Fifth Generation Communication Automotive Research and innovation

Deliverable D2.1
5GCAR Scenarios, Use Cases, Requirements and KPIs

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Abstract

5GCAR brings together the automotive industry and the mobile communications industry to develop innovation at the intersection of those industrial sectors together with academia to support a fast and successful path towards safer and more efficient future driving. To ensure this, 5GCAR identifies and clarifies use cases and requirements for future connected vehicles in this deliverable. The capabilities and functionality needs for the upcoming intelligent transport systems and future driving is foreseen to be

- very low latencies below 5 ms,
- with very high reliability (99.999%),
- at very high vehicle velocities, up to 150 km/h as an average for the upper limits in Europe
- which enables, even in a very high vehicle density, the support of a broad range of V2X services,
- and achieves advanced positioning with vehicle accuracies of 30 cm and vulnerable road user accuracies of 10 cm,

to meet the future societal challenges and expectations. We differentiate between automotive (service) KPIs and communication network (radio) KPIs. The automotive KPIs describe the behavior or services for road users, whereas the communication network (radio) KPIs describe the requirements for information exchange between road users and between the road user and the infrastructure. Both KPIs sets are correlated to each other. Example for automotive KPIs are the required localization accuracy needs, completion time of maneuvers (lane merges, overtaking, intersections), required time frame for software patches to certain model years, etc. In general, we address highly up to fully automated driving scenarios. The automotive KPIs are related to business and regulatory requirements as well.

Executive Summary

The overall goal of the 5GCAR project is to contribute to the specification of 5G to become a true enabler of V2X applications that today are not realizable due to the limitations of current communication networks.

In this deliverable, D2.1, 5GCAR introduces five use case classes that has been identified as the relevant classes for the considered timeframe and scope. Those are

1) Cooperative maneuver,
2) Cooperative perception,
3) Cooperative safety,
4) Autonomous navigation, and
5) Remote driving.

D2.1 further defines one specific use case for each use case class. The aim for each of the five concrete use cases is to provide a detailed problem description as well as concrete requirements and Key Performance Indicators (KPIs). At the same time, these specific use cases are also intended to be relevant for a much wider class of use cases with similar challenges. In the appendices, an analysis of already existing V2X use cases is provided, as well as more detailed requirement descriptions and underlying assumptions.

Based on the use cases defined in D2.1 together with technical components yet to be developed, 5GCAR will propose candidate solution scenarios and evaluate those to meet the overall goal.

Contents

List of Abbreviations and Acronyms

3GPP	Third Generation Partnership Project
4G	Fourth Generation
5G	Fifth Generation
5G-PPP	5G Private Public Partnership
5GCAR	5G Communication Automotive Research and innovation
ABS	Anti-lock Braking System
AD	Autonomous Driving
ADAS	Advanced Driver-Assistance System
AEB	Automatic Emergency Braking
AI	Artificial Intelligence
API	Application Programming Interface
BD	Breaking Distance
BS	Blind Spot
BS/LCW	Blind Spot/Lane Change Warning
BSA	Basic Set of Applications
BSD	Blind Spot Detection
BSM	Basic Safety Message
C-ITS	Cooperative Intelligent Transport Systems
CA	Conditional Automation
CACC	Cooperative Adaptive Cruise Control
CAM	Cooperative Awareness Messages
CDF	Cumulative Distribution Function
CEN	European Committee for Standardization
CENELEC	Comité européen de normalisation en électronique et en électrotechnique
CITS	ITS Communication Standard
D	Deliverable
DA	Driving Assistance
DENM	Decentralized Environmental Notification Message
DNPW	Do Not Pass Warning

DNPW	Do Not Pass Warning
DSRC	Dedicated Short Range Communications
E2E	End-to-End
ECU	Electronic Control Unit
EEBL	Emergency Electronic Brake Light
EEBL	Emergency Electronic Brake Light
ESC	Electronic Stability Control
ESP	Electronic Stability Program
ETSI	European Telecommunications Standards Institute
FA	Full Automation
FCW	Forward Collision Warning
FCW	Forward Collision Warning
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HA	High Automation
HD	High Definition
HMI	Human Machine Interface
ICRW	Intersection Collision Risk Warning
ICV	Intelligent Connected Vehicle
IEEE	Institute of Electric and Electronics Engineers
IMA	Intersection Movement Assist
IMA	Intersection Movement Assist
IMT	International Mobile Telecommunication
ITS	Intelligent Transport System
ITS-S	ITS vehicle Station
ITU	International Telecommunications Union
ITU-R	ITU Radio communication Sector
IVS	In-Vehicle Signage
KPI	Key Performance Indicator
LCRW	Longitudinal Collision Risk Warning
LCW	Lane Change Warning

LDM	Local Dynamic Map
LDMi	Local Dynamic Map infrastructure
LOS	Line Of Sight
LTA	Left Turn Assist
LTA	Left Turn Assist
LTE	Long Term Evolution
LTE-V	LTE for Vehicle
LV2LV	Light Vehicle to Light Vehicle
MAC	Medium Access Control
mMTC	massive Machine Type Communications
NFV	Network Function Virtualization
NHTSA	National Highway Traffic Safety Administration
NR	New Radio
OBU	On Board Unit
OEM	Original Equipment Manufacturer
P-UE	Pedestrian User Equipment
PA	Partial Automation
PDU	Protocol Data Unit
PHY	Physical
POI	Point of Interest
PRtime	Perception-reaction time
QoS	Quality of Service
RAT	Radio Access Technology
RD	Reaction Distance

RHS	Road Hazard Signaling
RSC	Reliable Service Composition
RSU	Road Side Unit
RU	Road User
SAE	System Architecture Evolution
SDN	Software Defined Network
SDU	Service Data Unit
SNR	Signal-to-Noise Ratio
TIAA	Telematics Industry Application Alliance
TIV	Timer Inter Vehicles
TS	Technical Specification
TTC	Time To Collision
UBI	Usage Based Insurance
UC	Use Case
UCC	Use Case Class
UE	User Equipment
V-UE	Vehicle User Equipment
V2I	Vehicle to Infrastructure
V2N	Vehicle to Network
V2P	Vehicle to Pedestrian
V2V	Vehicle to Vehicle
V2X	Vehicle to Anything
VRU	Vulnerable Road User
WAVE	Wireless Access in Vehicular Environments

1 Introduction

5GCAR aims to contribute to the 5G specification. The goal is that 5G becomes a true enabler of V2X applications to enable economic and societal improvements, increase road-safety and driving efficiency, and boost well-being. This is not perfectly realizable today due to limitations in current vehicular communications. In particular, today's networks (e.g., 3GPP LTE and IEEE 802.11p) are not capable of simultaneously providing some of the following features:

- Providing ***end-to-end latencies*** below 5 ms, defined as the contribution by the radio network to the time from when the source sends a packet to when the destination receives it. If communication via the sidelink is used this value corresponds to the maximum tolerable air interface latency plus processing latency with the assumption that sufficient resources are reserved for sidelink usage.
- Providing ***ultra-high reliability*** close to 10^{-5}, defined as the maximum tolerable packet loss rate at the application layer. A packet is considered lost if it is not received by the destination application within the maximum tolerable end-to-end latency for that application. For example, 10^{-5} means the application tolerates, on the average, at most 1 in 100 000 packets not being successfully received within the maximum tolerable latency. This requirement is often formulated as a percentage (e.g. 99.999%).
- Handling a ***very large density of connected vehicles***, defined as the maximum number of vehicles per unit area for which the specified reliability can be achieved. For urban environments, the vehicle density can reach 1000 to 3000 vehicles/km^2. The density can be estimated to be 100–500 vehicles/km^2 and 500–1000 vehicles/km^2 for highway and suburban environments, respectively [ERF11].
- Providing the required ***positioning accuracy***, measured in cm, and defined as the maximum position error tolerated by the application. To position a car in a lane, an accuracy of 30 cm allows for additional errors due to different car widths and lane widths. A positioning accuracy of 10 cm might be desired for Vulnerable Road Users (VRUs), e.g., pedestrians or bicyclists.

The limitations of today's existing wireless systems restrict their use in providing off-board sensing for Advanced Driver-Assistance System (ADAS).

1.1 Objective of the document

In this document, the 5GCAR methodology to identify and classify uses cases is first described. Then, a taxonomy for the most representative V2X use cases is proposed, selecting one key use case for each class. Further, the challenging requirements for each of the specific selected use cases are identified and described.

1.2 Structure of the document

The remaining part of this document is organized as follows. In Section 2, the 5GCAR methodology is presented, with 3 main parts: the problem space, the enabler space and the solution space. This deliverable will focus on the problem space definition by providing descriptions of the use cases, their requirements and KPIs. The two remaining parts, namely the enabler and the solution spaces will be covered in WP3 and WP4 deliverables. Section 3 contains the 5GCAR use case classes and the use case descriptions, which constitute a fundamental input for the other work packages. For the sake of completeness, we also provide an overview of an important list of V2X use cases identified by other 5G projects, and standardization bodies and other technical fora (in Appendix A). In Section 4, the requirements and key performance indicators (KPI) are defined, with three main categories: automotive requirements, network requirements and qualitative or non-functional requirements. Section 5 covers a detailed analysis of the derived requirements, explanation of the values proposed for each requirement, starting always from the automotive definition of the use case and then moving into the network needs. The analysis is considered on manual and automated vehicles depending on the scenario. A summary of the deliverable and key conclusions are given in Section 6.

In addition, this document has several Appendices. In Appendix A, an analysis of already existing V2X use cases is presented, Appendix B briefly presents the functional architecture and finally in Appendix C, some on-board sensors' performances are provided.

2 Methodology

5GCAR will address the V2X challenges by providing novel and extending current technology components that can be used to address those. This section presents the proposed methodology that will enable us to study and prepare for the suggested scenarios and use cases. In order to properly describe the methodology, first a short definition of the terms used is provided before describing the proposed methodology.

The overall problem-solving strategy is divided into three spaces:

1) The **Problem** Space is focused on the set of use cases that will be analyzed.
2) The **Enabler** Space focuses on the combination of legacy or novel technological components in order to support a specific element of the problem space.
3) The **Solution** Space is determined by the application of detailed enablers to specific problems in the problem space.

These three spaces are described in more detail below. Note that the focus within this deliverable is on defining the problem space elements (see Section 3 and Section 4), whereas the enabler space and the solution space will be targeted by 5GCAR D2.3.

The **Problem Space** contains **use case classes, use cases, requirements, and Key Performance Indicators (KPIs)**. These terms are defined as follows:

- **Use Case Class**: A use case class contains several use cases with common aspects (e.g. features, functions, and requirements) identified as a possible part of the future enabled by V2X communications.
- **Use Case**: A practical and relevant aspect formulated from a functional or non-functional perspective. Each use case contains a set of requirements, the pre-conditions, the triggering events, the actors, flow of events, operational requirements and finally the post-conditions.
- **Use Case Requirements:** To fulfill a functional or non-functional demand, a requirement captures a concrete need. A requirement consists of four parts. One part is the label, which consists of one or several words that are used to represent the requirement. A second part is the definition, which describes the need and specifies how to measure the requirement. A third part is the value. A fourth part is the unit, which gives the requirement value meaning and which also relate it to the requirement definition. Note that the two-requirement parts label and definition is a performance indicator.
- **Performance Indicator:** A performance indicator consists of two parts. One part is the label, which consists of one or several words that are used to represent the performance indicator. A second part is the definition, which describes the representation and specifies how it indicates performance.

- **Key Performance Indicator (KPI):** A performance indicator that is highly relevant for a considered use case.

The **Enabler Space** contains legacy components, technology components and enabler settings. Those terms are defined as follows:

- **Legacy Component**: An established technology component that already exists.
- **Technology Component**: A technical 5GCAR contribution that potentially can contribute to enable and/or complement a solution.
- **Enabler Setting**: It consists of one or several components. The component(s) can either be only technology component(s), only legacy component(s), or a combination of both.

The **Solution Space** contains assumptions, scenarios, scenario results, feasible solutions, and non-feasible solutions. Those terms are defined below.

- **Assumption**: Preconditions and conjectures related to environments, models, and parameters. Each assumption needs to be validated somehow to ensure that it is valid.
- **Scenario**: A scenario consists of a selected use case from the problem space, an enabler setting from the enabler space and assumptions from the solution space.
- **Scenario Result**: A outcome from investigating and studying a scenario.
- **Feasible Solution**: If the scenario results fulfill all use case requirements, then the scenario is a feasible solution.
- **Non-Feasible Solution**: If the scenario results do not fulfil at least one of the use case requirements, then the scenario is a non-feasible solution.

The evaluation approach is described and visualized based on the terminology that was introduced above. In Figure **2.1**, the entire 5GCAR evaluation approach is illustrated.

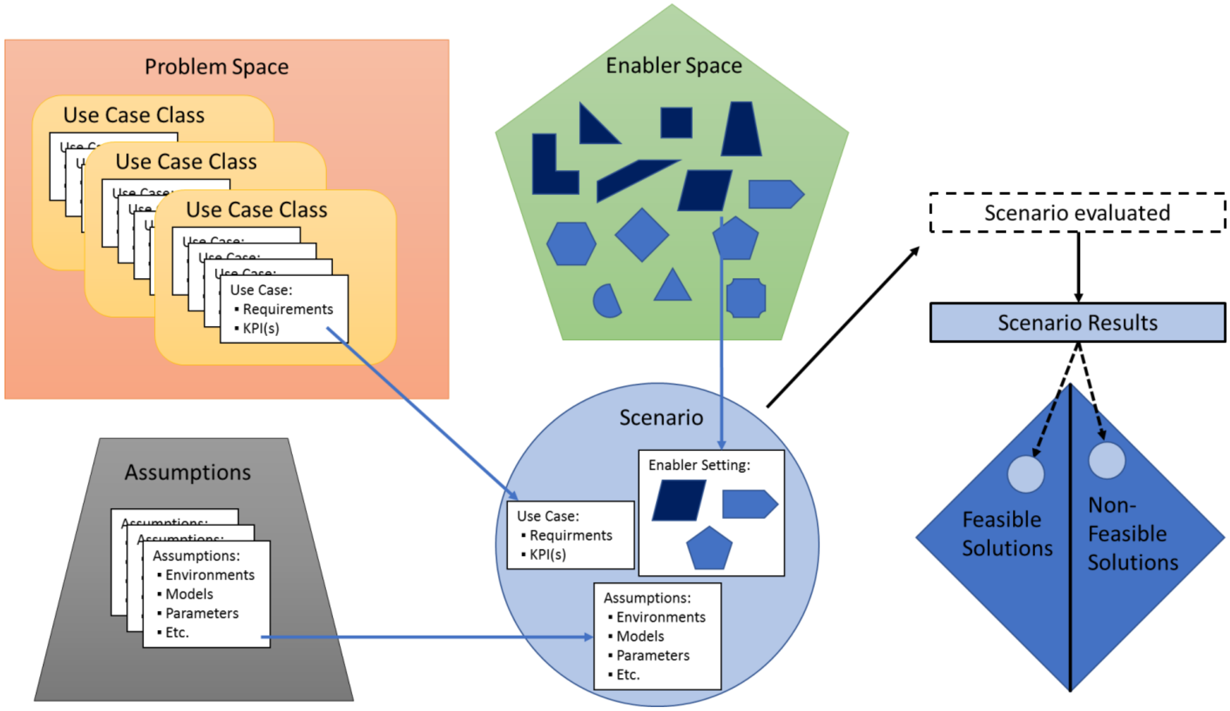

Figure 2.1: 5GCAR proposed methodology

The Problem Space (red) contains a number of use case classes (orange). Each use case class contains a number of use cases (white). Each use case contains a set of requirements and one or several KPIs. The Enabler Space (green) contains both already existing legacy components (dark blue) and future technology components (light blue). The assumptions (grey) contain environments, models, and parameters.

A scenario (blue) contains one use case from the Problem Space, one enabler setting from the Enabler Space, and a set of assumptions. The scenario is the basis for 5GCAR evaluation, thus it can be evaluated to attain scenario results (blue). Based on the scenario results one can determine whether the scenario fulfills the use case requirement or not and thereby determine if the scenario is a feasible solution or a non-feasible solution.

3 5GCAR Scenarios and Use Cases

A 5GCAR use case together with enablers and assumptions is a 5GCAR scenario. Relevant scenarios will be evaluated during the lifetime of the project to identify solutions that meet the 5GCAR goals specified in Section 1. I.e., the actual construction of 5GCAR scenarios and the evaluation of those will take place in future 5GCAR deliverables. An illustration of this evaluation approach has been provided in Figure **2.1**. The focus of this deliverable is to identify relevant use cases and to provide a detailed problem description as well as concrete requirements and Key Performance Indicators (KPIs) for those. To achieve this, the V2X area has been organized into broader 5GCAR use case classes defined in Section 3.1. To identify relevant use cases to study an analysis of already existing V2X use cases was conducted. Findings from analysis are provided in Appendix A. From the 5GCAR use case classes five specific use cases have been defined in Section 3.2. Note that these defined 5GCAR use cases are intended to be relevant for a wider class of use cases with similar challenges. In Section 4 the requirements and KPIs are presented.

Automated driving is becoming a reality and will be happening in several steps, each one increasing the level of automation of the vehicle functions and reducing the involvement of the driver. Today, in the early phases of partially automated driving, the driver is required to constantly monitor the environment to be able to take back the control of the vehicle whenever the needs rise. In the future, fully automated systems will allow the driver to remain completely out of the loop. This means that the vehicles are expected to take over the complete driving task, until now under the sole responsibility of the human driver, in all environmental situations and with the highest reliability. To achieve the vision of fully autonomous driving, several key capabilities need to be implemented in the vehicles and taking into consideration the significant driving scene complexity that might be encountered in the future.

For example, a vehicle should be able to center itself within the lane and control its trajectory and speed by performing automated steering interventions, combined with lateral and longitudinal motion control. To make reliable decisions on the best appropriate actions for any possible situation encountered in road traffic, the vehicle can perform a continuous surround sensing to maintain a complete awareness of its environment. This is achieved through processing a combination of data obtained from multiple sensors, e.g. radar, video sensors, etc., that are necessary for generating a complete and reliable model of the vehicle environment. This process of sensor data fusion from various sensors is known as **perception**. The local sensor information is usually complemented by information from other vehicles, roadside infrastructure, or back-end server using wireless communications. In particular, using sensor data shared by other vehicles is beneficial for extending the vehicle field of view, resulting in a 360-degree reliable environment model.

In addition to the environment perception, the automated vehicle can benefit from up-to-date and **high definition map information**, including road descriptions and context information, provided, for example, from an online server thus enabling the vehicle to navigate intelligently through all type of environments. This will result in alternative sources of information that create a form of redundancy which helps increasing the reliability of the automated driving system.

As part of the automated driving tasks, a vehicle should be able to apply **maneuvers,** e.g. automatically change lanes when appropriate. For this, the interaction with the surroundings and the cooperation with other vehicles in the vicinity will become more and more relevant. This cooperation by means of wireless communications will allow to perform joint maneuver decisions that enhance the safety and help the vehicles getting through difficult traffic situations.

In addition to cooperation with other vehicles, the **interaction with other vulnerable road users** (e.g. pedestrians, bicycles, motorcycles) can help increase the road safety and reduce the traffic accidents through early notifications about potential collisions and their avoidances with appropriate actuation system maneuvers. For this, the accurate localization of the vehicles and the vulnerable road users is a major need that requires a key enabling technology to be developed.

Finally, another potential form for bringing the autonomous driving into reality is **the remote driving**. This could be, for example, realized by having an operator remotely monitoring and controlling a vehicle from a distance (e.g. via a server on the cloud) to intervene if necessary and hence increase the vehicle safety.

The analysis of the autonomous driving needs described in this section constitutes a basis for the conducted use case selection within the 5GCAR project.

3.1 Use case classes

In order to enable the automated driving vision, described in the introduction of section 3, a set of enabling use cases need to be implemented that rely on the communication system connecting vehicles with other nearby vehicles or other road users and with the network infrastructure. 5GCAR has defined five Use Case Classes (UCCs) taking into consideration the different sets of operations required by cooperative and automated vehicles. Each UCC enables a different functionality and consists of various use cases. Each use case analyses the respective functionality or operation in a different context (i.e., road conditions, road environment, level of automation etc). The 5GCAR use case classes are:

1) Cooperative maneuver,
2) Cooperative perception,
3) Cooperative safety,
4) Autonomous navigation, and
5) Remote driving.

