LTE Evolution for Vehicle-to-Everything Services

Hanbyul Seo, Ki-Dong Lee, Shinpei Yasukawa, Ying Peng, and Philippe Sartori

The authors provide an overview of the service flow and requirements of the V2X services LTE systems are targeting. They also discuss the scenarios suitable for operating LTE-based V2X services, and address the main challenges of high mobility and densely populated vehicle environments in designing technical solutions to fulfill the requirements of V2X services.

ABSTRACT

Wireless communication has become a key technology for competitiveness of next generation vehicles. Recently, the 3GPP has initiated standardization activities for LTE-based V2X services composed of vehicle-to-vehicle, vehicle-to-pedestrian, and vehicle-to-infrastructure/network. The goal of these 3GPP activities is to enhance LTE systems to enable vehicles to communicate with other vehicles, pedestrians, and infrastructure in order to exchange messages for aiding in road safety, controlling traffic flow, and providing various traffic notifications. In this article, we provide an overview of the service flow and requirements of the V2X services LTE systems are targeting. This article also discusses the scenarios suitable for operating LTE-based V2X services, and addresses the main challenges of high mobility and densely populated vehicle environments in designing technical solutions to fulfill the requirements of V2X services. Leveraging the spectral-efficient air interface, the cost-effective network deployment, and the versatile nature of supporting different communication types, LTE systems along with proper enhancements can be the key enabler of V2X services.

INTRODUCTION

The concept of the "connected car" has emerged recently, in which the ability to provide a new dimension of services for drivers via wireless communications is considered as one of the most distinctive designs of next generation vehicles. Vehicles wirelessly connected to other vehicles and pedestrians within proximity can identify the possibility of collisions by exchanging information such as speed and direction at their location. Also, vehicles connected to network infrastructure can communicate with an entity in charge of traffic control so that they can be informed of unknown deterministic hazards on the road or guidance on the speed and route for traffic flow optimization. Numerous activities, including research projects and field tests, to enable connected cars are ongoing in many countries.

Widely deployed Long Term Evolution (LTE) networks and user devices can provide a means to realize this many new services for connected cars with limited cost for functional upgrade. LTE has potential to support various vehicle-to-everything (V2X) services (Fig. 1) successfully because it has an air interface of high spectral efficiency and is able to support different types of communications from one-to-one to one-to-many transmissions, and from conventional uplink and downlink cellular communications to device-to-device (D2D) direct over-the-air communications. In order to respond to this evolving market potential, the Third Generation Partnership Project (3GPP) recently started developing specifications for LTE-based V2X services with a target completion by 2016~2017.

In this article, we begin with a discussion on the significance of V2X services, and then introduce up-to-date LTE standardization activities for V2X, including the scope, use cases, and service requirements work in 3GPP. We also discuss some operating scenarios under which LTE-based V2X services are expected, and address the main challenges, such as high mobility and densely populated vehicle environments, together with technical design considerations.

V2X-RELATED ACTIVITIES OUTSIDE 3GPP

In standardization, the intelligent transportation system (ITS), which is based on V2X communication, can be utilized for safety, non-safety, and infotainment purposes. The European Telecommunications Standards Institute (ETSI) has defined safety messages [1], which are divided into two types: cooperative awareness messages (CAMs) [2] and decentralized environmental notification messages (DENMs) [3]. CAMs are periodic messages with, for example, a frequency of 10 Hz and maximum latency of 100 ms transmitted to interchange vehicle status among vehicles in close vicinity. It is noted that in spite of the periodic nature of CAMs, the size of each message can change in time because a relatively stable information component such as the device certificate can be transmitted less frequently. DENMs are used for road hazard warnings to warn road users of dangerous events. Dedicated short-range communications (DSRC) has been developed as a standard for V2X communication, which relies on the physical and medium access layer technologies of IEEE 802.11 such as carrier sense multiple access with collision avoidance [4, 5].

In the automotive industry, automakers established the Crash Avoidance Metrics Partner-

Hanbyul Seo and Ki-Dong Lee are with LG Electronics; Shinpei Yasukawa is with NTT DoCoMo; Ying Peng is with CATT; Philippe Sartori is with Huawei.

