Xuyu Wang and Shiwen Mao *Auburn University*
Michelle X. Gong *Google Inc.*

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AN OVERVIEW OF 3GPP CELLULAR VEHICLE-TO-EVERYTHING STANDARDS

With the growth of mobile data and devices, cellular networks have great potential to support various vehicular communication services for safety and non-safety applications. This paper presents an overview of the 3GPP cellular vehicle-to-everything (V2X) standards. We discuss various aspects of V2X standards, including types of V2X application support in 3GPP, requirements to support eV2X scenarios, different levels of automation, comparison of V2X and IEEE 802.11p, architecture, spectrum usage, and security and privacy for V2X services. Finally, we conclude this article with a review of typical V2X applications.

With the fast development of metropolitan areas, city roads and highways have faced many serious socio-economic problems because of vehicular crashes and congestions. For example, the World Health Organization (WHO) reports 1.25 million road traffic deaths globally in 2013; traffic jams also cause a tremendous waste of time and fuel, which all lead to huge economic losses [1][14]. However, most such problems can be mitigated by providing timely information to drivers and/or vehicles. Vehicular communications and networking are becoming important research areas for improving vehicular safety and optimizing traffic flow, to enable more efficient use of transportation resources, and to ensure high quality of user experiences.

Two main vehicular communication standard suites have been developed in recent years to enable information exchanges between vehicles, including the dedicated short-range communications (DSRC) standards in the US [12] and the intelligent transportation system (ITS)-G5 standards developed by the European Telecommunications Standards Institute (ETSI) [13]. Both standard suites are based on IEEE 802.11p for vehicular networks (VANETs). However, it has been recognized that vehicular communications based on IEEE 802.11p have several limitations when supporting mobility and quality-of-service (QoS) provisioning [13].

Alternatively, the fast commercialization of cellular systems, such as Long-Term Evolution (LTE), has made them useful for vehicular communications. The Third

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Generation Partnership Project (3GPP) has been developing standards for the cellular based Vehicle-to-Everything (V2X), aiming to offer more effective solutions for vehicular communications. Compared with IEEE 802.11p, cellular based V2X can provide better QoS support, larger coverage, and higher data rate for moving vehicles [15]. Moreover, device-to-device (D2D) underlay communications in LTE can be leveraged for cellular based V2X applications with high reliability and low latency [15].

In this paper, we provide an overview of 3GPP cellular V2X standards. The remainder of this paper is organized as follows. Section I discusses the types of V2X application support in 3GPP, while Section II introduces categories of requirements to support eV2X scenarios. In Section III, we review different levels of automation, while in Section IV, we compare V2X with IEEE 802.11p. In Sections V and VI, we discuss the architecture and spectrum usage for V2X services, respectively. We examine security and privacy issues for V2X services in Section VII, and introduce typical V2X services in Section VIII. Finally, we conclude this article in Section IX.

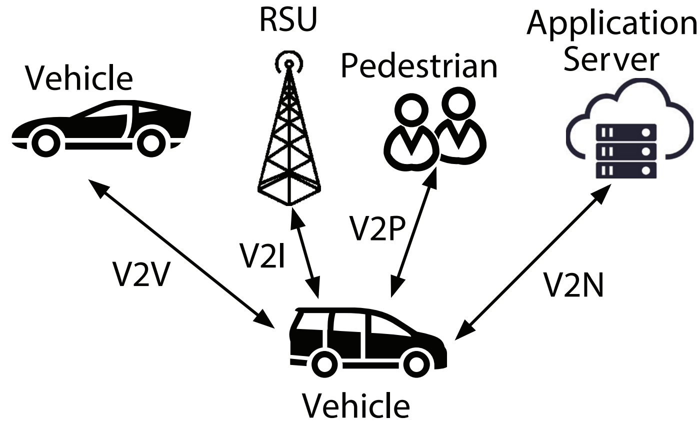

FIGURE 1. Four types of V2X application support in 3GPP (i.e., V2V, V2P, V2N and V2I).

