On Selected V2X Technology Components and Enablers from the 5GCAR Project

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***Abstract*—Cooperative intelligent transport systems (ITS) and connected vehicles are foreseen to change the way mobility is conceived today. Cooperative and connected vehicles will lead to improved road traffic safety and efficiency and will also trigger innovation in the infotainment area. These will foster the design of disruptive new business models for both the telco and automotive industries, triggering a profound impact in society and economy. However, before this can become a reality, many technical challenges still need to be solved. One important challenge relates to the provision of efficient and reliable vehicle-to-anything (V2X) communications for the vehicles. The new emerging generation of mobile communications, the so-called 5G technology, is aimed at giving an answer to this challenge. Among other coordinated efforts, the European-funded 5GCAR project is looking into such V2X technology components and enablers. This paper aims at presenting and describing the technologies that are being considered in 5GCAR to make the vision of the cooperative and connected vehicle a reality.**

I. Introduction

Two strong technology trends, one in the mobile communications industry and one in the automotive industry, are becoming more and more interwoven and will jointly provide new capabilities and functionalities for upcoming intelligent transport systems (ITS) and future driving.

Over the last 25 years, the mobile communications industry has connected more than five billion people. Today, mobile (smart) phones have become part of our daily lives and connectivity is highly ubiquitous. The next step in wireless connectivity aims at connecting all kinds of things, machines and devices. This brings the concept of the Internet of Things (IoT) where everything will be connected to the Internet as long as some value can be obtained from such connectivity [1]. The development of the next generation of mobile wireless communications, the so-called 5G technology, aims at offering a technical framework to the challenge of connecting people and devices in a single common communications network infrastructure, to complement existing LTE and evolved-LTE for more demanding use cases. 5G aims at offering efficient and reliable communications for three kinds of services: 1) evolved mobile broadband (eMBB), 2) ultra-reliable low-latency communications (URLLC), and 3) massive machine-type communications (mMTC). Therefore, 5G will enable the connection of all kind of devices to the communication networks; vehicles are an important part of this vision. The interconnection and Internet connection of vehicles enables a wide set of innovations that will change the automotive industry forever.

In its turn, the automotive industry is on a path where vehicles are continuously becoming more aware of their environment due to the addition of various types of integrated sensors; at the same time the amount of automation in vehicles increases, which – with some intermediate steps – will eventually culminate in fully-automated driving without human intervention. Along this path, the amount of interactions increases, both in-between vehicles, as well as between vehicles and road users in general and an increasingly intelligent road infrastructure. As a consequence, the significance and reliance on capable communication systems for vehicle-to-anything (V2X) communication is becoming a key asset that will enhance the performance of automated driving and increase further road traffic safety with combination of sensor-based technologies.

In such context, the interaction and cooperation among the telco and automotive industries is necessary if 5G technology aims at offering what the automotive industry needs. Motivated by this, the 5GCAR project [2], funded by the European Commission under the Horizon 2020 program and under the framework of the 5G Public Private Partnership (5G-PPP) [3], brings together a consortium gathering partners from the automotive industry, the mobile communications industry, and also academia to conduct research and innovation actions at the intersection of those sectors to support a fast and successful path towards safer and more efficient future driving. The activity of 5GCAR is mainly focused on the next generation of communication networks, 5G, to facilitate V2X services which are not feasible today due to the limitations of existing communication networks. The general objectives of 5GCAR are aiming at improving wireless V2X communication technologies to reduce end-to-end latency, improve reliability, ensure very high availability, guarantee interoperability of heterogeneous radio technologies, increase scalability (massive access), and secure vehicular communications. The concept is illustrated in Fig. 1. The specific objectives of 5GCAR are:

- To develop an overall 5G system architecture which can provide optimized end-to-end V2X network connectivity for highly reliable and low-latency V2X services. It shall also support security and privacy, manage quality-of-service, and provide traffic flow management in a

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multiple Radio Access Technology (multi-RAT) and multi-link V2X communication system.

- To ensure interworking of multi-RATs that allows embedding existing communication solutions (including short range technologies) and novel 5G V2X solutions.
- To develop an efficient, secure, and scalable side-link interface for low-latency, high-reliability V2X communications leveraging 3GPP solutions [4].
- To propose 5G radio-assisted positioning techniques for both Vulnerable Road Users (VRUs) and vehicles to increase the availability of very accurate localization.
- To identify innovative business models and spectrum usage alternatives that support a wide range of 5G V2X services, which drive the functional design of the 5G V2X architecture.
- To demonstrate and validate the developed concepts and evaluate the quantitative benefits of 5G V2X solutions using highly and fully automated driving scenarios in test sites.
- To contribute to 5G standardization and regulatory bodies and the 5G automotive association (5GAA) for enabling radio-supported and automated driving solutions.
- To collaborate and integrate the 5G V2X radio access network concepts of the 5GCAR project into the overall 5G radio access network (RAN) framework, through participation in the 5G-PPP initiatives and events and interaction with other projects.

