VEHICLE-TO-EVERYTHING (V2X) SERVICES SUPPORTED BY LTE-BASED SYSTEMS AND 5G

Shanzhi Chen, Jinling Hu, Yan Shi, Ying Peng, Jiayi Fang, Rui Zhao, and Li Zhao

ABSTRACT

Vehicle-to-everything (V2X), including vehicle-to-vehicle (V2V), vehicle-to-pedestrian (V2P), vehicle-to-infrastructure (V2I), and vehicle-to-network (V2N) communications, improves road safety, traffic efficiency, and the availability of infotainment services. Standardization of Long Term Evolution (LTE)-based V2X has been actively conducted by the Third Generation Partnership Project (3GPP) to provide solutions for V2X communications, and has benefited from the global deployment and fast commercialization of LTE systems. LTE-based V2X was widely used as LTE-V in the Chinese vehicular communications industry, and LTE-based V2X was redefined as LTE V2X in 3GPP standardization progress. In this article, the overview of requirements and use cases in V2X services in 3GPP is presented. The up-to-date standardization of LTE V2X in 3GPP is surveyed. The challenges and detailed design aspects in LTE V2X are also discussed. Meanwhile, the enhanced V2X (eV2X) services and possible 5G solutions are analyzed. Finally, the implementations of LTE V2X are presented with the latest progress in industrial alliances, research, development of prototypes, and field tests.

INTRODUCTION

Intelligent transportation systems (ITS) can be pushed forward by V2X communications with cooperative operations. Wireless interconnected vehicles, pedestrians and infrastructures can collect information about the environment and exchange this information with other nearby entities in real time. Thus, potential dangerous situations in an extended time and space horizon can be perceived. The users of V2X communication devices can be utilized as computing systems with computers and extended sensors onboard.

Dedicated Short Range Communications (DSRC), a family of standards, are designed as Wireless Access in Vehicular Environments (WAVE) to support V2X communications, specifically focused on enabling vehicular safety applications. IEEE and the European Telecommunications Standards Institute (ETSI) are cooperating with the standardization organizations in the automotive industry, such as the Society of Automotive Engineers (SAE) International, to define the DSRC protocol stack. V2X communication messages often contain vehicle state information (e.g., location, speed, acceleration, and heading, etc.). In ETSI, the V2X messages are classified into two types: cooperative awareness messages (CAMs) [1] and decentralized environmental notification messages (DENMs) [2]. CAMs are the periodic messages to exchange status within proximity with maximum latency of 100 ms; DENMs are triggered by the detected event to alert road users.

Numerous research projects and field tests have been conducted by the effort involving government, industry and academia to enable V2X communications in many countries, such as the Crash Avoidance Metrics Partnership (CAMP) in America and the Car 2 Car Communication Consortium (C2C-CC) in Europe.

Because of the asynchronous disadvantages of DSRC, performance may be degraded by the collisions with hidden node problem in carrier sense multiple access with collision avoidance (CSMA/CA). The link budget is reduced by the convolutional codes and without using a frequency division multiplexing (FDM) scheme. The spatial duplex gain may be inefficient because of the fixed sensing thresholds. Meanwhile, the deployment of roadside units (RSUs) cannot be cost-effective in the future. Currently, the next generation of DSRC has no clear evolutionary path for enhancements with respect to reliability, robustness and coverage together [3].

With versatile communication types from one-to-one to one-to-many transmissions, LTE systems can be enhanced to enable V2X services. LTE-based V2X was widely used as LTE-V in the Chinese vehicular communications industry, and LTE-based V2X was redefined as LTE V2X in 3GPP standardization progress. To achieve better system performance and to respond to evolving market potential, the standardization to support LTE-based V2V and V2X services is planned to be completed in 2016 and 2017 in 3GPP with Release 14 to apply to LTE systems in the automotive industry [4, 5]. With the harmonization of reusing the application-layer standard of SAE, LTE V2X can focus on standard development for the radio and network layers with a spectral-efficient air interface.

Based on the progress of LTE V2X standardization in 3GPP, there are research projects and field tests of LTE V2X in some countries or regions. In China, 20 MHz (5905–5925 MHz) frequency has

Shanzhi Chen, Jinling Hu, Ying Peng, Jiayi Fang, Rui Zhao, and Li Zhao are with the State Key Laboratory of Wireless Mobile Communications, China Academy of Telecommunication Technology (CATT), and the State Key Laboratory of Networking and Switching Technology, Beijing University of Posts and Telecommunications (BUPT);
Yan Shi is with the State Key Laboratory of Networking and Switching Technology, Beijing University of Posts and Telecommunications (BUPT).

