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C-V2X Vision in the Chinese Roadmap: Standardization, Field Tests, and Industrialization
Tao Cui, Lantao Li, Zhaoyu Zhang and Chen Sun

Abstract

Cellular-based V2X (C-V2X) technology promoted by Third Generation Partnership Project (3GPP) is gaining increasing attention globally, after many year-long competition with dedicated short-range communications (DSRC) supported by the Institute of Electrical and Electronics Engineers (IEEE) for vehicular to everything communication. As a rising star, China continuously and actively focuses on and contributes to the C-V2X technology development in this technology marathon. Starting from the standardization progress, a quite few Chinese-specific use cases and communication messages are defined for the complicated urban traffics. Based on these dedicatedly designed higher layer protocols, the annual field tests are progressively conducted to testify the interoperability among chipsets, modules, security certificates, and original equipment manufacturer (OEM). Putting enough efforts on industry standards and tests, China is fast commercializing the C-V2X-based road services, for example, robotaxi and robot-bus in representative cities. Thus, in this chapter, we propose to provide sufficient technology views and a summary to show such advanced Chinese C-V2X philosophy.

Keywords: C-V2X, DSRC, sidelink, message dictionary, interoperability, relay

1. Introduction

Connectivity is always regarded as one of the key facilitators for the evolution of the intelligent transportation and the automobile industry. The actual meaning of wireless and/or wired connectivity for vehicles can be interpreted as a communication network for the scenario of “vehicle-road-cloud” by following certain communication protocols and data exchanging specifications. Specifically, such connectivity of V2X (vehicle-to-everything) is wired and/or wireless connection of intra and inter vehicles between vehicles and the road, and the vehicles and the cloud. For inter-vehicle communication, two major technology directions are widely accepted, that is, C-V2X led by 3GPP and DSRC led by IEEE. Both technologies target a global solution with a unified series of short-range communication protocols design. For the application layer specification, regional characteristics are the major contributors for specifying customized standards in order to fulfill the demands of various use cases country by
country. Though DSRC first version standards came out in 2010, which is far earlier than the freezing of Rel-14 LTE-V2X in 2017, major players in this field started or even implemented cellular-based solutions in many different regions of the world. The main reason behind this is the natural superiority of cellular communication over the IEEE 802.11p on mobility, coverage, and throughput. Hence, China chose the C-V2X technology roadmap in the very beginning, and took the form of a general intelligent transportation system with an architecture of “vehicle-road-cloud” depicted in

Figure 2. China C-V2X timeline and milestones.
Figure 1. The hierarchical structure takes full advantage of wireless communication to build up a China-specific intelligent transportation ecosystem. From both the regulation and standardization point of view, China paves a way for a booming C-V2X testification and industrialization in a number of pilot zones. Sections 3 and 4 show the progress and examples in detail (Figure 2).

2. Standardization of C-V2X in China

In November 2018, an agreement of C-V2X standards cooperation framework protocol on the reinforcing management of vehicles, intelligent transportation, communication, and transportation management was jointly signed by National Technical Committee 485 on Communications of Standardization Administration of China, National Technical Committee of Auto Standardization (NTCAS), China National Technical Committee and National Technical Committee 576 on Traffic Management of Standardization Administration of China in order to accelerate the C-V2X associated standardization and industrialization.

When it comes to the standardization progress, a list of standards is in Table 1 across C-V2X general architecture, air interface, safety, network layer, message layer focusing on technical aspects, and test specifications are specified incorporating vehicle, roadside, base station, and core network. Complying with 3GPP specifications on the general framework of sidelink operation, China puts a lot of efforts on the message layer protocol design, whose target is to meet the requirements of different C-V2X use cases from the application point of view. Based on such understanding and

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envision, standards of cooperative intelligent transportation system: Application layer specification and data exchange standard (Phase I and Phase II) were accomplished by C-SAE and C-ITS in 2017 and 2020, respectively. There are 34 use cases specified in total, with dedicatedly designed messages for each of them, except for the basic message set constituting of five messages, that is, basic safety message (BSM), signal phase and timing message (SPAT), road safety message (RSM), map data, and road side information message (RSI). Compared to the data dictionary defined by the Society

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Table 1. LTE-based C-V2X standards in China.
of Automotive Engineers (SAE) J2735 [1], the Chinese standards are compatible for a general road and vehicle attribute on the basis of the data frame and data element.