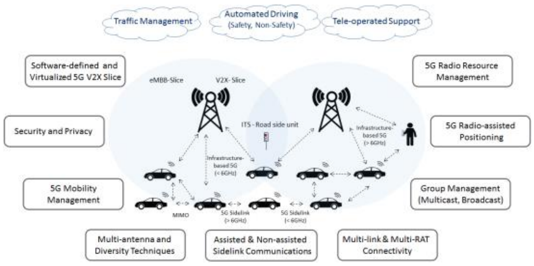

Fig. 1. The V2X concept and its key technical components, where 5G comprises the new radio (NR) and new core components as well as LTE and evolved-LTE.

To meet these objectives, the activities of 5GCAR are split in four main building blocks that interact with each other along the execution of the project following a continuous delivery approach:

1. Definition and refinement of key scenarios and use cases of focus of the activity of the project. These are use cases that cannot be satisfied today with existing technologies and, therefore, require the design of 5G networks. The project works towards the definition of their technical requirements, and the definition and identification of the suitable key performance indicators (KPIs). The first deliverable of the project was focused on this building block and the main findings can be found in [5].
2. Design and validation of innovative technical solutions to be included in 5G specifications. These consist of a set of advanced communication protocols and also support mechanisms, such as improved radio-based positioning techniques.
3. Study and design of innovative business models that can be devised on top of the connectivity enabled by 5G in the automotive industry.
4. Proof-of-concept and demonstration: one of the main objectives of the 5GCAR project is to show the feasibility and capability of the proposed solutions to fulfil the targeted objectives in real deployments. Towards this end, three representative applications will be showed, demonstrating that applications not realizable with today’s technologies can be facilitated by the 5G technology developed in the project.

This paper aims at introducing the technical components that have been identified as relevant enablers for the 5GCAR project. They can be split into two groups: 1) those relevant to the design of a new V2X radio interface, and 2) those related to the design of an innovative V2X 5G architecture. They are introduced and described in Sections II and III, respectively. Finally, Section IV concludes the paper.

II. V2X RADIO AIR-INTERFACE DESIGN

Regarding the V2X air-interface, 5GCAR aims to develop efficient and scalable enhanced 5G air interface to enable low-latency, high-reliability V2X communications. Towards this end, 5GCAR is considering both infrastructure-based communication interfaces, i.e. between vehicles and network infrastructure, and sidelink communication interfaces, i.e. direct data exchange among vehicles without routing data traffic through the network infrastructure.

Within 5GCAR project, starting from radio research related challenges derived from the identified 5GCAR use cases, various technology components have been proposed to address the major challenges. The studied technology components have a broad coverage ranging from the Uu interface (i.e., 3GPP terminology used for the wireless interface between device and network) and sidelink interface, 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, such as the road traffic authorities, OEMs (Original Equipment Manufacturers) and transport companies, as illustrated in Fig. 2.

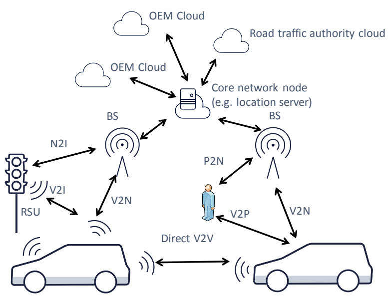

Fig. 2. Various V2X communication scenarios.

For a robust air-interface design, one important prerequisite is the availability of appropriate channel models. For that reason, 5GCAR is studying existing channel models for V2X, their limitations, the gap analysis, as well as to contribute beyond the state of the art. 5GCAR is providing a channel modeling and model selection framework that helps to select correct V2X environment, link types, propagation mechanism and, finally, the relevant channel models which could be used for system simulation and verifications.

The major contributions, named technical components, of 5GCAR regarding the V2X radio interface can be grouped as:

1) Infrastructure-based solutions,
2) Sidelink-based solutions,
3) Positioning enablers for V2X.

The specific areas of contribution for each group are listed in the following subsections.

A. Infrastructure based solutions

- Study of fundamental trade-offs between reliability and latency,
- Multiple antenna related enhancements;
- Design of efficient multiplexing between enhanced mobile broadband (eMBB) and ultra-reliable and low latency (URLLC) services,
- Beam-based mmWave broadcasting for V2X applications,
- Advanced channel state acquisition for efficient and highly reliable Uu links,
- Fast and robust mmWave multi-node/multi-beam tracking with/without cooperative sidelinks assistance
- Optimization of link adaption/HARQ, power setting between pilot and data,
- Enhancement of reliability by exploiting diversity from cooperative links including sidelinks.

