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Current and future developments to improve 5G-NewRadio performance in vehicle-to-everything communications

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Abstract

Vehicle to Everything (V2X) communication is a technology that provides connectivity between vehicles, pedestrians, and road infrastructure. Dedicated Short-Range Communication (DSRC) is proposed by different standards such as ETSI, IEEE, and others since ten years ago to provide wireless connectivity in V2X. Recently, the LTE-V2X based cellular communication is standardized by the 3rd Generation Partner Project (3GPP) Release 14 as an alternative V2X technology to support autonomous driving. 5G-NewRadio (5G-NR) is being proposed by the 3GPP Release 16 as a new radio access technology to offer enhanced radio coverage and wide ultra-high reliability services. 3GPP Release15 was published in 2018 to include Phase 1 5G-NR standard. 3GPP Release 16 is designed to provide the 5G phase 2 and scheduled for being delivered in June 2020. In this paper, we study V2X based DSRC and LTE-V2X standards and introduce the current 5G-V2X standards progress. We present the 5G-V2X architecture design, core elements, challenges, essential requirements, security enhancement, and radio techniques. Also, we consider the security aspects of architecture and issues of 5G-V2X.

Keywords 5G-NewRadio · C-V2X · DSRC · LTE-V2X · Security · D2D communication · Autonomous driving

1 Introduction

Vehicle to Everything (V2X) is an information technology to connect vehicles with everything. V2X technologies attract industrial and academic efforts to provide wireless connectivity between all road entities and support several V2X services. World-Health-Organization has published that traffic accidents annually cost 1.2 million deaths and 50 million injures [1]. American Automobile Association (AAA) has announced that road-accidents cost 300billion dollars every year [2]. V2X applications and services can provide road safety and reduce accidents. Different V2X infrastructures incorporate a lot of standards, such as DSRC, Mobile Cellular, and Infrared technologies [3]. The increasing rise of smart devices produces a new generation of applications that can allow drivers to access vehicles remotely [4]. The deployment of V2X infrastructure demands high investment overhead. V2X structure differs among different standards; however, the common network blocks are Road Side Unit and Onboard-Unit. Road Side Unit (RSU) is considered a fixed powerful access point that deployed on roads to support massive V2X services for road users. Onboard Unit (OBU), it represents the DSRC communication device used in each vehicle to provide communication between them. V2X communication modes are Vehicle to Vehicle (V2V), Vehicle to Infrastructures (V2I), Vehicle to Pedestrians (V2P), and Vehicle to Network (V2N) that allow the exchange of road real-time information, as shown in Fig. 1. V2V communication supports message broadcasting about road status and allows vehicle communication while vehicles are not covered by network infrastructure.V2I is the communication mode among vehicles and road infrastructures (e.g., road-signs, traffic-lights, and lane marks) using DSRC or cellular radio interface [5]. Infrastructure shares real data about traffic jams, crashes, sharp curves, and promoted speeds. DSRC and Long Term Evolution based V2X (LTE-V2X) are considered as essential V2X communication technologies. DSRC technology consists of both IEEE and SAE standards [6]. DSRC utilizes the IEEE802.11p communication

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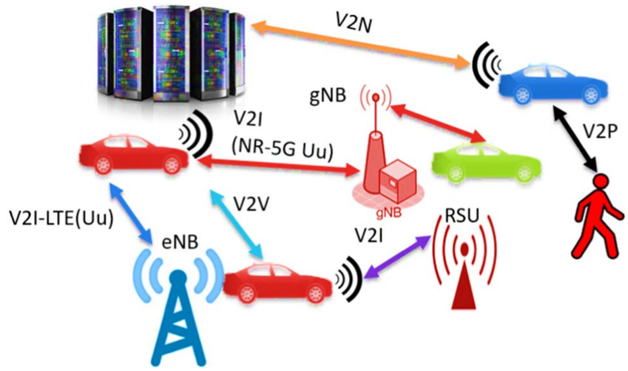


Fig. 1 V2X different communication modes

protocol to broadcast safety messages among vehicles and pedestrians [7]. The structure and communication protocols for DSRC are described in the IEEE-1609 WAVE standards [8–10].

SAE J2735 standard defines a DSRC application layer message format [11], and the J2945/x standards define many scenarios for V2X communication with different requirements. LTE-V2X is a technology proposed for V2X communication with high communication rates and controlled conditions of QoS, based on cellular mobile communication [12, 13]. LTE is recommended to provide different communication enhancements and services that improve the V2X network performance. LTE-V2X efficiently uses application layer protocols of the DSRC and enhanced physical layer protocols with modified radio air-interface. LTE includes two cellular communication modes, (Uu) mode and PC5 direct mode [14–17]. The Uu radio mode utilizes LTE network-core to provide direct V2V communication using forwarding. The LTE PC5 mode enables direct connectivity between vehicles [13, 18]. PC5 radio interface has been modified in different directions to satisfy the dynamic change of V2X requirements [19]. 3GPP recently has evolved the Cellular-Vehicle to everything (C-V2X) that allows vehicles to be managed in a coordinated way while the network coverage is absent. 3GPP aims at enhancing the performance of V2X and satisfying the tight requirements of V2X within Rel-14 and Rel-15. 3GPP utilizes the cellular infrastructure to support efficient resource allocation for vehicles within mobile coverage. C-V2X communication supports automated and semi-automated driving modes. C-V2X presents different communication modes of V2V, V2I, and V2N. Vehicle-to-Barrier (V2B) communication is proposed recently in C-V2X to facilitate wireless communication between roadside barriers and vehicular communication systems. The existing vehicular technologies may not address V2B, but some recent literature discussed its importance [20, 21]. Current research shows that C-V2X proposes performance improvements over the DSRC technology in terms of immense resilience to interference, link budget, and better positioning capabilities [22].

Moreover, researches indicate that both C-V2X and DSRC can probably support many safety applications with 100 ms end-to-end delay under low and medium vehicle density. The advanced V2X applications demand a high quality of service (QoS) requirements. The current V2X technologies become insufficient to provide the required performance. The development of 5G-NR is conducted by the 3GPP to enhance the current LTE-V2X performance. Some of the V2X applications are requiring high-reliability reach 99.99% with end-to-end delay less than 1 ms [23]. Moreover, the existing challenges imposed by the high-mobility scenarios make 5G-V2X evolution a significant problem. Next Generation Mobile Networks Alliance (NGMN) and 5G Automotive Association (5GAA) projects [24] cooperate to evaluate V2X services based 5G-NR. C-V2X is proposed in 3GPP Rel-15 to support different V2X communication modes and offer new enhanced V2X services. 5G-V2X targets supporting high data capacity, high throughput, and low latency of broadband services. In this paper, we extend our previously published works in [25] that briefly describes the 5G-V2X standards and topics. In [25], we discussed the cellular evolution from the LTE-4G radio technology to the 5G-NewRadio (5G-NR). We also introduced the current technologies that proposed to evolve the 5G within V2X communications. We continue the work in this paper and summarize the paper contribution over the chapter as follows:

- The 5G-V2X security issues, architecture, and important functions are studied extensively.
- The 5G-V2X different authentication protocols are described.
- The 5G-V2X use cases requirements within the 5G-NewRadio are introduced.
- The 5G-V2X system structure and design consideration of 5G-V2X critical requirements are proposed.
- The importance of Mmwave technology in 5G-V2X is introduced.
- Study the previous vehicular communication technologies and the drawbacks of each technology.
- Highlight the V2X based DSRC technology features and requirements.
- Compare the proposed LTE-V2X security and the expected 5G-V2X security.
- Conclude the paper with some conclusions and the future trends of 5G-V2X.

Research and standards community continued the enhancements and deployments of LTE that defines the 5G specifications. In this paper, we introduce 5G-V2X challenges and discuss the current V2X technologies, technical issues, and scenarios. The paper organized as follows:

Section 2 provides V2X based DSRC technology. Section 3 explains V2X based cellular technologies. In Sect. 4, we present the 5G-New Radio and millimeter wave technology. Section 5 describes the proposed 5G system structure. Section 6 presents the 5G-V2X security aspects and challenges. Section 7 provides conclusions and future work. Table 1 summarizes the used acronyms in this paper.

2 V2X based DSRC technology

We introduce the current V2X standards and technologies in this section. The V2X framework and architecture are studied in the European and American standards through by ETSI and WAVE standards. DSRC standard has been implemented to meet and satisfy the V2X requirements efficiently with high performance. The American Federal Communications Commission (FCC) defines the frequency band of 5.9 GHz for V2X by expanding the Wi-Fi standard with an IEEE802.11p standard to support the V2X ad-hoc communication mode. DSRC protocols and message formats are designed and implemented by ETSI, IEEE, and SAE J2735 standards [26]. Many commercial V2X projects have been cooperated to enhance the V2X services such as the Car 2 Car Communication Consortium (C2C-CC) in Europe and Crash Avoidance Metrics Partnership (CAMP) in America [27]. DSRC formed a new group for V2X next-generation in March 2018 to offer new V2X services and enhancements. IEEE-802.11bd task group formed in January 2019. The DSRC V2X next-generation group targets improving DSRC performance and providing high throughput V2X communication and enhanced the V2X driving modes. However, DSRC limitations in V2X have been confirmed due to different communications and mobility challenges. IEEE802.11p has been improved to control the high V2X dynamic mobility changes because of high speeds, Doppler obstructions, and various reflections. Carrier Sense Multiple Access with Collision Avoidance (CSMA-CA) and Distributed-Congestion-Control (DCC) mechanisms are handling the high congested network scenarios efficiently within IEEE802.11p [28]. DSRC standards define several requirements for safety and non-safety V2X services. IEEE 802.11p is one of the DSRC protocol stacks that supports the ad-hoc mode between vehicles and infrastructure.

Many modifications are made to the DSRC layers, primarily physical and MAC layers, to enhance the ad-hoc mode connectivity. DSRC has a lot of disadvantages, such as collisions due to the hidden node problem and asynchronous problem that degrades the total performance. Moreover, the high-cost of RSUs deployment is a critical disadvantage. These challenges prevent DSRC improvements in the future. We illustrate the drawbacks of DSRC standard as follow.

