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5G-V2X: standardization, architecture, use cases, network-slicing, and edge-computing

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Abstract

Vehicular communication is one of the critical technologies in intelligent transportation system to provide connectivity between vehicles, road side units, and pedestrians. Multiple wireless accessing technologies designed to provide connectivity in vehicular networks such as conventional Wi-Fi, IEEE 802.11p, and cellular communications. Recently, cellular V2X (C-V2X) is standardized and designed by the third generation partnership project (3GPP) for automotive services. C-V2X supports two communication modes through a single platform to provide both Wi-Fi and cellular communication. LTE-V2X is the current 3GPPRelease 14 standard that has many enhancements to provide the new 3GPPRelease 16 for the new 5G radio generation. 5G-new radio (NR) is expected to address the automotive capabilities, improvement, and services for 2020 and beyond. 5G-NR becomes a competitive technology compared with other wireless technologies because of extensive coverage, high capacity, high reliability, and low delay support. In this paper, we propose the Optimizing of 5G with V2X, and analyzing the current V2X standards, introducing the development of 5G, challenges, features, requirements, design, and technologies.

Keywords 5G radio · C-V2X · 3GPP · IEEE802.11p standard · LTE-V2X · Autonomous driving · Slicing · Edge-computing

1 Introduction

The recent advent of Vehicle-to-Everything (V2X) communications has made it possible to decrease the number of vehicle accidents, and all its associated fatalities [1] dramatically. Not only does the advantages of V2X vehicles confine on shrinking accidents, but it can also assist in traffic management and thus lead to greener vehicles and a decrease in fuel costs [2]. Both safety and other non-safety vehicle applications are presented in intelligent transportation systems (ITS) and the Radio Access Technologies (RATs) used for communication in V2X are Dedicated Short Range Communications (DSRC), which operates in the 5.9 GHz band, and the 3rd Generation Partnership Project (3GPP) has presented Cellular-V2X (C_V2X)—a Long Term Evolution (LTE) based RAT—which also operates in 5.9 GHz band in addition to the licensed carriers of cellular operators and can also operate in the absence of the cellular infrastructure in a distributed manner [3].

DSRC is developed based on the IEEE 802.11p standard but is still not widely used in V2X communications due to its poor scalability and its deficiency in performance in a highly mobile environment. C-V2X is the complete integrated road safety solution, which proposed in the 3GPP Rel.15 C-V2X can be used in automated and semi-automated driving modes by integrating it with other existing vehicle technologies. C-V2X introduces different communication modes of Vehicle-to-Vehicle (V2V) communication, Vehicle-to-Infrastructure (V2I) communications within the radio spectrum 5.9 GHz frequency band, Vehicle-to-Network (V2N) communication using the licensed mobile spectrum, and Vehicle-to-Barrier (V2B) communication. V2B is proposed recently in vehicular

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communications to facilitate wireless communication between roadside barriers and vehicular communication systems. Within C-V2X, it's expected to decrease the Run-Off-Road (RoR) crashes, which estimate significant losses of the roadside crashes. The existing vehicular technologies may not address V2B, but some recent literature discussed its importance, you can refer to [4, 5], which describes the V2B communication mode based orthogonal frequency division multiplexing (OFDM) and proposing the first real test of V2B, with addition to describing V2B communication in vehicular cloud.

C-V2X exceeds DSRC in performance in the following aspects: it increases the link speed, more suitable to V2X communications in its decease of interference, and its capabilities of non-line-of-sight (NLOS) [6].

Recent studies proved that DSRC and C-V2X could both perform acceptably in safety applications if the density is not very high [7], and the required end-to-end latency is not more than 100 ms. However, as such applications require a very high Quality of Service (QoS), both RATs are not yet up to the expected performance [8].

To decrease the gap between the performance of DSRC and C-V2X and to increase the facilities offered by both as more modes of operation and higher throughput, IEEE 802.11 Next Generation V2X began in March 2018 [9] formed in 2019 IEEE Task Group 802.11bd (TGbd), Also, 3GPP is working on developing a New Radio (NR) V2X for its Rel. 16, building atop of 5G NR that was standardized in 3GPP Rel.15. The QoS of use cases required to be supported by NR V2X is expected to be far much higher than that mentioned earlier for C-V2X [10] as it requires an end-to-end latency that does not exceed 3 ms and reliability of 99.999%.

The design of 802.11bd and NR V2X is very challenging, with these additional constraints with the stringent specifications of high mobility environments make the design of 802.11bd and NR V2X.

5G applications can achieve a very high data capacity with higher throughputs and lower latency to support multimedia services. As the requirements for 5G applications grow more, enhancing RATs to be more suitable for them becomes a high priority. 3GPP has many trials of defining the 5G specifications and applications. 5G is a very challenging radio technology to support the earlier discussed high QoS needs of V2X and the challenging specifications of highly mobile environments. Projects as Next Generation Mobile Networks Alliance (NGMN) [11], and 5G Automotive Association (5GAA) are working to evaluate 5G-New Radio (5G-NR), and LTE based V2X in cooperation with vehicular industry.

As all the available studies about V2X challenges based on 5G are mostly white papers and commercial announcements, this paper is introduced as the first technical study to analyze these challenges and compare between DSRC and C-V2X applied in 5G networks with security recommendations. It is also concerned with the requirements of V2X in 5G networks and the available trials of standardization of deployment in V2X and LTE. In this paper, we extend the previously published book chapter in [12] that briefly includes the V2X based 5G standards. In [12], we introduced the 5G current technologies that were proposed to evolve the 5G within V2X communications. We continue the work in this paper and summarize the paper contributions as follows:

- The paper introduces the current V2X technologies
- It compares the V2X based DSRC technology and V2X based cellular technology
- It introduces the evolution of 5G New Radio in V2X communication
- Study the 5G-V2X challenges and issues.
- Study the new 5G-V2X use cases and the critical requirements of them.
- Study the 5G-New Radio (5G-NR) design consideration and importance.
- It defines the proposed 5G-V2X system structure and design consideration
- Study the network slicing features in 5G-V2X.
- Finally, we introduce the 5G-V2X data properties and Edge-Computing capabilities in 5G-V2X.

The rest of this paper is organized as follows: Sect. 2 provides an overview of vehicular communication technologies. Section 3 explains cellular network evolution from 4G to 5G. In Sect. 4, we introduce 5G-V2X requirements and challenges. In Sect. 5, we present V2X use cases and critical requirements for 5G. Section 6 explains in detail the proposed 5G system structure. In Sect. 7, 5G-V2X slicing technology is given. Section 8 presents the edge-computing features of 5G and the 5G-V2X data properties. Conclusions are given in Sect. 9. Table 1 represents all the acronyms used throughout the paper.

2 Overview of V2X technologies

In this section, we discuss V2X based DSRC technology and V2X based cellular technology.

2.1 DSRC V2X technology

WAVE and ETSI both worked on two standardizations for DSRC technology in V2X communications by the US and EU, respectively, using different architectures. Two blocks mainly characterize VANET networks; road side unit (RSU) which gives the road vehicles security and

Table 1 Summary of acronyms

CDF	Cumulative distribution function	CA	Certificate authority
C-ITS	Cooperative intelligent transport system		
4G	Fourth generation mobile networks		
5G	Fifth generation mobile networks	D2D	Device to device
C2C CC	Car-2-Car communication consortium	BSM	Basic safety message
CAM	Cooperative awareness message	eNodeB	Evolved NodeB
CRL	Certificate revocation list	IEEE	Institute of electrical and electronics engineers
C-V2X	Cellular vehicle to everything	MTC	Machine type communications
DENM	Decentralized environmental notification message	MTC-M2M	Machine type communications/machine-to-machine
DoS	Denial of service	NOMA	Non-orthogonal multiple access
DSRC	Dedicated short-range communications	mMTC	Massive machine type communications
DSRC	Dedicated short-range communications	MIMO	Multiple-input multiple-output
eMBMS	Enhanced multimedia broadcast multicast service	MME	Mobility management entity
eMTC	Enhanced machine type communication	MNO	Mobile network operator
ETSI	European telecommunications standards institute	QoS	Quality of service
FDM	Frequency division multiplex	5G-NR	5G-NewRadio
GNSS	Global navigation satellite system	NHSTA	National highway safety transportation administration
HSM	Hardware security module	OFDM	Orthogonal frequency-division multiplexing
I2N	Infrastructure to network	OFDMA	Orthogonal frequency division multiple access
I2N2V	Infrastructure to network to vehicle	SDN	Software-defined networking
I2V	Infrastructure to Vehicle	U Plane	User plane
LTE-V2X	Long term evolution-vehicle-to-everything		
ITS	Intelligent transport system	OSI	Open systems interconnection
ITS-G5	Intelligent transport system @5.9 GHz	UTRAN	Universal terrestrial radio access network
IVI	In-vehicle infotainment	UE	User equipment
KPI	Key performance indicator	URLLC	Ultra-reliable low latency communications
LTE	Long term evolution	PHY/MAC	Physical layer/medium access control
MBB	Mobile broadband	CAMP	Crash avoidance metrics partnership
MIMO	Multiple input multiple output	SIM	Subscriber identity module
OBU	On board unit	PPP	Precise point positioning
PCA	Pseudonym certificate authority	PKI	Public-key infrastructure
PCO	Protocol configuration options	USIM	Universal subscriber identity module
PLMN	Public land mobile network	WAVE	Wireless access in vehicular environments
ProSe	Proximity services	WAN	Wide area networking
PSK	Pre-shared key	PCO	Protocol configuration options
RAT	Radio access technologies	CSI	Channel-state-information
RSMA	Resource spread multiple access	NLOS	NonLine of sight
RSU	Road side unit	ECDSA	Elliptic curve digital signature algorithm
SAE	Society of automotive engineers	5GAA	5G Automotive association
SCMS	Security credential management system	BVR	Beyond visual range
SCPTM	Single-cell point to multipoint	3GPP	3rd generation partnership project
V2X	Vehicle to everything	V2V	Vehicle-to-vehicle
VRU	Vulnerable road user	V2B	Vehicle-to-barrier
V2I	Vehicle-to-infrastructure	SPS	Semi persistent scheduling
V2P	Vehicle-to-pedestrian	SDN	Software defined networks
CSMA/CA	Carrier sense multiple access/colloision avoidance	FCC	American federal communications commission
NGMN	Next generation mobile networks alliance	AAA	American automobile association
C-V2X	Cellular-vehicle to everything	DCC	Distributed-congestion-control

infotainment services through a fixed access point and also handles communication between vehicles and the infrastructure and vice versa, the second block is an Onboard Unit (OBU) used inside each vehicle for wireless communications in between.

The communication from vehicle to infrastructure and vice versa is handled by the RSU, which communicates with the vehicles within its communication range.

V2V communications support message broadcasting about road status and allow vehicles to communicate even they are not covered by network infrastructure. While V2I is a bi-direction wireless communication between vehicles and infrastructures such as road signs, traffic lights, and lane markings that can be enabled by a system of software, hardware, and firmware components. Infrastructure can communicate with vehicles to share information about traffic jams, crashes, sharp curves, and promoted speeds. Intelligent and Innovative infrastructure is required to maintain digital V2I ecosystems. Some new technologies are involved to increase and improve roadways safety, such as advanced road markings and smart digital signs to provide faster and accurate decisions for both vehicle systems and drivers.

The American Federal Communication Commission (FCC) defined 5.9 GHz communication range as the range for Vehicular Ad Hoc Networks (VANETs) in 1999, IEEE802.11a (Wi-Fi) standard was extended and IEEE802.11p was introduced to support the ad hoc mode. It can control high mobility conditions caused by high speeds from multi-path reflections, and Doppler shifts obstructions. The congestion scenarios caused by high density are handles in IEEE802.11p by Distributed Congestion Control (DCC) and Multiple Access with Collision Avoidance (CSMA-CA) [13].

