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BARCELONATECH
Escola Tècnica Superior d'Enginyeria
de Telecomunicació de Barcelona

5G NR in Advanced Driving

Design, Architecture and Techno-Economic Assessment of a V2X Communication Service

[Image Reference]

Authors: Helena Calatrava, Long Yee Esther Gottschalk, Cristina Insalaco and Helena Pujolar
Teacher/Consultant: Jordi Pérez-Romero
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Abstract

This project deals with the assessment of a V2X communication service. It gives a brief introduction of different use cases of the 5GCAR, 3GPP and 5GAA. The selected sub- use cases given by the 3GPP are Information Sharing for Partial/Conditional Automated Driving (PAD), Cooperative Collision Avoidance (CoCA) of connected automated vehicles, Cooperative Lane Change (CLC) of automated vehicles and Use of Multi-RAT Dual-Connectivity in the case of semi-automated driving (Levels 2 and 3 of automation).

The different scenarios of the sub-use cases are first described briefly. Afterwards, network requirements and KPIs like latency, reliability and data rate are given. Design aspects and relevant 5G technologies, like core network slicing, the use of sidelink and Mobile Edge Computing (MEC), are later considered in the implementation of the chosen use cases.

In total, two slices are used in this project. The first slice is responsible for all V2X communications and its respective sub-use cases. It regards the Vehicle to Pedestrian (V2P) information,Vehicle to Network (V2N), Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I) communication. In contrast, the second slice takes care of eMBB services for users in the vehicle. Relevant network functions for the slices are SMF, AUSF, PCF, UDM, NRF,UPF, NEF, NWDAF and AF. Also, NFV-MANO is used for network management and orchestration. The spectrum used is FR1 (410 MHz-7125 MHz). Furthermore, the general sidelink architecture describes the interaction between UE and AMF to gNB and UPF which is connected to the V2X Application Server. A QoS model where the same QoS flow ID in traffic corresponds to the same traffic forwarding treatment, is implemented.

Regarding the techno-economic aspects, the V2X market is estimated at $11,718.7 million by 2027 with a Compound Annual Growth Rate (CAGR) of 28.4% with Europe being the top contributor. New technologies from hardware and software companies are generating new revenues in the V2X market.

Executive Summary

This document is part of the ***Use Case Development*** project within the 5GMCS course of the MET and MATT Master Degrees (UPC, ETSETB). The authors of this document are Helena Calatrava, Long Yee Esther Gottschalk, Cristina Insalaco and Helena Pujolar. This document is to be delivered the 21st of December of 2021, which corresponds to the last lecture day of the 5GMCS course. For this project, we have selected a state-of-the art Use Case that makes use of the improvements that 5G has brought to Mobile Communications (MCs): **Advanced Driving V2X**. The aim of the project is to describe the motivation of this use case, while introducing design aspects to take into account when proposing a system architecture that can provide users with advanced driving V2X service. We propose an architecture design and finally, we provide the reader with a techno-economic assessment of the selected use case.

The document is divided into five chapters. The first chapter, **Chapter 1: Introduction**, consists in an introduction to the topic of Advanced Driving and Vehicle-to-X (V2X) communications. Also the innovation opportunities of applying 5G NR to this sector are discussed in this section. The state-of-the-art use cases proposed by the 5GCAR, 3GPP and 5GAA organizations are described. Finally, we provide a list with the three sub-use cases that we have selected for the project: **Information Sharing for Partial/Conditional Automated Driving (PAD)**, **Cooperative Collision Avoidance (CoCA) of connected automated vehicles** and **Cooperative Lane Change (CLC) of automated vehicles**. We also mention two use cases that are related to the use of Multi-RAT Dual-Connectivity (MR-DC), as we are including this radio technique in our architecture design. It is important to note that we have chosen these use cases from the 3GPP documentation **(3GPP TR 22.886)**.

In the **introductory chapter**, the information given with regard to the use cases is the motivation of their implementation and also a general description of their functioning. However, in **Chapter 2: Technical Requirements and Specifications**, we describe the technical requirements of each selected use case. These requirements are relevant and must be taken into account when thinking of the architecture design. This is why throughout the document we refer to information presented in this section several times. Furthermore, in chapter 2, we also list the technical requirements of the use cases proposed by the 5GCAR, 3GPP and 5GAA organizations.

In **Chapter 3: Design Aspects and 5G Technologies for Autonomous Driving**, we present the architecture design that we have thought of in order to provide the Advanced Driving V2X service to the users. Nevertheless, before going into detail, we list some factors that must be considered for the implementation of each of the selected use cases. When presenting the architecture, we first talk about the general architecture we thought of. In particular we put emphasis on components specifically designed to support V2X communications, like the **V2X Application Server**. Then we talk about the 5G Core Network. In this subsection, we mention the **Core Network Slicing** slices that we propose and also the use of **NFV-MANO**. Consequently, we also mention that we are proposing a **Software Defined Network** (architecture). When talking about the 5G Radio Access Network (5G RAN), the **RAN Slicing** slices are described, as well as the spectrum usage, the use of **Multi-RAT Dual-Connectivity (MR-DC)** and also the use of **Sidelink (SL)** communications. In the end, we made some considerations about the **Quality of Service (QoS)**, mentioning the most recent enhancements introduced to support V2X applications, like **QoS Sustainability Analytics**. Finally, we provide the reader with more figures that describe the architecture that we are proposing for this project.

Considering the structure of the document, we can state that the selected use cases are not described in a specific section. The motivation of each use case can be found in chapter 1, the technical requirements and specifications of each use case can be found in chapter 2 and finally the details about the implementation of each use case and their proposed architecture can be found in chapter 3.

Chapter 4: Techno-Economic Assessment is an analysis of the **situation of Advanced Driving V2X in the current market**. There are several places in the world where some test-beds have been deployed, such as in Europe, the United States and Asia (China). We have listed the strengths, weaknesses, opportunities and threats of Advanced Driving V2X technologies, completing a **SWOT analysis**. This analysis can help the reader understand which are the actual innovation opportunities and limitations of this technology. Finally, a comment on the **regulatory aspects** with regard to Advanced Driving V2X concludes the section. In this last subsection, we have tried to collect all the 3GPP standard documents that regulate the use of these use cases.

Finally, in the **Chapter 5: Conclusion** chapter, we reflect about what we have learned throughout this project while we highlight the most relevant points and architecture decisions that we have made. Besides, the next steps of the Advanced Driving V2X technology are posed. After this chapter, you can find the References section and also an ANNEX. In the ANNEX, we have included all the information that we found interesting but that finally was not part of the main core of our text.

Thank you for reading,

Helena Calatrava helena.nereida.calatrava@estudiantat.upc.edu

Long Yee Esther Gottschalk long.yee.esther.gottschalk@estudiantat.upc.edu

Cristina Insalaco cristina.insalaco@estudiantat.upc.edu

Helena Pujolar helena.pujolar@estudiantat.upc.edu

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Abbreviations

Note that some abbreviations have not been included in this list, such as the case of several NFs (the abbreviations are defined in the corresponding section, 3.3.2. Network Functions (NFs)).

3GPP - Third Generation Partnership Project

5GAA - 5G Automotive Association

5GC - 5G Core (Network)

5GCAR - Fifth Generation Communication Automotive Research and innovation

5G NR - Fifth Generation New Radio

ADAS - Advanced Driver Assistance System

BS - Base Station

CAM - Cooperative Awareness Messages

CoCA - Cooperative Collision Avoidance

CLC - Cooperative Lane Change

CN - Core Network

D2D - Device-to-device (communication)

DC - Dual-Connectivity

DENM - Decentralized Environmental Notification Messages

EPC - Evolved Packet Core

ITS - Intelligent Transportation System

KPI - Key Performance Indicator

LoA - Levels of Automation

LTE - Long Term Evolution (4G)

MANO - Management and Orchestration

MEC - Multi-access Edge Computing

MR - Multi-RAT

NF - Network Function

PAD - Partial Automated Driving

PPPP - Proximity Service Per-Packet Priority

PPPR - Proximity Service Per-Packet Reliability

RAN - Radio Access Network

RAT - Radio Access Technology

RSU - Roadside Unit

MANO - Management and Orchestration

NFV - Network Function Virtualization

NFVO - Network Function Virtualization Orchestrator

NWDAF - Network Data Analytics Function

PFI - PC5 QoS Flow ID

PSBCH - Physical Sidelink Broadcast Channel

PSCCH - Physical Sidelink Control Channel

PSFCH - Physical Sidelink Feedback Channel

PSSCH - Physical Sidelink Shared Channel

QoS - Quality of Service

SCI - Sidelink Control Information

SCS - Subcarrier Spacing

SDN - Software-defined Network

SDAP - Service Data Adaptation Protocol

SL - SideLink

SSSB - Sidelink Synchronization Signal Block

UPF - User Plane Function

V2X - Vehicle-to-Everything

VIM - Virtualized Infrastructure Manager

VNF - Virtualized Network Function

VNFM - Virtualized Network Function Manager

1. Introduction

In this section, we are giving insight into the Advanced Driving V2X communications topic. First, the topic is introduced by referencing some papers that contain very useful information and that have been key for us to start getting to know about the V2X. After this, the different Levels of Automation (LoA) are stated so that we can clarify which is the LoA that we are targeting in this project. Then, we link the reader to the document sections that include some information regarding the Innovation Opportunities that arise with the use of Advanced Driving V2X. After this, we describe the state-of-the-art use cases defined by the 5GCAR, 3GPP and 5GAA organizations. Finally, we mention which are the use cases that we have selected for our project, which have been defined by the 3GPP standard, more specifically in the TR 22.886 document.

1.1. State of the art

1.1.1. Introduction to Advanced Driving and V2X

One connected vehicle services segment that has received major public attention in recent years is called Advanced Driver Assistance System (ADAS). ADAS can also be seen as a stepping stone towards full Autonomous Driving (AD). Connectivity is commonly regarded as a complement to increasingly advanced on-board sensors (RADARs, LIDARs, cameras, etc.), by delivering real-time, reliable information between vehicles and their cloud-based service providers, which in turn gather data from other vehicles and road infrastructure [1].

Vehicle-to-Everything (V2X) communications have drawn great attention in both industrial and academic fields for more than ten years. The three different types of V2X communications that are defined by the 3GPP standard can be found in the following figure [2]. They are V2V (Vehicle-to-Vehicle), V2P (Vehicle-to-Person), V2I (Vehicle-to-Infrastructure) and V2N(Vehicle-to-Network).

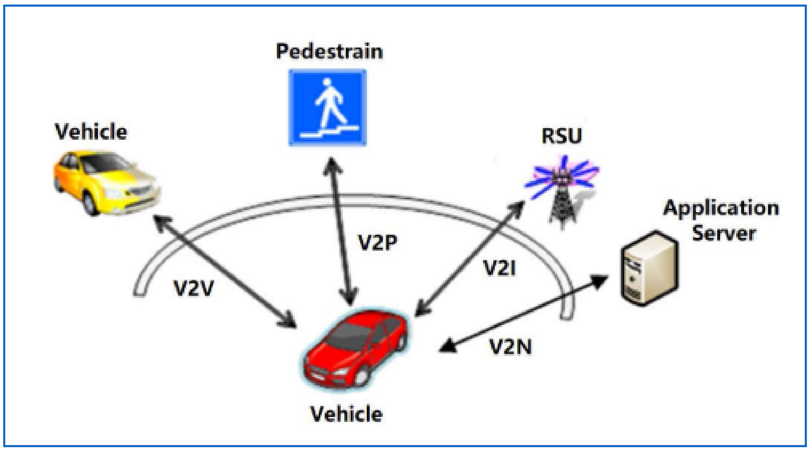

Figure 1.1. Types of V2X applications defined in 3GPP [2].

According to the J3016 standard published by the SAE organization in 2014, the levels of autonomous driving are five. They go from level 1 (Driver Assistance) to level 5 (Full Automation). So far, autonomous vehicles up to level 4 have been developed. However, they are currently not used as people please, as this is limited by regulatory aspects. If the reader wants to get more insight into regulatory aspects regarding V2X, they can go to Section 4.5. Regulations.

The combination of V2X and autonomous driving enables the creation of cooperative autonomous driving which has two key cooperative features: sensing and maneuvering. The integration of onboard sensors and V2X communication could also result in a solution that is more cost-effective than an approach based on high-quality sensors only. To achieve this target, cooperative autonomous driving needs to impose strict requirements (see Section 2. Technical Requirements and Specifications for more information about the use case requirements and specifications).

1.1.1.1. Levels of Automation (LoA)

The Level of Automation (LoA) is an indicator that has been standardized by SAE International and it is a measure of requirements and functional aspects in automation systems. The LoAs which have been defined are 6. They are described in the following bullet list.

- **Level 0: no automation**. The driving systems needs a human driver to monitor all driving environments and driving by themselves, even though assistance is available from warning and intervention systems
- **Level 1**: **driver assistance**. The driver system will provide either steering or acceleration/deceleration assistance based on the current driving environment. All remaining aspects of driving are expected to be controlled by the driver.
- **Level 2**: **partial automation**. The driving system will supply both steering and acceleration/deceleration assistance based on the current driving environment. All remaining aspects of driving are expected to be performed by the drivers themselves.
- **Level 3**: **conditional automation**. The driving system can intervene in all kinds of dynamic driving tasks based on the current driving environment, while drivers will respond appropriately to a request to intervene.
- **Level 4**: **high automation**. The driving system can intervene in all kinds of dynamic driving tasks based on the current driving environment, whether or not drivers will respond appropriately to a request to intervene.
- **Level 5**: **full automation**. The driving system can execute all dynamic driving tasks all the time under all roadway and environmental conditions that can be managed by a human driver.

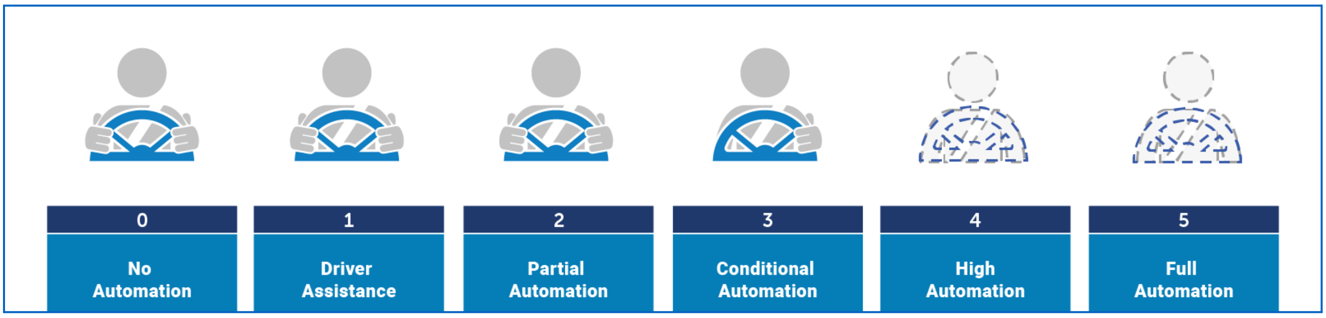

Figure 1.2. Different Levels of Automation (LoA), according to [3].

