Research Article

Network Performance Test and Analysis of LTE-V2X in Industrial Park Scenario

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As one of the mainstream technologies of vehicle-to-everything (V2X) communication, Cellular-V2X (C-V2X) provides high reliability and low latency V2X communications. And with the development of mobile cellular systems, C-V2X is evolving from long-term evolution-V2X (LTE-V2X) to new radio-V2X (NR-V2X). However, C-V2X test specification has not been completely set in the industry. In order to promote the formulation of relevant standards and accelerate the implementation of industrialization, the field test and analysis based on LTE-V2X in the industrial park scenario is conducted in this paper. Firstly, key technologies of LTE-V2X are introduced. Then, the specific methods and contents of this test are proposed, which consists of functional and network performance tests to comprehensively evaluate the communication property of LTE-V2X. Static and dynamic tests are required in both line-of-sight (LOS) and non-line-of-sight (NLOS) scenarios to evaluate network performance. Next, the test results verify that all functions are normal, and the performance evaluation indexes are appraised and analyzed. Finally, it summarizes the whole paper and puts forward the future work.

1. Introduction

Internet of Vehicles (IoV) refers to the realization of a comprehensive network connection of vehicle-to-everything (V2X) with the help of a new generation of information and communication technology. It can improve the intelligent level and autonomous driving ability of vehicles, thus improving traffic efficiency, building new formats of transportation services, and providing intelligent, comfortable, and efficient comprehensive services for users [1]. V2X communication technology is used to realize information sharing between vehicles and the outside world and promote the evolution of IoV to the direction of intelligence and cloud [2]. In the future autonomous driving, V2X communication technology is one of the important technologies to realize environmental perception. It can complement the advantages of traditional vehicle-mounted laser radar, camera, and other vehicle-mounted equipment, so as to provide vehicles with beyond-line-of-sight and complex environment

awareness that cannot be realized by radar. In this way, the vehicle's perception range of traffic and surroundings can be expanded from the dimension of time and space, so that the vehicle has the ability to make multi-information fusion decisions [3].

At present, the main technologies for the V2X communication in the world include dedicated short-range communication (DSRC) technology based on the IEEE 802.11P standard and V2X technology based upon the cellular mobile communication system (C-V2X) [4, 5]. The United States completed the formulation of the DSRC standard in 1999, and a lot of testing work also verified the effectiveness of DSRC, but it has obvious disadvantages like poor reliability, hidden nodes, high delay, and intermittent V2I connectivity [6]. From an industry perspective, widespread deployment of DSRC requires significant investment in the network infrastructure. In order to solve the deficiency of DSRC in testing and industrial application, 3GPP designed C-V2X and completed the formulation of the first stage LTE-based
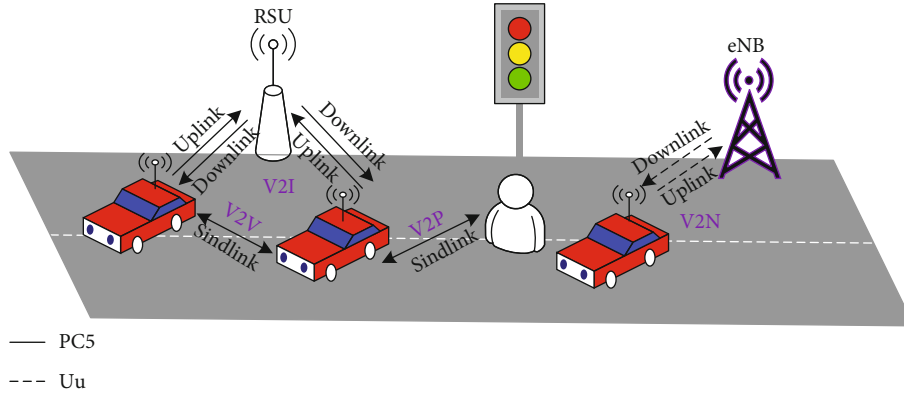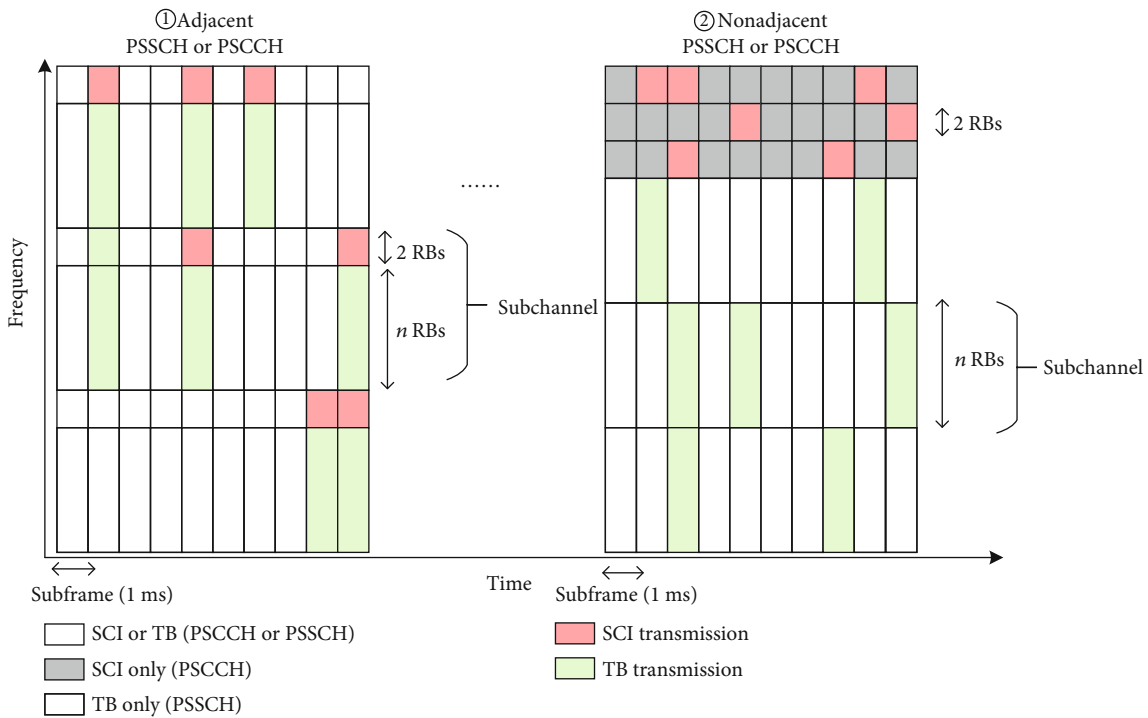
Figure 1: LTE-V2X transmission scenario.