I. TYPES OF V2X APPLICATION SUPPORT IN 3GPP

As shown in Fig. 1, there are four more specific types of V2X application support in 3GPP, including Vehicle-to-Vehicle (V2V), Vehicle-to-Pedestrian (V2P), Vehicle-to-Infrastructure (V2I), and Vehicle-to-Network (V2N) [2]. By employing "co-operative awareness," the above four types of V2X applications can be jointly used for smarter services for end-users. For example, vehicles, pedestrians, application servers, and road infrastructure can obtain local environmental information by receiving messages from sensors in proximity or other vehicles, to enable more intelligent services such as autonomous driving, vehicle warning, and enhanced traffic management. We discuss these four types of V2X applications in detail below.

1. V2V applications: V2V applications allow surrounding devices to exchange useful information by broadcasting, which requires the user equipment (UE) to subscribe to a network operator and obtain authorization. V2V applications expect UEs to transmit messages carrying V2V application information, such as traffic dynamics, location, and vehicle attributes. To adapt to the varying amount of V2V application information, the message payloads should be flexible. Additionally, 3GPP transport of messages can be predominantly based on broadcasting. If the direct communication range of V2V is limited, the transported information can be forwarded by infrastructure-based V2V communications, such as roadside units (RSU), application servers, and so on.

2. V2I applications: V2I application information is transmitted from a UE supporting V2I applications to an RSU or locally relevant application server. Then, the RSU or application server can choose the received UE information based on different transmission modes, such as broadcast, unicast, and multicast. Also, the RSU or application server can transit messages to one or more UEs supporting V2I applications. A locally relevant application server serves a particular geographic area, while multiple application servers can serve overlapped areas, with the same or different applications.

3. V2P applications: V2P applications are similar to V2V applications, and the V2P service information is exchanged between pedestrian UEs and vehicular UEs. V2P application information can be transmitted by a V2X UE in a vehicle to warn a pedestrian, or by a vulnerable road user UE to warn a nearby vehicle. Different from V2V, a pedestrian UE supporting V2P applications usually has a lower battery capacity, and the radio sensitivity will be lower than vehicular UEs because of the antenna design. Therefore, a UE supporting V2P applications cannot send messages as frequently as UEs supporting V2V applications.

4. V2N applications: A UE supporting V2N applications can communicate with the application server supporting V2N applications, while the parties communicate with each other using Evolved Packet Switching (EPS). V2X services are required for different applications and operation scenarios.

II. ENHANCEMENT OF 3GPP SUPPORT FOR V2X SERVICES (EV2X)

3GPP specifies the Enhancement of 3GPP support for V2X services (eV2X) in the following four areas: (i) Vehicles Platooning; (ii) Advanced Driving; (iii) Extended Sensors; and (iv) Remote Driving [3], which are discussed in this section.

In the case of *vehicles platooning*, vehicles can automatically join a group of vehicles traveling together. The vehicles in the platoon can obtain periodic information from the leading vehicle for carrying on platoon operations, such as keeping the gap between two adjacent vehicles small (e.g., as small as a sub second). Moreover, the vehicles can operate in a distributed manner in platooning applications. eV2X supports vehicle platooning, information exchange within the platoon, automated cooperative driving for short distance grouping, information sharing for limited automated platooning, information sharing for fully automated platooning, and changing driving-mode [5].

Advanced driving refers to semi-automated or fully-automated driving, where longer inter-vehicle distance is assumed. RSUs and vehicles can collect information from local sensors and nearby vehicles and share such information with each other, to coordinate the maneuvers or trajectories of surrounding vehicles. By sharing a vehicle's driving intention with nearby vehicles, safer driving, higher traffic efficiency, and collision avoidance can be achieved. Examples of advanced driving include cooperative collision avoidance (CoCA), information sharing for limited automated driving, information sharing for fully automated driving, emergency trajectory alignment, and the provision of intersection safety information for urban driving [5].