A short description for each of these use case classes followed by the goal, main benefits, main challenges, as well as the foreseen needs are presented in Section 3.1.1 to Section 3.1.5.

3.1.1 UCC1: Cooperative maneuver

Cooperative maneuver is based on the principle of sharing local awareness and driving intentions and negotiating the planned trajectories. The information is shared among vehicles in the vicinity or infrastructure via wireless communication. Based on the shared information, the driving trajectories of the considered group of vehicles can be coordinated and even optimized in a centralized or decentralized manner. This includes availability of additional information, e.g. driving intentions and planned trajectories, besides typical awareness information, potential negotiation, including request and acknowledgement among vehicles, and possible joint optimization of trajectories among vehicles.

Goal: coordinate driving trajectories among a group of vehicles to improve safety and efficiency.

Benefits: Several benefits can be achieved, with an improvement of decision making, driving comfort (e.g. smoother maneuver), traffic safety and efficiency, as well as reducing emissions and fuel consumption, e.g. in context of platooning.

Challenges: The main difficulties of this use case class are related to common interpretation of driving intentions and trajectories, joint optimization of trajectories (especially in a distributed manner), acknowledged maneuver plans, authenticity and integrity of shared information (to trust the information and the source of it, while preserving the privacy), and perhaps the most challenging task is the integration of legacy vehicles for the trajectories calculation. A combination of fine-grained object detection, precise positioning, online and offline data analysis, and timely communication is needed to make UCC1 a reality.

Needs: The vehicles should be equipped with wireless communication capabilities and a precise positioning system. An authentication mechanism for the shared information is required too.

Examples: Cooperative lane change (vehicles collaborate to perform a lane change of one or a group of cooperative vehicles in a safe and efficient manner), convoy driving (a number of vehicles are grouped together in a stable formation with small inter-vehicle distances to increase road capacity, driver safety, and comfort), and cooperative intersection management (cooperative vehicles to traverse an intersection in a safe and efficient manner).

3.1.2 UCC2: Cooperative perception

The cooperative extension of the perception range is built on the basis of exchanging data from different sources, e.g., radars, laser sensors, stereo-vision sensors from on-board cameras. The information is shared among vehicles in the vicinity and/or infrastructure via wireless communications. The principle is to merge the local sensor information with remote information (locally and on a remote server). One of the key principles for enabling cooperative perception is to know the relative pose (relative localization) between spatial information from various sensors of different vehicles which should be treated as a map merging problem. The perception results can be represented in a form of see-through, lifted-seat or satellite view (bird's eye view).

Goal: Two main goals shall be highlighted in this use case class: (1) to extend the local perception range beyond the line-of sight and local field-of-view and sensing angles of an individual vehicle by designing a driver assistance system which can mitigate traffic accidents caused by the limitations of local perception; and (2) to enable cooperative and autonomous driving by enabling the construction of a local dynamic map (LDM) where static maps and traffic data will be complemented with dynamic sensor data in order to facilitate autonomous navigation of vehicles through different road/traffic environments.

Benefits: A cooperative perception will increase situational awareness without substantial additional costs, i.e. communication modules have more affordable prices compared to advanced vehicle sensors (see Appendix B for more details). The traffic safety will be increased with more efficient driver assistance for safe maneuvers such as overtaking or lane changing/overtaking, smooth breaking/acceleration efficiency by detecting and avoiding hidden or sudden obstacles. In addition to providing better driving comfort, smooth driving will reduce harmful emissions and reduce fuel consumption. Driving decisions will be facilitated: the driver (or the autonomous driving system) can learn about upcoming traffic situations ahead which is useful for short-term perspective driving decisions for hidden obstacle detection and collision avoidance and long-term perspective planning for better routing selection. At last, fusing remote information (obtained via wireless communication) with local senor information will improve perception reliability and decision making.

Challenges: The key challenges in this UCC are related to multi-vehicle sensor information fusion and map merging to make sure that vehicles have a common referencing system (time and space) for localizing detected objects, with no guarantee that sensors configuration in different vehicles is identical. Furthermore, related to localization and relative positioning, each map has different scan points even in the overlapping area and the overlapping area may not be sufficient due to longer safety gaps for collision avoidance.

Needs: Vehicles should be equipped with sensors for the vision, sensors for classification and identification of vehicles and pedestrians, and range sensors for vehicle detection and tracking. The other needs are a localization and time-synchronization system with an accuracy beyond current GNSS and, of course, a communication system (to provide connectivity between vehicles and between vehicles and infrastructure).

Examples: Bird’s eye view (an intersection equipped with sensors such as cameras or radar can provide real-time information to approaching vehicles to assist their movements in the intersection), sensor and state map sharing (raw or processed data of different vehicles are shared to build collective situational awareness with higher spatio-temporal fidelity), and 3D video composition for V2X scenario (multiple UEs supporting V2X applications take videos of the environment and send them to a server, which are then used and processed by the server to create a single 3D video of the environment).

3.1.3 UCC3: Cooperative safety

The cooperative safety can be achieved by exchanging the information about detection of the presence of road users. Various methods can be employed to detect the presence of VRUs, for example local sensor/camera/radar and/or positioning system and/or communication system.

The last scenario can be supported by cellular systems if the VRU has a smartphone or cellular communication devices. The available VRU information can be exchanged between all relevant users and/or infrastructure entities. Such information can be processed/analyzed by application server or the vehicles. An alert message can be generated and delivered to the vehicle driver or fully Autonomous Driving (AD) vehicle. With the awareness of the VRU, the vehicle can take appropriate actions such us reducing speed to protect the VRU. Note that this use case class consists of use cases where the sole purpose is to provide safety to the surrounding, whereas e.g. the purpose of UCC1 is to enable maneuvers (in a safe way) and where the purpose of UCC2 is to perform cooperative extension of the perception range (where an extended perception for example can serve as an enabler for maneuvers or can provide safety to its immediate surrounding).

Goal: To extend safety protection for VRU (e.g. pedestrians, cyclists, motorcyclists, pets) by enabling reliable interaction between active vehicle and surrounding passive users in a direct or indirect way.

Benefits: An improved traffic safety thanks to the provision to the vehicle driver assistance information (for example alert message) by detecting the presence of VRUs. This will also result in an increased environment awareness without substantial additional costs (prices of sensors and radio devices are already presented in the upcoming collision detection and safety functions).

Challenges: The main difficulties of this use case class are related to the reliable detection of the presence of a VRU in proximity in different environments and weather/light conditions and the high accurate location and relative positioning of the VRUs, especially in case such capability may not be available for all vehicles and VRUs.

Needs: Vehicles should be connected and equipped with a video camera device and additional sensors such as gyrometer and accelerometer inside the vehicle and a GNSS receiver.

Examples: Cooperative traffic jam warning (a vehicle informs other vehicles approaching through cooperative channel, that there is a traffic jam and they should reduce the speed), cooperative traffic light violation warning (cooperative information given to the vehicles approaching an intersection, in order to let them know that a vehicle has violated the red light, and can interrupt in the intersection), cooperative emergency vehicle approaching (information given to the vehicles from an emergency vehicle, to let them know that a fast emergency vehicle is approaching their location).

3.1.4 UCC4: Autonomous navigation

For the purpose of building Real-time Intelligent High Definition (HD) Map, and aggregation of information collected e.g. in the UCC2 Cooperative perception and map updates with very precise context information (road structures, reference objects for localization, etc.) must be performed. Then, the distribution of the localized HD map to vehicles will be performed based on their locations.

Goal: To provide optimal route selection for semi and full automated driving by exploiting the availability of information gathered from sensor information shared by other vehicles.

Benefits: A save of energy and time for optimized routing decisions will be achieved by using an HD dynamic map. This is possible as a result of processing the detailed lane level information that can be obtained about the drivable area in front of the vehicle, e.g., in which lane the vehicle is driving, what lies in the surrounding of the vehicles, and knowledge about the other road users whether driving/moving/positioned etc. The logical security will be increased because the map distribution will be made by a unique and well known trusted source. This benefit will enable semi and full autonomous driving (accurate HD-map information enabling accurate vehicles position estimates) and will improve the driving experience in terms of comfort both for the driver and passengers.

Challenges: Centralized and or distributed computation in real-time routes for all vehicles, taking the actual traffic and environment condition into consideration (presence of VRU, road signs, etc.). Afterwards, the distribution of the updated map information to make sure that vehicles within the same location have the same version of the map is also a tough action.

Needs: Distributed route computation server strategy is needed, with servers placed next to the area where calculations are made to speed-up the route calculation and to perform a fresh and fast map information distribution.

Examples: Emergency trajectory alignment (the different trajectories of nearby vehicles are shared in a hazardous driving situation in order to avoid accidents and increase traffic safety and an updated map distribution is pushed by the arrival of an emergency vehicle), traffic flow optimization (a system to propose to each driver the best route towards its destination taking into account the local and global traffic context, convoy driving (a number of vehicles are grouped together in a stable formation with small inter-vehicle distances to increase road capacity, driver safety, and comfort).

3.1.5 UCC5: Remote driving

Remote driving is to be able to control the different actuators of the car (steering wheel, brake and throttle) from outside the vehicle through wireless communication. To perform a safety remote driving it is necessary to receive information about the perception layer (vehicles sensors and map), and, if possible, also infrastructure information.

Goal: To enable a remote driving, from a human operator or an application server, of the vehicle to provide more safety, convenience and efficiency, as well as removing any driving task for the people inside the car.

Benefits: The possibility of controlling the car remotely has several advantages: It enables to drive a car to people who cannot drive by themselves even in cars without highly automated driving functions (SAE levels 4 and 5). However, when the vehicle has the capabilities to drive autonomously without the supervision of the driver, the option that the vehicle can be driven remotely would add a point in safety as a back-up in case of problem. These will highly increase the comfort of the driver since they can leave the driving task or even getting out of the car. Furthermore, it will be possible not only to control one vehicle but also a fleet of vehicles that would increase safety and efficiency overall.

Challenges: There are some challenges to face in case of remote driving. The first one is safety. Autonomous driving functions are critical systems, so wireless communication has to ensure a very small latency and almost 100% of reliability since a few milliseconds of coverage loss could be fatal. Another one is security. It would be necessary to guarantee that only authorized people or trusted application servers, can have access to control the vehicle and OEMs have to agree to provide such permissions.

Needs: There has to exist a remote cloud server from which to receive information about the vehicle (position and surrounding objects) to control it remotely. The vehicle must have a proper perception and allow access to the actuators. Furthermore, the vehicle and the control center need to be able to communicate.

Examples: Remove driving for automated parking (a remote server controls the vehicle in order to park it in a free parking spot, taking into account vehicle sensors and actuators), Public transport remote driving (in the example given, public transport vehicles are autonomously driving by themselves, but when they face a complex situation that cannot be handle by the autonomous driving system, a remote driver placed in a control center, takes remote control of the vehicles in order to drive the vehicles to a simpler scenario), Remote driving for last mile delivery (a remote server remotely drives delivery electric vehicles, in order to deliver last mile packages. The system is also able to remotely drive the electric vehicle to the charging station, in order to have the vehicles charged every day).

3.2 Use cases

5GCAR has selected one relevant and representative Use Case (UC) from each of the Use Case Classes (UCCs) defined in Section 3.1 taking into account their impact (e.g., societal, safety purposes, business opportunities), their frequent occurrence in future highways or urban environments and the challenges that they set for the communication system. The five use cases selected in 5GCAR are:

1) Lane merge (UCC1: Cooperative maneuver),
2) See-through (UCC2: Cooperative perception),
3) Network assisted vulnerable pedestrian protection (UCC3: Cooperative safety),
4) High definition local map acquisition (UCC4 : Autonomous navigation), and
5) Remote driving for automated parking (UCC5: Remote Driving).

A short description for each of these use cases followed by the goal, main benefits, main challenges, as well as the foreseen needs are presented in Section 3.2.1 to Section 3.2.5.

3.2.1 UC1: Lane merge

In this use case, one vehicle has the intention to merge from one road to another. The vehicle preparing the merge and the one in the main lane can share their local awareness and driving intentions. Based on information and data fusion techniques, trajectories can be computed and then proposed to the vehicles involved. Thereafter, the driving trajectories and speeds of both vehicles can be adjusted, so that the subject vehicle merges into the intended lane in a safe, efficient, and smooth way. Note that legacy vehicles can also be involved as in Figure **3.1**, even though they are not connected and thus do not have wireless communication capabilities.

Goal: Provide trajectories for the vehicles that are on the main lane to merge smoothly into the main lane without collisions and with minimal impact on the traffic flow.

Target environment: Anywhere including highways, urban roads, and intersections.

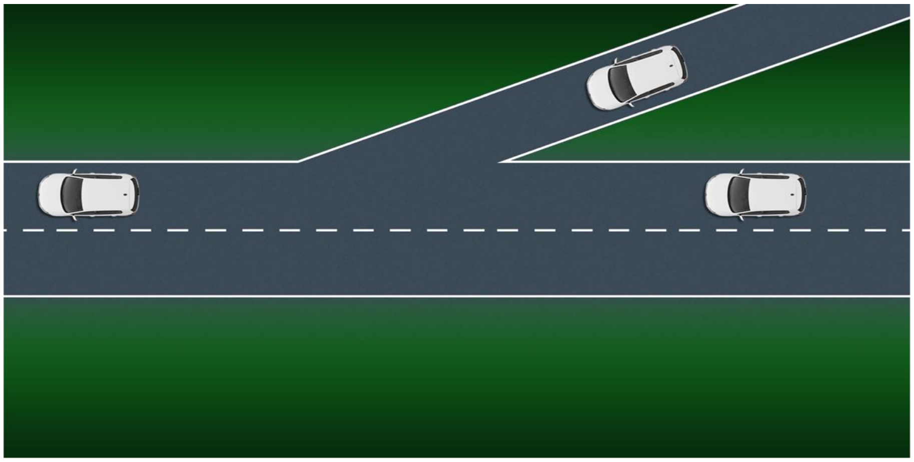

Figure 3.1: The 5GCAR Lane merge use case (UC1)

Pre-conditions: Vehicles are in the vicinity of each other. A remote vehicle is a connected and equipped vehicle, where connected implies wireless connectivity capabilities and equipped implies on-board sensors and autonomous driving capabilities. Involved vehicles are authenticated.

Triggering event: A vehicle wants to merge the insertion to the main lane.

Actors:

- Actor 1: The vehicle who wants to merge into the main lane it can be a connected or unconnected vehicle.
- Actor 2: The vehicle that is driven in the main lane and will let Actor 1 to merge into the main line, it has to be a connected vehicle.

Optional actors:

- Actor 3: infrastructure equipped with sensor(s). It can provide a LDM of vehicles detected by a system of sensor(s) covering the lane merging area,
- Actor 4: application server. It can assist the lane merging of the HV.

Flow of events:

- HV, i.e., Veh2, intends to start a lane merging, where Veh2 can be connected or unconnected. The HV also transmits its intention messages and status information (e.g., position, speed) if it is connected.

- An RV, i.e., Veh3 (the car furthest to the left in Figure 3.1) that is unconnected, is unaware of the request from Veh2 (the car furthest to the right in Figure 3.1), and thus continues driving.
- Another RV, i.e., Veh1 that is connected, transmits its status information (e.g. position, speed).
- Meanwhile, the RV Veh1 acquires the merging request of Veh2 and some other merging related information, which can be achieved through various manners
    - Veh1 can receive the merging request and merging related information from Veh2 if Veh2 is connected, where the merging related information can include the status of Veh2, e.g., position, speed, etc.
    - Veh1 can receive the merging request and merging related information from infrastructure or application server, where the merging related information can include the status of Veh2, e.g., position, speed, etc.
    - Veh1 can receive the merging request and merging related information from infrastructure or application server, where the merging related information can include collision warning messages and maneuver advise/control messages such as speed acceleration/deceleration profiles.
- The HV, i.e., Veh2, receives merging related information if it is connected
- HV and RVs agree on the appropriate actions to enable a safe and efficient lane merging
- HV and RVs applied the appropriate actions based on the received information and/or detections obtained from on-board sensors and/or in-vehicle drivers to execute a safe and efficient merging

Operational requirements:

- The connected vehicle needs a wireless communication capability and a Global Navigation Satellite System (GNSS)

Optional operational requirements:

- The infrastructure can use a system of vision-based sensors, object detection algorithms (vehicles), lane detection algorithms, GNSS (for the reference time) and LDM management
- The Application server can use communication, computation, and storage capabilities

Post-conditions: The safety distance between vehicles is to be respected, i.e. no collision due to the vehicle maneuvers.

3.2.2 UC2: See-through

In this use case, a cooperative perception system exploits the exchange of data objects detection or video between vehicles via wireless communication to increase safety either by facilitating automated driving or by assisting the driver during maneuvers. The data representing the scene in front of the vehicle ahead of a line is captured by a camera vision system and transferred to the rear vehicle to allow it to see through the forward vehicle and bypass the occluded area. As represented in Figure 3.2, it will allow for example safe overtaking maneuver.

Goal: To overcome the visibility limitation of a subject vehicle due to the occultation caused by the vehicle driving ahead by providing the driver of the subject vehicle with a direct overview of the scene in front of the vehicle driving ahead.

Target Environment: All national roads, highways, urban roads, road crossings (e.g. intersections).

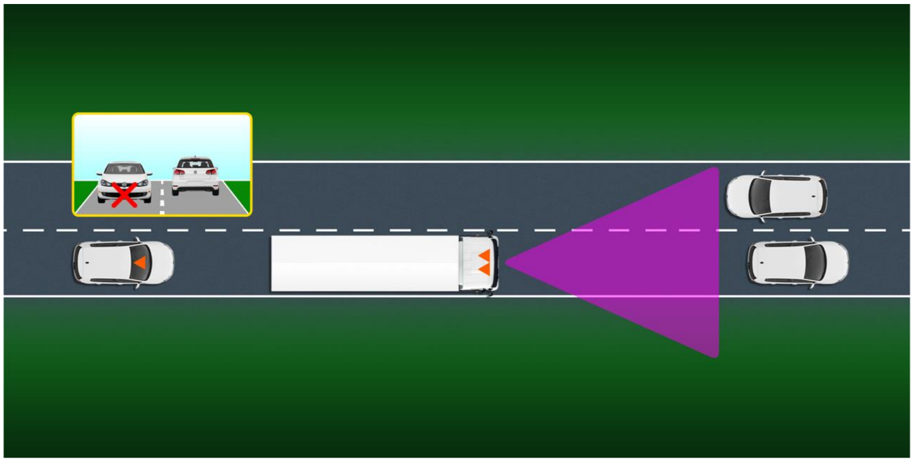

Figure 3.2: The 5GCAR See-through use case (UC2)

Pre-conditions: The Front Vehicle and Rear Vehicle are in the communication range of each other. Video data sharing is enabled and the involved vehicles are mutually authenticated.

Triggering Event: The Rear Vehicle (with obstructed view) wants to start certain maneuvers (e.g., overtaking, lane changing) or is driving in certain locations (e.g. close to a road crossing, high risk area (identified based accident statistics) where a see-through assistance is needed to cross the area safely.

Actors: Vehicles involved.

Flow of events: The rear vehicle (Veh2) asks the support of front vehicle (Veh1, the truck) for the extension of its perception about road conditions (e.g. other vehicles from opposite direction, objects that are not visible) in order to make a safer maneuver. The following events occur:

- Estimation of the relative pose between the two vehicle reference systems so that the visual perceptions of both vehicles can be related to a common spatial reference in a consistent way.
- Transformation of 3D perspective between the visual perceptions of the two vehicles.
- Veh1 transmits a video data to Veh2 (i.e., image representing the region of interest from the point of view of Veh2).
- Veh2 performs appropriate cropping of the received video image and stitches it on the current image (on top of the occulated area).

The video-data transmission streaming is ended with the completion of the maneuver.

Operational requirements: Both vehicles need a vision-based sensor (e.g. stereo camera) and a computational server to run the corresponding computer vision processing part required for the application.

Post-condition: Drivers have a good awareness about the traffic situations and scenes ahead.

