Fifth Generation Communication Automotive Research and innovation

Deliverable D1.2
5GCAR Mid-Project Report

Version: v2.0

2019-01-31

This project has received funding from the European Union's Horizon 2020 research and innovation programme *under grant agreement No 761510.* Any 5GCAR results reflects only the authors' view and the Commission is thereby not responsible for any use that may be made of the information it contains.

European Commission

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Grant Agreement Number:	761510
Project Name:	Fifth Generation Communication Automotive Research and innovation
Project Acronym:	5GCAR
Document Number:	5GCAR/D1.2
Document Title:	5GCAR Mid-Project Report
Version:	v2.0
Delivery Date:	2019-01-31
Editor(s):	Mikael Fallgren (Ericsson), Markus Dillinger (Huawei)
Authors:	Mikael Fallgren, Bastian Cellarius, Yunpeng Zang, Gabor Fodor, Yunxi Li (Ericsson), Markus Dillinger, Konstantinos Manolakis, Apostolos Kousaridas, Hanwen Cao (Huawei), Antonio Eduardo Fernandez (PSA Group), Zexian Li, Stephan Saur, Juergen Otterbach (Nokia), Sylvain Allio, Laurent Gallo (Orange), Taimoor Abbas, Per Lindberg (Volvo Cars), Nadia Brahmi (Bosch), Rémi Theillaud (Marben Products)
Keywords:	5GCAR, 5G-PPP, 5G V2X
Status:	Final
Dissemination level:	Public

Abstract

This mid-project deliverable contains an overview of the 5GCAR results attained up until the writing of this report. The deliverable highlights the main results and provides references to the relevant deliverables. The results address a wide range of V2X challenges, ranging from use case and requirement definitions, investigation of business and spectrum related aspects, development of cellular, sidelink and position technical enablers as well as architectural components. The ongoing preparations for the final demonstration of three use cases are, together with the main dissemination and exploitation activities, are also outlined.

Generated technical findings will contribute to pre-standardization and normative standardization bodies like 5GAA and 3GPP to shape eventually 5G Rel-16 and Rel-17 for some of the technical enablers. For instance, 5GCAR project was able to agree on automotive service level agreements which help to define network and radio level requirements for assisted and autonomous driving use cases.

5GCAR was also able to contribute to the 5G-PPP activities by being the major driver for the Automotive WG. Moreover, project members organized external activities like conference panels and workshops to engage a broader external V2X community. Numerous publications have also underlined our ambition to be a power house for 5G V2X targeting to external organizations.

Contents

List of abbreviations and acronyms

3GPP	Third Generation Partnership Project
3GPP SA1	3GPP Service and System Aspects
5G	Fifth Generation
5G-PPP	5G Private Public Partnership
5GAA	5G Automotive Association
5GCAR	5G Communication Automotive Research and innovation
AS	Automotive Supplier
BF	Beam Forming
BLER	Block Error Rate
BS	Base Station
D2D	Device to Device
E2E	End to End
eMBB	enhanced Mobile Broadband
ETSI	European Telecommunications Standards Institute
EU	End User
GPS	Global Positioning System
HARQ	Hybrid Automatic Repeat reQuest
HMI	Human-Machine Interface
IMT	International Mobile Telecommunication
ITS	Intelligent Transport System
JPSON	JavaScript Object Description
KPI	Key Performance Indicator
LTE	Long Term Evolution
MIMO	Multiple Input Multiple Output
MNO	Mobile Network Operator
MWC	Mobile World Congress
N2I	Infrastructure to Vehicle
NR	New Radio
OEM	Original Equipment Manufacturer
OTDOA	Observed Time Difference of Arrival
OTT	Over The Top service provider
P-UE	Pedestrian User Equipment
P2N	Pedestrian to Network
PC5	Proximity Services (ProSe) direct Communication interface 5
Q1	Quarter one
QoS	Quality of Service
RAT	Radio Access Technology
Rel	Release
RRM	Radio Resource Management
RSU	Road Side Unit
SDN	Software Defined Network
SM	Smart
SON	Self-Organizing Network
SOTA	State Of The Art
SW	Software
TEV	Telecom Equipment Vendor
UC	Use Case
UCC	Use Case Classes
UE	User Equipment
URLLC	Ultra-Reliable and Low-Latency Communications
UTAC-CEVA	United Test and Assembly Center Ltd - Centre d'Essais pour les Véhicules Autonomes (i.e. test center for autonomous vehicles)
Uu	Air interface between BS and UE
U.S.	United States of America
V2I	Vehicle-to-Infrastructure
V2I2V	Vehicle-to-Infrastructure-to-Vehicle
V2N	Vehicle-to-Network
V2P	Vehicle-to-Pedestrian
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-Anything
VRU	Vulnerable Road User
WG	Working Group
WP	Work Package

1 Introduction

5GCAR is a European Union co-funded project that started 1st of June 2017 and is running for two years. The total project budget is close to 8 M€ and 30 full time equivalents working during the project duration.

This document is the 5GCAR mid-project report which gives an overview of the 5GCAR achievements during its first year. The highlights are on main project results in focus together with references to the deliverables for interested readers who wish to learn more. These project deliverables can be found on the project website, https://5gcar.eu/ [5GC17-D11].

1.1 Objective of the document

This mid-project deliverable contains an overview of the 5GCAR results attained up until the end of the first project year together with future outlooks for the remaining part of the project. References to the 5GCAR project deliverables behind these main results are also provided. The objective of this document thereby goes very much hand in hand with what the 5GCAR project works to achieve:

- clarify use cases and requirements for future connected vehicles as well as identifying innovative business models and important spectrum aspects;
- develop a 5G radio and architecture design that provides
    - very low latencies below 5 ms,
    - with very high reliability (99.999%),
    - at very high vehicle velocities,
    - which enables, even in a very high vehicle density, the support of a broad range of V2X services,
    - and achieves advanced positioning with accuracies below 1 m;
- develop a 5G system architecture that is flexible in its functional and topological configuration, with advanced quality-of-service management to efficiently support a wide range of V2X services and business models;
- demonstrate – with real 5G test equipment and vehicles – three exemplary V2X use cases for assisted/automated merging of multiple lanes, cooperative perception for maneuvers of connected vehicles, and vulnerable road user protection;
- disseminate results into the standardization, industry harmonization, and regulation via both the telecommunication and automotive industries as well as into international conferences, workshops, peer reviewed journals, magazines and books.

This range of V2X challenges together with the 5GCAR results and status at the first year into the project is what this document is all about.

1.2 Structure of the document

Section 1 gives a general introduction. Section 2 provides an overview of the project use cases, requirements, business models and spectrum aspects. Section 3 contains the 5G V2X radio interface highlights and in Section 4 the 5G V2X system and architecture work is summarized. In Section 5 the demonstration work is presented whereas Section 6 provides information on the dissemination activities. Section 7 concludes the deliverable with a future outlook, while the references are provided in Section 8. The 5GCAR project structure and 5GCAR consortium is provided in Annex A.

2 Scenarios, requirements, business models, and spectrum aspects

The requirements, business and spectrum activities of the first year are shown in two project deliverables. The first, focused on the requirement specification [5GC17-D21] and the second with a two axes approach one for the business model analysis and the other one for the spectrum aspects [5GC18-D22].