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ship (CAMP) Consortium in 2001, focused on addressing the technical challenges with vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I). Several projects have been conducted in CAMP, such as Vehicle Safety Communications (VSC) [6], automated vehicle research, and the Vehicle Infrastructure Integration Consortium (VIIC). In Europe, the Car 2 Car Communication Consortium (C2C-CC) was established in 2007 [7]. C2C-CC is dedicated to increasing road traffic safety and efficiency by means of cooperative ITS (C-ITS). C2C-CC supports the creation of European standards for communicating vehicles spanning all brands.

In the government and regulatory bodies, there has been growing involvement over the past years to advance ITS. The U.S. Department of Transportation's National Highway Traffic Safety Administration (NHTSA), a federal agency authorized to oversee motor vehicle safety, together with the automotive industry and academic institutions have been researching V2V for more than a decade. In August 2014, NHTSA published an Advance Notice of Proposed Rulemaking and a supporting research report on V2V readiness that explore technical, legal, and policy issues for V2V applications. From 2012 to 2014, a safety pilot involving approximately 2800 cars, trucks, and buses from different vendors was conducted as a joint effort involving government, industry, and academia.

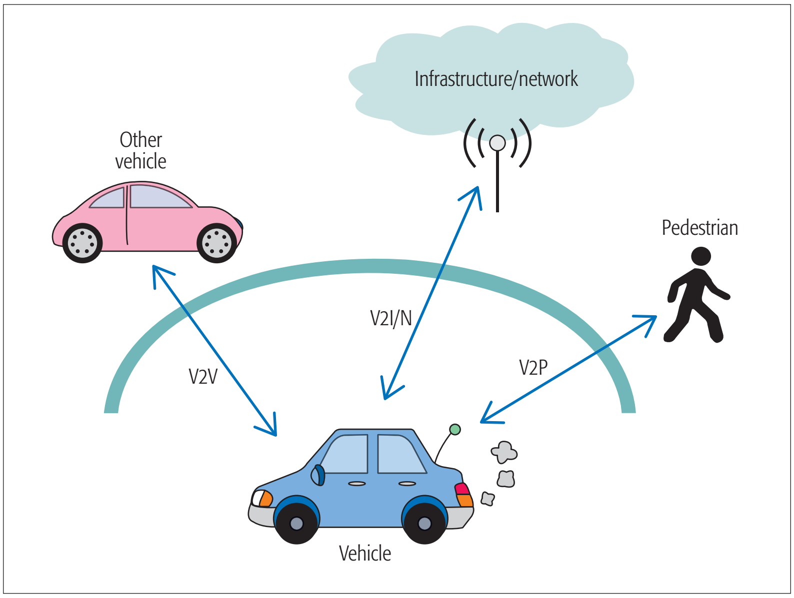

Figure 1. Types of V2X services.

Standardization for V2X Services in 3GPP

The aforementioned V2X-related activities made outside 3GPP have played an essential role in motivating V2X study and normative work in 3GPP since 2014. Those activities mostly include sensor/actuator and application-layer V2X message design; however, one of the most critical problems to make the associated technology feasible in the market is how to communicate better over a wide geographic area in a more cost-effective manner; that is, the capital/operational expenditures (CAPEX/OPEX) for deployment/operation of infrastructure equipment. This is how 3GPP can provide a means for better communication (e.g., more reliable, with low latency) to make V2X more useful and cost-effective in reality. Under the ongoing standardization work, 3GPP is liaising with the other organizations to inform the outcome of the 3GPP activity as well as to solicit input [e.g., 8].

Since its first standardization, Release 8 in 2008, LTE has continued to evolve over several releases. Such evolution not only includes uplink and downlink enhancements to one-to-one communications between user equipment (UE) and base stations (also known as evolved NodeBs, or eNodeBs), but also covers other types of wireless communications. LTE supports one-to-many communications via downlink transmissions from a single cell by using single-cell point-to-multipoint (SC-PTM) transmission or from multiple cells by using multimedia broadcast multicast services (MBMS). Additionally, LTE provides a communication link called a sidelink, also known as D2D direct communications, whereby a UE directly transmits data, including data for one-to-many communications, to other UEs in its proximity without routing via an eNodeB. The one-to-many communication mechanisms in LTE are useful building blocks for V2X services, especially for safety-related services where the same message needs to be sent to multiple UEs.