Extended sensors allow exchange of data and information from local sensors or exchange of camera video data between RSUs, vehicles, devices of pedestrians, and V2X application servers. With extended sensors, vehicles can improve the perception of the environments for more intelligent decision-making. Extended sensors use cases include sensor and state map sharing, collective perception of environment, and video data sharing for automated driving [5].

Remote driving involves enabling a V2X application or a driver to control a vehicle remotely. This would be utilized when a remote vehicle is in dangerous scenarios or for people who cannot drive themselves. Moreover, driving based on cloud computing can be employed for remote driving, where a cloud-based back-end service platform can be accessed for public transportation. eV2X use cases include remote driving and tele-operated support (TeSo) [5].

TABLE 1. Comparison of V2X and IEEE 802.11p [11]

	V2X	802.11p
Synchronization	Synchronous	Asynchronous
Resource Multiplexing Across Vehicles	FDM and Time Division Multiplexing (TDM) Possible	TDM Only
Channel Coding	Turbo	Convolutional
Waveform	SC-FDM	OFDM
Retransmission mechanism	Hybrid Automatic Repeat Request (HARQ)	No HARQ
Resource Selection	Semipersistent transmission with relative energy-based selection.	Carrier Sense Multiple Access with Collision Avoidance (CSMA-CA)

III. LEVEL OF AUTOMATION

Level of Automation (LoA) is a measure of requirements and functional aspects in automation systems [3]. SAE International's new standard "J3016: Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems" defines six LoAs, including full automation (level 5), high automation (level 4), conditional automation (level 3), partial automation (level 2), driver assistance (level 1), and no automation (level 0). These levels are distinguished by how much human operator involvement is required in monitoring the driving environment and maneuvering the vehicle.

Level 0: no automation The driving system needs a human driver to monitor all driving environments and driving by themselves, even though assistance is available from warning and intervention systems.

Level 1: driver assistance The driving system will provide either steering or acceleration/deceleration assistance based on the current driving environment. All remaining aspects of driving are expected to be controlled by the driver.

Level 2: partial automation The driving system will supply both steering and acceleration/deceleration assistance based on the current driving environment. All remaining aspects of driving are expected to be performed by the drivers themselves.

Level 3: conditional automation The driving system can intervene in all kinds of dynamic driving tasks based on the current driving environment, while drivers will respond appropriately to a request to intervene.

Level 4: high automation The driving system can intervene in all kinds of dynamic driving tasks based on the current driving environment, whether or not drivers respond appropriately to a request to intervene.

Level 5: full automation The driving system can execute all dynamic driving tasks all the time under all roadway and environmental conditions that can be managed by a human driver.

IV. V2X VERSUS 802.11P

In this section, we examine the main differences between V2X and IEEE 802.11p [11] as summarized in Table 1. It can be seen that V2X is synchronous, while IEEE 802.11p is asynchronous. Since synchronization allows time division multiplexing (TDM) and has a lower channel access overhead, V2X achieves a higher spectral efficiency than 802.11p.

For resource multiplexing across vehicles, V2X uses FDM and TDM if possible, while IEEE 802.11p only employs TDM. Because FDM allows for a larger link budget, an extended range or more reliable performance at the same range can be achieved. Similarly, the turbo codes and SC-FCM waveform used in V2X can also achieve a longer range or more reliable performance at the same range.

For retransmission, V2X incorporates the Hybrid Automatic Repeat Request (HARQ), a combination of high-rate forward error-correcting coding (FEC) and ARQ error-control, where corrupted messages are still useful for the purpose of recovering the original data [16]. Compared with IEEE 802.11p which does not use HARQ, V2X can achieve a higher link efficiency, longer transmission range or more reliable performance.

For resource selection, V2X uses semipersistent transmission with relative energy-based selection, while IEEE 802.11p employs carrier sense multiple access with collision avoidance (CSMA-CA). The V2X scheme optimizes resource selection by choosing the close to "best" resource, with no contention overhead. On the contrary, IEEE 802.11p with CSMA-CA protocol selects the first "good enough" resource, thus leading to contention overhead [11].