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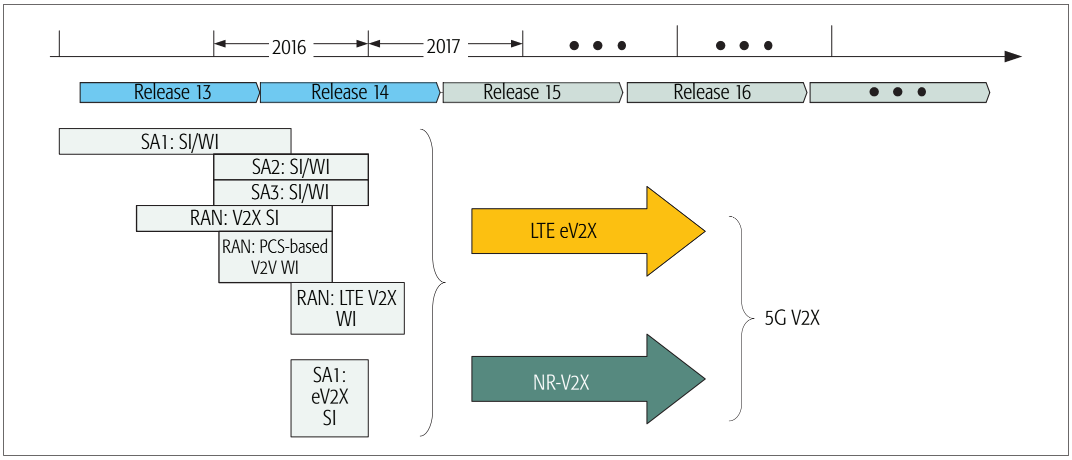

Figure 1. The progress of V2X standardization in 3GPP.

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been officially allocated for the validation of LTE V2X in six pilot areas. The standardization and prototype validation of the LTE-V project has been suggested as one of the National Science and Technology Special projects. Meanwhile, the Next Generation Mobile Networks Alliance (NGMN) V2X task force and 5G Automotive Association (5GAA) was established in 2016, and TD-LTE stakeholders are cooperating with the automotive industry to promote LTE and NR (New Radio) based V2X solutions.

In this article, an overview of the requirements and use cases in V2X services in 3GPP is introduced. Then the up-to-date standardization of LTE V2X in 3GPP is surveyed. The challenges and detailed design aspects in LTE V2X are also discussed. Meanwhile, eV2X services and possible 5G solutions are analyzed. Implementations of LTE V2X are presented with the latest progress in industrial alliances, research and development of prototypes, and field tests. Finally, the article concludes with a discussion of future research directions of 5G V2X.

V2X Service Requirements and Use Cases in 3GPP

The Progress of V2X Standardization in 3GPP

The progress of V2X standardization in 3GPP is summarized in Fig. 1. The study item and work item about the basic set of requirements and use cases of Technical Specification Group (TSG) Services and System Aspects Working Group 1 (SA1) was completed in June 2016. The enhancements of architecture in SA2 and security issues in SA3 were completed in December 2016. The initial standards supporting V2V services in TSG Radio Access Networks (RANs) was completed in September 2016, and the further enhancements of additional V2X scenarios with cellular networks were planned to be completed in Release 14 in March 2017. The eV2X requirements were completed in TSG SA1 in December 2016, and the related research in 3GPP RAN was widely proposed at the end of 2016. Some of the eV2X requirements can be realized by LTE eV2X with specification efforts and further enhancements. Because some eV2X use cases require extremely high data rates, extremely high reliability, and extremely low latency, NR V2X is considered to complement LTE eV2X. LTE eV2X and NR V2X can thus provide 5G V2X solutions.

V2X Service Requirements and Use Cases in 3GPP

In 3GPP, TSG SA1 is in charge of identifying safety and non-safety use cases and associated potential requirements for LTE support of V2X services. When the transmitting UE is served by the Evolved Universal Terrestrial Radio Access Network (E-UTRAN), the message transmission shall be under control of the 3GPP network. Furthermore, the security requirements of LTE V2X are provided with authorization, pseudonymity and privacy.

V2V can exchange V2V-related application information between nearby UEs directly. RSU can receive the information transmitted by the UE supporting V2I applications, and transmits application layer information to a UE or a group of UEs supporting V2I applications. With LTE networks, the serving entity supporting V2N applications can communicate with the UE. V2P communications can be realized by LTE-based communication for the vulnerable road users carrying the device supporting V2P applications. Due to the limited direct communication range of V2V/V2P, the V2V/V2P-related application information between UEs can be transmitted via infrastructure supporting V2X Service, e.g., RSU, application server, etc. [6].