In response to the increasing demand for vehicular communications, 3GPP has started standardization activities for LTE-based V2X services. As a first step, Technical Specification Group (TSG) Services and System Aspects (SA) Working Group 1 (WG1), which is responsible for defining use cases and requirements for new services and features, recently completed a study item on LTE support for V2X [9] and has started the corresponding specification work. In accordance with this outcome, TSG Radio Access Network (RAN) is conducting a study on the feasibility and identification of necessary enhancements to the LTE air interface and protocol [10]. TSG SA WG2, responsible for the overall architecture, also recently launched a study on the main functions, entities, and network interconnections required to support V2X services [11]. The 3GPP activities include V2V, vehicle-to-pedestrian (V2P), and V2I/N as target services, and cover all uplink, downlink, and sidelink communications. After the studies and corresponding specification work are finalized in 2017 as part of Release 14, a full set of technical enablers, from the air interface and protocols to the service requirement and management functionalities, will be available to support V2X services in LTE.

3GPP also recently started studies on new services that will be enabled by the new generation radio communication technology, so called fifth generation (5G), targeting specifications beyond Release 14 [12]. In this study, enhanced V2X is one of the five service categories, and the following use cases are under initial consideration:

- Autonomous driving use cases, which require very rigorous reliability (nearly 100 percent), very low end-to-end latency (e.g., a few milliseconds), and very high data rates

Scenarios	Parameters					
	Effective distance	Absolute speed of a UE	Relative speed between 2 UEs	Maximum tolerable latency	Minimum radio layer message reception reliability	(Example) cumulative transmission reliability
#1 suburban/major road	200 m	50 km/h	100 km/h	100 ms	90%	99%
#2 freeway/motorway	320 m	160 km/h	280 km/h	100 ms	80%	96%
#3 autobahn	320 m	280 km/h	280 km/h	100 ms	80%	96%
#4 NLOS/urban	150 m	50 km/h	100 km/h	100 ms	90%	99%
#5 urban intersection	50 m	50 km/h	100 km/h	100 ms	95%	–
#6 campus/ shopping area	50 m	30 km/h	30 km/h	100 ms	90%	99%
#7 imminent crash	20 m	80 km/h	160 km/h	20 ms	95%	–

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

(e.g., tens of megabits per second), even when the density of vehicles is very high such as in multi-lane and multi-layer road scenarios
- High Mobility Mobile Broadband use cases, ensuring V2X services are available with high priority when appropriate for safety, and making mobile broadband communication seamlessly available whenever possible
- Infotainment use cases

V2X Use Cases and Service Requirements in 3GPP Release14

The study in 3GPP SA WG1 forms the basis of transport-layer-specific service and system requirements that will allow V2X-type applications (based on standards developed by other standards development organizations such as ETSI) to operate on LTE technology. The study covers three types of V2X services to be specified in 3GPP Release 14 [9]:
- V2V: covering LTE-based communication between UEs using V2V applications.
- V2P: covering LTE-based communication between UEs supporting V2P applications, where P represents vulnerable road users including pedestrians, motorcyclists, bikers, roller skaters, and so on.
- V2I/N: covering LTE-based communication between a UE and a roadside unit (RSU), both using V2I applications. An RSU is a transportation infrastructure entity (e.g., an entity transmitting speed notifications), which is implemented in an eNodeB or a stationary UE. V2N (e.g., for traffic signal control) is also included.

Both safety and non-safety use cases are possible with each type of V2X service:
- Safety-related use cases: critical-event warning (e.g., collision warning, emergency stop warning)
- Non-safety-related use cases: supplemental services that can help drivers/passengers reap the benefits of using advanced V2X services (e.g., automated parking assistance, traffic route information support)

The Technical Report [9] being produced by the feasibility study includes a wide range of categories characterizing the service requirements:
- Authentication (how to authenticate the V2X users/UEs)
- Capacity
- Charging (how mobile operators should charge for the use of V2X service)
- Communication range (measured in response time; e.g., 4 s)
- Control
- Energy consumption (communication energy efficiency due to frequent message transfer)
- Frequency of message transmissions (e.g., 10 times per second)
- Inter-operator/country (when multiple mobile operators are involved in V2X service)
- Latency (e.g., 100 ms)
- Location (sharing of location information with an improved accuracy)
- Message size (e.g., up to a maximum of 1200 bytes, excluding security overhead)
- Message transfer (timely transfer of V2X-related messages)
- Reliability
- Security (anonymity/integrity protection)
- Speed (e.g., absolute: 160 km/h; relative: 280 km/h)