2.1 Scenario definitions and requirement specifications

The overall goal of the 5GCAR project is to contribute to the specification of 5G to become a true enabler of V2X applications that today are not realizable due to the limitations of current communication networks. In [5GC17-D21] 5GCAR has defined five Use Case Classes (UCCs) taking into consideration the different sets of operations required by cooperative and automated vehicles. Each UCC enables a different functionality and consists of various use cases. Each use case analyses the respective functionality or operation in a different context (i.e., road conditions, road environment, level of automation etc). Here is the list:

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

5GCAR has selected one relevant and representative Use Case (UC) from each of the Use Case Classes (UCCs) taking into account their impact (e.g., societal, safety purposes, business opportunities), their frequent occurrence in future highways or urban environments and the challenges that they set for the communication system. The five 5GCAR use cases are illustrated in Figure 2.1. For each of them, a study based on Key Performance Indicator (KPI) have been made focusing into three categories: automotive requirements, network requirements and qualitative requirements. Each use case and its most important KPI(s) are highlighted here:

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

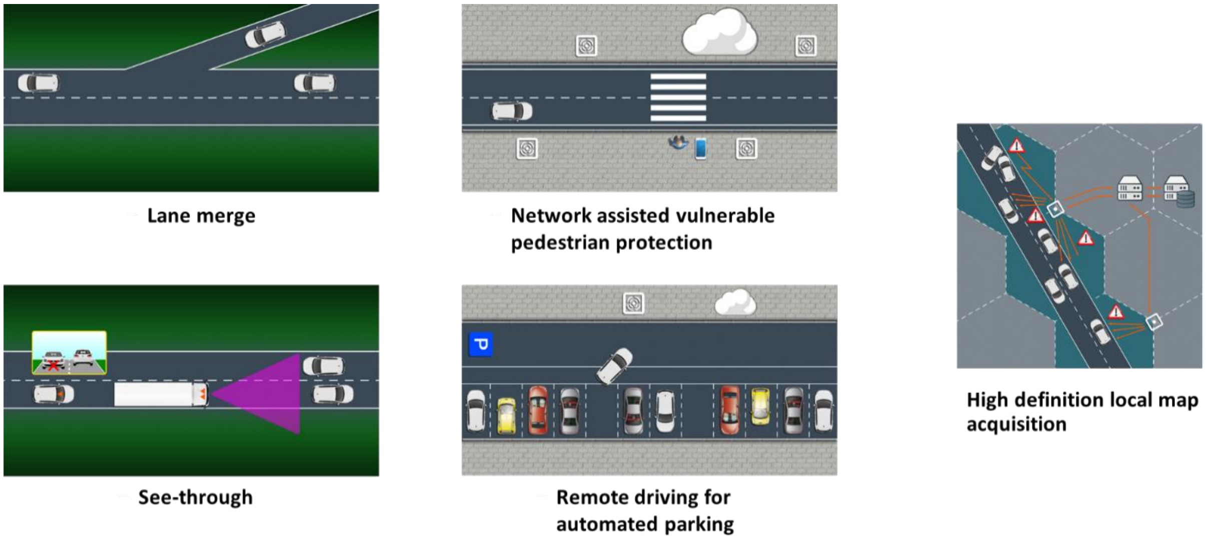

Figure 2.1: The 5GCAR use cases

The scenario definitions and requirement specifications work in [5GC17-D21] serves as input for the technical work in the project, see Section 3 and Section 4. From the list of five use cases, the first three of them will be practically demonstrated in the project, see Section 5 for details.

2.2 Business models

The objectives of the business model part of this study are to identify how 5G can enable new business models, based on new technologies and features of 5G. The study in [5GC18-D22] has discovered:

- There are technical features in 5G that can enable new business models for various stakeholders in the value chain. Network slicing and mobile edge computing are examples of such features.
- Existing services as well as autonomous driving features and convenience services may be enhanced by 5G technologies, thereby building added value in these services.
- The value chain as it looked at the writing of [5GC18-D22] (Q1 2018), may be disrupted by 5G, driven by new 5G technologies, as well as changing eco-systems around the connected car, where a rapid digitization of existing industries is complemented by new types of digital and industrial stakeholders.

A high-level description of a number of services that can be used with 5G has been described. These services will differ from the use cases developed in [5GCAR-D21], to extend the scope of which elements in 5G that will have an impact on the business model. The services identified, should expose all the different elements that constitute a complete business model, and specifically highlight new features in 5G that has not been available in previous generations of mobile technology.

The services have been divided into three different categories:

- Existing services,
- Autonomous driving features, and
- Convenience services.

Existing services are services already available on the connected car market. There are opportunities to enhance the quality, lower costs or in other ways modify the delivery and value chain using 5G technologies, for this category of services.

Autonomous driving features are a set of services intended to enable the use of autonomous driving vehicles. Some autonomous driving features could be mandatory for higher levels of autonomy; other services may be used to enhance the user experience.

Convenience services are services intended to enhance the user experience, not directly related to the task of transportation. These are services that in some cases could only be supplied by the use of 5G, other services could be enhanced by the use of 5G.

On the high level we could argue that the two key technology **enablers** are:

1) An innovative Radio Access Technology (RAT) for V2X communications, enabling both infrastructure based and sidelink based communications (direct communication between devices, a.k.a. Device to Device, D2D, communications). This enabler, together with high accuracy positioning techniques, is being studied and further developed in 5GCAR, especially targeted for future scenarios.
2) The virtualization of the communications network, from the radio to the core. The virtualization of all the elements of the end-to-end communication network allows for a highly dynamic and reconfigurable setting of the infrastructure. This technology enabler is being studied and further developed in 5GCAR.

Elements such us the provision of the connectivity, the continuity of the service in roaming (much more when a European digital single market is now available) and coverage availability are crucial and may jeopardized any new business. There is work still to be done related to the cross-MNOs, cross-OEMs or cross-border communication aspects. These elements have high importance and shall be studied in the next 3GPP releases.

To highlight the impact, on a business model perspective, of the arrival of 5G into automotive, two representative applications have been selected, namely: over the air updates and autonomous driving. In each application, an evolution is given from the traditional business model towards the new possibilities enabled by the technological components coming with 5G.

The transition from current telecom sector and automotive sector value chains into possible ecosystem for future is illustrated in Figure 2.2. More details are provided in [5GC18-D22].

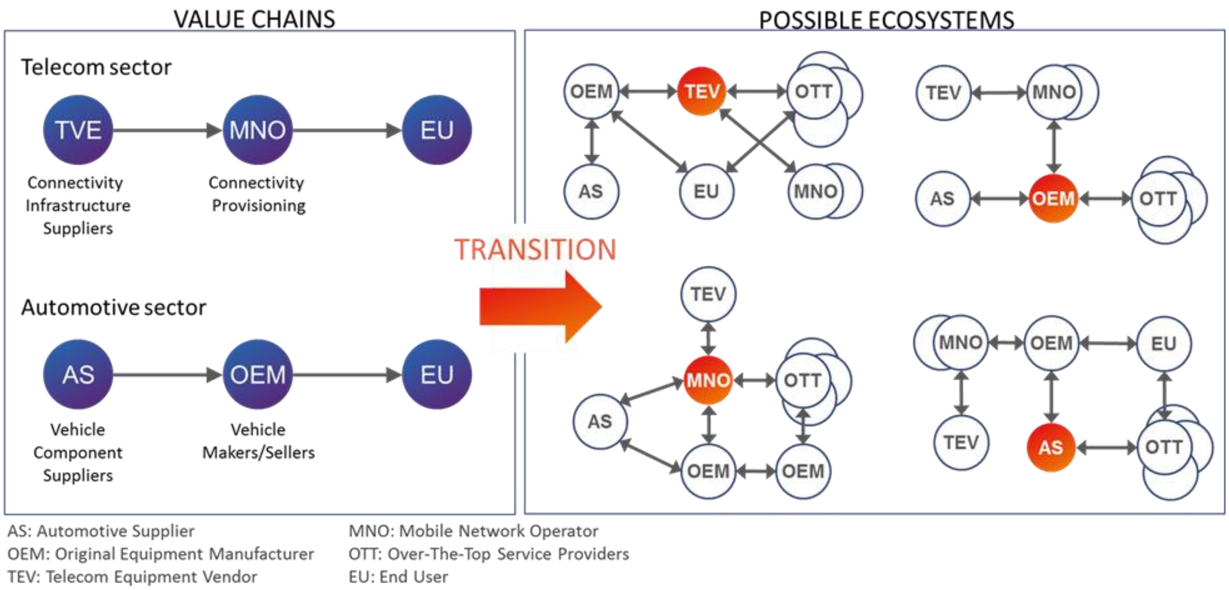

Figure 2.2: Different perspectives on how connectivity and new services can change the automotive and telecom value chain

The new business model analysis described above is complemented by the 5G Automotive working group white paper [5GA18-WP], published by 5G-PPP as a first outcome of the automotive working group concerning analysis of the 5G V2X deployment cost, triggering a discussion on revenue and benefits, and taking into consideration that advanced driving solutions will be first applied in highways (deployment of 5G digitalized highway) to enable safe transportation. The launching and success of 5G V2X (which is considered fundamental to enable ITS services) is directly related to the investments costs and expected revenue, mainly during first years of deployment. The business case is built under a commercial vision, any regulation on this topic would affect the outcome of this of studies. There is still a lack of understanding of the required rollout investments, business models and revenues – on which 5G V2X deployment is strongly dependent – in order to provide future ITS services. The white paper [5GA18-WP] provides a 5G ITS landscape including the main stakeholders, relationships and proposes an investment and possible business model to describe the cash flow.