DSRC was introduced to support vehicular communications with safety and non-safety applications, and thus, IEEE802.11p was in its stack to handle the ad hoc mode and to support traffic safety and prevent accidents in bandwidth spectrum from 5850 to 5925 MHz for both V2V, V2I modes. Many changes are made to the physical and MAC layer of DSRC to handle the ad hoc mode. DSRC had many challenges to resolve to support vehicular communications, and these challenges are as follows:

- *Network congestion control* IEEE 802.11p includes contention-window techniques and adaptive messages frequency techniques to decrease the congestion, but are not applicable in high-density networks.
- *Variety of applications* RSUs were not widespread in the early deployment of V2X, and thus IEEE802.11p was not efficient in supporting all requirements.
- *Communication overhead* IEEE802.11p is yet not suitable for high data ultra-low latency applications as it has a significant communication overhead that consumes bandwidth and increases latency in error retransmissions.
- *Resources allocation* A single communication medium is shared between all vehicles using the same network resources in IEEE802.11p. IEEE802.11p is obliged to use a fair management algorithm for coordination between vehicles and efficient resource management.
- *Reliability delivery* Unreliable delivery is a problem sill faced by IEEE802.11p in large scale networks due to the available radio spectrum limitations.
- *Authentication and privacy* New security challenges are raised in large density networks that could not be satisfied by PKI as anonymity, driver authentication, lightweight message, privacy solutions, and integrity.

IEEE 802.11p cannot satisfy the requirements of the new V2X requirements, which motivates moving from WAVE standard to cellular standard, as mentioned earlier. Nowadays, the standardization community is moving towards introducing cellular technologies in V2X communication [14].

2.2 Cellular V2X technology

In this section, we go through all the stages 3GPP has gone through for enhancing C-V2X standards and then compare C-V2X to IEEE V2X technologies.

Cellular technology has been a powerful candidate for supporting vehicular communications because of its wide coverage, security and mobile services, and high network capacity. As shown in Fig. 1 the enhancement of C-V2X has gone through three stages as follow [14]:

1. *Stage 1* Since 2015, in the 3GPP Release 14 [1], LTE has been used for basic V2X applications as CAM, DENM, and BSM. 27 use cases have been defined by 3GPP covering V2N, V2I, V2V, and V2P applications. It has proved to support V2X services using Uu interface-based LTE networks and also an efficient resource allocation and selection service, an enhanced physical layer, and synchronization service.
2. *Stage 2* In Rel-15 [14] enhancements have been introduced to support V2X advanced scenarios [15] as remote driving, vehicle platooning, extended sensors, and advanced driving. Some functionalities are introduced while remaining compatible with Rel.14 as CA for mode-4, radio resource pool sharing between mode-3 and mode4 UEs, reduction of time between packet arrivals at Layer 1–10 ms (compared to 20 ms at Rel. 14) [16], TTI shortening and resource selection. Also, 5G 5G-V2X has been started 3GPP recently to define performance metrics, simulation scenarios, channel modeling, and spectrum to evaluate enhanced

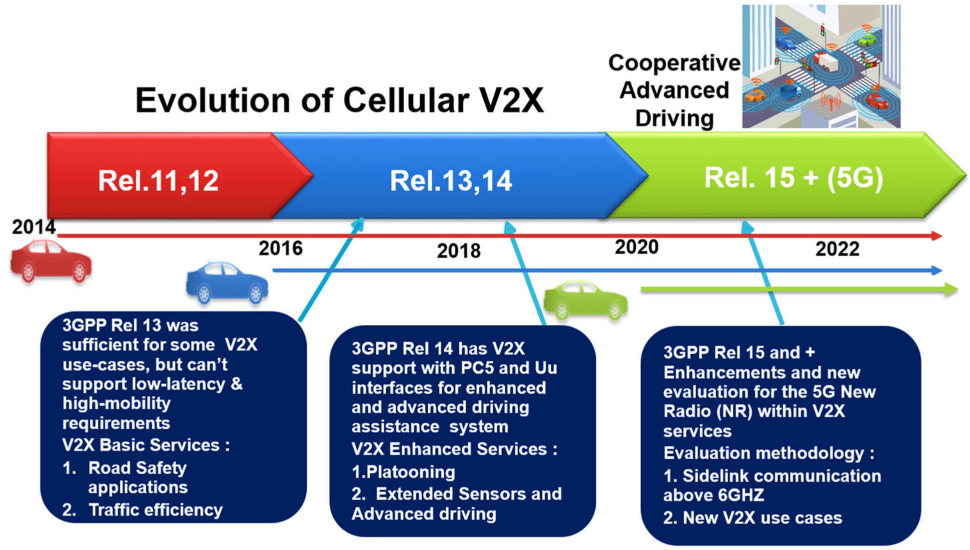

Fig. 1 C-V2X standardization and evaluation

V2X services. Datang and Huawei Chinese telecom companies help 3GPP in the standardization of V2X and LTE-V2X application development [17].

3. *Stage 3* Starting in 2016, V2X solutions have been developed through 5GAA and NGMN [18] to cover road safety solutions and connected cars.

In TS 22.185 [19] the services required by typical V2X applications, which are defined to include: message transfer frequency to be in the range (10–50) Hz, a long communication range to give a longer response time, V2X communication should be supported in and out of coverage of the network, transmission latency less than 100 ms should be supported and up to 20 ms in some cases.

LTE-V2X uses two transmission modes as shown in Fig. 2 to support the services mentioned earlier:

1. *LTE-PC5* PC5 supports V2X communications using sidelink. This allows users to communicate directly without using the infrastructure and thus gaining lower delay, higher throughput, lower energy consumption, and better spectrum utilization [20–22].
2. *LTE-Uu* When the UE is inside network coverage LTE-Uu interface supports V2X communications. V2X transmissions in this mode are scheduled; thus, interference and collisions can be controlled (3GPP TS36.321, July 2015).

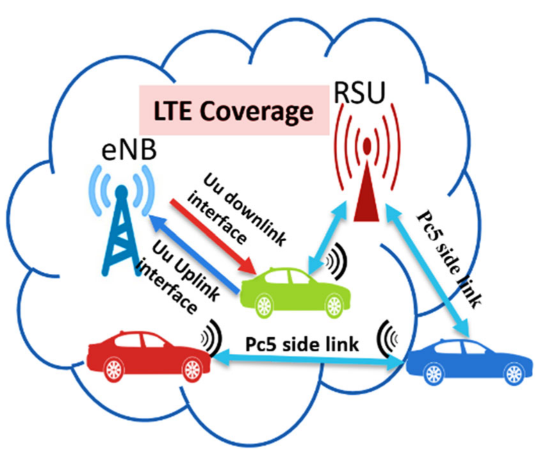

Fig. 2 LTE-V2X different communication Links

LTE-V2X structure about the 3GPPRelease14/15 definitions [23] is composed of the following as shown in Fig. 3: User-Equipment (UE) and this is the end-user equipment, V2X application server and it distributes V2X messages, Evolved Node B (eNB), and it is the base station that gives the transmission interface between UEs and finally, Multimedia broadcast multicast service which supports multicast services.

2.3 Performance of existing technologies

2.3.1 DSRC

DSRC has gone through several evaluations to study its performance under different scenarios. It has been studied analytically as in [24] and through simulation studies as in [25] and finally in real applications as in [26]. The main metric for studying DSRC performance has been the Packet Delivery ratio (PDR), which is defined as the ratio between the numbers of received packets to the number of transmitted packets. The studies [27] have shown that DSRC shows acceptable performance in safety vehicular applications that need a latency of not less than 100 ms. DSRC performance begins to deteriorate dramatically when the density of the network increases due to packet collisions that result from simultaneous transmissions and hidden nodes. To overcome the problem of scalability in

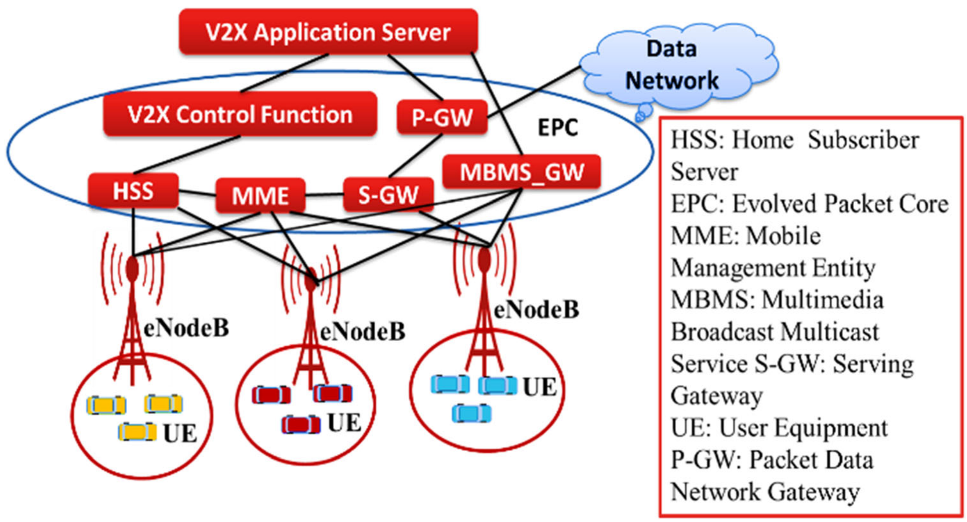

Fig. 3 Overall network architecture for LTE-V2X

DSRC, some congestions control mechanisms have been used as those standardized in [28, 29]. These mechanisms try to control congestion by controlling some parameters as message transmission rate and transmission power.

2.3.2 C-V2X

The studies available for C-V2X are not as much as those for DSRC, as it is a newer technology. Most of these studies are ran through simulation. In [30] authors prove that C-V2X sidelink mode 4 performance exceeds that of DSRC in the link budget, and this has been confirmed in real applications in [31]. While in using sidelink mode 3 centralized resource control in C-V2X, there appears a better performance from better spectrum utilization as in [32]. But as traffic density increases, the performance of C-V2X also deteriorates [33] due to interference resulting in C-V2X mode 4 from frequency reuse, which decreases reuse distance.

2.4 Nature of supported applications

The discussed V2X technologies DSRC and C-V2X, according to the QoS requirements for safety applications [34], are suitable for supporting the basic requirements for vehicle safety applications, which include aiming drivers and alerting them for dangerous situations. These applications require a 50–100 ms end to end latency and periodicity ranging from 1 to 10 Hz.

2.5 Advanced V2X applications

The discussed basic safety applications are not the only applications required for the RATs proposed for supporting vehicular communications. There is a need to improve the performance of these RATs to increase the reliability of the discussed use cases for evaluating them. Self-driving autonomous car requirements also need development in these technologies to be more assisting. Existing electronic brake lights and left turn assist [35] are helpful, but there is a need for message exchange between different vehicles to indicate platoon formations, sensor data exchange, trajectory alignments, and maneuver changes [36]. Also, in vehicles driven by humans, there is a need for data exchange for sharing information as the live camera for another vehicle to increase safety and prevent dangerous situations sensed by other cars. The 3GPP has studied use cases for advanced V2X applications [37] to help in improving road safety and help in other applications as traffic management and a better spread of data among passengers. Some of these advanced applications are remote driving, vehicle platooning, extended sensors, and advanced driving. The required QoS required for these advanced V2X applications is summarized in Table 2; it shows that reliability and latency requirements are much higher than those required from basic safety applications. Extensive and variable-sized packets are required in these applications while, on the other hand in basic safety applications, messages are periodic (every 100 ms typically). To meet these challenges, it is apparent that a major development in these V2X technologies should be done.

3 New radio (NR) V2X: evolution of C-V2X

5G has evolved based on the skeleton of LTE mobile fourth-generation 4G. It differs from 4G signals in some aspects as 4G is based on transferring signals in a long distance through a massive number of high power base stations while 5G transfers its signals through a huge

Table 2 Summary of QoS requirements for advanced V2X use cases

Use case class	Maximum latency (ms)	Packet size in (bytes)	Packet reliability (%)	Data rate (Mbps)	Min + imum range (m)
Vehicle-platooning	10–500	50–6000	90–99.99	50–65	80–350
Advanced-driving	3–100	300–12,000	90–99.999	10–50	360–500
Extended-sensors	3–100	1600	90–99.999	10–1000	50–1000
Remote-driving	5	–	99.999	Uplink: 25 Downlink: 1	–

number of small base stations that support millimeter waves in a range of 30–300 GHz and these stations may be located on light holes or roof buildings. 5G structure can be built through radio operators as a new 5G mobile generation sends its signal in the low-frequency spectrum. 5G signals are immune to weather, building obstacles, and can travel short distances [38]. Wireless communications of the previous generation worked in low-frequency spectrum band, and thus some challenges must be managed by the millimeter-wave, which is interference and distance. The previously used low-frequency spectrum transfers are carried along in long distances but with low speed and capacity on the contrary of 5G generation millimeter-wave. 5G has been the most recent technology introduced by industry communities and telecommunications to upgrade wireless communications. Release 15 and 16, which is about to be announced, as shown in Fig. 1 3GPP has introduced 1 as phases 1 and 2 for 5G technologies.