The selected use cases for this project, which we will explain in detail later, refer to the LoAs 2 and 3. Thus, we are still under the conditions in which it is required that the human driver takes full control of the vehicle, as we are not talking about high/full automation levels. This would be the case of LoAs 4 and 5.

1.1.2. Innovation Opportunities of applying 5G in this sector

This subsection has been developed as part of Section 4.6 Current State. Also, some aspects related to the innovation opportunities of the 5G sector are referenced in Section 5. Conclusion. If the reader wants to get some insight into this topic, they should refer to those sections.

1.1.3. State of the art Use Cases

Several institutions, such as 3GPP, ETSI, ITS, IEEE and 5GAA are working on the definition, requirements and specifications of Advanced Driving systems. In order to define these future systems, they list several usage scenarios. We will be referring to these usage scenarios as *use cases* throughout this document. In this subsection, the use cases proposed by the 5GCAR and 3GPP organizations are described. Also, we mention the New 2030 Roadmap published by 5GAA. However, the specification and requirements of these specific use cases are introduced in Section 2. Technical Requirements and Specifications.

1.1.3.1. 5GCAR

The **5G Communication Automotive Research and innovation (5GCAR)** project created a consortium of partners from the automotive and mobile communications industry and academia to conduct research to a safer and more efficient future driving. The different functionalities under study are described in the following bullet list.

- **Cooperative maneuvers.** Sharing information among the nearby vehicles or roadside infrastructures via wireless communications about driving intentions and negotiating and planning the best trajectory.
- **Cooperative perception/ sensors.** Merging data from local vehicle sensors with remote information from other vehicles or cameras and map sharing to increase the field of view of the driver.
- **Cooperative safety.** Exchange of information between vehicles and pedestrians, cyclists etc. with the intention to reduce accidents and prevent risky situations.
- **Intelligent autonomous navigation.** Communication of real-time high definition maps for optimal route selection by aggregation information from vehicle sensors, localized high definition maps and accurate real-time localization of vehicles.
- **Remote driving.** Controlling the mechanical parts of the car (steering wheel, brake, throttle) from outside the vehicle through wireless communication. It is the most demanding application as it requires high reliability, low latency and network infrastructure.

The different use cases analyzed by this consortium are described in the following enumerated list, according to source [4].

1) **Lane merge:** from cooperative maneuvers. Represents the situation where vehicles must adapt their trajectory when a car wants to join a main lane already occupied by others.

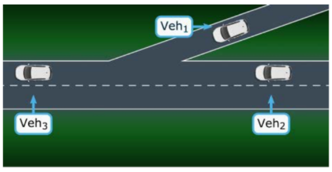

Figure 1.3. Lane merge use case illustration, according to [4]

2) **See-Through:** from cooperative perception. The scene of the front vehicle is captured with a camera and transmitted to the rear vehicle to give to the driver a more extended field of view of the road current situation.

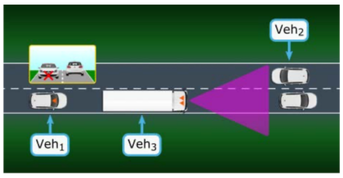

Figure 1.4. See-Through use case illustration, according to [4]

3) **Network- Assisted Vulnerable Road User (VRU) Protection from cooperative safety:** With geolocalization and wireless communications, the system can warn the driver of the pedestrian presence on the road (the pedestrian may be out of the field of view of the driver) and prevent a collision.

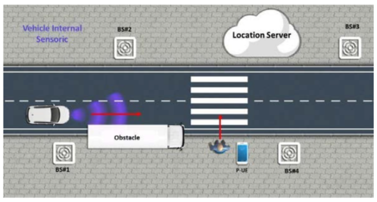

Figure 1.5. Network- Assisted Vulnerable Road User (VRU) Protection from cooperative safety use case illustration, according to [4]

4) **High Definition (HD) Local Map Acquisition from intelligent autonomous navigation:** The goal is to assist drivers with a high definition, real-time and precise local dynamic map that is updated on the move for proper route selection.

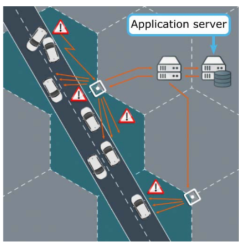

Figure 1.6. High Definition (HD) Local Map Acquisition from intelligent autonomous navigation use case illustration, according to [4]

5) **Remote Driving for Automated Parking:** The objective is to remotely park the car in the correct spot without human intervention and making use of the remote cloud server indications and maneuver instructions for efficient and safe parking.

Figure 1.7. Remote Driving for Automated Parking use case illustration, according to [4]

1.1.3.2. 3GPP

Moving on to 3GPP, the reported use cases are different from the ones specified in the 5GCAR subsection. They are briefly explained in the next lines [5]. All the information we have obtained regarding the 3GPP Use Cases has been found in the 3GPP TR 22.886, which provides the technical specifications on the support for 5G V2X Services.

- **Vehicle Platooning:** set of vehicles travelling together that exchange periodic data to move in a cooperative way. It optimizes transport by using roads more effectively, reducing traffic jams and in case of trucks, delivering goods faster.
- **Extended Sensors:** the goal is to properly process the data coming from sensors over vehicles or road side units (RSU) as well as cameras, lidars etc. to provide a better perception of the scenario to the driver.
- **Remote Driving:** the intention is that a remote operator takes control of the vehicle in specific situations such as in a complex environment or in case of breakdown.
- **Advanced Driving:** which requires sharing the driving intentions with the vehicles in proximity for complex manoeuvres or collision avoidance.

We consider it relevant to highlight that the use case that has been selected for the project (**Advanced Driving**) is within the just mentioned use cases. However, we want to comment that within each of these use cases, there are several (sub-)use cases that appear in the **3GPP TR 22.886** document. Consequently, we have selected Advanced Driving as a general use case and three of its (sub-)use cases as the specific use cases to assess for our system. The selected (sub-)use cases are **Information Sharing for Partial/Conditional Automated Driving (PAD)**, **Cooperative Collision Avoidance (CoCA) of connected automated vehicles** and **Cooperative Lane Change (CLC) of automated vehicles**. In the following sections, we refer to these (sub-)use cases as use cases.

1.1.3.3. 5GAA

5GAA has released a New 2030 Roadmap with the expected timelines for the deployment of the connectivity technologies of advanced driving use cases. The roadmap can be found in the following figure. As part of this project, they are considering the use of extended sensors. This is something that we have not focused on as part of this project.

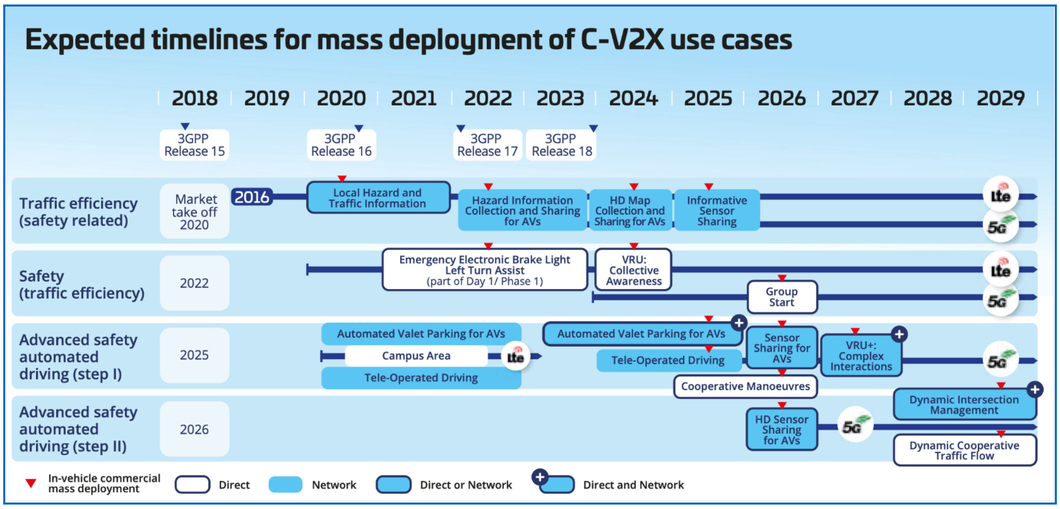

Figure 1.8. 5GAA C-V2X Use Cases Roadmap [6].

1.2. Selected (Sub-)Use Cases (3GPP TR 22.886)

As it has been previously mentioned, we have selected **Advanced Driving** as a general use case and three of its (sub-)use cases as the final use cases to assess for our system. The selected (sub-)use cases are **Information Sharing for Partial/Conditional Automated Driving (PAD)**, **Cooperative Collision Avoidance (CoCA) of connected automated vehicles** and **Cooperative Lane Change (CLC) of automated vehicles**. In the following sections, we refer to these (sub-)use cases as use cases. The aim of this subsection is to describe these use cases which have been defined by 3GPP (TR 22.886).

The advanced driving use case involves the participation of different vehicles and infrastructures in order to cooperate and provide information for planning and operating a complex manoeuvre. The technologies that are used in this scenario are the following. After the bullet list, these technologies are introduced to the reader. Before going into the description of each use case, we state which are the technologies that are considered for our architecture design.

- Dual-connectivity
- 5G NR Sidelink
- Reliable Time Synchronization
- Advanced Roaming Techniques
- Accurate Positioning
- Network Slicing

With the use of **dual-connectivity (DC)**, each participant may use a different communication technology. Thus, the interoperability provided by multi-modal/multi-radio technologies of 5G is critical to allow the information exchange from all the surrounding actors. With DC, an user equipment can be connected to more than one Base Station (BS). Also, this is done not only to use two different technologies (LTE and 5G), but also to increase the throughput, as the original goal of dual-connectivity was to connect an LTE device to two BSs so that it was possible to receive information from two base stations.

Enhanced **Sidelink (SL)** offers the possibility of short range connectivity of vehicles with the road infrastructure, pedestrians and other vehicles in traffic without the need of a base station [1]. This leads to several advantages as higher throughput, lower latency, increased reliability and positioning.

Regarding **Reliable Time Synchronization**, as the manoeuvre requires a synchronised response and coordination from vehicles, the network needs to deal with the timely delivery of messages to foster a solid and consistent knowledge at once. Here, the generalized Precision Time Protocol (gPTP) provides reliable time synchronisation as declared in 3GPP TS 23.501.

Advanced Roaming Techniques are important to minimise communication interruptions and outages while some participants are migrating towards other cells (handover) or other networks (roaming) with low-latency migrations between the network infrastructures. From the latency perspective, advanced roaming techniques boost the migration of sessions along vehicles, and sidelink communications simplify the protocol to exchange coordination messages to create more direct and quick communication among the surrounding participants. However, we are not considering the concept of *roaming* for this project. The only migration taken into account for our system would be towards other cells. As it has just been mentioned, this would correspond with a handover operation.

Positioning accuracy can be especially crucial in autonomous driving. Driving in dense urban spaces would be more convenient with cm-precision positioning. MmWave technology can be exploited exhaustively for this purpose. However, we have decided to use spectrum located in the FR1 range, because 3GPP defines the spectrum region for V2X communications in the 5.9 GHz band (5850-5925 MHz), which is globally harmonised for ITS by the ITU-R [7].

Finally, the use of **Network Slicing** gives a lot of flexibility to the network as we are able to assign resources in different ways to different services. This is one of the 5G features that allows flexibility when designing an architecture. More insight into Network Slicing is given in the following sections.

The technologies that we have decided to take into consideration for our architecture design are **Multi-RAT Dual-Connectivity (MR-DC)**, **5G NR Sidelink** and **Network Slicing**. In the following sections, the reasons why we have decided to implement these technologies are described in detail.

In Section 3. Design Aspects and 5G technologies for Autonomous Driving, we describe the design aspects that we have considered when proposing a final architecture scheme. In that section, we go one by one the previous technologies, justifying the reason why we want to use them for our proposed system design or not. However, we do not mention again Reliable Time Synchronization, Advanced Roaming Techniques and Accurate Positioning, as we do not consider them relevant for the project scope.

1.2.1. Use Case 5.10: Information Sharing for Partial/Conditional Automated Driving (PAD)

One of the topics that is gaining momentum among the advanced driving applications is the automated driving. Vehicles communicate one to each other and exchange information to make autonomous decisions. Moving towards this concept of automated driving is part of a stepwise process that still nowadays comes with several limitations, in particular before the implementation of

5G NR and more advanced technologies. Indeed, it is fundamental that this exchange of information is reliable, and low in terms of latency.

Moreover, the exchanged messages are size varying and changing in periodicity, thus we are facing a diversified environment that requires specific guidelines to be implemented. Concerning the information that are shared between vehicles, there are included both data obtained from local sensors and driving intentions. Hence, the 3GPP discriminates between the following two families of information.

- **Cooperative perception**: sharing local perception data using V2X communication to expand detectable range of on-board sensor capability. Each vehicle and/or RSU shares its own perception data obtained from its local sensors (e.g. camera, LIDAR, radar, etc) with vehicles in proximity.
- **Cooperative manoeuvre**: sharing driving intention information using V2X communication for cooperative manoeuvre. Each vehicle shares its driving intention with vehicles in proximity.

Additionally, the 3GPP clearly discriminates between *partial automated driving* and *fully automated driving*, associated them with different LoAs and thus with a different set of requirements to be fulfilled. The selected use case refers to the LoA 2 and 3.

1.2.2. Use Case 5.9: Cooperative Collision Avoidance (CoCA) of connected automated vehicles

Collision Avoidance among vehicles, is an issue that has been worried experts during the last years. Evaluating the probability of an accident and to coordinate maneuvers, data from sensors, list of actions like braking and accelerating commands, lateral and longitudinal control are exchanged amongst vehicles to coordinate in the application the road traffic flow through 3GPP V2X communication. [8]

There are a number of reasons from which a collision between two vehicles or with pedestrians can occur. A distracted driver not seeing the incoming vehicle, underestimating the vehicle speed and violating traffic signals like stop signs or traffic lights are examples of that. The purpose of this use case is to design a system capable of preventing collisions by applying automatic control to vehicles in case of necessity. [9]

Vulnerable road users are the category likely to suffer the worst outcome in case of road accident, so it is of paramount importance for vehicles to be able to detect them, even when their location is out of the reach of the onboard sensors. Apart from preventing vehicle to vehicle accidents, this use case also pretends to improve the safety of pedestrians and cyclists, through improvements in localization, movement prediction and collision detection enabled by the network infrastructure.

Thanks to the exchange of information between users via wireless communications, the overall system will determine the VRU position based on cellular radio signals, GNSS, or sensor/camera data. All of this location information will be processed from multiple users to generate alerts to vehicle drivers or automated vehicles with highly accurate positioning. The network infrastructure provides both the position of the pedestrian and a collision warning to the vehicle to avoid the collision.

The implementation of this use case in 5G does not start from scratch. Indeed, avoiding collisions and the transfer of safety messages were already taken into account with 4G technology with the introduction of Cooperative Awareness Messages (CAM) and DENM (Decentralized Environmental Notification Messages) between vehicles.