Table 1 presents the key performance parameters with the suggested values for 3GPP Release 14 V2X services. The parameter *effective distance* is greater than the range required to support time to collision of 4 s at the maximum relative speed. This allows multiple V2X transmissions in order to increase the cumulative transmission reliability. *Minimum radio layer message reception reliability* denotes the probability that the recipient gets a V2X message in the effective distance and within the *maximum tolerable latency*. The parameter *cumulative transmission reliability* denotes the probability that the application at the recipient receives the required information, assuming the application layer can operate with one received V2X message during a certain time window (e.g., a 200 ms window as shown in the example; $1 - (1 - p)^2$, where p is minimum radio layer message reception reliability). Also, LTE-based V2X is working on targeting a maximum relative speed of 500 km/h for one possible scenario, although it is not listed in Table 1.

Operation Scenarios being Considered for LTE-Based V2X Services

On the operation of LTE-based V2X, two air interfaces (cellular interface based on uplink/downlink and D2D interface using sidelink) will be jointly operated and selected according to the requirement of each V2X service. The cellular communication and D2D communication, which are part of LTE-based V2X, will introduce significant operational benefit and efficient utilization of the spectrum. This subsection briefly describes the operational scenarios of LTE-based V2X together with the spectrum aspect, which is crucial in order to operate the two air interfaces and exploit conventional LTE network infrastructure.

In general, ITS consists of four types of entity; vehicles equipped with an onboard unit (OBU), vulnerable road users like pedestrians and bicycle riders, RSUs, and central ITS servers. All the entities can communicate with each other by means of cellular-based communication or D2D-based communication. D2D-based V2X will provide low latency and short-range communication even for out-of-network coverage, while cellular-based communication is for wide-area communication with high capacity. Examples of V2X deployment and transport options are shown in Fig. 2. A major difference from DSRC and ETSI ITS [4, 13] is direct network connectivity and network controllability by means of LTE infrastructure.

The RSU is a transportation infrastructure entity that could be implemented in an eNodeB or a stationary user terminal. The RSU provides several services based on the knowledge of local topology obtained from neighboring vulnerable users, sensors (e.g., cameras, induction loops), and the central ITS server. When a limited number of vehicles are equipped with OBUs, for example, at the initial stage of V2X service launch, the RSU provides local topology information obtained by roadside sensors instead of V2V communication. If an existing eNodeB can work as an RSU, rapid growth of the V2X market might be expected. Even in the mature stage, an RSU can provide wider topology information with high reliability.

A central ITS server provides centralized control for other entities as well as traffic, road, and service information. The central ITS server could be deployed outside of the LTE network by the transportation industry (e.g., a road management authority and government bodies like the Department of Transportation). Ongoing study on mobile edge computing [14] may enable deployment within the core network, that is, Evolved Packet Core (EPC), in the future in order to reduce latency.

Figure 3 shows several scenarios of spectrum usage for LTE-based V2X. It is noted that each spectrum allocated to either cellular or D2D in the figure may include multiple carriers in order to cope with high capacity requirements for future V2X services. For cellular-based V2X, existing LTE spectrum and infrastructure can be reused to offer sufficient capacity, and existing LTE networks are operated by several operators with multiple LTE carriers in a specific region. This corresponds to scenario A in Fig. 3, and as each UE uses spectrum of its own operator for both cellular and D2D links, the same spectrum can be used for both links. In this case, it is important to consider how to provide the required quality of service (QoS) for the V2X communications across UEs belonging to different operators where tight coordination and fast data transfer may not always be assumed.