In a typical use case of sensor sharing, RSM and sensor sharing message (SSM), which are not defined by the US and EU are utilized for enlarging the host vehicle sensing range, especially at its blind zone, with the help of sensor data collection from roadside sensors and other vehicles, respectively. An example of roadside unit (RSU)-aided sensor sharing scenario is given in Figure 3 while the detected object is notified along with the attributes of type, location, and status. It is well noted that such information-sharing mechanism only prefers the exchange of formatted data after being processed to the point-cloud-based raw sensing data due to the constraint of C-V2X bandwidth (20MHz for LTE and 40MHz TBD for new radio (NR)). The sharing of raw data has opportunities to become possible in the future once the operation frequency band goes up to the mmWave with comparable bandwidth to

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**Figure 3.**
RSU-aided sensor data sharing to avoid blind zones.

**Figure 4.**
Sensor data sharing reference model.
the Uu link, which was approved as a work item for one of the new features for 3GPP Rel-18[2]. The undergoing discussion targets a frequency range-2 (FR2), such as solutions on the Uu link, with multiple beams operation for stable and robust sidelink communications.

For better clarification of the sensing data exchanging principle, the following reference model (Figure 4) shows different entities and corresponding interfaces for supporting the sensing data routing in the system. In a normal working flow, the sensor module outputs Red-Green-Blue (RGB) image data via direct inputs from CMOS. Imported into the V2X interface function via V2X API, post-processing is facilitated to turn the image data into the given format that RSU recognizes, that is, object type, status, location, etc. Through the communication API, the sensing data contained in RSM or SSM are sent out over LTE or 5G communication module. If the application perception and decision engine request sensing data from other nodes of the traffic, the data flow will be imported to the engine over the communication module and application API at the receiver. It is well noted that the exchanging data could be either decision-level or raw data-level depending on the sensor fusion algorithms and system tolerated latency at the engine.

3. C-V2X field test

In China, the C-V2X large-scale interoperability test is recognized as the most influential demo show and test activity in the C-V2X field, which is held by IMT-2020 (5G) promotion group and aims at testing and verifying the various applications of cooperative vehicle infrastructure system through the real application scenarios. At this point, the C-V2X working group under IMT-2020 (5G) promotion group plays a vital role in organizing the activities, including the C-V2X research, on core technology verification and the promotion of the C-V2X industry based upon China’s intellectual property principle. With the advancement of C-V2X technology and standard, the C-V2X large-scale interoperability test has also extended its application scenarios, from driving safety to driving efficiency in the annual test event. The test results not only contribute to the improvement of products but also become samples to provide a new basis for the construction of the national demonstration area of the V2X. In Nov. 2018, the activity of three layers interoperability V2X application demonstration was held in Shanghai for its world first time, showcasing the interoperability for the interconnection cross chip modules, terminals, and vehicles. 3GPP Rel-14 LTE-V2X specifications were adopted with regulated 20MHz from 5905Mhz to 5925Mhz as a physical layer sidelink principle. Meanwhile, the Chinese-specific message layer protocol of cooperative intelligent transportation system – vehicle communication application layer specification and data exchange standard (Phase I) was taken as a message dictionary in the activity. On top of “Three Layer” event, the C-V2X working group held a “Four Layer” demonstration activity by emphasizing communication security scenarios in Oct. 2019. With such joint verification, it paves a way for China C-V2X in its commercialization process. To be further closer to the actual traffic scenarios, the third term event called “New Four Layer” was promoted in Oct. 2020 by considering a high-precision map.

In Nov. 2021, Sony participated in the C-V2X large-scale interoperability test as one of the fourth-term event organized by the China Academy of Information and Communications Technology (CAICT). The test field is located in Wuhan economic development district, a blocked T-junction road area with 200 OBUs
arranged alongside to simulate realistic C-V2X packet transmission in a crowded traffic area seen in Figure 5. A series of required tests were conducted for different application scenarios, the test result shows that the packet reception rate remains highly stable (e.g., 95% or above) within the transmission range of 50 meters, and gradually declines to 80% or worse with transmission range growing to 400 meters. As observed in the bird’s eye view figure that the road is curved at a certain level, and trees and bushes in the middle of the road happen to be a natural fence for long transmission between sender and receiver along the path of B to D, and the rough relief terrain between B and C also leads to typical NLOS transmission along the path of B to C. The worst test result shows that the data packet reception rate of 70% or even 60% may be achieved based on the current Rel-14 C-V2X chipset OBU with a transmission range from 300 meters to 400 meters (Figure 6).