CAMs are a kind of heartbeat messages periodically broadcasted by each vehicle to its neighbors to provide information of presence, position, temperature, and basic status. On the contrary, DENMs are event-triggered messages broadcasted to alert road users of a hazardous event. Both CAM and DENM messages are delivered to vehicles in a particular geographic region: to the immediate neighborhood in case of CAMs (single hop), and to the area affected by the event for DENMs (multi-hop). [14]

For the developing of Collision Avoidance use case, it is assumed that:

- Vehicles support message exchange via 3GPP V2X communications.
- They have the V2X safety application (CAM and DENM), so they already know their relative positions.

Combining both aspects and with the appropriate technology, vehicles in 5G should be able to operate Cooperative Collision Avoidance.

1.2.3. Use Case 5.23: Cooperative Lane Change (CLC) of automated vehicles

Lane changes have been prone to accidents and traffic for many years. Therefore, in traffic with multi-lane roads, the initiation of a lange change that is efficient and safe is fundamental. Hence, in this scope an exchange of the trajectory plans between vehicles is required. The 3GPP TR 22.886 specifies a Cooperative Lane Change (CLC) V2X scenario in which vehicles guarantee a smooth maneuver of the following two controls.

- **Lateral control (Steering)**
- **Longitudinal control (Acceleration / Deceleration)** .

Steering and required acceleration / deceleration with the help of safety distances and other parameters can be accurately calculated due to recent research [18].

Depending on the considered time frame, the CLC use case can be applicable to semi-automated or fully automated driving. As we are assuming partial / conditional automated driving (level 2 / 3 of automation), we are hereby selecting the semi-automated driving case [15].

1.2.4. Use Cases 5.7 and 5.17: Use of Multi-RAT Dual-Connectivity

Use cases 5.7 and 5.15 are related to the use of Multi-RAT in 5G NR. Multi-RAT networks combine several Radio Access Technologies (RATs) with the aim of delivering the best possible service to users. Depending on the Original Equipment Manufacturer (OEM), vehicles can be equipped with modules supporting only LTE or with modules supporting both LTE and 5G NR. According to section 5.7.1 of the 3GPP TR 22.886 document, there are three possible scenarios that depend on the type of coverage. These three scenarios are described in the following bullet list.

- **No Coverage**: neither E-UTRAN nor NR access network is found. Because there is no network support for the communication among vehicles, direct Prose communication based on LTE and/or NR is the only option available for the communication between the vehicles.
- **LTE only coverage**: Because there is no NR-based Access Network, NR-based vehicle is not provided with any network support and the only choice for the NR-based vehicle is to use Prose direct communication. On the other hand, within LTE coverage, LTE-based vehicle can be controlled by the network, i.e. whether to use LTE- based direct communication or not. Based
- **LTE/NR coverage**: Because both LTE-based vehicle and NR-based vehicle are within coverage of networks, communication between the vehicles are possible indirectly via the network, regardless of whether the vehicles can use direct Prose communication or not, or whether they use the same radio access technology or not.

For this project, we are **assuming that LTE+NR coverage is provided to the users in the whole area**. Also, it is assumed that **all vehicles contain modules that support 5G NR**.

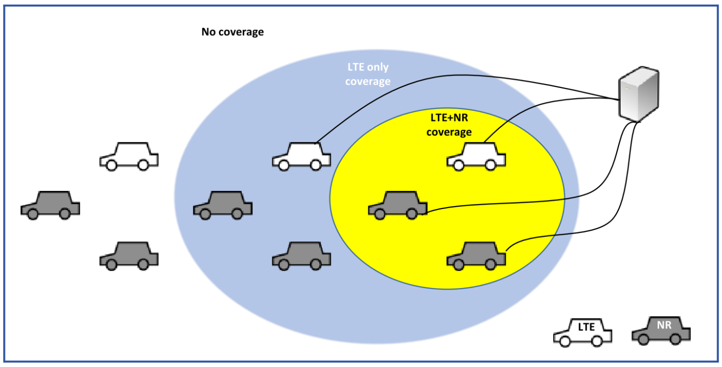

Fig 1.9. Example scenario of mixed 3GPP RATs deployment, according to **3GPP TR 22.886**.

2. Technical Requirements and Specifications

The technical requirements and specifications of the proposed system are included in this section. The improvements of advanced driver assistance systems (ADAS) as well as the introduction of remote driving applications to enhance comfort and convenience, have increased the necessity of developing V2X communications with stringent requirements on communication performance in terms of latency, high reliability connectivity with safety-critical nature.

2.1. Network Requirements and KPIs

Institutions like 3GPP, ETSI, ITS and 5GAA are working, among other aspects, on defining the specifications and requirements of these network applications to develop end-to-end solutions for future mobility and transportation services.

2.1.1. 5GCAR

The network requirements that need to be specified to guarantee the communication established by 5GCAR [13] are:

- **Maximum service data unit (SDU) size:** maximum size of payload required by a specific service.
- **Latency:** time from the SDU is requested to be transmitted by an end-node application until it is made available to the other end-node application.
- **Reliability:** probability that the SDU is correctly received within a specified maximum latency.
- **Availability:** probability that the requested service is declared as available (at the time when the service is requested by the application, the communication system can declare it available or not).
- **Data rate:** number of bits sent per unit of time.
- **Communication range:** maximum distance between a transmitter and the receiver that the communication can be established under some constraints (latency, data rate…).

Apart from network requirements, the automotive sector has also defined some requirements and KPI (Key Performance Indicators):

- **Completion time:** The total time it takes from when the maneuver is initiated until it has been completed.
- **Localization accuracy:** needed geographical accuracy.
- **Inter-vehicular time:** recommended/required distance between two vehicles.
- **Mobility:** velocity at which an object is moving with respect to a reference object or point.
- **Relevance area:** area where the messages have to be distributed to guarantee the automotive service.

Both automotive and network requirements need to be taken into account when defining the technical requirements of the different use cases. Before analyzing the specifications and requirements of 3GPP, this work will focus on the less restrictive requirements established by 5GCAR use cases.

Table 2. Network requirements for the 5GCAR use cases.

Requirement \ Use Case	Lane Merge	See Through	Network Assisted Vulnerable Pedestrian Protection	High Definition Local Map Acquisition	Remote Driving for Automated Parking
Communication Range	>350 m	<100 m	>70m	>1 km	several kms
Latency	<30 ms	50 ms	<60 ms	<30 ms	5 to 30 ms
Reliability	99.9% (high)	99% (medium)	99% to 99.99%	99.9% (high)	99.999%
SDU Size	12,00–16,000 bytes per message	41,700 bytes per frame	1600 bytes per message	Up to 60 bytes	UL: 41,700 bytes DL: 16,000 bytes
Data Rate	1.28 Mbps	from 14 to 29 Mbps	128 kbps	DL: 960 kbps + 1920 kbps	from 6.4 to 29 Mbps
Availability	99% (medium)	99% (medium)	99.9% (high)	99% (medium)	99.999% (ultra-high)

Table 2.1. Network requirements for the 5GCAR use cases, according to [10].

From the previous table it can be observed that See Through use case reports the most critical communication range but the most permissible in terms of payload length. The situation which permits the lowest data rate is the Network Assisted Vulnerable Pedestrian Protection. Remote driving requires the highest availability of network connectivity and the most restrictive in terms of latency.

2.1.2. 3GPP

The requirements defined by 3GPP are mainly focused at the communication layer and based on the four use cases recently explained (see the following table).

Use Case Group	Payload (Bytes)	Latency (ms)	Reliability (%)	Data Rate (Mbps)
Vehicle Platooning	50–6500	10–20	90–99.99	0.012–65
Advanced Driving	300–12000	3–100	90–99.999	0.096–53
Extended Sensors	1600	3–100	90–99.999	10–1000
Remote Driving	-	5	99.999	UL: 25 DL: 1

Table 2.2. Summary of V2X Performance Requirements in 3GPP TS 22.186, according to [10].

From the previous table it can be stressed out that remote driving is the application which requires the highest reliability and a non-flexible latency and data rate due to its critical nature. Moreover, the extended sensor use case requires the largest data rate, as real-time video streams must be processed. Advanced driving and vehicle platooning are the ones which permit larger payload lengths. More details regarding the technical requirements of the selected 3GPP use cases are given in the next section, Section 2.2. Requirements of the Selected Use Cases.

2.1.3. 5GAA

The 5G Automotive Association (5GAA) defined some requirements to be fulfilled with the implementation of autonomous driving [11]. The lateral position accuracy should be around 0.1m and the guaranteed longitudinal accuracy near 0.5m.

From now until 2024, it is expected that the digital road infrastructure will promise real-time or dynamic traffic updates, hazard warning and high definition mapping services. Towards 2026, advanced vehicle-to-vehicle (V2V) cooperation will enhance automated driving developments such as sharing sensor data and cooperative manoeuvring. To make these expectations feasible, 5GAA recommends both national and regional administrations to guarantee sufficient radio spectrum available for communication networks in the 5855-5925 MHz band between users and roadside infrastructure [11].

2.2. Requirements of the Selected Use Cases

2.1.1. PAD

According to the 3GPP technical specifications report [8], it is required that vehicles share detected objects among vehicles in the same area and coarse driving intention (e.g. changing lanes or moving/stopping/parking in T seconds in a specific position) for changing lanes at highway and roundabout, crossing at 4-way stop and have consensus among all involved vehicles via V2X.

KPIs of Importance

The Key Performance Indicators (KPIs) defined in the 3GPP technical specifications report to support this use case are listed below.

- Data rate of 0.5 Mbps per link for cooperative perception and data rate of 0.05 Mbps per link for cooperative manoeuvre. These numbers derive from the assumption that vehicles and RSUs generate new messages every 100 ms
- End-to-end latency up to 10 ms
- Reliability
- Communication range greater than 10 seconds * (maximum relative speed [m/s])
  The maximum relative speed depends on the mobility scenario. In case of inter-UEs exchange, these values apply:
  - Urban: 0-100 km/h
  - Sub-urban: 0-200 km/h
  - Autobahn: 0-250 km/h

  In case of UE-RSU communication:
  - Urban: 0-50 km/h
  - Sub-urban: 0-100 km/h
  - Autobahn: 0-250 km/h
- High density of connection devices

Potential Requirements

In the following table, the potential requirements of the PAD use case according to [8] can be found.

	Data Rate [Mbps]	Payload [bytes]	Message Frequency [message/sec]	Max end-to-end latency [ms]	Reliability [%]	Communication Range
UE-UE Interaction	0.55	6500	10	10	99,99	[10]sec*maximum relative speed [m/s]
UE-RSU Interaction	0.5	6000	10	10	99.99	[10]sec*maximum relative speed [m/s]

Table 2.3. Potential Requirements of the PAD use case, according to [8].

2.1.2. CoCA

KPIs of Importance

The Key Performance Indicators (KPIs) for this use case, defined by the technical specifications report of 3GPP are the following.

- Throughput of 10 Mbps to exchange CoCA application messages between UEs in proximity to perform coordinated driving maneuvers at intersections.
- Message size up to 2 kByte depending on the number of involved vehicles, to exchange pre-planned trajectories between vehicles.
- Less than 10 ms latency for regular manoeuvre coordination within the CoCA application time limit.
- 99.99 % reliability for safety coordinated driving manoeuvre.

Potential Requirements

The requirements for this use case are presented in the table below and have been extracted directly from 3GPP specifications [8].

Communication scenario			Payload (Bytes)	Tx rate (Message/ Sec)	Max end-to-end latency (ms)	Reliabi-lity (%)	Data rate (Mbps)	Commu-nication range (meters)
Section #	Description	CPR #						
5.9	Between UEs supporting V2X applications Fully automated driving	[CPR.A-001]	[2000]		[10]	[99.99]	[10]	

Table 2.4. Potential Requirements for CoCa use case, extracted from [8].

- The 3GPP network shall enable communication between UEs to support message exchange with [10] Mbps data throughput with less than [10] ms latency.
- The 3GPP network shall enable UE's message exchange with [99.99] % reliability and message sizes in range up to [2] kByte.

2.1.3. CLC

KPIs of Importance

Due to the 3GPP document the main KPIs for semi-automated driving are the following [15]:

- Small Message Size of 300-400 Bytes
- For exchanging CLC packets between vehicles an end-to-end latency of less than 25 ms is required
- To receive the update trajectory plan for the lane change, a reliability of 90 % needs to be fulfilled.

Potential Requirements

The 3GPP specifies for the CLC potential requirements as seen in the table below.

	Payload [bytes]	Max end-to-end latency [ms]	Reliability [%]
UE-UE Interaction supporting V2X: Limited automated driving	300-400	25	90
UE-UE Interaction supporting V2X: Fully automated driving	12000	10	99.99

Table 2.5. Potential Requirements of the CLC use case, according to [8].

In this table the specifications for the fully automated case can also be seen which are of course stricter. The 3GPP does not specify further variables than the ones discussed in the KPIs.

To gain a broader understanding however, we could compare the values with Table 2.1 which show the network requirements of the 5GCAR use cases. In terms of payload, latency and reliability the values seem to be similar, yet for the fully automated case. Owing to this, it can be derived that the communication range might not exceed 350 m. Furthermore, the data rate would be slower than 1.28 Mbps and availability less than 99%.

2.1.4. eMBB Services

This eMBB traffic can be considered as an extension of the 4G broadband service. Its main characteristics are the larger payload and a device activation pattern that remains stable over an extended time interval. This allows the network to schedule wireless resources to the eMBB services such that no two eMBB devices access the same resource simultaneously. The main objective of this slice is to maximize the data rate with a moderate reliability [12].

As we have also added a slice with eMBB services, we are commenting on the requirements linked to this kind of service in this section. However, we consider that our target of study is not the slice of eMBB service, but the one linked to Advanced Driving V2X communications. Services within the eMBB category have the following characteristics/technical requirements.

- Peak data rate: 10 to 20 Gbps
- 1000 Mbps whenever needed.
- 10000 times more traffic
- Supports macro and small cells.
- Supports high mobility of about 500 Kmph.
- It helps in network energy savings by 100 times.

It is important to note that this service is not the target of our project and that, consequently, these technical requirements are just orientative values [other references - 10].

3. Design Aspects and 5G technologies for Autonomous Driving

In this section, we are going to describe in detail the aspects that have been taken into account when designing the proposed architecture. Also, the proposed architecture is described with several figures throughout the section.

First, some aspects to take into account with regard to the implementation of each use case are stated. This is done by assessing the technical requirements listed in the previous section. Architectural decisions are made depending on the service requirements and on the technologies that we are willing to support to provide the users with our service. The objective of **Section 3.1.** is therefore to state some basic architectural decisions such as whether the use of the Sidelink and of Multi-Edge Computing (MEC) can be of interest for the different use cases.

In Section 3.2., we talk about the 5G Core Network. In this subsection, we mention the Core Network slices that we propose and also the use of NFV-MANO. We also describe the reason why we are not using an SDN architecture. The V2X Application Server is also mentioned, as it is an important part of the V2X architecture. When talking about the 5G Radio Access Network (5G RAN), in Section 3.3., the RAN slices are described, as well as the spectrum usage, the use of Multi-RAT Dual-Connectivity (MR-DC) and also the use of Sidelink (SL) communications. Finally, in Section 3.4., a final table with a summary of the general system characteristics is provided.