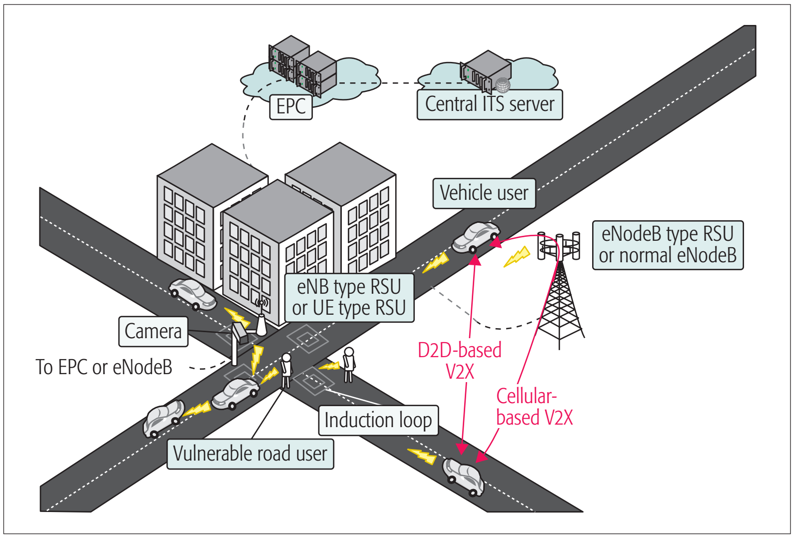

Figure 2. Examples of V2X deployment and transport options.

Depending on the frequency allocation policy, it is possible that a new dedicated spectrum is allocated to D2D-based V2X. An LTE carrier for D2D operation is not necessarily licensed to an operator. In such a case, all the D2D operation for V2X takes place in the dedicated D2D spectrum as in scenario B, and the issue of inter-operator operation is limited to the cellular link. In this case, the operator may use the cellular link for V2X services posing relatively low latency in order to account for the latency caused by the inter-operator operation, while using a D2D link for services requiring short latency and short coverage. It is noteworthy that even for D2D-based V2X, operator operation is considered for centralized control. Network control will be utilized for radio parameter optimization, radio resource allocation, congestion control, authentication and security, and so on. If no LTE coverage is provided for some areas, D2D links will be used for V2X without having such network control as in scenario D. All the parameters that would be controlled by the network can be set to predefined ones, and this may lead to relatively non-optimized operation.

If mission-critical services are supported by cellular-based V2X, dedicated spectrum for the entire V2X can have advantages in terms of capacity and QoS control. In this case, a single operator per specific area (i.e., a non-overlapping operator area) and RAN sharing operation among operators are considered as operational options with low deployment cost. As a result, the operation scenario will be in the form of scenario C in Fig. 3.

There are mainly two technical challenges in fulfilling the V2X service requirements: high vehicle speed and high UE density. It is noteworthy that UE capability may be different for vehicles and pedestrians. Higher capability and virtually unlimited battery may be assumed for UEs installed within vehicles, but the same assumption is not generally valid for pedestrian UEs.