3.2.3 UC3: Network assisted vulnerable pedestrian protection

This use case is focused on situations where a pedestrian is moving close to the road or crossing the street. A vehicle is coming down the street with its view hidden behind parked cars. Thanks to the exchange of local sensor/camera information between users via wireless communications the overall system will determine VRU positioning based on cellular radio signals, GNSS or sensor/camera data. All this location information will be processed from multiple users for alert generation to vehicle drivers or AD vehicles with high accurate positioning

Goal: To detect the presence of vulnerable pedestrian users in proximity of a vehicle and deliver such information to the vehicle to avoid the potential collision with the help of accurate positioning technology.

Target environment: Crossroad or roads without pavement where pedestrians shall be in the trajectory of a vehicle.

Pre-conditions: A pedestrian is crossing a road in bad visibility conditions. The vehicle involved is equipped with communications capabilities. The equipped pedestrian user is carrying a P-UE device and registered in infrastructure network and a location server with enhanced positioning algorithm and data fusion.

Triggering Event: A risk for the pedestrian safety is detected when crossing the road.

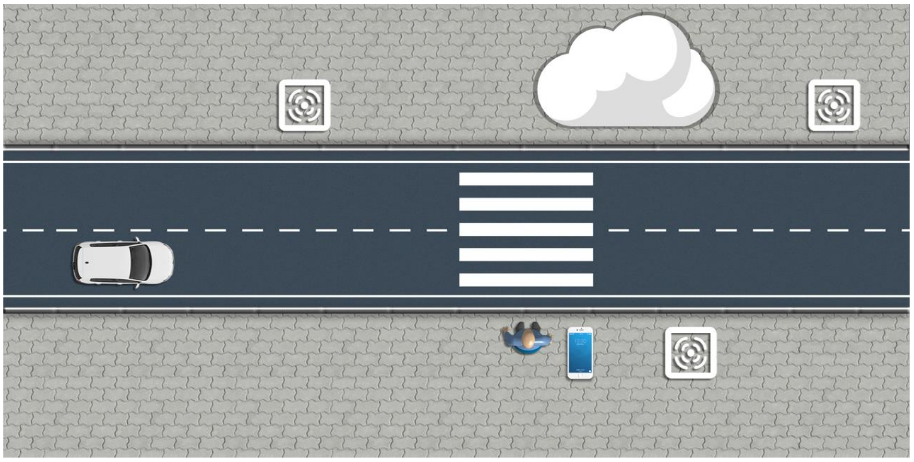

Figure 3.3: The 5GCAR Network assisted vulnerable pedestrian protection use case (UC3)

Actors:

- Actor 1: Telecom operator provide components for a synchronous network with multiple base stations. Infrastructure provides a broadcast signal of multiple base stations to the Vehicle with V-UE device and to the Pedestrian with P-UE device. Using V2N/V2I communication, localization data (x,y) and alert information are provided from Actor 1.
- Actor 2: Pedestrian UE (P-UE)
- Actor 3: Vehicle UE (V-UE)

Flow of events: Equipped car able to connect via communications channel to infrastructure and location server to warn the driver or decide consequently driving corrections (avoid collision)

- Actor 1 controls the V-UE and P-UE communication, and exchanges status of these users.
- Actor 2 manages independently to come close to the street and stop or cross the street with the P-UE unit.
- Actor 3 the vehicle is connected to the mobile network and gets the status of V-UE and P-UE for monitoring. The network will communicate the P-UE position and/or stop alert to the vehicle, which will decide by the vehicle itself how to react.

Operational requirements:

- Components for synchronous infrastructure and base stations.
- 5G User Equipment V-UE and P-UE.
- Location server and processing algorithm.

Post-conditions: Potential collision is avoided and pedestrian users safely cross street.

3.2.4 UC4: High definition local map acquisition

An off-board system gathers all the information from different sources according to different layers starting from the map provider (static layer) to the cooperative sensing of the different vehicles available (temporary and dynamic layer) to build an optimal route map. This information is organized and divided in polygons for being distributed by push/polling methods to the vehicles. Polling methods are used on a regular frequency and push methods by major changes or hazardous events.

Goal: To update the local dynamic map of vehicles on the move.

Target environment: Any driving environment (urban, road or highway) to be enabled for semi and full autonomous driving.

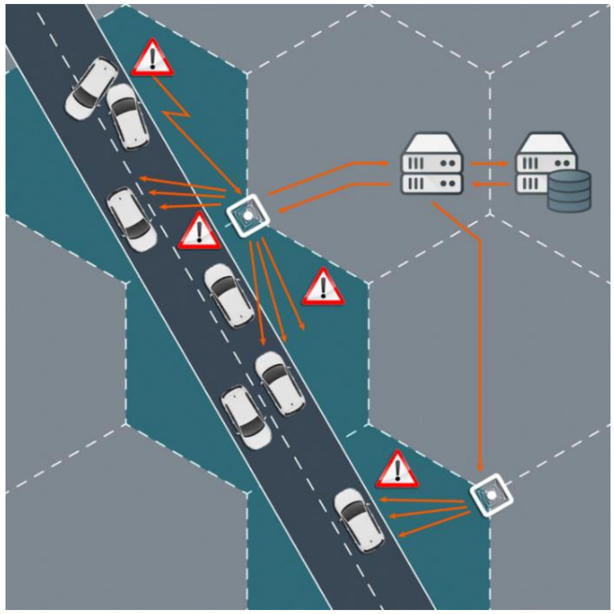

Figure 3.4: The 5GCAR HD local map acquisition use case (UC4)

Pre-conditions: The vehicle receiving the map must be in a cellular coverage zone to receive the map updates. The vehicle is equipped with wireless communication capabilities to interact with the application server.

Triggering Event: Two different events may trigger the map update: the periodically refreshed information polled by the vehicle with a frequency determined by the vehicle driving conditions (speed, environment, manual or autonomous driving, etc.) or a push made by the server towards the vehicles involved in a precise area due to a major map update or a hazardous change in the driving conditions.

Actors:

- Actor 1: Application server in charge of processing and aggregating the information collected from different sources including vehicles sensors, construct a high definition map and transmit the relevant information to the vehicles.
- Actor 2: Host Vehicle receiving the HD map and aggregated information from the server.

Optional actors:

- Actor 3: Road Side Infrastructure providing also information collected from the sensors connected to it.

Flow of events:

- The application server gathers the information from different sources and organized in layers, namely: in Layer 1, static information map from a map provider; in Layer 2, landmark information for space references based on relevant natural or artificial features; in Layer 3, temporary information of a precise area obtained from the infrastructure or from other vehicles such us the appearance of a fog bank (detected by cameras or by the fog lights activation of the vehicles) or a slippery zone on the road (ABS or ESP activation in a car); in Layer 4, dynamic information coming from vehicles nearby due to the usage of cooperative perception and trajectories shared by the cooperative maneuver.

- Once the information is organized and localized, the map is divided in sectors or polygons. The surface of these will depend on the driving environment (highway, urban conditions, etc.).
- The host vehicle will contact the application server and verify the cellular coverage needs and the identity of the map provider.
- The host vehicle, once it has defined its destination, will make a first download of layer 1 and 2 map of the way planned. These first 2 layers may have a lower frequency update (days or even a week) depending on the surface covered by the map downloaded.
- Further download of the map (e.g., layers 3 and 4) may be triggered by two types of events: 1) The host vehicle will pool updates of the map to the vehicle according to the frequency negotiated during the connection establishment. This frequency will be based on the driving conditions (less than 10 seconds for driver assistance); 2) The application server will push a major update due to important changes in the map information: dangerous road conditions, emergency vehicle, hazardous situations, etc.

The host vehicle will process the information according to the type of driving situation, representing them in a suitable human machine interface (HMI) for driver assistance or transforming them into commands for driving actuation once analyzed with data fusion techniques for autonomous driving situations.

Operational requirements:

- The host vehicle needs wireless communication capability to communicate with the application server
- The application server must have communication, computation, and storage capabilities
- Infrastructure (optional), a system of sensors to collect information and wireless communication capability to transmit the collected information to the application server

Post-conditions: The host vehicle will make optimal driving decision based on an up-to-date, precise, and reliable vision of the environment.

3.2.5 UC5: Remote driving for automated parking

The remote cloud server provides to the vehicle that is remotely driven the appropriate trajectory and maneuver instructions for the efficient and safe parking. The decisions and remote driving are supported by real time video streaming and sensor data that are sent from the remote vehicle and/or parking facilities to the cloud server.

Goal: To drive remotely, by an application server, a vehicle from the “last mile” near a parking to the parking entrance to the parking spot without a human driver inside the car.

Target Environment: Public or private parking (indoor or outdoor) and "one-mile" distance area around it.

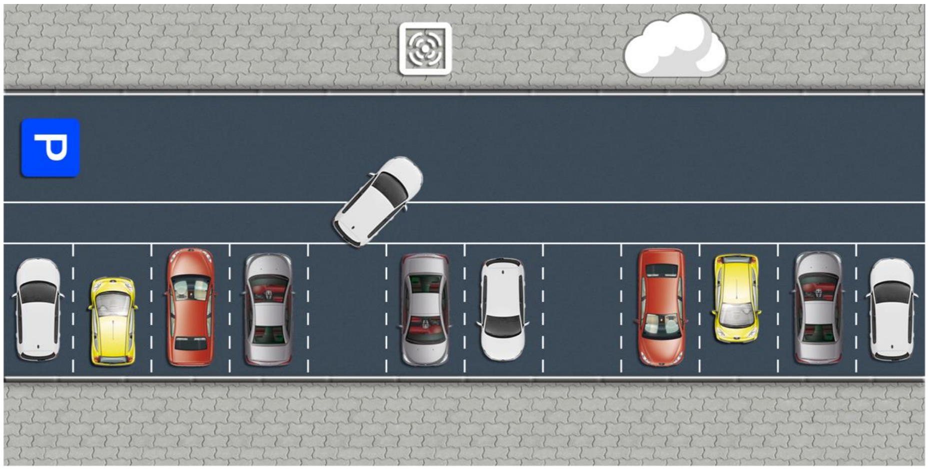

Figure 3.5: The 5GCAR Remote driving for automated parking use case (UC5)

Pre-conditions: The vehicle and the remote cloud server are mutually authenticated for sharing video and sensor data. The vehicle can communicate with the cloud server. The vehicle has enough perception capabilities and allows access to its actuators. The parking area has installed sensors and/or cameras that could facilitate the remote cloud server decision of trajectories.

Triggering Event: The driver leaves the vehicle in the "Pick up/Drop off" zone and request an automated remote parking

Actors:

- Actor 1: Cloud server in this use case to replace human driver and control the vehicle remotely.
- Actor 2: Vehicle that is remotely driven.
- Actor 3: Parking facilities can provide assisted information to the cloud server.

Flow of events:

- The Vehicle establishes the communication channel with the Remote Cloud Server,
- The Vehicle collects sensor information (e.g., LIDAR, RADARs), vehicle Status (e.g., speed) and video streaming images (e.g., two cameras (front, end))
- The vehicle transmits, periodically, to the cloud server the information of the model of surroundings.
- The Remote cloud server considering the destination parking position that has identified, the local road situation, map/traffic information, received sensor/camera data from vehicles and/or parking facilities, calculates the driving commands.
- The Remote cloud server, periodically, transmits driving demands (e.g., steering wheel, speed, acceleration).

- The Remote vehicle executes the driving commands.
- Feedback is sent to the remote cloud server by the execution of the maneuver.

When the vehicle has reached its destination and it is parked to the parking place then the remote driving process ends.

Operational requirements:

- Vehicles some panoramic vision sensors.
- Parking facilities equipped with cameras or other type of sensors.

Post-condition: The vehicle is successfully parked in one of the parking spots.

4 5GCAR Requirements and KPIs Definitions

The 5GCAR requirement labels and definitions are specified in this chapter. More specifically, the requirements have been divided into automotive requirements, network requirements and qualitative or non-functional requirements which are presented in Section 4.1 to Section 4.3.

4.1 Automotive requirement definitions

Wireless communication shall improve the performances of the current Advanced Driving-Assistance Systems (ADAS) by increasing the Line Of Sight (LOS) of the on-board sensors. First, a briefly functional explanation of what the current autonomous driving systems is.

For any ADAS application, the equipped vehicle will have to localize all the objects which could interfere with its own trajectory. These objects will be either static (poles, barriers, walls, curbs, non-moving vehicles and pedestrians) or mobile (vehicles and pedestrians on the move). For all the other mobile objects, a prediction of their trajectories will be necessary to adapt its own equipped vehicle trajectory (heading, speed, acceleration) to avoid any possible collision.

For the perception of the road environment specific radars, lidars, camera and possible cooperative sensing systems are designed to cover essentially the longitudinal axis of the equipped vehicle, in the front and in the rear for all scenarios where a longitudinal collision could occur. The detection / tracking area around the vehicle can be described in two main situations that are the longitudinal situations and the Intersection situations, see Figure **4.1**.

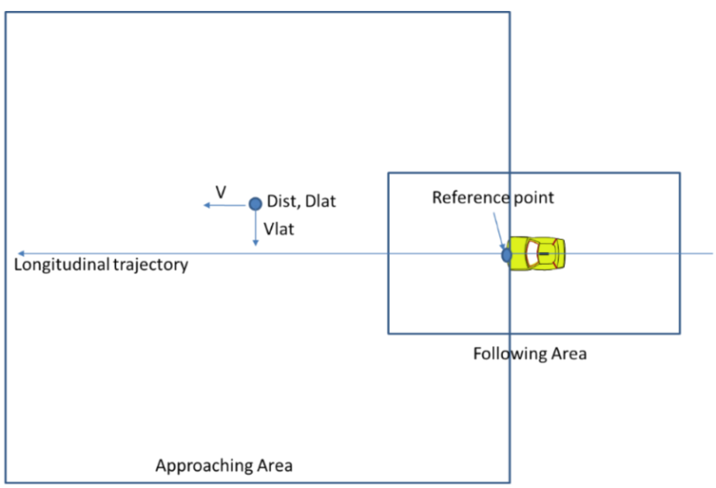

Figure 4.1: Detection/tracking areas in intersection situations

In principle, radars, lidars and cameras give a radial localization of objects by their relative distance and their sight angle. The quality of distance, angle and relative speed measurements decreases when the distance of these objects increases. This is due to the fact that the signal to noise ratio decreases when the distance increases. More detailed information can be found in the Appendix Section C.

Taking into account the ADAS sensors detection distance limitations, there is room for V2X communications to improve the detection distance thanks to the wireless range, if the end to end delay is short enough to compete with the response time of the sensors.

For the use case characterization, 5GCAR automotive requirement labels and definitions are specified in Table 4.**1**.

Table 4.1: The 5GCAR automotive requirement labels and definitions

Requirement Label	Requirement Definition
Intersection crossing time	Intersection crossing time determines the minimum and the maximum passing time for road intersections.
Localization	The localization is the needed geographical position accuracy.
Maneuver completion time	Maneuver completion time is the total time it takes from that the maneuver is initiated until it has been completed. E.g. a lane merging maneuver can be completed within x seconds given certain car velocities, weather conditions, comfort aspects and safety requirements.
Minimum car distance	Minimum car distance is the recommended minimum distance to keep between two driving cars. This is e.g. addressed by regulatory (safety) and business requirements (fuel saving, minimum vehicles per time unit to avoid congestions).
Mobility	Mobility is the velocity (speed and direction) at which a object is moving with respect to a reference object or geographical point. If the reference object also is moving, the maximum relative velocity between the devices should be considered.
Relevance area	Relevance area is the distance/shape and traffic direction where the messages have to be distributed to ensure the automotive service.
Software updates completion time	Certain car models need to successfully complete a software update for all cars (belonging to that car model) within a certain time period (e.g. two weeks).
Takeover time	Take over time is a max value which determines an upper limit when the takeover must have been completed.

4.2 Network requirement definitions

We make a distinction between the system that provides the service (i.e., the "(5G) communication system") and the application that uses the service (i.e., the "application").

A communication system consists of a number of protocol layers that always include the medium access control (MAC) and physical (PHY) layers, but can also include network and other layers as needed (e.g., for multi-hop functionality). Perfect error detection is assumed, i.e., only error-free packets are delivered to the receiving end-node application. Hence, from the application point of view, messages are delayed and potentially lost in transmission. See Figure **4.2** for a simple illustration. Note that the inner working of the communication systems (segmentation of application messages, coding, modulation, routing, retransmissions, etc.) is hidden to the application. Hence, application requirements should not presume any special *implementation* of the communication system.

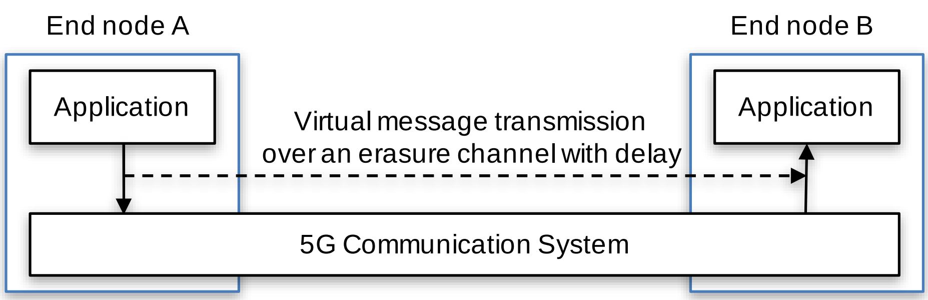

Figure 4.2: Illustration of two end-node applications using the service that is provided by the communication system

From now on, we will denote the application messages as "packets". The size of the packets and their timing characteristics (e.g., intermittent, even-triggered packets or periodic, time-triggered packets) are important service requirements. For instance, the application may require transmission of *X* byte packets just once (one-shot traffic), every *Y* ms (periodic or continuous traffic), or at random time instances over the service life-time (event-triggered traffic).

We assume that the communication system has perfect error detection and that only error-free packets are delivered to the end node application. Hence, from an application point of view, transmissions are done over an erasure channel[1] with delay. That is, when the application at end node A requests transmission of a packet, that packet is either delivered error-free after a certain finite delay to end node B, or not at all.

According to this framework, the 5GCAR communications network requirement labels and definitions are specified in Table **4.2**.

[1] Depending on the setup, a packet loss can be noticed by the application or not. In the latter case, the application-to-application virtual channel is strictly speaking not an erasure channel.

Table 4.2: The 5GCAR network requirement labels and definitions

Requirement Label	Requirement Definition
Availability	Availability is the probability that the requested service is declared as available. If the communication system declares that the service is unavailable, then the application needs to initiate a fallback procedure to e.g. limit the risk of an accident. One often has a tradeoff between Availability and Reliability, in the sense that one can make a system more available by reducing the Reliability, and vice versa. A further discussion of the interrelation between Availability and Reliability is given below in the main text.
Communication range	Communication range is the maximum distance between a transmitter and its intended receiver allowing communication with a targeted Service Data Unit (SDU) size, Latency, and Reliability, and for a given effective transmit power and receiver sensitivity. This definition applies to both the communication between vehicles and between vehicles and infrastructure.
Data rate	Data rate is the number of bits sent per unit of time, typically measured in bit/s. For the transmission of a single SDU, this is given as (Service data unit size)/(Latency requirement). For a stream of SDUs that arrive with a rate R SDUs/s, then the average data rate is R ×(Service data unit size).
Latency	Latency is defined by ITU-R as the contribution by the radio network to the time from when the source sends a packet to when the destination receives it (typically expressed in ms). The intended layer in focus has to be indicated when the term latency is used. Unless specified otherwise, this would be the default value used. To be precise, the latency of layer-n is defined as the time from when the layer-$(n+1)$ entity as the transmitter node requests transmission of a SDU until the SDU is delivered to the layer-$(n+1)$ entity at the receiver node. In case an SDU is not delivered, due to transmission errors or other circumstances, the SDU is said to have infinite latency. For example, the time it takes to transmit a frame (i.e., a MAC layer PDU) from the ingress of the physical layer of node A to the egress of physical layer of node B should be specified as Physical Layer Latency of node A to node B. The Application Layer Latency, which is the time it takes to transmit an application message from the application layer of the source node to the application layer of the destination node, can also be referred to as "end-to-end delay" or "end-to-end latency".
Reliability	Reliability is the probability that the actual layer-n latency is less or equal to the latency requirement, subject to the other relevant requirements and conditions, e.g., SDU size and Communication range, transmit power, propagation conditions, and mobility.