2.3 Spectrum aspects

The objectives of the spectrum analysis part are to identify appropriate spectrum usage alternatives for enabling advanced ITS and automotive services applications using 5G technologies. In the first part of 5GCAR a survey of the already designated frequency bands that are under consideration for 5G technologies on their suitability for V2X communications in different regions of the world was conducted [5GC18-D22]. The 5GCAR spectrum activity is currently idle and will reappear towards to end of the project to contribute in the analyses of how the 5GCAR use cases can be supported, considering their capacity needs, the features of candidate spectrum bands as well as further explored novelties of the ones being presented in Section 3 and Section 4. In the already conduced survey, [5GC18-D22], it was discovered:

- The usage of 5.9 GHz band for ITS services applications using short-range Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication is harmonized in many regions of the world.
- Licensed frequency bands for mobile networks over the world are available suitable for providing Vehicle-to-Network (V2N) communications.
- The combination of 5G candidate frequency bands in the low, middle, and high band ranges in different regions of the world will enable ITS and automotive services that have requirements of both large coverage range and high system capacity.

Spectrum regulations are issued by regional regulators and can vary from region to region. In this study we investigate the spectrum resources that are usable for V2X communication to support ITS and automotive applications in different regions and countries, particularly in Europe.

To fulfil the requirements of advanced 5G mobile services, including ITS and automotive services, new 5G spectrum are being identified in different regions of the world. In Figure 2.3 an overview of the ITS dedicated spectrum worldwide is illustrated. The frequency bands being considered for 5G in different regions, e.g. European Union, the U.S., and China, mainly fall into three ranges: 600 MHz / 700 MHz in the low band range, 3.1-4.2 GHz and 4.4-4.99 GHz in the mid band range, as well as 26/28 GHz and 38/42 GHz in the high band range. Identifying 5G frequency bands in low, mid, and high band ranges will enable the 5G system fulfilling a wide range of requirements of the services, ranging from wide coverage range to high system capacity.

V2X as a social benefit, everybody need to contribute to the deployment of these new services while high prices for frequency band allocation may become a penalty for V2X deployment. Cost-free renewal of the concession of current licensed bands with specific conditions applied to V2X could also be an option. According to the 5GCAR use cases analyzed in the project, the better spectrum bands are medium or low frequencies with lower propagation loss and better range. Coverage has precedence over bandwidth for V2X use cases so far.

The uncertainty in spectrum usage remains, unless coexistence of multiple radio technologies in the same frequency band and interoperability among them are resolved, particularly for the safety-related ITS applications. This uncertainty in spectrum usage has also impacts that may slow down the market roll-out and business development of V2X technologies.

From a regulatory point of view, **spectrum allocation should be technology neutral**. This applies both to unlicensed spectrum, as for the European Union 5.9 GHz ITS band discussed above, and to licensed spectrum. It is observed that the newly developed 5G NR technology in 3GPP Rel-15 plans to re-uses the IMT bands currently being used by the 4G LTE technology.

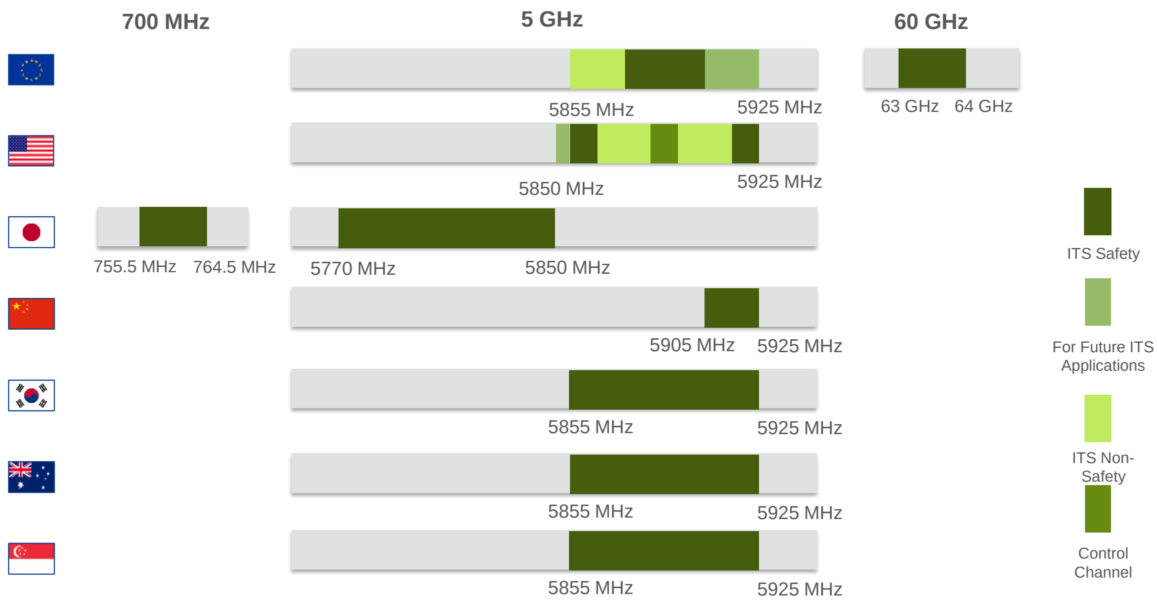

Figure 2.3: Overview of the spectrum dedicated for ITS worldwide

High reliability and availability of V2X communications are clear demands from the automotive industry for satisfying the functional safety requirements of safety-related applications including connected autonomous driving. Using redundant transmissions in distantly separated bands in the frequency domain is one way to achieve this, which is also supported by the findings of this study. Many spectrum bands, including both licensed and unlicensed bands, have been identified suitable for V2X communications. It must be emphasized that the usage of licensed spectrum is up to the licensees, i.e. the MNOs, who need justified business models to make appropriate decision.

2.4 Next steps

The main activities planned for the second half of the project are:

- There will be a global review of the requirements expressed in the deliverable [5GC17-D21] in the last term of the project, according to the practical tests made in the demos and any feedback provided by other dissemination activities in other projects related to network performances which shall confirm or modify our initial assumptions
- The business model investigation will continue. The opportunity given by the 5G-PPP automotive working group to exchange analysis and possibilities with other projects and entities will remain an important platform.
- Any frequency auction made for 5G during next year will be taken into account, to update the frequency survey conducted in [5GC18-D22] as well as paying attention to any new frequency band which may be proposed. The quantities involved in these auctions will be taken into account in the business perspective as well.

3 5G V2X radio interface

The 5G radio interface for V2X communication plays an increasing essential role for supporting the emerging new use cases targeting to support fully autonomous driving in all kinds of environments. The 5GCAR project aims to contribute to 5G network design, and specifically to design V2X technology components for V2X use cases identified in the project. It is quite clear that the key requirements derived from the identified use cases including reliability, latency, data rates, spectral and energy efficiency cannot be fully supported by today's wireless networks. In order to effectively support the future fully autonomous driving, novel V2X solutions which can meet the stringent End-to-End (E2E) latency, reliability, data rate, spectral efficiency and energy efficiency requirements become necessary which can result in designing a new radio interface.

As discussed in Section 2.1, the use case classes (UCC) identified in the 5GCAR project include cooperative maneuver, cooperative perception, cooperative safety, intelligent autonomous navigation and remote driving, which impose a broad range of challenging requirements on the radio interface. The 5G radio interface is expected to support high date rates with low latency and ultra-high reliability simultaneously. To meet the 5G V2X requirements the 5GCAR project have studied a number of new technology components that can be combined and deployed jointly such that these requirements can be met. The studied technology components are summarized in [5GC18-D31] and have a broad coverage ranging from the Uu interface (i.e., 3GPP terminology used for the wireless interface between device and network) related concepts and sidelink interface (i.e., 3GPP terminology used for the wireless interface between devices), in addition to efficient ways of using positioning information for V2X communications. They include direct communication between vehicles (V2V), communication between vehicle and road infrastructure (V2I), between vehicle and pedestrian (V2P) and vehicle to radio network (V2N). The needed functionality can be provided by different actors as illustrated in Figure 3.1.