Table 1 Summary of Acronyms

Acronyms	Definition
5G	Fifth Generation Mobile Networks
AUSF	Authentication Server Function
C2C CC	Car-2-Car Communication Consortium
CAM	Cooperative Awareness Message
CAMP	Crash Avoidance Metrics Partnership
CHAP	Challenge-Handshake Authentication Protocol
C-ITS	Cooperative Intelligent Transport System
CRL	Certificate Revocation List
CSMA/CA	Carrier Sense Multiple Access/Colloision Avoidance
C-V2X	Cellular-Vehicle to everything
DCC	Distributed-Congestion-Control
DENM	Decentralized Environmental Notification Message
DoS	Denial of Service
DSRC	Dedicated Short-Range Communications
EAP	Extensible Authentication Protocol
eMBMS	Enhanced Multimedia Broadcast Multicast Service
eMTC	Enhanced Machine Type Communication
ETSI	European Telecommunications Standards Institute
FDM	Frequency Division Multiplex
GNSS	Global Navigation Satellite System
HSM	Hardware Security Module
I2N2V	Infrastructure to Network to Vehicle
I2V	Infrastructure to Vehicle
IaaS	Infrastructure-as-a-service
IoT	Internet of Things
ITS	Intelligent Transport System
ITS-G5	Intelligent Transport System at 5.9 GHz
IVI	In-Vehicle Infotainment
LTE	Long Term Evolution
MBB	Mobile Broadband
MIMO	Multiple Input Multiple Output
N3IWF	Non-3GPP Inter-Working Function
NGMN	Next Generation Mobile Networks Alliance
OBU	On Board Unit
PCA	Pseudonym Certificate Authority
PCO	Protocol Configuration Options
PLMN	Public Land Mobile Network
ProSe	Proximity Services
PSK	Pre-Shared Key
RAT	Radio Access Technologies
SA	Standalone mode
SAE	Society of Automotive Engineers
SBA	Service-based architecture
SCMS	Security Credential Management System
SCMS	Security Credential Management System
SCPTM	Single-cell Point to Multipoint
SDO	Standards Developing Organization
UDM	Unified data management
V2I	Vehicle-to- Infrastructure
V2P	Vehicle-to-Pedestrian

Table 1 (continued)

Acronyms	Definition
V2X	Vehicle to Everything
VRU	Vulnerable Road User
DENM	Decentralized Environmental Notification Message
AAA	American Automobile Association
D2D	Device to Device
5G-NR	5G-NewRadio
EPC	Evolved-Packet-Core
PAP	Password Authentication Protocol
64QAM	64-Quadrature Amplitude Modulation
AAS	Active Antenna System
eNodeB	Evolved NodeB
V2B	Vehicle-to-Barrier
SDN	Software Defined Networks
FCC	American Federal Communications Commission
HSPA	High Speed Packet Access
MTC	Machine Type Communications
EAP	Extensible Authentication Protocol
NOMA	Non-Orthogonal Multiple Access
mMTC	Massive Machine Type Communications
MIMO	Multiple-Input Multiple-Output
MME	Mobility Management Entity
MNO	Mobile Network Operator
QoS	Quality of Service
NHSTA	National Highway Safety Transportation Administration
OFDM	Orthogonal Frequency-Division Multiplexing
NFV	Network Function Virtualization
OFDMA	Orthogonal Frequency Division Multiple Access
SDN	Software-Defined Networking
U Plane	User Plane
LTE-V2X	Long Term Evolution-Vehicle-to-everything
OSI	Open Systems Interconnection
UTRAN	Universal Terrestrial Radio Access Network
UE	User Equipment
SUPI	Subscriber Permanent Identifier
SPS	Semi Persistent Scheduling
URLLC	Ultra-Reliable Low Latency Communications
PHY/MAC	Physical layer/Medium Access Control
CAMP	Crash Avoidance Metrics Partnership
SIM	Subscriber Identity Module
PKI	Public-Key Infrastructure
USIM	Universal Subscriber Identity Module
WAVE	Wireless Access in Vehicular Environments
NSA	Non standalone mode
CSI	Channel-State-Information
ARPF	Authentication Credential Repository and Processing Function
NLOS	NonLine of Sight
SEAF	Security Anchor Function
ECDSA	Elliptic Curve Digital Signature Algorithm
5GAA	5G Automotive Association

Table 1 (continued)

Acronyms	Definition
SUCI	Subscription concealed identifier
BSM	Basic Safety Message
V2V	Vehicle-to-Vehicle
BVR	Beyond Visual Range
3GPP	3rd Generation Partnership Project

2.1 High communication cost

Safety messages are transmitted periodically to broadcast information about road and surrounding neighbors that produce a high communication overhead. Significant communication overhead affects network performance as it consumes the shared bandwidth and increases the latency. However, a lot of the adaptive approaches are proposed to change beaconing frequency and reduce the communication overhead [29], which makes IEEE 802.11p not suitable for ultra-low latency and high data-rates applications.

2.2 High deployment cost

V2X communication can support safety services and non-safety services. Non-safety services such as infotainment, gaming, chatting, and internet sharing can tolerate high levels of latency. However, safety services are critical and require ultra-low latency and high-reliability requirements.

DSRC technology utilizes the infrastructure to support connectivity and information sharing between vehicles. In the early deployment phases of V2X, infrastructure is not entirely widespread and needs high-cost for deployment. Therefore, DSRC cannot support the diverse requirements of applications without utilizing infrastructure.

2.3 High congestion level

The DSRC dedicated radio spectrum is fully optimized due to the periodically broadcasting of beaconing messages. High beaconing transmissions consume the bandwidth quickly and prevent the network scalability. For the maturity of standard, it must provide an efficient light-weight congestion-control solution to minimize the congestion and increase the scalability of the network for the high-density scenarios. DSRC technology supports contention-window and adaptive message frequency techniques to expand the network scalability. However, these techniques cannot efficiently work in high-density networks.

2.4 Limited resources allocation

The high mobility conditions and different communication patterns in V2X, allow vehicles in signal communication range to have different network states and topology. Many requirements have been proposed by the new V2X applications and services in terms of network resources, safety messages frequency, and transmission power. In IEEE 802.11p, all vehicles share the same communication medium with the same network resources. Therefore, IEEE 802.11p must enable efficient network-accessing solutions to manage and coordinate resources between vehicles [30].

2.5 Low message reliability

V2X applications demand a reliable delivery with low latency. The messages delivery in DSRC cannot be granted due to the limited lifetime of messages, and DSRC does not provide a practical mechanism for retransmission of failed delivered messages. In large scale networks, failure message transmissions occur due to network congestion and high-interference rates. Therefore, DSRC must introduce a priority solution to enhance the V2X message's reliability.

2.6 Expensive security solutions

In DSRC standards, an IEEE1609.2 security layer is introduced to describe the certificate formats, the cryptography solutions, messages formats, and several authentication mechanisms [31]. The standard security mechanism in 1609.2 based on the Public Key Infrastructure (PKI) protocol that utilizes the Elliptic Curve Digital Signature Algorithm (ECDSA) to sign and verify messages [32]. However, PKI provides high-security level and message integrity; it introduces high communication costs and consumes long processing time. ECDSA attaches a full PKI certificate with each message that consumes the dedicated bandwidth and decrease the network efficiency. In the high-density networks, vehicles need a light-weight authentication protocol to support message integrity and authenticity efficiently. As mentioned earlier, DSRC technology cannot offer the high-reliability and low-latency requirements of the future V2X needs that motivate the standards community to move to cellular technology [33].

3 V2X based cellular technology

The 3GPP project proposed new V2X standards based on cellular communication to support low-latency and high-reliability demands of V2X applications. Phase I of 3GPP Rel-14 has been introduced for Long Term Evolution (LTE) radio generation. Phase II aimed at the evolution of LTE towards the new 5G radio generation in Rel-15 and beyond [34]. Phase I can support some limited V2X beaconing messages, such as Cooperative Awareness Message (CAM) and Decentralized Environmental Notification Message (DENM). Device to Device (D2D) communication in Rel-12 and Rel-13 is designed to provide the high-network density scenarios, and low latency V2V application requirements. The 3GPP standardized LTE-V2X in 2016 within LTE Rel-14. LTE-V2X contains two necessary interfaces, the first one is the wide-area network interface (Uu), and the second one is a direct communication interface (PC5 or sidelink). The LTE-Uu interface is responsible for connecting vehicles directly to the base stations of mobile networks and supporting V2N services. The sidelink PC5 interface provides V2V and V2I applications with high-reliability and low-latency requirements. PC5 interface does not necessarily require frequency assistance from the mobile base station. The Uu interface can support V2X Multimedia Broadcast services with the Uplink Semi Persistent Scheduling (SPS) mechanism [18]. RSU in the LTE-V2X scenario is a stationary infrastructure to offer V2X services and applications. The traditional RSU exchange messages with different network entities, and provide V2X communications through the Uu and PC5 interfaces. In LTE-V2X, traditional RSU is regarded as an option and cannot be considered as an essential entity in the V2X network architecture [35]. The LTE-V2X network structure is a collection of network entities and the V2X application server, as described later in the next Sect. 3 GPP Rel-14 supports direct communication between V2X entities with or without base station coverage using the straightforward communication PC5 interface. LTE V2X mode 3 supports V2I communication to provide several services such as efficient scheduling and high management solutions. LTE mode 3 is not suitable for applying in scenarios without network coverage and handovers with high-mobility conditions. Improve the D2D functionality to support low-latency and high-density scenarios. A lot of LTE-V2X efforts and contributions are proposed in the literature, however, LTE-V2X has not reached its maturity yet.

3.1 LTE-V2X technology

In this section, we illustrate the LTE-V2X architecture and requirements. Previously, we mentioned that many efforts had been proposed to enhance the V2X communication-based DSRC standard. However, in high-density networks, DSRC failed to satisfy the requirements of high network scalability and reliability. 3GPP published an initial version of LTE-V2X Rel-14 by the end of 2016 that utilized the cellular communication in V2X. LTE-V2X radio links support the connectivity between the User Equipment (UEs) and evolved-NodeBase stations (eNBs). The uplink interface defines connection from the user equipment to its base station, and the downlink interface represents the transmission from a base station to the user equipment, as illustrated in Fig. 2. Cellular technologies support high-coverage with a wider communication range.