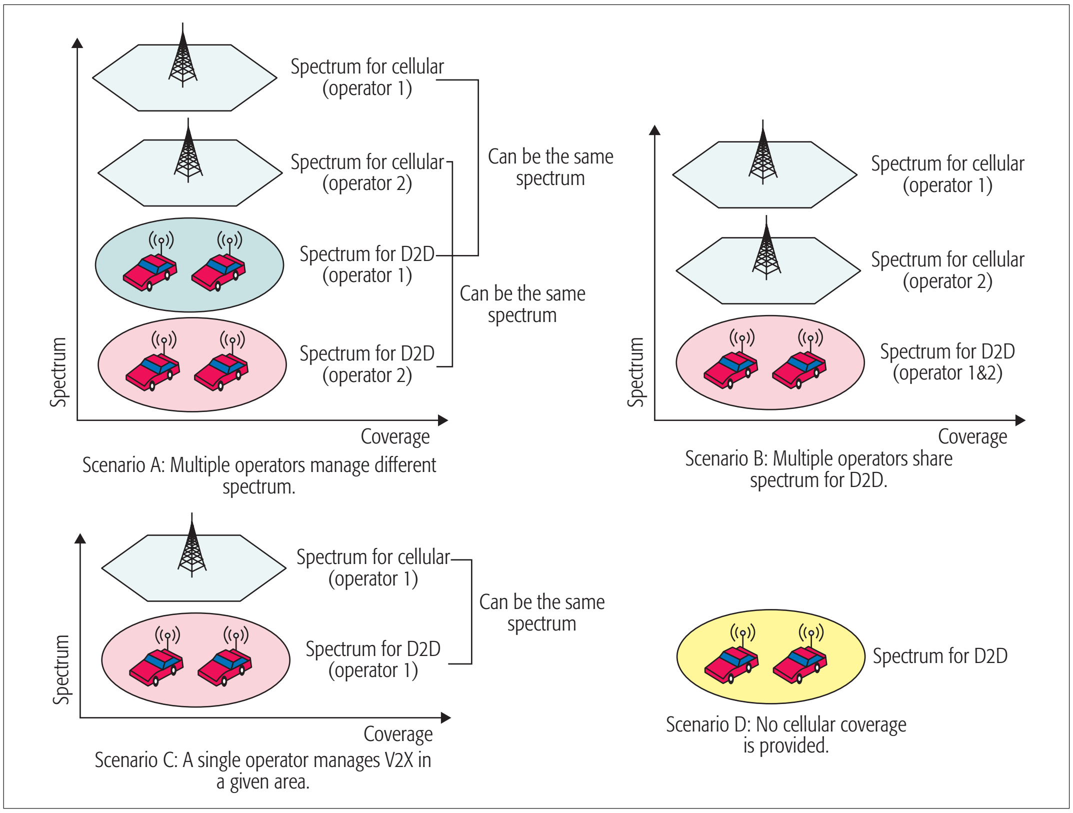

Figure 3. Spectrum options for V2X operation in a given area.

Technical Challenges and Design Considerations

There are mainly two technical challenges in fulfilling the V2X service requirements: high vehicle speed and high UE density. It is noteworthy that UE capability may be different for vehicles and pedestrians. Higher capability and virtually unlimited battery may be assumed for UEs installed within vehicles, but the same assumption is not generally valid for pedestrian UEs (e.g., those installed within smartphones). Thus, consideration needs to be given to this difference in designing technical solutions.

The physical layer (PHY) design of the existing LTE system supports about 300 km/h of UE velocity at 2 GHz carrier frequency. However, PHY design for V2X faces the design objective of supporting up to 6 GHz to support a wider frequency allocation range. Also, in the D2D-based V2V scenario, the transmitter and receiver may be driven at very high velocity in opposite directions, which reaches a very high relative velocity. With such high carrier frequency and relative velocity, Doppler effects, including frequency error and inter-carrier interference, and insufficient channel estimation due to shorter coherence time, become much more serious, and current PHY design may not satisfy all scenarios.

One instance is that in the existing PHY design, two reference signals are separated by a 0.5 ms gap as shown in Fig. 4. With 500 km/h relative speed at 6 GHz spectrum, the coherence time becomes about 0.15 ms, which is smaller than the current time interval of reference signals. Consequently, the demodulation performance of the data will fall sharply because reference signals with that separation are unable to track such fast channel variations. The corresponding consideration of enhancement in the 3GPP PHY includes improving the ability to track the channel variation. Figure 4 also illustrates an example of enhanced reference signal structure where four reference signal symbols are uniformly located within a 1 ms subframe to reduce the time interval between reference signals [10]. In addition, several techniques are also under consideration by comparing the phase of the first and second half of each reference signal so that very high frequency offset can be estimated even within a single reference signal symbol.

Furthermore, high vehicle speed leads to frequent change in communication topology, which includes uplink and downlink between eNodeB and UE as well as sidelink between two UEs. Handover (i.e., change of the serving cell) is a representative example of the topology change in LTE systems, and a UE takes the new serving cell as the new reference in terms of synchronization and other communication configurations. Such change generally causes interruption in communication for some time duration. As V2X services pose tight latency and reliability requirements, V2X communications should be robust to this frequent topology change. As an example for synchronization, signals transmitted from satellites (e.g., by using GPS) can be used as the reference for sidelink, thereby allowing a reference independent of the cell change.

Compared to traditional cellular communications, V2X services are unique in terms of deployment scenarios and traffic characteristics. Vehicle density can be high, with most vehicles concentrated on a few arteries, as seen in Fig. 5.