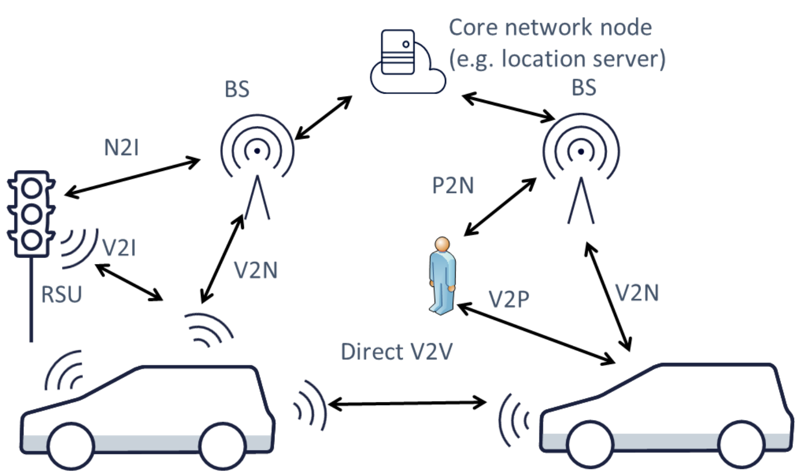

Figure 3.1: Various V2X communication scenarios

3.1 Infrastructure-based 5G V2X radio interface

With respect to infrastructure-based technologies, realistic multi-antenna channel estimation and prediction schemes, as well as their validation in outdoor field trials was performed. For mmWave transmission, taking into account different transceiver architectures, broadcast and beamforming schemes have been studied to meet different sets of requirements. Multi-beam/multi-node multi-vehicle communication techniques for enhanced reliability with various source of diversity were studied. We have investigated reference symbol design for high speed scenarios and also optimal power setting between data and pilot signaling. Initial proposals of dynamic multiplexing of mission critical messages and other traffic types, trade-offs between signalling overhead and achievable spectral efficiency have been investigated and the work will continue in the second year as well. Another aspect which has been studied within the project is the radio frame design aspects. Moreover, we have investigated the optimal retransmission schemes to achieve very low BLER. Here is the list of the proposed technology components:

- Sensitivity analysis of the predictor antenna system
- Predictor antenna for massive MIMO adaptive BF
- Genetic-algorithm based beam refinement for initial access in millimeter-Wave mobile networks
- Beam-domain broadcasting for V2N/I links
- Beam-based broadcast schemes for V2X applications
- Efficient preemption-based multiplexing of services
- Decentralized pilot-to-data power ratio configuration in multi-cell multi-user MIMO Systems
- Enhancing reliability in V2X Communication by exploiting diversity from cooperative links
- Fundamental trade-offs between reliability and latency
- Joint optimization of link adaptation and HARQ retransmissions for URLLC services in a high-mobility scenario

3.2 Sidelink for 5G V2X radio interface

The sidelink-based V2X technology components enable the delivery of V2X services in the absence of infrastructure nodes and take advantage of network assistance under infrastructure coverage. The 5GCAR sidelink technology components we have studied include a network assisted reliable discovery mechanism, synchronization and reference signals, adjacent channel interference mitigation and several radio resource management, power control and scheduling mechanisms. In addition, we have also studied to use sidelink for cellular communication reliability enhancement. Benefits due to full duplex capability at vehicles are studied as well. The list of the studied technology components is as below:

- Power control and scheduling to mitigate adjacent channel interference in vehicle-to-vehicle communication
- Sidelink resource allocation with network assistance using multiple antennas
- Synchronization for the V2V sidelink: sequences and algorithms
- Sidelink assisted reliable communication
- Reference signals design for direct V2X communication
- Code-expanded random access for reliable V2X discovery
- Distributed RRM for direct V2X communication
- Radio resource management in 5G enabled vehicular networks
- Cognitive full duplex communications in V2X networks

3.3 Positioning and channel modelling

Within 5GCAR, positioning and channel modelling are another two important topics. We have studied the channel modeling gap in terms of the key missing components required for complete solution for V2X channel modeling. Based on the gap and beyond prior art, we have carried out: i) new V2V measurements and characterization of channels above 6 GHz; ii) multi-link shadowing model based on measurements below 6 GHz; and iii) channel measurements for massive MIMO adaptive beamforming, see [5GC18-D31].

In terms of positioning, the following technology components that are essential for a positioning solution needed to enable 5G V2X use cases:

- Trajectory prediction with channel bias compensation and tracking
- Beam-based V2X positioning
- Tracking of a vehicle’s position and orientation with a single base station in the downlink
- Harnessing data communication for low latency positioning
- Enhanced assistance messaging scheme for GPS and OTDOA positioning

3.4 Next steps

For the next steps, in terms of the V2X radio interface, 5GCAR will further develop and evaluate the proposed technology components, investigate newly developed concepts, and continue to investigate the applicability of these technology components in 5GCAR scenarios. We also plan to integrate selected technology components into a unified system and thereby contribute to fulfilling the objectives of the 5GAR project. In addition, partners are encouraged to bring the outcome from 5GCAR to standard development for example in 3GPP.

4 5G V2X system and architecture

5GCAR studies cellular-based V2X communications from a system and architectural point of view by starting from the 3GPP Rel-15 Service-Based Architecture as a baseline, with the goal of identifying its limitations and proposing innovations to overcome them. These innovations, which we refer to as “technical components”, are proposed in the context of three main domain areas, notably “5G E2E architecture for V2X communications” (Section 4.1), “Traffic flow optimization and coordination of multi-link and multi-RAT connectivity framework” (Section 4.2), and “5G Security and privacy for V2X communications” (Section 4.3). A global overview of how these domain areas interconnect is provided in Figure 4.1. Each technical component addresses a specific limitation of the current network architecture, and proposes a solution, which could require the definition of a new type of network function, and/or the extension of the capabilities of a network function already defined in the baseline architecture.

Network slicing also plays a fundamental role in 5GCAR, as it constitutes an important technical enabler for delivering stable performance to the different V2X use cases, with the stringent reliability and availability requirement imposed by vehicular applications. Network slicing is studied in 5GCAR, both from the core network and radio access network perspectives.

The studies performed in the first part of the project concerning the V2X system and architecture resulted in the publication of the deliverable [5GC18-D41]. The outcomes of the 5GCAR works will contribute to the evolution of the standardization of the 5G architecture, to make it a true enabler for vehicular applications.