V2X based Cellular communication integrates a V2X server to support unicast communications with each vehicle and periodically broadcasting communication of beaconing messages to all vehicles connected through a single communication cell. LTE-V2X supports unicast communication between the base station and the attached user's equipment's

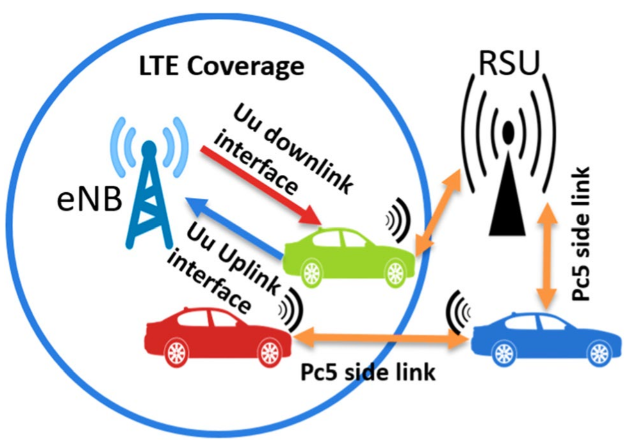


Fig. 2 LTE-V2X communication Links and modes

using the uplink interface. While downlink connections support multicast communication in LTE-V2X. D2D communication enables direct communication to support multi-hop mode among vehicles that can reduce the total end-to-end latency.

LTE sidelink interface proposed under Rel-12 for the safety applications and combined two modes of operation, mode 1 and mode 2. The two modes are implemented to improve the battery lifetime of mobile nodes; however, this improvement costs and increase of latency. LTE modes 1 and 2 are not suitable for high reliability and low latency V2X application requirements. Rel-14 proposed modes 3 and 4 of D2D that are suitable for V2V communications. In D2D mode 3, the mobile network assigns and maintains the network radio resources for the V2V direct communication. In D2D mode 4, Rel-14 allows vehicles to choose the radio resources autonomously without depending on the cellular network coverage by incorporating efficient decentralized scheduling to allow the selection of radio resources. D2D communication utilized LTE network coverage to offer several V2X services. D2D communication dedicates the 5.9 GHz frequency band for ITS applications. Pair connected devices in D2D communication use inband or outbound communication modes, as illustrated in Table 2.

LTE-V2X structure consists of some essential entities, as mentioned in Rel-14 and Rel-15 [36]. The LTE-V2X structurer described below and shown in Fig. 3.

Table 2 D2D communication modes

Inband D2D	Outband D2D
Underlay: In Underlay case D2D and cellular communications share the same spectrum resources Overlay: the problems of interference from D2D communication on cellular transmission can be avoided because of the allocation of dedicated cellular resources	Controlled: can be controlled by the network Autonomous: operate autonomously
Advantages Mobile radio spectrum is used for D2D communications and cellular communication that allow them to share the same resources QoS management is achieved very easy due to entirely controlled by base stations All devices in this mode have the ability to use all cellular devices and entities Radio Spectral efficiency increased due to spatial diversity	*Advantages* The unlicensed radio frequency bands like 2.4 GHz that used for medical use-cases, scientific research are utilized for this mode No interference among cellular and D2D subscribers Easy to allocate resources There is possibility for simultaneous transmissions of D2D and cellular users
Disadvantages The collisions and interferences between mobile connections and D2D considered as one critical problem for Inband mode In overlay D2D, it's possible to waste cellular resources It's very complex to manage resource allocation procedures and power control mechanisms There is no possibility for the cellular and D2D concurrent transmissions *Solution* Using efficient resources allocation mechanism to reduce interference and collisions among mobile radio links and D2D	*Disadvantages* No direct radio interfaces for Wi-Fi and Bluetooth *Solution* It should provide new direct connections interfaces to support Wi-Fi and Bluetooth Infrastructure in this mode can be a stationary RSU to receive the V2X messages through the Sidelink from different UEs Second, RSU can be an eNB that gets V2X communication through the Uu LTE-radio interface using the V2X-application in vehicle

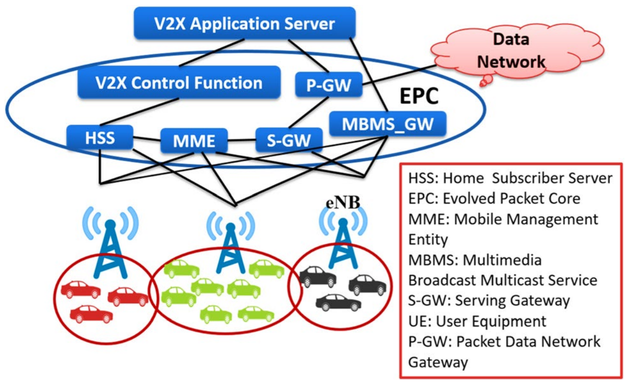


Fig. 3 LTE-V2X structure

User Equipment (UE) is the end-user device that connected directly to eNBs, RSUs, and nearby UEs.

The V2X application server A server to broadcast V2X safety and non-safety messages.

V2X control function It's responsible for providing authentication, key generation, certificate distribution, and revocation processes for vehicles.

Evolved NodeB (eNB) is the mobile base station that allows vehicles to communicate with the cellular network core directly through single-cell or multi-cell.

Multimedia broadcast multicast service It offers multicast V2X services through vast areas that are controlled by different and multiple radio cells. C-V2X is the new commercial paradigm that lunched recently to describe V2X technologies based on cellular communication. C-V2X is available for market deployment in vehicles using different ecosystems includes tier-1 suppliers, global automobile, experiment equipment, chipset companies, system integrators, telecommunication suppliers, wireless operators, and road operators. C-V2X carmakers include Nissan in Japan, Audi in Germany, Ford in the US, and PSA in France participate in the 5G-V2X evolution process. C-V2X commercial deployment has announced various collaborations with automotive suppliers, including Continental, and LG Electronics [37]. 3GPP Rel-14/15 supported the sidelink direct PC5 interface for broad ecosystems, including the automaker's suppliers, automotive developers, mobile operators, road operators, and road infrastructure suppliers. C-V2X can be seen ready for the commercial markets in many 5G projects and announcements [38]. An example of C-V2X readiness is the announcements of the Automotive Association (5GAA) project that have more than 80 significant carmakers members. The new C-V2X generation utilizes direct communications within the defined ITS spectrum that reduce the development time and years to propose new V2X software. C-V2X security is determined by the ETSI, ISO, SAE standards communities, and IEEE 1609 standard. C-V2X makers reduced the development time by changing only the PHY/MAC layers features of DSRC while keeping the DSRC upper layers. 5G is the next cellular mobile generation that considers V2X communication as one of the most critical applications [39].

3.2 5G-V2X technology evolution

In this section, we present the LTE fourth generation of mobile radio can be regarded as the fundamental core of the upcoming 5G technology. The 5G transmissions are based on a high number of base stations located at very short distances. However, 4G is based on high power towers to allow mobile devices to send and receive over long distances. 5G supports the sending of high-speed network signals using a millimeter-wave radio spectrum of 30–300 GHz.

In 3GPP Phase I of Rel-16, V2X use the millimeter wave-spectrum below 6 GHz to send the 5G signals. 5G signals travel short distances with high immunity to obstacles, weather, and interference [40]. The previous mobile radio technologies use low frequencies to transfer radio transmission for long distances. 3GPP has been proposed 5G phase I in Rel-15 and phase II in Rel-16 that announced by the end of 2019, as shown in Fig. 4.

The evolution of 5G always preserves complete backward compatibility to the earlier 3GPPP releases of the same radio generation and requires the enabling of service interoperability among releases and productions. The backward compatibility concludes that after the updating and launching of new versions of the 3GPP network, the devices running in earlier releases operate correctly and function as expected.

Additionally, it guarantees that devices from different 3GPPP releases can also communicate with each other. Inter-vehicle connectivity is designed for direct communication of V2V. It ensures that a device that operates according to Rel 15/16 can directly communicate with the Rel-14 device for utilizing the V2X services suggested by Rel-14. 5G and LTE enabled devices can communicate among them using V2V direct communication. The conclusion is that Rel-14 supports essential safety services, while 5G-NR supports advanced safety services. Hence, it is expected that at the initial deployment of V2X services, there will be LTE-V2X enabled devices. 5G-V2X enabled devices will likely operate with dual-mode to support both 5G and LTE. C-V2X utilizes this approach to include the 5G-NR features that support high-throughput, reliability, and ultra-low latency.

5G-V2X will utilize V2V direct communication using many advanced radio access technologies such as beamforming and massive MIMO. This evolution path to 5G can enable many advanced V2X use cases. As the 5G operators start updating their network cores to the 5G core, the operating devices will benefit from advances of network architecture such as network-slicing support.

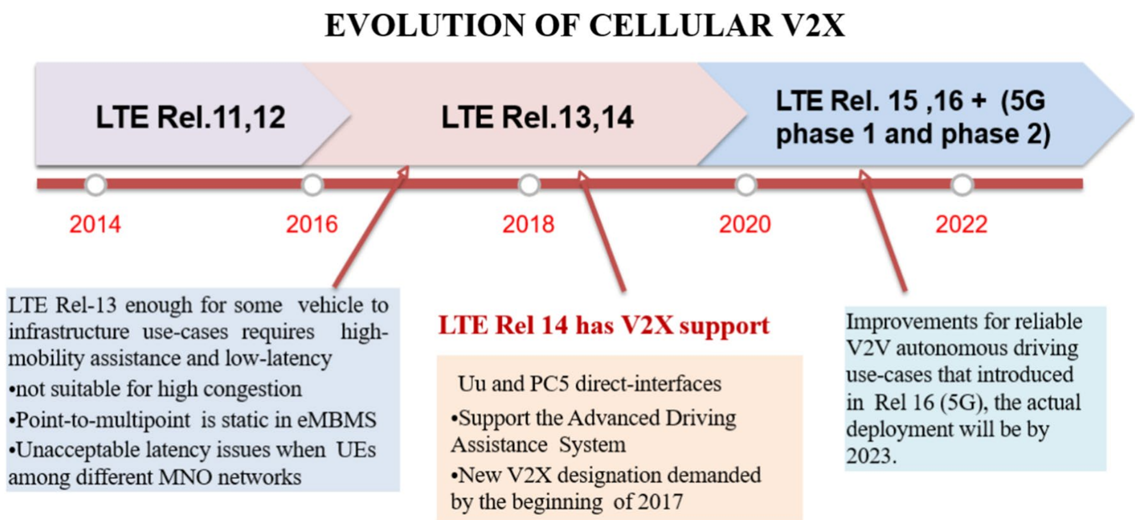


Fig. 4 3GPP evolution of cellular V2X

5G is expected to cover the high requirements of applications with ultra-low latency and high reliability. 5G-NR offers many new features such as Software Defined Networks (SDN) management, simple network topology, Proximity Service (ProSe), and cloud computing. The deployment of 5G in 3GPP enhance the C-V2X services to provide:

- The expected high-precise localization and positioning techniques that encourage autonomous and cooperative driving.
- It is expected to support low-latency and high-throughput demands of critical time applications (e.g., Dynamic-map updating).
- It is expected to provide high reliability in high-density network scenarios.