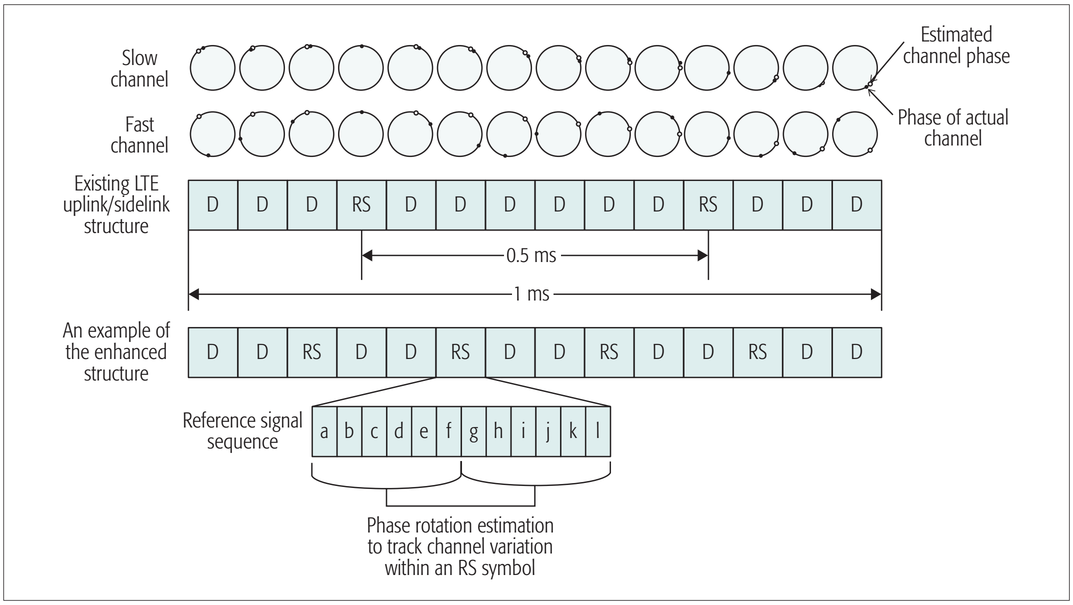

Figure 4. Illustration of existing LTE uplink and sidelink channel structure and possible enhancement to track fast channel variation.

Similarly, pedestrians are concentrated in streets. In order to provide reliable safety services, it is imperative that all V2X actors transmit relatively frequently, typically every 0.1 to 1 s, using small payload sizes (less than a few hundred bytes). These traffic characteristics are very different from typical cellular communications, where a relatively small number of users are active at the same time. 3GPP is looking at several techniques in the two air interfaces to meet the demands of this challenging deployment.

The D2D interface of LTE was developed in part for public safety communications. The primary application traffic was voice, and the number of concurrent transmissions was low (tens of users in a cell area). 3GPP is investigating improvements to the D2D interface to accommodate V2X traffic. Some of the improvements being discussed include advanced resource allocation procedures to leverage the V2X traffic characteristics; for instance, most V2X traffic is periodic with a relatively predictable size. Using semi-persistent resource allocation techniques is a means to enable a large number of actors to all transmit in an efficient manner with limited signaling cost. In addition, traditional techniques such as detecting other UEs' transmission can improve the overall system performance. Given the dense environment, collision avoidance will need to be deployed. Several such techniques are currently being studied, like interference coordination, either fully autonomous between actors or with base station guidance.

Improvements for the cellular interface are also under consideration. At least for V2I/N, communication from the network needs to be considered. The transmission range typically needs to be larger than for V2V/V2P communication, and the communication is by nature point-to-multipoint. In order to accommodate this traffic demand, broadcast mechanisms are being considered with the possibility of further enhancement for the spectral efficiency and latency performance. Multi-cell broadcast based on MBMS has the benefit of reinforcing the signal strength of the message as signals from neighboring cells also act as useful ones. Single-cell broadcast using SC-PTM is beneficial in that the resource reusability of the cellular network can be exploited, and V2X messages can be efficiently multiplexed with unicast transmissions for other services.

Figure 5. An example of street deployed in the city (Seoul, Korea).

The possibility of using LTE for V2X and the expected pros and cons have been studied in several papers [e.g., 15]. Although the design for LTE-based V2X is not completed yet, its potential benefit over the existing DSRC can be summarized below.