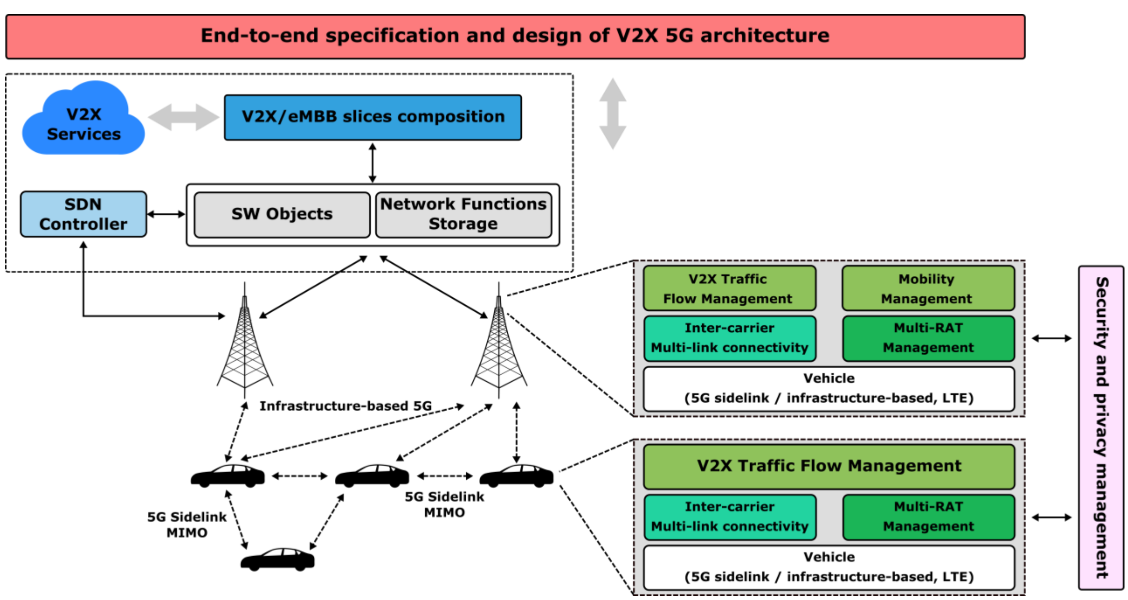

Figure 4.1: 5GCAR V2X system and architecture

4.1 5G E2E architecture for V2X communications

This domain area includes the solutions that directly involve the 5G architecture from an end-to-end perspective, resulted in four technical components (RSU-enabled smart zone, Infrastructure as a Service for vehicular domain, Multi operator solutions for V2X communications, and 5G core network evolution for edge computing-based mobility), briefly described in the following paragraphs.

“RSU-enabled smart zone (SM-Zone)” addresses the fact that V2X communications related to road safety and efficiency have local scope, by partitioning the road network into an ensemble of smart zones. Each of these SM-Zones is served by a 5G-RSU, which is a network entity controlled by the 5G cellular network, capable of supporting local communications using direct transmissions over the sidelink.

“Infrastructure as a Service for vehicular domain” is a paradigm conceived to ease the deployment, management, configuration, and upgradability of the ITS services and components deployed on the 5G network.

“Multi operator solutions for V2X communications” deals with the fact that vehicular UEs will need to be capable of connecting to multiple network operators, to be able to achieve high reliability. To address this issue while respecting the stringent V2X requirements, this technical component proposes a location-based management of the connectivity with multiple operators.

“5G core network evolution for edge computing-based mobility” is related to the deployment of applications related to the vehicular UEs on computing resources located on the edge of the network. This technical component addresses the timely migration of UE jobs running on the edge when the related UE perform a handover, in order to minimize the service interruption time.

4.2 Traffic flow optimization and coordination of multi-link and multi-RAT connectivity framework

User plane traffic optimization, which includes the management of multiple links and multiple radio access technologies, represents a topical area of research for V2X communications, and thus resulted in nine technical components (SON based multi-mode RSU for efficient QoS support and congestion control, sidelink and Uu multi-connectivity for high reliable and/or high data rate V2V communications, Location aware scheduling, Redundant mode PC5 + Uu, Evolution of infrastructure-based communication for localized V2X traffic, Use case-aware multi-RAT, multi-link connectivity, V2X service negotiation, Edge computing in millimeter wave cellular V2X networks, and Dynamic selection of PC5 and Uu communication modes), which are described in the next paragraphs.

“SON based multi-mode RSU for efficient QoS support and congestion control” is related to the concept of smart zoning. In this technical component, the problem of scalable and efficient support of V2X communications is tackled, by studying how the network can configure and control the operations of the 5G-RSU on the fly, based on dynamic road traffic characteristics and service demands.

“SL and Uu multi-connectivity for high reliable and/or high data rate V2V communications” addresses those scenarios wherein the sidelink may result inadequate to support the data rate and reliability required by V2V communications, by establishing simultaneously a direct link between vehicles and a second data path routed through the network infrastructure.

“Location aware scheduling” aims at extending the concept of QoS defined in 3GPP, by also considering the location-specific requirements of V2X data flows. This technical component proposes a mechanism to improve the efficiency of scheduling, allowing the network to optimize the usage of resources when distributing location-sensitive data (such as high-definition maps, which are considered as a case-study).

“Redundant mode PC5 + Uu” is a technical component the focuses on the contemporary utilization of both the direct PC5 link and of the infrastructure routed traffic, this time in order to improve reception reliability. The problem is treated in terms of redundant scheduler, of which multiple possible implementations are analyzed, each locating the redundant scheduler at a different layer in the protocol stack.

“Evolution of infrastructure-based communication for localized V2X traffic” is a technical component focused on the minimization of the latency introduced by the data path routed via the base station. To do so, an end-to-end local radio path is defined for user plane traffic, along with a low-level radio bearer management, which enables optimized, low latency local breakout communications touted via the infrastructure.

“Use case-aware multi-RAT, multi-link connectivity” is a technical component focused on the determination of the better combination of links and radio access technologies to efficiently satisfy the requirements of diverse V2X services, while taking into the consideration the high mobility of vehicles.

“V2X service negotiation” introduces the capability of exchanging information between V2X services and the network, in order to improve the mutual level of awareness, with the goal of optimizing the service delivery.

“Edge computing in millimeter wave cellular V2X networks” is a technical component that aims at optimizing the data rate and minimizing the energy consumption, in a scenario wherein multiple vehicular UEs cause interference to each other when communicating with mmWave-equipped road side units.

Finally, “Dynamic selection of PC5 and Uu communication modes” is related to the support of multiple links, specifically PC5 and Uu (i.e. between the UE and the base station). This technical component deals with the dynamic selection of the appropriate link for a specific V2X service, considered the benefit that each interface can provide at a specific point in time and space.

4.3 5G Security and privacy for V2X communications

Privacy and security implications of 5G-based V2X communications constitute a domain that overarches all of the architectural aspects. One major technical component is hence defined, named "Security and privacy enablers". As a baseline, a state of the art of the security architecture for V2X communication is provided, covering both the European and the American standards. These include the architecture of the Public Key Infrastructure to deliver the digital certificates to on board units and road side units, and the format of the digital certificates.

In the technical component, the legitimacy of the sender, and privacy are identified as key requirements of safety V2X messages. Two different approaches are investigated to offer the highest possible degree of security and ensure the privacy of V2X safety and non-safety transmissions. These solutions respectively foresee end-to-end security, wherein all verifications are performed by the receiving UE, and network-based security, wherein the capabilities of 5G network are exploited to perform consistency and relevance checks against V2X messages.

4.4 Next steps

In this first half of the project, the study efforts have been concentrated on the identification of the V2X related challenges and of the limitations of the current architecture. This resulted on the production of the fourteen technical components, each of which has an impact on the baseline 3GPP architecture, which until now have been studied individually and independently. In the next phase of the project, further analysis on system level will be conducted, with the focus on identifying the overlap, dependency, and interaction among the technical components. Evaluation of the technical components will be performed considering performance, feasibility, business considerations and other aspects, and additional technical components might be specified if the ongoing development will highlight new challenges. Studies on network slicing will continue, with the objective of defining the most suitable configuration for the 5GCAR use cases, in terms of performance, complexity, feasibility, and ability to integrate and support the novel technical components defined within the project. The goal of this process is the definition of the final 5GCAR V2X system and architecture, including the newly defined network functions and detailing the modifications required to the existing ones, already defined by 3GPP. The result will serve as input for the 3GPP standardization, in order to fully enable the support of 5G-based V2X communications.

5 Demonstration

The 5GCAR demonstration work focuses on devising and specifying the planned setup of each demonstration, based on input from [5GC17-D21], but also considering the ongoing technical work described above in Section 3 and Section 4. As part of that, a functional architecture for each demonstration was defined that is foreseen to enable implementation of the corresponding use case while fulfilling the corresponding use case requirements.

In the first months of the project, the demonstration task force specified the functional architecture of the demonstrations, different concepts for implementing the demonstration, the contributions of each project partner, a first sketch on the interaction between different demonstration parts, as well as a development and integration timeline for each demonstration. In the following months, the functional architecture was discussed and specified in more detail, interfaces were agreed on, including message formats and contents, and development of individual demonstration parts started as the concepts behind were discussed in more detail and overall refined. A major part of this was the planning of a common framework to acquire and disseminate information on road users over the cellular network, including the specification of a message format, as well as a common HMI solution for presenting different types of information in all demonstrations. Furthermore, a common communication unit in all vehicles facilitated the abstraction of the in-vehicle integration, needed for reading out sensor information from the vehicles.