3.3 Cellular V2X benefits

In this section, we discuss the importance of C-V2X and the critical points concerning deployment.

(1) Radio performance

Cellular technology adds design enhancement for the modulation, coding techniques, and radio-receivers. Mobile technology doubles the communication range of V2X in the case of Line-of-Sight and raises the performance in the case of Non-Line-of-Sight. Moreover, C-V2X supports high-density networks by decreasing the packet error rate using efficient congestion control to enhance message reliability. As previously mentioned, IEEE 802.11p can't support high-density networks because of hidden-terminal problems that cause high interferences and collisions at the physical layer. C-V2X support efficient resource allocation mechanism to ensure that two devices with the same subframe and communication range could not use the same resources that enhance the network performance, especially in high-density networks.

Initial results from Qualcomm shows that C-V2X using PC5 direct communication outperforms EEE 802.11p [13, 16, 41–45]. C-V2X based PC5 mode designed to improve the V2X network performance using the minimum radio requirements of the 4G to deliver great practical improvements. 3GPP outlined the minimized Block Error Rate (BER) for speeds up to 500 km/hr. IEEE802.11p in DSRC standards is not suitable for practical automotive applications. Since 802.11p prone to interference due to the lack of interleaving time between symbols.

(2) Compatibility and cost

C-V2X support the forward and backward compatibility for V2X communication technologies. Since the C-V2X design can support the new radio generations and the previous radio generations. Rel-14/15 is proposed for basic safety applications. C-V2X, based on the new 5G-NR, is designed to provide high throughput and high-reliability applications. Rel-14/15 and beyond may work without depending on wireless coverage or network infrastructure. 5G-NR based V2X will offer robustness, safety, and reliability. The cellular chipset integrates the C-V2X functionality to support cost-effective solutions compared with the high-cost DSRC deployment. C-V2X integration with the LTE will be profitable according to the North-America firm P3 consulting [46].

(3) High-speed and Ultra low-latency

The physical layer in DSRC needs a new improvement for the receiver implementation to deliver future high-speeds. However, C-V2X has initially been designed to support high-speed V2X cases. C-V2X communications in Re1-14/15 can provide more than 500 km/h speed in the 5.9 GHz ITS band. C-V2X network design can offer high-speed scenarios with reliable performance without advanced receivers implementation. C-V2X is designed to provide low-latency requirements for the safety messages with at most 4 ms or less depending on the application.

(4) Tight Network Synchronization

C-V2X supports strict methods to provide synchronization and positioning using different synchronization sources, while the GNSS is not available. V2X services depend on GNSS availability to request the location information; however, sometimes vehicles lost the GNSS connection due to interferences. 3GPP defines another synchronization source if the GNSS not available such as nearby vehicles or base station timing.

3.4 5G-V2X challenges and requirements

In this section, we present the 5G-V2X vital features and challenges. In 5G-V2X, V2V and V2I communication modes require new needs and performance requirements. The V2I and V2V performance requirements in 5G-V2X is expressed in Fig. 5. In V2V communications, vehicles can provide low latency, high throughput, and availability of PC5 connection. While V2I transmissions have less sensitivity rather than V2V and support unicast and multicast communications. 5G-NR faces many vital challenges; we describe the 5G-V2X difficulties in this section.

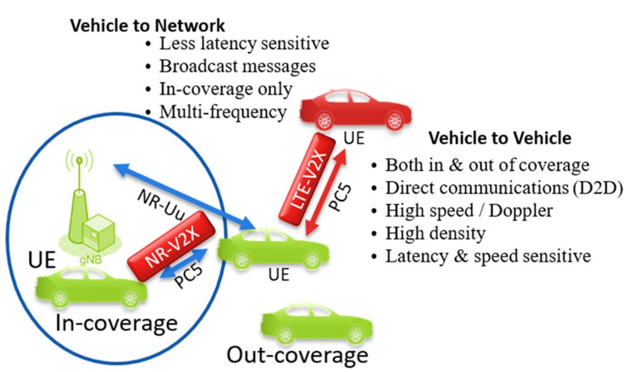


Fig. 5 V2V and V2I requirements in 5G-NR

(1) Latency and Data Rate

The autonomous driving system must be supported by real-time information to enhance the connectivity between the cellular network and vehicles. This information could be speeds, video streaming, and locations. Ultra-low latency applications require a short time delay in microseconds scale and ten times data-rates per second. 5G techniques have been proposed and tested to support the ultra-high data rate and ultra-low latency and communications, while all tests in static scenarios with low-mobility. The V2X channel conditions and system architecture show some differences compared with cellular networks. Low-latency in mobile communication is a necessity to secure autonomous driving. Vehicles need to discover road situations, neighbors, and pedestrians. Typically, environmental sensors can supply this information to vehicles through RSUs or near vehicles. As an example of latency measurements of 5G-V2X scenarios, the Rohde & Schwarz project has been approved accurate analysis of the V2X latency using experimental testing. The measured latency for a single broadcast message was less than (2 μs). The transmitted data in the conducted experiments were beaconing and video streaming packets. The accuracy of latency was confirmed by adopting high-accurate GPS receivers. The conducted tests in Munich focused on vehicle's remote control, while tests at Shanghai focused on the beaconing broadcasting adjustment for the platooning scenario [47–50].

Platooning is a V2X use-case with many vehicles travel in the same direction and at the same speed. The total latency combines the transmission time from source to destination, processing time, propagation time, and additional delays at the receiver. In 5G-V2X, a D2D direct interface is needed for in and out network coverage to enhance the connectivity among vehicles. In LTE-V2X, the PC5 direct interface represents the straightforward radio-interface among vehicles within network-out coverage. Three vehicles 1, 2, 3 broadcasts using the direct D2D-PC5 interface during in or out network coverage to reduce V2V applications latency, as shown in Fig. 6. A lot of improvements for the physical/MAC layer are proposed for the D2D direct communication.

(2) Architecture Design

5G-V2X architecture must be designed carefully to provide future V2X needs. The centralized system is required to provide and control the real-time information exchanging between vehicles. The 5G-V2X system should be secure, open, efficient, and compatible to support broadcast data dissemination, low latency, high-data-rate, and control of the vehicle's mobility. 5G-V2X network scalability is

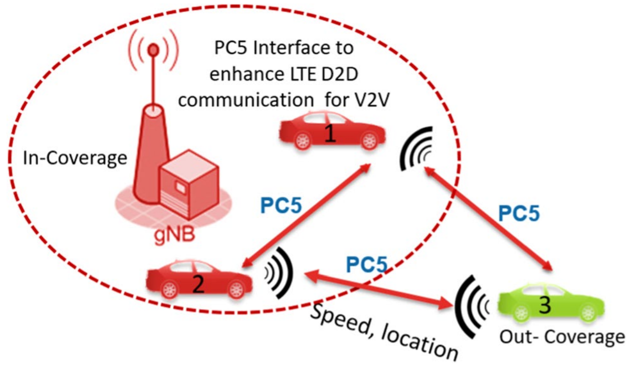


Fig. 6 5G-NR PC5 interface in two cases (in and out coverage)

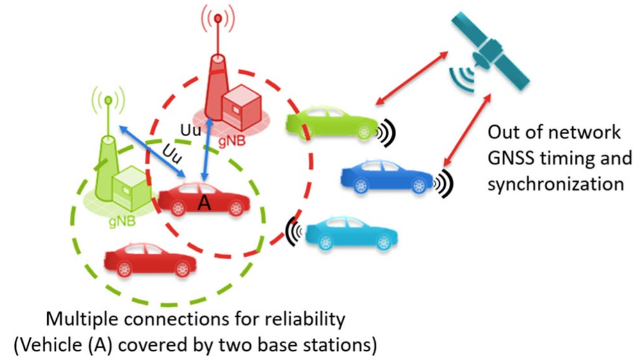


Fig. 7 vehicle's reliability and synchronization in 5G-NR

considered as a critical requirement for the future vehicle increase [51–54].

(3) Environmental Virtual Sensing

5G-V2X will provide Beyond Visual Range (BVR) environmental virtual sensing data for communication. 5G-V2X will offer a virtual sensors network for the inter-communication between vehicles. This virtual network is helping the on-board vehicle sensors like LiDAR, millimeter radar, and video camera to gather surrounding information about other vehicles. The resolution and latency of the connection between the virtual sensing network and local vehicle sensors are considered as a critical problem in 5G-V2X. Enhancing this virtual sensing network results in significant improvements in vehicle environmental sensing perception.

(4) Network Capacity

In V2X communication, several concurrent broadcasting to all vehicles through the same communication domain to share road status and send events alerts. A storm of beaconing broadcasting results in high network congestion. Various V2X applications require several message types to distribute many network status messages using different sizes. 5G-V2X improves the resource-allocation mechanism and enhances the receiver's systems by adopting a new antenna design such as adaptive-beam-forming under high-density conditions. Efficient resource allocation can assist various sender's requests. Vehicles are communicating with the base station in a unicast way to allocate resources. The base station allocates the transmitter's resources to allow them to use PC5 direct communication in subsequent future communication.

(5) Network Reliability and Availability

V2X applications require high network availability and reliability. 5G suggests adopting the Global Navigation Satellite System (GNSS) to provide tight-synchronization and high accurate-positioning. A lot of significant improvements in GPS methods are proposed for the vehicle out coverage scenarios. The availability demands adjustment of the D2D MAC and Physical layers to support effective resource-allocation, and many redundant links to prevent network failures. As shown in Fig. 7, vehicles can join many base stations at the same time using the WAN-Uu interface, and vehicle synchronization being done using the GNSS.

