and adapting the speed, considering both the roadworks' presence and other vehicles moving in the neighbourhood. Approaching roadworks, the AD vehicle performs an automated manoeuvre in order to change lane and pass the obstacle.

4.3.2.2 Urban driving

Urban driving: Pedestrian detection with roadside cameras and connected bicycles. Information coming from the IoT (other vehicles, infrastructure and cloud) can provide information on other vehicles, VRUs presence and on the traffic light status. The remaining time until the change of the actual traffic light's state is a useful information that cannot be acquired from any other sensor. Thanks to this information the AD vehicle can optimise its speed, considering also the presence of a bicycle, in order to safely cross the intersection when the traffic light is green. If the AD vehicle receives, from the IoT, a pedestrian traffic light violation warning, it can automatically reduce its speed and eventually stop before reaching the intersection.

[Urban driving / Highway pilot: Potholes detection: This last use case of urban driving/highway pilot and potholes detection does not directly involve the AD functions so it is not going to be treated in this chapter.]

In order to perform the above described use cases, the functions highlighted in blue in the scheme below have been modified to integrate new inputs coming from the IoT. In addition, some of the in-vehicle sensing systems have needed an upgrade to setup AUTOPILOT prototypes.

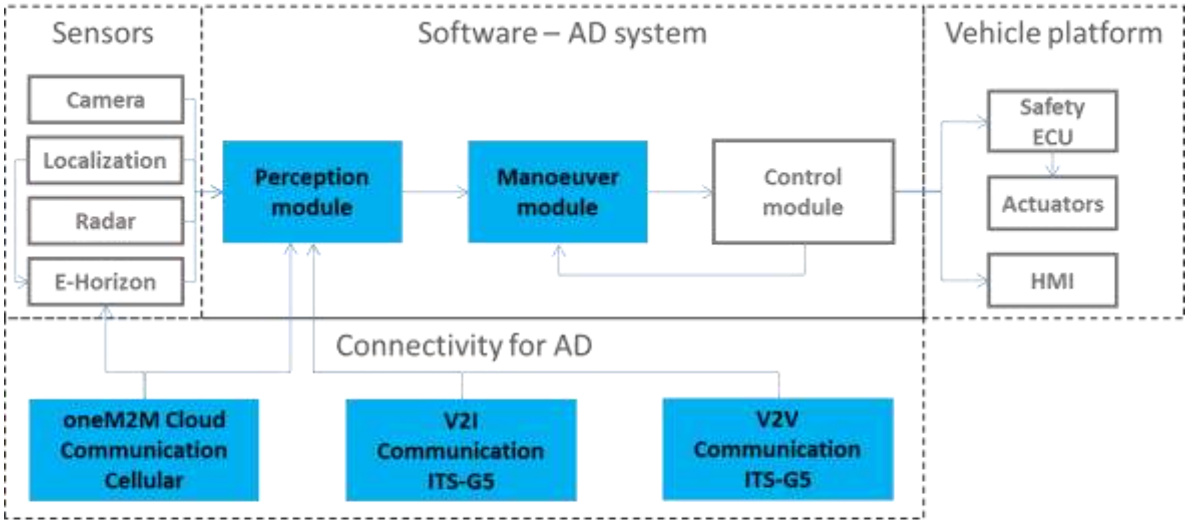

Figure 34: Adapted AD functions of the Italian prototype with IoT.

The V2V communication based on ETSI ITS-G5 can provide to AD vehicles the following messages and information:

- CAMs (Cooperative Awareness Messages): provide information of presence, position, speed and other information on vehicles/road users in the neighbourhood.
  The set of received CAMs is filtered in order to identify relevant vehicles/road users for AD prototypes. The main data used from AD prototypes is vehicle position: latitude, longitude, height, vehicle speed, lateral and longitudinal accelerations, vehicle status as breaking action, gas pedal position etc.

The I2V communication based on ETSI ITS-G5 can provide to AD vehicles the following messages and information:

- DENMs (Decentralised Environmental Notification Messages): contain information related to a road hazard or abnormal traffic conditions. DENMs are crucial for the AD scenarios described in the use cases. The most relevant DENMs are the ones that warn the vehicle on the hazards due to slippery road conditions, on the presence of a lane closed for roadworks and on the presence of vulnerable users on the road.
  From each message it is possible to extract information on the type of event, on causes and sub-causes, on the location of the event, the interested area and other specific information related to the type of event. For example in case of a lane closed due to roadworks an optional container can be added to the DENM that provides information on the closed lanes, on the speed limit, on the recommended path, on the traffic flow (right or left for overtake the obstacle), etc.
- SPaTs (Signal Phase and Timing): contain information on the presence and the status of a traffic light. The more relevant data useful for AD functions are: actual traffic light phase, timing of the actual phase change, next traffic light phase, timing of the actual phase change, latitude and longitude of the traffic light.
- MAPs: contain information on the road geometry and topology. In particular, in urban scenarios, the prototypes need to have some intersection topology information as the stop line position and the lanes description.

The OneM2M cloud communication based on mobile technology can provide general warning on the road environment based on aggregated information coming from road users and the infrastructure. In CRF AD prototypes, cloud information can be pre-processed by the Continental Connected

Electronic Horizon and then sent to the AD system or it can be directly transmitted to the AD system.

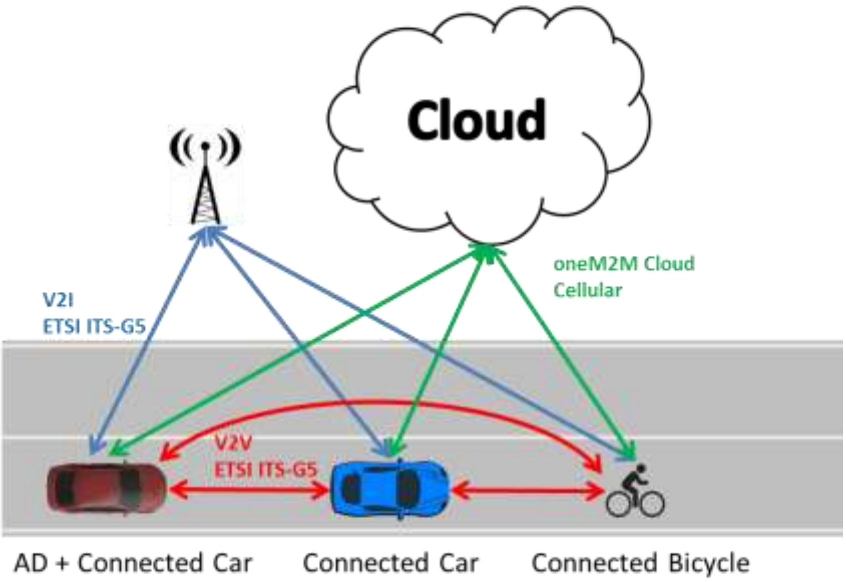

Figure 35: IoT information exchange.

The Perception Module receives data from the local perception sensors and from connectivity modules. Its role is to fuse the data and extract a reliable description of the surrounding environment. It can receive contradictory information from different sources. It has to assign different priorities and extract the useful data that better represents the real scenario. Considering for example the use case hazard avoidance along the highway, the vehicle detects from camera (or as static e-horizon information) a certain speed limit. The Traffic Control Centre sends an avoidance of slippery road condition which takes the form of a dynamic speed limit reduction through the cloud and to the Continental e-Horizon. In this case the perception module has to fuse the received data and establish that the input from IoT has a higher priority with respect to the static sign post speed limit detected by the camera. The Perception Module has also to discard information that is not relevant for the AD prototypes. E.g. it filters the SPaT messages providing only the information on the traffic light of the intersection branch that the AD prototype is travelling. Traffic light information related to other intersection branches has to be discarded.

The Perception Module feeds the manoeuvre module with the fused information coming from the sensing and connectivity devices.

The Control Module gets fused data coming from the Perception Module on the surrounding environment as speed limits, presence of obstacles (other vehicles, pedestrians, bicycles, etc.), warnings, road geometry information, traffic light information. On the basis of this data it elaborates an automated manoeuver for the lateral and longitudinal control of the vehicle.

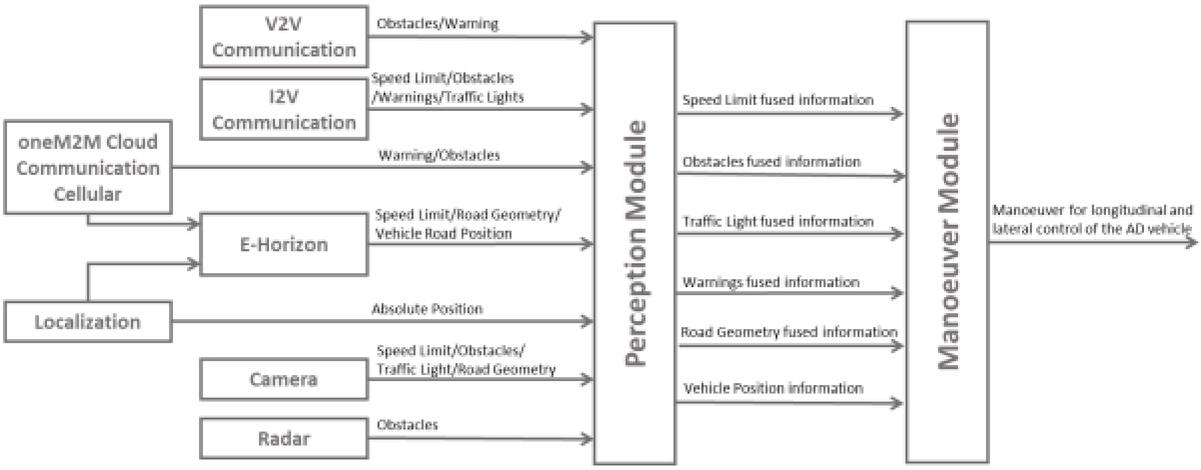

Figure 36: Data fusion and manoeuver generation

4.3.2.3 Security considerations

For a vehicle to avoid a hazard, be it a person, a pothole, another car, roadworks, or anything else, it must be able to accurately recognise it. This recognition will drive the AD intelligence to take countermeasures and to act in order to minimise damage up to possibly getting no damage to any involved user or property. One critical part of the recognition is the discrimination of *"false positive"* and *"false negative"* classification, i.e. the accuracy and sensitivity of said classification. One possible threat to take into account by the AD engine is the presence of digitally falsified messages that are maliciously crafted by an attacker to produce harm.

The AUTOPILOT introduction of IoT into the AD context extends by a great margin the possible attack surface and may introduce many new threats. Such threats are described in deliverable D1.9 and have been taken into account during the implementation of the IoT enhanced AD functionality. In this regard security features can be considered as sensors and intelligence that will make the vehicles' AD engines smart enough to also avoid (malicious) digital/virtual obstacles or threats. A security sensor is capable of detecting anomalies which could be of little interest until correlated to other events from other sensors. The AD engine could take into account the information from a number of security sensors when taking decisions about whether or not to completely trust a source of information. For example information from a RSU which manifests signs of *"compromission"* (e.g. connects to unexpected hosts, transmits contradictory information, generates many timeouts or transmits a lot of malformed traffic) could be either discarded or verified with other sources of information before being accepted. The Risk Analysis in D1.9 is a tool that is being used to prioritise development activities targeted at risk mitigation. Because of budget and time constraints the current implementation has not already matured full compliance to all D1.9 requirements, but at least from the architectural point of view an important component has been introduced. In fact, between the AD engine and the IoT components, an *"on board gateway"* has been introduced. As of now this AD component is not already fully implemented to recognise malicious or otherwise *"wrong"* messages. The mitigations to adopt are still under investigation at the present moment. The main concern regards time and budget constraints. In fact, while D1.9 covers the necessary requirements to fully address security and privacy, the necessary AD adaptations could result in much more effort than what has been foreseen at project start-up. For this reason the D1.9 risk analysis will be used in order to mitigate the most important risks so that residual risk is minimised even possibly even by means of further AD and IoT messages adaptations.

A fully compliant AD will be able to e.g. ignore false messages related to inexistent, digitally inserted, obstacles and will be able to avoid digitally hidden threats.