B. Sidelink based solutions

- Design of reference and synchronization signals,
- V2X discovery mechanisms with code-expanded random access,
- Sidelink radio resource management strategies,
- Adjacent Channel Interference (ACI) mitigation strategies.

C. Positioning as enablers for V2X communications

- 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 Observed Time Difference of Arrival (OTDOA) positioning.

D. Discussion

In the following, we briefly discuss some of the technology components proposed by the 5GCAR project. The interested reader may refer to [6] for a detailed discussion.

The first one is beam-based V2X broadcasting with mmWave. We have investigated efficient ways to set up beam group with the help of location information, beam management, frame structure design and so on. The broadcast beam optimization can refer to determining the azimuth and zenith angles (α, β) and beam width θ of the broadcast/multicast beam for a given awareness-area-group or relevance-area-group based on the location information hosted by the location server for example. In addition, flexible frame structure has also been studied to support both unicast and broadcast services.

Actually, flexibility is a key driver of the definition of 5G in 3GPP. The standard introduced the support of URLLC communications in the same framework than eMBB. Though eMBB was the priority target to complete the specification by the end of 2017, URLLC support was drafted, introducing the baseline that will enable efficient and secured V2X services. Some of the high-level principles rely on preempting eMBB services with regard to URLLC. In 5GCAR, efficient preemption techniques are developed to support fast retransmissions. Such techniques will enable URLLC transmission that can support efficiently the V2X related services.

Channel state information at the transmitter side (CSIT) is key for robust and spectrally efficient vehicle-to-infrastructure (V2I) links. 5GCAR builds on top of a previously proposed predictor antenna concept that provides an efficient way of acquiring CSIT by adding one additional antenna in front of the receive antenna(s) in the direction of mobility. In 5GCAR, this concept is being further studied with regard to sensitivity to important system parameters and how to compensate for them, integrating the predictor antenna concept with advanced beamforming schemes, and evolving the concept for large multiple-input multiple-output (MIMO) scenarios.

Further, multi-node/multi-beam refinement and tracking is important to enable fast and seamless mobility in dense mmWave networks. Motivated by this, 5GCAR has proposed a genetic-algorithm based beam refinement scheme that outperforms the state-of-the-art methods in terms of end-to-end throughput with moderate complexity. 5GCAR is currently generalizing it to include knowledge of vehicles' mobility directions and assessing the advantage of utilizing sidelinks for cooperative multi-vehicle beam refinement and tracking.

Another group of technology components that are being studied in 5GCAR is devoted to improve reliability with the help of effective combing of sidelink and infrastructure link. Assuming that the discovery phase is completed, in case of transmission failure due to various reasons, the sidelink can be used as complementary link for improved reliability, for example using sidelink as a relay link. Efficient sidelink resource allocation/selection is another key topic studied in 5GCAR. The considered cases cover efficient sidelink resource allocation via "knowing" the interference situation, cooperative sensing for optimal sidelink resource selection, joint V-UE/C-UE resource allocation. Cellular radio-based positioning plays a key role in the future V2X communication as well. For example, with the help of highly accurate location information (radio-based positioning and tracking), safety can be improved significantly.

In the remaining execution of 5GCAR it is planned to further develop the proposed technology components and investigate new ones. On top of this, efficiently integrating the most important technology components (e.g. mmWave based V2X broadcast, Uu plus sidelink interfaces, making full advantage of the available positioning information) into a unified system and thereby to contribute to fulfilling the objectives of the 5GCAR project.

III. V2X SYSTEM LEVEL ARCHITECTURE

Yet another aspect of the 5G V2X communications is the end-to-end system architecture that can deliver the KPIs for connected autonomous driving. Such network architecture should provide optimized end-to-end network connectivity for highly reliable and ultra-low latency services, enabling cooperative driving and safety scenarios, and providing the security and privacy required by the automotive industry.

To this end, we identify the general technical challenges brought by connected autonomous driving in five main technical areas, including,

1) V2X main characteristics (mobility, and simultaneous requirements for massive numbers of ultra-reliable, low latency, high bandwidth communications),
2) Multiple access network connectivity (including the management of multiple network slices),
3) Resilience requirements,
4) Security and data privacy,
5) Roaming between operators.

Most of the above challenges needs to be addressed considering a wide area coverage that covers the extensive road network, i.e. by improvements and enhancements to the cellular network, this is to a large extent being handled by regular work in standardization organizations such as 3GPP and continues extensions of road coverage. 5GCAR is also investigating technical solutions that are based on short range technologies and road side units (RSU[1]), these types of solutions might be economically feasible in certain urban areas.