Service data unit size	Number of bytes of the SDU. In case the SDUs do not have a fixed size, the minimum and maximum SDU size should be specified. Note that the SDU is the data unit (message, packet, frame, …) that the layer-$(n+1)$ requests layer-n to send. Hence, the SDU size does not include headers, parity bits, and other overhead introduced by lower layers (i.e., layer n, $n-1$, …). Together with the latency requirement, the SDU size specifies the minimum effective data rate provided by layer n as (Service data unit size)/(Latency requirement), assuming that a single SDU is transmitted. With this definition, it is clear the effective data rate for layer $n-1$ is larger or equal to the effective data rate for layer n.

In the following, we further elaborate on the interrelation between **end-to-end latency**, **reliability**, and **availability**, as defined in the previous table of requirements.

Most, if not all, applications rely on timely delivery of data. Hence, the end-to-end latency must be limited in some sense. The application need of "timeliness" is easiest to model with hard deadlines, i.e., we consider messages whose end-to-end latency exceeds the deadline as discarded. It is noted that this is in contrast with soft deadlines, i.e., when the value of the information carried by the message decreases smoothly with the latency. Deadlines are obviously dependent on the application: some applications require short deadlines, perhaps in the order of a few milliseconds, while others can tolerate seconds, minutes, or even much longer latencies. If we use the convention that undelivered messages due to, e.g., transmission errors, have infinite latency, then we can define the *service reliability* as the probability that the latency is less or equal to the deadline. That is, the service reliability can easily be found from the latency cumulative distribution function (CDF), see Figure **4.3** (the inter-packet spacing is defined as the time between two consecutive delivered packets, to the receiving end node application. The down arrows indicate when the sending-end application requests transmission and the up arrows indicate when the receiving-end application receives error-free packets. By convention, undelivered packets have infinite latency**)** and Figure **4.4** (reliability is found as the CDF evaluated at the deadline, and the probability of packet drop, undelivered packets, is found as the difference between 1 and the CDF asymptote).

Note that the end-to-end latency includes all delays that affect the packet, e.g., MAC processing delays, channel access delays, transmission delays, retransmission delays, etc. Hence, it makes sense to model latency as a random quantity, which, of course, is completely characterized by its CDF.

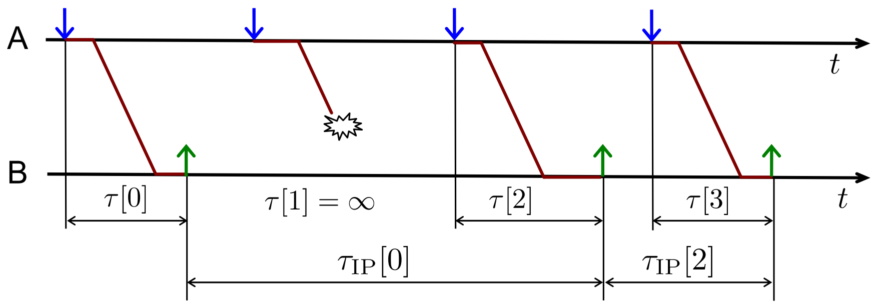

Figure 4.3: End-to-end latency ($\tau[k]$) and inter-packet spacing ($\tau_{\mathrm{IP}}[k]$) realizations for three consecutive messages

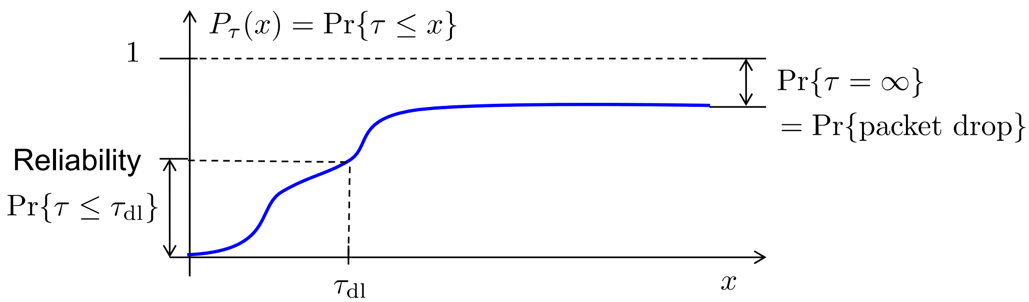

Figure 4.4: Latency CDF, reliability and packet drop probability

Moreover, the time between two consecutive received packets, i.e., the received inter-packet spacing, τ_{IP}, is an interesting performance metric for many applications. The *k*th packet end-to-end delay $\tau[k]$ and the inter-packet spacing $\tau_{\mathrm{IP}}[k]$ is illustrated in Figure **4.3**. We can interpret the inter-packet spacing as the additional aging of the packet before a new fresh packet arrives. For example, suppose packet *k* is received at time $t = t_k$. At delivery, the *k*th packet has age $\tau[k]$. The next packet will then arrive at time $t = t_k + \tau[k]$, and during the time interval $t_k \leq t < t_k + \tau_{\mathrm{IP}}[k]$, the age of the *k*th packet is $(t - t_k) + \tau[k]$.

An ultra-reliable service typically provides very high reliabilities, e.g., 99.999% (five nines). The deadline could be quite small, say on the order of milliseconds, but could also be more relaxed, e.g., on the order of seconds or higher. What is important is that, whatever the deadline is, an ultra-reliable service should deliver messages before the latency exceeds the deadline with very high probability.

It may be very costly or even impossible to provide ultra-reliable services at all times, due to unfavorable shadowing, excessive pathloss, intermittent high interference, shortage of radio resources, etc. It might therefore be necessary to at times declare the communication service as unavailable [SRG+14]. That is, the application makes a request for service (for a certain service life time), which is either granted or not. If the service request is granted, then the communication system will transfer the packet(s) with the requested reliability until the service is completed, i.e., when the service life time has expired. However, the communication system can, at the request time instance, declare the service as unavailable. In this case, the application should initiate a fallback procedure to gracefully degrade the application performance. This can be done, e.g., in the framework of reliable service composition (RSC) [Pop14]. Using RSC, the application can negotiate a less demanding service from the communication system, see [Pop14] for details.

Needless to say, the *service availability*, i.e., the probability that the service is declared as available, is an important performance metric for the communication system providing the service.

We often have a tradeoff between availability and reliability in the sense that we can make a system more reliable by reducing the availability, and vice versa. To illustrate this point, consider a highly simplified example of packet transmission over a fading channel (without retransmissions, rate control, or power control) when the transmitter has knowledge of the instantaneous signal-to-noise ratio (SNR). Furthermore, suppose reliability is bounded by the packet error probability (i.e., the latency CDF has reached its asymptotic value at the deadline, see Figure **4.4**). We can then increase reliability by declaring the service as available only when the (predicted) channel SNR is above a threshold. By increasing the SNR threshold, the transmitted packet error rate decreases and reliability increases. However, the availability also decreases, as the service will be declared as available more seldom as the SNR threshold increases.

Now, if the service is declared as available and if the requested reliability is not satisfied by the communication system, then we say that service failure event has occurred. This event has potentially catastrophic consequences and the probability for this must be made negligible. In other words, the system must make conservative estimates of its ability to satisfy the reliability requirements. Neglecting the possibility of a service failure, availability in this document is equivalent to the 3GPP definition: “communication service availability: percentage value of the amount of time the end-to-end communication service is delivered according to an agreed QoS, divided by the amount of time the system is expected to deliver the end-to-end service according to the specification in a specific area.” [3GPP17-22261].

4.3 Qualitative or non-functional requirement definitions

Apart from the automotive requirements and the network requirements there are also other relevant requirements that should not be ignored. Although no values and units are specified for these requirements within this deliverable, any relevant 5GCAR solution still needs to take them into consideration as qualitative requirements. These qualitative requirement labels and definitions are provided in Table **4.3**.

Table 4.3: The 5GCAR qualitative or non-functional requirement labels and definitions

Requirement Label	Requirement Definition
Cost	Cost refers to all additional investments and expenses needed to construct the considered scenario setting. Hence, already existing legacy components are not included in the cost while new technology components are included in the cost.
Power consumption	Power consumption is an important requirement from network infrastructure standpoint, user standpoint, even in a car since high power consumption may generate thermal dissipation issue in the car and drain the battery (e.g. for electric cars or when cars are unused).
Security	Privacy or information privacy is often related to personal data. It is an individual's right. It aims to ensure that whoever is handling personal data is applying the right level of security allowing individuals to control what information is collected, identifying how it is used, who can access it, and what purpose it is used for. It is also applying to the protection of UE identity to avoid the vehicle to be tracked or identified by any other UE or non-V2X entity beyond a certain short time-period required by the V2X application. Confidentiality is a security principle that ensures that information is not disclosed to unauthorized parties. This could be ensured by the use of cryptography schemes. Integrity is a strong security feature to ensure data/messages will not be corrupted during the transmission. This requirement becomes very sensitive for V2X road and traffic safety applications. Authentication is a pillar in information security. It proves that a subject is what it claims to be. It's often linked to other pillars such as identification (claiming to be someone or something) and authorization (defining the access and actions that a subject can do on the system). Authentication is based on one of the three methods a subject: knows, has or is. Combining more than one authentication method is often referred as strong authentication or a multi-authentication.
Resiliency	Resiliency is the capability of the system to provide a service under failures or defaults. This will be analyzed in terms of the impact to the automotive function of the use case considered. Connectivity will always be considered for an AD vehicle as a complementary sensor. The system will always count first on the onboard sensors. Connectivity will provide efficiency and comfort to any use case.

5 5GCAR Use Case Requirements and KPIs Analysis

This chapter provides a detailed analysis of the requirements and KPIs of the 5 use cases described in chapter 4. First an introduction of automotive background is provided to explain the key aspects taken into account for the KPI analysis. Section 2 provides a detailed explanation of the KPI values defined for each use case considered in 5GCAR.

5.1 Automotive background

As an introduction, we provide here some basic concepts about speed, reaction time and distances.

The Reaction Distance (RD) is the distance traveled during the perception-reaction time (PRtime). For a human driver, this time is from 1.3 to 1.5 second. With on-board sensors the PRtime is lower but decision time must be added. An overall value from 200 to 500 ms may be achieved depending on the distance to the target, and the weather conditions.

The Braking Distance (BD) is the distance traveled by the vehicle while its speed decreases, that is to say from the moment when the brakes come into action. This includes a deceleration slope, due to the jerk (the jerk is the variation of the acceleration). The Stopping Distance (SD) is the sum of Reaction Distance and Braking Distance. Acceleration is about -11 m.s² for a dry road, and -8,5 m.s² for a wet road.

Table 5.1: Reaction distance, braking distance and stopping distance at different speeds

Speed (km/h)	RD (m)	BD (m)	SD (m)
30	10	5	15
50	17	12	29
70	23	22	46
90	30	36	66
110	37	52	89
130	43	72	115
150	50	94	144
180	60	134	194
200	67	164	231
250	83	253	337

Detection/tracking Areas in Longitudinal situations:

- A Following area, where the vehicle is following or is followed by other vehicles. In this condition, longitudinal relative speeds are low but lateral maneuvers can occur (cut-in, cut-out, overtaking, following, platooning).
- An Approaching area, where other vehicles are cruising at different speeds:
    - From 0 to the maximum legal speed, in the same direction than the subject vehicle
    - From 0 to the maximum legal speed in the opposite direction

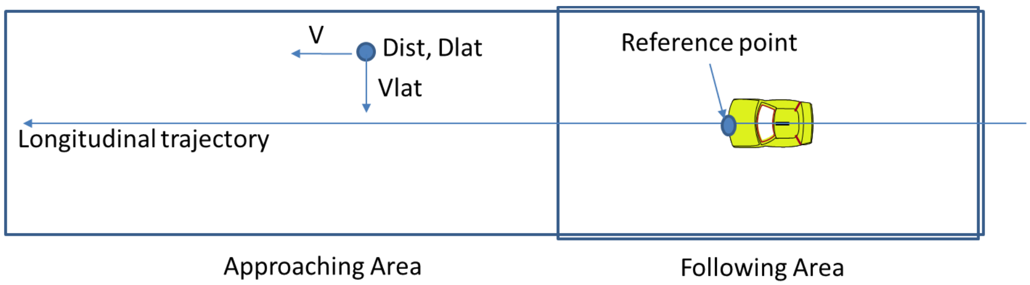

Figure 5.1: Detection/tracking areas in intersection situations

In the case of intersection areas, the width of approaching area can be wider. Globally measurement needs around the vehicle and especially on its longitudinal axis are depending on two different areas (following, approaching) with different associated requirements.

For the localization values, the 68–95–99.7 rule is used. This means the percentage of values that lie within a band around the mean in a normal distribution with a width of two, four and six standard deviations, respectively; more accurately, 68.27%, 95.45% and 99.73% of the values lie within one, two and three standard deviations of the mean, respectively.

These minimum requirements are defined by a rectangular of 80 by 200 meters in front of and behind the vehicle for the following area, and up to 300 meters for the approaching area. The distance accuracy must be around 10 centimeters for the following area and can be up to 50 centimeters for the approaching area.

The above requirements are partially covered by the LOS sensing technologies. In terms of the maximum vehicle detection distance, a camera is around 100 meters, the Lidar goes up to 150 meters and radar can increase the detection distance up to 250 meters. Lidar is better for angular resolution, but less efficient in bad weather conditions. These distances are strongly reduced for moto detection (getting a maximum of 150 meters) or even worst for pedestrians (with an upper detection limit of 70 meters). The response time of the sensors vary from 30 to 500 milliseconds. More precise and detailed information can be found in Appendix C.

5.2 Use case requirements and KPIs analysis

The requirements defined in section 4.1 are studied in here in details for each of the use cases defined in the project. For each use case we provide a brief background to motivate the assumptions used for the estimation of the different requirements.

5.2.1 UC1: Lane merge

Background and motivation

The following scenario is the motivation of the Lane Merge use case requirements.

Two vehicles (Veh2 and Veh3) are considered in the main lane, with a speed of 130km/h and a mandatory headway of 2 seconds (70 meters at 130 km/h). A third vehicle (Veh1) wants to merge to this lane. Veh2 needs to decelerate to provide a headway of 4s between Veh2 and Veh3. The final situation will be Veh3 <- 2s -> Veh1 <- 2s -> Veh2.

The deceleration of Veh2 should be around 2-3 m/s² to be comfortable for the driver and the passengers.

Taking this into account, to change the distance between Veh2 and Veh3 from 70 to 140 m, with a constant speed for Veh3 and a deceleration of 2m/s² for Veh2, Veh2 has to be warned 5.4 seconds before. In distance, this means around 200 m. If the detection of a camera that could take around 500 ms is added, then 20 more meters are needed.

In the case of autonomous driving and platooning, the TIV (Time Inter Vehicles) is reduced to 0.3 s, this means 10 m. But as Veh1 is not an autonomous car, a distance of 4 s need to be respected to let it merge. Therefore 8 seconds are needed for the maneuver, this means 290 m.

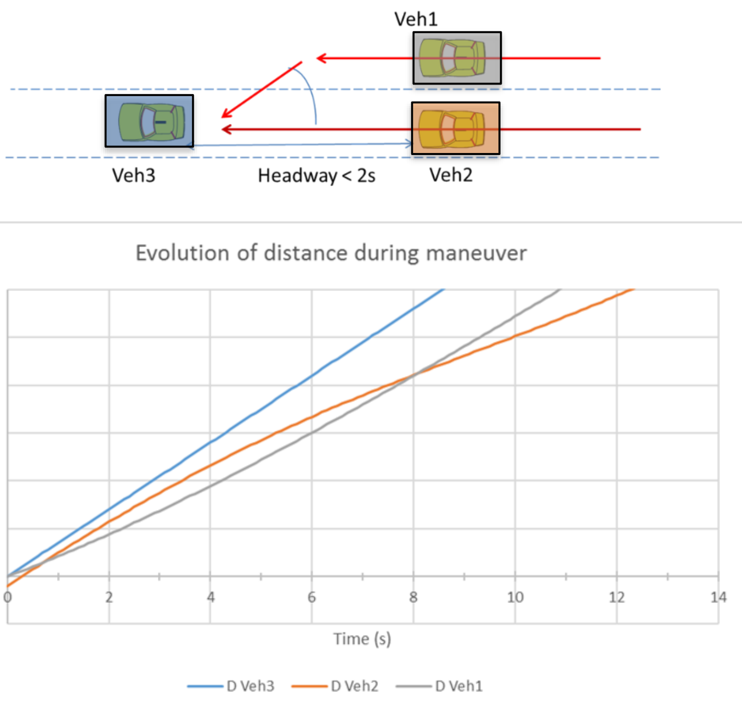

Figure 5.2: Representation of the time – distance relation between the vehicles involved in the use case

KPIs and requirements

Table 5.2: UC1 Requirement explanation

Requirement Label	Requirement Value and Requirement Unit
Automotive requirements	
Intersection crossing time	Not Applicable
Localization	Medium: an accuracy of 4 m at 3 σ (Standard deviations) would be enough along the driving direction in the main lane for driver-assist driving. For future autonomous driving, an accuracy below 1 m should be attainable, in order to give precise trajectories for the vehicle. Global system localization constraints are expected for the autonomous car itself. For instance, keep track of positioning of the vehicle in the lateral axis.
Maneuver completion time	With a lateral speed of 1 m/s, to change the line (4 meters) we will need around 4 seconds. As an example, for a speed of 90 km/h this time will mean a distance around 100 meters.
Minimum car distance	This distance must be 2 seconds between any vehicle, but during a maximum of 3 seconds we may reduce it to 0.9 seconds. Note that this is a regulatory definition.
Mobility	For the case of merging from e.g., on-ramp, to the main lane, the relative speed can vary from 0 to a maximum of 150 (medium maximum speed in Europe, this may vary depending on the country) km/h between both vehicles needs to be supported.
Relevance area	From 250 m to 350 meters are needed for a soft insertion from the vehicles in the line.
Take over time	For AD vehicles this time should be a maximum of ten seconds.
Network requirements	
Availability	Medium 99%: the availability is set to medium due to the fact that the trajectory contains many redundant information. Precision without the infrastructure the global intelligence is lost as well as the external information sources (cameras…)
Communication range	At least the same of the relevance area, to enable the vehicle communications. So, more than 350 meters are needed.
Data rate	Trajectories are sent with a frequency of 10 Hz (due to the fact of having many samples in each trajectory message), then this end up with a date rate of 1,28Mbps per vehicle.
Latency	Less than 30 ms depending on the vehicle speed. This is motivated by a maximum margin of 10% of the TIV (Time Inter Vehicles) which is 0,3 seconds with automated vehicles from level 3.

Reliability	High (99.9%). In order to be useful for the lane merge decision, the system has to offer a high reliability, in certain conditions the connectivity will provide a larger line of sight than the on-board sensors, this information can only be trusted if it is reliable.
Service data unit size	Safety messages, can go up to 800 bytes per message. If trajectories messages are sent, for 5 seconds trajectory with 10 ms accuracy we need 32 bytes per trajectory which results in 16 000 bytes per message
Qualitative requirements Non functional requirements	
Cost	Medium: on-board connectivity and sensors will be available in vehicles, as an option. A camera may be included in the lane merge intersection to help in the event detection for legacy vehicles. Positioning techniques for vehicles can increase the cost, when the accuracy hast to be lower than 4 meters.
Power consumption	Low: on-board elements are already prepared for low consumption and off-board cameras do not represent an important consumption.
Security	Privacy: High. The usage of cameras in the intersections may be a threat for personal data. Only real time, no right to store and share the images. Confidentiality: Low. Only to be limited to the system and not to be made public. Integrity: High. Messages must not be corrupted or modified Authentication: High. V2X messages must be trusted
Resiliency	Driver: The driver must be warned through HMI that the system is not working. AD mode: The connectivity will be used to facilitate the insertion, if it does not work the AD vehicle, will modify the driving conditions according to the on-board sensors and if the conditions are not respected a lower AD level will be proposed or even the car will do a stopping manoeuvre.

5.2.2 UC2: See-through

Background and motivation

The two following scenarios are the motivation of the See-Through use case requirements.