5G targets to support wireless communications in high reliability with ultra-low latency and ultra-high throughput. A massive number of wireless connections are expected to be supported in 5G for future and existing applications. 5G offers several new services as Proximity Service (ProSe), which a critical feature that based on locality data, gives awareness of nearby devices and deployed services, D2D communications provide this service. Also, it gives services as data managing of Software Defined Networks (SDN), cloud computing, and basic network topology and structure. 5G is expected to be part of the future C-V2X structure as well as cove the inter-vehicle communication services.

3GPP has worked on previously introduced LTE technologies, LTE-Advanced and LTE-Pro, to build 5G technology with back and forward compatibility [39] and will soon introduce the new air-interface for 5G technologies. In Release 16, 3GPP has announced several launchings as PC5 and LTE-Uu interface enhancements and NR standardization as the first phase of 5G technology for enhancing C-V2X communications. The NR supports ultra-low latency ultra-high capacity and massive connectivity of vehicular communications with very high reliability. NR has been made by GPP to support various previous wireless communications in 5G.

As shown in Fig. 4, 5G works in Non-Standalone and Standalone modes. In Non-Standalone mode networks, devices are attached to 5G-NR and send the signal to EPC directly or through 4G stations. While in Standalone mode, which was introduced by the end of 2018, signals are sent directly to 5G core. Standalone mode provides user plane facilities and full control using a 5G core network. 3GPP works on compatibility so that subsequent releases of 5G NR are integrated with recent releases. 3GPP aims to improve scalability, performance, and flexibility of wireless communications by using licensed and unlicensed spectrum frequency bands.

3.1 5G-V2X objectives

In [40], it is indicated that NR V2X is not coming to replace C-V2X since C-V2X has already started in commercial use [41], but it is coming to help C-V2X support the use cases that are of advanced requirements and cannot be supported by C-V2X. New vehicles are expected to have both NR V2X and C-V2X capabilities in the same field, so supporting both technologies is a must. In these cases of using both in the same regions, situations of use cases that are supported reliably in C-V2X are handled by C-V2X while NR V2X handles those that are not and described in CV-V2X use cases and procedures. NR V2X is being designed to handle advanced requirements in addition to basic safety requirements that are now handled by C-V2X. NR should be able to handle situations of variable latency, traffic, and throughput in different reliability degrees as some use cases require periodic messaging while others require aperiodic traffic. In all these cases NR must be able to handle the situation efficiently. Two communication types will be supported in NR called unicast and group cast to handle use cases where data has to be sent in a broadcast transmission or to a group of receivers (UEs) or to only to a specific vehicle.

The NR V2X Study Item outlines its following objectives. mmWave bands will be considered to be used in NR as in IEEE 802.11bd in services that need a short-range and

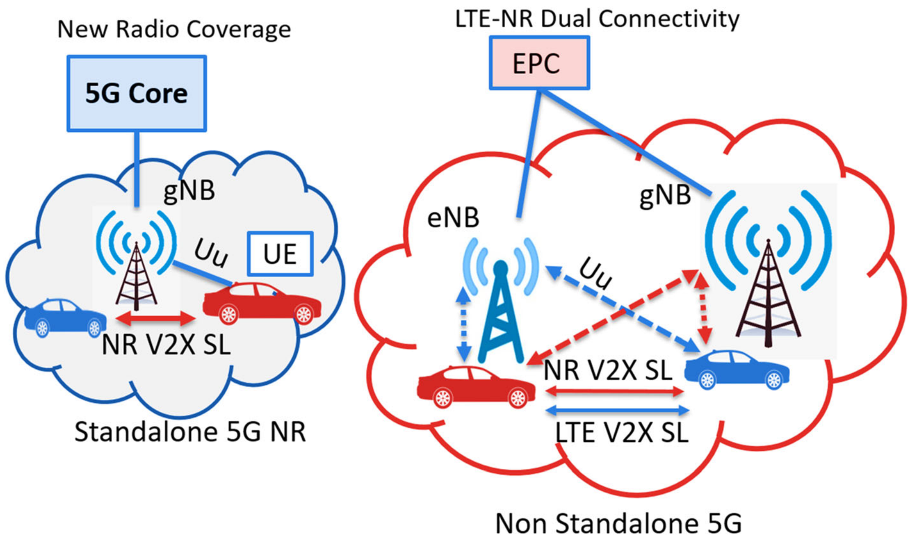

Fig. 4 5G standalone and non-standalone communication modes

ultra-high throughput. But due to the limited time available for the release, it is expected not to put the use of mmWave band in a high priority in this Study item. The objectives of the Study of NR are aligned as follows:

1. Uu interface enhancements to support the advanced requirements of some V2X applications.
2. Study mechanisms to identify the best RAT/Interface selection for any message transmission from the following selections (NR sidelink, LTE sidelink, NR Uu, and LTE Uu).
3. Sidelink design enhancements to support advanced V2X requirements.
4. Enhancing the NR Uu interface for configuration/allocation of sidelink resources.
5. As mentioned earlier coexistence of both C-VTX and NR VTX in the same region has to be studied for technical solutions and making feasibility studies.
6. As mentioned, NR VTX is required to support variable degrees of QoS from basic to ultra-high in different radio interfaces.

3.2 5G-V2X sidelink modes

5G-V2X works in two sidelink modes just as C-V2X; sidelink mode 1 works when all UEs are inside the coverage range of gNodeB, and thus this mechanism allows direct vehicular communication, and resources are allocated to UEs by gNodeB in that case. Sidelink mode 2 works in out of coverage case and allows direct communication between vehicles.

C-V2X only supports broadcast transmission while 5G-V2X may use unicast, group cast, or broadcast transmission modes.

If it wished to send to only one UE, it uses unicast transmission, but if it wished to send to set group of UEs within its vicinity, it will use group cast transmission and lastly, to send to all UEs within its coverage area it will use broadcast transmission. A specific UE may use more than one transmission mode at the same time; for example, if a vehicle needs to send a message to a specific member, it may use group cast or unicast mode while it is using simultaneously to send periodic message broadcast to all vehicles. These transmission modes were also defined in LTE D2D communications [42]. When a packet arrives to be transmitted, the higher layers are assumed to notify of the mode of transmission needed, whether unicast, group cast, or broadcast. This procedure is done at Layer 2, and thus PHY layer needs to decode the packet and send it to the upper layers so to reduce this burden 5G-V2X defines these modes at the physical layer, and nonparticipant UEs do not need to decode the entire packet at its physical layer.

3.3 The 5G-V2X core design

5G-NR includes the following three elements:

1. Multiple access with optimized waveforms based OFDM: OFDM (Orthogonal Frequency-Division Multiplexing) is a multiplexing technique used for allocating resources based on frequency division. LTE and Wi-Fi used OFDM, and thus 5G does not require full multiple access and waveform design. It just enhances the previously used methods with its advanced requirements to offer high performance with low technical complexity and supporting various spectrum bands for a variety of applications.
2. An integrated and flexible framework: 5G offers a flexible framework that is compatible with previous C-VTX; it also aims at providing flexibility and

compatibility with all future extensions to 5G. As scalability was a primary issue that needed a solution in previous LTE models, 5G offers scalability at the ultra-high performance.

3. Novel wireless technologies: 5G aims at providing ultra-high efficiency and performance metrics by introducing new use cases. 5G offers three primary services which are listed below and to make them applicable and practical wireless techniques are added:

   – Ultra-Reliable and Low-latency Communications (uRLLC): This type of communications is used for time-critical and latency-sensitive applications as C-VTX, autonomous driving, and real-time applications. These types of applications require very efficient security, very high availability, reliability. It is also a must for applications with no failure requirements like multiplexing to give a higher priority to the mission-critical communication using redundant links or regular traffic so that any mission-critical end-user device can connect to the multiple networks.
   – Enhanced Mobile Broadband (eMBB): gaming and multimedia applications needs very high bandwidth to get efficiency as that of fiber optics. mmWave, Gigabit LTE, MIMO, channel coding, spectrum sharing are the proposed techniques for supporting that.
   – Massive IoT or Massive Machine Type Communications (mMTC): applications that require many low cost and low energy devices to communicate small data packets as IoT and smart buildings, homes, and cities could be enhanced with technologies capable of giving them low latency high throughput and speed, multimedia support, location awareness, mobility and updating firmware efficiently over the air. The design of efficient uplink multiple access has been proposed by Qualcomm through Resource Spread Multiple Access (RSMA) together with a multi-hop mesh network WAN to increase the coverage of the network [43].

- Millimeter-wave technology

There are some significant differences between 5G and mmWave, although sometimes used for the same purpose actually, mmWave is just part of 5G technology. As shown in Fig. 5 mmWave represents part of the frequency spectrum that has short wavelengths between 24 and 100 GHz. As this part of the spectrum, no is not in use, mmWave can use it to increase the bandwidth significantly. Low frequencies between 800 and 3000 MHz are very crowded with applications as TV and radio signals and 4G LTE applications. mmWave short wavelengths send data at very

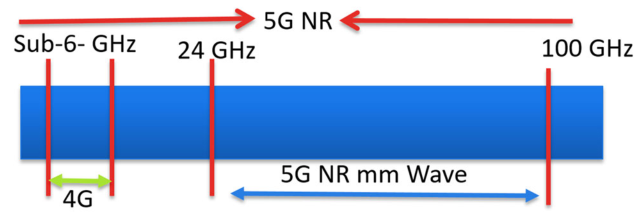

Fig. 5 5G mm wave radio frequency spectrum

high speed but through short distances only. mmWave can be used in small areas of high population and thus is used as part of the future 5G technology in covering cases like clubs, stadiums, and malls. On the contrary, in broad areas where distances are long as in towns and rural villages low-frequency bands ranging from sub-6 GHz and below 2 GHz can work efficiently. The challenges in front of mmWave is area coverage and obstacles. 5G is a promising technology to send with high data rates and could replace the use of low latency applications and fiber lines. 5G has a very robust infrastructure with high mobility applications. Autonomous applications are mostly interested in mmWave technology as an essential part of future 5G technology to offer ultra-high throughput and ultra-low latency, and this can be mainly interesting for the following applications:

- V2V communications and here it is used to support near direct communications between vehicles as collaborative sensing in use cases of high density.
- V2I communications which are used in high data transfers such as downloading and updating and sharing HD 3D maps using short time messaging from or to the RSU. Also used in object detection and recognition. The problems and obstacles of data propagation can constitute a challenge especially a beam transfer in high mobility with the effect of obstacles as human bodies [44].
- Multi-Antenna Techniques

  Multi-antenna techniques are considered as key 5G V2X technologies, as they can be used to increase the spectral efficiency as well as improve link reliability for highly mobile V2X scenarios. The benefits of antenna beamforming and multiple-input multiple-output (MIMO) signal processing are shown in this section by novel technologies and solutions. Besides unicast, multicast, and broadcast schemes are also considered. Available antennas are used to predict the radio channel for future time instants and compensate in this way the effects of channel aging caused by mobility. Practical aspects such as sensitivity analysis of coupling effects between antenna elements and efficient rate adaptation are studied.

The extension of predictor antennas for massive MIMO systems and experimental validation shows the practical feasibility and high potential of this technology. To guarantee URLLC, fast and reliable initial access and beam refinement and tracking are investigated, resulting in a novel codebook-based beam refinement scheme also suitable for the mmWave frequency bands. Utilization of multicast/broadcast transmission at mmWave bands enables high data rate V2N/V2I communication links with the resource-efficient transmission of shared content to multiple users. Beamforming is used to provide coverage and high reliability. Due to the directivity of angular beams at mmWave frequencies, beam management for multicast/broadcast imposes a challenge in highly-dynamic scenarios, which are very typical for the V2X use cases.

