Architecture and Enablers of 5G V2X Network Slice for Reliable and Low-latency Communications

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***Abstract*— This paper presents a set of architectural solutions for the connected car, by introducing a 5G V2X architecture being able to work in multi-operator and multi-OEM scenarios. 5G technologies will enable vehicles to be connected to the networks and also to be able to communicate with each other with ultra-high reliability and very low latency. Leveraging such kind of connectivity will enable disruptive new applications that will allow improving driving efficiency and boosting road safety. Objectives, use cases and results from the EC-funded 5GPPP 5GCAR project are presented, including a set of technology components such as local end-to-end data paths, multi-link and multi-RAT traffic flow and QoS management, location-aware scheduling techniques, and 5G V2X Network Slicing.**

Keywords—wireless communications; V2X; 5G QoS; Multi-PLMN; Network slicing

I. INTRODUCTION

5GCAR project, which is a 5G PPP Phase 2 project, brings together a consortium from the automotive industry, the mobile communications industry, and academia. The goal of the project is to develop technologies at the intersection of automotive and mobile communication sectors in order to support a fast and successful path towards safer and more efficient future driving [1]. The key objectives of 5GCAR are to reduce end-to-end latency, improve reliability, ensure high availability, guarantee interoperability of heterogeneous radio technologies, and increase scalability (massive access) and security of vehicular communications.

5GCAR has defined five Use Case Classes (UCCs) taking into consideration the different sets of operations required by cooperative and automated vehicles [2]. 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, level of automation etc). The 5GCAR use case classes are: a) cooperative maneuver, b) cooperative perception, c) cooperative safety, d) autonomous navigation, and e) remote driving.

5GCAR has selected one relevant and representative use case from each of the 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 use cases selected in 5GCAR are:

- Lane merge (Cooperative maneuver)
- See-through (Cooperative perception)
- Network assisted vulnerable pedestrian protection (Cooperative safety)
- High definition local map acquisition (Autonomous navigation), and
- Remote driving for automated parking.

According to the analysis in [2], the key requirements for each of the above 5GCAR use cases, are as follows: a) latency (< 30 ms) and high resolution localization for the lane merging, b) data rate (15 to 29 Mbps) for the see-through, c) reliability (99% to 99.99%) and localization (10 to 50cm) for the network assisted vulnerable pedestrian protection, d) localization (5 to 50 cm), density and security, for the high definition local map acquisition, and e) availability (99,999%), reliability (99.999%) and latency (5 ms) for the remote driving for automated parking.

Apart from the demanding performance requirements, Vehicle-to-Everything (V2X) communications also put several challenges on the 5G architecture. First, there are a multitude of V2X use cases and services, each of which has its own set of requirement and also its specific stakeholders involved. As a consequence, different services or even network functions may be provided and controlled by different administrative entities; furthermore, different applications have different service requirements, some of which have very demanding requirements as mentioned above. In addition, the traffic and vehicle situation can change very dynamically due to the inherent high mobility of vehicles; therefore, service provisioning can be dynamic in time and space. The 5G networking architecture will also likely witness a redesign on the flow of uplink and downlink data streams. While cellular networks have been designed for a dominating amount of downlink (DL) traffic, we are observing that uplink and sidelink are becoming more and more important with the growth of high definition video sharing among vehicles as well as data and safety applications.

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II. 5G V2X Technological Components

In this paper, we introduce V2X solutions that are developed in the context of the 5GCAR project [1] that allow the design of a 5G V2X architecture working in multi-operator and multi-OEM scenarios. The developed V2X solutions also enable integrated seamless connectivity for multi-link, multi-Radio Access Technologies (RAT) operation, where ultra-low latency and ultra-high reliability Key Performance Indicators (KPIs) must be supported to enable new critical communication use cases in the automotive industry like next generation of connected driving and cooperative automated driving. More specifically,

- Local end-to-end (e2e) data paths over the Uu interface is proposed to support fast and guaranteed transmission of localized data traffic among the involved vehicles (e.g., cooperative maneuver, cooperative perception).
- Multi-link and multi-RAT traffic flow and Quality of Service (QoS) management solution is introduced to support a massive number of vehicles whilst insuring the requirements for low latency and high reliability.
- A location aware scheduler is proposed to help QoS requirements for packet delivery to be interpreted in terms of geographical region or distance from a target reference area.

The introduction of regional split among the operators, where only one operator is responsible for one region, simplifies the multi-operator environment and enables efficient, low latency and reliable V2X communication. All the above technologies are smoothly integrated by forming a dedicated 5G V2X network slice with network and application functions to support different types of V2X traffic.

III. Slicing the Network for V2X

As discussed throughout this paper, V2X is an umbrella term that entails multiple traffic types, spanning from cooperative safety, to high definition maps distribution, remote driving, and remote maintenance. Each of these classes of service is characterized by a unique Service-Level Agreement (SLA) and area of relevance. For instance, while remote driving requires ultra-Reliable and Low Latency (uRLLC) unicast connections between a vehicle and a server within the cloud of its manufacturer, cooperative perception foresees the transmission of broadcast messages which are meant to be received by users in proximity of the transmitter.

Network slicing is a technological enabler that will be adopted in 5G for supporting multiple services with different SLAs on the same infrastructure. Slices are virtual networks, all sharing the same physical infrastructure, whose implementation is tailored to serve a specific service class. Numerous works are already available in literature, investigating and proposing solutions for network slicing; however, to best of our knowledge, no in-depth study is currently available considering the diversity of traffic patterns, data paths, and at the same time the stringency of requirements demanded by V2X applications.

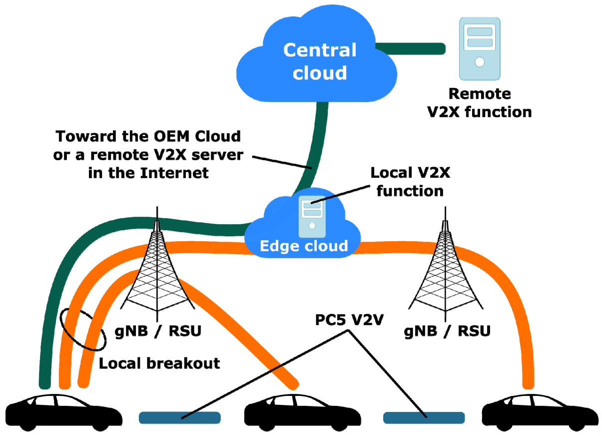

Fig 1. Multiple E2E communication links in 5GCAR.

Differently from previous 5GPPP projects, in 5GCAR we focus our attention on automotive needs, which require a redefinition of the concept of "end to end". As described in this paper, V2X transmissions include messages directed to servers located in the Internet, messages locally routed by the infrastructure (in local breakout configuration), and direct V2V transmissions over the PC5 interface, these latter being both unicast and broadcast. In all these configurations, a road user (either a vulnerable user or a vehicle) constitutes one end, whereas the other end can either be a remote server, a server located at the edge of the cellular network, or a vehicle in proximity, as illustrated in Fig. 1.

In 5GCAR, we aim at defining flexible network slicing able to support all of these communication paradigms. The scenarios described in this paper are some important examples. For instance, locally routed traffic operates only in proximity of road users: the related slice may hence only involve network elements from the gNB up to the edge cloud. This may also be the case for the distribution of CAMs utilizing location-aware scheduling.

On the other hand, Multi-RAT and multi-link connectivity is necessary to achieve the strict reliability constraints imposed by automated driving applications. Such messages hence need to be contemporarily transmitted over multiple interfaces (PC5 and Uu) and/or over different RATs, which will extend the current slice concept and require novel design.

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