The study in TSG SA1 contains the above mentioned four types of V2X services, and 27 use cases are defined in Release 14 [6]. Because 27 use cases can be divided into safety and non-safety of V2X services, the transmission of messages should be classified and provided with means to prioritize according to the message type (e.g. safety vs. non-safety). The safety related use cases focus on the avoidance and mitigation of accident and the protection of life and property. The non-safety use cases are the supplemental services for improving transportation mobility and environmental performance.

The five categories of service requirements of the 27 use cases are defined as follows [6].

Speed: The maximum absolute velocity 160 km/h and the maximum relative velocity 280 km/h shall be supported. The maximum relative speed of 500 km/h is supported for the possible scenario without speed limitation.

Because V2X applications beyond road safety services have been considered in the automotive industry, such as platooning and automated driving, the characteristics of advanced applications are expected with more stringent latency, very rigorous reliability, higher data rate, and larger communication range, although the requirements for most applications are not necessary to be satisfied at the same time.

	Effective distance	Absolute speed	Relative speed	Maximum latency	Message generation period	Minimum radio layer message reception reliability (%)	Cumulative transmission reliability (%)
Freeway	320 m	140 km/h	280 km/h	100 ms	100 ms	80	96
Freeway	320 m	70 km/h	140 km/h	100 ms	100 ms	80	96
Urban	150 m	60 km/h	120 km/h	100 ms	100 ms	90	99
Urban	150 m	15 km/h	30 km/h	100 ms	100 ms	90	99
Urban	150 m	15 km/h	30 km/h	100 ms	500 ms	90	99

Table 1. Example parameters for V2X Services in 3GPP Release 14.

Communication range: The effective distance is larger than the distance calculated as the ample response time (e.g. 4 seconds) for the driver(s) to avoid collision according maximum relative speed.

Latency/reliability: The maximum end to end latency between two UEs supporting V2V/V2P applications, directly or via an RSU, shall be 100 ms. The maximum latency between a UE supporting V2I applications and a RSU shall be 100 ms. In order to support pre-crash sensing, the maximum latency between two UEs supporting V2V applications can be reduced to 20 ms. The minimum radio layer reliability should be supported without retransmissions of application-layer messages in the effective distance and the restricted latency. The cumulative transmission reliability is calculated in the continuous transmission in certain time window.

Message size: Not including security-related message elements, the variable length of a periodically broadcast message payload between two UEs supporting V2X applications is only about 50-300 bytes. The message size of event-triggered messages can be up to 1200 bytes.

Message generation period: The minimum message generation period can be 100 ms.

To accelerate the technical evaluation in TSG RAN, the above requirements are summarized and the example parameters for V2X services of 3GPP Release 14 are presented in Table 1 [7].

Because V2X applications beyond road safety services have been considered in the automotive industry, such as platooning and automated driving, the characteristics of advanced applications are expected with more stringent latency (only a few milliseconds), very rigorous reliability (nearly 100 percent), higher data rate (about tens of megabits per second), and larger communication range (e.g., 1000 meters), although the requirements for most applications are not necessary to be satisfied at the same time. TSG SA1 has identified 25 use cases with different levels of automation for eV2X services, which are classified into five groups of use cases including vehicle platooning, advanced driving, extended sensors, remote driving, and general [8]. TSG RAN has recently agreed that it is not intended for NR-based V2X to replace the services offered by LTE-based V2X. Therefore, NR-based V2X shall complement LTE-based V2X for advanced V2X services and support interworking with LTE-based V2X [9].

Technical Challenges and Design Aspects of LTE V2X in 3GPP

Enhancements of Architecture and Physical Layer Design for LTE V2X in 3GPP

Based on the V2X service requirements defined in TSG SA1, the architecture enhancements are identified by TSG SA2 [10]. In Fig. 2, reusing the LTE Device to Device (D2D) architecture, the new V2X Control Function model is added into the legacy LTE network architecture to operate the network related control functionality, such as service authorization and provisioning. The LTE-Uu interface can be reused for unicast and/or evolved Multimedia Broadcast Multicast Service (eMBMS). Thus, the communication link for the V2X application of the vehicular UE and the V2X application server can be established. Meanwhile, direct sidelink communications can be supported with the PC5 interface to exchange the information of V2X applications between vehicles or between vehicle and pedestrian.