Development and performance analysis of beam-based broadcast schemes for V2X scenarios with different beam patterns, beam configurations, frame structures, and block error rates requirements are presented. When multiple users are geographically close to each other, redundant information of neighboring beams can be exploited to enhance the received signal quality and enable the usage of high-order modulation and coding schemes (MCS) that improves the achievable data rate. At the same time, the network exploits feedback sent from the users as an acknowledgment or negative acknowledgment (ACK/NACK) to enhance the reliability of the broadcast/multicast service. Finally, for V2V links often having LOS and deploying MIMO schemes, the antenna separations at the transmitting and receiving vehicles are optimized to maximize the spatial degrees of freedom. The impact of separation on the rank of the channel is analyzed for different distances between the vehicles. It is found that larger antenna separations can be preferred for the design over a range of distances between the two ends of the link.

4 Key requirements and challenges for 5G-V2X

5G-NR is a promising technology for vehicular communications but still faces many critical challenges, which will be described in this section, in addition to the predicted 5G enhancements.

4.1 Dynamic mobility and high relative velocities

As this has been one of the significant problems in previous technologies supporting varying mobility speeds in on-demand mobility is one of the primary objectives that 5G technology should support, this mainly depends on the application and service being supported. High mobility expected application requires many restrictions on analysis, modeling, design, and evaluations on use cases of 5G based C-V2X applications. There are several challenges, for example, for high mobility vehicular applications as mobile relays, distribution of antenna optimally across the network, massive MIMO technique, and channel estimation efficiently to support high mobility situations robustly as these are non-error applications. 5G has improved the synchronization techniques employed, and a significant number of signals have been added to improve signaling to support the previously described high mobility applications. Mobility has been enhanced in 5G technology to support a relative vehicle speed of up to 280 km/h in LTE based V2X, and for the 5G target, it is expected to reach 500 km/h relative speed [45].

4.2 Extremely low-latency

One of the main requirements of 5G communications is supporting a deficient latency transmission. Vehicular communications are one of the most essential use cases for such a requirement, but as their communication involves vehicles moving with broadband applications, latency will not constitute a problem there. In autonomous vehicles application, low latency is essential for security in cellular connection. Environmental sensors are used in autonomous vehicles to sense obstacles, pedestrians, other vehicles, and road conditions. Other vehicles or RSUs should supply autonomous vehicles with this data. Using low latency links in such applications between vehicular systems and RSUs will help in reaching a correct decision in time and thus improving safety. Rohde and Schwarz and Huawei, in part of a current project, have tested an accurate end to end time measurement system. For collaborative driving application, in 5G V2X Over-the-air IP communications were examined in a moving vehicle, and the end to end accurate measurements returned less than two µs for each transmitted packet. Video streaming, different IP packets such as the ITS beaconing messages, and a LIDAR for a remote-controlled vehicle was the data broadcasted. Two accurate GPS receivers on both sides guaranteed the accuracy of timing on both sides. Two tests were run one in Munich and the other in Shanghai, and the earlier was done on remote control vehicles while the later was beaconing in platooning application in V2X communication where it is a V2X use case with vehicles moving with the same direction and speed. Latency from end to end is calculated by adding transmission time, processing time, transit time propagation time, and any caused delay. These measurements are essential in enhancing upcoming tests as latency is one of the major issues in 5G communications and especially safety applications [46]. A direct communication interface is needed in two modes of network coverage (in and out) in 5G base V2X to reduce latency and improve network communication between vehicles. In the case of network out coverage PC5 interface, which is based on the LTE-V2X, will be used as the direct radio interface between vehicles. In Fig. 6, three vehicles communicate using the PC5 interface in two modes of network coverage to provide extremely low latency in the V2V applications. Several enhancements, including physical and MAC layer improvements, have been made for that enhanced OFDM for channel estimation with less than 1 ms as a latency design target in 5G.

4.3 Ultra-high rate

In autonomous driving applications, real-time data as map exchanging, video streaming, speeds, locations are exchanged. The time delay must not be more than microseconds, and the data exchanging rate should be ten times per second. D2D, Massive MIMO, and mmWave communications have been tested were tested and proposed to give low latency high data rates, but all tests were run under low mobility or static networks. V2X networks differ from traditional cellular networks structure in architecture and channel conditions due to high mobility in V2X with critical interference and fast channels fading, which affects 5G performance and deteriorates it. Also, topology frequent changes due to mobility and vehicles high movement, data dissemination, QoS requirements, and network resources accessing designs face several challenges [47].

4.4 5G C-V2X system architecture

Designing the system architecture of 5G for vehicular communications is challenging to support all requirements of vehicles and services. To support real-time communications a centered distributed proposal of architecture is expected also to control coordination information exchanging among vehicles. It should be open and safe with ultra-low latency and efficient for broadcast communication of data, dynamic control of vehicles under high mobility conditions, and self-organizing. Scaling the network is one of the major requirements of 5G networks to be able to support the extension in the number of mobile users that are expected.

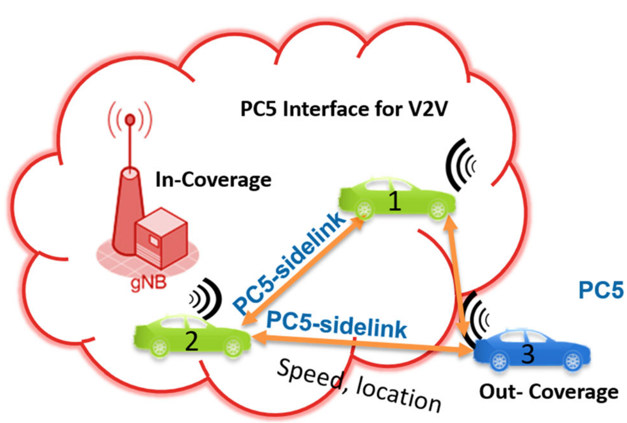

Fig. 6 In-coverage and out-coverage for V2V communication in V2X based 5G

4.5 5G the technology of environmental sensing

Beyond Visual Range (BVR), environmental information is expected for 5G to provide for inter-vehicle communication. For inter-vehicle connectivity, 5G acts as a virtual sensor with onboard sensors inside vehicles as multi-beam LiDAR, video camera, and millimeter radar. Another critical challenge for 5G C-V2X is optimizing local sensors connectivity and remote heterogeneous in different latency and mobility levels.

4.6 High capacity for high message volume

In vehicular communications, many messages may be broadcasted at the same time to share data as accident alerts or network status, which results in a massive number of messages that may overload the network. Different types of messages may be shared in V2X communication different applications as pre-crash alerts use local broadcasting between vehicles in the vicinity. 5G has the challenge of managing resource allocation in high overhead networks using 5G technologies used for antenna design as tracing and adaptive beamforming. Multiple transmitter requests can be handled by well-managed resource allocation. A vehicle sends a request to the base station for resource allocation, and the base station allows them to communicate the PC5 interface directly.

4.7 High availability and reliability

Safety applications are one of the significant applications in V2X that need high availability and reliability and a lot of other applications that should have zero failures. Modification of D2D physical and MAC layers is required to enhance availability to ensure the efficiency of resource allocation while supporting numerous redundant connections to overcome network failures. Global Navigation Satellite System (GNSS) is proposed by 5G to give accurate positioning altogether with enhancements of LTE GPS timing takes care of synchronization, and these are used especially in out of network coverage mode. Using the air Uu interface, various connections to any base station can be made simultaneously while GNSS takes care of synchronization as shown in Fig. 7.

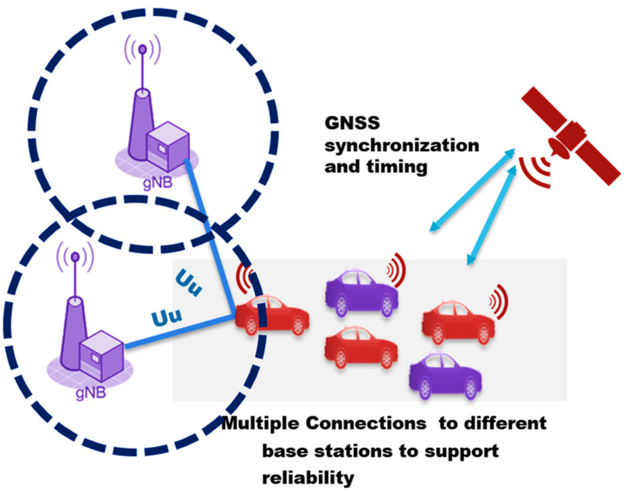

Fig. 7 Availability and reliability requirements in V2X based 5G

5 5G V2X use cases

Coordination between vehicles marched out as a critical requirement as the high automation level of vehicles is increasing significantly. Vehicles choose the driving trajectories using their trajectories based on what they sense and based on data received from the surrounding environment. To support an ultra-high level of safety, V2X vehicular communications use a set of strict performance metrics for autonomous driving as latency, availability, capacity, and reliability. V2X use cases may have numerous scenarios as platooning (convoy management), cooperative lane change, and collective collision avoidance. Use cases gather data from onboard sensors and vehicles in the vicinity to be used by autonomous vehicles to handle situations as efficient traffic flow and emergency maneuvering [48]. Use cases are used for supporting a fully automated driving experience with the basic traffic applications and safety requirements. 5G based V2X is expected to deploy use cases for supporting different situations as shown in Table 3. Sharing massive traffic data and different traffic types between the new generation of autonomous vehicles with high security, reliability, availability and tight synchronization are essential. A multi-technology and a programmable multi-layer framework are supported by 5G based V2X for providing real-time network services and SDN workflow automation. Multiple RAN is supported by 5G V2X technology including LTE-Advanced Pro, LTE, and RAN network core functions and virtualization a distributed-cloud infrastructure. Due to the advanced requirements of 5G V2X, there is progress in the networks to optimize utilization and equipment while the overall framework meets the defined quality and services in complicated use cases. 3GPP Releases 14 and 15 support the previously mentioned use cases from the perspective of radio access. Also as mentioned earlier 5G supports a very high QoS as ultra-low latency and ultra-high throughput and scalability guarantee and thus it gives optimal principles for the scenarios of these use cases. To support applications a sub-slice or a distinct-slice, 5G has a great advantage of supporting slicing. Many types of services and use-cases supported by V2X could be supported by 5G network slicing technology by enhancing MBB critical communications and IoT [49]. One of the most important use cases of 5G is C-VTX as it increases road safety besides offering new job opportunities in OEMs. In this use case, the communication industry and the automotive industry are collaborated and benefiting. Its main aim is to connect vehicles to vehicles (V2V) or vehicles to infrastructure. CV2X communication includes other connected-vehicle technologies to support the performance-critical type of services as semi-autonomous, autonomous, and assisted in driving these technologies to include radar systems, cameras, and in-car sensors. To offer better coverage and reduce deployment cost using the 'operator's 5G public network for support for V2X services is provided on the contrary of running V2X services on a dedicated network. In the design of 5G offers also high QoS as ultra-low latency and ultra-high throughput in addition to customized network services that could be tailored according to the requirements of the customer.

Table 3 Summary of 3GPP release 14 use cases

	Effective distance (m)	Speed of UE supported V2X (km/h)	Maximum latency (ms)	Minimum message reception reliability (%)
Major road	200	50	100	90
Urban	150	50	100	80
Campus/shopping area	50	30	100	90
Imminent crash	20	80	20	95
Urban intersection	50	50	100	95
Freeway/motorway	320	160	100	80

Thus, to deploy C-VTX applications successfully, you need to be aware of the automotive industry and the available use cases.