4.4 Brainport: TNO/Tass prototype

4.4.1 Existing AD functions

In AUTOPILOT, the automated driving prototypes are used for the platooning and AVP functions. These are both high level functions for which the vehicle needs to have both longitudinal and lateral automation, i.e. accelerating/braking and steering. In the vehicle these functions are realised by using several other lower level automated driving functions, see also Figure 37:

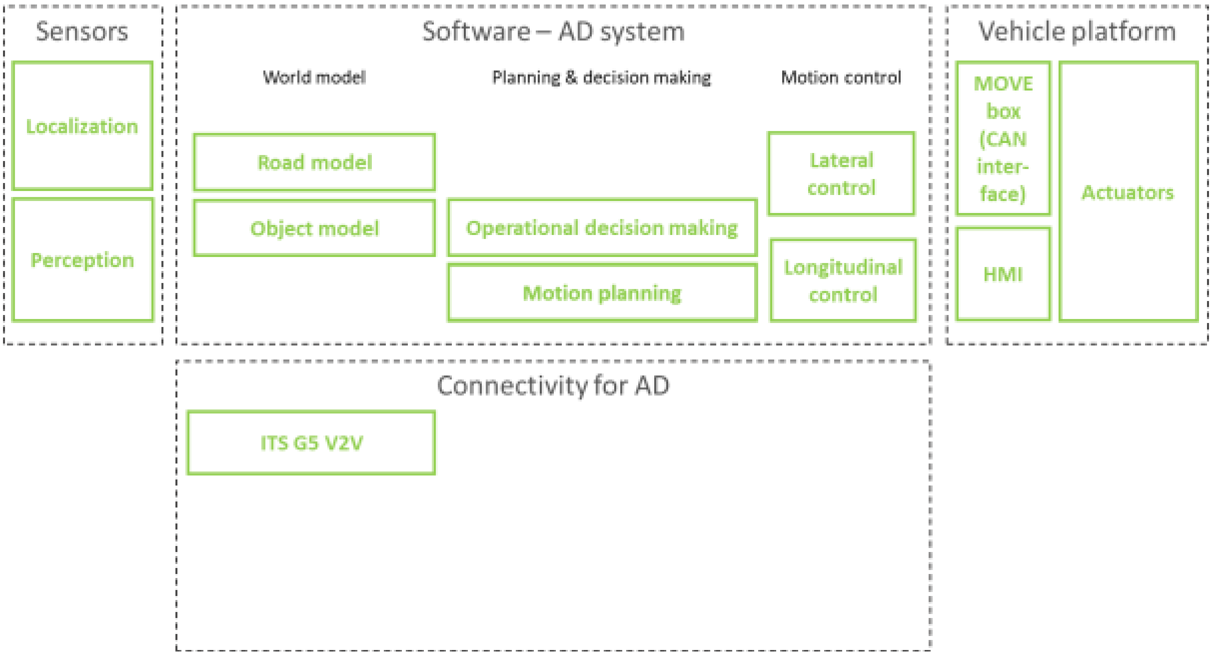

Figure 37: AD functions of the TNO/Tass prototype

World model
Here all information obtained from both in-vehicle sensors and V2V communication is collected and processed. The road model contains the relevant information about static components, such as the desired typical trajectory and road markings. The object model represents all object pose information of other traffic participants, i.e. dynamic objects that can move on the static road model.

HMI
The HMI is used to select and activate the AD functions and displays the system information to the user.

Planning & decision making
Depending on the user input, vehicle states, environmental perception and V2X communication, the operational decision making and motion planning functions decide on usage and objectives (e.g. desired velocity, path, etc.) for the lower level longitudinal and lateral controllers.

Longitudinal control of the vehicle
The longitudinal control functionality consists mainly of a C-ACC (Cooperative Adaptive Cruise Control) function that realises a desired vehicle velocity. It is basically an ACC (Adaptive Cruise Control), using radar to derive the distance to the vehicle in front, extended with V2V communication providing the preceding vehicle's acceleration, which is then used in a feed-forward control loop. Next to the C-ACC controller a collision avoidance functionality exists.

<u>Lateral control of the vehicle</u>
The vehicles have an automated steering function. A lateral controller generates a steering angle set point for the Electric Power Steering (EPS) steering system low-level controls. Depending on the control objectives, different functionalities exist, e.g.:

- Automated lane keeping: camera line information is used to steer the vehicle in the lane;
- Vehicle following: tail of preceding vehicle is followed;
- Automated lane change: a generated path for a lane change is followed;
- Path following: following a pre-determined path, e.g. RTK-GPS waypoints;
- Lateral collision avoidance: performing an evasive steering manoeuvre.

As mentioned above, the platooning and AVP automated driving functions can be realised by combining lower level functions, e.g.:

- Platooning: HMI, world model (e.g. distance to preceding vehicle from radar, acceleration of preceding vehicle from V2V communication), C-ACC longitudinal controller, automated lane keeping, collision avoidance;
- AVP: HMI, world model (e.g. GPS position, objects around vehicle), CC (cruise control), path following of a given pre-determined path (e.g. route to parking lot), collision avoidance.

4.4.2 Adaptation of AD functions

The TNO/TASS prototypes will be used for the Platooning and AVP use cases, as described in the previous sections of this deliverable, as well as in D1.1 (use case specification) and D1.5 (Platform specification).

4.4.2.1 AVP

To realise the AVP application, the AD functions of the vehicles have to be adapted with respect to the following components listed below. The additional and modified components are highlighted in the architecture overview in the figure below.

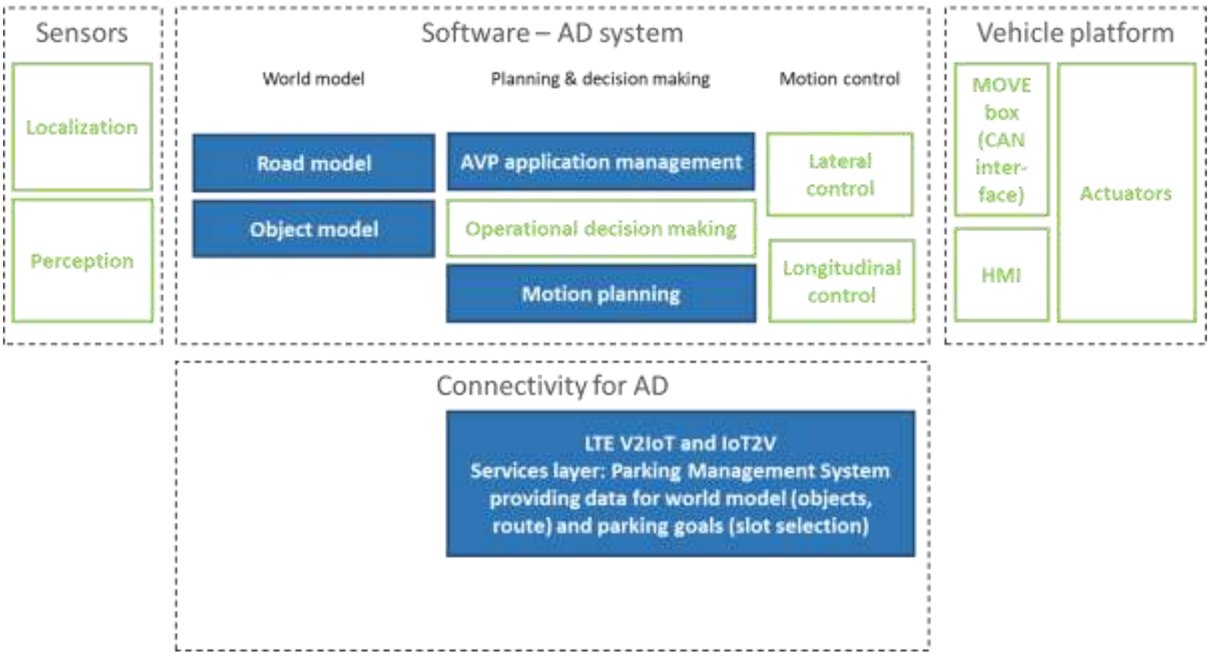

Figure 38: Data fusion and manoeuver generation.

World model

The vehicle must be able to localise itself in the AVP area (road model). Localisation based on (visual) SLAM is explored, where an a-priori map of the parking lot is received over IoT. Also localisation based on RTK GPS is investigated. The object model is enriched with objects received over IoT from the Parking management System.

Motion planning

For the application to work properly a path from the drop-off location to reaching the parking position must be obtained and vice versa from the parking position to the pickup location. The generation of this path might be split in several sub functions: motion planning function from pickup / drop-off location to a particular parking slot (global path planner, based on waypoints), parking manoeuvre planner to actually park the car into the parking slot such that it reaches its final parking position (local path planner), obstacle avoidance functionality that adapts the (global) motion planning if sudden obstacles on the planned route occur (local path planner).

AVP application management

The Parking Management System at the backend will detect free parking spaces, (static) objects and obstructions. Based on this information, it will provide route waypoints to a selected parking slot to the vehicle via IoT. The AD driving function for motion planning needs to handle this information, e.g. the motion planner uses the waypoints as input. Next to this, commands for the AD system and vehicle states are exchanged over IoT, such as position and current action (e.g. 'Driving to Parking spot', 'Parking', 'Parked'). The in-vehicle AVP application passes the commands to the operational decision making function and publishes the states to be exchanged to the IoT communication module.

4.4.2.2 Platooning

To realise the envisioned Platooning application, the AD functions of the vehicles have to be adapted with respect to the components listed below. The additional and modified components are highlighted in the architecture overview in Figure 39.

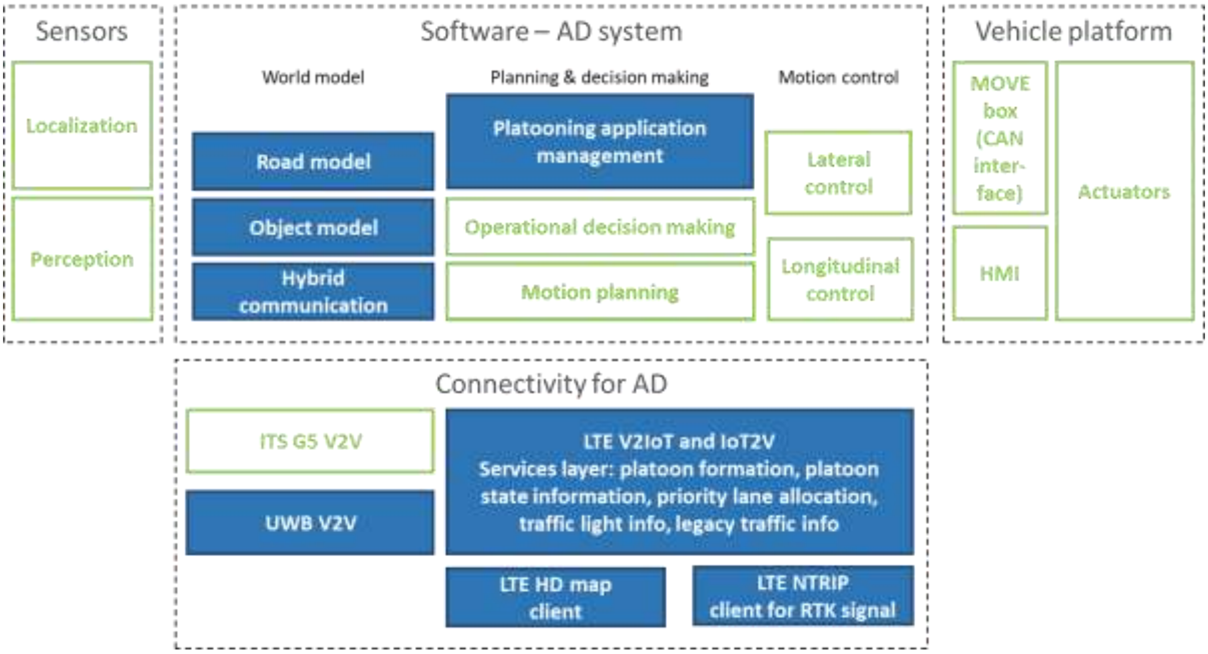

Figure 39: Adapted AD functions of the TNO/Tass prototype with IoT for platooning

Platooning application management

Platoon management

To create awareness of C-ACC vehicles being a platoon, the vehicles have to exchange information about their role (leading, following and trailing) in the platoon and the (control) mode in which they are (platooning, engaging, disengaging and standalone). Additionally, information is exchanged about the platoon state (assembling, disassembling, steady-state platooning) and platoon size (number of vehicles, length of the platoon). The IoT connection will allow the platoon information to be published to the IoT platform, allowing services to make use of it.