The V2X design results in a higher spectral efficiency to serve more road users. In addition, although V2X services can coexist with IEEE 802.11p–based radio access in adjacent channels, V2X has the additional advantages of being evolvable and scalable. This is because the cellular network can handle all V2X application services with the same technology in an end-to-end manner, and V2X can provide an evolution path from 4G LTE to 5G wireless systems.

V. SPECTRUM FOR V2X SERVICES

The spectrum study of V2X services based on LTE sidelink (i.e., the LTE D2D interface) are examined in this section. 3GPP should clearly specify the V2V UE RF requirements based on adjacent coexistence evaluation of LTE-based V2V operation and DSRC/IEEE 802.11p on adjacent carrier frequencies in the 5.9GHz ITS spectrum. In the following, we discuss the regulatory requirements in different regions for ITS in the 5.9GHz band [9]. We also provide a comparison of technical characteristics of the standards for V2X services in the three regions in Table 2 [9].

TABLE 2. Comparison of V2X and IEEE 802.11p [9]

Parameter	ETSI	IEEE	TTA
Operating frequency range	5.855-5.925 MHz	5.850-5.925 MHz	5 855-5 925 MHz (Pilot system)
RF channel bandwidth	10 MHz	10 MHz or 20 MHz	Less than 10 MHz
RF transmit power/EIRP	Max 33 dBm EIRP	N/A	23 dBm
Modulation scheme	BPSK OFDM, QPSK OFDM, 16QAM OFDM, 64QAM OFDM	BPSK-OFDM QPSK-OFDM 16QAM-OFDM 64QAM-OFDM 52 subcarriers	BPSK OFDM, QPSK OFDM, 16QAM OFDM, Option: 64QAM
Forward error correction	Convolutional coding, rate = 1/2, 3/4, 2/3	Convolutional coding, rate = 1/2, 3/4	Convolutional coding, rate = 1/2, 3/4
Data transmission rate	3 Mbit/s, 4.5 Mbit/s, 6 Mbit/s, 9 Mbit/s, 12 Mbit/s, 18 Mbit/s, 24Mbit/s, 27Mbit/s	3, 4.5, 6, 9, 12, 18, 24 and 27 Mbit/s for 10 MHz channel spacing 6, 9, 12, 18, 24, 36, 48 and 54 Mbit/s for 20 MHz channel spacing	3, 4.5, 6, 9, 12, 18 Mbit/s, Option: 24, 27 Mbit/s
Media access control	CSMA/CA	CSMA/CA	CSMA/CA, Option: Time Slot based CSMA/CA
Duplex method	TDD	TDD	TDD

1. ITU Region 1: In Europe, Intelligent Transport Systems (ITS) is regulated in the ETSI HS between 5.855 GHz to 5.925 GHz. The spectrum utilization conditions in the frequency range have been defined between 5.875 GHz to 5.905 GHz by ECC Decision (08)01. It aims for non-safety ITS and proposes CEPT frequency with sub-band 5.905-5.925 GHz for the spread of ITS spectrum. ECC Recommendation (08)01 states that spectrum utilization should be in the range of 5.855 GHz to 5.875 GHz for non-safety ITS. Moreover, a harmonized use of the frequency band 5.875 GHz to 5.905 GHz dedicated to safety-related ITS applications is considered in the Commission Decision 2008/671/EC.

2. ITU Region 2: In the US, as shown in Fig. 2, IEEE Working Groups 802.11 and 1609 have standardized the V2V architecture and protocols, named as "WAVE" (Wireless Access Vehicular Environments), which operate in the 5.850 to 5.925 GHz range [14].

A guard band of 5MHz is considered from 5.850 to 5.855 GHz. In V2X, there are three types of channels, including the control channel 178, shared channels 172, 174, 176, 180, 182, and 184, and aggregated channels 175 and 181. These two aggregated channels, which have a 20MHz bandwidth, are used to support multi-channel operations.

According to FCC 06-110, Channel 172 is intended for V2V safety communications to avoid and mitigate accidents, and for safety of life and property applications. For higher-power and longer distance communications, Channel 184 is used for public safety applications relating to safety of life and property, such as road intersection collision mitigation.