5.1 Analysis of existing V2X use cases

To meet the requirements and needs of new technologies, 3GPP is working on improving the performance and QoS of both 4G and 5G. For example, the problem of massive communication of machine type, low latency, and needing zero failure reliability in LTE of 4G and New Radio was recently addressed by 3GPP, 5GCAR is interested in such a feature, and it would be of great benefit to it. In Release 14, published in March 2016 and services defined in the first release of ETSI ITS ETSI09-2638. This group of use cases, main features are as follows:

- Awareness of the environment and warnings are their primary use.
- DENM and CAM messages are the base for Level1 communication, the period of transmission is low as for warnings of roadworks and high for situations as vehicle warning emergency.
- Level 1 use cases maximum one-way end to end latency requirement is 100 to 1000 ms.

The following are some of the use cases of 5G CV2X:

1. Infotainment

In this use case, the vehicles connect through mobile devices with application servers, which are generally provided by the automotive manufacturer or their authorized third-party service provider. These kinds of services give both drivers and passengers a pleasant vehicular experience and especially passengers, as they have no critical safety restrictions. Data is exchanged through Mobile Broadband (MBB), and some of the examples of these services are audio or video conferencing (office in a car), music, live TV, movies, web browsing, and online gaming.

2. Telematics

This kind of service is the same as mentioned before in that vehicles connect through mobile devices with application servers. It is mainly concerned with assisting the driving experience. Some of the examples of these use cases are remote precise position provisioning, health monitoring of the vehicle, navigation provision, automated parking, and parking slot discovery. A software or a control module firmware update can be scheduled for a selected range or type of vehicle by an automotive manufacturer over the mobile system.

3. Road Safety and Efficiency

The user should be supported with information that guarantees essential safety services as road safety and efficiency, and this information may be as follows:

- Road Warning

These use cases are usually event triggered by specific situations met by the vehicle on the road, and that is the difference between them and those of telematics. The action is required to be taken by the driver, and that makes it not very much delay-sensitive as autonomous vehicles, but it preferred to be delivered with high speed to be useful for action. The information delivered to the user may be traffic jam warning, hazard warning, intersection collision warning, or imminent dangers such as red light violation, and the actions taken by drivers could be lowering the speed or lane change or any other suitable recommended action.

- Information (Sensor data)

Information sharing of the surrounding environment is one of the most critical aspects and facilities in road safety services. Sharing real-time data between vehicles may help drivers avoid expected dangers by receiving data by receiving, for example, a video stream from the car in front. Environmental data that may be shared is, for example, traffic information captured by the vehicles or on-vehicle sensors. “See-Through” is a typical use case to improve/extend ‘driver’s visibility by using a camera or radar information sharing. In autonomous driving, sharing information is a very crucial aspect, as will be mentioned below.

- Advanced Driving Service

Advanced driving services enable fully automated driving and semi-automated driving.

- Cooperative driving

Cooperative driving has significant use cases to avoid crashing and collisions. The information needed includes brake usage, accelerating, or on-vehicle sensor data. Also, a very useful use case for improving traffic flow is the one for lane merging by exchanging information between vehicles about their intended trajectories to change their lanes safely without collisions.

- Platooning

To reduce the fuel consumption and the number of drivers needed platooning use cases can be an excellent candidate where vehicles travel in a row very close to each other as if a virtual string is linking them. But to do this successfully and safely, information has to be shared between vehicles about acceleration, braking, heading, and speed.

- Tele-operation

In this use case, a user can remotely control an autonomous vehicle and control it for certain periods. The user can be located in a remote control center and receive video streaming from cameras placed on the vehicle, and the user handles it as if he is driving it in reality. To improve the 'driver's experience, advanced video technologies as VR can be used.

5.2 5GCAR use cases for 5G V2X

Although automotive use cases impose a lot of restrictions on 5G QoS in mobility and other aspects, it is essential as it has very high business potential. 3GPP in Release 14 supported C-VTX in LTE while in Release, 16 technical plans for 5G are expected to be supported. 5GCAR project aims at developing the specifications of 5G to be recognized as V2X 'applications' enablers as they are still not in the spot due to the hinders in communication networks right now. 5GCAR in [50] covers five essential use cases, as shown in Figs. 8 and 9.

- UCC1: Cooperative maneuver

In this use case, data is shared among vehicles in the vicinity about planned trajectories, driving intentions, and local awareness. Wireless communications are used for sharing information in the infrastructure or vicinity. Decentralized or centralized optimization of the shared trajectories is done based on this shared information. Possible joint optimization of trajectories among vehicles, potential negotiation, typical awareness, and including request and acknowledgment among vehicles are additional information that needs to be shared among vehicles in this use case.

Goal to improving efficiency and safety by coordinating driving trajectories within a set of vehicles.

Benefits Several benefits can be achieved through this use case as traffic efficiency and safety, reducing emissions, driving comfort (e.g., smoother maneuver), an improvement of decision making, reducing fuel consumption as the case in platooning.

Challenges The main challenges facing this use case are trajectories and driving intention interpretation, security issues of integrity and authenticity in how to trust the information received and its source, maneuver plans that are acknowledged, trajectories joint optimization and especially in a distributed manner and integration of legacy vehicles in trajectory calculations is the most challenging job. To make UCC1 applicable, we need a combination of online and offline data analysis, precise positioning, fine-grained object detection, and timely communication. The needs of this use case are equipping vehicles with wireless communication means, authentication mechanisms for security, and an accurate positioning system.

Example: Lane merge

Lane merge refers to the process where a vehicle is intending to change its lane while another vehicle in the main lane shares its local awareness and driving intentions.

Goal Vehicles on the main lane to be provided with trajectories to aid a vehicle to merge smoothly into the

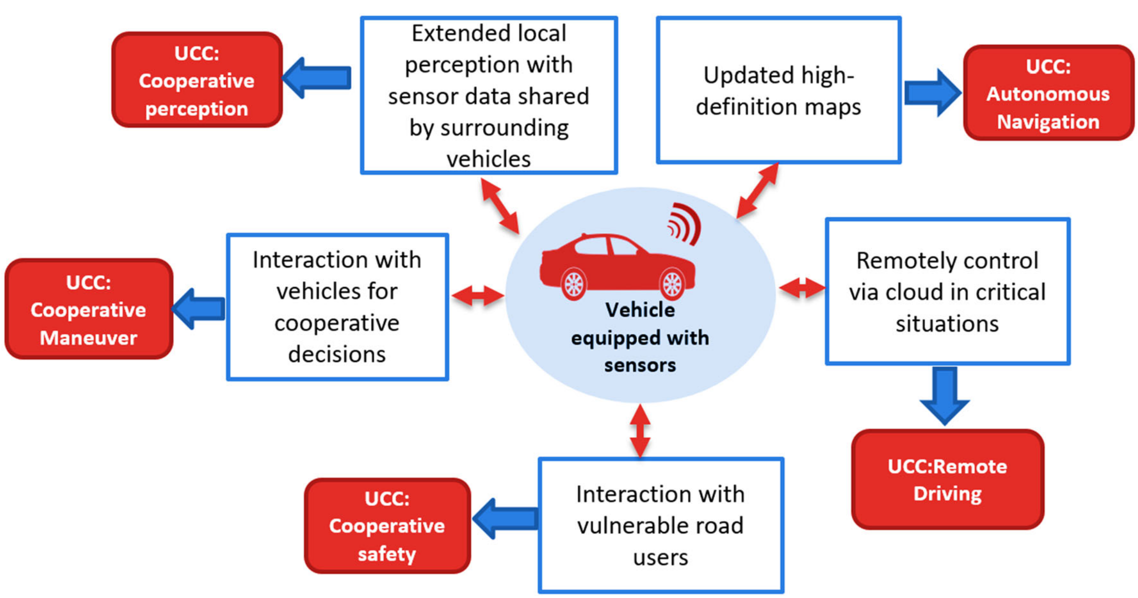

Fig. 8 5GCAR project use case classes in V2X based 5G

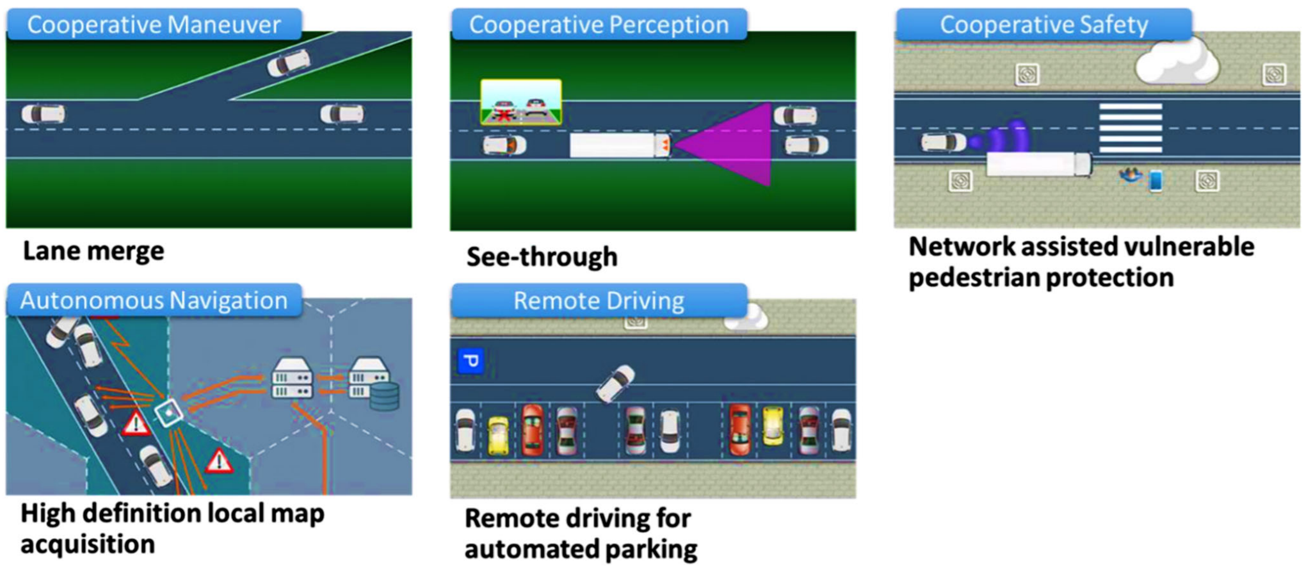

Fig. 9 5GCAR use case examples for basic classes in V2X based 5G [50]

main lane with minimal impact on the traffic flow and without collisions.

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

- UCC2: Cooperative perception

Cooperative Perception is based on sharing information from different sources and vehicles in the vicinity. These sources may be onboard cameras stereo-vision sensors, laser sensors, and radars. Wireless communications are used for sharing information between infrastructure and vehicles. The basic aim is to integrate information from the vehicle's local sensors and remote information. A key benefit of cooperative perception is to know the position of vehicles relative to each other and thus a map merging problem can be done. Bird's eye view, lifted-seat, or see-through can be the representation of the perception results.

Goal This use case targets two main goals; the first one is designing a driving assistance system that could extend the local vision of the vehicle to improve safety, and the second goal to make a Local Dynamic Map (LDM) that could help in autonomous and cooperative driving by merging the data of static maps with dynamic data of sensors to help autonomous vehicles through different traffic patterns.

Benefits cooperative perception can bring numerous benefits as self-awareness increase without having to increase the cost of using expensive sensors inside the vehicle as wireless communication modules used for cooperating data is much cheaper. Also, driving assistance is improved, and in turn, traffic safety also improves by helping the vehicle take more reliable decisions in avoiding obstacles, smooth acceleration or braking, and lane overtaking or changing. Smooth driving reduces fuel consumption and harmful emissions. Facilitating driving decisions on the short term for avoiding obstacles or collision prevention and the long term for improving route choices base on shared information and a wide perspective.

Challenges The main challenges facing this use case is merging the information of vehicle sensors and map merging to be assured that localizing objects and detecting them is done based on a standard reference of time and space, taking into account that sensors of every vehicle are not identical. Another challenge in relative positioning and localization is related to the fact that the scan points of maps are different even in the overlapping areas taking into account that there may not be sufficient overlapping areas to keep enough space between vehicles for safety and preventing collisions. Needs: several sensors should be added to vehicles as sensors for identification and classification of vehicles, vision sensors, range sensors for tracking of vehicles and detection, sensors for identification of pedestrians. Also, there are needs for adding a communication system for facilitating the communication between vehicles and the infrastructure and adding a synchronization and localization system with higher accuracy than that of GNSS.