Platoon formation function

IoT will facilitate finding other vehicles as members for platooning and will extend the distance at which vehicles initiate towards platooning. The matching of vehicles at large distance is expected to be done using a cloud-based service. Bringing the vehicles together such that the platoon can finally be assembled using engaging functionalities (see platoon management) first requires synchronisation of vehicles such that these will be in the correct order and within ITS-G5 V2V communication range. In AutoPilot a platoon formation functionality is developed that brings vehicles together based on exchanging routes, vehicle states (e.g. position, velocity and acceleration), traffic state and traffic light information via IoT. Based on the exchanged information an algorithm is developed to generate velocity advice to the platooning vehicles.

Tactical planning & decision making

The platooning vehicles will receive information of traffic lights, the road authority/traffic management and legacy traffic. Planning and decision algorithms have to be developed that interpret the received information and translate it into mainly tactical decisions. These decisions are then translated to set points for the vehicle controllers, e.g. a velocity set point can be given to the longitudinal C-ACC controller. Some example functionalities:

- when knowing the time to red of a traffic light and the platoon state (velocity, length of platoon), the algorithm can decide on the desired speed for passing a traffic light without platoon break-up;
- similar when knowing the time to green, the leading vehicle may reduce its speed to avoid stopping the platoon to standstill;
- the road authority may provide a maximum speed or speed advice to the platooning vehicles based on the observed traffic conditions;
- the road authority may open/close a priority lane for automated driving, which can be used by the platooning vehicles.

World model

Road model

The platooning vehicles have automated steering to stay in the lane. As mentioned in Chapter 3, two concepts exist to achieve this objective: 1) path following and 2) lateral vehicle following.
To realise the path following concept, a path generation and localisation function are required. Different technologies exist. The baseline technology is that the path (lane centre line) is constructed from the observed left and right lane markings using a camera system. This camera system is also used for localising the vehicle with respect to the observed lane markings. In AUTOPILOT two additional localisation and path generation technologies are explored:

- HD map: in this case a HD map is streamed to the vehicle over IoT, which contains details of the road such as the number of lanes, lane markings, centrelines and road boundaries. To be useful for lateral control, the HD map must be correlated with the ‘map’ generated from the vehicle sensors. In this way, the path (road centreline) the vehicles have to follow can be generated in a more robust way and for short time periods the vehicle can follow the (correlated) map path if camera line information is unavailable. For localisation it is then temporarily relied on dead reckoning.

- RTK GPS: in this case an absolute GPS path in waypoints, e.g. road centre line, is available. Localisation with respect to this path is done using RTK GPS positioning fused with dead reckoning, where in AUTOPILOT the GPS correction signal is communicated over the internet from NTRIP (Networked Transport of RTCM via Internet Protocol) base stations instead of using the traditional radio communication.

As all of the above-described methods have their shortcomings, in the world model, fusion algorithms for path generation and localisation have to be developed in order to achieve the required reliability and safety level for highly automated platooning.
Additionally, the road model is enriched with traffic light information received from the IoT platform.

Object model
Information about legacy traffic is received from the IoT platform, e.g. (average) speed.

<u>Hybrid wireless V2V communication</u>

In C-ACC the preceding vehicle's acceleration is used in a feedforward loop. In current state-of-the-art solutions, the preceding vehicle's acceleration is obtained from V2V communication using ITS-G5. Due to this, the performance of the platooning function depends strongly on high reliability and (very) low latency of the wireless communication. In particular, the safety case related to automated platooning shows that the communication subsystem may have to fulfil an ASIL-C reliability. It must be noted that the (safety) performance is dependent on the headway between the platooning vehicles, i.e. achieving a certain performance gets more difficult when the headway is reduced.
The mutual localisation (distance) of the vehicles also is a safety-critical parameter.

An analysis shows that performance-wise, the required performance 'from sensor to actuator, i.e. CAN-bus-to-CAN-bus', may be lower than 20 ms – dependent on targeted and speed headway between the vehicles. This includes the overhead of the ADAS engine, the in-vehicle networks and the non-synchronisation between them. Since automotive CPUs and networks typically are non-synchronised, running on their own internal clock, the 20 ms budget is extremely harsh, leading to the request that the wireless subsystem performance including message processing is of the order of a few ms only, giving 'the other part' of the architecture and network essentially all the headroom to be able to comply. The thought here is that it is easier to optimise one subsystem, than that it is to change the complete de-facto in-vehicle architecture.

Realising the technical safety concept within the bounds of these requirements calls for
1) strongly optimised message processing, certainly if the wireless system is used for multiple types of communication (not just platooning, but also ETSI use cases and possibly audio and video communication across the platooning vehicles) and
2) mitigation of the risk of failure of communication in a wireless channel.

On 1) this task undertakes developments to optimise performance in the presence of platooning messaging, multi-modal (audio-video) and ETSI standardised messaging over 802.11-OCB (802.11p) to reach a very high communication performance.
On 2), an analysis of the technical safety concepts show that redundant communication is one of the ways to lower the ASIL-requirements per wireless sub-system.

To that purpose:

a) This task develops a concept and system by which 802.11-OCB can be introduced in a redundant way
b) This task introduces a novel IoT technology for evaluation of its capability to provide redundant and reliable communication whilst being in platooning mode. From its adoption in future IoT devices this technology will find its way in automotive. Since its properties are widely different from narrow-band wireless communication such as 802.11-OCB this technology may be very suitable as a truly non-interfering and independent wireless channel. The technology has an additional advantage that it can provide a second measure of distance between the platooning vehicles, thereby simultaneously taking care of a redundant measure of the safety-critical distance in platooning
c) This task introduces and evaluates a TNO version of pre-LTE-V (R14) cellular communication technology(c). Since customer samples of LTE-V chips are not expected to be available before H2 2018, (and then system-PCBs and communication subsystems have to be developed and derived after that (!)), TNO and NXP have foreseen to test a cellular technology that incorporates some aspects of LTE-V (essentially an LTE-A solution in which on the Mobile Edge Computing side some R14-type of modifications are introduced).
d) Finally, this task specifies and implements detailed requirements related to the data-and also diagnostics-logging to enable a good quality of service evaluation for a.o. the platooning use case. This information is also discussed with and transferred to WP4.

4.5 Brainport: TU/e prototype

4.5.1 Existing AD functions

In AUTOPILOT, the automated driving prototype is used for the urban driving function on TU/e Campus. These are both high level functions for which the vehicle needs to have both longitudinal and lateral automation, i.e. accelerating/braking and steering. In the vehicle these functions are realised by using several other lower level automated driving functions:

<u>Vehicle sensors and fusion</u>
Here all information obtained from both in-vehicle sensors and V2X communication is collected and processed.

<u>HMI</u>
The HMI is not used for end-users, but only for trained drivers. The automated driving functions can be selected and activated on the HMI and it displays system information.

<u>Longitudinal control of the vehicle</u>
In the urban driving use case, the longitudinal control is based on a ACC & CC based algorithm given a velocity set point, using RADAR and/or front camera input to realise a desired velocity based on a predefined distance to the predecessor. In the use case, longitudinal control will possibly be extended with collision avoidance functionality (minimum of emergency braking).

<u>Lateral control of the vehicle</u>
The vehicle has an automated steering function. A lateral controller generates a steering angle set point for the steering system low-level controls. The following functionalities will be developed/are existing:

- Path following: following a pre-determined path, e.g. RTK-GPS waypoints. This will be extended with functionality on following a SLAM defined path.

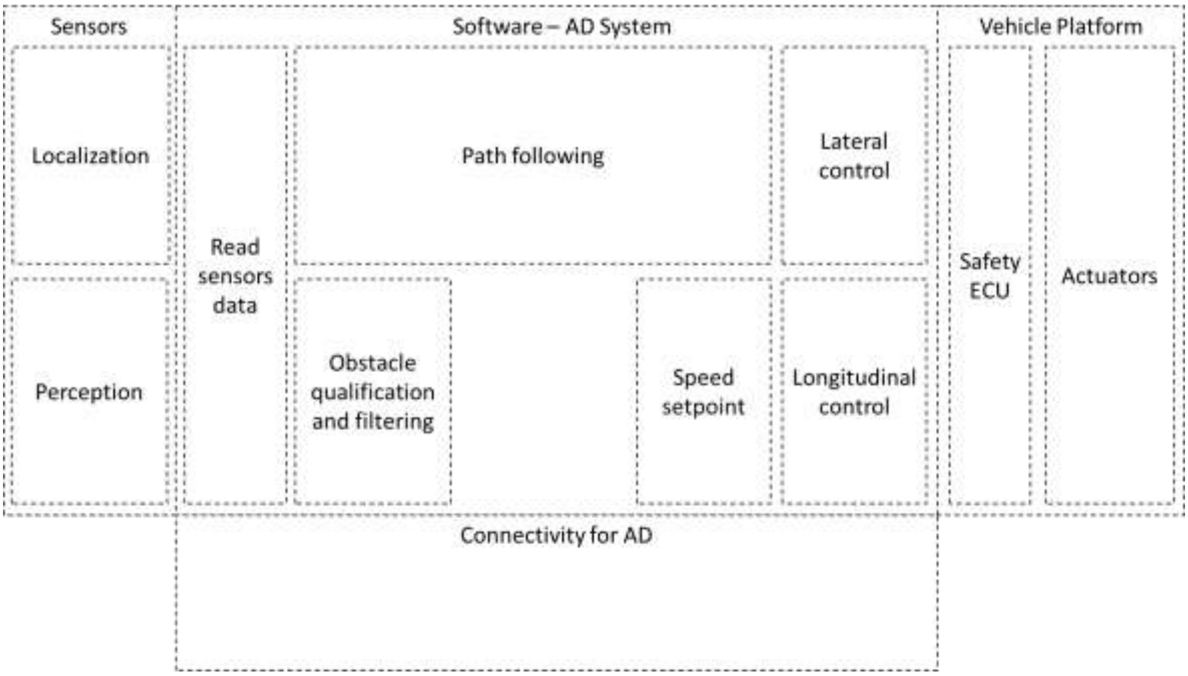

Figure 40: AD functions of the TU/e prototype

4.5.2 Adaptation of AD functions

Localisation

The vehicle must be able to localise itself on the TU/e campus. Localisation based on (visual) SLAM is explored, where predefined map of the campus is used as input. Also localisation based on RTK GPS is investigated.

Path generation

For the application to work properly a path from one parking spot to the other is set up. The generation of this path might be split in several sub functions: motion planning function between parking spots & obstacle avoidance functionality that adapts the (global) motion planning if sudden obstacles on the planned route occur (local path planner). The latter is to be determined during testing for feasibility.

Vehicle path control

The longitudinal and lateral control of the vehicle is adapted such that the vehicle can follow the generated path with a specified velocity and brake in time for an obstacle. The vehicle is not able to automatically reverse (without a human shifting manual the gear into reverse).

World Model

The world model takes into account two levels of operation: the highest level is on strategic level, where IoT data from CEMA and OSIRIS student lecture scheduling is used to determine on event base. This data is used to determine when it is the best time for the AD vehicle to drive over the TU/e campus terrain, based on the lowest probability of pedestrians & cyclists (VRU) being on campus, resulting in minimising the risk of collisions.
Second is on the operation level: where the AD vehicle is driving automated on campus and uses its limited set of in-vehicle sensors together with IoT enabled (based on ITS-G5) localisation to detect VRU's and decide on the appropriate driving action (braking, obstacle mitigation). The VRU detection operates principally at critical level and directly communicates to the car's central control unit for activating the emergency braking or avoidance manoeuvre. Nevertheless, considering the globally localised position of the car and calibrated cameras, the VRU detection also provides real-time input

to the IoT about the current situation of the VRUs at the nearby scene, and thus completes the current state of the world model. Each consumer of the world model will have to manage the different types of VRUs information sources, considering its effective actual position and detection modality (being specific to absolute location or probability distribution).
The world model takes into account these different modalities and gives input to the path planning and speed set point.