- **For non-urban environment:**

We consider two vehicles (Veh1 and Veh3 in Figure 5.**3**) in one lane, with a speed of 50 km/h and a legal headway of 2 seconds (28 meters at 50 km/h). A third vehicle (Veh2) is in the opposite lane, with a speed of 100 km/h. Veh1 wants to overtake, and can go up to 100 km/h for the overtaking maneuver. Its acceleration will be limited to 2 m/s².

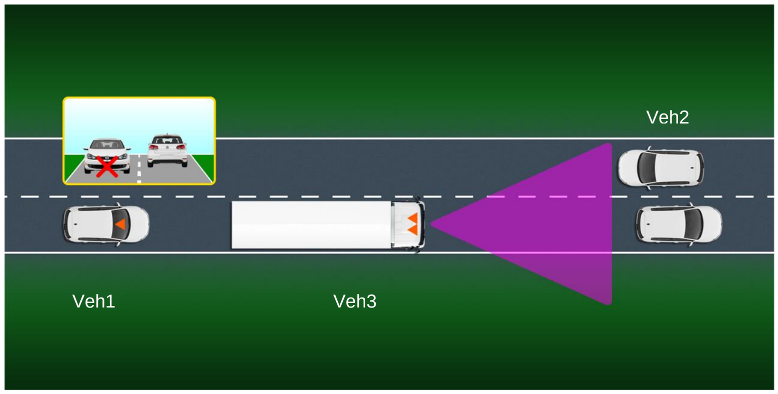

Figure 5.3: See-through scenario

In this configuration, it will take 6 seconds and 120 m to have Veh1 and Veh3 at the same level, and 2 seconds more to respect the correct headway at the end of the overtaking (corresponding to 28 more meters for Veh1).

During these 8 seconds, Veh2 has traveled 220 meters. To avoid the collision, we add 60 more meters, so the total distance for this scenario will be around 400 meters.

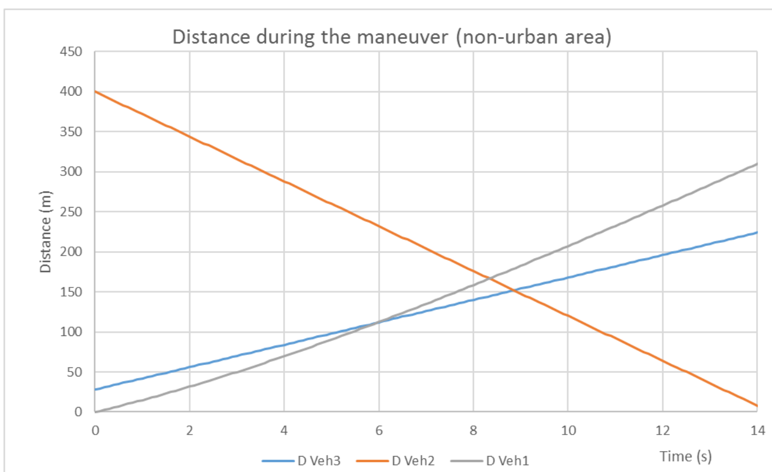

Figure 5.4: Representation of the time – distance relation between the vehicles involved in the use case for non-urban area

Distance over time of each vehicle from initial position of Veh1 at the start of See-through scenario. Point where curve D Veh1 and D Veh3 intersect indicates when Veh1 is overtaking Veh3. Point where curve D Veh1 and D Veh2 intersect indicates the location before which Veh1 needs to overtake Veh3 in order to execute the maneuver safely. Non-urban area.

- **For urban environment:**

We consider two vehicles (Veh1 and Veh3) in one lane, with a speed of 36 km/h and a reduced headway of 0.9 second (9 meters at 36 km/h). A third vehicle (Veh2) is in the opposite lane, with a mandatory speed of 50 km/h. Veh1 wants to overtake, and can go up to 50 km/h for the overtaking maneuver, with an acceleration of 2 m/s².

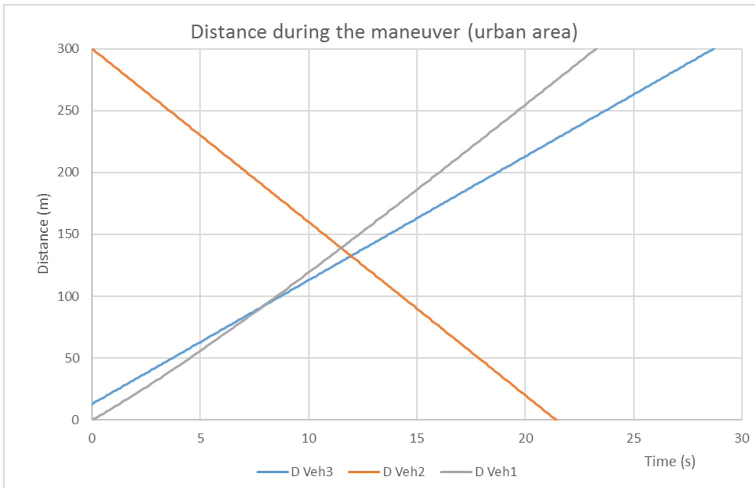

Figure 5.5: Representation of the time – distance relation between the vehicles involved in the use case for urban area

Distance over time of each vehicle from initial position of Veh1 at the start of See-through scenario. Point where curve D Veh1 and D Veh3 intersect indicates when Veh1 is overtaking Veh3. Point where curve D Veh1 and D Veh2 intersect indicates the location before which Veh1 needs to overtake Veh3 in order to execute the maneuver safely. Urban area.

Before the overtaking decision, the opposite vehicle (Veh2) is located at more than 400 m from the two vehicles. Hence, the camera must have a sufficient resolution for the detection of objects at about 500 meters.

KPIs and requirements

Table 5.3: UC2 Requirement explanation

Automotive requirements	
Intersection crossing time	Not Applicable
Localization	Low: we just need to detect the object in front of us, around 10 meters.
Maneuver completion time	With a lateral speed of 2 m/s, to change the line (4 meters) we will need around 2 seconds for each lane change. So the minimum time will be around 4 seconds
Minimum car distance	This distance can be reduced to 0.9 seconds during the start of the overtaking
Mobility	The transmitter of the video and the vehicle receiving the information will be more or less at the same speed. 0 to 30

	km/h
Relevance area	Depending on the speed we can go from 300 meters to 500 meters needed for a soft overtaking
Take over time	The minimum time will be around 4 seconds
Network requirements	
Availability	Medium 99%: the overtaking manoeuvre can be always avoided if the system does not work.
Communication range	As the two vehicles concerned by the exchange of video are driving in the same lane, the communication range is reduced: from 50 to 100 meters for non-urban area and two consecutive vehicles.
Data rate	Depends on the configuration of the video streaming. For instance, 14Mbps are needed to transmit a progressive high definition video signal with resolution 1280x720, frame rate 30 Hz, colour depth 8 bit, 24 bit resolution, subsampling 4:2:2 and a typical compression of 1:30 (e.g. with H.264). To reduce data rate only the relevant section of the frames is transmitted, In this case, the expected data rate us 10Mbps. A higher data rate of 29 Mbps could be necessary if no motion-compensation codes are used.
Latency	The Latency requirement depends on the vehicle speed and heading as well as pitch angle changes. A value of 50 ms should be kept, lower values would increase the experience of this function. The videos of both vehicles have to be stitched to each other in the rear vehicle. Additional delays would lead to additional buffering in the rear vehicle. In addition, the latency jitter should be small to avoid the loose of video frames.
Reliability	Reliability 99% to avoid massive artifacts in the video stream for assisted driving. For this case, the result would be binary (overtaking possible or not). For high automated levels this value shall be increased due to object detection messages. In this case an estimation of the possible maneuver may be done depending on distance and speed.
Service data unit size	Equal to the video frame. Similarly to the data rate, depends on the used configuration. To transmit a progressive high definition video signal with resolution 1280x720, frame rate 30 Hz, colour depth 8 bit, 24 bit resolution, subsampling 4:2:2 and a typical compression of 1:30 (e.g. with H.264). To reduce data rate (and frame size) only the relevant section of the frames is transmitted.41700 bytes per frame
Qualitative requirements	
Cost	Medium: Only on-board sensors are needed.

Power consumption	Low: on board elements are already prepared for low consumption
Security	Privacy: Medium. Vehicle track mechanisms must be avoided. Confidentiality: Low. Integrity: High. To avoid messages modification in the case of just one information source. If there are several, medium value may be accepted. Authentication: High a trusted source is needed.
Resiliency	Driver: The driver must be warned through HMI that the system is not working. AD mode: The connectivity will be used to facilitate the overtake manoeuvre, if it does not work the AD vehicle, will engage or not the overtaking manoeuvre based on the on-board sensors and according to the decision making process

5.2.3 UC3: Network assisted vulnerable pedestrian protection

Background and motivation

The VRU protection is achieved by the detection of the presence of VRU and the exchanging the information to the approaching vehicles. The position alone is not enough; speed in longitudinal and lateral direction is also needed – with the own vehicle movement (x,y in picture below) being the reference. The algorithms workanyway but the risk increases for false and/or missed activations. Following are the additional conditions and requirement that shall be met for a timely detection of a VRU for collision avoidance;

- Position update rate shall at least be 10Hz
- The sensors system shall detect VRU objects in the forward detection zone originating from a reference point at a range of 0-400m depending upon the driving conditions and with the assumption of semi-autonomous driving, e.g., on the urban roads at 50km/h a distance of 40m, at 70km/h a distance of 70m and on a country road, usually at night, the distance up-to 400m is suitable. However, country roads impose rather relaxed requirements on latency.
- For a fully autonomous driving, the required range for collision avoidance reduces to half of that in semi-autonomous, approximately, because the driver’s reaction time is not applicable there.
- Finally, the latency for VRU information exchange shall be maximum 90ms on Urban roads.

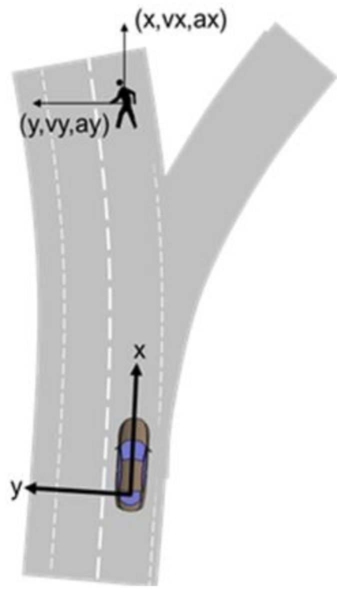

Figure 5.6: A simplified depiction of VRU use-case, where (x,y), (vx, vy), and (ax, ay) represent the position, velocity and acceleration in horizontal and vertical axis, respectively

Initially for this use case the localization will be based on the infrastructure base stations to locate the pedestrian. A strong time synchronization between the base stations is needed. As a second step the usage of the pedestrian smartphone may help to improve the trajectory prediction. In any case, human behavior is difficult to predict so this will always be a risk.

KPIs and requirements

Table 5.4: UC3 Requirement explanation

Automotive requirements	
Intersection crossing time	For a pedestrian crossing in an urban environment, a road with 2 lanes means 10 meters, so around 7 seconds are needed with 5km/h speed
Localization	The associated error shall be less than 0.5 m or 3% of the true range (distance between the object and the car itself), whichever value is greater. Note: assuming center point of the pedestrian. 25 cm expected localization accuracy, but for this if the smartphone of the pedestrian is used, then the place where it is it may affect.
Maneuver completion time	Not applicable
Minimum car distance	Not applicable
Mobility	Relative speed up to 100 km/h. (Highway environments are not considered due to pedestrians are forbidden in the area)

Relevance area	Somewhere between 40m to 70m in the city area and around 400m on the country roads at night
Take over time	Not applicable
Network requirements	
Availability	99.99% to ensure that this safety critical service is always available and treated as top priority by the network
Communication range	This has to be at least the same distance of the relevance area. The more range we have we will be able to anticipate the events.
Data rate	Minimum 10 Hz update of the pedestrian position. For the service data unit size estimated this means around 128 kbps.
Latency	Less than 60 ms for the network in order to respect the reaction time needed in the vehicle for autonomous driving vehicle.
Reliability	High 99.9% to guarantee a similar reliability as the local on-board sensors (1 error every 1000 operations),
Service data unit size	If pedestrian trajectories messages are sent we get 1600 bytes per message. For 5 seconds trajectory with 100 ms accuracy (10 trajectory samples per second) and 32 bytes per trajectory sample. This gives 320 bytes per second and a total of 1600 (320*5) for 5 second trajectory If the trajectories are estimated by the network then only warning message, e.g. DENM like message for which the size varies between 50 bytes and 100 bytes.
Qualitative requirements	
Cost	Medium to high depending on the environment. For non-urban area the density of base stations would not be enough to localize the pedestrian.
Power consumption	Low: only in the case of the pedestrian smartphone consumption it may be critical
Security	Privacy: High. People track mechanism must be avoided Confidentiality: Low. Only to be limited to the system and not to be made public. Integrity: High. Messages must not be corrupted or modified Authentication: High. V2X messages must be trusted
Resilency	Driver: The driver must be warned through HMI that the system is not working. AD mode: The connectivity will be used to facilitate the VRU detection and warnings, if it does not work the AD vehicle, will use his on-board sensors and adapt the driving conditions to mitigate the risk.

5.2.4 UC4: High definition local map acquisition

Background and motivation

A real-time, high definition intelligent map is a need for safer and more comfortable semi- or fully autonomous driving experience. The aim is to precisely aggregate the context information, such as vehicles, road structure reference objects and so forth, collected using cooperative perception, then used to update the local dynamical map and distribute the information based on the position in real-time. This information is available to any vehicle or road user in the vicinity to be used for an optimal route selection or to complete critical manoeuvres in a safe and comfortable manner.

The fact that makes this use case critical or challenging is that it requires highly accurate positioning and very low latency, it should work no matter how many vehicles or road users are present in the relevance area, as well as to handle highly dynamic driving scenarios.

To achieve such a HD real-time intelligent map, stringent requirements on localization accuracy and latency must be met, because the delayed or inaccurate information is either useless or can have severe consequences. On top of these requirements on latency, then a requirement on Global Time accuracy must be met, i.e. 5ms end-2-end in relevance area and typically 1ms internally in the vehicle network. The detailed requirements are mentioned below.

KPIs and requirements

Table 5.5: UC4 Requirement explanation

Automotive requirements	
Intersection crossing time	Not applicable
Localization	10cm: width of lane marking, the narrowest in use 15cm-25cm (30cm-50cm in total 2 vehicles) (velocity, heading angle, acceleration, trajectory) (under discussion: 5cm full AD vehicles, due to detecting half the width of lane marking)
Maneuver completion time	Not applicable - Continuous
Minimum car distance	This distance must be 2 seconds between any vehicle, but during a maximum of 3 seconds we may reduce it to 0.9 seconds. Note that this is a regulatory definition.
Mobility	0km/h – 250km/h (host speed 0-120km/h level4 AD)
Relevance area	5 seconds horizon at least or more than 250m
Take over time	10 seconds until Safe Stop
Network requirements	
Availability	Medium 99%: the availability is set to medium due to the fact that the trajectory contains many redundant information. Precision without the infrastructure the global intelligence is lost as well as the external information sources (cameras…)

Communication range	Few kilometres
Data rate	For dynamic objects and more than 100 meters, 960kbps globally. For less than 100meters is 2X960Kbps 960kbps with update frequency 100ms for LDM objects that are located more than 100m away 1920kbps with update frequency 50ms for LDM objects that are located less than 100m away. In order to build a continuous electronic horizon both flows will be sent simultaneously, so the overall data rate for downlink would be 2.88Mpbs per vehicle. Number of dynamic objects being 200 time SDU size (60bytes) / frequency. This requirement will be affected by traffic density.
Latency	It should be less than 30ms for network communication layer 150ms: End-2-End application layer represents End-to-End latency from LDM object report via LDM Application Server to Vehicle using LDM object report in Sensor Fusion (SF). SF function calculates the weight of sensor value relevance based on age of from detection or report, from 100ms "old" report the weight will get lower and reaching 150ms "old" the weight will be zero and the value be discarded. In the end to end latency three elements are taken into account: uplink, server process and downlink. If between 50 and 100ms are reserved for the server, then around 25ms would be expected for communication latency.
Reliability	High (99.99%) because this will affect the quality and freshness of the information from the map. The requirement is then high
Service data unit size	Up to 60 bytes for object definition and position
Qualitative requirements	
Cost	Medium-High. For this feature, an important effort in terms of server deployment is needed, in one side in terms of performances and on the other side in terms of having them close to the road where the map should be built.
Power consumption	Medium-High. More on-board and off-board sensors are needed so this will increase the power consumption, which is a challenging element especially for on-board equipment.
Security	Privacy: High. People and vehicles track mechanism must be avoided Confidentiality: High. The information is rich and available for several object, so the confidentiality must be preserved. Integrity: High. Messages must not be corrupted or modified Authentication: High. V2X messages must be trusted

Resiliency	Driver: No major immediate impact for the human driver AD mode: Driving conditions will be adapted or even stopped depending on the age of information and the driving scenario. It will not be the same for the line-marking information or for the dynamic object detection.

5.2.5 UC5: Remote driving for automated parking

Background and motivation

Remote driving for automated parking, is a use case where a user that arrives to his/her destination, doesn't need to look for a parking spot and park the car, because the car will be driven by a remote server, which will take care of everything, with the support of the onboard vehicle sensors, vehicle actuators, and parking sensors.

Different prototypes of automatic driving applications and remote control of vehicles have been presented in the lasts years, but the use of a reliable connectivity channel like 5G will mean a strong value added to develop a remote driving for automated parking use case.

The scenarios to be addresses will include last mile in order to let the vehicle approach by its own to the parking facilities, and automated maneuver where the remove cloud will select an available parking spot, and command the vehicle to that parking spot based on the information provided by the vehicle sensor and perception layer. Parking facilities could also include different sensor like cameras, in order to include more information about other vehicles or pedestrians, creating a more secure environment for the remote driving of the vehicle.

KPIs and requirements

Table 5.6: UC5 Requirement explanation

Automotive requirements	
Intersection crossing time	In an urban environment, 50 km/h would be the reference. To cross a road with 2 lanes this means 10 meters. So less than 1 second is needed. Speed may be lower and the street bigger, so a range from 1 to 6 seconds is proposed
Localization	High precision of localization, not only relying on GPS, as the remote driving for parking can take place in covered places. Parking maneuvers could require a high precision localization and identification of obstacles, in order to avoid collisions. 5 to 50 cm
Maneuver completion time	Depends on the maneuver
Minimum car distance	This distance must be 2 seconds between any vehicle, but during a maximum of 3 seconds we may reduce it to 0.9 seconds. Note that this is a regulatory definition.
Mobility	Urban area from 30-50 Km/h

Relevance area	100-1.000 for an urban environment
Take over time	Not applicable
Network requirements	
Availability	99,999% equivalent to a downtime of around 5 minutes per year.
Communication range	Km may be supported in order to let a server command the vehicle. Indoor coverage must be granted to end with the parking maneuver.
Data rate	For remote sensing, high upstream due to video upload. Between 14-29 Mbps per camera as it is explained in UC2. More than one camera is needed, on-board and off-board. The need is low for commands and trajectories, this could be up to 1.28 Mbps per vehicle.
Latency	300ms overall, for urban environment. 200ms for the server process and 100ms for round trip. For the uplink the need is lower due to the continuous data aggregation and trajectory prediction. For the downlink as a reference of the vehicle commands, the repetition rate of the steering wheel sensor is 10ms, then 5ms latency will be expected. Trajectory could also be uploaded to simplify the decision making.
Reliability	Ultra-high, 99.999%, in order to coordinate the information received with the control commands sent to the actuators.
Service data unit size	Uplink, for video streaming we use the UC2 assumptions. 41700 bytes per frame. Downlink trajectories with several vehicles in a row will be sent even if they may be modified for the following messages. 16000 bytes per frame.
Qualitative requirements	
Cost	Medium to High. The safety of the system is complex: high reliability is needed for the infrastructure and the car must be equipped of several cameras and a remote gateway.
Power consumption	Low: On-board and off-board elements not consuming
Security	Privacy: Medium. Vehicle track mechanisms must be avoided. Confidentiality: Low. Only to be limited to the system and not to be made public. Integrity: High. To avoid messages modification in the case of just one information source. If there are several, medium value may be accepted.