4 5G-NewRadio (5G-NR) and millimeter wave technology

In this section, the 5G-NR and mmWave technologies are presented. We propose the new functions of both technologies that defined especially for V2X communication. 3GPP announced 5G-NR standardization as the first 5G phase of Rel-16 that targets the enhancement of V2X applications. The NR offers flexible radio access procedures using high frequencies to deliver high data capacity, low network latency, high network reliability, and autonomous driving massive connectivity purposes. 5G-NR is the 5G new radio interface that implemented to enhance and provide a broad diversity of services, devices, and spectrums. 5G construction is executed based on earlier LTE cellular technologies and a set of services to guarantee compatibility [55–58]. 5G initially promoted by the developments and improvements of the LTE, LTE-Pro, and LTE-Advanced technologies. The 3GPP arrangements regarding the earlier wireless technologies can be used in the 5G-NR structure. The LTE devices can directly connect to the network core of LTE and the 4G Evolved-Packet-Core (EPC) network. The 5G primary mode is called Non-Standalone. In this mode, the gNB 5G base station routed the connected devices to the LTE-eNB base station, then to EPC, or routes them directly to EPC. The 5G Standalone mode allows the LTE devices to attach directly to the 5G core network using a 5G-NR interface, as

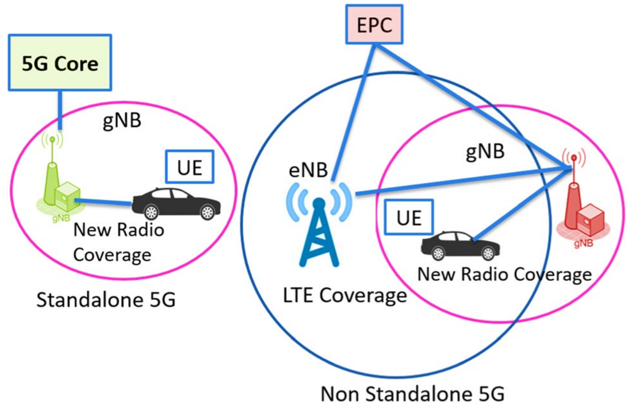


Fig. 8 5G-NR standalone and nonstandalone modes

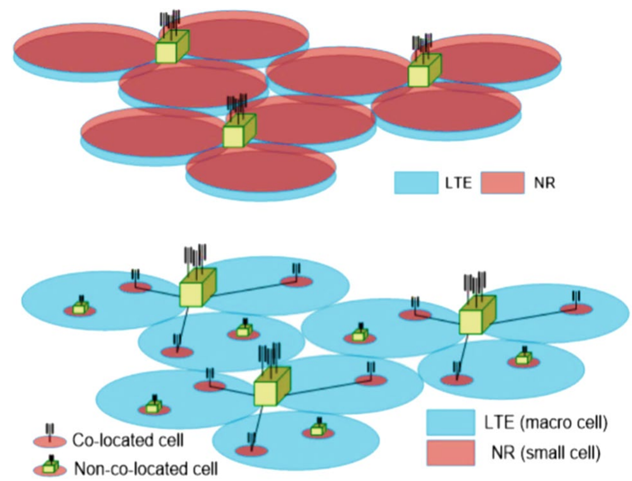


Fig. 9 5G-NR and LTE Cell Coverage Coexist [38]

shown in Fig. 8. The 5G-NR Standalone has been finished by the end of 2018 to provide user and control-plane-capabilities using the core of the 5G system. 3GPP defines the design compatibility of a 5G-NR core to provide integration among the following future releases of the 5G. 5G-NR improves network scalability, performance, and flexibility, efficiency by offering the use of an unlicensed and licensed spectrum with a large-scale frequency band. Furthermore, the 5G-NR interface must be efficiently designed to accommodate an extensive flexible system structure. 5G-NR must be able to address many services offered by sets of devices with high performance and low latency demands. 5G-NR must carry diverse scale deployments of the traditional macro-model and hotspot-model. 5G supports the choice among several Radio Access Technologies (RAT) [59–61]. 5G-V2X support improvements for RAT choice to present a stable and accessible service for vehicles. Using various RATs accelerates V2N communications throughput and capacity. Multi-RATS selection can provide robust behavior of the 5G-mmWave technology, including the beam form procedures, and provide a redundant, reliable connection to enhance the remote autonomous services performance. 5G can support the backward and forward compatibility to include both old and future wireless radio technologies. 5G-NR requires to exist with LTE coverage in adjacent neighboring bands and sometimes inside the same frequency band. 5G NR bandwidth parts allow 5G NR and LTE signals to the same carrier that adding new difficulties with signal interference due to overlapping signals and sometimes nearly spaced signals, as shown in Fig. 9. Some 5G operatives use a defined two-phase design in 5G-NR implementation to reduce the initial investment required by the operatives. LTE-NR mode or Non-Standalone(NSA) process will be started initially, accompanied by the standalone (SA) method. Many NSA parameters are presented on the 3GPP; for example, in option three the eNB can host the 5G-NR control plan, as shown in Fig. 8. The mmwave radio technology is considered as a promising part of the upcoming 5G technology. The sub-6 GHz band and mmWave, both represented in the 5G to allow low latency and more high-speed data. The mmWave assigns a particular part of the wireless spectrum within (24–100) GHz, as shown in Fig. 10. MmWave technology is using the assigned frequency band to increase the possible bandwidth. While lower frequencies are already congested with TV and radio transmissions, in addition to the assigned LTE frequency bands within (800–3000) MHz. A short-wavelength is operated to carry data quicker, however, it validates for small distances. The goal of mmWave is to improve the accessible data-bandwidth across small dense areas. MmWave can cover several cases such as stadiums, malls, clubs, and several places wherever the population crowding is the problem. However, for the coverage of long distances like towns and villages, the sub-6 GHz band can operate an essential role to support consistent and continuous coverage. The mmWave limitation is related to the covered area size and obstacles. The mmwave is a vital technology to develop the 5G autonomous driving high demanding applications. To ensure high throughput for the following V2X communication cases.

V2V communication case To allow the connectivity among all nearby vehicles through PC5 interface based LTE or NR, and support sharing of sensing information in very high-density scenarios such as platooning, co-operative lane changing, and sensor-sharing.

V2I communication case It supports transferring of massive data, such as objects recognition and detection data, updating and exchanging HD-maps with RSU using a short timeless message. It takes place over the Uu interface and 5G-NR core. The severe signal propagation limitations can control such cases. Challenges originate because of the beam training overhead under high-mobility situations such as pedestrian bodies [62–67]. It enables vehicles to

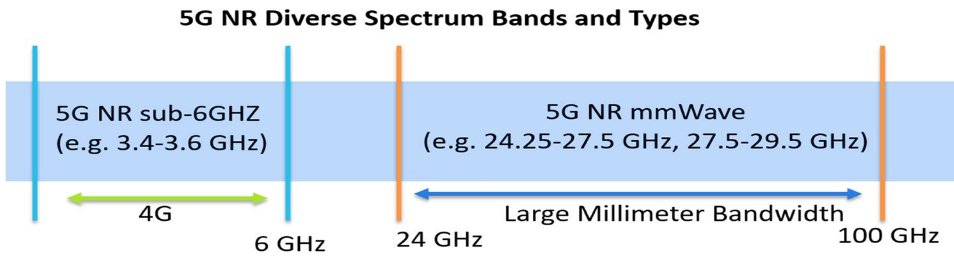


Fig. 10 5G-NR spectrum bands and types

communicate with V2X Application Server and vice versa. It can allow and facilitate access to high-resolution mapping, infotainment applications, such as video streaming and music, as well as weather and traffic condition updates.

In summary, extremely high-frequency signals of 5G don't travel long distances and cannot transfer well from inside to outside. However, the beamforming and massive MIMO technologies guarantee that stringent line-of-sight isn't a necessity to gain the use of millimeter-wave [66, 68, 69]. MmWave signals could not have the ability to penetrate constructions or obstacles; however, it can skip around them to warrant a fair 5G signal. Millimeter-wave signal power will diminish somewhat during rain, which results in slightly lower speeds with connection difficulties. MmWave is the shortest-range next-generation technology that can be used in the next-generation networks. Base stations can cover up to a kilometer, that's not a vast area. Several base stations should be installed closer together to cover the same regions of current LTE networks. MmWave deployment will seemingly only in urban places, wherever it can include the most significant number of vehicles in a small space. MmWave technology is proposed to support future 5G-V2X applications to provide higher data rates and wider bandwidth. The MmWave technology limitation, which principally in terms of covered area and sensitivity to obstacles, but Samsung and Qualcomm claim that 5G mmWave works.

5 5G-V2X architecture

In this section, we discuss briefly the 5G-V2X structure and functions according to the 5GCAR project and 3GPP recommendation. We also introduce the basic implementations that can affect the future of V2X communications.