To address the signal attenuation issue caused by obstacles, a Veins simulation platform is built up, which is based on simulation of urban mobility (SUMO) for mobility and objective modular network testbed in C++ (OMNeT++) for communication. The reason behind choosing Veins is that, besides the signal path loss model provided, the obstacle shadowing model [3] and vehicle obstacle shadowing model [4] added in the latest version of Veins make it easy to focus on how to define better-optimized relay selection algorithm in the upper layers to enhance V2X communication coverage. A very typical urban intersection area near Berlin is selected with around 30 vehicles near or approaching the intersection center, the vertical road has six lanes, and the horizontal road has only two lanes, thus different densities of vehicles are applied to different roads. In the no relay simulation, vehicles alongside the horizontal road achieved the data packet reception rate at 29.5%, while vehicles on the
vertical road at 75.1%, and vehicles within 50 meters range to the intersection center could achieve 95% above data packet reception if dividing simulation periods and focus on packet reception rate variance corresponding to location variance. This is a natural consequence since the LOS transmission path dominates the scenario when either sender or receiver is at the intersection, while NLOS is typical when both two sides are far from the center and not in the same section of road. The square area with 100 meters side length is specifically selected as the relay selection area, all vehicles within this area could switch their relay function on, and the maximum relay nodes number is applied to minimize redundancy of relayed transmission. Multiple methods could be used for relay node candidate confirmation, in our simulation, we use an announcement message to identify the existence of relay nodes to eliminate potential relay redundancy, the candidate node must listen for a period before switching on the relay function. With the relay switched on in simulation, the performance increased to 91.3% for horizontal direction vehicles and 98.9% for vertical direction vehicles, at the cost of 1.99 times more transmission budget for relaying data packets (Figure 7) [5].

It is a popular design in the C-V2X demonstration area that RSU will be deployed at such areas for information collection, information refinement, and relay function, however requiring substantial infrastructure costs, the vehicle-based relay may provide another route. Though such relay candidate selection, the area seems easy to find, and the various real road conditions introduce a wide variety of scenario-specific difficulties in accurately identifying the area in details. However, with the development of network data analytics function (NWDAF) and other artificial intelligence (AI) topics, such as federated learning introduced into 3GPP, the exposure of V2X communication characteristics from UE to gNodeB and core network may provide a platform for data analysis, relay on-request area, and relay candidate selection area determination. Similar to how the base station manages the area of the cell, the high-definition map can also be divided into different V2X communication blocks with the intersection area, the bend area, and semi-open location close to obstacles as relay node selection areas. The mechanism to define transmission block and intersection should be based on the quality of service (QoS) of packet transmission, the QoS

Figure 6.
Sony’s participation in the C-V2X large-scale interoperability test.
of packet transmission within one V2X communication block shall remain aligned and stable, while Tx UE and Rx UE belong to different communication blocks that differ largely with location difference. The relay node selection area shall be bridging multiple communication blocks, while the UEs inside the relay node selection area can establish stable short-range transmission link with UE in those surrounding multiple communication blocks. The base station may take the role of data collector to identify short-range data transmission quality characteristics with the locations of both sender and receiver, reporting the statistics to the core network, enabling NWDAF to analyze the V2X transmission quality in relation to different areas with the help of location management function (LMF), to decide V2X communication blocks and relay node selection areas. Vehicle type UE entering a relay node selection area can be validated by the base station or core network functions as relay nodes dynamically to minimize the non-line-of-sight (NLOS) transmission from obstacle (e.g., buildings and vehicles) shadow effects.

The solution introduced above is just one example of how the C-V2X large-scale interoperability test exposes technique issues and triggers corresponding solutions. Sony China will continue its participation in the coming years and make attempts to implement such solution in the module for validation under a more realistic C-V2X application environment.