	Authentication: High a trusted source is needed.
Resilency	For this precise use case, if the communication system fails there will not be remote driver. Then the car will make the decision relying on onboard sensors. The unavailability of the system will condition the decision to be made. Temporary interruption of the system will affect the maneuver depending on the use case, but the complete system failure will provoke a controlled stopped.

5.3 5GCAR use case requirements and KPIs chart

The 5GCAR use case requirement values and units are specified in this section as well as the KPIs. The 5GCAR use cases themselves have already been described in Section 3.2.

The 5GCAR requirements and KPIs for each use case is given in Table **5.7**. Details on how these use case requirements have been derived are presented in the Appendix Section B.

Table 5.7: The 5GCAR use case requirements

Use Case 1: Lane merge	
Requirement Label	**Requirement Value and Requirement Unit**
Automotive requirements	
Intersection crossing time	Not applicable
Localization	1 to 4 meters
Maneuver completion time	4 seconds
Minimum car distance	0.9 to 2 seconds
Mobility	0 to 150 km/h
Relevance area	250 to 350 meters
Take over time	10 seconds
Network requirements	
Availability	V2I/V2N 99% and for V2V 99.9%
Communication range	> 350 meters
Data rate	1.28 Mbps
Latency	< 30 ms
Reliability	High: 99.9%
Service data unit size	1200 to 16000 bytes per frame
Qualitative requirements	
Cost	Medium
Power consumption	Low
Security	Privacy: High Confidentiality: Low Integrity: High Authentication: High
Use Case 2: See-through	

Requirement Label	**Requirement Value and Requirement Unit**
Automotive requirements	
Intersection crossing time	Not applicable
Localization	10 meters
Maneuver completion time	4 seconds
Minimum car distance	0.9 seconds
Mobility	0 to 30 km/h
Relevance area	300 to 500 meters
Take over time	4 seconds
Network requirements	
Availability	Medium: 99%
Communication range	50 to 100 meters
Data rate	15 to 29 Mbps
Latency	50 ms
Reliability	99%
Service data unit size	41700 bytes per frame
Qualitative requirements	
Cost	Medium
Power consumption	Low
Security	Privacy: Medium Confidentiality: Low Integrity: High Authentication: High
Use Case 3: Network assisted vulnerable pedestrian protection	
Requirement Label	**Requirement Value and Requirement Unit**
Automotive requirements	
Intersection crossing time	7 seconds
Localization	10 to 50 cm
Maneuver completion time	Not applicable
Minimum car distance	Not applicable
Mobility	0 to 100 km/h
Relevance area	40 to 70 meters
Take over time	Not applicable
Network requirements	
Availability	High: 99.99%
Communication range	>70 meters
Data rate	128 kbps
Latency	< 60 ms
Reliability	99% to 99.99%
Service data unit size	1600 bytes per frame
Qualitative requirements	
Cost	Medium to High
Power consumption	Low
Security	Privacy: High Confidentiality: Low Integrity: High Authentication: High

Use Case 4: High definition local map acquisition	
Requirement Label	**Requirement Value and Requirement Unit**
Automotive requirements	
Intersection crossing time	Not applicable
Localization	5 to 50 cm
Maneuver completion time	Not applicable
Minimum car distance	0.9 to 2 seconds
Mobility	0 to 250 km/h
Relevance area	>250 meters
Take over time	10 seconds
Network requirements	
Availability	Medium: 99%
Communication range	>1 km
Data rate	960 to 1920 kbps
Latency	<30 ms
Reliability	High: 99.99%
Service data unit size	60 bytes per frame
Qualitative requirements	
Cost	Medium to High
Power consumption	Medium to High
Security	Privacy: High Confidentiality: High Integrity: High Authentication: High

Use Case 5: Remote driving for automated parking	
Requirement Label	**Requirement Value and Requirement Unit**
Automotive requirements	
Intersection crossing time	1 to 6 seconds
Localization	5 to 50 cm
Maneuver completion time	Not applicable
Minimum car distance	2 seconds
Mobility	30 to 50 km/h
Relevance area	1000 meters
Take over time	10 seconds
Network requirements	
Availability	99.999%
Communication range	Several kms
Data rate	6.4 to 29 Mbps
Latency	5 to 30 ms
Reliability	Ultra-high: 99.999%
Service data unit size	16000 up to 41700 bytes per frame
Qualitative requirements	
Cost	High
Power consumption	Low
Security	Privacy: Medium Confidentiality: Low

	Integrity: High Authentication: High

The respective KPIs of the 5GCAR use cases are:

1) Lane merge: Localization, Latency
2) See-through: Data rate
3) Network assisted vulnerable pedestrian protection: Reliability, Localization
4) High definition local map acquisition: Localization, Density, Security
5) Remote driving for automated parking: Availability, Reliability, Latency

The identified 5GCAR use case KPIs (requirements in Table **5.7**) address all 5GCAR goals.

6 Summary

5GCAR aims at contributing to the specification of 5G to become a true enabler of V2X applications that today are not realizable due to the limitations of current communication networks. To achieve this, 5GCAR will provide enablers for the following features:

- Providing ***end-to-end latencies*** below 5 ms
- Providing ***ultra-high reliability*** close to 10^{-5}
- Handling a ***very large density of connected vehicles***
- Providing ***Positioning accuracy*** of 30 cm for vehicles and 10 cm for a VRU

5GCAR has defined the following V2X use cases classes:

1) Cooperative maneuver
2) Cooperative perception
3) Cooperative safety
4) Intelligent autonomous navigation
5) Remove driving

To concretize those, 5GCAR has selected one representative use case within each class:

1) Lane merge (belonging to the Cooperative maneuver class).
2) See-through (belonging to the Cooperative perception class).
3) Accurate positioning assisted vulnerable pedestrian protection (belonging to the Cooperative safety class).
4) HD local map acquisition (belonging to the Intelligent autonomous navigation class).
5) Remote driving for automated parking (belonging to the Remove driving class).

The challenging requirements for each of these specific 5GCAR use cases have been identified and quantified in this document.

The technical enablers and 5GCAR solutions to these use cases will be derived during the lifetime of the project and will be presented in future 5GCAR deliverables.

7 References

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A Analysis of Already Existing V2X Use Cases

Prior to the 5GCAR project various V2X use cases already existed, e.g. from the research communities and the standardization bodies. Naturally it would be unrealistic to derive solutions to all of these use cases within the 5GCAR project. The conducted approach is instead to learn from the past, and based on that knowledge derive a few concrete 5GCAR use cases that span a V2X space that we foresee as relevant to investigate. An analysis of existing V2X use cases has been performed to gain necessary insights for the construction of the 5GCAR use cases. Relevant findings from this analysis is presented below.

A.1 5G PPP

With the help of representatives from automotive and telecom industry, 5G PPP has prepared a detailed vision of how 5G can enable the next generation of connected and automated driving and related critical services which could not yet be implemented using today's communication technologies [5GPPP15]. A great progress has been made on the characterization of 5G requirements through the identification of several uses cases from the automotive vertical that capture the diversity of these requirements. Although the requirements may vary from one use case to another, the high mobility of the users and the high connection densities are identified as common characteristics that differentiate the automotive vertical from other verticals. Based on their requirements, a non-exhaustive list of the main categories of the use cases identified by the automotive industry is the following:

- Automated driving: includes applications needed for enabling fully automated driving such as high-density platooning and cooperative manoeuvres for collision avoidance or automated overtaking. These applications set stringent requirements on latency in the order of few milliseconds coupled with ultra-high reliability to guarantees packet error rates up to 10^{-5} as well as on high positioning accuracy (down to few tens of centimeters).
- Cooperative sensing: includes use cases for the exchange of sensor data (e.g., raw sensor data), object information and real-video streaming that increase the environmental perception of vehicles, to help the driver or automated car to perform critical manoeuvres (e.g., overtaking) and navigate safely through dangerous areas (e.g., city intersections, highways merge-in). Low latency in the order of 10 ms and high data rates (above 20 Mbps) are characteristic requirements of this category.
- Traffic safety: includes road hazard warnings, collision avoidance, etc. One particular field of improved traffic safety is the protection of VRU, like pedestrians or cyclists. VRU protection builds on fast and precise positioning of VRUs, as well as fast communication in between VRUs and vehicles in proximity.

- Traffic efficiency: includes update of routes and dynamic digital map update and is supported using both the V2N and the V2I modes. Traffic efficiency does not have strict delay or reliability requirements, but requires high data rates for efficient route selection.
- Infotainment services: applications for enhancing the travel experience of both the drivers and the passengers by bringing connectivity to the car and providing smart navigation functionalities and entertainment contents (e.g., movies, games). Although the reliability and the latency are not very critical for this category, it is important here to provide very high data rates with relatively low latencies that guarantee a good user experience.

5GCAR is one of the 5G PPP Phase 2 projects [5GPPP17]. Naturally it is relevant to stay updated with other V2X related projects during the lifespan of the project.

Research projects from the previous phase, 5G PPP Phase 1, that are related to 5GCAR project activities are presented in Table **A.1**. A short description is provided for each project activity along with directions on how 5GCAR can leverage the results from this research work.

Table A.1: 5GCAR project in relation to 5G PPP Phase 1 research projects

5G PPP Project (Phase 1)	Relation to 5GCAR
METIS II https://metis-ii.5g-ppp.eu	METIS II develops an overall radio access network design for 5G. They explore common control plane and user plane framework architecture as well as spectrum managements. These aspects are relevant to 5GCAR, especially in the context of Connected cars which is one of the five METIS II use cases.
FANTASTIC 5G http://fantastic5g.eu	Technology components for air interface below 6 GHz supporting highly heterogeneous 5G requirements in terms of e.g., services (broad-/multicast services and vehicular communications) and high-speed mobility, and integration into an overall air interface framework.
5G NORMA https://5gnorma.5g-ppp.eu	Network architecture "unprecedented levels of network customizability, ensuring stringent performance, security, cost and energy requirements to be met; as well as providing an API-driven architectural openness". Outputs of 5G NORMA will help 5GCAR to understand how to customize a virtualized slice able to support the stringent requirements of ITS services.
SESAME http://www.sesame-h2020-5g-	Provides high manageable clustered edge computing infrastructure which is relevant for latency reduction. Small-cell integration provides useful solutions for high-mobility hand-over procedures.

ppp.eu	
5G-Ensure http://www.5gensure.eu	A security architecture is being defined and delivered within 5G-Ensure. The identified and developed security enablers for 5G are important to 5GCAR as V2X rely on secure communication.

Table **A.2** shows some examples of ongoing and completed EC research projects which are investigating use cases from the cooperative communications perspective in detail.

Table A.2: List of some European projects in the area of connectivity and automated driving

Project	Relation to 5GCAR
COMPANION www.companion-project.eu	Focus on a complementing use case for cooperative automated driving (platooning). But, 5GCAR can learn from the COMPANION experience for the performed evaluation in real-world traffic.
AutoNet2030 http://www.autonet2030.eu/	AutoNet2030 has extended the specifications of control algorithms and messages to support cooperative automated driving use cases, while using decentralized control system with 802.11p-based communications. These specifications could be used for the evaluation of the 5G-based solutions defined in 5GCAR and the implementation of the real prototypes.
GCDC http://www.gcdc.net/en/i-game	The GCDC aim to speed up real-life implementation and interoperability of wireless communication based automated driving. Functional architecture and requirements, supervisory control system and interaction protocol, validation tools for performance and interoperability testing of cooperative automated driving applications are all interesting inputs for 5GCAR.
HIGHTS http://hights.eu/	The HIGHTS project aim to achieve high precision positioning system with the accuracy of 25 cm, for applications such as highly automated driving, cooperative automatic cruise control, and VRUs discover. This type of findings can support the 5GCAR positioning accuracy required in the demonstrations and can also serve as input to WP3 in 5GCAR.

A.2 3GPP

3GPP is continuously developing the 4G and recently 5G technology, adding feature and capability to the wireless systems. For instance, 3GPP addressed recently in context of LTE (4G) and New Radio (NR, the 5G system as denoted by 3GPP) low latency and ultra-reliable communications, or massive machine type communication. Such feature is definitely of interest to 5GCAR.

In the 3GPP, the Technical Specification (TS) 22.185 (Service requirements for V2X services) is a Release 14 document for V2X service requirements published in March 2016 [3GPP16-22185] and is the first SA1 TS for V2X use cases and requirements. This document focuses mainly on ETSI ITS Release 1 use cases and requirements [ETSI09-2638] and it is analyzed in Section A.2.1.

In the Release 15 of 3GPP, the SA1 TS 12.186 for the enhancement of 3GPP Support for V2X Services published in March 2017 [3GPP17-22186]. This document presents different sets of V2X use cases and requirements considering automated driving and more challenging performance requirements. This document is analyzed in Section A.2.2.

A.2.1 Release 14

3GPP Technical Specification on Service Requirements for V2X Services [3GPP16-22185] was developed with focus on basic safety aspect and non-safety aspect using LTE-based technology. The V2X use cases that have been identified by 3GPP in Release 14 [3GPP16-22185], consider services and parameters defined in the first release of the ETSI ITS [ETSI09-2638]. The key features of this group of use cases are the following:

- Mainly used for warning and environmental awareness of the driver.
- Level 1 communication is mainly based on CAM and DENM messages, with transmission periodicity as high as 10 Hz (e.g. emergency vehicle warning) or lower (e.g. roadwork warning).
- The maximum one-way end-to-end latency requirement for Level 1 use cases is 100 to 1000 ms.
- The most stringent reliability requirement is 95%.

These use cases, see Table **A.3**, assume a single enabling technology, namely cellular-based V2X communication. For a detailed description, we refer the reader to the 3GPP technical report [3GPP15-22885].

Table A.3: 3GPP Release 14 use cases [3GPP15-22885]

	Effective distance*	Absolute speed of a UE supporting V2X services	Relative speed between two UEs supporting V2X services	Maximum tolerable latency	Minimum radio layer message reception reliability
Suburban/Major road	200 m	50 km/h	100 km/h	100 ms	90%
Freeway/Motorway	320 m	160 km/h	280 km/h	100 ms	80%
Autobahn	320 m	280 km/h	280 km/h	100 ms	80%
NLOS/Urban	150 m	50 km/h	100 km/h	100 ms	90%
Urban intersection**	50 m	50 km/h	100 km/h	100 ms	95%
Campus/Shopping area	50 m	30 km/h	30 km/h	100 ms	90%
Imminent crash	20 m	80 km/h	160 km/h	20 ms***	95%

Note*: Effective range is greater than range required to support TTC=4s at maximum relative speed. This is such that multiple V2X transmissions are required to increase the cumulative (overall, effective, or final) transmission reliability.

Note**: This scenario represents the scenario where a new incident presents itself at a short range, requiring a high level of reliability for short range radio transmissions to ensure timely message delivery, thus a cumulative transmission reliability may not be appropriate.

Note***: Example shown for two transmissions, for the statistical assumptions leading to a probability of 1 – (1-p)^2, where p is the probability of reception at the radio layer. V2X application layer requires a consecutive packet loss no more than 5%. If probability that a single V2X application layer message is lost is less than 20%, the requirement of less than 5% consecutive packet loss is met. Due to PHY retransmissions and the rapid cadence of application layer.

A.2.2 Release 15

The Release 15 SA1 Technical Report and Technical Specification on Enhancement of 3GPP Support for V2X Services [3GPP16-22886]. [3GPP17-22186] was developed with focus on enhancements of V2X Use Case scenarios, including more rigorous functional requirements for advanced features that cannot be achieved by [3GPP14-22156].

Different V2X scenarios require the transport of V2X messages with different performance requirements for the 3GPP system. This Technical Specification specifies service requirements to enhance 3GPP support for V2X scenarios in the following five areas:

- General Aspects: interworking, multi-RAT, communication-related requirements valid for all V2X scenarios.
- Vehicle Platooning: enables the vehicles to dynamically form a platoon travelling together, and allow the vehicles to drive closer (short time or distance inter-vehicle gap) than normal in a coordinated manner.
- Advanced Driving: enables the exchange of raw or processed data gathered through local sensors or live video images, and increase the perception of vehicles' environment beyond of what their own sensors can detect.
- Extended Sensors: enables semi-automated or full-automated driving, allows vehicles to synchronize and coordinate their trajectories or maneuvers.
- Remote Driving: enables a remote driver or a V2X application to operate a remote vehicle for those passengers who cannot drive by themselves or remote vehicles located in dangerous environments.

For each one of the above categories the following performance requirements have been discussed:

- Payload (Bytes) without considering the security payload
- End-to-end latency (ms): Time it takes to transfer a given piece of information from a source to a destination, measured at the application level, from the moment it is transmitted by the source to the moment it is received at the destination
- Reliability (%): The success probability of transmitting X bytes within a certain delay, which is the time it takes to deliver a small data packet from the radio protocol layer 2/3 SDU ingress point to the radio protocol layer 2/3 SDU egress point of the radio interface.
- Data Rate (Mbps)
- Communication Range (meters)
- Tx Rate (Message per second)

The full automated driving use cases do not require any human intervention either at the monitoring phase or at the application of a decided driving behavior (e.g., maneuver). The involved vehicles trigger a specific use case for safety reasons (e.g., emergency maneuver) or for more efficient traffic management (e.g., platooning) using the monitoring data from the installed sensors, together with the information received from neighboring vehicles. Thereinafter, the autonomous vehicles undertake to coordinate and plan their maneuvers or trajectories in order to address the triggering event, based on the built environmental perception. With the increasing availability of vehicles that are capable of supporting higher automation levels, the need for coordination among vehicles and their capability to do so becomes increasingly more relevant. All automated vehicles rely on the premise that they continuously plan their trajectories and, based on the observed environment, select the driving trajectory. Due to the safety requirements, automated driving sets the most stringent performance requirements for the communication layer in terms of delay, reliability, capacity.

Cooperative Lane Change, Cooperative Collision Avoidance, and Convoy Management (platooning) are typical examples of V2X use cases, where connected automated vehicles participate. The involved vehicles trigger a specific use case for safety reasons (e.g., emergency maneuver) or for efficient traffic flow (e.g., platooning) using the monitoring data from the installed sensors, together with the information received from neighboring vehicles. Thereinafter, the automated vehicles undertake to coordinate and plan their maneuvers or trajectories in order to address the triggering event, based on the built environmental perception. As vehicles advance towards higher automation levels and need to deal with increasingly complex road situations, there will be a need for a complementary communication technology for the exchange of cooperative information with higher bandwidth and improved reliability. In connected automated vehicles the performance requirements are more stringent, with certain use cases requiring ultra-reliable communication links (99.999%), with much lower maximum end-to-end latency, and higher data rate. V2X use cases from the aforementioned categories are enlisted in Table **A.4**.

Table A.4: List of Use Cases that belong to the categories: Advanced Driving, Extended Sensors, and Remote Driving. Further, the use cases used only for derivation of General Requirements are also listed

Section in 22.886 TR	Use Case
Advanced Driving category	
5.9	Cooperative Collision Avoidance
5.10	Information sharing for limited automated driving
5.11	Information sharing for full automated driving
5.20	Emergency Trajectory Alignment
5.22	Intersection Safety Information Provisioning for Urban Driving
5.23	Cooperative Lane Change of automated Vehicles
5.25	3D video composition for V2X scenario
Extended Sensors category	
5.3	Automotive: Sensor and State Map Sharing
5.6	Collective Perception of Environment
5.16	Video data sharing for automated Driving
Remote Driving category	
5.4	eV2X support for Remote Driving
5.21	Teleoperated Support
Use cases used only for derivation of General Requirements	
5.7	Communication between vehicles of different 3GPP RATs

5.8	Multi-PLMN environment
5.15	Use case on Multi-RAT
5.19	Use case out of 5G coverage
5.14	Dynamic Ride Sharing
5.18	Tethering via Vehicle
5.24	Secure software update for electronic control unit

Some examples of the General Requirements in the 22.886 TR are presented below, while a more detailed list of the general requirements is available in [3GPP17-22186] and the corresponding TS document [3GPP16-22886]:

- CPR.G-015: The 3GPP system shall be capable of supporting high reliability without requiring application-layer message retransmissions.
- CPR.G-004: The 3GPP system shall be able to support message transfer among a group of UEs supporting V2X application.
- CPR.G-021: The 3GPP system should provide integrity and confidentiality protection (end to end) for the network access traffic of a V2X UE via another such UE.