With the architecture enhancements of LTE V2X systems, the radio layer design is proposed according to the challenges with the following key aspects: the design of physical layer structure, resource allocation, and synchronization [11].

In order to accelerate standardization, the LTE D2D mechanism in 3GPP is considered as the baseline for PC5 based V2V communication with a number of proper and specific enhancements to support the V2V services. Because the message size of V2X services is variable, the scheduling assignment (SA) of a legacy system is reused to indicate the resources of initial transmission and retransmission of data. The control information within SA is still carried by the Physical Sidelink Control Channel (PSCCH) with modified contents, and the traffic payload is transmitted by the Physical Sidelink Shared Channel (PSSCH). To maintain a lower peak-to-average-power-ratio (PAPR), single carrier frequency division multiple access (SC-FDMA) is utilized for transmission. Considering the requirements of communication range for the LTE V2X services, the normal cyclic prefix (CP) is supported.

In legacy LTE systems, the current time interval between two reference signals is 0.5 ms. With the relative speed of 280 km/h at the center frequency 6 GHz of the transmission signal, the coherence time is about 0.277 ms and lower than the current time interval of reference signals. Therefore, data

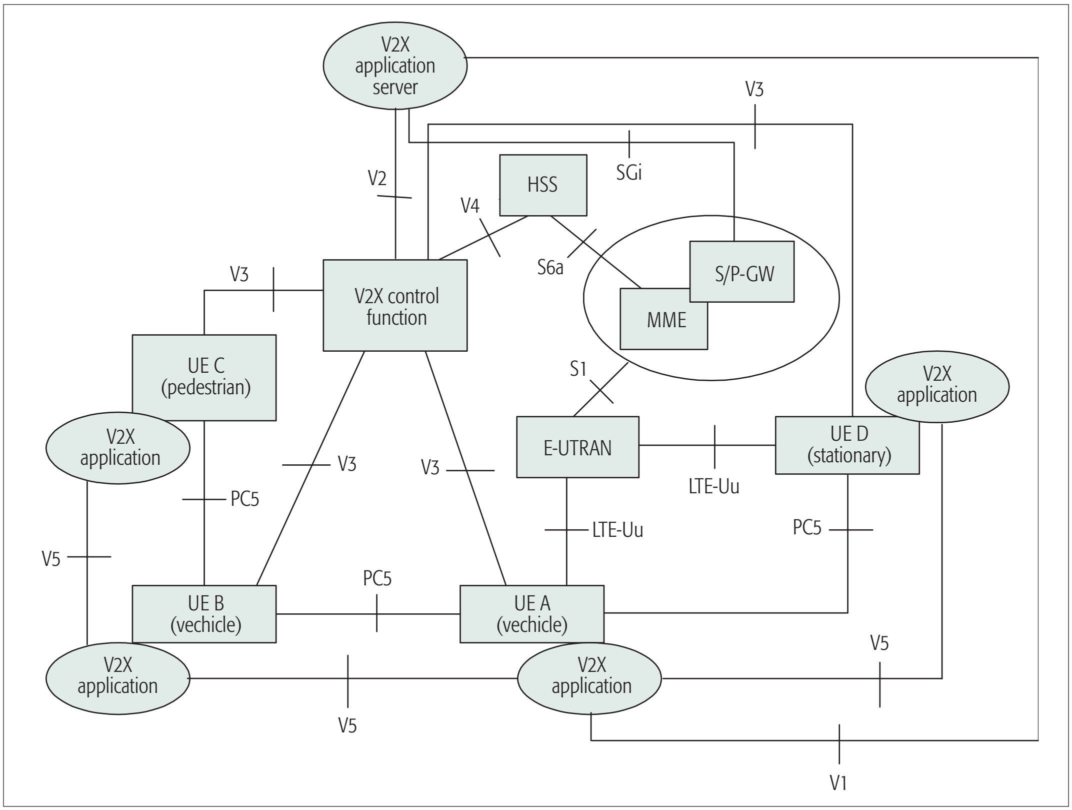

Figure 2. Reference architecture for PC5 and LTE-Uu based V2X communication in 3GPP.

