C-V2X Assisted Automated Driving

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***Abstract*— Cellular Vehicle to Everything (C-V2X) is a technology that has been developed by the Third Generation Partnership Project (3GPP). C-V2X is to provide not only direct communications but also network communications among vehicles, infrastructures, and other objects on roads to reduce a number of potential road traffic accidents. This paper begins with describing C-V2X, specifically how direct communications (PC5) and network communications work. Furthermore a comparison between PC5 and DSRC is described. Lastly, some use cases for C-V2X are presented. The use cases include, roadworks warnings, intersection movement assist, and see-through.**

***Keywords*— C-V2X, PC5, V2N, 5G**

I. Introduction

WHO reports that each year 1.35 million people die in traffic [1]. An investigation of 2,189,000 crashes in the US shows that 94% (2.2%) of them are due to human errors [2]. The development of self driving vehicles could drastically decrease the number of deaths in traffic. Because vehicular communications can help drivers make choices that directly prevent accidents. Eventually, the development of vehicular communications is a vital part in self-driving technology that entirely changes the concept of driving.

One of the vehicular communications that have been recently developed is Cellular Vehicle to Everything (C-V2X). C-V2X is a wireless vehicular technology that has been developed by the Third Generation Partnership Project (3GPP). Improved features of C-V2X in comparison to the already established Wireless LAN(WLAN)-based V2X (IEEE 802.11p) and further upgrades are therefore interesting to research as it is an important step towards safer road environments.

The rest of the report is organized with two main sections and the conclusion. Section II describes technical descriptions of C-V2X and comparisons with WLAN-based V2X. The section is divided into the direct safety communication (PC5) part and network communications one. Especially, comparisons between C-V2X and WLAN-based V2X are discussed in the direct communication. The other main section, which is Section III, shows three related use cases before the conclusion.

II. Technical description of C-V2X and comparisons with WLAN-based V2X

C-V2X is a newer generation of the WLAN-based V2X that is well-known as either Directed Short Range Communications (DSRC) or Intelligent Transport Systems G5 (ITS-G5). DSRC has been developed in the USA whereas ITS-G5 is a standard in the EU. The most significant difference between the C-V2X and WLAN-based V2X is that C-V2X provides mobile cellular connectivity. Mobile cellular connectivity can be implemented through either Long-Term Evolution (LTE) or Fifth-Generation wireless (5G).

Providing mobile connectivity enhances its performance. Since mobile connectivity increases a number of channels, data rates, and even distance. In other words, C-V2X is designed to enable network independent communication.

The main two interfaces of C-V2X are divided into Direct safety communication (PC5) and Network communications (Uu interface). Uu refers to the logical interface between the User Equipment (UE) and the base station. Detailed information about PC5 and Uu are described in the following subsections.

A. Direct safety communication - PC5

Direct safety communication of C-V2X is to provide interface channels for Vehicular-to-Vehicular (V2V), Vehicular-to-Infrastructure (V2I), Vehicular-to-Pedestrian (V2P), and etc. direct safety communication is an ad-hoc type communication, which means no mobile services are required.

1) Technology Standards [3]

a) *Physical layer:* The physical layer of C-V2X basically uses Single Carrier Frequency Division Multiplexing access (SC-FDMA) and provides either 10 or 20 MHz channels. Channels consist of subframes and subcarriers. Subframes are divided by time while subcarriers are divided by frequency. A Resource Block (RB) is a minimum unit of resource that is to be allocated to each UE and sub-channels are considered, in C-V2X, as a group of RBs in the same subframe. Sub-channels are to provide both data and control messages. An explanation of sub-carriers, sub-frames, RB, and sub-channels is seen in Fig.1.

There are two channels. One is Physical Sidelink Shared Channel (PSSCH) and the other one is Physical Sidelink Control Channel (PSCCH). As their names imply, PSSCH is to deliver data to multiple UEs whereas PSCCH is to transmit Sidelink Control Information (SCI). A figure that visualizes the channels is shown in Fig 2. When a UE has to transmit data, it has to deliver SCI first. Because SCI is used to control data transmission among UEs that use the sidelink. Modulations can be either Quadrature Phase-Shift Keying (QPSK) or 16-Quadrature Amplitude Modulation (QAM) for transmission data while only QPSK is used for transmission SCI.