3.1. Details on the implementation of each Use Case

3.1.1. PAD

In the 3GPP technical report, it is expected that vehicles and RSUs support V2X communication with vehicles and RSUs which are in communication range. It is assumed that the vehicles are travelling in proximity and that the inter-vehicle distance is not short, i.e. greater than 2sec*vehicle speed.

Vehicles retrieve information from their local sensors and they share their detected objects and/or coarse driving intention with other vehicles in range. RSUs, instead, share their detected objects with vehicles in range. Each vehicle utilizes the received information of detected objects and/or coarse driving intention of other vehicles as predictive information for its driving.

3.1.2. CoCA

According to the 3GPP use case definitions of CoCA, the transmission flow of information can be divided in the following 3 points:

1) Vehicle A detects risk of collision
2) V2X application of vehicle A exchanges information with CoCA Application messages (trajectories, sensor data, brake commands…) via 3GPP V2X communications service.
3) Another vehicle confirms on application layer to vehicle A the coordinated maneuver for CoCA by transmitting messages via 3GPP communication service.

After the completion of the service, the vehicles have performed coordinated maneuvers and luckily, they will have avoided collision.

For this special use case, the main role of the network is to identify which vehicles need to perform the proposed maneuver and send it to vehicle A. For instance, by identifying the active vehicles in the cell. Vehicle A will detect the risk of collision by its proper information and the road status reported by the network and will ask the network which vehicles need to perform the maneuver. Then he will send a message to the involved vehicles using sidelink, and the other vehicles will have to confirm the coordinated maneuver to vehicle A.

Consequently, for this particular use case, network information is only used for vehicle A to detect the risk of collision and to provide the list of vehicles that have to do the maneuver. CoCa messages are exchanged by sidelink by V2X Applications and therefore provide low latency communications.

3.1.3. CLC

Before mentioning the design aspects of CLC, the service flow by the 3GPP will first be explained for broader understanding.

- By observing the following image, vehicle **Veh1** wants to merge/change the lane and requests a gap creation to the adjacent vehicles **Veh2** and **Veh3**.
- These are then confirming the participation of the manoeuver.
- **Veh2** and **Veh3** create a gap.
- **Veh1** will move to the designated lane and periodically transmits the trajectory plan to other vehicles with the 3GPP communication service.
- The trajectory plan is updated based on the maneuver and location of **Veh2** and **Veh3**.

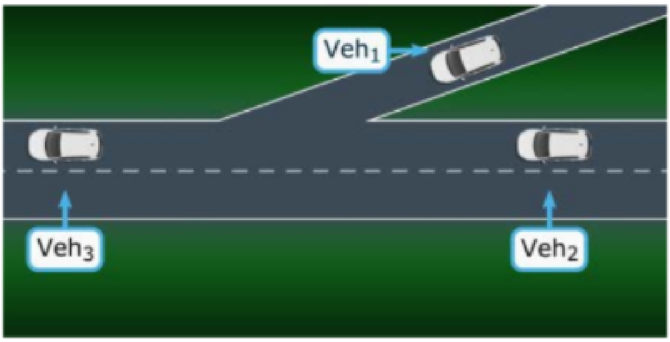

Figure 3.1. Cooperative Line Change use case illustration, according to [13]

The 3GPP released already in C-V2X Rel 14/15 and NR C-V2X (see figure below) that sidelink makes use of Blind Spot Warning/Lane Change Warning (BSW/LCW).

Moreover, the usage of MEC has been discussed in research. Connected vehicles are broadcasting beacon messages with the position, direction, speed and other data (CAM). Warning messages when a vehicle is near a dangerous position are transmitted via DENM [15]. Not all users on the road are accessing the network. That is why camera systems can help identify the location of connected and non-connected vehicles.

Figure 3.2. NR C-V2X, advertisement image provided by [14].

3.1.4. To be considered in the Architecture Design

A conclusion on whether the sub-use cases are making use of the sidelink and network information can be read from the following table. Also, it is specified whether they need to provide low latency services (URLLC). This table has been filled in by means of the conclusions stated in the previous sections 3.1.1. PAD, 3.1.2. CoCA and 3.1.3. CLC.

Use Case	Use of Sidelink	Cellular Mode (UL/DL)	URLLC
Information Sharing for Partial/Conditional Automated Driving (PAD)	X	X	X
Cooperative Collision Avoidance (CoCA)	X	X	X
Cooperative Lane Change (CLC)	X	X	X

Table 3.1. Conclusion on whether the use cases need the use of Sidelink (SL) communications, retrieving information from the network and a URLLC service.

This information is relevant in order to make decisions related to the slicing of the network. For example, in the case that the use of network information is required, it can be of our interest to include **Multi-Access Edge Computing (MEC)** in our system to provide low latency services, and this has some implication in the architecture, as there are several options when deploying MEC. One of the deployment options is to bring the UPF closer to the BS. If the services provided by these use cases needs the UPF closer to the BS, maybe it is of our interest to devote a specific slice to these use cases. The topic of **Network Slicing** is addressed in the following sections 3.2. The 5G Core Network and 3.3. The 5G Radio Access Network, as we are proposing to implement slicing both at Core Network and RAN levels.

As all the use cases need to retrieve and send information from/to the network, we have decided to implement a slice that covers the 3 use cases. Also, it is important to highlight that the use cases that make use of the information provided by the network, will be using the **V2X application server**. The same way we have decided to group the three use cases in one slice and to implement MEC for all of them, we have decided to connect the V2X application server to Slice 1.

Regarding the eMBB slice, it needs to handle high user density and particularly large data rates in mobility scenarios. When streaming in the vehicle, the use of MEC can be advantageous to leverage low latencies. However, we have decided to not include MEC in Slice 2 (associated to eMBB services), as the focus of our project is to solve the low-latency requirements of V2X communication services.

3.2 High-level Architecture Scheme

In the figure below, the general high-level architecture we deployed to support our use case is depicted. The aim of this subsection is to introduce the main concepts and interfaces that our architecture will make use of. As we can see from the picture, this architecture supports two operation modes for V2X communication: V2X communication over the **PC5 reference point or interface (SL)** and V2X communication over the **Uu reference point or interface (cellular mode)**. The PC5 interface supports Sidelink (SL) V2X communications for NR and LTE. Then, the communication between V2X Applications is supported by the **V5 interface** in case of UE-UE communication and by the **V1 interface** for interaction between Application Server and UE. These interfaces are used to exchange Application Server information and configuration parameters useful for the UE to configure its V2X communication.

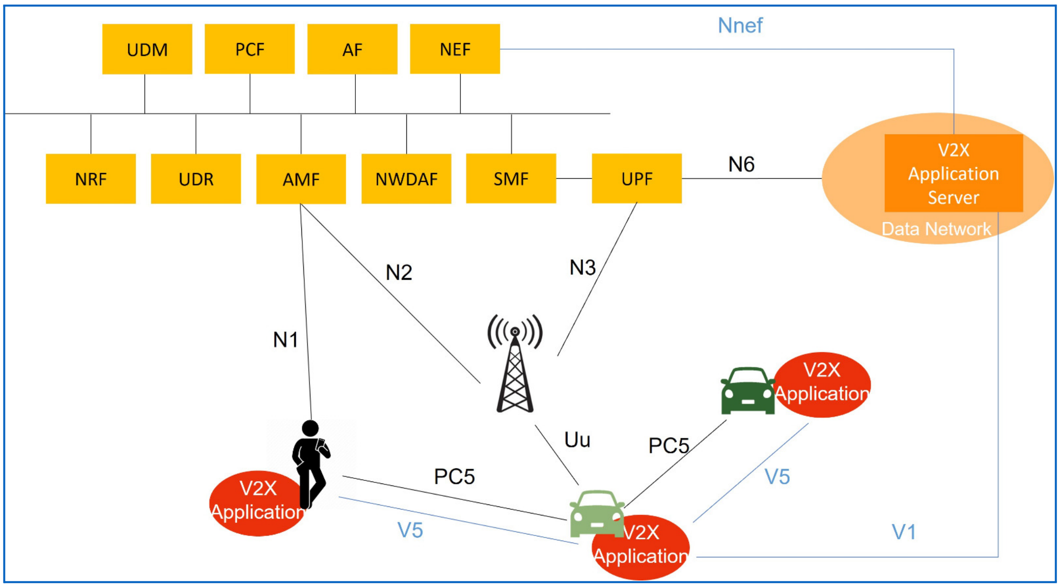

Fig 3.3. High-level architecture of the architecture that we are proposing throughout this section.

The common **Nx interfaces** between UEs/gNBs and the core network carry out additional functionalities to support the V2X applications. For example, the **N1 interface** is used to convey the V2X policy and parameters from the AMF to the UE and to convey the UE's V2X Capability and PC5 Capability for V2X information from UE to AMF. Similarly, the **N2 interface** conveys the V2X policy and parameters from the AMF to the gNB. In the end, the **Nnef interface** supports the V2X Application Server to use the services provided by the NEF to update V2X Service related information of 5GC.

The NFs that we propose to include in our architecture can be found in Section 3.3.2. Network Functions (NFs). Moreover, the functionalities of the V2X Application Server are described in Section 3.3.5. The V2X Application Server.

3.2.1 Road Side Units (RSUs) implementations

According to the 3GPP reference documents [13], we have considered two possible implementations for the RSUs: UE-based and gNB-based RSUs.

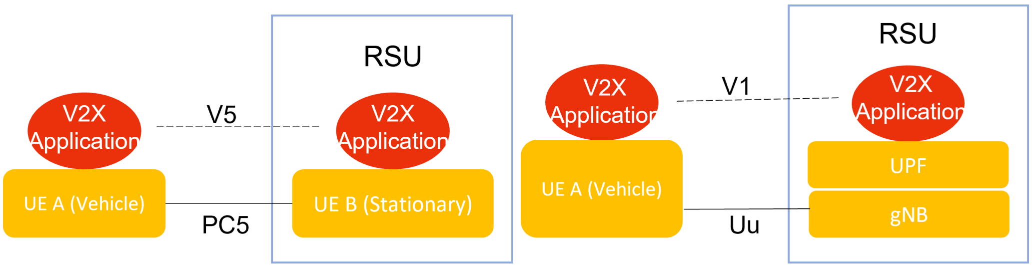

Figure 3.4. (left) UE-based RSU and (right) gNE-based RSU

The UE-based RSU simply combines a UE with the V2X application logic. Thus, communication occurs through the V5 and the PC5. The gNB-based RSU, instead, includes a gNB, a collocated UPF and the V2X application Server. This second option is a more powerful entity in terms of functionalities which can be carried out. The UPF, indeed, supports the routing of local traffic of the Application Server.

3.3. The 5G Core Network

We propose to use Network Slicing to adjust the structure of the network for the two different types of services that coexist in vehicular communications according to their functionalities and QoS. One slice for V2X communications and another slice for eMBB corresponding to users inside the vehicle or on the road that want to access the network for normal internet service. All the information regarding vehicle communications will be supported at the V2X slice.

3.3.1. 5G Core Network Slicing

The exchange of information in our network can be classified by the type of service requirements, in general terms is low latency for V2X communications and high data rates for eMBB services. Therefore, the slices that we will have in our system are the following ones.

- **CN Slice 1:** V2X communications, linked to the three already mentioned use cases (Partial Automated Driving, Collision Avoidance and Cooperative Lane Change). This slice supports all traffic regarding vehicle communications such as Vehicle to Pedestrian (V2P) information,Vehicle to Network (V2N), Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I).

- **CN Slice 2:** eMBB services which are less latency restrictive but so demanding in terms of data rates to satisfy those users that want to access the network to consume Netflix, Whatsapp, Instagram resources on the internet.

The common network functions in all the slices are the **AMF** and the **NSSF**, which allow the user equipment to access the core network via the AMF and select the appropriate slice by the NSSF. Only one instance of the AMF and one instance of the NSSF will be implemented as the AMF is the connection point from the radio access network and the core network. All the sessions will be treated at the same AMF that with the aid of the Network Slice Selection Function (NSSF) will select the proper slice according to the service characteristics.

3.3.2. Network Functions (NFs)

Every slice will have the NFs listed in the following bullet list with the corresponding functionalities:

- **SMF** (Session Management Function): in charge of the Session Management, UE IP address allocation and management, control of policy enforcement and QoS and configuration of traffic steering at UPF to route traffic to proper destination.
- **AUSF** (Authentication Server Function): provides the UE authentication service.
- **PCF** (Policy Control Function) : provides policy rules (e.g. authorized QoS for each service data flow) to the network functions in charge of enforcing them (e.g. SMF).
- **UDM** (Unified Data Management): User identification handling, subscription management, access authorization based on subscription data (e.g. roaming restrictions), generation of authentication credentials.
- **NRF** (Network Function Repository Function): repository with the profile of the available NF instances and their supported services. It allows a NF to discover the services offered by the other NFs of the core network. This provides a lot of flexibility and faster interaction between NF.
- **UPF** (User Plane Function): deals with the user plane communications. The main functionalities are packet routing and forwarding, QoS handling, packet inspection and traffic measurements and traffic usage reports.
- **NEF** (Network Exposure Function): exposure of capabilities and events, secure provision of information from external application to 3GPP network, translation of internal/external information.
- **AF** (Application Function): allows interacting with the applications making use of the network. This can be used for applications that require dynamic policy control, e.g. for dynamically modifying the bit rate to be provided. Based on interactions with these applications, policy requirements are provided to the PCF.

Furthermore, some network functions for the V2X slice will have additional functionalities as it is stated in the **TS23.287 of the 3GPP standard**.

- **NEF** (Network Exposure Function)**:** enables communication between the V2X application server and the NFs on the 5GC.
- **PCF:** provisions the UE and AMF with the parameters to use V2X communications.

- **AMF:** when dealing with V2X communications, it obtains the subscription information from UDM related to V2X and stores them as part of UE context data.
- **NWDAF** (Network Data Analytics Function), provides other NFs with QoS analytics information on the network behaviour, such as load level information on a slice level.

Slice 1, which includes low latency communications, will need to have software for Mobile Edge Computing (MEC) attached to the UPF so that all the information coming from **Road Side Units (RSU)**, sensors, pedestrians or cyclists informing about their presence on the road is rapidly processed. As the latency must be very low we are interested in making sure that vehicles are able to get the information and that the processing is done in a really short time.

The storing of the information regarding the status of the road will be gathered in the V2X Application Server connected to the UPF and the NEF. The procedure starts when a UE makes a request to the NSSF, that with the AMF performs ths slice selection procedure by leveraging additional information about the service type (vehicular communications or internet access). Once the NSSF has selected the corresponding slice for the type of service, by interactions with the AUSF and the UDM, the slice attachment procedure is performed and the services can be accessed. Next figure shows the implementation of both slices.

3.3.3. CN Proposed Schematic

In the following figure, the scheme that we propose for the Core Network of our system can be found. Network Functions linked to Slice 1 (associated to Advanced Driving V2X Communications) have been depicted in red color, while Network Functions linked to Slice 2 (Associated to eMBB services) have been depicted in green color. As the AMF and NSSF NFs are shared between the two slices, they are depicted in both red and green colors. The V2X Application Server is connected both to the NEF and to the UPF Network Functions of Slice 1. As it has been previously mentioned, we have decided that for Slice 1 the UPF will be located near the BS, with the aim of lowering the latency of the provided service by the addition of MEC.