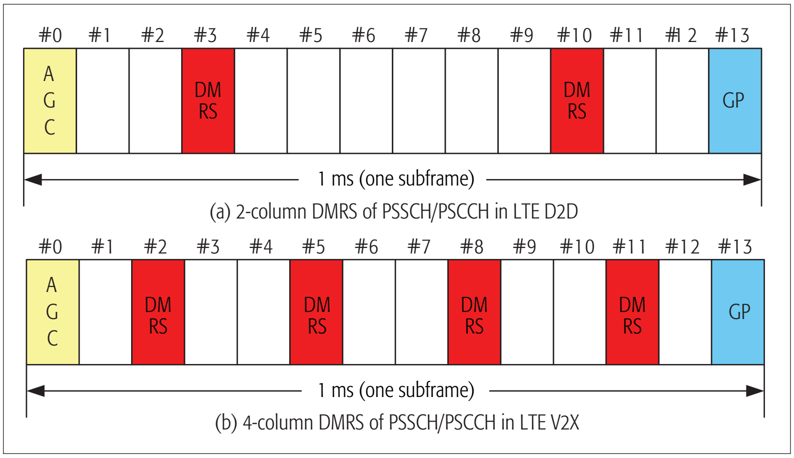

Figure 3. Enhancement of DMRS structure: 4-column DMRS of PSSCH/PSCCH in LTE V2X based on LTE D2D DMRS.

demodulation performance will decrease sharply due to poor channel estimation and the lack of channel information as the consequence. Because the maximum frequency offset that can be corrected is about 1 kHz with the legacy LTE reference signal design, when the synchronization reference is provided by the network, the maximum frequency error between UEs of neighboring cells may be more than 2.2 kHz. Here, the frequency error contains the transmission error and the Doppler shift between the network and the UE, and between UEs. To improve the performance in the high Doppler case, i.e., satisfying channel estimation and synchronization tracing, the number of columns of the demodulation reference signal (DMRS) within one subframe is increased from two to four symbols for PSSCH and PSCCH to achieve better link-level performance. Because the information of user identity is not utilized in the DMRS sequence, the cyclic redundancy check (CRC) of SA for PSSCH and the random selection with fixed parameters are considered for PSCCH to avoid the interference between UEs. The enhancements of the DMRS structure of LTE V2X is shown in Fig. 3.

With high accuracy of timing and frequency, the Global Navigation Satellite System (GNSS) can be considered as the synchronization source in LTE V2X. When PC5 and LTE-Uu are operated in the same band, if the timing offset between PC5 and LTE-Uu is large and the UEs synchronize with GNSS directly, the transmission of UEs through PC5 interface will generate interference to LTE-Uu uplink transmissions. eNB will instruct vehicle UEs to determine either eNB-based or GNSS-based synchronization. Reusing the legacy LTE D2D mechanism, the enhanced synchronization source priorities can be supported by the new combination of a sidelink synchronization signal (SLSS) and Physical Sidelink Broadcast Channel (PSBCH). Considering the protection for LTE-Uu uplink transmission and the accuracy of timing and frequency of the synchronization source, the rules of synchronization source priority should be applied according to the eNB-based or GNSS-based synchronization configurations. When the eNB timing has higher priority than GNSS, the priority of UE, directly or indirectly synchronized to eNB, is higher than GNSS, and then the priority is higher than that of the UE, directly or indirectly synchronized to GNSS and other remaining UEs. When GNSS has higher priority than eNB timing, GNSS holds the highest priority, and the priority of UE, directly synchronized to GNSS or eNB, is lower than that of GNSS

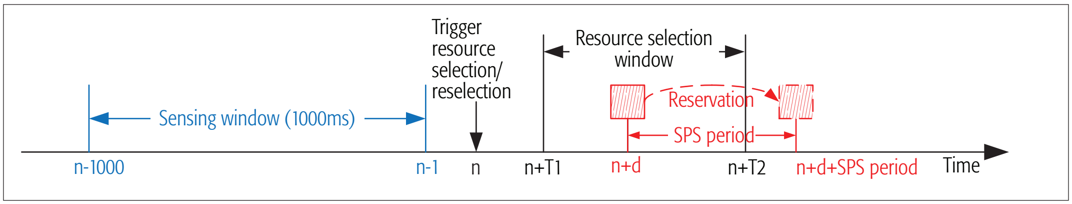

Figure 4. The timeline of LTE V2X PC5 based resource allocation mechanism.

but higher than that of UE, indirectly synchronized to GNSS or eNBm and is lower than that of other remaining UEs. With the proposed synchronization mechanism, global synchronization can be achieved to reduce the number of synchronized clusters and guarantee synchronization accuracy.

Enhanced Resource Allocation Mechanism for LTE V2X in 3GPP

Considering the impact of low latency and efficient resource utilization, the time-division multiplexing (TDM) mechanism in LTE D2D is not suitable for LTE V2X. Thus, the FDM mechanism is utilized for both the SA resource pools and data resource pools of LTE V2X without an extra time window. The 3 dB power boost helps SA achieve better link budget than that of data. Because FDM is selected as the multiplexing mechanism, inband-emission (IBE) by other UEs transmitting in different subchannels of the same subframe is particularly harmful for the system capacity due to the near-far effect. Thus, the SA and DATA are designed to be sent in adjacent or non-adjacent RBs in the same subframe.