It should be noted that different performance requirements have been proposed for similar use cases and this is due to different: Automation Level (Fully Automated Driving vs Driver Control), Density or distance among involved vehicles, and Involved entities (RSU Vehicles, App Servers, etc.).

A.3 ITU-R

In the recommendation ITU-R M.2083-0 [ITUR15-2083] from the International Telecommunications Union (ITU), it is described the vision of a framework and the overall objectives of the future development of International Mobile Telecommunication (IMT) systems for 2020 and beyond; this constitutes the foundational motivation for the 5G technologies being developed today.

That document describes a broad variety of capabilities associated with envisaged usage scenarios, where the vision of the connected car and driverless cars is included. The starting of the vision of ITU-R is that there are some growing trends that need to be observed. The ones relevant to 5GCAR are:

- The growing need to support **very low latency** and **high reliability** in machine-centric communications. Among the cited use cases, there are explicitly stated the driverless car and the real-time traffic control optimization as key examples where low latency and high reliability can improve the quality of life.
- The growing need to support high **user density** in scenarios where high traffic data exchanges is expected, including infotainment services where a large number of concurrent users may be active, such as platoon, for example. In particular, the ITU-R

identifies traffic jams and, transport systems in general, as key use cases. It is also mentioned the particular case of police, fire brigades, and ambulances, as key use cases where quick communications in dense network deployments must be solved.

- The growing need to maintain **high quality communication at high mobility**. The vision is that the connected society of the 2020 and beyond will need to have a similar connectivity and user experience on the move. For this, it is essential that the networks of the future can guarantee high mobile connectivity to users ensuring robustness and reliability, and, in general, offering the needed Quality of Service (QoS) for each application and/or service. The particular use cases of communications in cars and high-speed trains is mentioned in the document as key solutions that are expected to be deployed in several countries.
- The unstoppable growth of the **Internet of Things**; it is foreseen that every object that can benefit from being connected, will be connected to the Internet and/or with close objects in proximity. These connected things can be smartphones, sensors, actuators, cameras, etc., and cars and vehicles. To make the IoT possible and feasible, it is necessary to ensure low energy consumption, high reliability, scalability of the networks, and low latency to enable mission-critical applications.
- **Convergence of applications**; it is foreseen that different applications with very different requirements will need to coexist in IMT systems. This motivates the selection of 5 use case classes in 5GCAR; the purpose is to show that the solutions designed and proposed within 5GCAR take into account this variety and heterogeneity of applications and use cases related to the connected cars.
- **Ultra-accurate positioning applications**; the ITU-R considers that an improvement in positioning and location systems will allow for new applications based on location. In particular, it is explicitly mentioned the case of unmanned vehicles which can benefit from location information; in this sense, some of the selected use cases of 5GCAR take into account this growing trend of need for localization services to detect VRU, for example.

To provide a solution towards these trends, new technologies have to be developed; the requirements for them are called IMT-2020 and constitute the requirements to be met by 5G technologies. According to the vision of the ITU-R, these new technologies should aim at enhancing the radio interface and integrating Software Defined Network (SDN) and Network Function Virtualization (NFV) to enable massive machine type communications (mMTC), with particular emphasis on ultra-reliable and low latency use cases, and ensuring energy efficiency both on the network and device sides.

ITU-R collaborates actively with other bodies to focus on particular topics or applications and continue providing recommendations. With regard to 5GCAR activity, there is collaboration with ITS Communication Standard (CITS). As stated in the ITS website: *“The intent of the Collaboration is to provide a globally recognized forum for the creation of an internationally accepted, globally harmonized set of ITS communication standards of the highest quality in the* *most expeditious manner possible to enable the rapid deployment of fully interoperable ITS communication-related products and services in the global marketplace."*

The recommendation ITU-R M.1890 [ITUR11-1890], dating back to 04/2011, is entitled as "Intelligent Transport Systems – Guidelines and objectives". In this document, there are eight use case classes defined (not explicitly named as use case class), being defined a number of use cases for each of the classes. The summary of this analysis done by ITU-R is shown in Table **A.5**, together with the analysis of which of the use cases considered by ITU-R are fully or partially considered also in 5GCAR.

Table A.5: ITU-R use case classes and use cases [ITUR11-1890]

Use Case Class	Use Case	Studied in 5GCAR
Advanced Vehicle Control Systems	Longitudinal Collision Avoidance.	NO
	Lateral Collision Avoidance.	NO
	Intersection Collision Avoidance.	**YES**
	Vision Enhancement Systems: improves driver's ability to see the roadway and objects on or along the roadway.	**YES**
	Pre-crash restraint deployment: anticipates and imminent collision and activates passenger safety systems before the collision occurs.	NO
	Automated Road Systems.	**YES**
	Safety Readiness: provides warning about condition of the driver, vehicle, and the road.	YES
Advanced Traffic Management Systems	Traffic network monitoring and control: manages the movement of traffic on streets and highways.	NO
	Travel demand management: supports policies and regulations designed to mitigate the environmental and social impacts of traffic congestion.	NO
	Incident detection and management: helps public and private organizations quickly identify incidents and implement a response to minimize their effects on traffic.	NO
	Emissions testing and mitigation: provides information for monitoring air quality and developing air quality improvement strategies.	NO
	Parking management: provides information of parking lots or manages the entry and exit of vehicles.	NO
Advanced Traveller Information	Pre-trip travel information: provides information for selecting the best transportation mode, departure time and route.	NO
	En-route driver information: provides driver advisory and in-vehicle signing for convenience and safety during travel.	**YES**

Systems	En-route transit information: provides information to travellers using public transportation after the start of the trip.	NO
	Route guidance: provides travellers with simple instruction on how to best reach their destinations.	**YES**
	Ride matching and reservation: makes ride sharing easier and more convenient.	NO
Advanced Public Transportation Systems	Public transportation management: automates operations, planning and management functions of public transit systems.	NO
	Personalized public transportation: offers flexibly routed transit vehicles for more convenient service to customers.	NO
Advanced fleet management systems	Vehicle administration: provides electronic purchasing of credentials and automated mileage and fuel reporting and auditing.	NO
	Safety monitoring and tracking: senses the safety status of a commercial vehicle, cargo and driver.	NO
	Fleet management.	NO
	Vehicle preclearance: facilitates domestic and international border clearance, minimizing stops.	NO
	Automated roadside safety inspections: facilitates roadside inspections.	NO
	Hazardous material incident response: provides immediate description of hazardous materials to emergency responders.	NO
Emergency management systems	Emergency notification and personal security: provides immediate notification of an incident and an immediate request for assistance.	NO
	Public travel security: creates a secure environment for public transportation operators.	**YES**
	Emergency vehicle management: reduces the time it takes emergency vehicles to respond to an incident.	NO
Electronic payment services	Electronic payment services: allows travellers to pay for transportation services electronically based on short-range vehicle-to-infrastructure communication.	NO
	Electronic payment services: allows travellers to pay for transportation services electronically based on GNSS and wide area communication.	NO
Pedestrian supporting systems	Pedestrians route guidance: helps pedestrians to find appropriate directions to go to destinations.	NO
	Vehicle-pedestrian accident avoidance: detects dangerous situations, and to provide necessary alarm both for pedestrians and drives.	**YES**

A.4 ETSI

A.4.1 ETSI ITS standards

The use cases described in ETSI TR 102 638 BSA (Basic Set of Applications), [ETSI09-2638], are supported by the first release of standards produced by ETSI TC ITS, as described in

[ETSI13-1607] (release1 of ETSI ITS standards) and by other standardization organizations such as CEN TC 278.

The BSA document which has been initiated in the 2010 years entails a large set of use cases and applications, see Table **A.6**. This document is currently under revision to cope with ETSI ITS standards release2.

Table A.6: ETSI basic set of applications (release1) use cases [ETSI09-2638]

Applications Class	Application	Use case
Active road safety	Driving assistance - Co-operative awareness	Emergency vehicle warning
		Slow vehicle indication
		Intersection collision warning
		Motorcycle approaching indication
	Driving assistance - Road Hazard Warning	Emergency electronic brake lights
		Wrong way driving warning
		Stationary vehicle - accident
		Stationary vehicle - vehicle problem
		Traffic condition warning
		Signal violation warning
		Roadwork warning
		Collision risk warning
		Decentralized floating car data - Hazardous location
		Decentralized floating car data - Precipitations
		Decentralized floating car data - Road adhesion
		Decentralized floating car data - Visibility
		Decentralized floating car data - Wind
Cooperative traffic efficiency	Speed management	Regulatory / contextual speed limits notification
		Traffic light optimal speed advisory
	Co-operative navigation	Traffic information and recommended itinerary
		Enhanced route guidance and navigation
		Limited access warning and detour notification

Applications Class	Application	Use case
		In-vehicle signage
Co-operative local services	Location based services	Point of Interest notification
		Automatic access control and parking management
		ITS local electronic commerce
		Media downloading
Global internet services	Communities services	Insurance and financial services
		Fleet management
		Loading zone management
	ITS station life cycle management	Vehicle software / data provisioning and update
		Vehicle and RSU data calibration.

A part of these use cases have been selected to be considered in the Day1 deployment, according to the C-ITS platform final report (available [ETSI16]) and are presented in Table **A.7**.

Table A.7: ETSI use cases for Day1 services deployment, and Day1.5 services deployment

List of Day1 services	
Hazardous location notifications	Slow or stationary vehicles and traffic ahead warning
	Road work warning
	Weather conditions
	Emergency brake light
	Emergency vehicle approaching
	Other hazardous notifications
Signage applications	In vehicle signage
	In vehicle speed limits
	Signal violation / Intersection safety
	Traffic signal priority request by designated vehicles

	Green Light Optimal Advisory
	Probe vehicle data
	Shockwave Damping
List of Day 1.5 services	*Information on fuelling & charging stations for alternative fuel services*
	VRU (vulnerable road user protection)
	On street parking management and information
	Off street parking information
	Park and Ride information
	Connected & Cooperative navigation into and out of the City
	Traffic information and smart routing

Currently ETSI has standardized 3 road safety services in the framework of release1 ITS specifications:

- RHS (TS 101 539-1) Road Hazard Signaling service
- LCRW (TS 101 539-3) Longitudinal Collision Risk Warning application
- ICRW (TS 101 539-2) Intersection Collision Risk Warning application

An originating ITS-S (ITS vehicle station) is then serving several categories of applications without knowing which ones are implemented at the level of receiving ITS-S. Road safety standards have been developed by ETSI TC ITS WG1 and CEN TC 278 WG16 in the scope of the M/453 mandate.

RHS application is an application layer entity of the ITS-S that triggers the transmission of messages such as DENM and processes received messages to provide information on the road hazard to road user.

These are several data services which contribute to the primary safety goal and increase driver awareness and collision avoidance capabilities:

- The “driver information” may be achieved by digital radio broadcast channels or cellular network or “In-Vehicle signage” (IVS) covering fixed or variable message sign information such as currently under specification by road operators.
- The “driver awareness” may be achieved with the RHS application upon reception of CAMs and DENMs.

- The “driver warning” may be achieved with the ICRW and the LCRW applications upon reception of CAMs and DENMs from neighboring ITS –Ss under specification in ETSI TC ITS WG1.

Table **A.8** presents the main performance requirements related to the road safety applications.

Table A.8: ETSI main performance requirements related to the road safety applications

Road safety service	RHS	ICRW	LCRW
Communication range	300 m	300 m	300 m
system E2E latency	300 ms	300 ms	300 ms

ETSI ITS applications in ETSI TC ITS release2

More recently, ETSI has initiated pre-standardization studies with the purpose of specifying new ITS services to be applicable in the framework of ETSI ITS release2 standards. These new use cases are respectively addressing road safety and traffic efficiency ITS applications as defined by ETSI. The following pre-standardization studies are related to:

- CACC (Cooperative Adaptive Cruise Control) in TR 103 299
- VRU (Vulnerable Road User protection) in TR 103 300
- Platooning in TR 103 298

Note that these three documents ([ETSI17-3298], [ETSI17-3299], and [ETSI17-300]) are still in an early stage, and therefore the performance requirements are currently under investigation.

CACC

The C-ACC application is an extension of the in-vehicle Adaptive Cruise Control (ACC) system. It enables further reduction of the time gap with preceding vehicles compared to the ACC system, thanks to direct Vehicle to Vehicle (V2V) communications.

CACC defines an in-vehicle driving assistance system that adjusts automatically the vehicle speed to keep a desired target time gap with target vehicle or with target traffic, making use of information communicated from other vehicles and/or from the roadside infrastructure.

VRU

VRU applications extend the awareness of and/or about Vulnerable Road User such as motorcycles, bicycles, pedestrians and less impaired traffic participants in the neighborhood of other traffic participants. It enables further improvement of traffic safety and management based on direct ITS s.

VRU applications can exist in any ITS-S (ITS station) and are intended to provide VRU-relevant information to actors such as humans directly or to automated systems. VRU applications can increase the awareness of vulnerable road users, or provide VRU-collision risk warnings. VRU applications make use of data received from other ITS-Ss via the ITS network and may use additional information provided by its own station sensor systems and integrated other services.

A VRU system may be extended with other VRUs, other ITS-S and other road users involved in a scenario such as vehicles, motorcycles, bikes, and pedestrians. VRUs may be equipped with ITS-S.

Platooning

The main motivation of platoon is to maintain a very short time gap between vehicles by forming a stable vehicle group while satisfying the road safety requirements. To ensure the driving safety, such short time gap (typically less than 0.5 s) could not be realized by manual driving (e.g. human reaction time is typically higher than 0.5 s) and would require the automatic driving functions, including longitudinal and/or lateral control.

Platoon would bring benefits to driver, road operator and potentially to society. For the driver, the main benefit of platoon is related to the reduced fuel consumption, thanks to the reduction of air resistance between vehicles. For road operators, the main benefit of platoon may be related to increased road capacity and traffic efficiency.

The social benefits of platoon may be related to increased road safety, reduced traffic jam and or environmental benefits. Platoon as application of autonomous driving would contribute to the reduction of road accident by removing human errors during platooning.

A.4.2 CEN/ISO standards

CEN/ISO joint working group activity has been started to satisfy the mandate M453 in collaboration with ETSI. The use cases addressed by CEN are related to the road safety, the support of traffic management, and the reduction of greenhouse gas emissions.

CEN has standardized two other services for the purpose of traffic efficiency applications, these are:

- IVS (In Vehicle Signage) in [CEN16-17425]
- Contextual speed in [CEN16-17426]

In Vehicle Signage

IVS service aims at providing more focused and timely guidance to vehicle controllers and drivers by supporting continuous presentation of the content of roadside signage information in the vehicle along the impacted road section rather only during the short moments its takes for a vehicle to pass traditional road signs.

Direct in-vehicle presentation of roadside signage information, called In-Vehicle Signage, facilitates the potential provision of information to specific classes or characteristics of vehicles, and for potentially more granular definition of affected road sections than stationary-position traditional fixed plate signs and use of variable/dynamic road signs. Delivering the In-Vehicle Signage service to road users can improve road safety, support traffic management, and reduce greenhouse gas emissions.

Contextual speed

Cooperative Intelligent Transport Systems (C-ITS) will enable providing better guidance to vehicle drivers on what speed they can travel at when road, traffic, or environmental conditions are less than ideal. This Contextual Speed Information Service consists in delivering Contextual Speed information to road users to improve road safety, support traffic management, and reduce greenhouse gas emissions.

In a Cooperative ITS environment, Contextual Speeds are context-dependent (e.g. changed due to weather conditions), as well as time-specific and road section-specific speeds. Subject to local regulations, they can be mandatory speed limits or advisory speeds.

A.5 NGMN

In the NGMN White Paper on 5G use cases [NGM15] one identified eight use case families and analyzed 25 different use cases. The NGMN scope was much broader than merely V2X, but one family targets “Higher user mobility”. The use case families are then divided into categories. The “Higher user mobility” family consists of the following two categories: “Mobile broadband in vehicles” and “Airplanes connectivity”. The “Mobile broadband in vehicles” relates to cars (and trains). In Table **A.9** and Table **A.10** the user experience requirements and system performance requirements of the “Mobile broadband in vehicles” use case category are presented.

Table A.9: NGMN Mobile broadband in vehicles user experience requirements

Use case category	User Experienced Data Rate	E2E Latency	Mobility
Mobile broadband in vehicles (cars, trains)	DL: 50 Mbps UL: 25 Mbps	10 ms	On demand, up to 500 km/h

Table A.10: NGMN Mobile broadband in vehicles system performance requirements

Use case category	Connection Density	Traffic Density
Mobile broadband in vehicles (cars, trains)	2000 / km^2 (500 active users per train x 4 trains, or 1 active user per car x	DL: 100 Gbps / km^2 (25 Gbps per train, 50 Mbps per car)

	2000 cars)	UL: 50 Gbps / km^2 (12.5 Gbps per train, 25 Mbps per car)

The Mobile broadband in vehicles use case category consists of the following three use cases: “High speed train”, “Moving Hot Spots”, and “Remote computing”. Some of the “High Speed Train” key characteristics is that it targets high mobility, low latency, and various types of traffic.

Another use case that relates to 5GCAR is the “Automated Traffic Control and Driving” use case from the use case category “Ultra-high reliability & Ultra low latency” that belongs to the “Ultra-reliable communication” family. This use case targets high mobility, low latency, high reliability, high availability, much infrastructure, and various types of traffic. In Table **A.11** and Table **A.12** the user experience requirements and system performance requirements of the “Ultra-high reliability & Ultra low latency” use case category are presented.

Table A.11: NGMN Ultra-high reliability & Ultra low latency user experience requirements

Use case category	User Experienced Data Rate	E2E Latency	Mobility
Ultra-high reliability & Ultra low latency	DL: From 50 kbps to 10 Mbps; UL: From a few bps to 10 Mbps	1 ms	On demand: 0 km/h to 500 km/h

Table A.12: NGMN Ultra-high reliability & Ultra low latency system performance requirements

Use case category	Connection Density	Traffic Density
Ultra-high reliability & Ultra low latency	Not critical	Potentially high

The requirements presented in Table **A.9** and Table **A.10** as well as Table **A.11** and Table **A.12** are the most challenging ones for that respective use case category. Hence to find solutions that addresses and fulfill those, solve all the relevant use cases identified within that category.

A.6 V2X use cases around the world

This section describes the use case strategy form V2X in three main regions of the world: Europe, US and China. The purpose of it is to describe the main initiatives promoted by regulators in terms of use cases and evoke the current technology context between DSRC and cellular V2X related to the use case definition and possibilities.

A.6.1 EUROPE: Use cases prioritized by EC DGMOVE

By the [EUP10] European Union had mandated ETSI, CEN and CENELEC for specifications of all necessary standards which could contribute to accelerate a wide deployment of Cooperative ITS systems across European countries to reduce at term road fatalities. The ETSI has developed the major part of these standards (see: A4) known as the ITS stack.

The following set of road safety or traffic management use cases was defined for a starting deployment before 2020's as a V2X Day One deployment phase. This list of use cases was confirmed recently (01/2016) by the C-ITS Platform driven by the DG MOVE, where different actors of transportation sector had participated (car manufacturers, suppliers, road authorities, automotive associations).