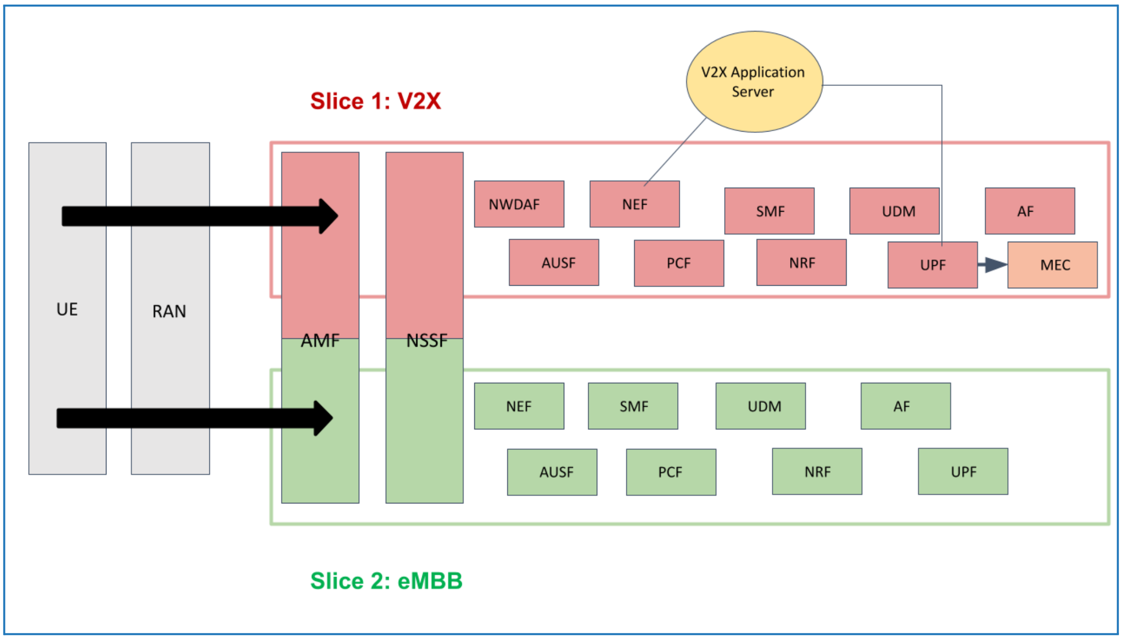

Fig 3.5. Scheme that we propose for the Core Network of our system, which contains Slice 1 (linked to Advanced Driving V2X Communications) and Slice 2 (Linked to eMBB services).

3.3.4. SDN Architecture and NFV-MANO (Management and Orchestration)

In this subsection we are exposing the benefits of including NFV-MANO in our system architecture. To do so, we are first defining the NFV technology and the NFV-MANO framework. Therefore, some theoretical aspects are included in this subsection.

Network Function Virtualization (NFV) is a key technology that consists in addressing NFs as *'pieces of software'* that can be implemented as virtualized functions. NFV is possible in 5G due to the strong decoupling between the logical and the physical architecture. NFV makes things cheaper (in time and resources). If wanting to add a new network function, the service provider can simply create a new virtual machine to perform that function. As a consequence, with NFV, we are reducing the cost and accelerating the service deployment. Operators can decouple functions from hardware and move them to virtual servers. Consequently, we have decided to **use the NFV technology in our system**.

NFV MANO (Management and Orchestration) is a framework developed by a group with the same name (NFV MANO) within the ETSI ISG NFV, which is the ETSI (European Telecom Standards) Industry Specification Group for NFV. This ETSI-defined framework is focused on the management and orchestration of NFV Infrastructures (NFVIs) and Virtualized Network Functions (VNFs). The VNFs refer to NFs (Network Functions) that have been deployed on VMs (Virtual Machines), while the NFVIs refer to the hardware and software components that build the environment where VNFs are deployed. They consist of a hardware layer and a virtualization layer [16].

In our proposed system, we would have a hardware layer (HW resources) and a virtualization layer (Virtual Resourced + Virtualization Software). Over these NFV Infrastructure, the Network Functions would be virtualized. Therefore, on top of the NFV Infrastructure, we could see some VNF Instances (on the SW Infrastructure). Our MANO Orchestrator would be divided in the following three blocks.

1. **The NFV (Network Function Virtualization) Orchestrator (NFVO)**, which is incharge of global resource and service management within the NFV networks.

2. **The VNF (Virtualized Network Function) Manager (VNFM)**, which is responsible for the lifecycle management of VNFs, including VNF instantiation, configuration, and termination.

3. **The Virtualized Infrastructure Manager (VIM)**, which is responsible for discovering resources, managing and allocating virtual resources, and handling faults.

In our case, MANO would be responsible for <u>allocating (managing and orchestrating) the resources of the MEC servers and the services deployed and running on top of these servers (such as the V2X Application)</u>. Finally, it would also be in charge of the management of the rest of the Core Network. To map these resources, MANO would make use of the Virtualized Infrastructure Manager (VIM) [16].

In this subsection, we also wanted to mention the differences between SDN and NFV. This is because in some papers we found the use of a Software-defined networking (SDN) architecture with NFV-MANO in V2X Communication services as a suggestion [17]. On the one hand, SDN decouples the control plane from the forwarding plane in the network infrastructure and applies programming to the control plane. On the contrary, NFV aims to virtualize all physical network resources through VM programs.

Furthermore, the key goal of an SDN architecture is **to achieve programmability of network hardware devices and centralized management and control**. In our case, we are not focusing on a centralized management of operations. This is because, for example, we are proposing the use of autonomous resource allocation between devices when talking about the Sidelink. Taking all of this into account we have decided that our system is not going to follow an SDN architecture, as the benefits that it provides are not really of our interest.

In the following figure, the high-level architecture of our MEC-enhanced vehicular network is shown. We can see how the NFV-MANO is connected to the Core Network and to the Edge layer, which contains the MEC servers. As it has been previously mentioned, this is because MANO allocates the resources of the MEC servers and the services deployed and running on top of these servers (such as the V2X Application). The V2X Application server would be included within the External Data Network.

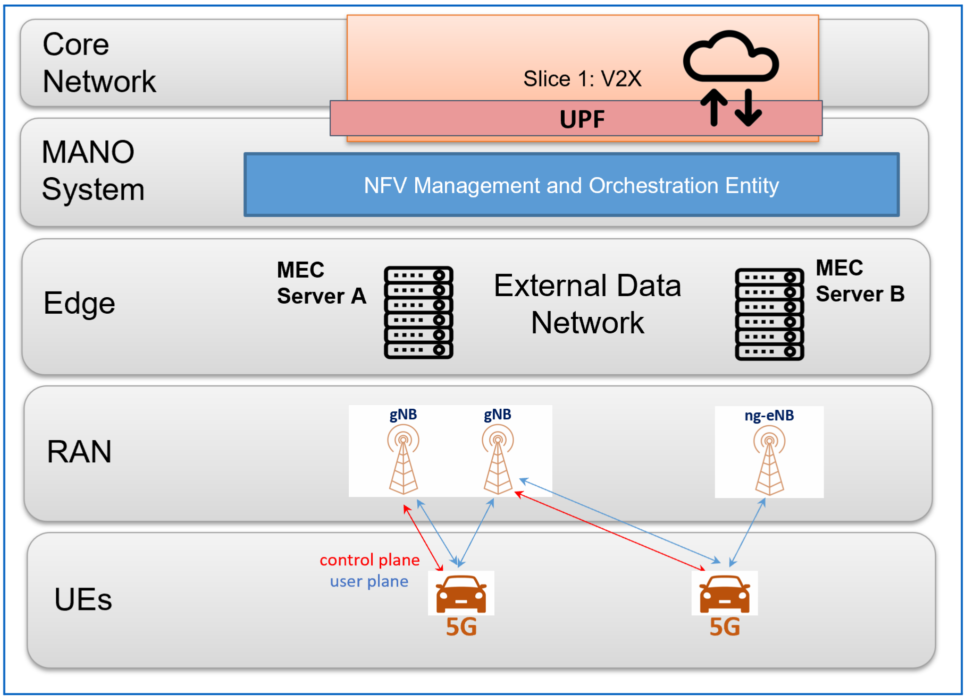

Fig 3.6. High-level architecture of MEC-enhanced vehicular networks, with the use of NFV-MANO.

3.3.5. The V2X Application Server

The first releases of LTE standardization documents with regard to V2X did not include the V2X application server entity. It did not contain the LTE V2X control function and MME entities either. It was from the 3GPP TS 23.285 document and on when these entities were included in architecture designs. However, in the case of 5G releases with regard to V2X communications, the V2X application server has always been included.

According to one of the latest 3GPP documents [39], the V2X Application Server includes AF functionality, and it is in charge for:

- Handling DL&UL data from the UE
- Provisioning V2X service parameters both for the UE and the CN to perform V2X communication
- Requesting QoS Sustainability Analytics for potential QoS changes in a geographic area from NWDAF

As it has been previously mentioned, we have decided to connect the V2X application server to slice 1. This can be observed in the following figure, which shows the architecture that we are proposing for the selected use cases. The location of the V2X applications matches for each of the use cases. However, we have decided to include the three use cases in the same slice, with this architecture, for simplicity.

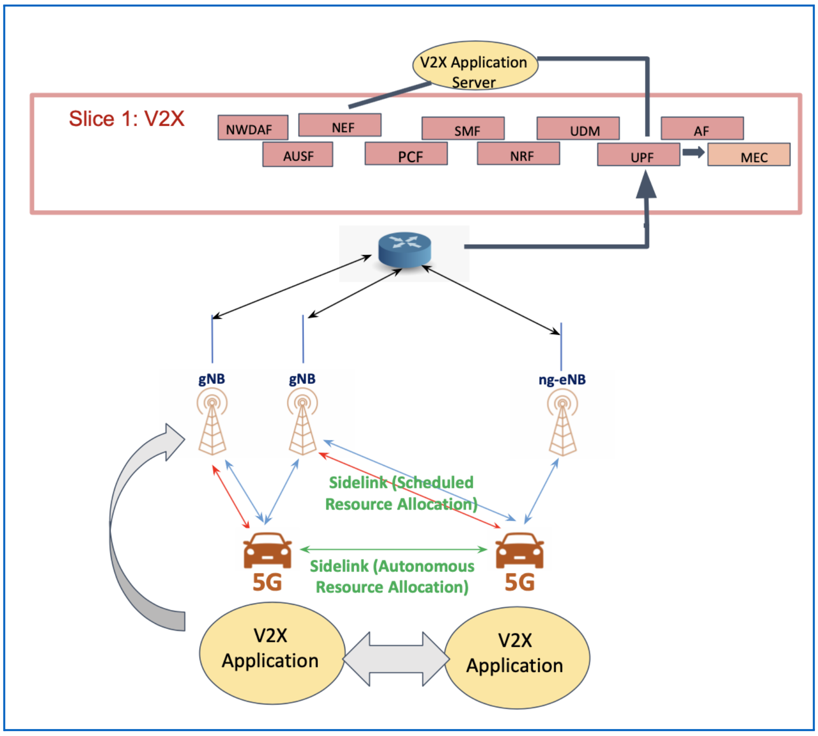

Figure 3.7. This figure shows the location of the V2X applications in the proposed architecture for the three use cases. There are two types of V2X applications: the local application, within the UE, and the V2X Application Server (which makes use of the MEC feature). The interfaces are not specified in this figure, as this is not the purpose of this figure.

It is interesting to highlight that in the case of slice 1, in order to get the maximum profit of the MEC feature, the UPF will be located closer to the BS than in the case of slice 2. This way, the low latency experience for URLLC services is better (as the propagation time is lower, due to having the UPF closer, which is connected to the MEC, closer to the BS).

3.4. The 5G Radio Access Network

In this section, we are going to describe the architecture of our Radio Access Network, which will be wireless, as we are assuming that our system will be used in urban areas where a physical radio link will not be needed to provide the users with a good service. In the proposed architecture, gNB, ng-eNB and eNB nodes are considered.

3.4.1. RAN Slicing

The use of slicing in RAN is implemented to adapt our network to the different covered services. The good organization of radio resources permits the network to perform efficiently and also reduce the possible interference between both types of services.

For that reason, according to the standardization of 3GPP for V2X communications and the characteristics of broadband internet services, we decided to implement RAN slicing. The organization of the radio resources is the following.

- **RAN Slice 1:** V2X Communications. 3GPP has defined the 5.9 GHz band for this type of service. This band is reserved for the Intelligent Transport System (ITS) within Europe and worldwide for vehicular communications.
- **RAN Slice 2:** eMBB services. Allocated at the 3.5 GHz band. One can think of mmWave for broadband services, but this 3.5GHz band performs better in this type of scenario where vehicles move at high speed. In mmWaves, we would have lots of HO on the road as we would need more BS. Furthermore, we would have limitations when performing beamforming due to the high speed of vehicles when needing to change the beam.

3.4.2. Spectrum Usage

According to the standardization of 3GPP, both 5.9 GHz band and 3.5 GHz, correspond to the FR1 frequency range that goes from 410 MHz to 7125 MHz.

Frequency range designation	Corresponding frequency range
FR1	410 MHz – 7125 MHz
FR2	24250 MHz – 52600 MHz

Table 3.2. 5G NR Frequency ranges (table extracted from the 5GMCS course slides).

V2X Operating Band	Sidelink (SL) Transmission operating band			Sidelink (SL) Reception operating band			Duplex Mode	Interface
	F_{UL_low} – F_{UL_high}			F_{DL_low} – F_{DL_high}				
n38	2570 MHz	-	2620 MHz	2570 MHz	-	2620 MHz	HD	PC5
n47	5855 MHz	-	5925 MHz	5855 MHz	-	5925 MHz	HD	PC5

Note 1: When this band is used for V2X SL service, the band is exclusively used for NR V2X in particular regions.

Table 3.3. V2X operating bands defined in 3GPP TS 38.101-1.

The 5.9GHz band corresponds to the n47 definition of 3GPP bands which has different possibilities of bandwidths. Whereas the eMBB slice frequency allocation is the n48 band according to 3GPP TS 38.104.

The required bandwidth is computed taking into account the 10Mbps of data rate needed for the most restrictive use case and the different possible modulation schemes standardized for 5G-NR that are QPSK, 16- QAM, 64-QAM and 256-QAM. Based on the slides of the course, which points out that the spectrum efficiency can vary from 0.2 b/s/Hz (QPSK and lowest coding rate) to 7.4 b/s/Hz (256-QAM and highest coding rate), for our 10Mbps of user throughput, we need a minimum bandwidth of 10Mbps / 0.2 b/s/Hz = 50 MHz per user.

According to 3GPP TS 38.101, the maximum channel bandwidth at the n47 band is 40 MHz. As we want to guarantee the service to the user even if it works at the most restrictive situation (QPSK and with the lowest coding rate), we will need to implement **Carrier Aggregation** with two channels of 30 MHz each one, providing a total 60 MHz spectrum to the user.