In LTE D2D communications, two types of resource allocation mechanisms (e.g., Mode 1 for centralized control and Mode 2 for distributed control) are standardized to support the typical services of voice-over-IP (VoIP) for public safety communications. In centralized resource allocation (Mode 1), downlink control information (DCI) format 5 is scheduled to indicate the SA and DATA resources. Meanwhile, in distributed resource allocation, the random selection is determined because of the simplicity in standardization and reasonable for the low density of transmitters in LTE D2D.

However, in high density scenarios, because V2X services are periodic or event-triggered messages, the attributes of V2X services are different from that of LTE D2D communications, such as period, message size, reliability, and latency. Compared to LTE D2D communications, the following enhancements for resource allocation were proposed to adapt the characteristics of V2X services:
- Centralized resource allocation mechanism of Mode 3 and the distributed resource allocation mechanism of Mode 4.
- Sensing and SPS resource allocation.
- FDM and TDM for resource multiplexing across vehicles.
- Geo-information utilized in resource allocation.
- Using the channel busy ratio (CBR) and consumption ratio (CR) for congestion control.
- Power saving of pedestrian UEs.

The UEs using centralized resource allocation have to connect to the eNB, causing extra signaling overhead, and the UEs using distributed resource allocation may make unilateral bad decisions locally. Therefore, in order to guarantee the QoS requirements of V2X services, the centralized resource allocation mechanism of Mode 3 and the distributed resource allocation mechanism of Mode 4 are both supported to adapt to the characteristics of V2X services. Relying on the centralized eNB, Mode 3 can only work for in-coverage scenarios, but Mode 4 can provide the distributed resource allocation mechanism for both in-coverage with eNB and out-of-coverage scenarios even without the eNB. Because of the periodic and predictable size of attributes of V2X services, semi-persistent scheduling (SPS) can be supported as a resource allocation mechanism in Mode 3 and Mode 4. Based on the periodic resource reservation of SPS, sensing transmissions of other UEs can avoid collisions and thus can be efficient to improve system performance.

The detailed mechanisms of sensing and SPS resource allocation are presented in Fig. 4. UEs should continue the sensing of the transmissions from other UEs in each receiving subframe in a 1000 ms sliding sensing window. If the resource selection or reselection is triggered, the UE will select the available resources in the resource selection window. The upper edge of the resource selection window is restricted by the current payload latency, and the lower edge of the resource selection window is determined by the process delay based on the UE's implementation. According to the occupancy state of the resources detected in the sensing window, if a UE selects the available resources in the resource selection window at $(n + d)$ subframe, the same frequency resource of $(n + d + \text{SPS period})$ will be reserved by the SA transmitted in $(n + d)$.

When resource selection/reselection is triggered, the SPS counter value is uniformly randomly selected between proposed ranges. After every transmission of traffic packets, the value of the SPS counter decreases by one. When the SPS counter meets the expiration condition, the current resources will be kept with probability p and reset the SPS counter, or the reselection is triggered with probability $(1 - p)$.

Furthermore, geo-information can be utilized in resource allocation to divide the communications areas into different zones. Allocation of different resources for UEs located in adjacent zones is usually used to alleviate interference and IBE. Because of the high mobility induced by the relative speed of vehicles, due to handover, exceptional pools are introduced for random selection to offer the continuity of V2X services.

In LTE V2X Mode 3, the dynamic scheduling and SPS scheduling mechanisms are both supported. DCI format 5A is used to indicate detailed resource information for traffic packet transmission. In DCI format 5A content, the carrier index field (CIF) can indicate the carrier for the V2V transmission even without the deployment of the eNB on the V2V

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dedicated carriers. Considering the characteristics of LTE-Uu, such as larger communication range and the centralized control, the broadcast mechanism has to be enhanced with spectral efficiency and latency requirements. Interference can be coordinately controlled with the configuration of transmission resource pools and receiving resource pools.

Pool-specific CBR measurement with a 100 ms period can be used to reflect the congestion level of the pool from the receiving UE. CR is defined as the ratio of the total number of sub-channels used by the UE for its transmissions, divided by the total number of configured sub-channels over a measurement period of 1000 ms. Supported by the CBR and CR measurement, the congestion control functionalities in LTE V2X can be realized in a distributed or centralized scheme. If the CBR is reported to the eNB, with the location information of the UE, the eNB will control the congestion on the systematic level more efficiently.