3. ITU Region 3: In South Korea, the revised ITS standardization in 2014, which was published by the Telecommunications Technology Association (TTA), supports vehicle communications at a maximum speed of 200km/h. Moreover, for international harmonization, the advanced ITS radio communications (i.e., the pilot system) is compatible with the described V2V/V2I communications and its service requirements, as well as WAVE.

VI. ARCHITECTURE FOR V2X SERVICES

V2X communications can be supported by over the PC5, which is a one-to-many communication interface, and by over LTE-Uu, which is the radio interface between UE and the Evolved Node B (eNodeB) [6][7]. It can be unicast and/or Multimedia Broadcast or Multicast Service (MBMS). A UE might use these two ways of operation independently for transmitting and receiving messages. For instance, a UE can only use LTE-Uu to transmit and it is unnecessary for a UE to use MBMS for reception. On the other hand, a UE can also employ MBMS for reception without using LTE-Uu for transmission. Moreover, V2X messages could be transmitted through LTE-Uu unicast downlink and received by a UE. In the following, we provide

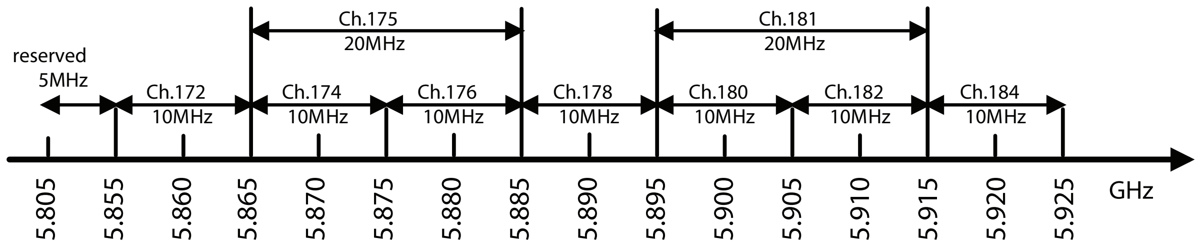

FIGURE 2. FCC channel allocation in 5.9GHz for V2X services. [9]

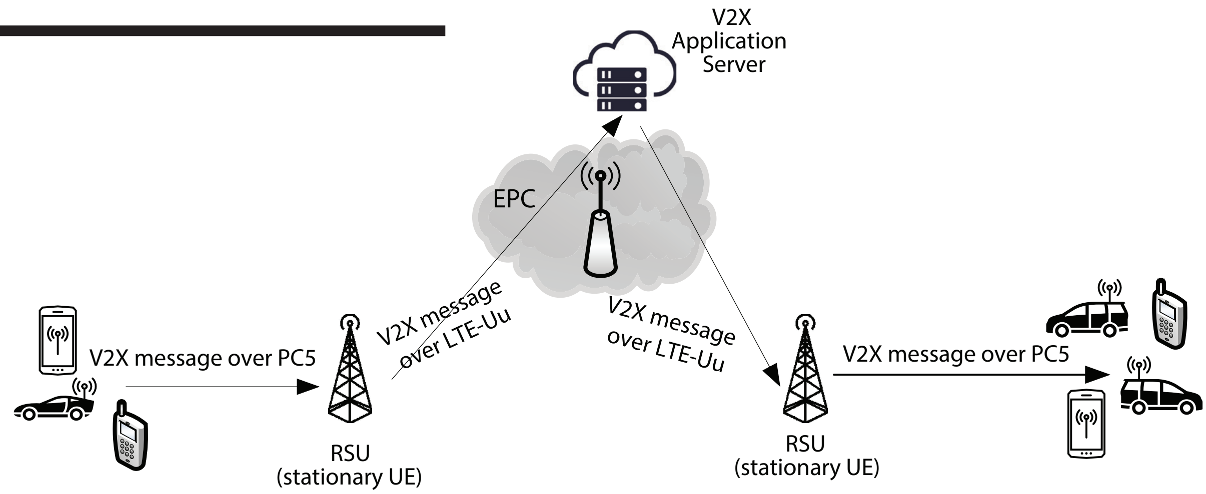

FIGURE 3. V2X message transmission and reception using UE-type RSU via LTE-Uu and PC5.

examples of how the two operation modes i.e., over the PC5 and over LTE-Uu, could be leveraged in a hybrid manner [6].