Recently, vehicles can be controlled by themselves; however, the vehicle's mobility depends on several technologies. All associated objects such as pedestrians, vehicles, public transportations, and all connected devices can offer services from their connectivity and network connectivity. Limitless broadcasting information is considered as the key to enhancing the vehicle knowledge within the transmission range of onboard sensors. Fifth Generation Communication Automotive Research and innovation (5GCAR) is a European innovation research project supported by the European Commission to implement and test the 5G-V2X networks [70, 71]. The 5GCAR project is one of the essential 5G designs that propose techniques, protocols, and network designs to advance the V2X communication using 5G. 5GCAR is a member of the ongoing 3GPP standardization. 5GCAR consists of some defined work packages, as shown in Fig. 11. The 5GCAR vital goals are to decrease the end-to-end latency, increase the network reliability, guarantee high network availability, ensure interoperability of different radio access technologies, enhance the massive access scalability while ensuring network security. Figure 12 shows the 5GCAR essential components, such as 5G positioning, 5G radio resources management, multi-RAT techniques, management of 5G mobility, 5G-V2X Slicing, Privacy, and Security. The 5GCAR workgroups packages are discussing the 5G-V2X management, the radio spectrum aspects, the 5G-V2X radio interface, the 5G-V2X system design, and architecture. In this section, we discuss the 5G-V2X design according to the 5GCAR project. We propose the 5G-V2X structure, as illustrated in Fig. 13, and consist of traffic

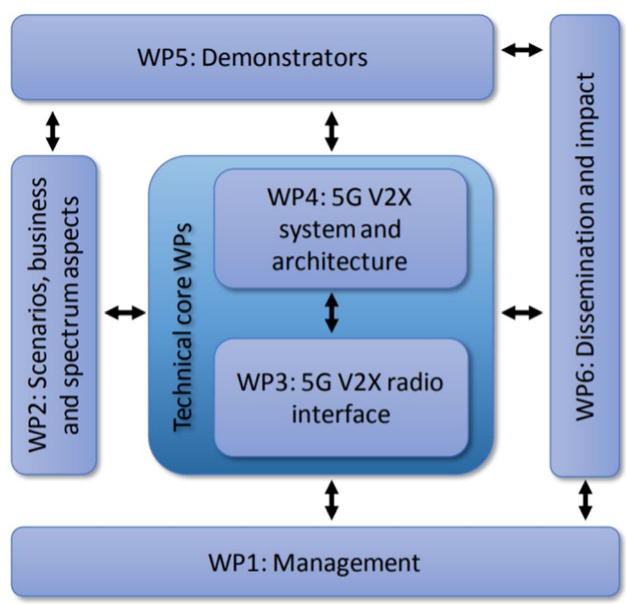


Fig. 11 5GCAR project work group packages [71]

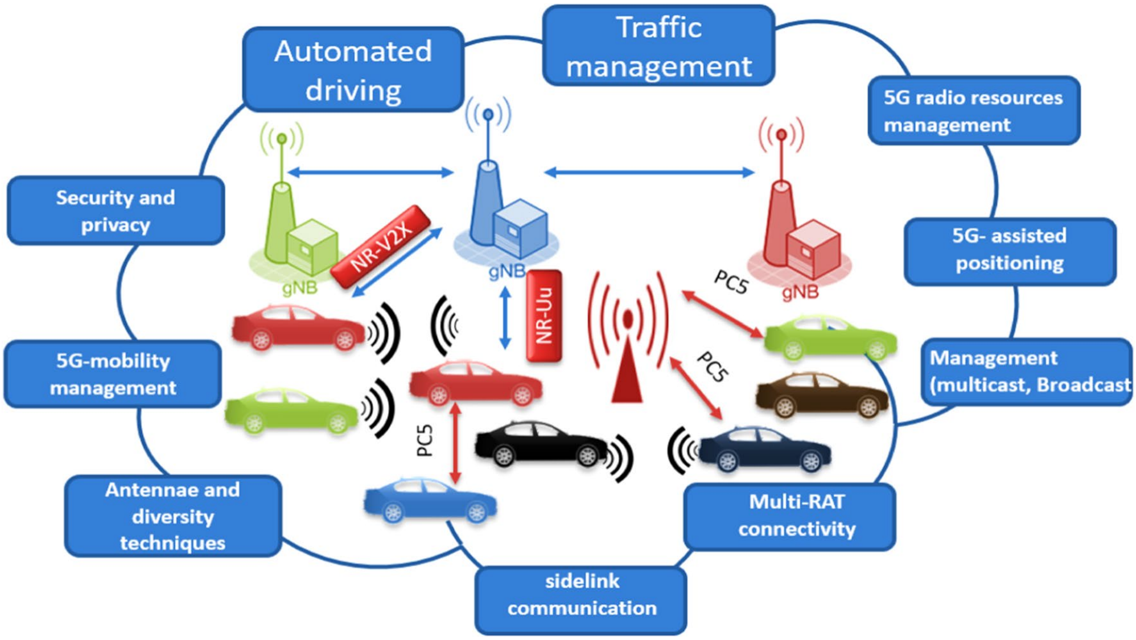


Fig. 12 5GCAR concepts and 5G aspects

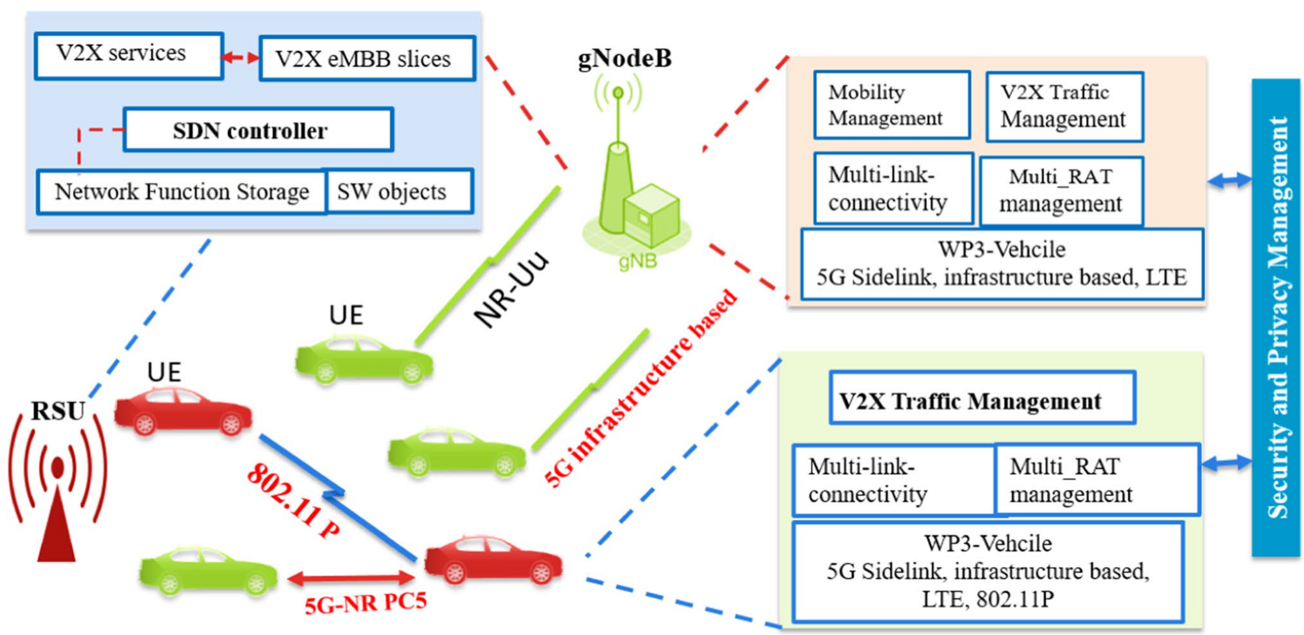


Fig. 13 5G-V2X system structure

management, multi radio-access technologies, and the 5G inter-connectivity. As well as, the 5G aspects are introduced, including the 5G management through SDN networks, the 5G virtualization, and the 5G slicing technology. We discuss the structure functions and how they can affect the future of V2X communications as follow.

(1) Network Management

The 5G-V2X network architecture consists of management function, multi-connectivity function, security, and edge-computing. Network management includes every essential operation for efficient, practical deployment and self-regulation of the essential V2X services. 5GCAR organized the Infrastructure-as-a-service (IaaS) as a primary definition for active system management. Network Function Virtualization (NFV) and SDN technologies are used to provide critical V2X services deployment according to the geographic locations of vehicles [72–74]. Security problems affect V2X networks badly. Hence, it's investigated heavily in earlier V2X technologies, such as DSRC technology. The 5GCAR project proposes two different approaches for the 5G-V2X security and integrity check for messages, respectively, by utilizing the security process at the UEs application layer while using the network connectivity presence.

(2) Multi Connectivity

V2X applications are assumed to use the infrastructure radio links (Uu), and the direct PC5 links for connectivity. Both communication links have different features. In the case of V2V sidelink communication, it is assumed to afford reliable resource-allocation, wide-coverage for the out-network case, and network low-latency. While the WAN (Uu) interface is considered to provide high-reliability and high-throughput. 5GCAR approved that utilizing a single communication link type can be enough to meet the V2X network requirements. Additionally, a system with multiple RATs ability is considered, that can expand the known challenges, assuming that every RAT way has its features.

(3) Network Slicing and Edge Computing

The computing capabilities at the network-edge is a significant improvement to advance V2X use cases. Completely utilizing the edge computing abilities require many enhancements of radio access technologies. According to the 5GCAR project, a lot of management and control improvements for all computing server's tasks on vehicles. Principally when a vehicle is considered to hand over between different base stations that are connected to different management edge servers, the ongoing jobs are assigned to the anew attached server to decrease the job time delay made by the handover. 5GCAR defined some methods for connecting the edge computing with the mmWave techniques to provide high optimization of the available radio resources and decrease the overhead of running tasks. Network slicing is a vital enabler to provide a variety of autonomous services with a common infrastructure offered by several participants. Heterogeneity of 5G network slicing can prove that vehicles can be connected to many network slices all the time. Every slice can serve a single V2X use case proposed by a different operator [73, 75–78].

6 5 G-V2X security

In this section, we introduce the security issues and aspects of 5G cellular V2X communication. We describe the security aspects, security architecture, issues, and primary authentication using the 5G-AKA authentication protocol [79–82].

6.1 5G-V2X security aspects and issues

In this section, we propose the 5G-V2X security issues and challenges according to standard and 3GPP SA3 workgroup. The 5G-NR system is assumed to offer several high-level industry models and designs that generate a lot of new vulnerabilities. Hence, offering common security structures for all models will not efficient and not applicable. The fundamental security systems proposed for LTE-V2X may be used again for securing the 5G networks. However, 5G systems require flexible authentication solutions to support different use cases evolving V2X, IoT, and several new access methods. The 3GPP SA3 is the workgroup that implements specifications of the security of mobile communication [83]. SA3 introduces two phases of authentication, the primary stage, and the secondary phase. The secondary phase demands a successful authentication validation in the first authentication phase. The primary authentication phase presents secure access for the 5G network.

In contrast, the second phase is based on the Protocol Configuration Options (PCO) in which the UEs make use of the CHAP and PAP security login credentials [84]. Both CHAP and PAP authentication protocols support the EAP protocol [85]. Authentication in 5G systems must provide several services demands and different applications. Now, the 3GPP standardization is interested in purposing security solutions for many areas of 5G to offer various applications as follows:

- The security of the termination point of the user plane (UP).
- The authentication, authorization, privacy of the UEs devices with privacy-preserving solutions of IMSI,
- End-user security including the managing of users eSIM (e.g., storage, credentials, and processing). supporting the security framework for the network slicing.