From a power saving point of view in pedestrian UEs, the sensing operation consumes most of the power in the communication. Thus, a tradeoff has to be considered between transmission performance and the limited battery capacity of pedestrian UEs. A pedestrian UE is not required to receive a message from a vehicle UE and could possibly sleep during certain subframes even when other vehicle UEs are transmitting in these subframes. If the UE capability is allowed to support partial sensing, the performance of resource selection can be improved to be better than the performance of random selection.

Based on the analysis of the performance requirements of the eV2X use cases, LTE-based V2X solutions should be enhanced as much as possible to cover eV2X services. LTE-based V2X can meet the basic requirements of some vehicle platooning applications and limited automated driving applications. NR-based V2X can be complementary to LTE based solutions to cover more advanced services. Further work will be expected to support fully automated driving applications by LTE-A Pro and/or 5G NR. Therefore, harmonization can pave the evolution path of LTE V2X and maintain the advantage over IEEE 802.11p.

LTE V2X Implementations

With the progress of LTE V2X standardization in 3GPP, cross-industry cooperation and the industry of TD-LTE with stakeholders are leveraged. Because many research projects and field tests based on IEEE 802.11p of connected vehicles have been carried out in some countries or regions for years, it is essential to provide suitable solutions of LTE V2X to fulfill the market requirements and promote the development of the LTE-based V2X communication related industry.

In July 2016, cooperating with the automotive industry, NGMN established the NGMN V2X task force to promote the view of operators on LTE-based V2X and DSRC, and the trial results will be shared to reduce the time-to-market of LTE V2X [12]. In September 2016, 5GAA was established to promote communications solutions to support connected mobility, road safety applications, ubiquitous access and integration into smart cities and intelligent transportation. The focus of information and communication technologies can be realized by LTE V2X and 5G-NR based solutions [13].


(a) (b)

Figure 5. OBU and RSU pre-commercial product based on the chipset solutions of Datang Telecom Group: a) DTVL3000-OBU and b) DTVL3000-RSU.

In China in May 2015, the Ministry of Industry and Information Technology (MIIT) developed the national strategy of "Made in China 2025" regarding intelligent connected vehicles. The overall technology and key technologies for intelligent driver assistance and automatic driving will be developed and proven in 2020 and 2025, respectively. LTE-V [5] (i.e., LTE V2X) solutions are the critical technologies to support such visions. Compatible with the Chinese situations, a series of industrial standards of communication based on LTE for vehicle applications have been developed by the China Communications Standards Association (CCSA). Research on the requirements, architecture standards, and spectrum were finished in 2016, and the air interface standards will be completed in 2017.

In order to accelerate the LTE V2X network, and the research and development of terminal prototypes, as well as laboratory testing and field testing, in November 2016, MIIT of China officially allocated 20 MHz (5905–5925MHz) frequency to facilitate the related trials for the validation of the direct communication of LTE V2X, including functional testing and compatibility testing between different applications. LTE V2X systematic solutions will be validated in the selected six pilot areas: Beijing, Shanghai, Hangzhou, Chongqing, Changchun and Wuhan.

Stimulated by the allocation of spectrum and the choice of the pilot areas, the communication industry is promoted to launch pre-commercial products. Aligning with the latest 3GPP LTE V2V standards, in November 2016 Datang Telecom Group launched the first LTE V2X pre-commercial products based on proprietary chipset solutions. The pre-commercial product of OBU and RSU are illustrated in Fig. 5. Huawei and other companies have been providing (pre-)commercial products starting 2016. The broader LTE V2X eco-system and value chain for the ICT industry and automotive industry will be upgraded to a new level with cross-industry collaboration.

Future Research Directions of 5G V2X and Conclusion

Vehicle-to-everything (V2X) can be utilized to improve road safety, traffic efficiency, and the availability of infotainment services. LTE V2X inherits the advantages of TD-LTE, including versa-

The network architecture should be improved to support the advancements of the eV2X services. Moreover, in order to meet the challenges for eV2X requirements, new features have to be developed to enable extremely low-latency, high-reliability, high-efficient PC5, and Uu communications.

tile communication modes, low deployment cost with ubiquitous cellular coverage, high capacity and a spectral-efficient air interface. Standardization of LTE V2X has been actively conducted by 3GPP to provide the solutions for V2X communications that benefit from the global deployment and fast commercialization of LTE systems.