LTE supports the frequency domain multiplexing of multiple UE transmissions in contrast to DSRC, where only one device can transmit at a time in a given channel. As a result, LTE can multiplex more UEs within limited resources without compromising each transmission's coverage, which is especially advantageous when the vehicle density is high.

Cost-Effective V2I/N: The existing LTE infrastructure, including eNBs and the core networks, can be reused with some upgrading in order to provide V2I/N services. A V2I/N service provider can save the cost of deploying new RSUs and connecting them to the network (e.g., the ITS server).

Better Coverage: LTE can provide better performance when the received signal power is weak. The receiver sensitivity is lower than that of DSRC, which means that LTE UEs can receive weak signals that are not detectable by DSRC receivers. In addition, the use of turbo code can provide better channel coding gain when compared to the convolutional code used in DSRC. Use of MBMS can be a good solution, if available, to enlarge V2X coverage.

Higher Multiplexing Capacity: LTE supports the frequency domain multiplexing of multiple UE transmissions, in contrast to DSRC, where only one device can transmit at a time in a given channel. As a result, LTE can multiplex more UEs within limited resources without compromising each transmission's coverage, which is especially advantageous when the vehicle density is high.

Robustness to Congestion: An eNodeB can allocate non-overlapping resources to different UEs in order to prevent resource collision, which is unavoidable in DSRC in a congested area. This eNodeB-based scheduling can be used for both uplink and sidelink transmissions whenever the transmitting UE is inside the network coverage. When eNodeB-based scheduling is not used, a UE can try to avoid resource collision by detecting other UEs' transmission as mentioned above, and use of semi-static allocation can be helpful in the sense that a UE can be aware of other UEs' future behavior.

Conclusions

In this article, we have discussed how LTE systems are evolving in order to support V2X services. Basic safety services such as collision warning as well as convenience services such as traffic flow optimization are identified as the first step of LTE-based V2X services. Those services can be provided in multiple operation scenarios using the D2D interface, the cellular interface, or their combination. The main challenges identified in supporting V2X services are high mobility and dense population of UEs, and LTE systems need to be enhanced so that the service requirements can be fulfilled in such a vehicular communication environment. Leveraging the spectrally efficient air interface, cost-effective network deployment, and the versatile nature of supporting different communication types, LTE systems along with proper enhancements can be a cost-effective enabler of V2X services. Furthermore, 3GPP has also started to discuss more advanced services of connected cars as the second step, and the related specification work is expected to continue for further LTE evolution and the new air interface design for 5G communications.

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Biographies

Hanbyul Seo received his B.S., M.E., and Ph.D. degrees in electrical engineering from Seoul National University, Korea, in 2001, 2003, and 2008, respectively. He joined LG Electronics in 2008 and has been working on 3GPP LTE standardization including the areas of wireless relay, CoMP, and D2D. He is Rapporteur of 3GPP V2X standard items in TSG RAN.

Ki-Dong Lee [SM '07] received his degrees in OR/industrial and systems engineering from Korea Advanced Insitute of Science and Technology (KAIST). As an author of a book, book chapters, and many journal publications, he has professional experience in probability models, scheduling, protocols, and cryptography in satellite/wireless networks. He has served as a co-Guest Editor for *IEEE Wireless Communications* and as Rapporteur of 3GPP V2X, and received awards from IEEE ComSoc, IFORS/APORS, Korea Math Society, and SK Telecom. He is an elected Vice Chairman of 3GPP SA1.

Shinpei Yasukawa received his M.E. degree from Doshisha University, Japan, in 2009. He joined NTT DoCoMo in 2009 and has been engaged in research and development of uplink MIMO in LTE. Since 2013, he has been engaged in 3GPP LTE standardization including the area of machine-type communications and device-to-device communication. He was a recipient of the IEICE Young Engineer Award and the Active Research Award in radio communication systems from the IEICE in 2011.

Ying Peng 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.

Philippe Sartori is with Huawei Technologies and received his engineering degrees from ENST, France, and Ecole Polytechnique, France. He has been actively involved in the standardization of LTE since 2008. He has focused on nearly all aspects of physical design and has recently been working on device-to-device technology. He is currently co-Rapporteur of the V2V work item in 3GPP RAN. He is currently focusing on connected/autonomous vehicles and their implications on wireless communication