1. PC5 based V2X communications with MBMS reception: In this mode, V2X messages are always transmitted by a UE via PC5 and are received by the UE through PC5 and through MBMS as well.

With PC5, V2X messages are received by a stationary infrastructure entity serving as a UE, such as an RSU. Then, the entity can forward the application layer processed V2X messages to a V2X Application Server using the V1 interface. For example, a PDN connection over LTE-Uu or other type of connection can be used. The V2X application server processed messages can be distributed to UEs through MBMS.

In this operation mode, the mobile network can deliver information from an extended range. It also fulfills the requirement for soft safety or strengthens more advanced driving assistance applications. This mode is helpful for combined sources in high-density use cases, where the UE may not be able to reliably obtain V2X messages from distant UEs over PC5.

2. Simultaneous LTE-Uu based and PC5 based V2X communications without MBMS: In this operation mode, other UEs, such as UE-type RSUs, could communicate with UEs via PC5 for both transmission and reception of V2X messages. The V2X Application Servers can communicate with the UE-type RSU through a mobile network. For example, LTE-Uu is required to manage the communications of V2X messages beyond the direct PC5 communication range. Based on such hybrid use of LTE-Uu and PC5-based V2X communications, MBMS broadcast of downlink data transmissions could be negligible.

Fig. 3 is a high-level example of this operation mode. This operation mode includes three components [6]:

- To offer adequate coverage to the vehicular traffic infrastructure, stationary infrastructure entities serving as UEs, such as UE-type RSUs, are incorporated. Moreover, the UE-type RSUs and UEs are set or provided with useful information for V2X communication over PC5. The V2X Application Servers may communicate with the UE-type RSUs.
- V2X messages are obtained from other UEs by the UE-type RSUs through PC5. The V2X application of the RSU(s) evaluates whether the messages should be routed to the V2X Application Server(s) over the LTE-Uu connection, if, e.g., the target area is larger than its V2X communication coverage over PC5. The target area and the size of the area are determined by the V2X Application Server(s), where the V2X messages are distributed. To determine the distribution of V2X messages and the target area, the V2X Application Server could communicate and coordinate with other V2X Application Servers.
- V2X downlink messages are sent by V2X Application Server(s) to the RSUs,

which is in the target distribution area, e.g., over LTE-Uu. Then the received V2X messages are broadcasted by RSUs based on V2X communications over PC5. RSU broadcasted V2X messages over PC5 are received by UEs in the same region.

In this case, a vehicle UE only operates using V2V/V2P services in the V2X communication mode over PC5. When UEs are employed as RSUs, they operate in the hybrid mode with simultaneous V2X communication over PC5 and LTE-Uu. The V2X communications based on both PC5 and LTE-Uu can also be implemented when the UE is unable to obtain a V2X signal directly from distant UEs via PC5. Then, the Selective IP Traffic Offload (SIPTO) can be employed to reduce the delay by UE-type RSUs for communicating with local V2X Servers.

VII. SECURITY AND PRIVACY

1. Security of V2X services: There are two types of V2X application data transmission methods, which are periodic transmissions from vehicle UEs and event-driven broadcast messages. Both of them can be manipulated through the PC5 interface and LTE-Uu interface [10].

The primary purposes of V2X are safety and efficiency, which can be achieved through sending realtime alerts to drivers and pedestrians, including road hazards, congestion conditions, presence of emergency vehicles, etc. The safety message is usually trusted as having been issued from a well-functioning and legitimate device.

In the PC5 mode, the transmitting vehicle UE does not know the recipients of these messages in advance, and a security association establishment between UEs is not necessary in an advanced setting. This is the nature of point to multipoint communications with a changing set of UEs. Thus, the current LTE security and Proximity based Services (ProSe) security mechanisms may not be applicable.