The 25 use cases have been identified for eV2X services with five use case groups: platooning, extended sensors, advanced driving, remote driving and other/general. The requirements of eV2X shall satisfy stringent reliability, low latency, high data rates and larger communication range even in the high density scenarios. The proper enhancements have to be proposed with the 5G-NR uplink, downlink, and sidelink operations, such as Ultra-Reliable Low latency Communications (URLLC) sidelink and Uu, enhanced Mobile Broadband (eMBB) sidelink, etc. The solutions for 5G-NR higher layers should include the following aspects: proximal group management, congestion control, mobility management, QoS management, and switching between PC5 and Uu. Because there are multiple RATs existing simultaneously, the efficient inter-working and coexistence of multi-RAT mechanisms have to be enabled. The network architecture should be improved to support the advancements of the eV2X services. Moreover, in order to meet the challenges for eV2X requirements, new features have to be developed to enable extremely low-latency, high-reliability, high-efficient PC5, and Uu communications.

In this article, the up-to-date standardization of LTE V2X in 3GPP is surveyed. The eV2X services and the possible 5G solutions are analyzed. In addition, the implementations of LTE V2X are presented with the latest progress in the industrial alliances, the research and development of prototypes, and typical field tests. Based on the evolution of LTE V2X and the emerging 5G-NR V2X, the fully automated driving and futuristic vehicular services can be realized with joint innovation through cross-industry collaboration.

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Biographies

Shanzhi Chen [SM'04] (chensz@datanggroup.cn) received his Ph.D. degree from Beijing University of Posts and Telecommunications (BUPT), China, in 1997. He joined Datang Telecom Technology & Industry Group in 1994, and has served as CTO since 2008. He was a member of the steering expert group on information technology of the 863 Hi-Tech R&D Program of China from 1999 to 2011. He is the director of State Key Laboratory of Wireless Mobile Communications, and a board member of Semiconductor Manufacturing International Corporation (SMIC). Since 2004 he has devoted his research and development to TD-LTE-Advanced 4G. He received the 2001, 2012 and 2016 National Awards for Science and Technology Progress, the 2015 National Award for Technological Invention, and the 2014 Distinguished Young Scholar Award of the National Natural Science Foundation, China. His current research interests include network architectures, 5G mobile communications, vehicular communication networks, and Internet of Things (IoT).

Jinling Hu (hujinling@catt.cn) received her master's degree from Beijing University of Aeronautics and Astronautics in 1999. She is the deputy chief engineer at Datang Wireless Mobile Innovation Center, where she works on research of key technologies in next generation mobile communications.

Yan Shi (shiyan@bupt.edu.cn) received her Ph.D. degree from Beijing University of Posts and Telecommunications (BUPT) in 2007. She is currently a member of the research staff of the State Key Laboratory of Networking and Switching Technology, BUPT. Her current research interests include network architecture evolution, protocol design and performance optimization of future networks, mobile computing and vehicular network, especially mobility management technology.

Ying Peng (pengying@catt.cn) received her M.Sc. and Ph.D. degrees from the University of Bristol, United Kingdom, in 2002 and 2006, respectively, and joined CATT in 2008. She has been working on 3GPP LTE/LTE-A standardization, including 4G self-evaluation, HetNet, eICIC, CoMP and D2D, and ITU-R WP5D, including 4G/5G technique evaluations since 2008. She is currently co-rapporteur of the V2X study item and V2V work item in 3GPP RAN and co-chairman of the 5G evaluation group in ITU-R WP5D.

Jiayi Fang (fangjiayi@catt.cn) received his M.Sc degree from the University of Electronic Science and Technology of China in 2004, and joined CATT this year. He has been working on the 3GPP LTE/LTE-A at RAN1/RAN2 working group from Release 8 since 2008. He is currently a senior technical manager at CATT, focusing on LTE-V2X technology.

Rui Zhao (zhaorui@catt.cn) received his M.Sc degree from Northwestern Polytechnical University (NWPU), China, in 2002, and received his Ph.D. degrees from Beijing University of Posts and Telecommunications, China, in 2006. He jointed CATT in 2007. Since 2007, he has been working on 3GPP LTE/LTE-A standardization. His research interests include LTE/LTE-A control signaling design, carrier aggregation, enhanced PDCCH and device-to-device communication. Currently, he focuses on LTE-V2X key technology research and standardization in 3GPP.

Li Zhao (zhaoli@catt.cn) received her master's degree from Beijing University of Posts and Telecommunications (BUPT) in 2004. She is currently an engineer at Datang Wireless Mobile Innovation Center. Her current research interests focus on vehicular networking and cellular high layer protocol.