Figure 2: LTE-V2X resource configuration diagram.

standard (3GPP Release 14) in 2016. C-V2X technology on account of the cellular network can reuse cellular network infrastructure, with lower deployment cost and wider network coverage. It can realize the scenario where vehicles can travel relatively fast. In dense circumstance, C-V2X supports longer communication distances, greater capacity, better non-line-of-sight communication performance, and congestion control. In addition, C-V2X can improve communication efficiency after node synchronization through GPS, which is also not available in DSRC system, but C-V2X still has problems in roadside unit (RSU) information interaction, security certificate management, and long-term dynamic maintenance in commercial applications. From the perspective of vertical industry, to eliminate the concerns of related industries that C-V2X has not yet been tested on a large scale, while improving the standard as soon as possible and clearing the commercial technical barriers, it is also time to prepare for testing work that complies with the C-V2X standard to verify the performance of the C-V2X communication system [7–9].

So far, manufacturers and institutions in some countries and regions have actively carried out technical research and test verification for the C-V2X communication. European countries have launched Drive C2X, C-ITS corridorl, simTD, and other projects to test and verify applications like road safety, traffic management, and environmental protection [10, 11]. In February 2012, Japan released the ARIB STD-T109 specification for 10 MHz in the 700 MHz band for V2V collision safety applications. And Japan began large-scale field testing in Hiroshima and Tokyo, respectively [1].
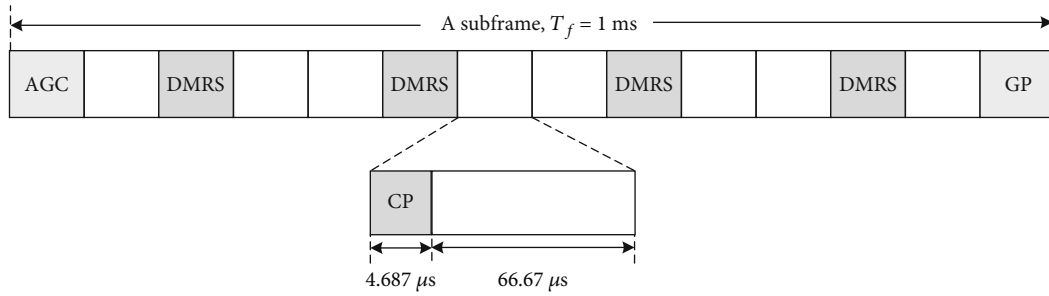
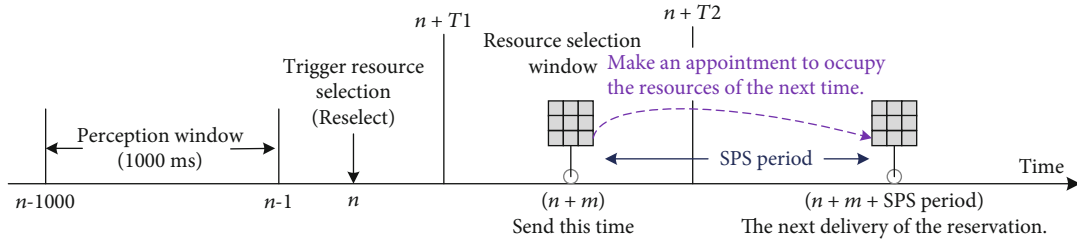FIGURE 3: Direct link subframe structure based on the PC5 interface.