Perception

As VRUs, mainly persons (including pedestrians, cyclists, etc.) will be considered. The detection of a VRU will be based on the current state of the art deep neural networks technology, fine-tuned to street-view specific scenarios and to near real-time response (with respect to the camera refresh rate). Special HW will be employed in order to obtain the real-time response. Currently, the implementation on the GPU accelerated DrivePX2 platform is foreseen.
The detection tasks, in general, are subject to a minimum resolution of the analysed object that varies for different perspective. The best state of the art results on common databases, e.g. the MS COCO challenge 2017, point on an average 30% or 48% increase of person detection of medium or large size view (area between 322 and 962, or larger than 962 pixels, respectively) when compared to small size objects (area smaller than 322 pixels). This demonstrates the limitation of the possible VRU detection that is subject to the VRU's distance from the camera, and thus the car, and, more importantly, the camera's view, distortion and resolution. The current implementation of the VRU detection will therefore be tuned to use the input from a single daylight HD camera, operating with wide angle lens set-up. The algorithms will be tuned to detect persons in near to mid distance view, i.e. when the whole person is visible and its resolution is greater than 962 pixels, with highest recall.

Note that in cluttered environments, such as can be upon low visibility caused by insufficient lighting in the night, rain, snow, fog or shadows, the daylight cameras may not provide sufficient sensitivity such as to be able to detect the VRUs well. Considering that sensors that could enhance the VRUs' visibility upon harsh weather conditions (e.g. thermal cameras, IR lighting) will not be installed, for the purpose of the current pilot only good visibility conditions will be considered.

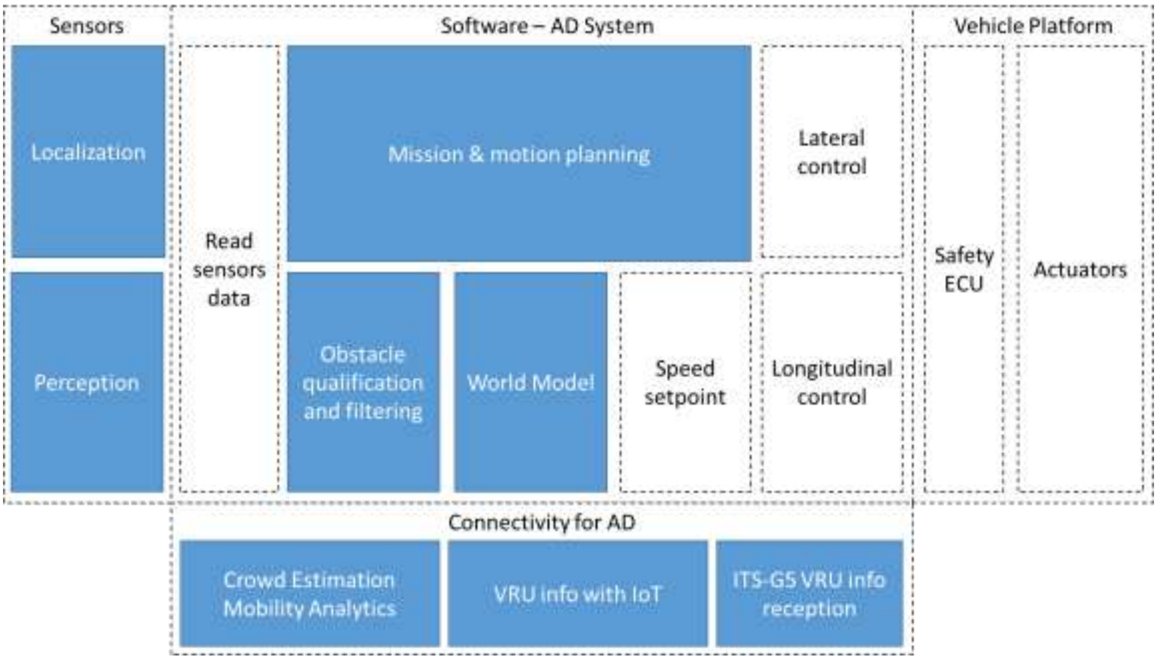

Figure 41: Adapted AD functions of the TU/e prototype

4.6 Brainport VALEO prototype

4.6.1 Existing AD functions

In AUTOPILOT, the prototype is involved in the Highway Pilot use case, which runs on the A270 and nearby roads at the Brainport area. This high level use case assesses the benefits of collaborative detection of road surface defects/obstacles for the enhancement of AD. For the proof of concept, the vehicle needs some level of longitudinal control, lateral control and signalling detection. However, it leaves out many features required for AD functionality.

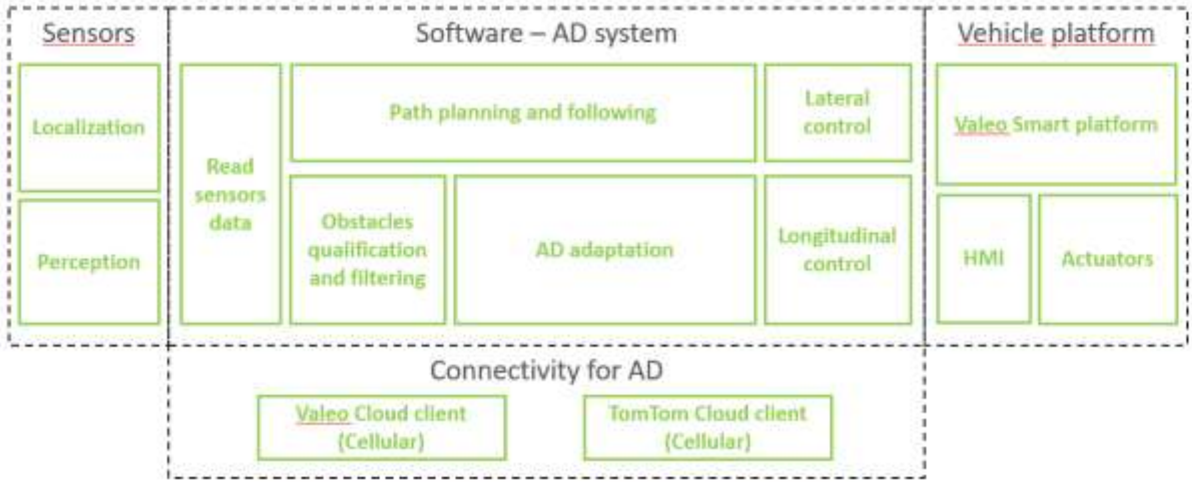

Figure 42: AD functions of the VALEO prototype

<u>World model and vehicle sensors</u>
Here all information obtained from both in-vehicle sensors is collected and processed.

<u>HMI</u>
The HMI is composed of the primary target representation, the lines around the vehicle, the detected road speed limit and preceding vehicle. It also informs when ACC is activated.

<u>Longitudinal control of the vehicle</u>
The longitudinal control is performed by the vehicle native ACC functions: AD activation, AD speed regulator and AD TIV setting.

<u>Lateral control of the vehicle</u>
The lateral control of the vehicle keeps the vehicle in its lane except if the driver asks for a lane change.

4.6.2 Adaptation of AD functions

The AD adaptation will remain higher-level rather than specific. The proof of concept, being about the benefits of 6th Sense Anticipation rather than mere AD planning and control, is demonstrated by leveraging on the existing native controls and building on top of them an adaptation module that can simply bypass, automate the existing system inputs, or apply new inputs as per the intent computed in the use case. Controlling higher-level parameters in such a way somehow mimics the experience acquired by a driver that influences driving on top of the standard set of driving skills.

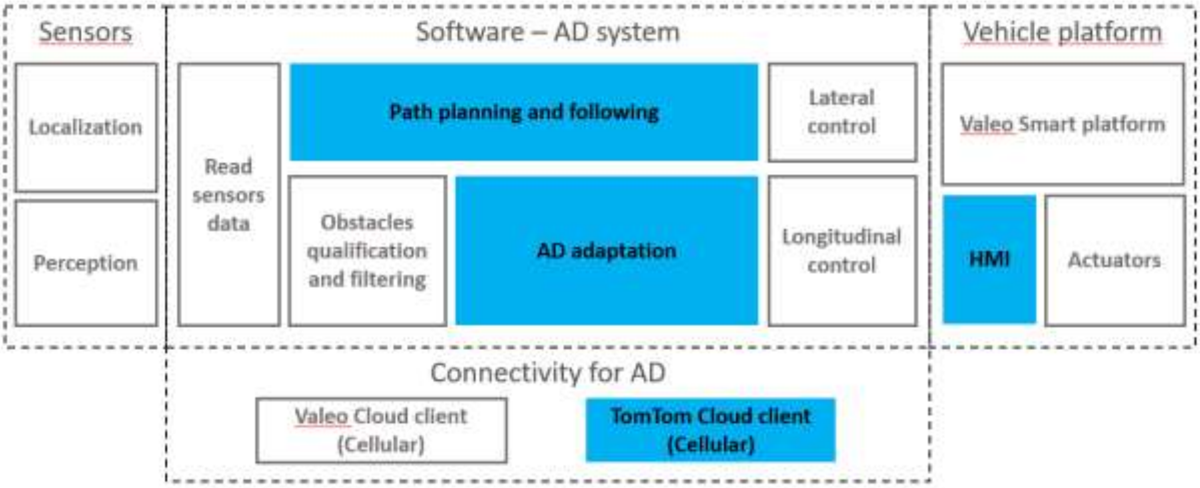

Figure 43: Adapted AD functions of the VALEO prototype

Environment sensing
In this use case, the focus is not placed so much on the traditional sensing of surroundings, as usually done, but rather on the road surface specifically. Therefore several sensors are added and tuned to enable a detailed scanning of the road.

A high-frame-rate wide-angle camera is placed forward, close to the road surface. A multi-purpose MobilEye camera located behind the windshield complements the vision setup.

LiDARs are also placed at the front, and tilted to the ground with slightly different angles in order to provide the best detailed scanning of the road surface.

A high-precision IMU is fixed to the frame of the vehicle at the back.

An extra GPS is added in addition to the default one for more accuracy.

Planning & decision making
A higher-level adaptation module is added to take into account incoming Road Hazards Warning and ADAS Instructions (or driving recommendations), as well as the current planning and control of the vehicle. This module alone computes independently the preferable strategy for driving adaptation.

World model
The world model will have to integrate new type of information from the Cloud and IoT.

Driving adaptation
The adaptation module judges the relevance of received ADAS Instructions and decides the strategy. When conditions are met, and when the strategy is computed, the new inputs are fed into the AD system. The four main driving adaptations are described below:

- The vehicle may reduce its speed below the regulatory speed limit as detected on road signs or as read on local maps or as set in controls.