In [5GC18-D51], a subset of the work was described, including the high-level architecture of each demonstration, and a brief summary of selected key concepts. On top of this, the requirements from [5GC17-D21] were picked up and corresponding demonstration KPIs were defined in [5GC18-D51]. Finally, plans on how to execute, demonstrate, and evaluate the demonstrations were elaborated on.

5.1 Lane merge coordination

In the lane merge coordination demonstration, a central lane merge coordination, connected some vehicles over a cellular network, orchestrates the merging process of an entering lane onto a motorway. This is assisted by an intelligent camera system that detects vehicles in the area of interest, thus also considering unconnected vehicles in the cooperative maneuver. The demonstration is illustrated in Figure 5.1.

One primary focus of the work on this demonstration so far was the interworking of multiple entities as part of an overall lane merge coordination entity, connected to vehicles over a cellular network. As this is a larger setup, including several types of messages and a non-trivial message flow, a substantial amount of work went into specifying this in detail.

Another focus was on the maneuver planning for lane merge coordination. Several aspects need to be considered here, including also things such as human reaction time, but also latency of information acquisition and dissemination of driving instructions. While this process is not yet finished, the task force managed to get a good understanding of the different challenges involved and identifying the different aspects to be considered during maneuver planning.

Finally, as the use case contains a closed loop between vehicle behavior and maneuver planning, integration tests are tricky, but very much needed. To facilitate part of the development and integration, and save time during common integration tests, a first set of field trials was conducted for gathering valuable data for further development, unit testing, and partial integration testing without the need to create the whole setup.

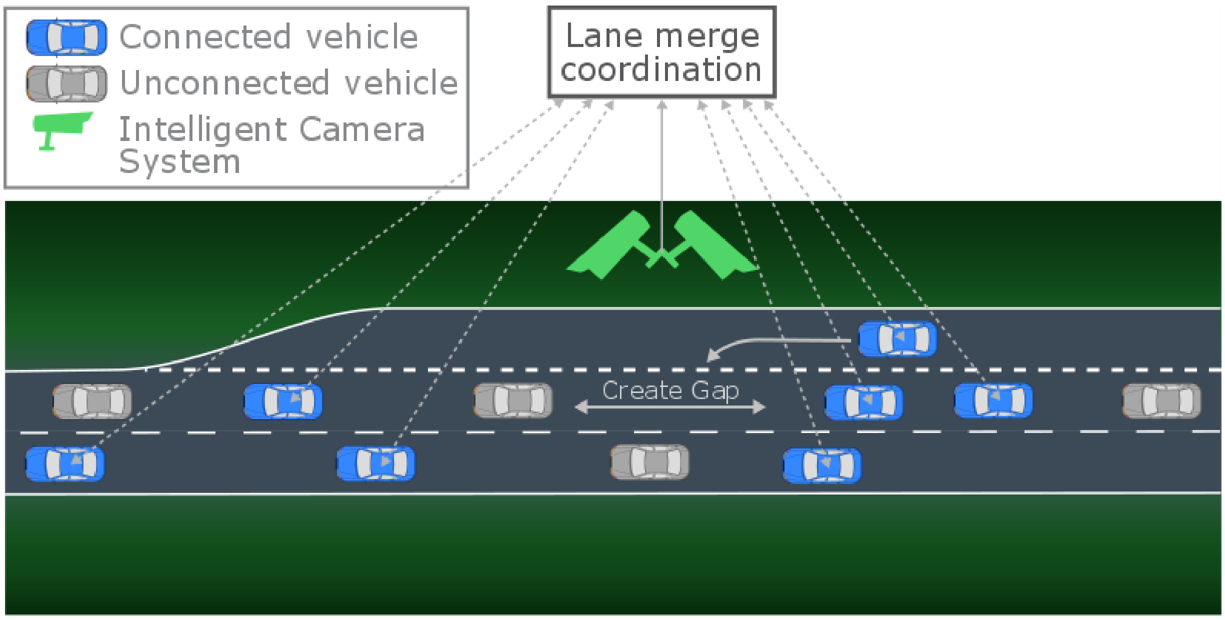

Figure 5.1: In the lane merge coordination use case, a central coordination entity plans the creation of a gap for vehicles entering a lane

5.2 Cooperative perception for maneuvers of connected vehicles

The cooperative perception demonstration originally planned to showcase a 'see-through' application for sensor sharing between two vehicles in proximity to assist in an overtaking maneuver. Further discussions with partners opened up the possibility of using the planned test network to facilitate long-range sensor sharing as a means to enhance perception cooperatively by identifying even unconnected vehicles and facilitate safer maneuvers at intersections. The scenario development for this latter "long-range" sensor sharing occupied a bulk of the partner's resources and time in the second half of the year. Both scenarios are illustrated in Figure 5.2.

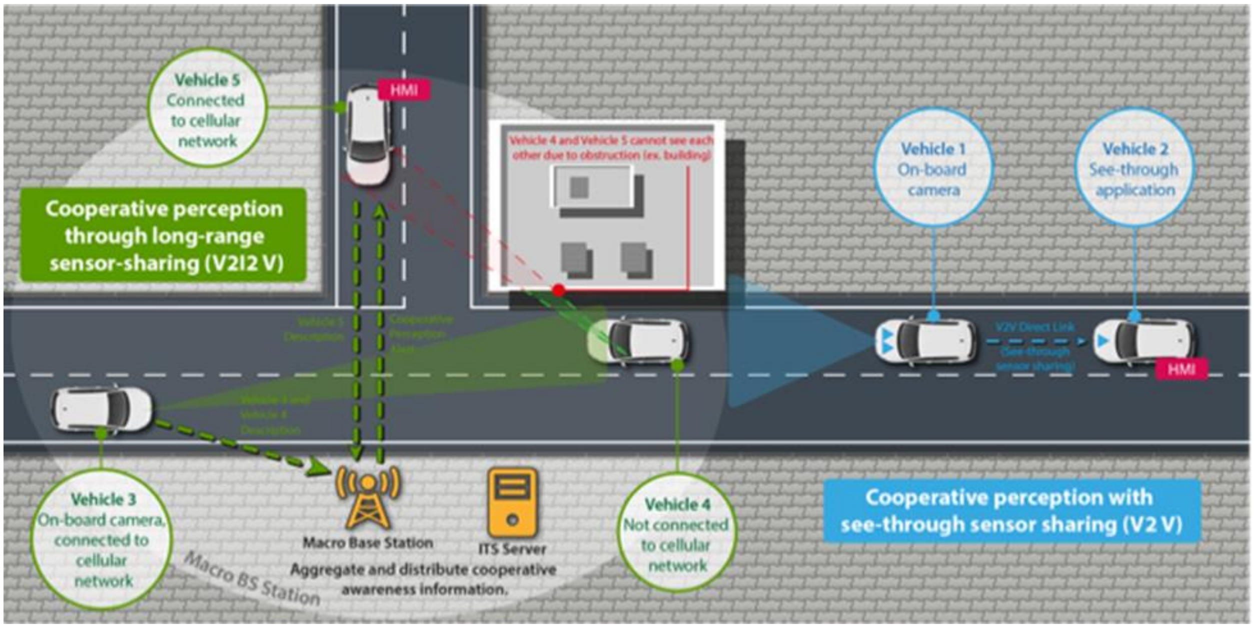

Figure 5.2: Overall demo scenario for 5G-enabled cooperative perception

The long-range sensor sharing demo will use the LTE test network deployed at the site together with an edge-ITS server to ensure reliable and context-aware message delivery to the connected cars. An on-board object detection and fusion solution that integrates with the car modem is being developed to detect velocities and positions of nearby vehicles. The message specifications for the cooperative perception alerts and the communication flows have been agreed between the partners and development work has commenced.

The see-through sensor sharing demo will use a communication prototype based on the ongoing 5G-V2X standard to ensure low-latency and high reliable direct communication for the see-through application. Development work for the prototype as well as the see-through system commenced at the start of the project and a successful first integration and field test of the two systems was achieved in May 2018. Further optimizations of the radio interface and the application are planned based on the analysis of the field test logs.