FIGURE 4: Distributed scheduling based on the PC5 interface.

Although the research of the V2X communication in the United States mainly focuses on DSRC, its domestic SAE (Society of Automotive Engineers) also established the C-V2X working group in June 2017 to implement the research on enhanced applications and direct communication [12]. In 2010, China Datang telecom technology industry group took the lead in the research of the IoV technology for intelligent transportation applications and proposed the LTE-V standard in 2013, which has now become the standard of 3GPP's LTE-V2X [3, 11]. Since 2015, China's C-V2X industry has developed rapidly, the standard system has been initially established, and the industry chain has taken shape. At the same time, enterprises related to the IoV already have a high technical strength as well as conditions for large-scale deployment and industrialization. Therefore, the CATRC (China Automotive Technology Research Center), together with CAICT (China Academy of Information and Communications Technology) [7] and other research institutes and equipment manufacturers, has actively performed laboratory and field test work in Wuxi, Shanghai, and other places. Test locations cover parks, open roads, highways, etc.

C-V2X technology is a communication technology on account of 3GPP global unified standards, including LTE-V2X for assisted driving and 5G NR-V2X for autonomous driving [12, 13]. In order to accelerate the large-scale implementation of the IoV industry, technologies and standards have been continuously improved from multiple levels. As the current C-V2X communication network technology, LTE-V2X can meet diversified IoV application scenarios and demands. In addition, it is assisted by TD-LTE [1, 3], which can make the best use of resources such as LTE deployed network and terminal chip platform, so as to save network investment and reduce chip cost. Therefore, in order to promote the industrialization of LTE-V2X and accelerate

its application as a comprehensive communication solution for vehicle-road collaboration, it is necessary to implement large-scale field tests of LTE-V2X before the formal commercial use.

Although testing based on LTE-V2X has been conducted in many parts of the world, the testing methods are not unified, and most research institutes are reluctant to publish the final test data and results. On the other hand, as the key to technology maturity and commercial use, the discussion and research of evaluation methods play a vital role in promoting technology maturity and commercial use [14, 15]. Its own scientificity and implementability are also the key factors that determine whether a certain technology or a certain product can be certified in the end. Based upon the realistic field measurement data, this paper is aimed at functional verification and network performance evaluation for typical business scenarios in LTE-V2X networking in Chongqing, China. The contribution of this paper can be summarized as follows:

(1) Aiming at the application scenario of direct vehicle communication unique to LTE-V2X, this paper introduces the key technologies applied in LTE-V2X in detail from the three aspects of physical layer, resource scheduling, and synchronization mechanism

(2) Considering the inconsistency of current IoV testing methods, this paper provides the testing scheme of IoV in the outfield. The test content consists of function and performance tests to comprehensively evaluate the communication property of LTE-V2X, where the performance test includes the static and dynamic tests. This paper also shows in detail the process of testing and the deployment of field equipment in typical scenarios

TABLE 1: Specific content of functional test.

Category	Mode	Test contents
Traffic safety	V2V	Forward collision warning
	V2V	Emergency brake collision warning
	V2V	Intersection collision warning
	V2V	Abnormal vehicle reminder
	V2V	Emergency vehicle reminder
Traffic efficiency	V2I	Speed guidance at intersections
Information service	V2I	Vehicle-mounted video player service

(3) In the design of the intelligent transportation system, it is required that LTE-V2X can be applied to improve road safety and traffic efficiency. Therefore, this paper shows the actual application results of devices supporting LTE-V2X, so as to verify the performance of LTE-V2X in the application layer. What is more, this paper verifies and appraise the network performance of LTE-V2X from two evaluation indexes of delay and packet loss rate (PLR) and exposes parts of the test data

The rest of this paper is organized as follows. Section 2 introduces the key technologies of LTE-V2X. Section 3 describes the methods, environment, and equipment for this test. Evaluation results and analysis are presented in Section 4. Section 5 draws a conclusion and offers ideas for future work.