Moreover, our system will work with a **subcarrier spacing of 15 kHz**, corresponding to the lowest numerology defined by 5G-NR, because with that we will have longer cyclic prefixes duration and we will be able to support longer delay spreads associated to large cells.

The different frequency allocation of both slices relieves the system to define scheduling algorithms between slices. The scheduling will have to be implemented by each separate slide. In the case of V2X, we will need individual scheduling for DL/UL and sidelink and for eMBB slice for DL/UL.

3.4.3. Multi-RAT Dual-Connectivity (MR-DC)

We need to use multi-RAT dual-connectivity (MR-DC) because we want to increase reliability for URLLC services. With DC, the same packet can be sent through both master and secondary nodes to increase the chances of correctly receiving it.

Another reason why we want to use MR-DC is because we are assuming that the coverage scenario will go through an evolution that will depend on the technology deployed by the operator. Also, we are assuming that all vehicles will be able to connect both to E-UTRAN and 5G NR. The different MR-DC scenarios that we are targeting can be found in the following table. **Scenario A** corresponds to the closer future, and it assumes that there are enough LTE and 5G NR base stations deployed nearby the road so that the vehicles can use our service. **Scenario B** is a more futuristic scenario, as it assumes that there are enough 5G NR base stations deployed nearby the road so that users can use our service by only connecting to 5G BSs.

Scenario A	Master/slave ng-eNB, slave/master gNB. Vehicles need to support 5G.

Scenario B	Master and slave gNB (5G NR), 5GC. Vehicles need to support 5G.

Table 3.4. Definition of the two scenarios that we have considered regarding MR-DC.

From an architectural perspective, the DC will be realized by means of three different types of radio bearers: Master Cell Group (MCG) bearers, Secondary Cell Group (SCG) bearers and Split bearers.

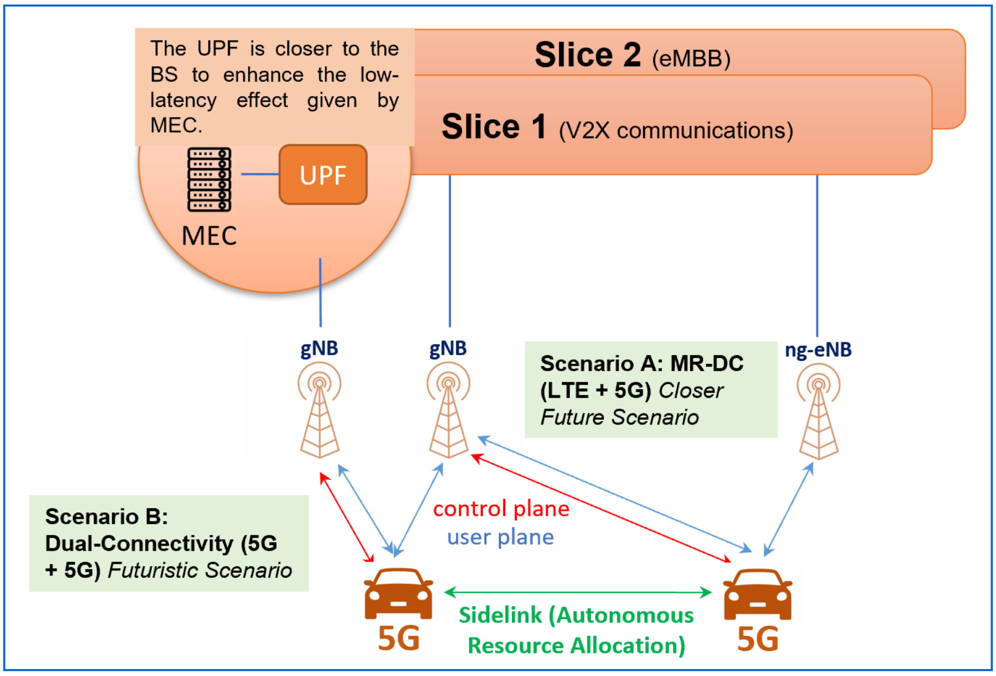

Figure 3.8. Proposed deployment of the different MR-DC Scenarios.

3.5 Sidelink (SL)

In V2X communications it is highly used the communication in the sidelink direction to enable inter-UEs communication. This implies that the bandwidth will have specific resource blocks allocated to the sidelink. These resource blocks are also used in the UL transmission, as in both cases (UL and SL), the UE is the one transmitting. We need to incorporate mechanisms for managing these radio resources. To decide which is the user that can transmit at each instant, we need to do the scheduling in the sidelink direction. The scheduling modes that correspond to this type of resource allocation are **Mode 2 in the case of 5G NR and Mode 4 in the case of LTE (V2V case)**, according to the 3GPP TS 23.287 document. We have decided to implement UE autonomous resource allocation, as this can be used even when the UEs are out of coverage of the eNB/gNB.

3.5.1. Supported Communication Cast Types

In the V2X communications it is highly used the NR sidelink to support direct communication between vehicles. This technology has been significantly enhanced with **5G-NR Rel 16** in order to deal with the most advanced applications, like the ones we propose. Indeed, we are facing use cases involving both periodic and aperiodic traffic with high requirements in terms of reliability and lower latency. Moreover, the SL is expected to support three different communication cast types:

- **Unicast:** direct communication between a pair of UEs
- **Groupcast (multicast):** a transmitter UE sends message(s) to a set of receivers
- **Broadcast:** a single transmitter UE sends messages to be received by all UEs which may decode the message (within the radio transmission range of the transmitter UE)

The current V2X communication deployment supports HARQ procedure for unicast and groupcast messages, resulting in better reliability.

3.5.2. SL Resource Allocation Modes

The resources are selected from a resource pool which can be (pre-)configured by the gNB when the UE is in network coverage. In alternative, the resource pool is configured through RAN signalling. A resource pool contains a given number of contiguous resource blocks, referred to as physical resource blocks (PRBs) and within a resource pool it is used one single numerology. In the frequency domain, a resource pool is divided into a (pre-)configured number of contiguous sub-channels, where a sub-channel consists of a group of consecutive PRBs in a slot. These sub-channels represent the smallest unit for a sidelink data transmission or reception. In the time domain, the slots belonging to a resource pool are (pre-)configured and occur with a periodicity of 10240 ms. The number of slots within a resource pool can vary, and they are (pre-)configured with a bitmap.

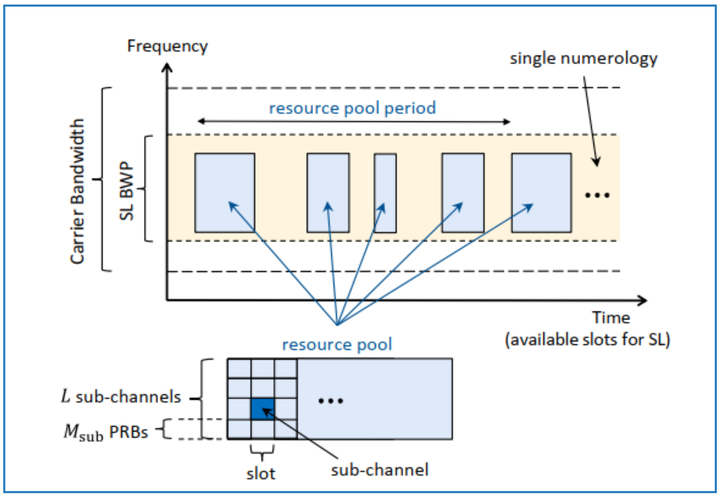

Figure 3.9. SL bandwidth part and resource pool for NR V2X sidelink [18].

A UE, which needs to transmit a Transfer Block (TB), first defines a selection window where it looks for candidate resources to transmit its TB. The extremis of this window depends on the the PDB of the TB itself, the processing time (in slots) required by the UE to identify candidate resources and select nel SL resources for transmission. This processing time depends on the subcarrier spacing applied, for 15 kHz it is equal to 3 slots. In the end, this window depends also on the priority of the TB. Overall,with a NR technology it is guaranteed a minimum latency level of 1 ms (in LTE 10 ms).
After this selection process, the UE identifies the candidate resources within the selection window. To this purpose it is carried out a sensing process and for our SCS this process occupies one slot. In this part, the UE decodes the first stage SCI (section 3.5.3) which indicates the SL resources other UEs have reserved for their TB. The selection of the resources goes through two steps. First, the UE

exclude candidate resources according to the previous sensing procedure. This is done until a given percentage of resources is available. In the second step, the UE randomly selects the SL resources.

They are also provided some congestion control mechanisms, but this it still something which need more studies. In NR Rel 16 the congestion control is handled by means of metrics and possible countermeasures: the Channel Busy Ratio (CBR) and the Channel occupancy Ratio (CR). The CBR is the ratio of occupied subchannels within the previous 100 subframes. The CR estimates the channel occupancy generated by a TX UE.

3.5.3. SL Physical Channels

Referring to the 3GPP TS 38.221 [19], they have been introduced these physical channels to support the SL communication:

- **Physical Sidelink Broadcast Channel (PSBCH).** It carries the Master Information Block for SL that is periodically sent and comprises system information for UE-to-UE communication. PSBCH is transmitted along with the Sidelink Primary Synchronization Signal/Sidelink Secondary Synchronization Signal (S-PSS/SSS) in the Sidelink Synchronization Signal Block (S-SSB).
- **Physical Sidelink Feedback Channel (PSFCH).** It is used to transmit the HARQ feedback from a receiver UE to the transmitter UE on the SL for a unicast or groupcast communication.
- **Physical Sidelink Shared Channel (PSSCH) and Physical Sidelink Control Channel (PSCCH).** Every PSSCH is associated with a PSCCH. The PSCCH is transmitted on the same slot as PSSCH and contains control information about the shared channel. The Sidelink Control Information (SCI) is split into two stages. The first stage is sent on the PSCCH, and the second stage is sent over the corresponding PSSCH. The SCI carries the information the receiving UE requires in order to be able to receive and demodulate the PSSCH.

The content of the SCI in the first stage is: priority, frequency resource assignment, time resource assignment, resource reservation period, DMRS pattern, second stage SCI format, modulation and coding scheme, reserved, beta_offset indicator, number of DMRS port. Then, in the second stage, they are sent: HARQ process ID, new data indicator, redundancy version, source ID, destination ID, CSI request. Splitting the SCI in two stages, allows other UEs which are not receiving UEs of a transmission to decode only the first stage SCI for channel sensing purposes. On the other hand, the second stage SCI provides additional control information required for the receiving UE(s) of a transmission.

3.5.4. SL Physical Signals

They have also defined specific reference signals and synchronization signals for the SL communication. Most of them are similar to those already existing and used in the ordinary DL and UL direction, with the difference that they are transmitted over the physical channels devoted to SL :

- **Demodulation Reference Signals (DMRS):** they are used for PSCCH, PSSCH, and PSBCH as reference signals for demodulation of messages in a receiver
- **Sidelink Channel State Information Reference Signal (SL CSI-RS):** it is a reference signal used for channel state estimation/sensing and reporting between a transmitter and a receiver UE.

- **Sidelink Phase Tracking Reference Signal (SL PT-RS):** it is used as a reference signal for phase noise compensation.
- **Sidelink Primary/Secondary Synchronization Signal (S-PSS/S-SSS):** together with PSBCH are parts of the Sidelink Synchronization Signal Block (S-SSB) and used for the SL synchronization.

3.5. QoS

In this section, we are going to mention how the QoS are handled in our system. Previously, with LTE, the packets are associated to priority (PPPP, Proximity Service Per-Packet) and reliability (PPPR, Proximity Service Per-Packet Reliability). However, the V2X applications we are dealing with demand for more stringent QoS requirements and so, the PPPP and the PPPR are not sufficient. Indeed, it is used a QoS model based on QoS flows where traffic with the same QoS flow ID receive the same traffic forwarding treatment. The 3GPP defined the QoS flow ID for our cases, and they are those shown in the following table.

PQI Value	Resource Type	Default Priority Level	Packet Delay Budget	Packet Error Rate	Default Maximum Data Burst Volume	Default Averaging Window	Example Services
23	GBR	3	100ms	10^{-4}	N/A	2000ms	PAD
57	Non-GBR	5	25ms	10^{-1}	N/A	N/A	CLC
90	Delay Critical GBR	3	10ms	10^{-4}	2000bytes	2000ms	CoCA

Table 3.5. Standardized PQI to QoS characteristics mapping from [14].

Each QoS flow ID identifies with a PC5 QoS Flow ID (PFI). These flows are then mapped to sidelink radio bearers using rules provided to the UE by the network via RRC signaling. This mapping is performed by the SDAP (Service Data Adaptation Protocol), which is responsible also for marking packets with the corresponding PFI. Finally, the sidelink radio bearer is established with the receiver and configured, i.e. application server parameters configuration.
An interesting difference with Rel15, is that the 5G QoS model applies also in out-of-coverage operation and QoS provisioning is supported also when the UEs are in idle state. Previously, the QoS model applied only under network coverage conditions and QoS provisioning only for connected UEs. When the UEs are in idle state, they are used pre-configured mapping rules provided by the network.

3.5.6. QoS Sustainability Analytics

An interesting new feature introduced in 5G Rel 16, and that our architecture supports, is the so-called *QoS Sustainability Analytics.* Basically, the experienced QoS may be affected by various factors (e.g., UE density, interference, mobility, handover, and roaming transitions) and this release introduces some mechanisms to monitor, collect and report information of the experienced QoS. Then, in case the QoS degrades, this is communicated to the Application Server so that the application can be suitably changed (e.g., safely stop an ongoing service like lane changing).

In this procedure, the AS plays a significant and innovative role. It may request notifications on QoS sustainability analytics for an indicated geographical area and time period. Then, it provides the network with location information in the form of a path of interest or a geographical area where to receive notifications of potential changes in QoS. Also, the AS sends to the network the QoS parameters that should be monitored along with the corresponding QoS thresholds for efficient and safe operation of an application. These thresholds are compared with the predicted values of QoS parameters to decide whether to notify the AS of an expected change of QoS.

This process is supported by a new network function, the NWDAF we introduced in section 3.3.2. This network function is responsible for collecting statistics about QoS, for computing the requested analytics or prediction about expected change of QoS for the requested area and time period. It's up to the NWDAF to detect the need to notify a potential QoS change by comparing the requested analytics of the target QoS profile against the threshold(s) provided by the V2X AS.

3.6. Final System Architecture

In the following table, the final decisions regarding the system architecture can be found.

General	
Supported Technology	5G
RAN	
Frequency Band	5G NR n47 band (FR1)
Sidelink (SL) Transmission operating band	5855 MHz - 5925 MHz
Sidelink (SL) Reception operating band	5855 MHz - 5925 MHz
Base Stations (BSs)	ng-eNBs and gNBs
Channel Bandwidth	Two channels of 30 MHz (60 MHz in total, **CA Support**)
Number of channels (V2X)	2
SCS	15 kHz
Modulation Support	Up to 256QAM
RAN Slicing	Yes (this table contains architectural decisions with regard to Slice 1: V2X)
Core Network (CN)	
Core Network Slicing	*Same as RAN Slicing*
Supported CN	5GC Network (we are not considering EPC)
UPF connected to MEC	Yes

Power Budget	
Maximum Tx Power	23 dBm (maximum defined by 3GPP. TS 136 321-V8.2.0-LTE document) [34]
Radio Interface Techniques	
Carrier Aggregation (CA)	Yes
Dual-Connectivity	Yes (MR-DC)
Device-to-Device (D2D) Communications	Yes
Virtualization and Orchestration	
MANO	Yes
SDN Architecture	No
NFV	Yes
V2X Specific	
V2X Application Server	Yes
RSU	UE-based and BS-based
Resource Allocation	Autonomous
Other Features	
ML/AI	Not mentioned
GNSS (Vehicle Positioning)	Not mentioned

Table 3.6. Table with the specifications and characteristics of the final system architecture we propose, regarding **Slice 1**, which is the focus of the project.