5.3 Vulnerable road user protection

The vulnerable road user protection demonstration uses a network-based positioning and collision prediction system for preventing collisions that cannot be predicted with in-vehicle sensors only. This is the case when pedestrian and vehicle are not in line of sight to each other. To achieve this, the vehicle and the pedestrian send out broadband 5G reference signals to several synchronized base stations. A central network element estimates the absolute positions using the individual time difference of arrival measurements and warns of impending collisions when applicable. The demonstration setup is illustrated in Figure 5.3.

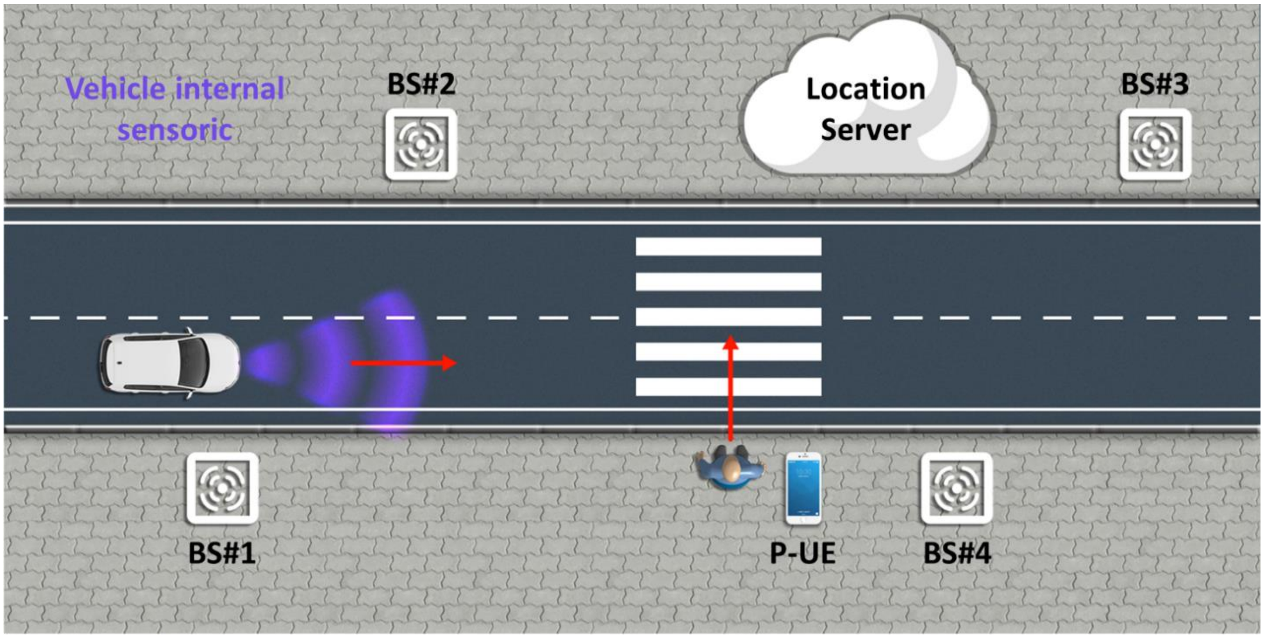

Figure 5.3: Top view for the VRU scenario

The top priority for the demonstration is to provide under all conditions safety of all involved participants. Due to that safety, it is planned to use a robot-controlled platform for VRU movement without any direct human interaction. Only remote operation is now foreseen. The used vehicle is only in operation by drivers with the appropriate test driver permission.

In the vulnerable road user protection demonstration, the primary focus is to determine positioning of the two participants by a 5G platform with appropriate modifications for this project. The timeline for further joint pre-integration in 2018 are aligned among the partners.

Inside the vehicle, an on-board unit will provide access to vehicle-internal signals. All communication will use LTE as communication path.

For the VRU protection demonstration, all required messages have been defined for vehicle and pedestrian. Communication links for message exchange using V2X gateway from partner are conceptually available. Furthermore, some V2X software modules are clarified and transferred planned to conduct further integration test.

First log files are provided by Orange using JSON format and enable further algorithm work in the location server element.

Inside the consortium there was a development started for non-critical and critical scenarios for final demo and described in [5GC18-D5.1] to a certain point. The scenario optimization will be done when further performance is known and measured. The scenarios are selected for a non-visible VRU by the vehicle sensors and behind an obstacle, e.g. a big truck in front of a zebra crossing.

The current project management communicated a new test side UTAC-CEVA to be used close to Paris area. Lure test side is not available anymore and all information up to know is obsolete. More local UTAC-CEVA information like available frequencies, robot-controlled systems for VRU and infrastructure details needs to be provided as soon as possible, latest in September timeframe for appropriate planning and ordering. Requirements from VRU demonstration are given to the management and to be considered to enable the further work.

5.4 Next steps

For each demonstration, the development and mainly the integration work will ramp up in the next months. This will include field trials in different constellations on a need basis, while some integration tests can also be performed over the internet, or by co-hosting different software parts. Finally, planning the final project event will be planned in more detail, including execution and presentation of the demonstrations, as well as evaluation of the demonstration performance.

For the lane merge coordination demonstration, a major part will be refining the maneuver planning concept and testing the feasibility in an overall integration test. Since the effort is quite high for this, sophisticated planning of the field trials will be needed in order to get the best out of short testing periods without time for major corrections during each field trial event.

For the cooperative perception demonstration, further optimizations on the 5G-V2V radio system and see-through HMI are expected for the short-range sensor sharing demo for a more seamless driver experience. Furthermore, a major work item will be the integration of the on-board object detection and fusion solution into the overall end-to-end setup. The VRU demonstrator needs a very specific infrastructure installation, and clarification for the planned test side on this installation and test frequencies needs to be done. Furthermore, the integration of testbed components in to the vehicle will be a focus, as well as iterative testing and finetuning of the collision prediction and warning system in different scenarios.

6 Dissemination and impact

The 5GCAR project implements a coordinated dissemination plan that foresees presentation and publication of project results at scientific conferences, journals, workshops, consumer expos, industry groups and forums, magazines and cross-project consortiums. The main purpose is to stimulate the international research community, thus accelerating the expected impact. Once the investigated technologies have reached a sufficient level of maturity and an early cross‑layer integration of concepts from all technical work packages has been achieved, project results are presented to a broader audience, e.g., in the scope of industrial exhibitions. The dissemination plan includes following major activities:

- International conferences, workshops, journals, magazines and books
- Workshop organizations
- Participation and contribution to European cluster and standardization meetings
- Interaction with worldwide consortia, forum and institutes
- Participation in public industry exhibitions
- Academic specific dissemination

Table 6.1 contains number of dissemination and communication activities linked to the project during its first year, from June 2017 to May 2018.

Table 6.1: Number of 5GCAR dissemination and communication activities.

Dissemination & Communication Activities	Number of activities
Participation in conference as invited speaker or presenter	10
Participation in a workshop as invited speaker or presenter	3
Conference paper published or accepted	9
Organization of a conference	0
Organization of a workshop	4
Participation in an event other than conference or a workshop, such as symposium, summit and so forth	10
Journal paper published or accepted	10
Submitted scientific papers	12
Press release	1
Popularized publication	1
Exhibition	2
Flyer	1
Training	1
Social media forums	3

Website	1
Communication campaign	1
Video/Film	1
Brokerage and pitch event/Trade fair	0
Participation in activities organized jointly with other H2020 projects	2
Organization of panel	4
Participating in panel as invited panelist	3
Organization of special session	1
3GPP	3

6.1 Dissemination and public communication

The 5GCAR consortium members very early in the project have identified a number of major activities for disseminating 5GCAR results. All these dissemination and exploitation activities have been selected with focus on technical objectives and performance research as well as on better understanding the societal impacts of various complexity levels of autonomous driving systems. In doing so, 5GCAR project during the first year in the project has organized a number of workshops, panels and special sessions as well as a demo at various conferences and industrial events. It has also published articles in peer-reviewed conferences, magazines and journals whereas some are already published in the proceedings and some are in the pipeline. The members of 5GCAR project are regularly invited as keynote speakers to give talks and give short courses on selected topics related to 5G for automotive. Besides that, the 5GCAR is able to bring relevant knowledge into the collaboration with other significant 5G-PPP projects, for instance in the 5G Automotive WG.