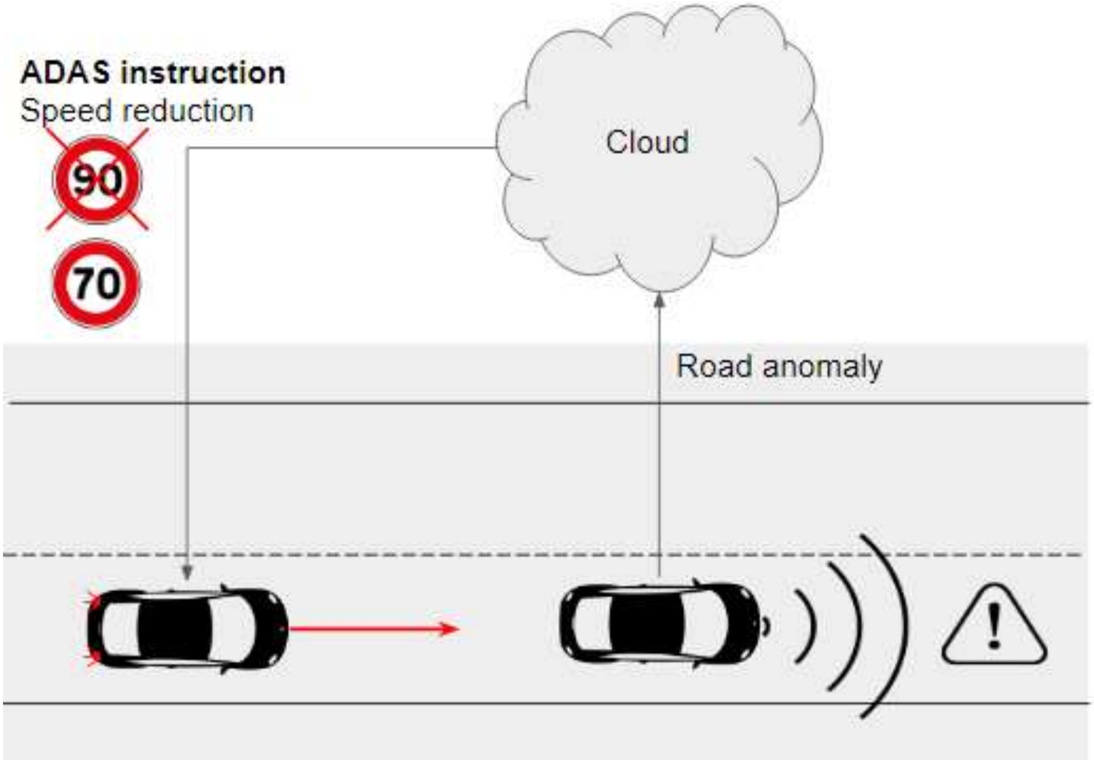

Figure 44 Vehicle reducing its speed

- The vehicle may change lane (simulated on HMI, and triggering of turning lights) instead of keeping the lane in planned path.

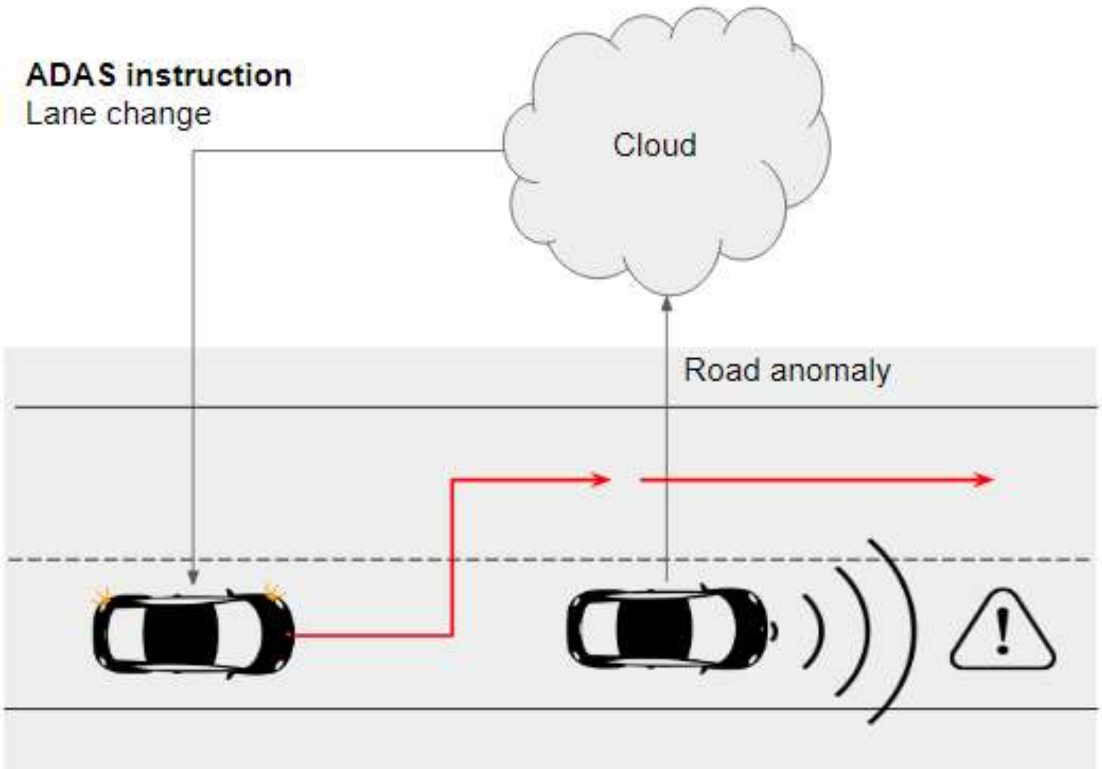

Figure 45 Vehicle changing lane

- The vehicle may increase or decrease the TIV.

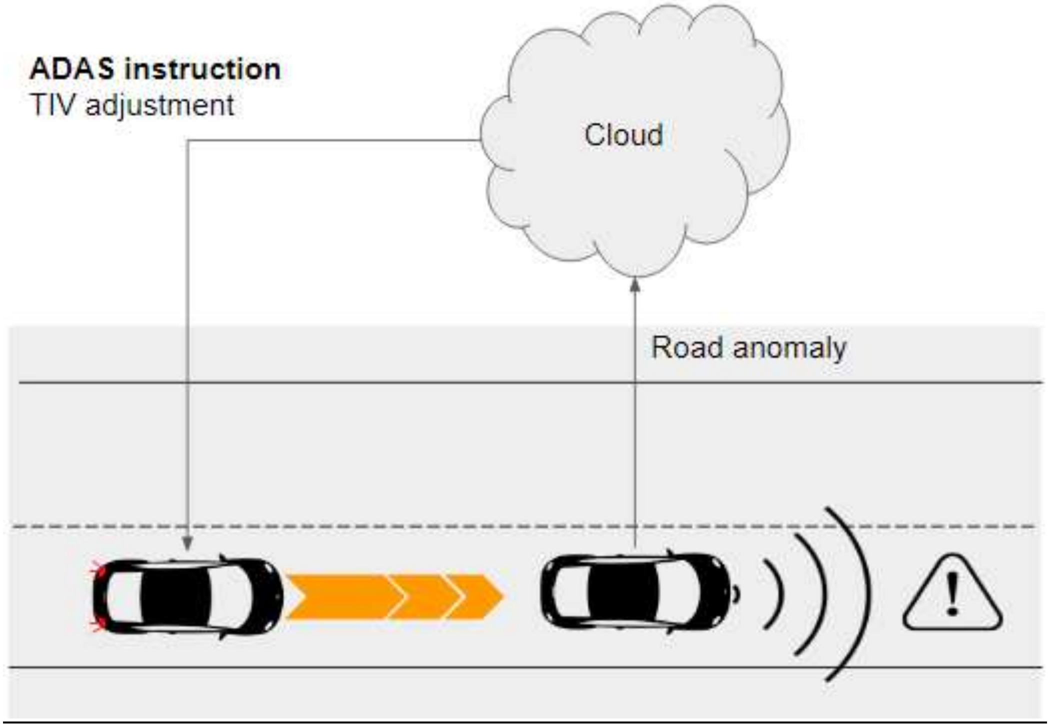

Figure 46 Vehicle increasing or decreasing the TIV

- The vehicle may force a takeover (disengagement of AD, switch to manual), in case of emergency or difficult situation. The Minimum Risk Manoeuver (MRM) of the vehicle applies afterwards.

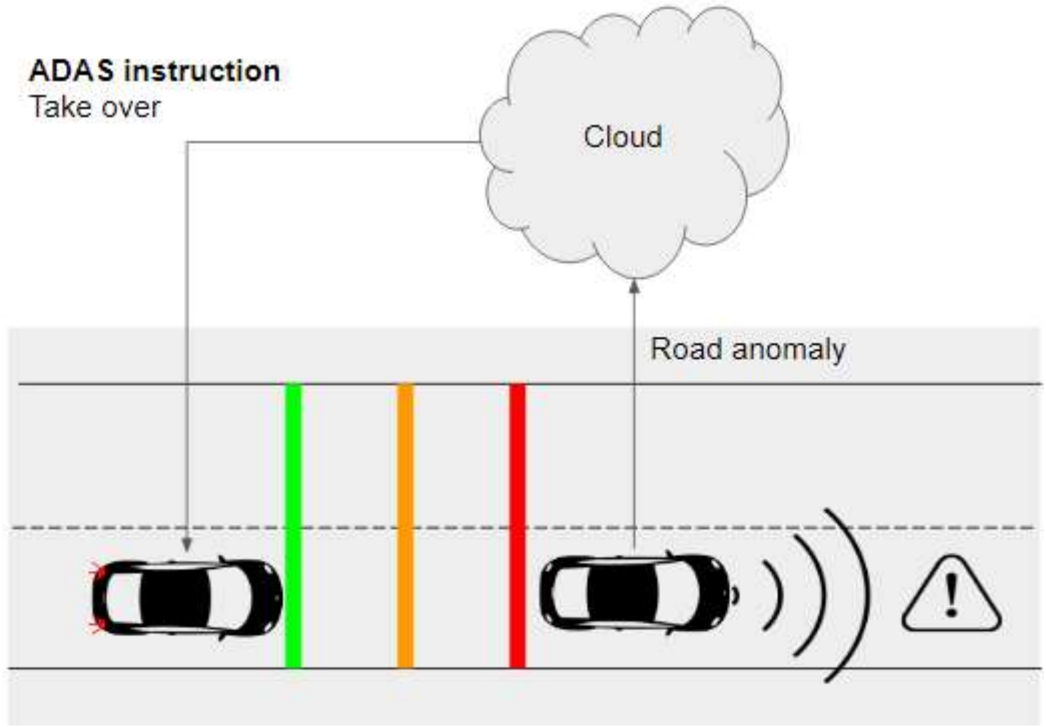

Figure 47 Vehicle forcing a takeover

Wireless communication
A telematics module is added to handle specifically communications with Valeo Cloud and TomTom server, in order to upload or retrieve driving data, such as maps.

HMI
A new HMI shall display:

- detailed maps with lanes, relevant hazards locations and driving recommendations
- the vehicle AD next intents, which are resulting from the adaption module computing, whenever the vehicle is in ACC/AD state.
- created anomalies

4.7 Brainport: DLR prototype

4.7.1 Existing AD functions

The DLR prototype will be used for the AVP use case. In this use case, the vehicle will drive completely autonomously, i.e. the automation will be responsible for both longitudinal and lateral control. An overview is given in Figure 48.

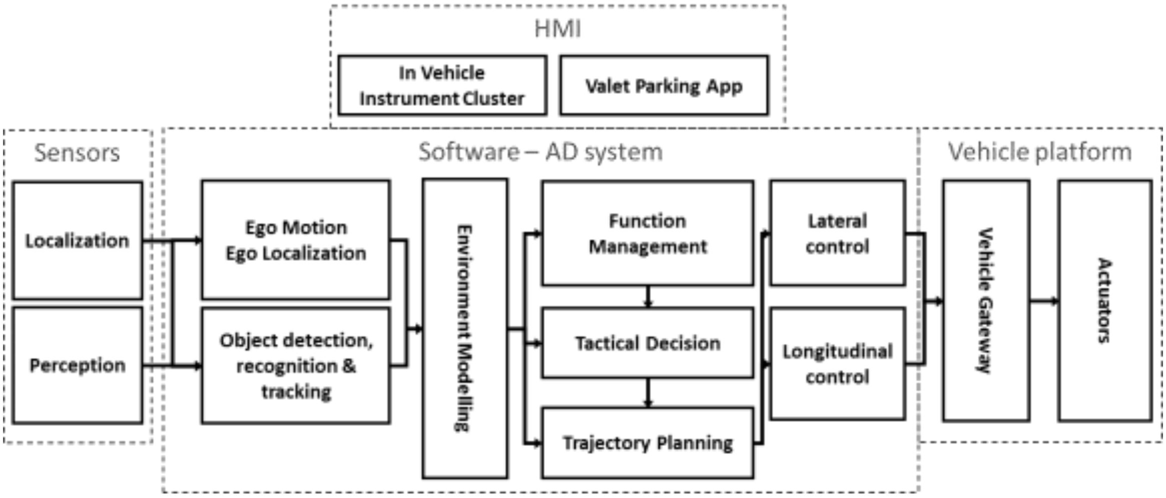

Figure 48: AD Functions of the DLR prototype

Sensors
The vehicle is equipped with LiDAR, RADAR for perception and differential GPS / IMU for localisation.