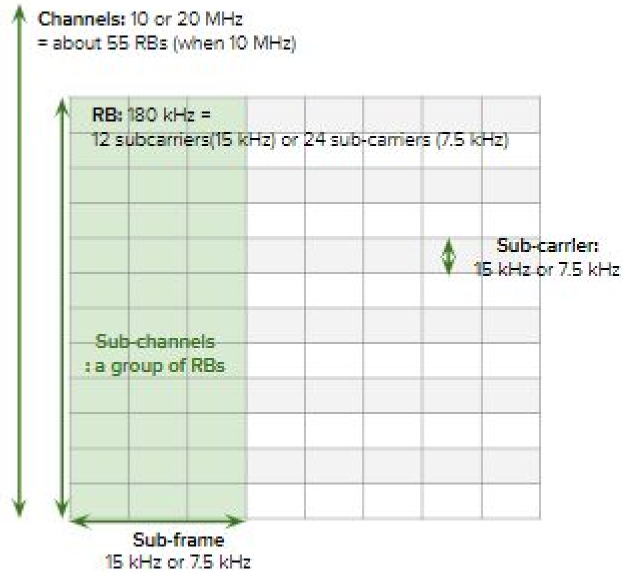

Fig. 1 Sub-carrier, sub-frame, RB, and sub-channels.

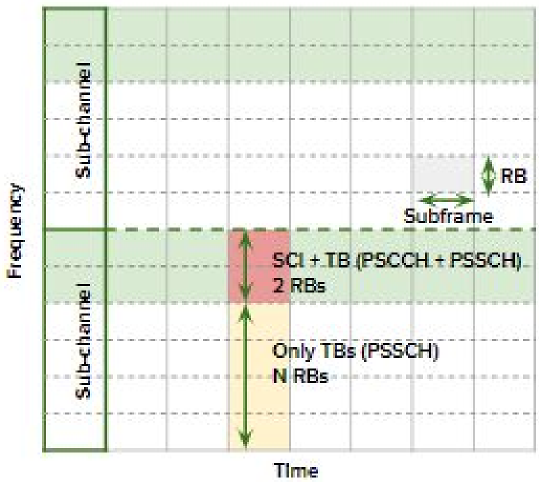

Fig. 2 Sub-channel, PSCCH, and PSSCH.

b) *MAC layer:* C-V2X uses a scheduling scheme to avoid collisions and that is Sensing-Based Semi-Persistent Scheduling (SB-SPS). In the scheduling scheme, each UE is able to reserve selected subchannels as many as their Reselection Counter (RC). RCs are selected by a random-based scheme. A RC is decremented by 1 when an UE uses the channel. Eventually, the RC becomes 0 after the UE uses all allocated times for the channel. After that, a new RC will be chosen with a probability that is selected randomly between 0.2 to 1.

Then how does an individual UE is able to know resources are occupied or available? By receiving SCI due to the fact that SCI contains information about reservations and their intervals. Thus UEs can transmit data without collisions.

Reliability in C-V2X is achieved by using Hybrid Automatic Repeat Request (HARQ). HARQ consists of high-rate forward error-correcting coding and Automatic Repeat Request (ARQ) error-control. HARQ uses Forward Error-Correcting Coding (FEC) to detect error and correct error while ARQ requires retransmitting the detected erroneous messages. As a result, HARQ can be a better choice than ARQ in poor signal environments.

2) Comparisons with DSRC: DSRC is a wireless vehicular technology that uses IEEE 802.11p for its physical and MAC layers. DSRC also provides communication among vehicles, infrastructures, and vulnerable road users (VRUs) on roads. DSRC is based on WLAN.

PC5 and DSRC are similar in some aspects. Both technologies are ad-hoc type communications and use 5.9 GHz for their frequencies. However, PC5 is more recent technology that is used in C-V2X. As a result, DSRC has been intensively tested and idealized more than PC5 has been. Thus, one of recent comparisons between DSRC and PC5 [4] shows that PC5 does not outperform DSRC. Furthermore, DSRC outperforms PC5 when the density of vehicles is high in end-to-end latency.

On the other hand, another study [5] that compared those technologies suggested that PC5 provides a higher rate of warning messages than DSRC. Moreover, the study [5] suggests that PC5 will reduce the expected amount of road traffic fatalities more effectively than DSRC will. The study focuses on the rate of successful warning messages delivery between two road users equipped with PC5 or DSRC respectively e.g. when two vehicles at a junction both use either PC5 or DSRC. Cases that vehicles use different direct communications were not investigated.

Overall, PC5 does not outperform DSRC in the aspects of E2E latency, PRR, or PIR. Especially when the density of objects that use direct communications becomes high, the PC5's performances were analyzed even lower than DSRC's. However, it is predicted that adopting PC5 will be able to raise the rate of successful warning message delivery in certain scenarios thereby creating significant decreases in the number of road traffic fatalities and serious injuries in comparison to DSRC from 2018 to 2040.