4. Industrialization of C-V2X in China

C-V2X technology has been developing for several years. Manufacturers continue to invest in integrated circuit (IC) design, on-vehicle devices, and roadside devices. Countries around the globe conducted test fields to verify the technology and performance of C-V2X. In the United States, the University of Michigan cooperated with Verizon to build a test bed that deploys video cameras with a 5G communication module to develop 5G solutions for autonomous and connected vehicles [6]. In Europe, a trinational test bed of C-V2X was built in 2019 in the border region of Germany, France, and Luxembourg [7]. In 2020, Softbank and Subaru testified use...
cases related to the safety of autonomous driving with C-V2X [8]. Comparing with the United States, Europe, and Japan, China invests and sets up more test fields with more cross-industry companies participating in deploying C-V2X in the country.

4.1 C-V2X deployment supported by the Chinese administration

In April 2021, the Chinese government announced the first six cities as pilot city for intelligent and connected vehicles (ICV). The six cities are Beijing, Shanghai, Guangzhou, Wuhan, Changsha, and Wuxi. The main targets for the pilot city include building intelligent infrastructure, enhancing network connectivity, and explore the function of “vehicle-road-cloud” platform, which is a unique system architecture for ICV in China.

In December 2021, another 10 cities were announced by the Chinese Government as the second pilot cities for ICV, including Chongqing, Shenzhen, Xiamen, Nanjing, Jinan, Hefei, Chengdu, Cangzhou, Wuhu, and Zibo. Specific goals were set for these cities. For example, the target of Chongqing is implementing ICV technologies into public transportation to improve the avenue of the tourism industry; the target of Nanjing is to explore the functions of ICV for the customer; and the target of Jinan is to combine the ICV technologies with the agricultural logistics industry.

From 2015, China started to build pilot zone in different cities as test zones for ICV, as shown in Figure 8. The purpose of the pilot zone includes testing key technology for ICV, demo platform for R&D testing, experimental verification, and providing standards and legislation for the ICV industry. Among all the pilot zones in China, the Shanghai pilot zone and the National pilot zone (Jingji) are the two very large ones.

The Shanghai pilot zone started in 2015, and it is the first and the most advanced national-level ICV test zone in China. It contains a closed test zone, open testing roads, and an urban roads demo zone. The closed test zone has 15 km test roads, which can provide a test for 200 vehicles. 42 RSUs are deployed in the closed test zone, which can provide DSRC, long-term evolution-based vehicular (LTE-V), and WiFi connection. The open testing roads is 73 km in length along with 182 RSUs, which can provide a test for 1000 vehicles. The urban roads demo zone is an area of

Figure 8. The pilot cities and pilot zone in China.
100 km² that can provide a test for 5000 vehicles at the same time. It can provide more than 200 test scenarios, including an autonomous driving test (lane changing, pedestrian detection), efficiency test (auto valet parking (AVP), platooning, and traffic control), and C-V2X test.

Another National pilot zone (Jingji) supported by Ministry of Industry and Information Technology (MIIT), Ministry of Transportation (MIT), and the local government was established in 2016 in Beijing. It can provide a test for 10000 vehicles with 1000 km test roads with different types of roads (highway, urban road, and country road). It has the first test road specifically for vehicles with the V2X function. It also has a test area with different road scenarios, such as railroad, N road, S curve, and five forks. The Beijing pilot zone publishes an annual report from 2018. In 2021, there were 124 total qualified autonomous vehicles for open road testing in the pilot zone with an accumulated 251 million kilometers of test mileage. From 2018 to 2020, one of the research targets of the pilot zone is a perception of autonomous driving with C-V2X. In its annual reports, the costs of sensors used for perception decreased due to the C-V2X technology and autonomous driving technology upgrade. In 2018, most of the autonomous driving testing vehicles were deployed with 128-beam or 64-beam Velodyne light detection and ranging (LiDAR). The price of 64-beam Velodyna LiDAR was more than 500K RMB. In 2021, most autonomous vehicles were deployed with 40-beam LiDAR. The total cost for one autonomous driving vehicle costs only 480K RMB.

4.2 C-V2X development of industry in China

As the Chinese government accelerates the massive deployment of C-V2X, enterprises in China are leading the market not only by advancing research but also by making it true in the market.