As it is stated in this table, we have not included the use of Machine Learning (ML) or Artificial Intelligence (AI) because, although we have found several papers that propose the use of ML/AI to improve, for example, the scheduling of the SL resources, or the power saving by turning off and on the base stations, we have not concluded that any of the found algorithms are suitable for the specific use cases we are targeting in this paper (maybe they were interesting in general, but not for the specific use cases). Also, we have not developed the aspect of GNSS vehicle positioning, but we are assuming that it would be advantageous to make use of this feature for our service. All the other aspects have been developed in detail throughout the document.

In the following figure, a general scheme with the proposed architecture for our system is provided. This figure is a mix of all the previous figures that we have been introducing throughout this section. We show an example scenario which covers the two proposed scenarios with regard to MR-DC (one where two gNBs play a role and the other one where one ng-eNB plays a role). The Slice 1 of the Core Network, which is the slice that is devoted to V2X services is described in detail as the NFs functions are detailed in this image. We can see that the UPF and the NEF NFs are connected to the

V2X Application server, which is located in the external data network. The use of NFV-MANO to orchestrate and manage the resources of the MEC servers is also shown in this figure. We have only included one MEC server. However, we assume that there would be several MEC servers in our deployment. We have also included V2X applications within the vehicle, which allows us to use the SL for autonomous resource allocation. An UE-based RSU has been included in the figure, as well as the most important network interfaces (PC5, Uu, N3, N2, N6, V1 and V5).

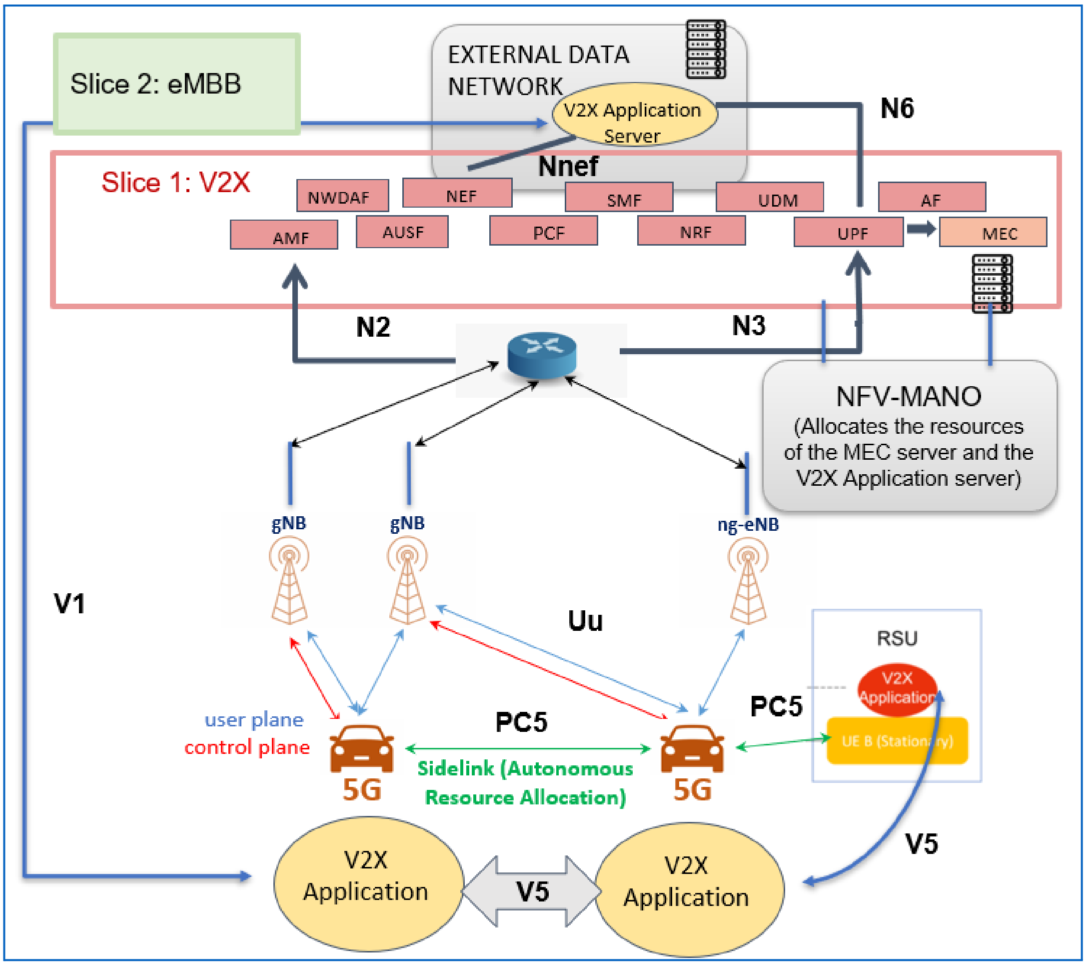

Figure 3.10. Final System Architecture design.

4. Techno-Economic Assessment

4.1. Insights on the V2X Market and Current State

The V2X market was valued at $2,565.6 million in 2019 and predicted to reach $11,718.7 million by 2027 with a Compound Annual Growth Rate (CAGR) of 28.4%. Europe is the highest revenue contributor as can be seen in the following figure. In this figure, the percentage of contribution to the V2X market for several geographical areas can be seen. The data used to compute this graph is from 2019 and the regions taken into account are the US, Europe, China and the rest of the world. Europe accounts for $851.8 million in 2019 and will approximately reach $3,030.5 million by 2027, with a CAGR of 24.4%.

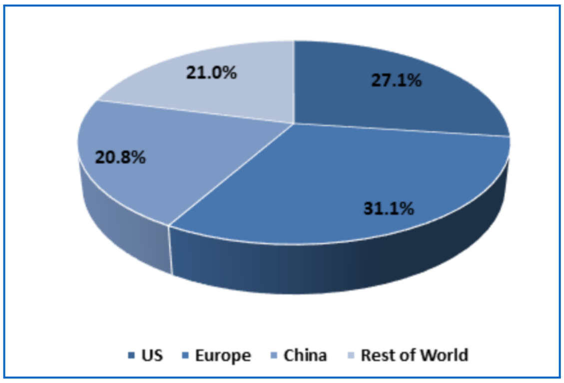

Figure 4.1 Percentage of contribution to the V2X market for several geographical areas: US, Europe, China and the rest of the world (data from 2019). Europe is the strongest contributor so far [20].

In the following figure, a comparison between segments of the V2X communication sector. The figure represents how lucrative each sub-sector is, comparing data from 2019 and expected market sizes in the future year 2027. Results suggest that the most lucrative segments within the V2X communication market are V2V (vehicle-to-vehicle communications) and V2I (vehicle-to-infrastructure communications).

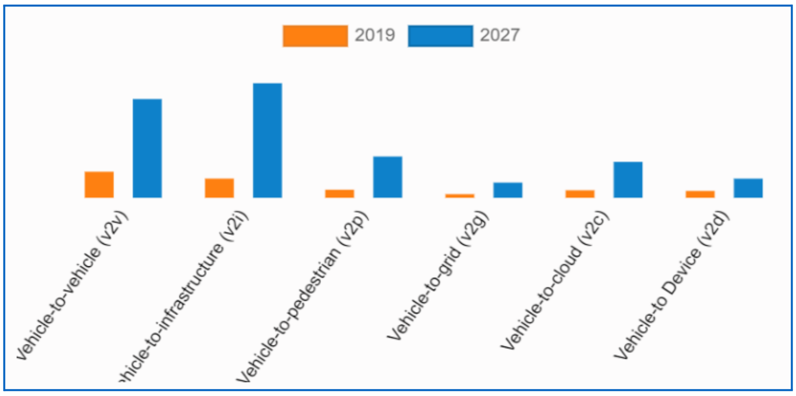

Figure 4.2. Comparison between segments of the V2X communication sector. The figure represents how lucrative each sub-sector is, comparing data from 2019 and expected market sizes in the future year 2027, according to [21].

The key players taken into account for the study are Altran, Autotalks Ltd., Continental AG, HARMAN International, Infineon Technologies AG, NXP Semiconductors, Qualcomm Technologies Inc., Robert Bosch GmbH, Savari Inc., and STMicroelectronics, according to the source found in [20].

Many countries are currently developing laws and regulations associated with autonomous driving. These rules are meant to address safety, liability, privacy and security related to the new-wave automobiles. Australia, Canada, China, Germany, New Zealand, the United Kingdom and the United States have started government-level discourse around autonomous vehicles, even though self-driving cars aren't yet deployed at scale. [22]

China and the United States are more advanced countries when it comes to V2X. At the moment, China is the only country that has 5G Cellular-Vehicle-to-Everything (C-V2X) enabled vehicles commercially available on the market. To this date, 14 C-V2X vehicle models are commercialized. In the United States, Ford has committed to deploy C-V2X in all new vehicle models from early 2022. In Europe, 5G-powered vehicles are foreseen to hit the market still this year thanks to BMW.

“When applied to the automotive field, 5G will have the most revolutionary impact by saving millions of lives and reducing accidents on roads”, 5GAA CTO Maxime Flament said. “The combination of long-range and short-range connectivity C-V2X offers, delivers the optimal setup for safety and efficiency of traffic, in addition to improving environmental footprints.” Global deployment of C-V2X technology will have a sustainable impact in the world. [23]

4.2. New Revenues (key market players)

In this section, we are exposing different automobile manufacturers, hardware and software companies striving for new revenues deriving from new technologies. The developers are in charge of the design and development of the V2X Application [20].

<u>**Hardware Developers:**</u>

LG Innotek has developed a Second Generation V2X Full Module combining three varieties of V2X core components (HCI module, Hardware Security Module (HSM) for controlling the communication protocol, Application Processor (AP)) in one product. Furthermore, the company has tailored V2X modules for V2X chip range manufacturers like Autotalks, NXP Semiconductors and Qualcomm.

Qualcomm has launched 9150 C-V2X ASIC providing automobile and roadside equipment with low latency connectivity for V2V, V2I, V2P with and without cellular connection.

Hyundai focuses on braking, steering, advanced control and autonomous driving sensor technologies. It has launched an Integrated Communication Controller enabling real-time communication between different vehicles through external communication systems.

Danlaw Inc. is working on smart city technologies with the help of connectivity technologies and sensor data. The RouteLink-V2X Roadside Unit can be easily integrated with current traffic networks. It warns of hazardous driving conditions.

Cohda's inventions are the most used in the market offering hardware solutions for Cellular V2X (C-V2X). The MK6C Evaluation Kit provides multiple connectivity options like 2xCAN, ETH, Wi-FI/BT additional to C-V2X capabilities.

<u>**Software Developers:**</u>
Airbiquity is well-known for providing connected vehicle services. It offers Choreo which is a cloud-based connected car content management network.

Bosch built with a start-up a V2X communication unit which can connect to any transmission protocol in a connected car.

Harman International launched a Dual-Mode V2X solution for improving automotive safety. The telematics system consists of hard- and software which can connect to DSRC and C-V2X networks.

Qualcomm Technologies has implemented the C-V2X reference platform for on-board unit (OBU) and RSUs. It offers computational power for a full suite of 4G and 5G wireless, V2X message security and ITS stacks.

As a conclusion of this subsection, we can say that these companies get revenues due to participating in the V2X market in very different ways. Also, we can refer to these revenues as *new revenues*, because this is a new market with new business opportunities that did not exist before. Software developer companies mostly get revenues from developing the V2X applications and maintaining the servers. Also, they can invest in the improvement of V2X message security, which is also an aspect that will be mentioned in the following Section 4.5. Regulations. Hardware developers get revenues from investing in the deployment of V2X-associated equipment.

4.3. SWOT Analysis

In this subsection, we are proposing a **SWOT analysis of the V2X communication market**. It has not been possible for us to find a SWOT analysis via the internet, as online sources were asking to contact consultancy firms in order to get a complete SWOT analysis. Taking this into account, we decided to do our own SWOT analysis, considering the information that we have found while doing some research about techno-economic aspects of the V2X market for this chapter [24].

STRENGTHS (S) ● Development of V2X-based intelligent transport system (ITS) in recent years enabling road safety, traffic efficiency. ● Development of smart cities with smart infrastructure facilities. ● Semiconductor and software companies helping in development of V2X.	**WEAKNESSES (W)** ● Requiring different players shaping the ecosystem. ● So far, it is a slow-evolving sector (although a peak is expected, as it is a potential market).
OPPORTUNITIES (O) ● It is a huge potential market. ● AI to add predictive capabilities. ● Cellular-V2X establishes lines of communication between vehicles, RSUs and pedestrians.	**THREATS (T)** ● Failure in design causes fatal accidents. ● Limitations/Difficulties due to legal frameworks and spectrum availability: V2X maturity differs in different regions of the world. ● Security of data communication: privacy, authenticity, hacking ● Covid-19 (although this is a common threat between other markets)

Table 4.1. SWOT Analysis of the V2X Market (considering the current state).

4.4. Standardization

In this section, a list with the **standardization documents** that we have checked throughout the development of the project is provided to the reader. Also, we are mentioning the standardization documents that play a role in the V2X systems that have not been used for this project. This is the case for documents that include regulations that are linked to LTE. When this is the case, we indicate it in the text.

- **3GPP TR 22.885 (Rel 14), with use cases identified for LTE → NOT CONSIDERED FOR THE PROJECT**

This use cases have not been considered. We are only considering use cases identified for evolved V2X (in 5G).

- **3GPP TR 22.886 (Rel 16), with use cases identified for evolved V2X (in 5G)**

This document contains a ***Study on enhancement of 3GPP Support for 5G V2X Services***. From this document, we got the different use cases of V2X communications defined by 3GPP, their description and characteristics.

In the State of the Art sections, 1.1.3. State of the art Use Cases and 2.1. Network Requirements and KPIs, we comment on the description and requirements of the V2X use cases defined by the 5GCAR, 3GPP and 5GAA organizations. However, the use cases that we have focused on are proposed by the 3GPP standard. Consequently, the 3GPP TR 22.886 document is the one that we have taken into account regarding the definition and development of the use cases. Nevertheless, the documents by the 5GCAR and 5GAA organizations that we read have been of use for the section related to Regulations.

- **3GPP TS 23.285 (Rel 16) → NOT CONSIDERED FOR THE PROJECT**

This TS proposes the addition of new entities (with respect to the previous LTE architectures): the V2X application server, the V2X control function and the MME. The proposed architectures for V2X in 5G include the V2X application server since the first release.