Example: See-through

In this example, the data shared through cooperative perception by wireless communications as video data or data object detection is used to increase safety by helping drivers to make the right decisions during maneuvers or by helping autonomous driving. The data collected by the vehicle ahead by a camera vision is shared with the ones behind to help them see through the vehicle and bypass the blind area in front.

Goal To help drivers see through the vehicles ahead to avoid any unexpected situations by overcoming the blocked area by the vehicle in front by letting it share its view with the rear vehicle.

Target Environment Anywhere, including urban roads, highways, intersections, and national roads.

- UCC3: Cooperative safety

The cooperative safety use case main target is mere safety while the primary purpose of previous use cases as UCC1 was maneuvering enabling securely, and the main target of UCC2 was extending the perception range using cooperative sharing of data. UCC3 is mainly concerned with protecting Vulnerable Road Users (VRUs), this can be done by detecting

the presence of VRUs using a local sensor or camera or radar or using a positioning system or using the communication system. Another way to detect the presence of VRUs is by using their cellular phone information if the VRU holds a smartphone or a cellular communication device. The gathered information can be shared between infrastructure entities or relevant users. For making drivers or autonomous vehicles take safe actions towards VRUs, an alert can be sent to them about the presence of VRUs in a particular area.

Goal The mere safety of VRUs using the roads as motorcyclists, cyclists, pets, and pedestrians. This is done by the sharing of information between passive users and vehicles directly or indirectly.

Benefits Increased road safety usage by giving drivers or autonomous vehicles assisting information using alerts for any present VRUs. This increases environmental awareness without any increase in costs as the needed detection sensors and communication system is already available for other needs.

Challenges The main challenge that faces this use case is determining the accurate position of VRUs in a different light, weather, and environmental conditions. Also, making a reliable localization of VRUs with relative positioning while such facilities may not be available in the vehicle. Needs: Video camera devices should be available in vehicles and sensors like accelerometers, gyrometers besides a GNSS receiver.

Example: Network assisted vulnerable pedestrian protection

In this use case, a pedestrian is trying to walk near the road or trying to cross the street, and the vehicle is not aware of that due to the blind area in front of the vehicle from parked cars. Information from local sensors, GNSS, or cameras are shared with cellular signal through wireless communications to determine the accurate VRU position, and this data is processed between multiple users to generate an alert to vehicles with the accurate position.

Goal Detecting the accurate position of VRUs and sending this information to vehicles to avoid possible collisions and to preserve the safety of VRUs.

Target environment Roads where pedestrians will be in the trajectory of vehicles as crossroads and roads without pavement.

- UCC4: Autonomous navigation

This use case is mainly for building a real-time intelligent High Definition (HD) map. In UCC2, data is gathered by cooperative perception to update maps and create environment awareness about reference objects for localizations and road structures. Aggregation of collected information is done and the HD map is distributed among vehicles based on their location.

Goal The main goal is to choose optimal routes for drivers and autonomous vehicles using the gathered information from sensors of vehicles.

Benefits Recommending optimized routes will save time and energy as the decisions will be made using the dynamic HD map gathered from road information and vehicles. The level of processed data for optimization is at lane level of the driving car and the drivable area in front of it and what is surrounding the vehicle and the status of other road users, whether driving or positioned or moving. One of the benefits also is increasing security as the HD map will be distributed from one trusted source only. It will enable fully, and semi-autonomous vehicles and will improve the driving experience for both drivers and passengers.

Challenges computing real-time routes in a centralized or distributed manner, taking into account the actual traffic condition, and then distributing one single version of the map for all vehicles is a tough job. Needs: Using distributed servers for road calculations with some of them near the calculated road to update information rapidly and accurately and distribute it freshly around vehicles.

Example: High definition local map acquisition

Information is gathered by an off-board server on different layers starting the map provider at the static layer, and the temporary and dynamic layer of information gathered from vehicles by cooperative sensing. The gathered data is split into polygons and distributed among vehicles using push/poll methods where the poll method is done periodically while the push method is used in special or hazardous events.

Goal The local dynamic maps to get updated in real-time on the move

Target environment Anywhere, including highways, urban roads, and intersections that could be enabled for fully and semi-autonomous driving.

- UCC5: Remote driving

This use case is concerned with enabling remote driving, which is controlling the car steer wheel, brakes, and throttle remotely from a far position using wireless communications. To ensure the safety of the experience, data should be gathered from the perception level about the environment and the infrastructure.

Goal To remove the driving task from passengers in the car by enabling remote driving using an application server or a human operator ensuring efficiency and safety.

Benefits this use case gives the facility of controlling a car remotely for people who cannot drive a car by themselves. And if the car is fully autonomous and can be driven without the supervision of a driver. But the car that is driven remotely with the supervision of a driver gives a higher safety level for any unexpected problems. The fully autonomous car will drop the burden of driving from the driver, and he can even leave the car beside it can control a set of vehicles, not only one which will increase safety and efficiency.

Challenges The challenges facing this use case are keeping the safety of the vehicle as this case needs an ultra-low latency and reliability of about 100% as there are no chances of failure and a minimal latency could be fatal. The second challenge is security, as we should ensure that only authorized users could control the car, and OEMs should agree to give these permissions. Needs: a cloud server should be available to receive information about the vehicle, and its surroundings and position and vehicles should allow access to actuators and have a proper perception.

Example: Remote driving for automated parking

This example is about making the car take suitable action for safe and efficient parking. The car takes instructions from a remote cloud server about the suitable trajectory and maneuvers to park the car safely. Real-time video streaming and sensor data are sent from the vehicle to the cloud server.

Goal Driving a vehicle remotely through an application server, from the" last mile" along to the parking entrance and then to the vacant parking spot without the intervention of a human driver.

Target Environment Outdoor or indoor public or private parking and "one-mile" distance area around it.

5GCAR aims at offering to the 5G requirements to enhance a real enabler of V2X services based 5G that is not realizable under the limitations of existing communication technologies. To realize this, 5GCAR provides the following V2X specification:

- Offering end-to-end delays under 5 ms
- Offering ultra-high-reliability near 10^5
- Handling the high-density scenarios of connected vehicles
- Ensuring Positioning precision of 30 cm for cars and 10 cm for pedestrian

5GCAR has outlined the following V2X use case classes: (1) Cooperative maneuver, (2) Cooperative perception, (3) Cooperative safety, (4) Intelligent autonomous navigation, (5) Remote driving.

5GCAR has picked one typical use case for each class: (1) Lane merge. (2) See-through. (3) Accurate positioning. (4) HD local map acquisition. (5) Remote driving for automated parking. The challenging demands for each 5GCAR use cases have been recognized and studied in this section. A summary of various representative use cases and their related classes with the corresponding performance metrics are shown in Table 4.

6 5G-V2X proposed architecture

The 5GCAR project is considered as one of the essential 5G projects that propose the 5G-V2X techniques, applications, use cases, and architectures to support the V2X connectivity within 5G. In this section, we propose the 5G-V2X design, which considered a result of the collaboration between companies, universities, projects, and V2X chipset makers. The 5G-V2X system structure is presented in Fig. 10, as mentioned in the 5GCAR project and provides the management of the homogenous traffic, the different multi-RATs technologies, and the inter-vehicle connectivity. The 5G-V2X network core is proposed, including the network management using SDN, the slicing technology, the 5G virtualized functions, security, and privacy are considered in [51].

The 5G-V2X design is involving five domains of network management, security, multi-RAT connectivity, edge computing, and network slicing. Network management includes all required procedures for the efficient automation and deployment of critical V2X functions. 5GCAR assigned the Infrastructure-as-a-Service (IaaS) as a fundamental idea for the practical system administration, using the Network Function Virtualization (NFV) techniques and SDN networks to maintain the efficient deployment of the V2X applications according. Consequently, security also is studied in preceding DSRC standards. The 5GCAR project involves different approaches for the 5G-V2X security check for the V2X messages by applying the security-checks at the vehicles while utilizing the network connectivity presence [52]. In the next sections, we mentioned the most two important components in 5G-V2X system

Table 4 Summary of 5GCAR use cases examples requirements

	Lane merge	See-through	Vulnerable road user protection	High-definition local map acquisition	Remote driving
Communication range	> 350 m	50–100 m	40 to 70 m in city areas	Few kms	Several kms
Data rate	1.28 Mbps	10–29 Mbps	0.128 Mbps	2.88 Mbps Downlink	1.28–29 Mbps
Reliability	99.9%	99%	99.99%	99.99%	99.999%
Localization accuracy	< 1–4 m	~ 10 m	~ 25 cm	5–50 cm	5–50 cm
V2X communication type	V2V, V2I, V2N	V2V, V2I, V2N	V2P, V2I, V2N	V2I, V2N	V2I, V2N
Latency	< 30 ms	< 50 ms	< 60 ms	< 30 ms	5–30 ms

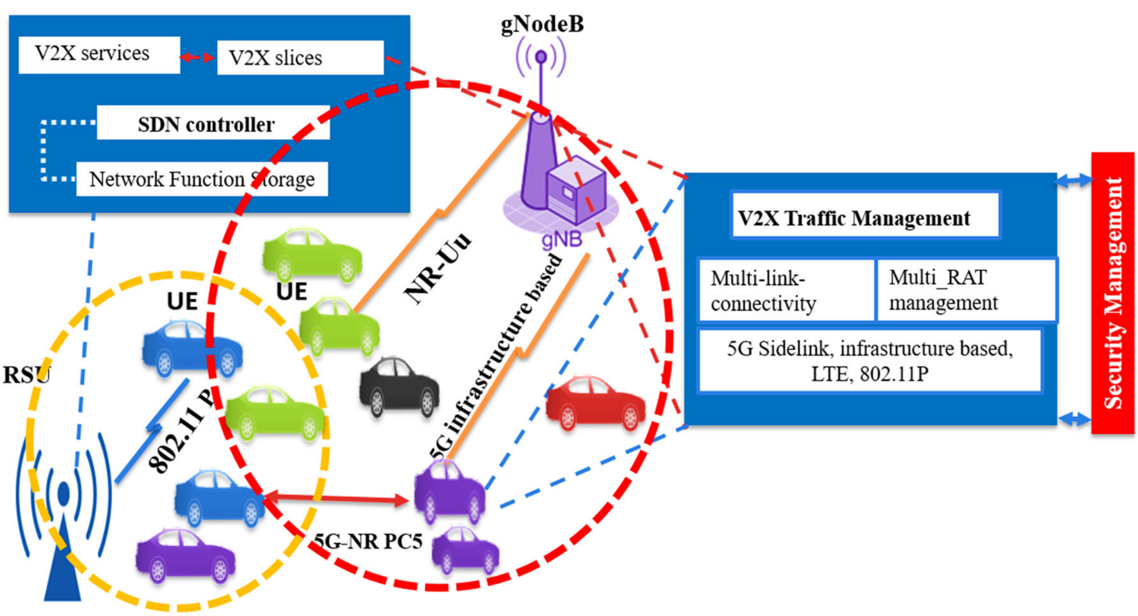

Fig. 10 End to end 5G based V2X architecture design

design. The first is 5G-V2X slicing and the second one is edge-computing in 5G-V2X.

7 5G-V2X slicing

Network slicing reasonably separates network functions (NFs) and network resources that are tailored to the ' 'market's demand on single shared network infrastructure. A slice possibly crosses all 5G network fields across the Radio Access Network (RAN) and core network (CN) segments. Slicing the CN portion changes, the control plane (CP) functions, such as session-management, mobility-management, and authentication. Also, slicing manages the user plane (UP) services to become auto-configurable and programmable [53]. Slicing the RAN segment is considered as a challenge due to the wireless shared nature, and different configurations parameters of the Radio Access Technologies (RATs), such as frequency, time resources, and frame size [40]. However, the network slicing, including both the CN and RAN complicate the overall network slice design, we aim at delivering the CN segment functions in the RAN segment to meet the tight constraints of latency and scalability of V2X different applications.