For the PC5 one-to-many communications, no security mechanism is used in this layer. Although the data frame includes fields relating to group keys, these fields are set to zero for PC5 based V2X communications. For LTE-Uu communications, the LTE security mechanism for air interface confidentially should be used.

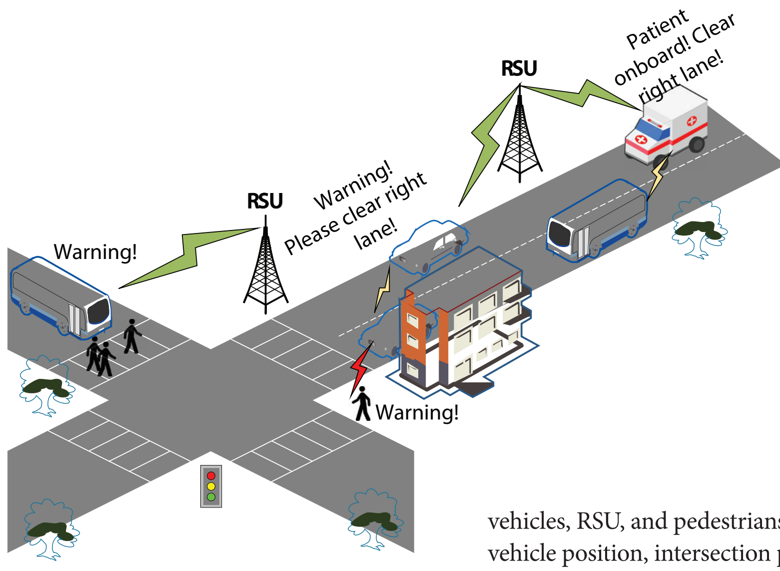

FIGURE 4. V2X safety applications.

2. Privacy in V2X services: High transparency will affect vehicle privacy by using broadcast to send UE messages. Under this condition, the V2X service will be operated under regional regulatory requirements and/or operator policy, whether or not such privacy will happen in the V2X service. Thus, it is optional to utilize the PC5 privacy mechanisms. For example, a service that is mandated for use by a regulator may not provide an "opt out" option [8][10]. For V2X communications in the LTE-Uu mode, there are no additional privacy features beyond those of the regular LTE.

In the application layer, privacy may be supported by using credentials and identifiers, which are not linked to long-term UE or user identifiers. Moreover, these credentials can be periodically refreshed.

VIII. V2X APPLICATIONS

V2X applications can be roughly classified as (i) V2X safety applications, and (ii) V2X non-safety applications [4]. We examine these two types of applications in this section.

1. V2X safety applications: V2X safety applications focus on reducing the potential of traffic accidents and the risk to passengers. The majority of annual car accidents can be linked to intersection collisions. Drivers can obtain useful information and assistance from V2X applications, thus helping them avoid collisions with other vehicles and pedestrians. Moreover, the information shared between vehicles, RSU, and pedestrians, such as vehicle position, intersection position, speed, distance, and heading, can be used to predict collisions. The information exchange among the vehicles and RSU or pedestrian can also be applied to distinguish and locate endangered sections of roads, such as slippery road surfaces. Fig. 4 shows an example of V2X safety applications. In the following, we examine several main V2X safety applications [17].

- **Forward Collision Warning:** The Forward Collision Warning (FCW) application serves to alert the driver of the Host Vehicle (HV) in case of a predictable rear-end collision with the Remote Vehicle (RV) ahead in traffic in the same lane and direction of travel. With V2V Service, FCW helps drivers to mitigate or avoid rear-end vehicle collisions in the forward path of travel.
- **Control Loss Warning:** The Control Loss Warning (CLW) application allows an HV to broadcast a self-generated control loss event to surrounding RVs. A warning will be generated to notify the driver, and the RV will determine the relevance of the event when such information is received.
- **V2V Use Case for Emergency Vehicle Warning:** The emergency vehicle warning service allows the emergency vehicle (e.g., an ambulance) to share its location, speed, and direction information with surrounding vehicles, which helps the vehicles to choose a safe course of action, such as to vacate the ambulance path.
- **V2V Emergency Stop Use Case:** V2V communications can be used in the case of an emergency stop to trigger safer behavior for other cars in the vicinity of the stationary vehicle.