- **3GPP TS 23.287 (Rel 17), changes in some 5G NFs**

This standardization document applies to our use cases. It proposes an improvement that consists in the 5GC architecture remaining the same but with some modifications in the functionality of the PCF, AMF and NEF Network Functions.

- **3GPP 38.101 (Rel 18)**

We have recovered this document from the Assignment 5 of the 5GMCS course. This document has been used in order to decide the SCS that is going to be used by our system.

- **3GPP 38.104 (Rel 17)**

This document has also been taken from the Assignment 5 of the 5GMCS course. This document has been used in order to decide the channel bandwidth of our system.

4.5. Regulations

The aim of this section is to understand that not only standardization plays an important role when designing an architecture of a V2X Communication system (and of any system in general). The regulatory aspects are placed at a higher level than the standards, and make more use of the 'common sense' that applies to each situation where the service can be deployed and, therefore, used. The regulatory organizations that we have considered for this section are 5GAA and ETSI.

One of the documents that we have considered is **The 5GAA study of spectrum needs for safety related intelligent transportation systems (ITS)** [32]. We have considered the information found in this document to decide which is the spectrum that we use for each RAN slice. The decision that we have made regarding the spectrum usage can be found in Section 3.3.2. Spectrum Usage.

The **5G Automotive Association (5GAA)** is a global, cross-industry organisation of more than 120 companies from the automotive, technology, and telecommunications industries (ICT), working together to develop end-to-end connectivity solutions for future mobility and transportation services. In the following list, we can find the most relevant ***regulatory aspects*** defined by this organization [25].

1. 5GAA considers **the availability of spectrum for digital communications** to be critical for road safety using 5.9 GHz ITS spectrum.
2. **Need for the development of mobile network coverage alongside the road network,** and calls for the adoption of regulation which stimulates investments in mobile network coverage.
3. **Need for continuous coverage and seamless handover of 5G connectivity for vehicles crossing country borders in Europe.** Further work is needed, notably in collaboration with standardisation bodies, to establish the right conditions to stimulate continuous coverage and seamless handover across borders. However, it should be noted that despite the importance of cross-border handover with 5G networks, given use of ITS spectrum, it is not a concern for the 5G sidelink case.
4. **Investments into connected intelligent traffic infrastructures to assure safe and efficient mobility**.
5. As **road safety and automated driving are prominent example of Quality of Service needs**, 5GAA calls for regulation which focuses on social benefits, outcomes and market adoption to position Europe as a global leader in the field. (e.g. enables prioritization of different service classes)
6. 5GAA would like to draw attention **to CCAM's needs in terms of direct communications for critical road safety use cases** as well as complementary network based communication and calls for the adoption of regulation which considers various ways of connectivity and keep regulation technology neutral.
7. 5GAA would like to point that there is an **opportunity to address the digital transformation of the transportation sectors** by stimulating synergies with other transportation sectors (as pedestrians, bikes, motorcycles, esp. in urban environments, as well as rail and tolling).

ETSI (European Telecommunications Standards Institute) is an independent, not-for-profit, standardization organization in the field of information and communications. ETSI supports the development and testing of global technical standards for ICT-enabled systems, applications and services [33].

The **ETSI TS 122 185 v14.3 (2017-03)** [34] and the **ETSI TS 133 185 v16.0.0 (2020-08)** [35] describe some of the regulatory aspects that are taken into account by this organization regarding V2X Communication systems. The most relevant document for us is the second one, as the first one is focused on Security aspects for LTE support of V2X. The second one is focused on Security aspects for both LTE and 5G support of V2X. Both documents are based on 3GPP standard documents because, as it has been previously mentioned, the regulations are at a higher level than the standard aspects. Regulations are built on the limitations stated by the standard.

We have found it interesting that the specification includes requirements of **safety** and also **non-safety** aspects. First of all, they state that transport of safety-related V2X application information can be prioritized over transport of non-safety-related V2X application information. However, in general, it is expected that operators can control the relative priorities of different services. Regarding **privacy and security**, they mention several aspects, such as that the data sent in the PC5 transmission should not allow UE identity to be tracked or identified by any other UE or non-V2X entity beyond a certain short time-period required by the V2X application. This shows that privacy and security are also important factors to take care of in these types of systems.

4.5.1. 5.9 GHz Spectrum Allocation

As it has been mentioned in Section 4.1. Insights on the V2X Market and Current State, many countries are currently developing laws and regulations associated with autonomous driving. These rules are meant to address safety, liability, privacy and security related to the new-wave automobiles. Additionally, it is also important to consider issues related to the coexistence of different technologies in the same spectrum. Indeed, the 5.9GHz spectrum is not devoted to V2X applications only. Historically, this band is employed for Intelligent Transportation Systems (ITS), more precisely by the ITS-G5 technology. Thus it is important to rule the communication so that different types of services can smoothly coexist. The discussion actually is still open and also allocations from the regional corporation (ETSI in Europe and FCC in America) are taking time on that.

Among the various studies which have been proposed, the 5GAA has recently published this paper with some interesting considerations[REF]. It is pointed out that the 5.9 GHz should be structured dedicating a portion for day-1 applications and a second portion for more advanced V2X applications.

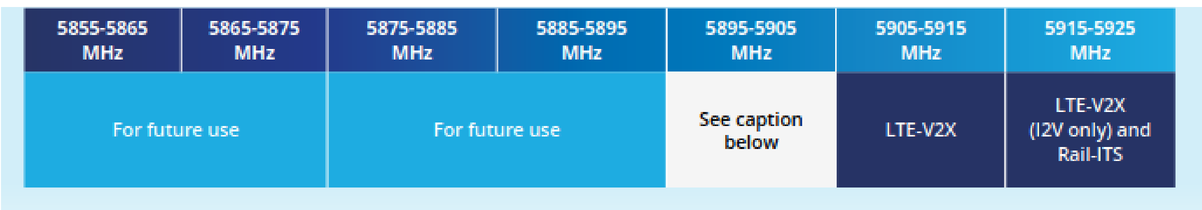

Figure 4.3 Deployment band configuration for C-V2X at 5.9 GHz in Europe [in 5895-5905 5GAA does not take a position on the use by V2X]

Day-1 applications are located in the higher part of the spectrum and require between 10 and 20 MHz of spectrum. These applications are supposed to leverage LTE or V2X technologies.

Advanced V2X applications, instead, require a spectrum or 40 MHz (or even more) and this portion would be colocated in the lower part of the band. These applications, instead, would use V2X technologies only.

The coexistence between LTE/V2X and ITS technologies in this band inevitably negatively impact on the safe delivery and reliable communications. Moreover, it is something which is related to many factors, like filtering techniques, MSC scheme used and also the resource allocation mode can impact. The conclusion drawn by the 5GAA is to dedicate a unique deployment band configuration for C-V2X communications only. This would simplify the management of communications and the devices would be easier as well.

5. Conclusion

5.1. Document Summary and Conclusions

Considering the different 3GPP use cases definition, our project has been focused on 3 use cases: Information Sharing for Partial/Conditional Automated Driving (PAD), Cooperative Collision Avoidance (CoCA) and Cooperative Lane Change (CLC). After having studied each case in depth, the proposed architecture covers the 5G core network and encloses both **gNBs and ng-eNBs** from the access network part using the **Multi-RAT Dual-Connectivity (MR-DC)** radio interface technique.

The scenario covered by our project considers the two types of services that can coexist on the road, which are the already mentioned **V2X communications**. This encompasses V2V, V2I, V2N and V2P. We have also considered the **eMBB services** devoted to the use of the Internet by, for example, passengers inside the vehicle that use to get content from Netflix, Instagram, WhatsApp, etc.

To cope with these two types of services, we have implemented **Network Slicing** both at theCore Network and RAN levels (what is known as RAN Slicing). The main difference between the two network slices is the use of the **V2X Application Server** and the **Multi-Access Edge Computing (MEC)** for the V2X slice. MEC is designed to be close to the UPF so that the network can process all the data faster and achieve lower latencies.

Moreover, for V2X communications, vehicles need to exchange information directly between them without the need to use the network infrastructure. For that reason, **Sidelink (SL)** communications are considered and implemented in **Mode 2 of the 5G standardization**, which means that the scheduling is done autonomously (autonomous resource allocation) by every vehicle given the opportunity to maintain communication even in out of coverage situations.

When it comes to the RAN slice, V2X is designed to work at the **5.9 GHz** band of FR1, following the standardization of 3GPP and the eMBB slice at **3.5 GHz**. To cope with high delay spread that we could have in the road, the subcarrier spacing selection is of 15 kHz and according to the requirements of the V2X use cases we needed **Carrier Aggregation** to reach the 60 MHz of total bandwidth.

5.2. Next Steps: Looking forward in V2X Communications

As it has been mentioned several times throughout this document, the digital era is just around the corner and the automotive industry is one of the most current sectors that can benefit from it. Indeed, LTE technology already incorporates some features to enhance vehicle communications, but the deployment of 5G will really make a difference in that sector. It is expected that in the future years, vehicles will be highly or fully automated with the main objective of reducing or nearly eliminating the number of road accidents and avoiding congestion.

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ANNEX

A1 - Design Aspects: Radio Technologies to consider

There are multiple design aspects beyond the ones mentioned in the report to be taken into consideration to enable autonomous driving. These can be realized with several 5G technologies proposed by 3GPP Releases.

Cross-border communication

When a vehicle changes areas, good communication services should still be provided. Technologies like roaming, multi-radio dual connectivity, multi-SIM and network slicing are the major contributors to cross-border communication.

Roaming

Control plane steering of roaming (CP-SOR) enables the coordination of roaming of home routed and local breakout traffic in a visited public land mobile network (PLMN) [5]. Operators can steer their roaming network onto preferred networks and update the content of preferred PLMNs on the roamer´s SIM [22].

Multi-Radio Dual Connectivity

Multi-Radio Dual Connectivity enables multiple RX/Tx UE to receive resources from different nodes via non-ideal backhaul [23]. Multi-Radio communication increases the capacity and scalability as future vehicles might be able to use multiple connections simultaneously, e.g. LTE and 5G NR [5].

Multi-SIM

As vehicles move between different areas which are part of different PLMNs with different QoS or inequal coverage (e.g. also in terms of overloading, network failure), it is practical to be able to switch seamlessly between PLMNs. This requires an onboard unit (OBU) with more subscriber identity modules (SIMs). Solutions are already available on the market [5].

Network Slicing

Network slicing provides multiple logical networks for different, specific services on one shared network infrastructure. Each of these logical networks can be configured flexibly with other reliability, security and topology [24]. A vehicle needs to offer multiple of these services (e.g. safety and infotainment) depending on the use cases [25]. Furthermore, there are concepts already where slicing improves roaming performance [25].

Communication among nearby devices

The communication between nearby devices, more specifically mostly from vehicle to vehicle can be improved with technologies like enhanced sidelink.

Enhanced sidelink

Enhanced sidelink offers the possibility of short range connectivity of vehicles with the road infrastructure, pedestrians and other vehicles in traffic without the need of a base station [5]. It is a means of avoiding traffic crashes [26]. The NR C-V2X sidelink has several advantages as higher throughput, lower latency, increased reliability and positioning. This is implemented by using an OFDM-based air interface with wideband carrier support and sub-carrier spacing and advanced channel coding [27].

Positioning Accuracy

Positioning accuracy can be especially crucial in autonomous driving. The 5G NR offers more scalability.

NR positioning

Driving in a dense urban spaces would be more convenient with cm-precision positioning. MmWave technology can be exploited exhaustively for this [5]. Sensors based on mobile signals and mobile technology (e.g. inertial sensors) will gain high importance in tracking positions [28].

Resource efficiency

Being efficient in processing information collected in traffic will be discussed in the course of broad- and multicast and edge computing technology.

Broad- and multicast

Broad- and multicast is much more efficient than unicast and can simplify spreading urgent alerts on road events in traffic in several destinations in a local area and time. Safety and scalability can be achieved with broadcasting [5].

Edge computing

Vehicular services demand for ultra-low latency and high bandwidth computing. Regarding this, edge computing enables offloading computing loads to computing nodes at the edge of the network and thus, alleviating core networks serving their local queries [29, 30].

Capacity

Mmwave communication can significantly improve the usage of bandwidth.

MmWave communications

Future vehicular applications, e.g. uploading collected sensor data, require high transmission rates in Gigabit-per-second range. In 3GPP Rel-15 and 16 the frequency range 2 (FR2: 24,250-53,600 MHz) mmWave bands were addressed in addition to the frequency range 1 (FR1: 410-7125 MHz). However, in newer releases higher bands with larger spectrum bandwidths are discussed.

As a summary, in the following figure can be seen the implementation and deployment of the above explained technologies for connected automated mobility (CAM) services:

Table 5. Implementation and deployment aspects of 5G technologies in cross-border CAM services.

5G Technology	Implementation	Deployment
Roaming	Availability of common APIs	Continuity on IP address
Multi-radio	Aggregate traffic Transform across radio technologies	Multiple network interfaces Dedicated infrastructure
Multi-SIM	Perform techniques for payload merge and payload discard based on timestamps	Accurate clock distribution technique granting common time basis
NR positioning	Apply sync to clock and timestamp signalling Local master/slave clocks	Dedicated infrastructure Hierarchical clock sync setup
NR Sidelink	Manage discovery Negotiate handshake & security	Edge system to boost discovery Edge system to enable trust
Broadcast & multicast	Employ compatible UE Remove dependency on feedback messages	Aggregate dedicated system to the Base Stations
mmWave comm.	High-performance bus High-capacity storage Employ compatible UE	High-throughput equipment High-capacity cache Short-range deployment
Slicing	Policies implementation Interfacing provisioning/virtualization system	Policies harmonisation across domains Open 3rd party APIs
Edge Computing	Mobility-based session continuity Geo-parcelling for instance subscription	Listen neighbour activity updates Geo-pinned deployment

A2 - Power Budget to calculate Maximum Distance between cars

(We did not manage to get the desired results, so we are not including this in the main text)

In this section we are providing some calculations we have done regarding the system power budget in an Uplink (UL) transmission from a car to a BS. First of all, we have used the information present in [31] to decide which would be an orientative value of the minimum gain of an antenna that is suitable to be used in a vehicle that participates in 5.9 GHz V2X services. In the following figure, we see that this value could be around -5 dBi.

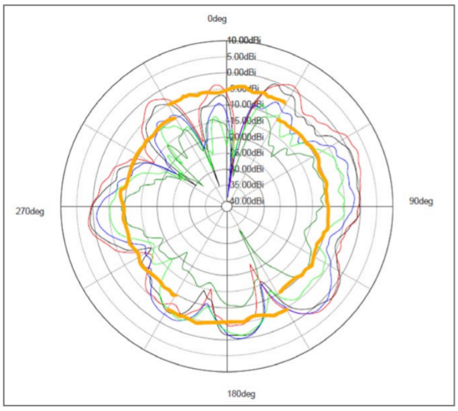

Fig X. Different radiation diagrams of 5.9 GHz antennas and the expected minimum antenna gain (in yellow), according to [32].

$$P_r = P_t * G_t * G_r * \left(\frac{\lambda}{4\pi r}\right)^2$$