Survey on Challenges and Solutions of C-V2X: LTE-V2X Communication Technology

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***Abstract*— In Vehicle-to-Everything (V2X) communications, various tasks have been performed to enable various applications for traffic efficiency, road safety and passenger infotainment. This paper deals with challenges and solutions of the core technology of Cellular V2X (C-V2X) communication that provides high reliability and low latency as it evolves from Long Term Evolution (LTE)-V2X to LTE-enhanced V2X (eV2X) and 5G-New Radio (NR)-V2X. And High throughput communication technologies. Finally, we will further invest gate and discuss research directions that can solve the challenges of C- V2X in the future.**

Keywords*— *C-V2X; LTE-V2X; 5G-NR-V2X

I. Introduction

In the past, to solve problems such as traffic accidents and traffic congestion, navigation has been used to guide drivers in one direction about traffic conditions. Since then, with the development of sensors and artificial intelligence technologies in vehicles, attempts have been made to prevent accidents by detecting the surroundings by vehicles themselves. However, new problems such as sensor recognition range and image processing misrecognition problems have arisen. To solve these problems, the need for mutual data exchange between vehicles and road facilities has emerged. Cooperative Intelligent Transport System (C-ITS) has been proposed. C-ITS enables cooperative and intelligent interactions between vehicles, infrastructure and, other road users through wireless communication, data exchange and real-time information sharing. The main communication technologies used in C-ITS are Cellular Vehicle-to-Everything (C-V2X) and Dedicated Short-Range Communication (DSRC) [1].

DSRC is a Wi-Fi based short-range dedicated communi cation system that connects vehicles and road facilities within a few hundred meters. However, DSRC has limitations in range and speed to process massive data, and to overcome this, a cellular-based communication technology called C-V2X has emerged [2]. V2X communication technology is essential for efficiently exchanging, sharing, collecting, and controlling traffic information in C-ITS.

V2X is Vehicle-to-Vehicle (V2V), Vehicle-to-Infra structure (V2I), Vehicle-to-Network (V2N), Vehicle-to-pedestrian (V2P), and Pedestrian-to-Network (P2N). Indicates communication throughout. V2I enables roadside base stations to exchange information with in-vehicle terminals, share traffic information, or enable automatic toll collection. V2V allows vehicles to understand road and traffic conditions like V2I through vehicle-to-vehicle communication. V2N provides services such as sharing information with a network or diagnosing a vehicle by accessing a vehicle using a portable terminal. V2P makes it possible to provide a warning service when a pedestrian is approaching. In addition, communication in various directions is performed [3]. That is, information is not necessarily transferred through the center and aims to quickly transfer information through bidirectional com munication between objects. Among V2X, C-V2X is an important technology for implementing autonomous driving and intelligent transportation systems and is a V2X communication technology developed based on cellular systems [4].

In the case of DSRC, many infrastructures for Wireless Access in Vehicular Environment (WAVE) communication standards have already been established and are characterized by stability [5]. On the other hand, C-V2X requires new invest ment, but since it is based on LTE and 5G, the serviceable area is widened, and information can be transmitted quickly without delay during communication. As cellular systems evolve from Long Term Evolution (LTE) to 5G, C-V2X evolves from LTE-V2X to 5G-New Radio (NR)-V2X [4].

In this paper, the core technologies, challenges, and solutions of C-V2X are presented, and the technological development path evolving from LTE-V2X to 5G-NR-V2X is highlighted. Finally, we will further investigate and discuss research directions that can solve the challenges of C-V2X in the future.

II. Challenges and Solutions of LTE-V2X

C-V2X technology is superior to DSRC technology, which is a short-distance two-way communication, in almost every aspect, such as data rate, reliability, latency, mobility support, effective communication distance, response to congested vehicle traffic, and adjacent channel interference. LTE-V2X provides basic traffic safety services based on LTE. Through LTE-V2X, it is possible to exchange status information (location, direction, speed, etc.) with surrounding vehicles, pedestrians, and infrastructure [6]. LTE-V2X is supplemented with improved wireless technology and network architecture, not replaced, and evolves into 5G-NR-V2X which provides advanced autonomous driving services with relatively large amounts of data.

Active communication enables C-V2X to configure a wide-range system that supports a variety of V2X applications and scenarios. The core technology of C-V2X is to increase Demodulation Reference Signal (DMRS) density in the time domain by considering high frequency (5.9 GHz), achieve high reliability through coding gain, and improve spectrum efficiency and system capacity [7]. In addition, the receiving terminal applies a resource allocation method that can receive data using overlapping resources to prevent collisions of resources. It also provides potential spatial segmentation multiplexing gains. Although LTE-based V2X communication has recently attracted a lot of attention, it is difficult to use LTE networks for large-scale V2X communication [8].

LTE's physical layer design cannot support vehicle terminal speed and high carrier frequency due to the Doppler effect. So, a new physical layer structure for LTE-V2X communication is required [9]. The following describes the challenges and solutions of LTE physical layer design.

The existing physical layer of LTE cannot support high frequency and high User Equipment (UE) speeds. However, for a wider frequency allocation range and utilization range, LTE-V2X technology should support higher frequencies up to 6 GHz [10]. When the vehicle is moving at high speed in the opposite direction, the relative speed in the opposite direction increases, which may result in a Doppler effect. The Doppler effect causes interference between carriers, and the Doppler effect reduces short-term consistency, making accurate channel estimation difficult [9]. Because the time interval of the reference signal is longer than the consistent time, applying the existing LTE physical layer to LTE-V2X significantly reduces de- modulation performance. The current LTE physical layer allows for frequency offset modifications of up to 1 kHz. However, the maximum frequency error between adjacent cell-to-cell terminals can be greater than 2.2 kHz. In other words, there is a need to improve the physical layer structure of LTE [10]. So, the 3rd Generation Partnership Project (3GPP) is considering improving the reference signal structure by introducing a subframe of 1 ms to reduce the time interval between the reference signals and placing the four reference signal symbols at specific locations. This structure reduces the time interval to improve the performance of the reference signal [11].