Software – AD System
The vehicle creates a world model based on its sensors and a digital map. The model is used in strategic decision making module and trajectory planning. The function management is responsible for controlling and monitoring the general AVP functionality, e.g. acquiring a route, interacting with the user and creating tasks to be executed by the trajectory planning. The trajectory planning is based on optimal control. It respects speed limits and obstacles such as other vehicles on the planned path based on the world model available to the vehicle and results in lateral and longitudinal control outputs.

HMI
Since the vehicle is supposed to be driving autonomously with the actual user being outside of the vehicle, the in-vehicle HMI is limited to displaying basic status information about the availability of

the AVP functionality. The main HMI for the user is a smartphone app that he/she can use to request parking or pickup (Figure 49).

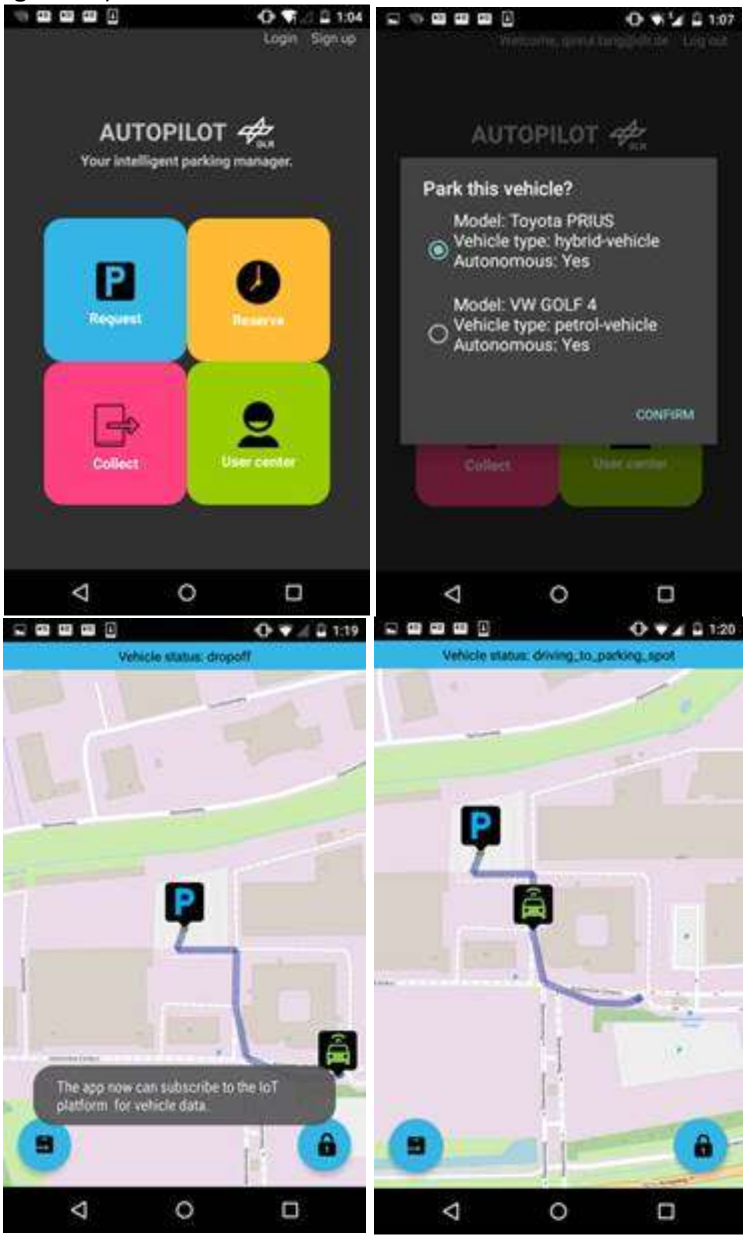

Figure 49: DLR valet parking app

<u>Vehicle Platform</u>

The prototype vehicle can be controlled by a controller area network (CAN) interface in longitudinal and lateral direction. For longitudinal control the signals of the adaptive cruise control (ACC) are rerouted to be able to accelerate the vehicle with $+2m/s^2$ to $-3m/s^2$ by software. For lateral control the signals of the active park assist are used.

4.7.2 Adaptation of AD functions

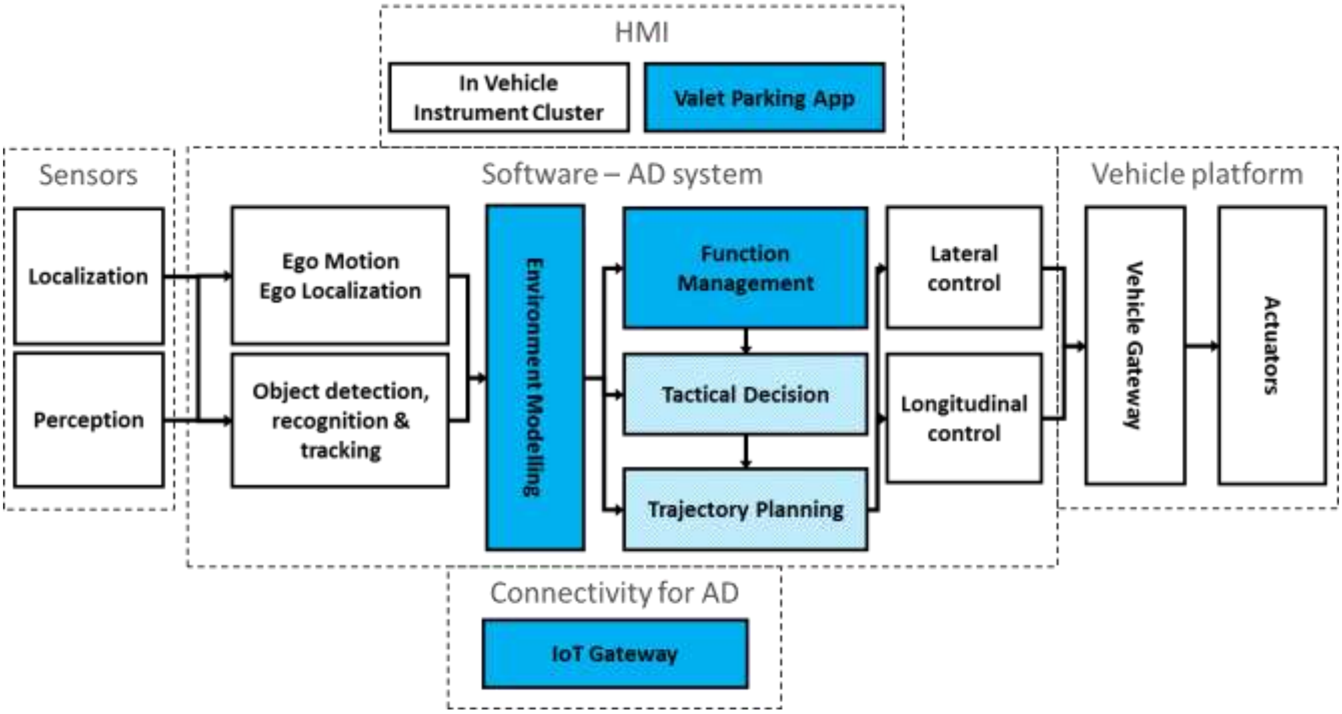

Figure 50: Adapted AD functions of the DLR prototype with IoT

The DLR prototype will be adapted for the AVP use case at the Brainport test site. First of all, an IoT gateway will be added to the vehicle so it is able to access the IoT functionality, in particular the AVP service. Likewise, the valet parking app will be enhanced to access and benefit from IoT services. Furthermore the environment modelling will be adapted to incorporate information from the AVP IoT service such as available parking spots and objects detected by IoT cameras / drones. The function management module will be enhanced by accessing the IoT AVP and user management service. Specifically, it will be able to request a free parking spot from the drone or an obstacle-free route from the AVP Service running on the IoT platform. Minor adaptions may also be necessary to the trajectory planning to account for uncertainties or time lags from IoT-based environment information.

4.8 Vigo: CTAG prototype

4.8.1 Existing AD functions

The three CTAG prototypes have the same architecture and AD platform. All of them are used for the urban driving and automated valet parking use cases with the following sub functions:

<u>World model and fusion algorithms</u>
The perception layer receives the information of all the sensors (LiDAR, camera, radars, Ultrasounds, DGPS, maps, C2X and IoT) and, with some algorithms, it is able to provide the vehicle position, a road description and a list of dynamic objects in the electronic horizon of the car.

<u>HMI</u>
In the urban driving use cases the HMI will show information received by the IoT in-vehicle platform

such as traffic light information, hazard warnings or VRUs in the trajectory. The AD function is started from the HMI.
In the case of the automated valet parking use case, there is no HMI in the car, since there is no driver inside. However, the driver`s smartphone will show information about the status of his/her car.

Longitudinal control of the vehicle
The longitudinal control of the prototypes will depend on the sensor information. The speed will be modified by the maximum speed of the map, traffic light status, hazards and VRU events, and other cars ahead. In AVP it will be also necessary to control the gear, since the parking manoeuvre will happen backwards.

Lateral control of the vehicle
The steering wheel will be controlled through the EPS. The prototypes will follow the information of the cameras, maps and DGPS in urban scenarios; and in the indoor parking the information of the LiDARs, maps and IMUs of the vehicle will be used.

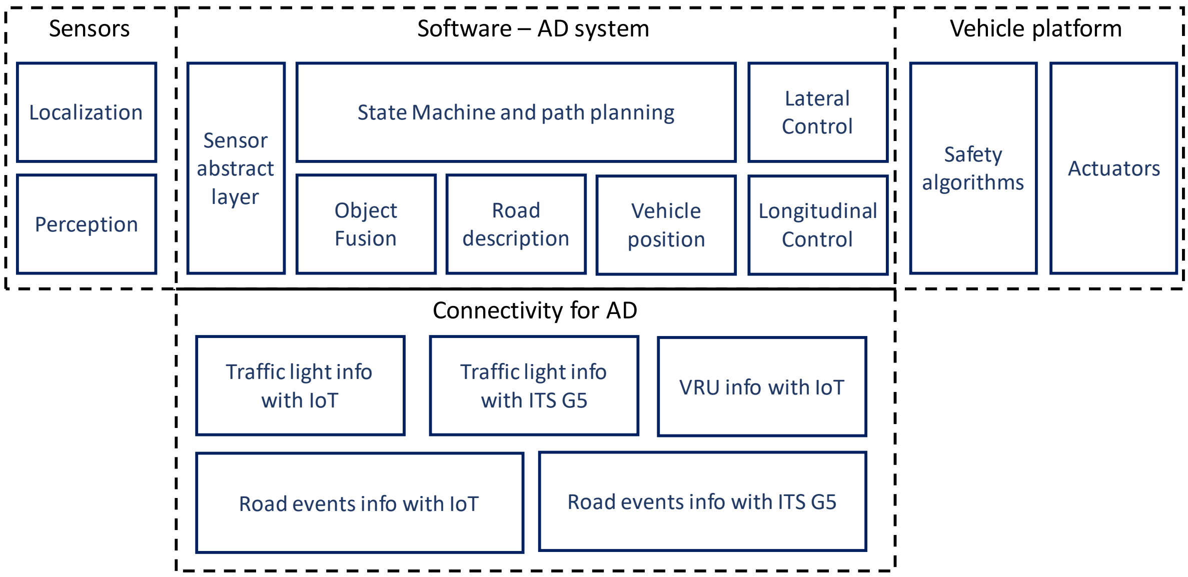

Figure 51: AD functions of the Spanish prototype

4.8.2 Adaptation of AD functions

The three prototypes of the Spanish pilot are adapted to be able to deploy the two different use cases with IoT information: Urban driving and automated valet parking.