The most promising approach to achieve network slicing is by separating the User Plane (UP) and Control Plane (CP) functions and providing open applications programmable interface (API) to support network functions programming provided by SDN and Network Function Virtualization (NFV). UP functions must be distributed near to the user to reduce the latency of service access. In contrast, CP functions must be placed in a centralized site, to make the network operations and management less complicated. In this section, we illustrate the 5G-V2X slicing design and requirements.

7.1 Slicing for V2X services

In this subsection, we introduce the V2X network slicing that can propose different V2X use cases with diverse requirements presented over the 5G network infrastructure. Hence, based on the principal performance indicators and practical needs of the classified V2X use case, we introduce different V2X slices, as shown in Fig. 11. The network slice for autonomous driving and critical safety-services that relies on ultra-low-latency V2V mode is shown in Fig. 11. Furthermore, reliable and low-latency data exchange requires to be supported within V2X autonomous system and deployed at the network edge to help vehicles to process the 3Dmap of the surrounding areas and build full vision behind their visual observation. Different V2X slices for autonomous services are described blew:

1. The slice that supports the Tele-operated driving use case must guarantee end-to-end high-reliability and ultra-low latency for connectivity between the controlled and the remote vehicle, which is hosted outside the core network (CN). In contrast, the autonomous driving slice will be restricted to some vehicles and initiated under special conditions, therefore resulting in reducing the load over CN entities.
2. On the other hand, the slice for Infotainment applications is supposed to use muli-RATs to increase the throughput, and to receive contents either close to the user or the remote cloud.
3. The slice for assigned for remote management and diagnostics has to be pre-configured to maintain the transfer of small data volumes between several vehicles and remote-servers outside the core network. We summarize the configuration for each V2X slices, and the main design issues as follows:

- The end-to-end V2X slice design must allow the flexible presentation of various slice cases in the CN or RAN segments. For example, autonomous driving slicing, that shares several CN functions with different slices, however, requires specific slice configurations over the RAN for V2V connectivity.
- The 3GPP multi-dimensional slicing in 3GPPP must be enhanced with additional parameters to classify the slice arrangements and configurations [54].
- Vehicular enabled devices would be expected to be multi-slice devices that capable of attaching many slices, maybe concurrently.
- For example, of multi-slicing connectivity, a driver could start the self-driving vehicle that depends on the autonomous-driving slice for exchanging V2V messages. Meanwhile, kids on the car back seat request HD movie video streaming that is offered by the V2X infotainment slice.
- Various services, such as V2V safety communication and HD video streaming, are attached to several slices and offered by several providers that

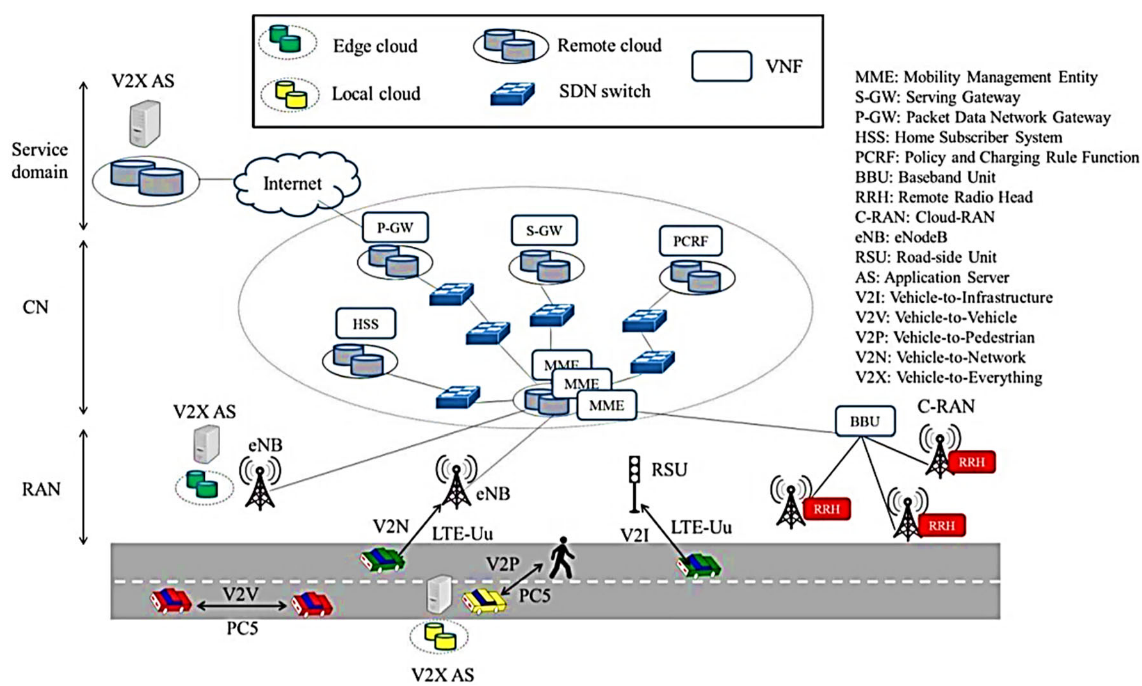

Fig. 11 5G based V2X high-level structure of the proposed slices [40]

may be owned by diverse operators. This complicates slice attachment processes and subscriptions.
- Different varieties of devices could demand the activation of slicing: slice setting and customization are related to the device type; it can be a radio transceiver that embedded into vehicles a smartphone for pedestrians.

7.2 RAN slicing for V2X

Slicing the RAN segment functionalities can cross from the choice of the RAN structure and the network communication-mode to the decision of the policy of radio resource allocation and the configuration of radio-interface parameters. 5G will utilize the existence of 3GPP technologies (e.g., LTE, 5G NR) and non-3GPP radio access networks (e.g., 802.11). V2X based on cellular radio technologies provides almost everywhere coverage, whereas 802.11 mostly considered for V2V communications over the unlicensed radio spectrum. This makes it advisable to offload the 3GPP access networks.

A V2X slice arrangement and configurations include:

1. The RAT selection that able to satisfy the key performance indicators of slicing.
2. Flexibility and dynamicity for network changing and conditions.

In general, the usage of many RATs could be configured to improve the V2I communication capacity for the V2X infotainment-slice or to afford redundant connection to the tele operated-driving slice. V2X slices utilize the on-demand deployment of the RAN essential functions that delivered within the Cloud-RAN technology. C-RAN technology divides the baseband and radio processing functionalities with the cloud.

C-RAN resources can be dynamically assigned to the eNodeBs using the virtualization concept based on the network-load. This guarantees adaptability to the non-uniform V2X traffic, which describes different V2X scenarios (e.g., during rush hours, in rural/urban environments). Furthermore, a centralized manipulation of the collected functionalities is contrasted with the distributed processing in each base station. The centralizing pooling processing reduces the signaling information and time for handovers. The configuration of the V2X slice requires the choice of traffic communication mode cellular or sidelink and type of traffic dissemination (e.g., unicast, multicast, broadcast). For example, the slice for autonomous driving is based on the sidelink communications for localized intercommunications. However, mobility and varied density conditions could require the reconfiguration of the slice to turn from the PC5 interface to the Uu interface.

7.3 5G-V2X slicing

5G networks are expected to enhance the network performance in terms of latency, reliability, throughput, and mobility while satisfying different user QoS requirements within diverse applications. V2X includes different use cases, characterized by various service requirements. Therefore, a 5G structure should be improved to meet the high V2X needs. Network slicing is appreciated by the academic community as a leading solution to meet the V2X critical requirements.

Network slicing is defined as a concept of managing different end-to-end logical networks as separate and independent networks on one shared physical-infrastructure. Slicing demands programmability and high flexibility that can be afforded by the Software Defined Networks (SDN) to deliver more reliable utilization of network resources and cost-efficiency. In the 5G-V2X slicing situation, the vehicle’s high-mobility purposes the requirement to modify the Point of Attachment (PoA), which triggers a slicing handover. A user served by a current slice should change the POA to the target slice to receive the new slice services.

The intra-slicing handover happens when the UE switches its PoA to a new target PoA within the same operative domain; thus, the vehicle continues attached to the same network slice. On the other hand, the inter-slicing handover stands to the occurrence of handover within different operative domains that include a need to connect a new network slice.

Several articles have proposed the network slicing design. But, a few of them are dedicated to analyzing the network slicing selection and mobility management. Mobility Driven Network Slicing (MDNS) algorithm is proposed in [55], to maintain on-demand mobility management. MDNS protocol introduces a detection of a mobility profile that consider as a component of the slicing selection function. Therefore, when the user equipment entering the network, the slicing selection function determines the vehicle mobility demands and accordingly selects a proper network slice. In [56], the authors introduce a Context Enhanced Mobility Management (CEMOB) scheme for V2X communications. This scheme demands an improvement of the V2X information to enhance mobility management. Authors in [57] investigate the implementation of a new mechanism for slice selection that allows UE to join multiple network slices based on the type

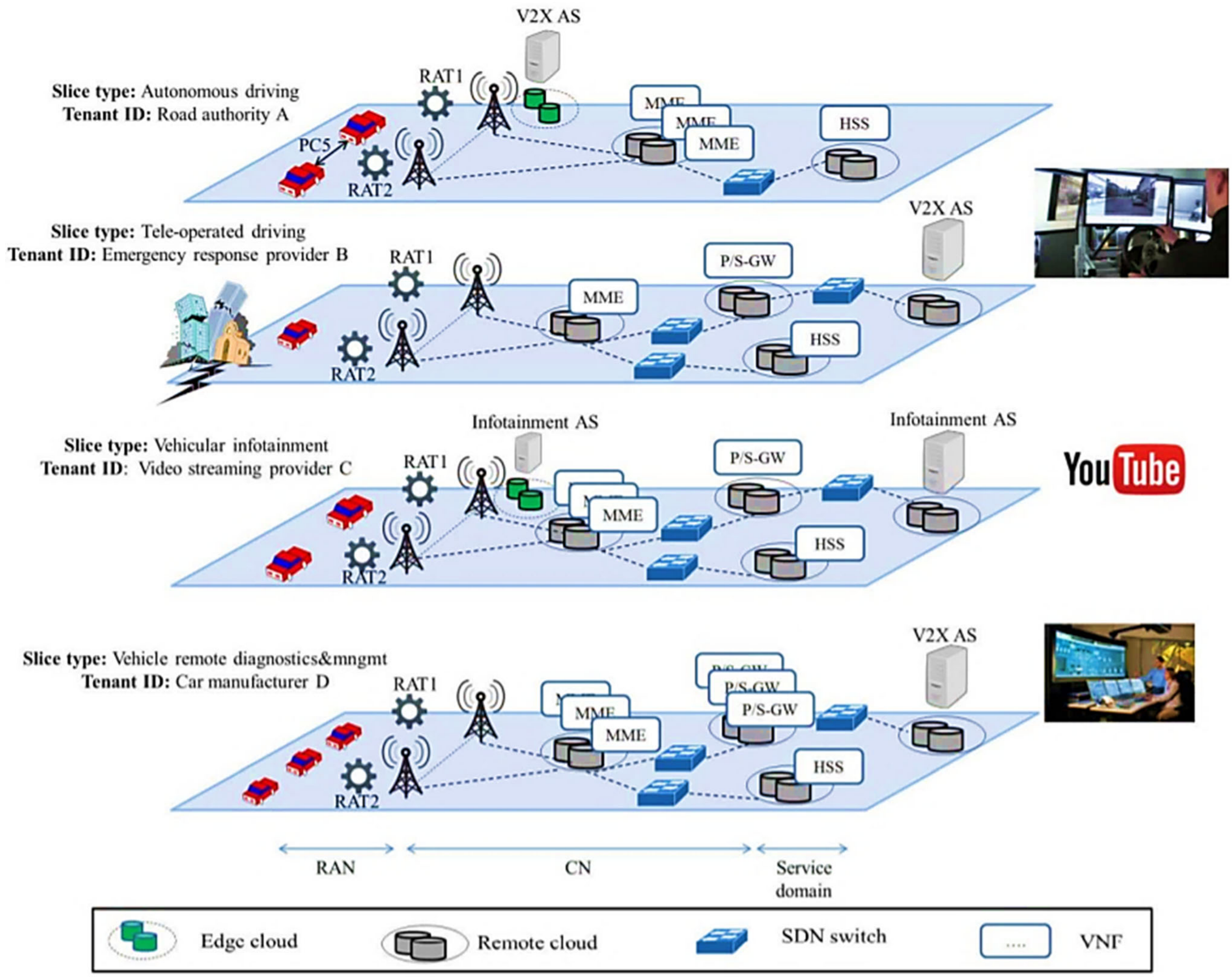

Fig. 12 5G based V2X different slices [54]

of services. In this section, we present the 5G-V2X logical slicing architecture and types that are presented in Fig. 12.