- **Wrong Way Driving Warning:** This use case describes V2V communication used between two vehicles driving in opposite directions, to warn of wrong way driving and trigger safer behavior for cars in the area.
- **Pre-Crash Sensing Warning:** Alerts are generated by the application to vehicles in an imminent and unavoidable collision by exchanging vehicles attributes after the inevitable crash is detected.
- **Warning to Pedestrian against Pedestrian Collision:** This service is to share vehicle information with vulnerable road users, e.g., pedestrian or cyclist, to avoid dangerous situations, e.g., alerts are sent to vulnerable road users to avoid collision with a moving vehicle.

2. V2X non-safety applications: V2X non-safety applications mainly focus on traffic efficiency and management applications for improving the vehicle traffic flow, traffic coordination, and assistance [17]. Moreover, they also provide updated local information, maps, and space and/or time-related messages. V2N traffic flow optimization and cooperative adaptive cruise control are the two main non-safety applications.

- **V2N Traffic Flow Optimization:** V2N traffic flow optimization focuses on managing the speed of the vehicle for smooth driving and avoiding unnecessary stopping when the vehicle approaches an intersection. This involves the situation when the vehicle must slow down because there are explicit traffic light signals or has to stop even though no other vehicles are around at an intersection. Based on traffic conditions, the traffic lights can be adapted to reduce congestion at intersections.
- **Cooperative Adaptive Cruise Control:** This application focuses on improving the traffic efficiency by controlling the navigation of vehicles through cooperation among vehicles, where a vehicle with V2V capability can leave and join a group of Cooperative Adaptive Cruise Control (CACC) vehicles. This application can provide safety benefits and convenience for CACC vehicles, and reduces road congestion, thus improving traffic efficiency.

IX. CONCLUSIONS

This paper presented an overview of the 3GPP cellular V2X standards. We first discussed types of V2X application support in 3GPP and the categories of requirements to support eV2X scenarios. We then examined different levels of automation and provided a comparison between V2X and IEEE 802.11p. We next reviewed the architecture, the spectrum usage, and security and privacy for V2X services. Finally, we concluded this article with a discussion of V2X applications. ■

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Xuyu Wang received a M.S. degree in Signal and Information Processing from Xidian University, Xi'an, China in 2012 and is now pursuing a Ph.D. degree in the Department of Electrical and Computer Engineering, Auburn University, Auburn, AL. His research interests include indoor localization, health sensing, deep learning, wireless communications, software defined radio, and big data. He received the Woltolsz Fellowship at Auburn University.

Shiwen Mao received a Ph.D. in electrical and computer engineering from Polytechnic University, Brooklyn, N.Y., in 2004. Currently, he is Samuel Ginn Endowed Professor and Director of Wireless Engineering Research and Education Center at Auburn University, Auburn, AL. His research interests include wireless networks, multimedia communications, and smart grid. He is a recipient of the Best Demo Award from IEEE SECON, the Best Paper Awards from IEEE GLOBECOM 2016 & 2015, IEEE WCNC 2015, and IEEE ICC 2013, NSF CAREER Award in 2009, and The 2004 IEEE Communications Society Leonard G. Abraham Prize in the Field of Communications Systems.

Michelle X. Gong received her Ph.D. in Electrical Engineering from Virginia Tech in 2005, and is currently working on machine learning and data mining at Google Analytics. She has explored a wide range of research areas, including wireless communications, high-throughput Wi-Fi, 60GHz systems, user modeling, machine learning, and data mining. She is an editor of GetMobile, the ACM Mobile Computing and Communications Review, and an editor of the IEEE MMTC E-newsletter.

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