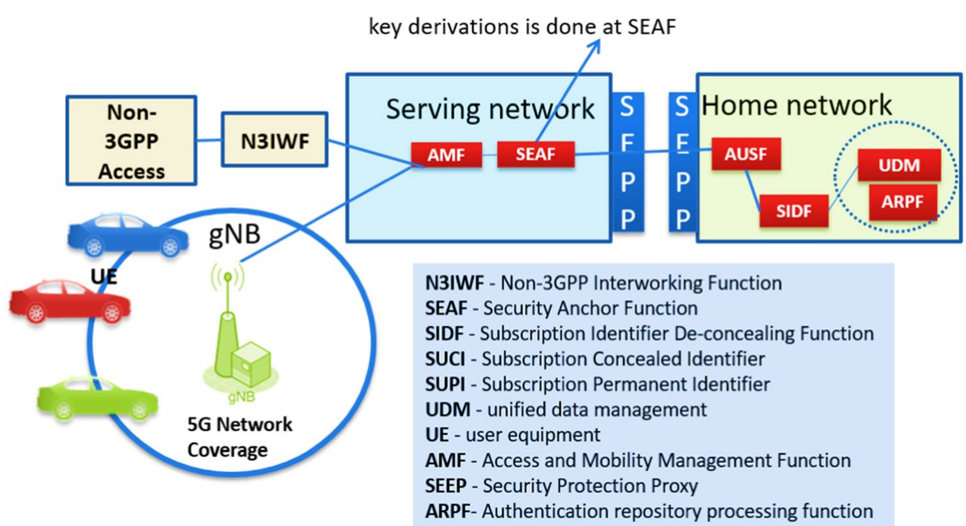
In the 5G-V2X, there is a lack of studies regarding the safety aspects and concerns in 5G-V2X. The current studies regarding NS-5G mainly focused on the LTE issues defined to the LTE network infrastructure. In 3GPPP Rel-15, 5G-V2X security is discussed for both modes of Non-Access Stratum and Access Stratum [86]. The primary security is determined to utilize the 5G-AKA protocol or EAP-AKA protocol to support key distribution. Although Rel-15 presents a full reasonable design of the 5G network security, the V2X security within 5G still has to be studied as the V2X nature is different from the normal UE due to different communication modes and high mobility. Security of user's credentials and authentication are the key issues to be analyzed in the 5G-V2X. Moreover, network layout and planning must be studied, and the effect of handover problems in different communication modes [87]. The deployment of 5G new functions at the 5G core and edge should be studied. 5G security mainly depends on the backward methods, which considered as very complex solutions to apply it in 5G-V2X. Moreover, using of Certificate Revocation List (CRL) method in the primary authentication phase for high-density RSU scenarios. CRL needs a significant dependence on a centralized authority existence, which represents a problem. The 5G design targets the protection of credential and security material that will be used in the next authentication phase. However, sniffing the vehicle information and credentials break the forwarding-secrecy property. Hence, delivering comprehensive forward secrecy is a significant aspect of V2X security [88]. Another problem is the initial authentication dependency and several assumptions that are made with the security schemes [89, 90]. The generation of secret long term keys is not yet decided to be at the 5G core network or the 5G units of the OEMs. The next section explains the 5G security architecture and the 5G-AKA protocol. It also introduces the 5G-AKA message flows.

6.2 5G-V2X security architecture

In this section, we present the 5G-V2X security structure, as shown in Fig. 14, and propose new security functions such as Authentication Server Function (AUSF), Security Anchor Function (SEAF), Processing Function (ARPF), Authentication Credential Repository, and, Security Context Management Function (SCMF), and Security policy control function (SPCF), as explained below:

- *Service-Based Architecture (SBA)* It proposed to the 5G core network to support several various service entities and requests outlined in the 5G.
- *Security Anchor Function (SEAF)* It is placed in the serving network to manage the authentication process between vehicles and their home networks and considered as the middle gate in this authentication process. It can deny the UE authentication request, but the acceptance for authentication requests depends on the vehicle's home network.
- *Authentication Server Function (AUSF)* It's located at the home network of each vehicle to support the mutual authentication. It determines the vehicle authentication, however, it depends on another entity to provide the security and authentication parameters during the 5G-AKA is applied.
- *Unified Data Management (UDM)* Is the function that can host tasks related to data management, and determines the authentication algorithm based on pre-configured policies and user's identity. It can also calculate the authentication parameters for the AUSF entity at need.
- *Subscription Identifier De Concealing Function (SIDF)* It used to decrypt the Subscription Concealed Identifier (SUCI) to find the SUCI long-term identity of the Subscription Permanent Identifier (SUPI) as, in 5G, the users' long-term identity is sent encrypted. A public-key encryption algorithm is used to secure the user's permanent identity (SUPI). The SIDF is the single function that has access-rights to the UEs private key information that has been transmitted to each UE for the encryption process of its SUPIs.

Fig. 14 5G-V2X security framework



6.3 5G-AKA protocol primary authentication

In this section, we provide the 5G-AKA protocol authentication for 3GPP networks and non-3-3GPP networks. A central authentication solution has been implemented to provide open 5G authentication for both non-3GPP access networks and 3GGP access networks. Extensible-Authentication-Protocol (EAP) is proposed for 5G authentication, EAP-authentication is between the vehicle as an EAP client and AUSF function as an EAP server. Authentication across untrusted non3GPP access utilizes a new network function, called Non-3GPP-Interworking-Function (N3IWF). It is crucial to design the VPN server to support the access of non-3GPP devices over IPsec tunnels. Several security frameworks are built with one authentication process to allow vehicles to pass from a 3GPP to non-3GPP systems without repeating the authentication process. 5G security literature defines five perspectives to guarantee security in 5G use cases (e.g., V2X) such as resilience, communication security, identity management, privacy, and security self-reliance [91]. For communication security, both user and control plane data must be encrypted. Furthermore, user plane data and signaling data must support message integrity requirements.

5G-V2X provides the same mechanism for identity management as LTE-V2X, i.e., the same mutual authentication between vehicle and core network, the security-functions, and security materials.

Moreover, it illustrates the EAP framework to provide extra flexibility for mobile operatives to choose authentication parameter formats. 5G Authentication and Key Agreement (5G-AKA) protocol are used for session key distribution and authentication [92].

Further, it explains the EAP protocol to implement additional flexibility for mobile operators to determine the proper formats for the authentication parameter. 5G-AKA) protocol is utilized during the distribution of session key and authentication parameters [93]. In Fig. 15, 5G-AKA is described, as the SEAF function begins the authentication operation after the receiving of requesting messages from the vehicle. Each vehicle needs to send a temporary identifier (GUTI) for the SEAF entity or the encrypted-permanent- identifier (SUCI) if GUTI is not designated for the vehicle by its serving network. The SUCI identity is the encrypted value of the SUPI using the public key value of the vehicle home network. Hence, the permanent value of IMSI cannot be sent in plain text through the 5G networks. The vehicle permanent-identity encryption is acknowledged as a significant protection enhancement across the previous generations, such as LTE-V2X.

The authentication producers are started by allowing SEAF to send a message authentication request to the AUSF. It first confirms that the Uu serving network is authorized to request this authentication service.

- In the case of authentication success, the AUSF transmits an authentication request to the ARPF/UDM.
- SUCI value is given by the AUSF, next the SIDF will decrypt the SUCI message to verify the SUPI.

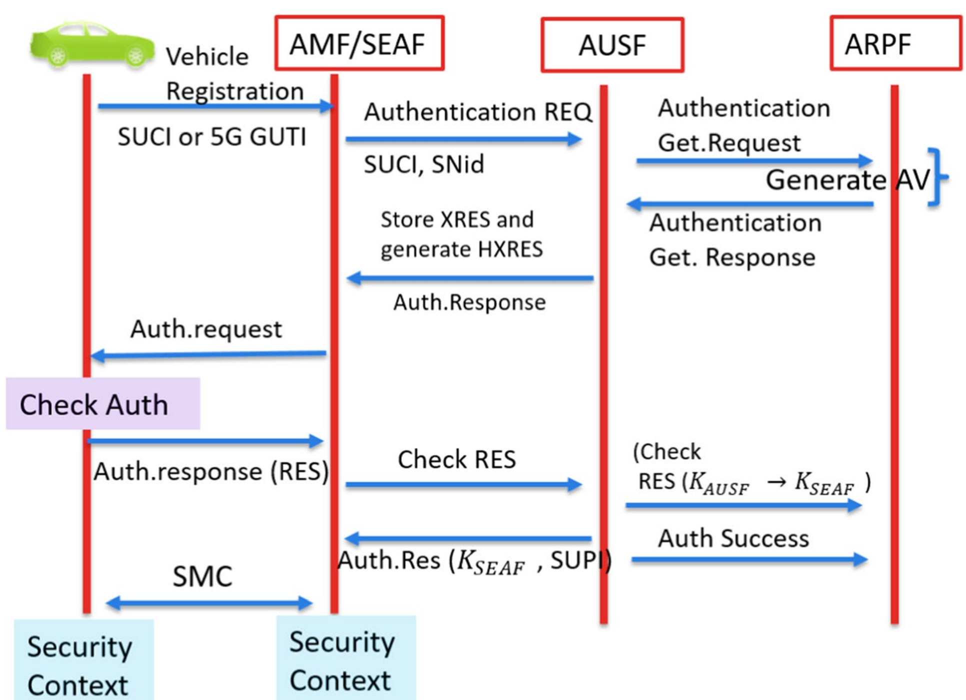


Fig. 15 5G-AKA authentication protocol for primary security phase in 5G-V2X

- SUPI is further used to choose the proper authentication method which configured and assigned for the subscriber. The 5G-AKA is applied in this case.
- ARPF/UDM initializes the 5G-AKA process by sending a response message to the AUSF function with the key material and authentication parameters that were consisting of an expected response token (XRES), AUTH token, the key KAUSF, and the SUPI if suitable.
- The AUSF calculates a hash value of the expected response token (HXRES), then stores the KAUSF, and sends back the authentication response to the SEAF, with the HXRES and AUTH token. Through this response, the SUPI is not included, while it is sent to SEAF after the authentication succeeds.
- The SEAF stores HXRES and sends back the AUTH token parameters within an authentication request to the UE.
- The UE starts validation of the AUTH token using previously shared secret key with the home network.
- If the authentication succeeds, the UE recognizes the network to be valid. The UE proceeds the authentication by calculating and sending a RES token to the SEAF to validate it. After success, the RES token is sent for the AUSF by the SEAF for validation.
- AUSF is the home network that makes the last decision on authentication. If the RES token received from the UE is confirmed, the AUSF calculates the security key (KSEAF) and forwards it to the SEAF with the SUPI. The AUSF also notifies ARPF/UDM about the authentication results for accessing events logs the auditing purposes.
- After receiving the security key KSEAF, the SEAF function calculates the AMF key (KAMF) and deletes the KSEAF immediately. SEAF sends the KAMF key to the Mobility Management Function (AMF) [94].
- The integrity and confidentiality keys needed to protect the signaling messages between the AMF and the UE KgNB key, which is forwarded to the gNB for computing the required security keys to protect the consequent communication between the gNB and the UE.
- Each UE has a long-term key that considered as the root key of the key derivation hierarchy. The UE can share a set of keys between the network functions and the UE.