With use of RSUs, we further explored potentials of edge-cloud functionality hosted at the RSU in addition to the normal hosting of edge applications at the cellular site. Second, we examine the use of multiple links (multi-link) and multiple radio access technologies (multi-RAT) through number of different solutions, e.g. using advance context information such as location. Using such context information, we further study enhanced scheduling and admission policy techniques. Some of these solutions are elaborated with more details in the reminder of this section.

[1] The RSU defined in [7] as “a stationary infrastructure entity supporting V2X applications that can exchange messages with other entities supporting V2X applications”.

Smart Zoning: Most of V2X service data flows related to road safety and road efficiency are local or specific to individual roads which are originated or terminated by road users on the same road or even particular area of the road. Assuming a number of RSUs are deployed along the road, they could potentially shape a zone together to support the V2X services throughout the service and while the vehicle is moving between coverage area of different RSUs. The smart zone concept addresses network integration and deployment arrangement, network access and admission control as well as mobility, for enabling fast, reliable and efficient vehicle communications in various mobility environments and road traffic conditions. In a conceptual view, a smart zone can be considered as a flexible and dynamically reconfigurable V2X service coverage which is local to a specific road or a limited area of the road.

Dynamic use of Multi-RAT and Multi-Links: various options of connectivity have so far been considered for connected autonomous driving including use of different technologies or different RATs. Also, direct communication of vehicles with each other, i.e. sidelink communication adds an additional link to the communication with the network entities, i.e. mobile base stations or access points. Dynamic and smart use of such diverse connectivity option is an essential part of any V2X solutions. In this regard, we examine the use of multi-link, i.e. using both sidelink and network-based communications, possibility of switching between them dynamically when and where needed and utilizing advance context information for making choices from multi-link and multi-RATs to support the required KPIs.

Use of advance context information: advance context information such as location, and speed of vehicles, type of cooperative driving or safety application that triggers communication at the vehicle, as well as detailed network capabilities could be exploited for further improving V2X communications. For example, location-aware scheduling that assigns or adjusts quality of service provisioning for each individual packet based on position-related information. Context-aware selection of multi-link/multi-RAT can ensure complete delivery of a cooperative driving or safety application that has been initiated from any vehicle. Finally, service negotiation will ensure only those cooperative driving or safety application will be initialized that can be completed successfully.

Support of multi-operator: it has been identified that V2X communication needs to de facto be addressed for a multi-operator environment, to consider e.g. cross border cases, but also the sidelink communication between two vehicles that are subscribed with different operators. While sharing of infrastructure have been widely discussed in the literature, however it requires complex agreements between operators. Splitting the overall area in regions where only one operator is responsible simplifies the multi-operator environment, could enable efficient V2X communication, however such a setup would also involve agreements between operators, e.g. agree on areas, allowing its UEs to use other operator networks (national roaming is not used nowadays). Furthermore, such a setup might have implications regarding free competition laws

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by excluding some operators. 5GCAR has investigated various options with respect to business model in [8].

Security and Privacy: V2X messages exchanged over the air may trigger safety (or not safety) actions on receiving vehicles: actions initiated by the driver when notified of some alerts or triggered automatically by autonomous vehicles. The consequences of such actions can be very serious. It is therefore critical to ensure the authentication of the V2X message sender, its permissions for sending such a message with such a content, the relevance of the message. The two potential solutions are the end-to-end security, where all verifications performed by the receiving UE, and network-side-based security, where all consistency and relevance checks against a V2X message are performed in the network. The current security solution for direct communication handled on the application layer and is based on that the authenticity of a message is ensured by signing each message using an anonymous certificate, i.e. a vehicle should alternative the signing among a high number of certificates, up to hundreds of certificates that should be exchanged every week. This create quite some challenges on the undelaying public key infrastructure (PKI) considering the scale of the solution with millions of vehicles performing this certificate handling.

IV. Summary

This paper has given an introduction to the activities within the 5GCAR project, which aims at contributing to the design of a 5G technology which can satisfy the needs of an automotive industry which is aiming at enabling new services based on cooperative and connected vehicles. The particular approach in 5GCAR is to propose a 5G radio interface and network architecture, leveraging the overall development of 5G by 3GPP, but tailoring it for the needs of the automotive industry. The aim of 5GCAR is to provide technical solutions which can enable a 5G network capable of delivering very low latencies below 5ms, very high reliability (99.999%), and radio-assisted positioning techniques which can guarantee accuracies below 1 meter. All this has to be achieved at very high vehicle speeds, even in very high vehicle densities, in order to support of a broad range of V2X services which can thus foster the development of innovative business models and facilitate the market revolution that is to come in the mobility industry.

The 5GCAR project is expected to be finished by mid-2019; by then, all technical components will be made publicly available and the demos will be ready to be shown, demonstrating the capabilities of 5G technology to satisfy the needs of the automotive industry to bring to life the provision of the cooperative, connected, and autonomous mobility paradigm.

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