In order to make reliable decisions on the best appropriate actions for any possible situation encountered in road traffic, the vehicle is required to perform a continuous surround sensing in order to maintain a complete awareness of its environment. This is achieved through a combination of data obtained from multiple sensors (in our case radar, LiDAR, ultrasound and camera sensors), that are necessary for generating a complete and reliable model of the vehicle environment. This is achieved through the perception algorithms. In these use cases, the local sensor information is complemented by information from IoT services such as vehicles, roadside infrastructure or pedestrians. This new data is beneficial for extending the vehicle field of view, resulting in a 360-degree reliable environment model.

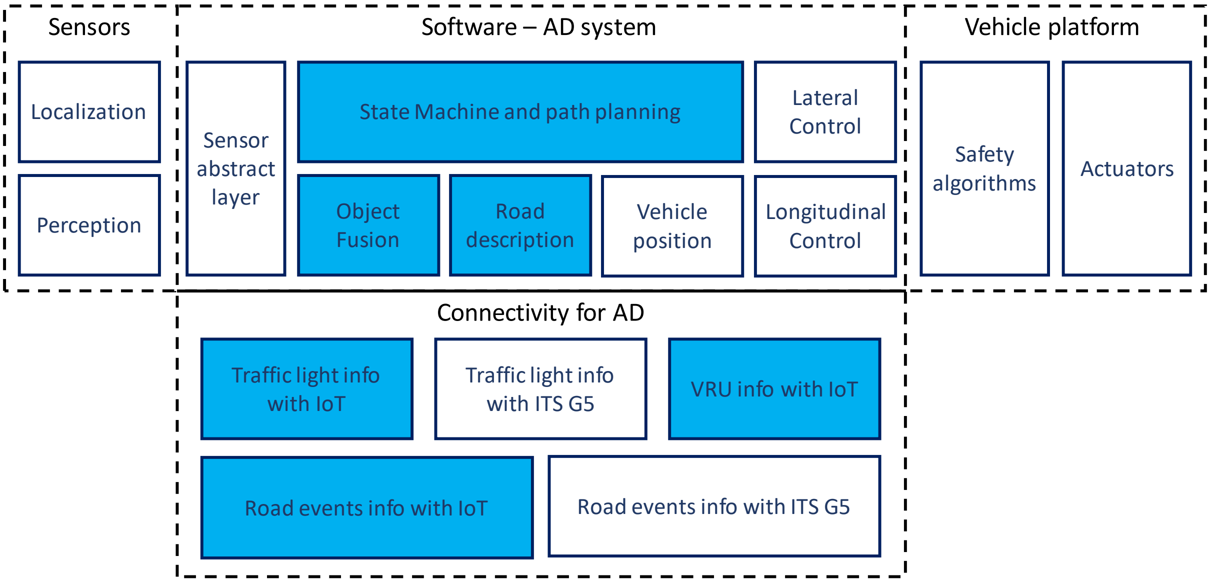

Figure 52: Adapted AD functions of the Spanish prototype with IoT.

4.8.2.1 Urban driving

The circulation of an Automated Driving vehicle in the urban scenario is improved thanks to the reception of information from many actors like VRUs, other cars, traffic lights and the traffic management service.

In this use case, the IoT platform will send information about the existence of a VRU which can interfere with the path of the automated car (provided by a traffic camera or another car sensors), about the state and the remaining time to change of a traffic light, as well as information about hazardous events (traffic jam, car accident and roadworks).

The perception layer of the AD platform has a new source of information coming from the car sensors and from V2X. This IoT information could be redundant, so it will be fused with the information from other sensors (such as a VRU on a crosswalk) or new data. The information will be processed and the car is going to act according to its reliability and precision.

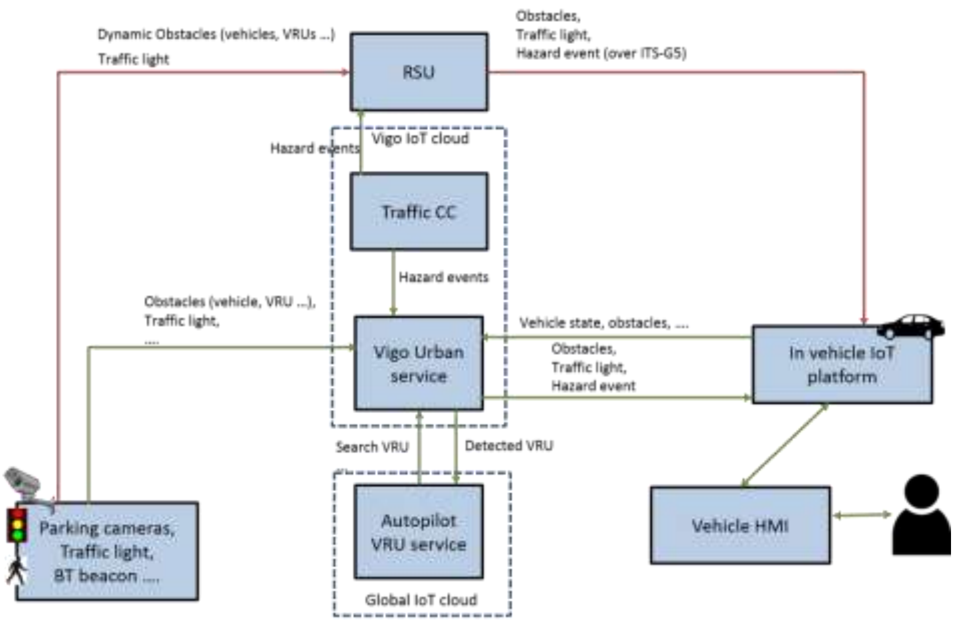

Figure 53: Spanish Urban Driving

4.8.2.2 Automated valet parking

In the automated valet parking function from the Spanish PS, the perception of the prototype is enhanced by the information provided by an IoT camera. This device is positioned in a strategic place where the own sensors of the prototype do not have enough perception to perform a safety manoeuvre. The camera sends information about the presence of an obstacle (pedestrian/vehicle) and its position.

The perception algorithms of the AD prototype are modified to take into account the information provided by the parking camera and this information is fused with the rest of the objects. In the same way as in the urban driving use case, once the vehicle is approaching the obstacle provided by the camera, it decreases its speed until stop if the IoT device keeps sending the information.

All the possible communications and actors involved in the AVP use case are shown in the scheme below:

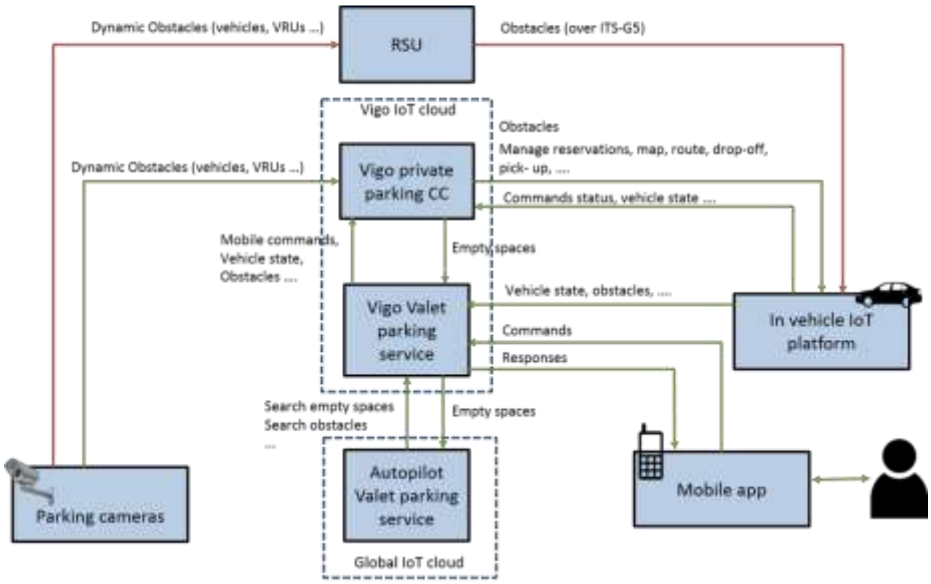

Figure 54: Spanish Automated Valet Parking

4.9 Vigo: CTAG prototype

5 Experienced difficulties and solutions

After having described the adaptations of the automated driving functions of the AUTOPILOT vehicle prototypes, chapter 5 focuses on the encountered difficulties and the possible solutions. They are listed by pilot site (and by prototype leader in the case of Brainport).

5.1 Tampere

Difficulties	Solutions
Location accuracy	
The traffic camera cannot directly measure the location of objects identified, but they have to be calculated from the position and the orientation of the camera.	In the first iteration, areas are selected within a fixed camera view and the presence of obstacles in these areas is detected, and transmitted.

5.2 Versailles

Difficulties	Solutions
Collaborative perception: Standardisation of exchanged data with IoT	
On the contrary to more common V2X communication based on Cooperative ITS protocols and messages, there is no existing standardised data dictionary to enable communication between road users and an IoT cloud server. This lack of existing standard concerning the data shared between the vehicles and the smart devices used by vulnerable road users was a main difficulty for the partners involved in the use case.	The main work has consisted in determining the necessary data which has to be shared by vehicles and vulnerable road users for addressing the use case. The adopted solution relies on the ETSI EN 302 637-2 standard which describes the implementation of cooperative awareness messages (CAM) to enable road station to share data concerning their dynamic and static variables. To enable the IoT platform to completely benefit from such data, CAM has been extended with parameters such as absolute timestamp, vehicle height, battery level and automation level. These data are sent to the IoT platform using JSON format.
Collaborative perception: Positioning of vulnerable road users	
Due to the large imprecision of GPS, positioning data that is transmitted by vulnerable road users can be irrelevant for the vehicle that receives such information.	As the IoT devices carried by pedestrians are usually equipped with standard GPS receivers, we cannot hope to improve the precision of vulnerable road users positioning. Instead, the system relies on a data fusion with the information provided by the local sensors of the vehicle. To handle such imprecision, the covariance of the input data are used to discriminate the different observations provided by all the data sources used by the cooperative fusion

	algorithm. In addition, the cooperative fusion algorithm should rely on statistical metrics so that it takes into account different precision levels.
Platooning: Longitudinal control function	
Define a complex function for each vehicle to follow the speed profile of the lead vehicle with respect to the minimum authorised distance to the previous vehicle based on the information coming from the IoT units. High possibility of collision between vehicles or possibility of problem of big inter-vehicle distance established between the vehicles due to the lack of on-time information. The integration of all time variables stay complex in the simulation modelling because they depend on the order of the vehicle in the platoon.	The communication latencies have to be taken into account in the control law and calculate the necessary speed for longitudinal movement for each vehicle. The latencies due to the motor reaction following the order of the control law are also modelled to avoid possible collisions.

5.3 Livorno

Difficulty	Solution
In-vehicle network load	
The implementation of AD functions requires a large amount of additional information with respect to a traditional vehicle, mainly aimed at sensing and understanding the surrounding environment and controlling the on-board actuators. Several sensors are used to detect external obstacles and this information has to be transmitted to the control unit of the car which uses it to plan the manoeuvre to be performed. Moreover, several messages have to be exchanged between the control unit and the actuators (e.g., steering wheel, brake and accelerator). A vehicle which implements AD functions is therefore characterised by an increased bus load. Additional information coming from the IoT (other vehicles, infrastructure and cloud) can even worsen this situation.	In order to avoid network load issues, two additional dedicated CAN networks have been integrated in the AD vehicles. These additional networks are aimed at transporting all the additional messages related to IoT and on-board sensors for AD. This solution minimises the possibility to have communication problems on the car.