6.4 4G-AKA and 5G-AKA authentication protocols

In this section, we introduce the differences between 4G-AKA and 5G-AKA. Moreover, we highlight the improvements in the 5G-AKA protocol over 4G-AKA. We also describe each protocol operation and functions within V2X communication. We summarize the differences as follow:

- Entities included in the authentication are changed because of the new service-based 5G architecture. Notably, the SIDF entity is unique and does not exist in 4G/LTE.
- The UE uses the public key of its home network to encrypt the permanent identity of each UE before sending it to a 5G network.
- However, in 4G, the UE sends its permanent identifier in plain text to the system, which allows it to be stolen or sniffing by a faked malicious base station or a passive attacker over the communication radio links.
- The home network, such as the AUSF entity, makes the final UE authentication decision in 5G.
- The UE authentication results are sent to the UDM entity for auditable purposes.
- In 4G/LTE, the home network is negotiated during the authentication process to generate authentication vectors; and it does not make any authentication decisions concerning the authentication results.
- The key hierarchy in 5G is longer than 4G because 5G proposes two intermediate keys, KAMF and KAUSF, while KSEAF represents the anchor key in 5G and equivalent to the KASME key in 4G.

6.5 5G-V2X D2D security

Some related works suggest utilizing 5G-AKA in V2X applications, with some enhancements to reduce the communication overhead and computation cost of the authentication process [14, 95–98].

5G-V2X D2D security is started after the primary authentication using the 5G-AKA protocol finished. As shown in Fig. 16, all nearby devices broadcast discovery messages to connect with near devices. Each vehicle establishes a connection with other vehicles to share critical road information or offer infotainment information. Each gNB verify the connected vehicle and generate a D2D token for each vehicle for future D2D communication. The verification process established between the two vehicles to share one secret key that protects the data transmission among them. After sharing one secret key, both vehicles can choose one light-weight algorithm for securing information between them. Figure 17 illustrates the D2D token generation after the primary 5G-AKA process is finished. Each vehicle connected to its base station for D2D token generation, the base station after verifying the identity of a vehicle, it assigns one token signed with the public key of the base station and including the SUCI identity of the attached vehicle. 5G-V2X security under research consideration and don't have clear plans about the efficient algorithms that should be applied within the 5G-V2X to reduce the latency of the security process [99–105]. Recently, some light-weight authentication protocols are proposed for

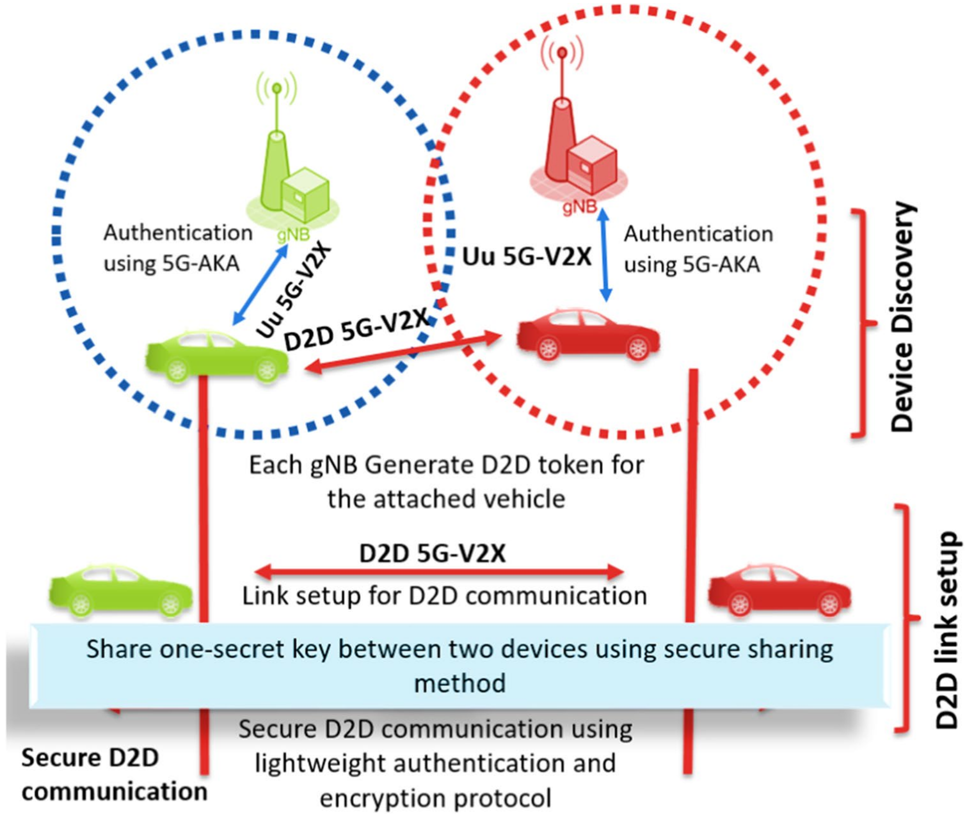


Fig. 16 D2D security in 5G-V2X

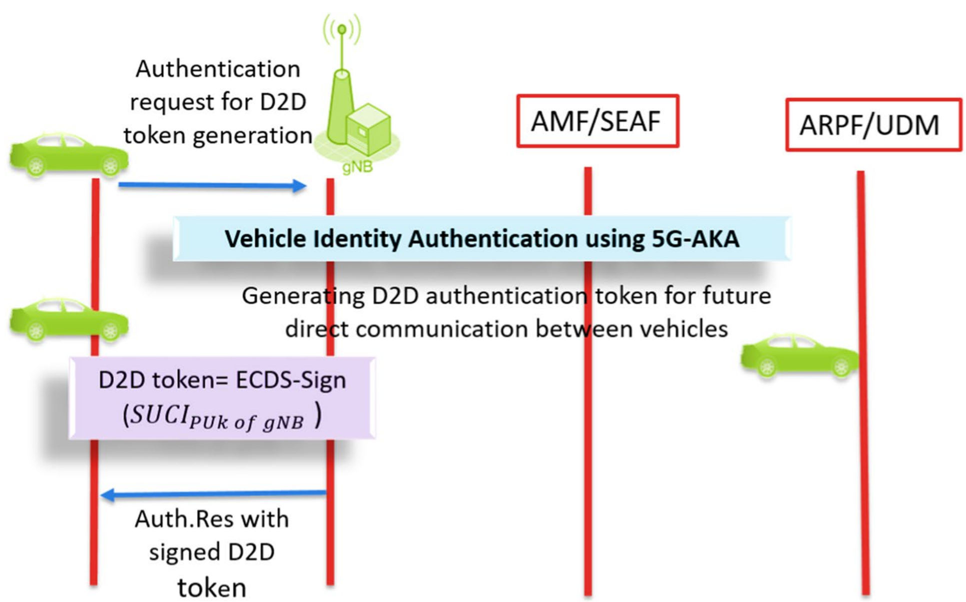


Fig. 17 D2D token generation in 5G-V2X

securing V2X communications, it can also be proposed for D2D securing [106, 107].

7 Conclusions and future works

In March 2017, the 3GPP project declared an arrangement to accelerate the development of 5G-NR Stand-Alone (SA)and the Non-Standalone (NAS). It was assumed that enabled outcomes of 5G-NR could be available in 2020. Many efforts are made to get 5G applicable. Though, 5G development shows that the practical deployment of the 5G will be developed by the end of 2021. A lot of research activities and industry white papers are published to discuss the 5G communication system structure, use cases, capabilities, and technology directions, with no deliverables outcomes. All the future work in all several 5G fields aims at allowing the ultra-low-latency and high-reliability communications for the 5G system. Lately, research is involved in the 5G networks as the latest generation of radio communication with summaries about the proposed structure and used technologies.

In this paper, we introduced a 5G tutorial to explain the earlier V2X techniques, the improvements over LTE-V2X, 5G-NR demands, technologies, challenges, security improvements, and 5G-V2X security model.

Our future work target the study of the 3GPP works on 5G-V2X architecture and implementation that currently in progress. Also, many 5G-V2X aspects and issues must be studied according to the 3GPP release 17 and beyond. We also will study the differences between LTE-V2X system architecture and 5G-V2X architecture. New enhancements for 5G-V2X in 3GPP release 17 are introduced to study the design of the physical layer, Multiple Input Multiple Output (MIMO) and beamforming techniques with more powerful distributed antenna panels installed on the vehicles. Different relaying perspectives such as UE to UE relaying and UE to network-core relaying are under study to support the coverage extension and enhance some of the high-level V2X services in release 17. We also intend to study the security issues in 5G-V2X to propose some light-weight security solutions. One of our proposed future work is the enhancement of the physical layer access mechanisms and the resource allocation mechanism.

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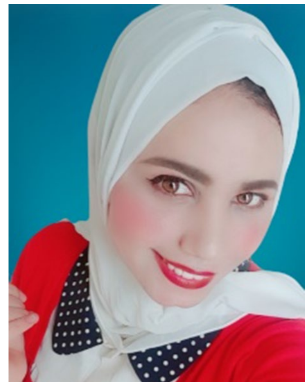

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