Finally, the presence on social media is also very important to reach out to a broader audience and share the latest results and activities within the project. To achieve that the 5GCAR project has created a website (www.5gcar.eu), and also used twitter, and LinkedIn as social media tools for dissemination.

All the dissemination and exploitation activities conducted in the 5GCAR project during its first year, from June 2017 to May 2018 are summarized in [5GC18-D61].

6.2 Standardization and exploitation activities

The 5GCAR project partners have been participating continuously to the standardization and regulation bodies meetings such as 3GPP and ETSI, industrial alliances such as 5GAA and European Union project partnerships such as 5G-PPP. The 5GCAR project addressed multiple topics from telco industry to car industry. Standardization and regulation bodies are also dealing either directly or indirectly with V2X. Even before the project officially started, the consortium identified a list of possible relevant bodies to be monitored (to ensure good alignment with project activities and the major trends of the ecosystems) and for contribution (to promote project outcome at a standardization level).

The exploitation activities in 5GCAR are bringing seemingly diverse areas together given the diversity of partners' area in the project. There is a various type of challenges that each of these industries are facing and that these challenges are interconnected to some extent, therefore partners coming together to address these challenges having difference perspective and expertise give a greater strength [5GC18-D61].

6.3 Next steps

The first year until this mid-term report has been successful for the 5GCAR project in terms of dissemination, public communication and exploitation activities. In the second half of the project several dissemination events, workshops, special sessions, special issues in journals, panels and publications are already planned and it is foreseen to increase even further.

Some of the 5GCAR dissemination events to take place in the second half of the project are listed in [5GC18-D61].

7 Conclusions and future outlook

The 5GCAR main achievements during its first year is highlighted in this mid-project document. There are many interesting details in the project deliverables that described.

From a general view point on 5G V2X, we still have to foster collaborations between car and telco industry, because not all requirements, required technical enablers and business cases are still under definition and changing. Already derived 3GPP SA1 requirements are first estimates and still lacking of thorough analysis and testing.

5GCAR was able to define for the first time automotive service KPIs, which so far were not properly addressed by 5GAA or by 3GPP SA1 for performance requirements on assisted and autonomous driving use cases. Derived from those service level requirement, one can now derive network and radio KPIs for 5G V2X.

The technology defining work has started to define integrated sidelink and network related technical enablers based on 5G, which exceed those technical enablers defined in 3GPP Rel-14. In 5G Rel-15 we are still lacking sidelink technical enablers. These new technical enablers have been partially evaluated as well by simulation tools and tested with real cars. New challenges beyond LTE-V2X are addressed here for better reliability and less delays. Other technical enablers support better positioning and interworking between control and data channels.

In state-of-the-art (SOTA) V2X technologies many activities focused on safety use cases enabled by broadcast technical components for V2V and V2I. However, for future comfort driving use cases around assisted and autonomous driving we must focus on more robust, less delay and more efficient communications in coverage and non-coverage situations. Techniques for switching from different coverage scenarios are also not yet defined by SOTA publications. In addition, 5GCAR has investigated recommendable configurations of technical enablers to optimize reliability and delays in mixed traffic scenarios.

5GCAR is also the founder of 5G-PPP Automotive WG which first deliverable has been published for MWC 2018. The published business analysis has shown that 5G connected, cooperative and automated mobility has a large economical potential in coming years. In addition, it has shown the requirements for needed collaboration between road operators, MNOs, OEMs and telecom industry.

In second project year we will define and evaluate more technical components and integrate essential ones in test beds to demonstrate their usefulness. It is our ambition to contribute to pre-standards and 3GPP for 5G V2X, Rel-16 which is planned for completion end of 2019. Besides the definition of technical enablers, 5GCAR must still contribute to ongoing eco-system building between the two industry sectors.

8 References

[5GA18-WP] 5G-PPP Automotive WG White Paper, "A study on 5G V2X Deployment", February 2018. https://5g-ppp.eu/wp-content/uploads/2018/02/5G-PPP-Automotive-WG-White-Paper_Feb.2018.pdf

[5GC17-D11] 5GCAR Deliverable 1.1, "Project Website", June 2017.

[5GC17-D21] 5GCAR Deliverable 2.1, "5GCAR Scenarios, Use Cases, Requirements and KPIs", August 2017.

[5GC18-D22] 5GCAR Deliverable 2.2., "Intermediate Report on V2X Business Models and Spectrum", March 2018.

[5GC18-D31] 5GCAR Deliverable 3.1, "Intermediate 5G V2X Radio", May 2018.

[5GC18-D41] 5GCAR Deliverable 4.1, "Initial Design of the 5G V2X System Level Architecture and Security Framework", April 2018.

[5GC18-D51] 5GCAR Deliverable 5.1, "Demonstration Guidelines", May 2018.

[5GC18-D61] 5GCAR Deliverable 6.1, "Intermediate Report on Standardization, Dissemination and Exploitation Activities", May 2018.

A 5GCAR project structure and 5GCAR consortium

A.1 5GCAR project structure

To address the objectives related to a successful deployment and completion of 5GCAR, the project is structured in four technical Work Packages (WPs), one work package for the management and one for the dissemination and exploitation of results. Each WP is coordinated by a WP leader. The technical WPs are further split into three detailed tasks, where each task has a partner appointed as task leader responsible for that particular task. The overall 5GCAR structure is illustrated in Figure A.1.

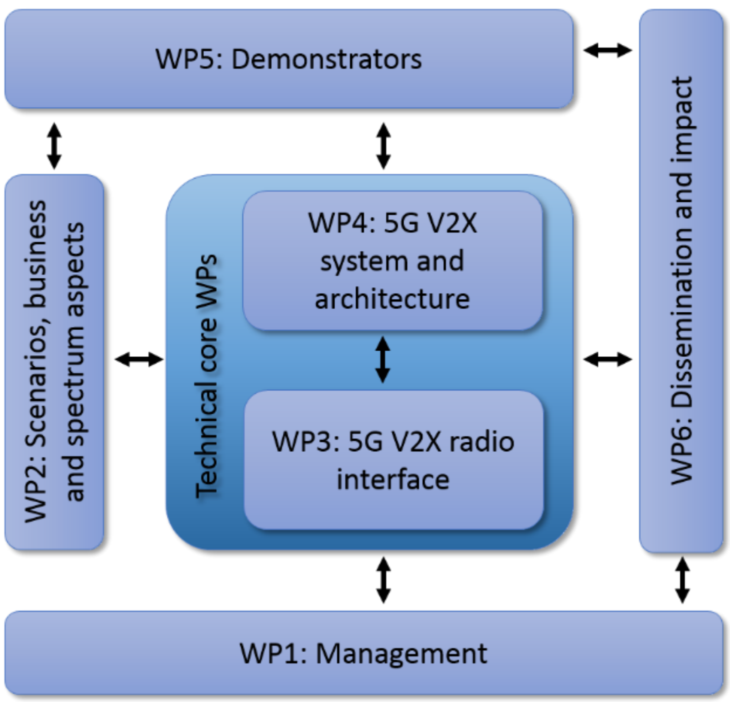

Figure A.1 : 5GCAR structure

In this document the mid-project highlights of the work packages two to six are presented on section-one-level from Section 2 to Section 6, with the WP2 highlights provided in Section 2, the WP3 highlights in Section 3, WP4 in Section 4, WP5 in Section 5, until the WP6 highlights that are provided in Section 6. Within these sections, the tasks of the respective work packages are being highlighted on section-two-level (part from the last section-two-level for each of these sections which instead highlight the next steps).

A.2 5GCAR consortium

The 5GCAR consortium consists of:

- **Telecom infrastructure providers**: Ericsson, Huawei, and Nokia
- **Telecom operator**: Orange
- **Car manufacturers**: PSA Group, and Volvo Car Corporation
- **Industrial equipment vendor**: Bosch
- **Academic partners**: Centre Tecnològic de Telecomunicacions de Catalunya (CTTC), Centro Tecnológico de Automoción de Galicia (CTAG), Chalmers University of Technology, and King's College London (KCL)
- **Small to medium sized enterprises**: MARBEN, SEQUANS, and VISCODA