Another technique to solve the problem is to estimate the high-frequency offset by comparing the phases of the first and second halves of a single reference signal symbol. Performance comparison between IEEE 802.11p and LTE-V2V was performed. In the proposed method, a frame of 10 ms composed of 10 subframes of 1 ms consists of two slots in each subframe. At this time, the subcarrier interval is variable at 15 kHz, and the minimum schedulable unit in the time domain is 0.5 ms, and the minimum unit in the frequency domain is 12 subcarriers. The structure of these frames and subframes affects the data rates of 802.11p and LTE-V2V. As a result, LTE-V2V howed superior performance compared to long-distance communication and IEEE 802.11p [12].

III. ADVANCES FROM LTE-V2X TO 5G-NR-V2X

Developed from LTE-V2X, 5G-NR-V2X supports enhanced services for features that LTE-V2X cannot support. Looking at the detailed development stage, C-V2X is now evolving from LTE-V2X technology to LTE-enhanced V2X (eV2X) and 5G-NR-V2X technologies [13]. A detailed description of each detailed step is provided below.

LTE-V2X technology provides basic traffic safety services. In addition, LTE-V2X uses a Uu interface and a PC5 interface for V2V and V2I to send and receive V2X service messages [14]. First, the Uu interface can activate up to 8 uplink Semi Persistence Scheduling (SPS) sessions and provides short-term scheduling for V2X support in evolved Multimedia Broadcast and Multicast Services (eMBMS) and Single Cell- Point to Multipoint (SC-PTM). The PC5 interface supports DMRS pattern design for high-speed mobility support, two transmission resource selection modes, packet priority transmission support, channel congestion control technology, and V2X service reception from base stations and terminals of other operators. Therefore, LTE-V2X effectively supports V2X communication by providing various functions and services through Uu interface and PC5 interface [15].

LTE-eV2X technology provides transportation convenience services and supports additional features to support improved V2X use cases. First, the technology uses up to 8 Sidelink Carrier Aggregation (CA) to enhance the PC5 interface [16]. This may improve communication capacity and efficiency in the Sidelink mode by aggregating multiple carriers. Second, the technology use Sidelink 64 Quadrature Amplitude Modulation (QAM) transmission. This means the use of 64-QAM modulation in Sidelink communication. This modulation scheme enables higher data rates and improved spectral efficiency. Third, Packet Data Convergence Protocol (PDCP) level Packet Duplication transmission technology is used to improve stability. This technique replicates packets at the PDCP layer, helping to reduce packet loss and improve reliability in transmission. Finally, LTE-V2X terminals and LTE-eV2X features are enhanced by applying the transmission (Tx) profile option. This option supports the coexistence of terminals with different functions and capabilities. This ensures compatibility and enables efficient communication [17].

5G-NR-V2X technology provides a key service for autonomous driving and uses Uu interface and PC5 interface to send and receive messages between gNB and UE. 5G's base station consists of GNB and UE. The system supports Level 4 and Level 5 autonomous driving and supports various communication modes such as unicast and group cast to support advanced service performance requirements such as autonomous driving. It also improves communication reliability through feedback-based packet retransmission and improves data transmission quality by improving data transmission rates through 256 QAM modulation and 40 MHz channel bandwidth support. With these different communication modes and improved technologies, the 5G-NR-V2X system provides key services for autonomous driving and can meet advanced service requirements such as autonomous driving levels 4 and 5 [18].

LTE-(e) V2X and 5G-NR-V2X technologies are expected to be equipped with multi-modes in vehicles, just as our current smartphones can use 3G, 4G, and 5G technologies at the same time. To commercialize autonomous vehicles, not only self-driving support, and safety improvement services, but also basic safety services are required, so both LTE-V2X and 5G-NR-V2X must be utilized, and simultaneous communication must be possible.

IV. CONCLUSION

This paper investigated the core technology of LTE-V2X of C-V2X. And the challenges and solutions of LTE-V2X were discussed. It also emphasized the explanation and path of the detailed steps of developing LTE-V2X into LTE-eV2X and 5G-NR-V2X as 5G progress from LTE.

The 5G-NR-V2X aims to support intelligent transportation system and advanced applications in autonomous driving to users by coexisting with LTE-V2X and DSRC, rather than just being a single one. If basic safety services are provided only with a 5G-NR-V2X single road, there will be a problem in supporting basic safety services between autonomous vehicles and autonomous vehicles. The reason for this is that as the speed of the vehicle increases, the Doppler effect increases, and the signal interference increases, resulting in loss of reliability of the safety service. Therefore, technologies such as DSRC that provide stability in a high-speed mobile environment should be mixed and used together. C-V2X technology is expected to continue to develop even after 5G-NR-V2X technology, including precision positioning between vehicles and extended frequency support. It is also expected that as these technologies develop, more related infrastructure facilities will be in place. In addition, given that about 40% of domestic traffic accident deaths are pedestrians, future C-ITS safety services need to be studied to provide high connectivity to safety services to many people through portable smart devices using mobile communication technology. In addition, improved research is needed on communication security and privacy in vehicles while securing connectivity with portable smart devices. Further research is also needed to improve the scalability and reliability of vehicle communication services through improvement and expansion of the infrastructure that provides services.

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