2. The Key Technology

2.1. Physical Layer. LTE-V2X is an advanced information and communication technology applied in road transportation systems, with the objective of enabling information exchange between vehicle, human, infrastructure, and network. Hence, as shown in Figure 1, LTE-V2X consists of V2V (vehicle-to-vehicle), V2I (vehicle-to-infrastructure), V2P (vehicle-to-person), and V2N (vehicle-to-network) communication [15]. The vehicle establishes communication with the vehicle, RSU, or the base station in LTE (evolved Node B, eNB) through the on-board unit (OBU). In accordance with the difference of transmission modes, LTE-V2X can be divided into two communication methods: LTE-V2X-Direct and LTE-V2X-Cellular. Through the PC5 interface, V2X-Direct can not only use the dedicated frequency band of IoV (such as 5.9 GHz) to realize V2V, V2I, and V2P but also share cellular spectrum resources with cellular users. In this mode, the delay is low, and the moving speed of the vehicle is high, but good resource allocation and congestion control algorithm are needed. V2X-Cellular transmits information through the Uu interface of the cellular network and adopts the frequency band of the cellular network (such as 1.8 GHz) to make the V2X communication range wider and more stable.

The physical channel of LTE-V2X can be separated into subframes, resource blocks (RBs), and subchannels [16]. In LTE-V2X, the subframe is the most basic time series of the system. A resource block refers to a "physical resource unit" that occupies a bandwidth of 180 kHz (twelve 15 kHz subcarriers) in the frequency domain and has a duration of 1 ms in the time domain. All control signaling and data information of LTE are based on RBs. LTE-V2X supports variable bandwidth of 10-20 MHz by flexibly allocating RBs at the physical layer. Subchannel refers to a combination of RBs with the same subframe, and each subchannel may have a various number of RBs. The subchannel is used to transmit data information and control information. Data information is transmitted in the transport block (TB) of the physical sidelink shared channel (PSSCH), and sidelink control information (SCI) is transmitted in the physical sidelink control channel (PSCCH). A TB contains complete data packets to be transmitted, like beacon beacons and information transfer protocols. A node that wants to transmit TB must also transmit its associated SCI, which includes information such as the modulation and encoding scheme used to transmit TB and the RBs occupied. Since TB and its associated SCI must be transmitted in the same subframe, LTE-V2X can use either frequency division multiplexing or time division multiplexing for resources reuse. Consequently, the LTE-V2X supports HARQ (hybrid automatic repeat request transmission) which allows the same transmission to be repeated at time offset either on same frequency resources or different resources to convey the same data as needed.

Clearly by inspection of Figure 2, two resource pool configuration methods are defined in LTE-V2X. The first is the adjacent PSSCH and PSCCH, and the second is the nonadjacent PSSCH and PSCCH. The SCI of the two resource pool configurations both occupy 2 RBs to improve reliability, while the TB can occupy multiple RBs. In the first configuration mode, the SCI first occupies the first 2 RBs, and the TB occupies multiple RBs afterwards, so that one subchannel can be formed. Of course, TB can also occupy multiple subsequent subchannels (depending on its size). In the second configuration mode, the resource block is separated into multiple pools, one of which is dedicated to SCI transmission. The remaining pool is used to transmit TB and is divided into service subchannels [15, 16].

LTE-V2X uses single-carrier frequency division multiple access (SC-FDMA) technology to reduce the impact of the excessive peak-to-average power ratio (PAPR), so that it can have a larger transmission under the same power amplifier power. In order to improve the spectrum utilization ratio under the condition of high mobility, LTE-V2X transmits an
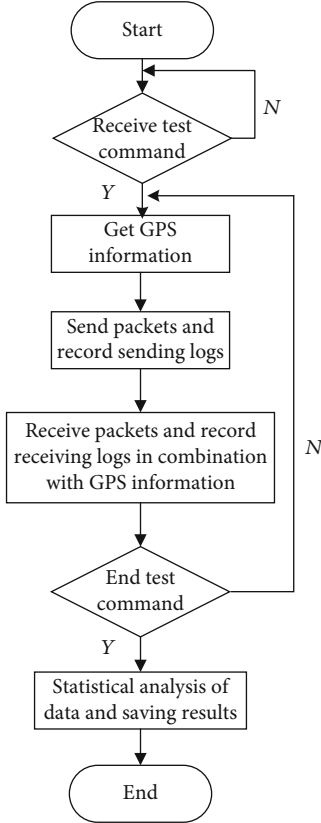
FIGURE 5: LTE-V2X performance test process.