- Autonomous driving slice

This slice based on two different communication modes: this slice targets the guarantee of ultra-low latency for V2V communication. Also, this slice should guarantee the ultra-reliable low latency in V2I communication supported by the network edge application servers.

- Tele-operated driving slice

This slice must ensure the end-to-end high-reliability and ultra-low-latency connectivity among the teleoperation device located outside the core network and the controlled vehicle.

- Vehicular infotainment slice

This slice guarantees the high-throughput infotainment services and data transferred with the V2X infotainment application server.

- Vehicle remote management and diagnostic slice

This slice provides the low-frequency data exchange between several vehicles and the outside V2X application server.

In the 5G-NORMA project [58], they propose the following slicing structure that consists of 3 different layers: the infrastructure-layer, the control-layer, and the service-layer.

Infrastructure Layer it consists of physical network entities, including the RAN access network physical structure to the CN. It includes the following components: RAN devices, computing devices, and storage.

Control Layer it encapsulates the behaviors of the logical network that controls the slice. This layer includes two main control entities based SDN: Dedicated-SDN-Controller and Shared-SDN-Controller.

Shared controller-based SDN provides some network functions that shared among all slices. The shared functions are implemented as SDN applications and listed as follows: slice selection function, load-balancing among slices, and mobility management of slices.

Service Layer the layer contains use cases and services of each V2X market that supported by the designed slices. For further details, readers can refer to [59].

8 NR V2X edge computing

5G is the next generation of cellular networks to provide different requirements for next-generation systems. 5G controls three principal characteristics:

- Firstly, as mentioned by the International Telecommunication Union (ITU), a large amount of data is generated. In 2017, it was mentioned that there are higher than 7.5 billion wireless portable devices in the world [60], and this number is expected to grow by 2020 to be 25 billion [39]. This tremendous mobile device's numbers are contributing to form an ultra-dense network. Thus, there is an increasing growth in the data amount in 2014 from 16.5 exabytes to 500 exabytes by 2020, which considered as 30 times growth.
- Secondly, robust QoS demands are required to maintain ultra-low-latency and high-data throughput.
- Thirdly, a 5G heterogeneous network should be supported to provide inter-operability of different UEs (e.g., tablets, smartphones), QoS requirements (e.g., many levels of throughput and latency for various applications), and network types (e.g., Internet of things, IEEE 802.11).
- Thirdly, massive multiple-input multiple-output (MIMO) technology allows the base station to handle a massive number of antennas more than 16 antennas per division to afford directional communication or beamforming to decrease interference and to allow nearby nodes to broadcast simultaneously. Thirdly, massive multiple-input multiple-output (MIMO) technology allows the base station to handle a massive number of antennas more than 16 antennas per division to afford directional communication or beamforming to decrease interference and to allow nearby nodes to broadcast simultaneously.

8.1 Characteristics of 5G-V2X data

Data in 5G can be classified into three categories, accordingly to the data time properties as follows:

- Hard real-time data: this type of data has some stringent predefined latency requirements (e.g., gamin, video steaming, and healthcare) services
- Soft real-time data: this type of data can tolerate bounded predefined latency (e.g., such as control system of traffic signal)
- Non-real-time data: this type of data tolerates any latency and is not time-sensitive.

Edge computing is proposed to manage applications data with hard real-time requirements utilizing edge-computing servers that are close to the UEs that reduces the latency. For applications and services with soft-real time requirements or bounded end-to-end latency, the edge servers manage these data if the network response delayed. For the non-real-time applications, computing tasks are offloaded to the network cloud for load balancing.

Edge computing utilizes a decentralized design that produces cloud-computing abilities closer to the UEs to reduce network latency as shown in Fig. 13. Edge computing can operate as a single or collaborative computing platform, that can or a collaborative with other entities, including the network cloud [61]. Edge computing is also essential, as the old traditional cloud, computing design is not proper for the high demanding interactive services that have high QoS requirements and have high-computation costs. Network cloud servers, particularly placed at the core network, while the network edge-servers for mini-clouds are placed at the network edge [62].

8.2 5G-V2X computing edge features

Computing meets the millisecond demand for 5G services and decreases the consumption of energy by approximately 40% [63], which considered five times lesser than accessing the network clouds [64]. The availability of edge-computing capabilities is a critical improvement to support the use-cases of V2X. Fully utilizing edge-computing abilities demands many network resources and RAN enhancements. According to the 5GCAR project, a lot of management and control enhancements for all running tasks at computing servers under the high mobility conditions of vehicles. Particularly, when a v ehicle is expected to move from its base station to another one, which is connected to another computing server, the vehicle running tasks are assigned to the anew connected MEC server, to reduce the handover delay caused by changing the servers.

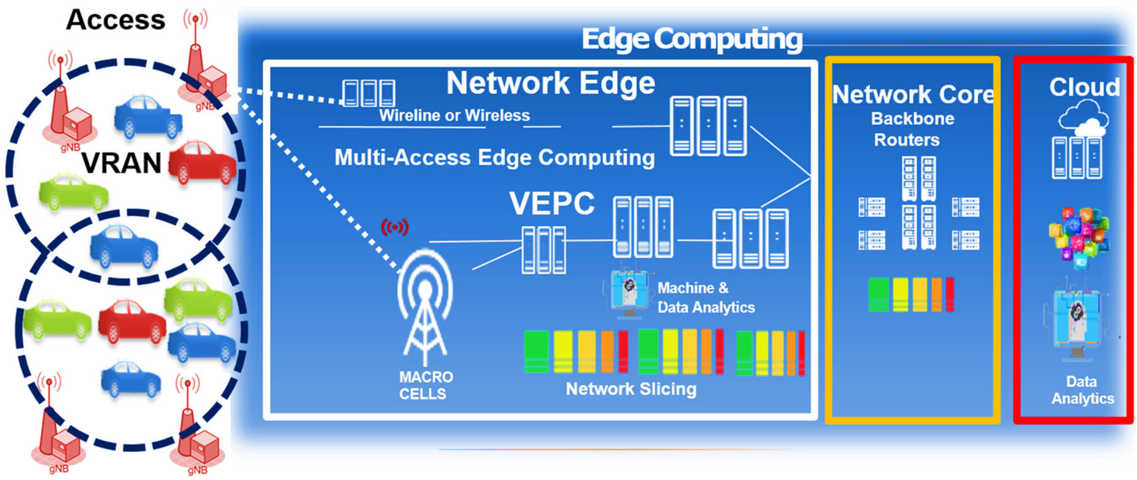

Fig. 13 Edge computing support to services for connected and autonomous vehicles

5GCAR recognized techniques for joining the edge-computing abilities with the mmWave techniques to provide concurrently heavy-load computing tasks and to support maximum utilizing of the radio-access resources. Network slicing is a critical technology to maintain a diversity of V2X services with a single physical platform infrastructure that presented by several shareholders.

This heterogeneity shows that vehicles stay connected to many network slices all the time; each slice is supporting a use case, offered by a particular holder [65]. Whereby the vehicles can gather and share information to avoid the critical situation in real-time processing to prevent accidents.

Computing edge capabilities with an overall centralized and management resources open up the opportunity for many enhancements in the mobile networks to maintain different V2X use-cases [66–69]. 5GCAR recognized several improvements for core-network and access networks. For core-network, 5GCAR improved the mobility concept to support different mobility procedures such as handover and node's synchronization for the attached edge servers. Another improvement proposed by 5GCAR is relevant to the optimization task execution time, considering the network and computing-edge resources.

The first improvement for mobility issue is being handled by distributing some edge servers that can be hosted on small data centers and can serve a limited number of vehicles within the base station proximity. 5GCAR analyzed the handover enhancements procedures in the 3GPP by considering the re-location of edge cloud servers through mobility procedures.

The vehicle is configured to send information about its location to the RAN, and this information is analyzed to recognize if a handover must be triggered or not. The location information yo check if the edge-cloud servers are close to the vehicle or not based on analytical data procedures.

In this scenario, when the signal power of the attached vehicle decrease and vehicle handover to a new target base station, it sends the information of handover to the target RAN to start the process of choosing a new edge computing server.

Another perspective considered by the 5GCAR is task execution optimization considering that edge computing resources jointly with millimeter-wave techniques. Particularly when studying sensitive computation V2X use-cases, for example, cooperative-perception, acquisition of local HD-maps, and cooperative-maneuvers, edge computation is needed to run some tasks of relevance for the use cases locally.

The millimeter-wave access technology utilization can provide valuable results for the offloading of the computation tasks nearby the access vehicles by utilizing the available near edge-cloud servers. In 5GCAR, the total latency for tasks offloaded is calculated considering the sending and receiving time of the tasks to the edge cloud and the latency of processing this task at the edge server.

It is assumed that base stations and RSUs are supported by edge-computing feature, and access vehicles are sectored by directional patterns antennas. To optimize the resource allocation and the scheduling of the offloading tasks from the vehicles to the attached access servers, the following method is proposed whenever a vehicle sends an offloading task request to the access node. In this model, the access node is the controller that can be responsible for making the tasks optimization decisions.

- The queue of computing tasks of each vehicle is updated with some new arrivals and the tasks that needed to be offloaded.

- The channel model between the access node and the vehicle is estimated, considering the vehicle distance from the access node and the vehicle speed.
- The total latency of computing for the queued offloaded tasks that consist of the following delays:
- The latency of uplink transmission of the offloaded task from the vehicle to the controller.
- The execution time of the task at the access node.
- The latency of the download transmission link from the controller to the vehicle to receive the computing result of the offloaded task.
- (Uplink and downlink latencies based on the estimation of dynamic channel model, millimeter wave bandwidth, the transmission power of the vehicle and RSU, and the interference of the uplink.
- A model is estimated for computing the total energy consumption by the access node and the vehicle.
- An optimization model is proposed for minimizing energy consumption and maximizing the transmit powers.
- The entities to be optimized are vehicles and RSU in terms of transmit power and the offloaded tasks number. The result of the optimization process determines if a predefined number of the tasks can be offloaded to a predefined access node.

Autonomous Driving uses cases bring a completely new system architecture with new network and cloud requirements to maintain the new workloads and to provide real-time service requirements. Such an ecosystem involves the network infrastructure, vehicles, RSUs, and the cloud. We conclude this section by the edge-computing important features to support V2X based 5G:

- Network Slicing to define the capabilities and capacity of the network for each different autonomous slicing services.
- Hardware acceleration to optimize the computation and the storage based on concurrent requirements of different services.
- Hierarchical architecture of the Edge Computing ecosystem using a hierarchy of arranged roadside units with Edge Computing capabilities to reduce the offloaded tasks latency and share the processing load.

9 Conclusions

By March 2017, the 3GPP project declared an agreement to quicken the evolution of the 5G NR, which was an important step onward the road to 5G, and the satisfaction of non-standalone and standalone 5G NR. 5G NR enabled outcomes are supposed to be ready in 2019 with Qualcomm newly released RF antennas and modules. Many attempts to make 5G real and applicable. However, the 5G development signifies that the actual deployment of 5G may be late by the end of 2020. A lot of industrial activities are announced to discuss the 5G radio structure, capabilities, technology directions, and use cases. To that end, all the current and future work in the separate 5G areas intend to promote the high-reliability and ultralow-latency requirements for the overall 5G system.

In this paper, we proposed a V2X based 5G standard process, different available use cases requirements within the new 5G radio. We also describe the 5G-V2X architecture according to the 5GCAR project and the available autonomous V2X classes. We served the most recent research papers and project outcomes that describe the 5G-V2X enablers, methodology, concepts, and framework. We light the shade on the edge computing capabilities and slicing concept in 5G-V2X according to 3GPP and 5GCAR project.

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