Table A.13: Day 1 V2X use cases

Use Case	V2X	Class / Environment
Emergency electronic brake light	V2V	Safety
Emergency vehicle approaching	V2V	Safety
Slow or stationary vehicle(s)	V2V	Safety
Traffic jam ahead warning	V2V	Safety
Hazardous location notification	V2I	Motorway
Road works warning	V2I	Motorway
Weather conditions	V2I	Motorway
In-vehicle signage	V2I	Motorway
In-vehicle speed limits	V2I	Motorway
Probe vehicle data	V2I	Motorway
Shockwave damping	V2I	Motorway
GLOSA / Time To Green (TTG)	V2I	Urban
Signal violation/Intersection safety	V2I	Urban
Traffic signal priority request by designated vehicles	V2I	Urban

These use cases above, served in a first step by the current ITS-G5 technology (DSRC in US), are dedicated to tactical application (short horizon) would be completed after cellular hybridation by more strategical applications named Day 1.5 use cases:

Table A.14: Day 1.5 V2X use cases

Use Case	V2X	Class / Environment
Off street parking information	V2I	Parking
On street parking information and management	V2I	Parking
Park & Ride information	V2I	Parking
Information on AFV fuelling & charging stations	V2I	Smart Routing
Traffic information and smart routing	V2I	Smart Routing
Zone access control for urban areas	V2I	Smart Routing
Loading zone management	V2I	Freight
Vulnerable road user protection	V2X	VRU

Cooperative collision risk warning	V2V	Collision
Motorcycle approaching indication	V2V	Collision
Wrong way driving	V2I	Wrong Way

A.6.2 USA: Safety use cases prioritized by US DOT for a possible regulation

NHTSA believes the greatest gains in highway safety in coming years will result from broad-scale application of crash avoidance technologies along with continued improvements in vehicle crashworthiness that can reduce fatalities and injuries. To encourage adoption of such technologies, in February 2015 the agency announced that it would add two types of automatic emergency braking systems—crash imminent braking and dynamic brake support—to the list of recommended advanced safety features in our New Car Assessment Program, known to most Americans as NHTSA's Five Star Safety Ratings. In March, 2016 the agency announced an agreement with vehicle manufacturers to voluntarily make automatic emergency braking (AEB) a standard safety on future vehicles.9 These technologies, along with technologies required as standard equipment like electronic stability control (ESC), help vehicles react to crash-imminent situations, but do not help drivers react ahead of time to avoid crashes.

This proposed rule would require vehicles to transmit messages about their speed, heading, brake status, and other vehicle information to surrounding vehicles, and to be able to receive the same information from them. V2V range and "field-of-view" capabilities exceed current and near-term radar- and camera-based systems -- in some cases, providing nearly twice the range. That **longer range and 360 degrees of field of "view",** currently **supported by DSRC**, provides a platform enabling vehicles to perceive some threats that sensors, cameras, or radar cannot.

Further statistical analysis focusing on the frequency and severity of pre-crash scenarios identified the top 10 (priority) pre-crash scenarios that V2V could potentially address:

Table A.15: Use case list based on DSRC

Pre-crash scenarios	Pre-crash groups	Associated Safety Application	Acronym
Lead Vehicle Stopped	Rear-end	Forward Collision Warning	FCW
Lead Vehicle Moving	Rear-end	Forward Collision Warning	FCW
Lead Vehicle Decelerating	Rear-end	Emergency Electronic Brake Light	EEBL
Straight Crossing Path at Non Signal	Junction Crossing	Intersection Movement Assist	IMA

Left-Turn Across Path/Opposite Direction	Left Turn at crossing	Left Turn Assist	LTA
Opposite Direction/No Maneuver	Opposite Direction	Do Not Pass Warning	DNPW
Opposite Direction/Maneuver	Opposite Direction	Do Not Pass Warning	DNPW
Change Lanes/Same Direction	Lane Change	Blind Spot/Lane Change Warning	BS/LCW
Turning/Same Direction	Lane Change	Blind Spot/Lane Change Warning	BS/LCW
Drifting/Same Direction	Lane Change	Blind Spot/Lane Change Warning	BS/LCW

(1) **Forward Collision Warning (FCW)**: warns drivers of stopped, slowing, or slower vehicles ahead. FCW addresses rear-end crashes that are separated into three key scenarios based on the movement of lead vehicles: lead-vehicle stopped (LVS), lead-vehicle moving at slower constant speed (LVM), and lead-vehicle decelerating (LVD).
(2) **Emergency Electronic Brake Light (EEBL)**: warns drivers of heavy braking ahead in the traffic queue. EEBL would enable vehicles to broadcast its emergency brake and allow the surrounding vehicles' applications to determine the relevance of the emergency brake event and alert the drivers. EEBL is expected to be particularly useful when the driver's visibility is limited or obstructed.
(3) **Intersection Movement Assist (IMA)**: warns drivers of vehicles approaching from a lateral direction at an intersection. IMA is designed to avoid intersection crossing crashes, the most severe crashes based on the fatality counts. Intersection crashes include intersection, intersection-related, driveway/alley, and driveway access related crashes. IMA crashes are categorized into two major scenarios: turn-into path into same direction or opposite direction and straight crossing paths.
(4) **Left Turn Assist (LTA)**: warns drivers to the presence of oncoming, opposite-direction traffic when attempting a left turn. LTA addresses crashes where one involved vehicle was making a left turn at the intersection and the other vehicle was traveling straight from the opposite direction.
(5) **Do Not Pass Warning (DNPW)**: warns a driver of an oncoming, opposite-direction vehicle when attempting to pass a slower vehicle on an undivided two-lane roadway. DNPW would assist drives to avoid opposite-direction crashes that result from passing maneuvers. These crashes include head-on, forward impact, and angle sideswipe crashes.
(6) **Blind Spot/Lane Change Warning (BS/LCW)**: alerts drivers to the presence of vehicles approaching or in their blind spot in the adjacent lane. BS/LCW addresses crashes where a vehicle made a lane changing/merging maneuver prior to the crashes.

Overall the NHTSA estimates that, together, FCW, IMA, LTA and BS/LCW potential safety applications could potentially address nearly 89 percent of LV2LV crashes and 85 percent of their associated economic costs (more than $100 Billions).

Safety systems based on on-board sensors

In recent years, US vehicle manufacturers have begun to offer, or have announced plans to offer, various types of crash avoidance technologies that are designed to do just that. These technologies including radars, lidars and cameras, are designed to address a variety of crashes, including rear end, lane change, and intersection. Nevertheless, these technologies based on “Line Of Sight” detections, show some limitations depending on weather conditions (cameras, lidars) or propagation obstructions (neighboring vehicles or obstacles, intersections areas). In this context it has been proposed to develop a cooperative sensing system, based on a mutual sharing of some fundamental data like ego position (GPS), heading, speed, accelerations, etc.
A first approach to assume such local wireless communications between vehicles has been realized by some adaptations of WIFI IEEE 802.11 standards beginning of this century, to be applied to automotive applications. The associated technology named DSRC (Dedicated Short Range Communications) uses a set of standards (WAVE) developed by IEEE and SAE in USA.

Safety systems based on DSRC

Devices enabling vehicles to communicate with one another (V2V) or with road-side equipment and/or infrastructure (V2I) have been prototyped and tested in USA, in field operational tests like the Safety Pilot Model Deployment. These devices, when eventually developed for mass production, could be fully integrated into a vehicle when manufactured, or could be standalone aftermarket units not restricted to a single vehicle. These devices offer varying degrees of functionality, but all are designed to communicate safety information to help mitigate crashes.

Safety information that can help mitigate crashes includes data elements like vehicle position, heading, speed, and so forth – data elements that could help a computer-based safety application on a vehicle calculate whether it and another vehicle were in danger of crashing without driver intervention. These pieces of information are collected into what is known as a “Basic Safety Message,” or “BSM.”

Source extracted from [NHTSA16].

A.6.3 China TIAA future forum V2X scenarios

China is showing an important activity in automotive use cases. On May 29th, 2015, State Council has unveiled a ten-year national plan, “Made in China 2025”, designed to transform China into a world manufacturing power and new energy vehicle (including Intelligent Connected Vehicle, ICV) is listed as one of key sectors. This ICV includes two main vectors: autonomous vehicles and V2X connectivity scenario.
The MIIT (Ministry of Industry and Information Technology), responsible for the ICV overall planning and technical roadmap has defined in 2016 some of the future ambitions:

- 2020: 50% of new vehicles will have DA/PA (Driving Assistance / Partial Automation)
- 50% of new vehicles will have Telematics OBU installed

- 10% of new vehicles will have Connected Driving Assistance System installed
- 2025: 80% of new vehicles will have DA/PA/CA (conditional automation) and have HA launch to the market
- 80% of new vehicles will have Telematics OBU installed
- 30% of new vehicles will have Connected Driving Assistance System installed)
- 2030: 10% of new vehicles will have HA/FA (high automation / full automation)

In terms of communication technology for V2X use cases, China is only focusing cellular communications and does not consider as a development priority C-ITS (DSRC, 802.11p). In mid-Nov, 2016, Ministry of Industry and Information Technology (MIIT) has approved the trial spectrum (5905-5925 MHz) for LTE-V

The MIIT with the Ministry of Transportation (MoT, responsible of traffic efficiency and transportation safety) created in 2010 the TIAA (Telematics Industry Application Alliance). The TIAA has released at the end of 2016, 72 use cases grouped into three categories: safety, traffic efficiency and telematics.

Table A.16: TIAA V2X use case list

Use case	V2X	Class / Environment
Forward Collison Warning	V2V	Safety
Following Too Closely Warning (Before FCW)	V2V	
Collison Warning from RSU (in the absence of V2V)	V2I	
Pre-Crash Warning	V2V/V2X	
Left Turn Assistance/Warning	V2V	
Merging Assistance/Collison Warning	V2V	
Intersection Collison Warning (In the Presence of RSU)	V2I	
Intersection Collison Warning (In the absence of RSU)	V2V	
Overtaking Assistance/Reversing Overtaking Notification	V2V	
Blind Area Warning/ Lane Changing Assistance	V2V	
Emergency Brake Notification	V2V	
Vehicle Safety Function Failure (e.g. failure on steel wheels, brake system) Warning	V2V	
Abnormal Vehicle Warning (Including static/slow-speed vehicles ahead)	V2V	
Static Vehicle Warning (caused by traffic accident, broke down, etc.)	V2V	
Motorcycle Approaching Warning	V2V/V2P	
Slow-Speed Vehicle Warning (tractors, trucks, etc.)	V2V	
Non-Motorized Vehicle (e-bike, bike) Approaching Warning	V2P	

Non-Motorized Vehicle (e-bike, bike)/Pedestrians Crossing Warning	V2P	
Emergency Vehicle Notification	V2V/V2I/V2N	
Over-Sized Vehicle Approaching Warning	V2I	
Driving In Opposite Direction Warning (to notify host vehicle and remote vehicles)	V2V	
Congestion Ahead Notification	V2I/V2V/V2N	
Road Under Construction Ahead Notification	V2X	
Accident Ahead Notification	V2I	
Slippery Road/Dangerous Zone Notification (e.g. windy, frog, icy...)	V2I	
Collaborative information Sharing (e.g. slippery road, dangerous zone, windy, frog, accident ahead...)	V2I	
Running At A Red (Yellow) Light Warning	V2I	
Adaptive Lowbeam/Highbeam (e.g. switch the light automatically when meeting the car in opposite direction)	V2V	
Train Approaching/Intersection Notification	V2I/V2P	
Height/Weight/Width Limit Notification	V2I	
Fatigue Driving Notification	V2V	
Distraction Notification	V2V	
Overloading/Overman Warning	V2N/V2P	
Decelerate Zone/Speed Limit Notification (e.g. tunnel, special zone, curve...)	V2I/V2N/V2V	Traffic Efficiency
Decelerating/Stop Sign Notification (triangle warning stand)	V2I	
Decelerating/Stop Sign Violation Warning	V2X	
Speed Suggestion	V2I/V2V/V2N	
Traffic Information/Route Suggestion (notify by RSU)	V2I/V2N	
Enhanced Navigation (connect to internet)	V2N/V2I	
Navigation for Commercial Vehicles	V2N	
Intersection Crossing Assistance	V2V/V2I/V2N	
Dynamic Usage of Accommodation Lane (other vehicles drive on this accommodation lane temporarily)/Accommodation Lane Hours/ Peak Time/Emergency Vehicles	V2I	
Do Not Enter/ Detour Notification (e.g. road closed,	V2I	

temporary traffic controls…)		
Traffic Signs In the Vehicles	V2I	
Truck/Over-Sized Vehicle Wrong Lane Notification (occupy the inner lane for long time on highway)	V2I	
Adaptive Cruising (with driver in the vehicle behind)	V2V	
Platooning (no drivers in the vehicles behind)	V2V	
POI notification	V2I/V2V	Telematics
Near Field Payment (e.g. ETC, congestion charge, traffic violation fine, parking, gasoline…)	V2I/V2N	
Parking Guidance and Control	V2I/V2N	
(Wired/Wireless) Charging Station Route Guidance	V2I/V2N	
Electrical Car Parking and Wireless Charging	V2I/V2N	
eCommerce Nearby	V2I/V2N	
Cars to Share	V2I/V2N	
Cars to Share for Electrical Cars	V2I/V2N	
Media Download	V2I/V2N	
Map Management, Download/Update	V2I/V2N	
Eco-Driving Suggestion	V2X	
Instant Messager (V2V)	V2V	
Personal Data Synchronization	V2I/V2N	
SOS/eCall	V2I/V2N	
Vehicle Stolen/Damage (partial or whole vehicle) Notification	V2I/V2N	
Remote Diagnostic, Maintenance Reminder	V2I/V2N	
Vehicle Relationship Management (connect to internet)	V2I/V2N	
Vehicle Lifecycle Management and Data Collection	V2I/V2N	
Insurance on Demand Service (e.g. UBI)	V2I/V2N	
In-Vehicle ECU Software over-the-air Update and Notification	V2I/V2N	
Unloading Zone Management (for commercial truck driver to manage his delivery tasks)	V2I/V2N	
Data Calibration Between Vehicles and RSUs	V2I	
Electronic Vehicle Plate Identification	V2I	

B Functional Architecture

A vehicle is a powerful moving (mobile) device that will be equipped with various sensors (camera, radar, ultra-sound range finders, etc.) and will have adequate computational resources to support the wide range of services. Vehicles will be connected to the Internet and will communicate directly with each other and other road users (e.g., pedestrians, bicycles) to extend their perception beyond the capabilities and the range offered by their integrated sensors. The ability to exchange related information (e.g., cooperative awareness, road hazards, etc.) is expected to improve the decision making process for self-driving.

Table B.1: Autonomous driving levels and features

Levels	Features
Level 1: Driver Assistance “Hands On”	Cruise Control, Lane Departure Warning
Level 2: Hands OFF with Driver supervision	Partial Automated Driving: Automated parking, ACC, Lane Keeping System
Level 3: Temporarily Without supervision “Eyes Off”	Traffic Jam Chauffeur, Highway Chauffeur
Level 4: Without supervision “Mind OFF”	Traffic Jam Pilot, Highway Pilot
Level 5: Driverless	Valet Parking, Taxi Robot

The automated driving use cases require limited or no human intervention either at the monitoring phase or at the application of a decided driving behavior (e.g., maneuver). The involved vehicles trigger a specific use case for safety reasons (e.g., emergency maneuver) or for more efficient traffic management (e.g., platooning) using the monitoring data from the installed sensors, together with the information received from neighboring vehicles. Thereinafter, the autonomous vehicles undertake to coordinate and plan their maneuvers or trajectories in order to address the triggering event, based on the built environmental perception. With the increasing availability of vehicles that are capable of supporting higher automation levels, the need for coordination among vehicles and their capability to do so becomes increasingly more relevant. All automated vehicles rely on the premise that they continuously plan their trajectories and, based on the observed environment, select the driving trajectory.

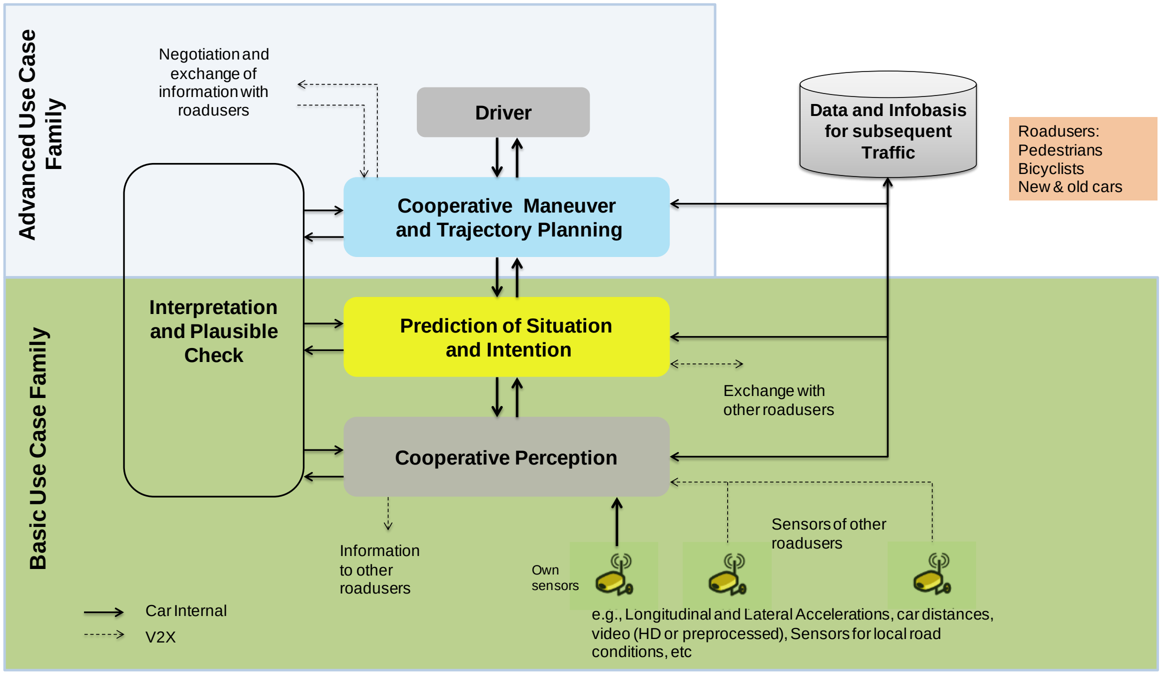

Figure B.1: Functional architecture

Figure **B.1** illustrates this functional architecture and information exchange between different functional entities. The basic use cases address assisted driving and advanced use cases represent the fully automated vision where the driver is not needed anymore.

C On-Board Sensors Performances

Table C.1: On-board sensors requirements

Requirement	Following area	Approaching area	Comments
Length (m)	-80 to +80	-80 to 300	
Width (m)	-10 to +10	-10 to +10	
Dist (m)	-80 to +80	-80 to 300	X position on longitudinal axis
Dist accuracy (m)	0.1*	0.5	Accuracy on X axis
Speed (m/s)	-55 to +55	-55 to +55	
Speed Accur. (m/s)	0.05*	0.3	* required for platoon
Dlat (m)	-10 to +10	-10 to +10 *	Y position from longitudinal path
Dlat accuracy (m)	0.1	0.5	Y accuracy
Vlat (m/s)	-25 to +25	-25 to +25*	* Tracking in intersection
Vlat accuracy	-0.1 to +0.1*	-0.3 to +0.3	* pedestrian crossing detection
Object size/type	Yes	-	
Object Z position	Yes	Yes	
Number of tracks	Yes	Yes	
Refresh cycle (ms)	10*	50	* Required for platoon
No detection rate	1%	10%	
Response (ms)	30*	100*	* New track

Existing Line of Sight sensors performances:

Table C.2: LOS sensors performances

Performance	LR radar	MR radar	SR radar	Lidar	Cameras
Max. Distance (m) Car	200 - 250	150 - 170	40 - 100	150	90 - 130
Max. Distance (m) Moto		105 -120	30 - 75	150	40 - 80
Max. Dist. (m) Pedestrian		40 - 70	17 - 40	50	25 - 40
Dist. Accur. (m) @ Dmax	0.1 - 1	0.1 – 0.5	0.1 – 0.2	0.1 – 0.5	9 – 12
Relative Speed range	-400 + 200	-400 + 200	-400 + 200		

Rel. Speed Accuracy (m/s)	0.04 – 0.3	0.03 – 0.3	0.03 – 0.3	0.1	1
Field of view (°)	15 – 30	20 – 60	70 – 120	145	40 – 55
Angular Resolution		3.3 – 18	5.7 – 25	0.25	0.05 – 0.8
Angular Accuracy	0.2 – 0.4	0.2 – 0.6	0.2 – 2.5	0.25 – 1	
Lat. Dist Accur. @ Dmax	1.0 – 2.0	0.6 – 1.8	0.3 – 3.5	0.65– 2.5	
Refresh cycle (ms)	40 – 120	40 – 120	30 – 100	40 – 80	30 – 40
Response time (ms)		40 – 360	40 – 360	40 – 400	30 – 500
Number of tracks	32 - 64	32 - 64	32 - 64	32 - 64	32

Sources: The OEMs in the project.