Early in 2017, Huawei, China Mobile, and Shanghai Automotive Industry Corporation (SAIC) demonstrated the world’s first 5G-based remote driving with a consumer vehicle, as shown in Figure 9 [9]. In the demo, Huawei provided the 5G wireless solution, SAIC provided the smart concept car, while China mobile provided
the 5G connectivity. The driver was located 30 kilometers away from the car. 4 HD video cameras were installed on the car, which can provide a 240-degree view of the vehicle’s surroundings. The control signals were also transmitted over a 5G network. Huawei said the video streaming was flawless and the end-to-end latency of the control signal was less than 10ms. Two years after, in 2017, Huawei brought a 5G vehicle module MH5000, which was the industry’s first 5G vehicle module. It integrates 5G and C-V2X technology. The module has been tested in the 2019 Shanghai C-V2X application demonstration. [10].

Pony.ai, a leading autonomous driving technology company in China, has been focusing on the robotaxi service since 2016. It received approval to run autonomous robotaxi services in the Beijing pilot zone in November 2021 [11]. In the same year, it received a permit to conduct public road tests in Shenzhen [12]. Besides the robotaxi service, Pony.ai launched its autonomous trucking tests on the open highway in Beijing. Its autonomous trucking business had already accumulated 50,000 km of commercial operation and delivered over 16,400 tons of goods by the end of 2021.

Apollo is a project of autonomous driving developed by Baidu in 2017. Its consortium is more than 100 companies, which aims to be the world leader in the driverless vehicle industry to the intelligent traffic system. Baidu Apollo launched the world’s first V2X platform that enables L4 autonomous driving on open public roads using roadside sensing in May 2021 [13]. The aim of this platform is to achieve autonomous driving through vehicle-road-cloud coordination. Baidu has achieved a cumulative mileage of 2019230 km over a three-year period in Beijing pilot zone, accounting for 91.23% of Beijing’s total testing mileage in 2018, 2019, and 2020. It operated a fleet of 55 autonomous vehicles on the roads of Beijing, accounting for 75% of the overall number of vehicles that conducted autonomous driving tests in the capital of

Figure 10.
Traffic light detection by V2X [13].
China. Its robotaxi service began in Beijing in 2020. From October 10 to December 31, 2020, a total of 15006 users used the taxi service through their mobile devices. Chongqing, China, and Baidu provide an intelligent traffic system, which decreases wait time at the intersection by 6.31% and mean time of parking by 2.6 minutes. In order to improve the management of the intelligent traffic system, Baidu also provides an HD-map service that can capture road information, such as lanes, traffic signs, roadside devices, and facilities, with sub-meter level positioning error. The vision of Baidu’s V2X business is to enable level-4 autonomous driving on public roads using cooperative sensing by both roadside and on-vehicle sensors. Baidu has tested its cooperative sensing technology with C-V2X communication at multiple intersections in Beijing, Guangzhou, and Cangzhou. One of the test scenario is that, when vehicles turn or change lanes at intersections, roadside sensors can detect road conditions and transmit data to cars in real time. Another scenario that reliable safety can be provided via Baidu’s technology is the limitation of on-vehicle perception in severe weather conditions. For example, if the traffic light has a bright backlight, vehicles with only self-sensing system may not correctly identify the traffic signal. However, with V2X, the vehicle can get the traffic light status in real time, allowing it to pass through safely, as shown in Figure 10.

Another world’s leading tech giant, Didi Chuxing, launched its robotaxi service in Shanghai within a designated public area in 2020. Key C-V2X devices were deployed on the road to minimize the blind spots and enhance the coordination among the autonomous taxi fleet in order to guarantee the safety of the passenger.

5. Conclusion and perspectives

This chapter gives a general view of China-specific C-V2X developing roadmap in terms of standardization, field test, and industrialization. The paradigm of China’s ICV is through architecting localized solutions of cyber-physical systems by combining the characteristics of automation and connection, which underlines the concept of “human-vehicle-road-cloud.” The hierarchical framework fully utilizes the properties of complex and driving behavior-led traffic in China, and paves the way for ensuring ICV security and industry security under all-dimensional support of the government. As such, there is a reasonable prospect that advanced autonomous driving technology aided by C-V2X is on the way to ease people’s lives in a superfast manner.

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