5.4 Brainport

Difficulties	Solutions
VALEO prototype	
Geolocation of road hazards	
Due to the classic GNSS with an accuracy of 10	To improve the positioning accuracy (at max 1

meters, we need plenty of crossovers to precise the position of the road hazard relatively to the vehicle and of the vehicle itself on the lane.	meter) with a more sophisticated GNSS appliance (RTK and/or odometry for example). The GNSS mounted on the leading (detection) vehicle has built-in accelerometer/gyroscopical correction. The precision announced by the manufacturer is 2 meters Circular Error Probable. This, plus the detection of the lane number by another system, give us enough accuracy to place hazards within their respective lanes with a longitudinal error of 2 meters maximum.
Transformation of Hazard into ADAS instruction	
The transformation of a hazard into an ADAS instruction is delegated to a human operator from the control centre. It is indeed very risky to automate it. However the human operator may not have all information needed.	To learn adaptation/avoidance behaviour from drivers in order to enhance our ADAS instruction. The whole point of the human operator is indeed to let a local road expert to make wise decisions. We trust that with his/her tools, the reported hazards and the accompanying images, information is enough. However, there was also the idea of logging the leading (detection) vehicle dynamical data of vehicles reporting anomalies, along with anomalies themselves. That way we'd propose averaged manoeuver approaches with published hazards.
Geolocation of ADAS instruction	
Once we have a validated road hazard and we fixed an ADAS instruction, there is still an open question as to where the instruction must take effect.	According to the heading and the speed of the vehicle, we have to define a threshold area upstream and downstream of the road hazard. So a road hazard should have a in and out ADAS instruction.
Acceptation/Trustability in ADAS instruction vs World Model/Local planning	
Before considering incoming ADAS instruction as an input to define the AD strategy, we'd have to check its relevancy to the vehicle (its world model and the local planning) and trustfulness (safe source, knowledgeable source)	To develop safety mechanisms (redundancy, integrity checking, encryption, certification, etc.) on any such data that could impact AD controls. ADAS instructions are additional information for the vehicle’s decisions, and are not intended to override the vehicle’s own world model and local planning. As such: - redundancy is not needed for the vehicle which shall be able to operate without ADAS instructions altogether - integrity is checked via a series of rules to reject any instruction that would fail local security (ex: speed over the speed limit) - encryption and certification are valid points to consider for a commercial application which isn't the purpose yet Current safety mechanisms in both connections (point to point connection between vehicle and

	TomTom) and vehicle control (everything going through the default safety controls of the vehicle) are sufficient for the experiment.

TU/e prototype	
Localisation of VRUs	
Due to high inaccuracy of GNSS (typically +/- 10m) in smartphones, sensor fusion with the existing in-vehicle sensors is required for localising VRUs at close range for safety reasons. However ground truth of the vehicle location is solely provided by RTK-GPS, but that does not correct of the obstacle locations. Using cameras alone proves insufficient.	Adding LiDAR sensors to the vehicle will add increased obstacle & ego vehicle localisation accuracy to increase safety.
Integration of signal data loss (IoT) in AD controls which expect deterministic sampling	
The current control system requires a deterministic sampling rate to perform robustly. IoT (over LTE-4G) introduces packet-loss and therefore inherently non-deterministic sample rates, which introduce difficulties in safety critical situations.	IoT signals are weighted in the world model and not taken into account for close perimeter obstacle avoidance algorithms (obstacle mitigation / operational manoeuvring), but are only for tactical manoeuvring (speed adaptation, rerouting).
TNO prototype	
Robustness and safety of the AD system	
The aim of the Platooning use case is to pilot it on public road in mixed traffic conditions. This requires a high safety level, which puts strict demands on the maturity of the developed technology. Also an admittance from the Netherlands Vehicle Authority is required for access to public roads.	Development of a robust and safe system, which is well tested and documented. For example, one should do a risk control analysis such as the Failure Modes and Effects Analysis (FMEA), an EMC test showing that the adapted vehicles are not vulnerable to unwanted outside signals and do not transmit harmful radiation themselves, and ensuring safety and reliability of data communication.
Architecture of the AD system	
Traditionally, the vehicle architecture consists of in-vehicle sensors, controllers, and actuators that are used by a higher-level AD driving software, which runs on a rapid control prototyping platform that fulfils hard real-time constraints. However, the new IoT based functionality does not fit into this traditional architecture and requires a different approach. The reason is that information becomes available to the vehicle after being published in the IoT cloud and received in the vehicle via the communication unit. Consequently, a new architecture is developed that combines the traditional vehicle control and communication network worlds. The integration of these two worlds appeared far from trivial and required quite some reengineering of existing functions and interfaces to fit the new architecture.	A middleware (ROS) was used to build an AD software network consisting of traditional vehicle control functions, originally programmed in Simulink, and new application and communication functions programmed in different languages such as e.g. C++, JAVA. To achieve this, not only the newly developed functions had to be considered, but also all the existing AD functions.
Trustworthiness of communication for platooning	
As specified in previous chapters, reliable low latency communication is important in platooning at short headway distances.	UWB has been introduced as a redundant communication channel. It is shown to be reliable and low latency in stable platooning

Wireless communication can inherently not be trusted.	conditions.
Trustworthiness of distance in platooning	
As specified in previous chapters, reliable range information is important in platooning. When distance is solely derived from radar-information, vehicles cutting-in may be misinterpreted as being part of the platoon.	Two measures are taken 1) UWB also provides ranging information at very high performance (meaning: accurate, and with short latency). 2) Sensor fusion of GPS information, radar-ranging information and UWB-ranging information reliably allows to determining inter-vehicle distance as well as vehicles cutting-in.
AVP: Localisation of the vehicle	
The vehicle must be able to localise itself in the AVP area (road model). Localisation based on (visual) SLAM is explored, where an a-priori map of the parking lot is received over IoT. However, obtaining an accurate and generic map of the parking lot was found not to be an easy task. Although the map itself may not be a part of the AD driving function, without it, SLAM cannot be used for localisation.	A possible solution is still searched for.
DLR prototype	
Ego Localisation	
Ego localisation by DGPS turned out to be too inaccurate for AD driving.	The ego localisation is being improved by using RTK data. First test indicates that this is sufficient for the use case given no adjacent large buildings.
No user in vehicle during AD	
During autonomous driving the vehicle cannot rely on the user as backup because the user is no longer in the vehicle in the AVP use case. Therefore the vehicle must take all decisions itself and react accordingly to unexpected situations such as the assigned parking spot being already occupied. Furthermore, even though the user cannot take control over the vehicle, he may want to monitor the vehicle's actions on his mobile phone.	A STRIPS based task planning module provides a flexible way to plan tasks and react to unforeseen situations. Additionally, the separation of actions into tasks offers a way to describe the current action of the vehicle in human-understandable terms. +

5.5 Vigo

Difficulties	Solutions
Indoor positioning	
In order to know the exact location of the autonomous car, the information of the differential GPS and lane markings are usually used, however in an indoor parking you do not have any.	CTAG developed SLAM algorithms with the information of the 3D LiDAR. These algorithms provide an accuracy of cms in the localisation of the prototype.
City centre positioning	
The GPS signal between the buildings of a city is very poor, so it is not reliable to position the car on the road.	Positioning algorithms were enhanced with the information of an Inertial Measure Unit and references in the route of the vehicle.
Integration of all platforms in the vehicle	
Automated Urban Driving and Automated Valet Parking are two complex functions which require information from many platforms. It was necessary to integrate, in the same prototype, developments from HMI, Vision, LiDAR, Digital maps, OBU, perception and control. This caused space and power supply problems.	As it was not possible to integrate in one vehicle so many rapid-prototyping platforms, some of them had to be ported to embedded boards.

6 Conclusion

In deliverable D2.2, *"Adaptation report of AD functions with IoT technologies"*, we provided a view on the impact of IoT on the use cases by describing first, today's performances of the AD functions without IoT, and second, the expected impacts of IoT. The core part of the deliverable are chapters 3 and 4 describing the vehicle prototypes and their automated driving functions, as well as all the adaptations made to these automated driving functions in order to take into account information coming from the IoT to be able to exchange information with other objects. Chapter 5 described the experienced difficulties and possible solutions put in place by the prototype leaders to complete the adaptations of the AD functions of the vehicles. Some issues have been encountered by several partners such as positioning issues or handling of big amounts of data (space and latency issues linked to the new information coming from the IoT). The different challenges were all overcome or should be handled before the start of the demonstrations. It can be noted that most of the difficulties reported in this chapter are not related to the introduction of IoT in the connected and automated driving.

The detailed work plan schedule is presented below (see next page).

As a matter of fact, all adaptations will not be ready by the end of June 2018, as the work plan states, but will indeed be ongoing until autumn and the end of the year at the very latest. T2.2 activities are going to stay within the planned timeframe of WP2 which runs until M24.

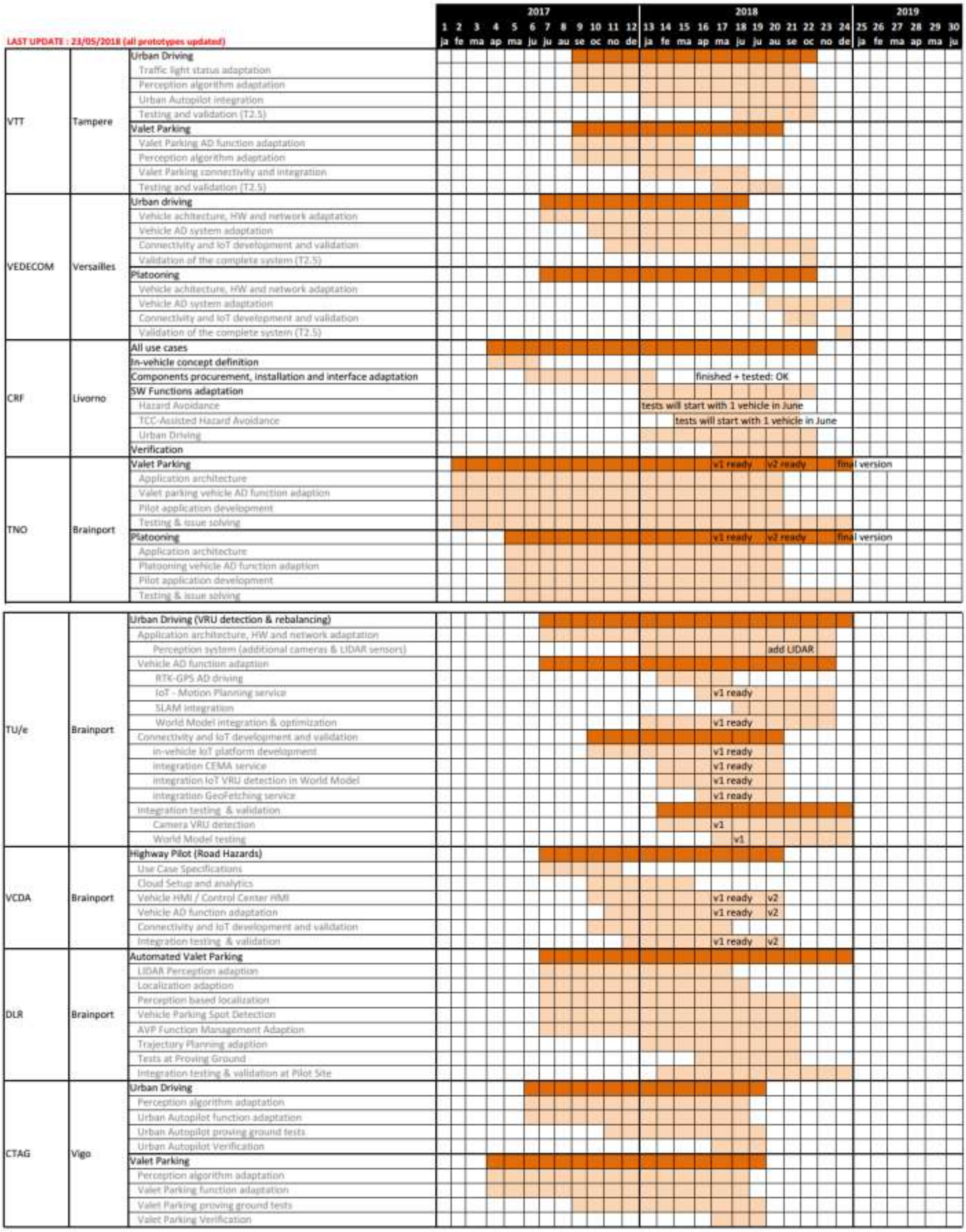

Figure 55 Work plan schedule of the AUTOPILOT prototypes