B. Network communications for complementary services

V2N networks enable vehicles to communicate with pedestrians, other vehicles and road infrastructure with use of licensed cellular spectrum. These communications are provided by mobile network providers through the Uu interface[6]. An overview of different Uu connections can be seen in Fig. (3), where infrastructure to network (I2N) and pedestrian to network (P2N) is also visualized. These communications have longer delay than direct communications and they are not expected to be used where low latency is critical [6]. Multi-access Edge Computing (MEC) can be used to reduce delays in the network by bringing application hosting closer to the end user [7]. MEC is an important enabler for V2N because it mitigates the load of massive access to the cloud.

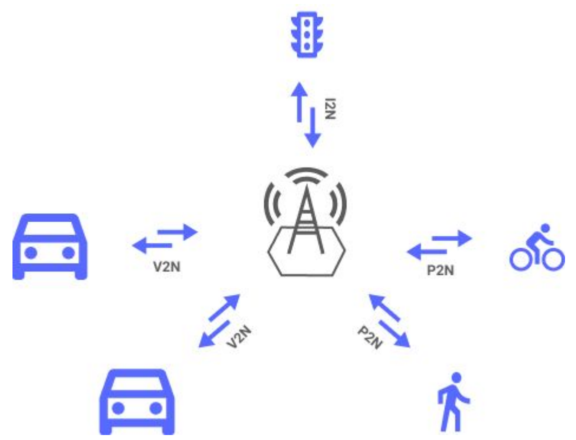

Fig. 3 Overview of different C-V2X connections through Uu links.

III. Use Cases

Some of the use cases related to C-V2X will be explained in the following subsections.

A. *Roadworks warnings*

Roadwork warnings can be sent through C-V2X to warn incoming traffic beforehand. ConVeX have field tested this and managed to receive the warning in an C-V2X equipped Audi Q7 and display it on its dashboard [8]. The test involved a roadside warning trailer equipped with C-V2X to be able to broadcast the warning to incoming traffic.

A similar use case is specified by 5GAA where hazardous location warnings are shared between vehicles [9]: A vehicle detects a hazardous situation with on-board sensors, and then broadcasts this information to following vehicles and vehicles incoming in the opposite direction.

B. *Intersection Movement Assist*

Due to the fact that in an intersection, objects including cars on the road have to cross each other, it is one of places that any objects who are in intersections must be alerted. Fortunately, by using C-V2X, the possibility of accidents in intersections can be reduced and its use case is suggested by 5GAA [8]. In the use case, two vehicles are about to cross an intersection and they spontaneously decide how dangerous the situation will be based on estimated trajectory related information. Specific requirements suggested by 5GAA are shown as below.

- Range: at least 100 m
- Necessary Information: awareness messages such as cooperative awareness messages (CAM), or basic safety messages (BSM).
- Service level latency: below than 100 ms
- Service level reliability: higher than 99.99%

C. *See-through*

It is advantageous to be able to see through vehicles that obstruct the view of vital information. For example before passing a vehicle, information as if there is an incoming vehicle can help decide if the maneuver is possible. 5G Automotive Association (5GAA) presents some specifications for this use case [9]:

- Latency of maximum 50ms between image frames.
- Time from asking for a see-through until the first frame is delivered is 500ms.
- 15 Mbps to be able to transmit a progressive high definition video signal (1280x720).

ConVeX has successfully field tested see-through in a limited scale only transmitting a 640x480 video at 480kbps over the PC5 stack [8]. They further explain that Rel-16, where 5G New Radio (NR) capability is added, will enable higher data rates between vehicles which will let vehicles transmit high definition video.

IV. Conclusion

This paper presents what C-V2X is, more specifically, direct communications that is the connection between vehicles, pedestrians and infrastructure. Furthermore PC5 and DSRC are compared with a conclusion that PC5 doesn’t outperform DSRC. However, it is also expected that PC5 outperforms DSRC in successful delivery of warning messages thereby decreasing expected amount of fetal injuries on the EU’s roads. Network communications is presented where with the use of cellular networks vehicles, pedestrians and infrastructure can communicate at longer distances but with higher latency. Lastly some use cases are presented. Roadworks warnings can through C-V2X warn vehicles of roadworks and hazards detected by other vehicles. Intersection movement assist can decrease accidents in intersections by letting vehicles do a risk estimation before crossing. See-through can for example help decide if an overtaking is possible with the use of the leading vehicles cameras.

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