OFDM waveform with a conventional cyclic prefix (CP) and sets the subcarrier spacing to 15 kHz. The structure of the direct link subframe based upon the PC5 interface is shown in Figure 3. The length of each subframe T_f is 1 ms, and the length of each symbol in the subframe is $71.357 \mu s$, so each subframe of direct link can contain 14 OFDM symbols. In a subframe, the first and last symbols are used for automatic gain control (AGC) and guard period (GP), respectively. What is more, in order to reduce the impact of the Doppler effect, the design of the demodulation reference signal (DMRS) column structure in LTE-D2D (device-to-device) is used in LTE-V2X. The DMRS in each subframe is increased from 2 columns to 4 columns, which increases the pilot density in the time domain, so that the channel detection, estimation, and compensation of high frequency in typical high-speed scenes can be effectively processed. The remaining 8 symbols are used to transmit data information. Moreover, LTE-V2X uses turbo codes, which can achieve higher reliability at the same transmission distance. LTE-V2X with turbo codes is designed to facilitate decoding capability even at lower signal-to-noise ratio (SNR), whereas for DSRC with convolutional codes requires higher SNR for successful decode [17, 18].

2.2. Scheduling of Resources. LTE-V2X supports both centralized scheduling (mode 3) and distributed scheduling (mode 4). Mode 3 implements centralized scheduling based on the Uu interface. The selection and coding method of the subchannel of the communication link are directly controlled by the eNB in the cellular network. The eNB provides dynamic scheduling or activated semipersistent scheduling (SPS) according to the service type of the terminal. In order to reduce the delay caused by signaling interaction, mode 4 provides distributed resource scheduling for vehicles. This scheduling scheme uses a "sensing + reservation SPS" approach, as shown in Figure 4. User equipment (UE) selects subchannel access by itself and then perceives resource occupancy by measuring received signal strength indication (RSSI) energy in the resource pool. Resource selection measures the RSSI energy on resources available and sorts them in descending order per energy levels. It then chooses the lowest 20% energy resources and randomly picks resources from these for transmission [18]. After selecting appropriate resources, the UE will periodically send these resources a certain number of times or until resource reselection is triggered. This method can be conducted without the support of any cellular base station, taking advantage of the periodic characteristics of V2X services. This distributed scheduling scheme based on the PC5 interface can not only carry the periodic V2X services waiting to be sent but also make full use of the sensing results to avoid resource conflicts, which helps to improve resource utilization and transmission reliability.

2.3. Synchronization Mechanism. In LTE-V2X, there are three synchronous sources: eNB, Global Navigation Satellite System (GNSS), and UE. When the eNB is used as the synchronization source, the nodes in the cellular coverage are synchronized with the eNB. Some uncovered nodes can receive the synchronization signal forwarded by the nodes in cellular coverage, so the partially covered nodes forward the synchronization information of the nodes in cellular coverage to the nodes outside cellular coverage. In the LTE-V2X system, communication nodes support GNSS module, which has high timing and frequency accuracy. Therefore, nodes that can directly obtain reliable GNSS signals are able to directly serve as synchronization sources to provide synchronization information to surrounding nodes. When LTE-V2X shares carriers with cellular systems like LTE, the transmission signals of LTE-V2X through communication may interfere with the uplink of cellular networks. In this case, eNB is still considered as the main synchronization source, and then eNB can broadcast the time deviation between eNB and GNSS to UE for adjustment compensation. In general, the synchronization source and mode are configured by the eNB in cellular coverage, and the synchronization source is determined by the preconfiguration mode outside cellular coverage, so as to achieve unified synchronization timing of the whole network [3, 12].

In accordance with the traditional LTE-D2D mechanism, the enhanced synchronization source priority can be supported by establishing a new connection to the sidelink synchronization signal (SLSS) and the physical sidelink broadcast channel (PSBCH) [19]. Considering the protection of the LTE-Uu uplink transmission and ensuring the accuracy of the timing and frequency of the synchronization source, the rules of the synchronization source priority should be implemented according to the eNB or GNSS
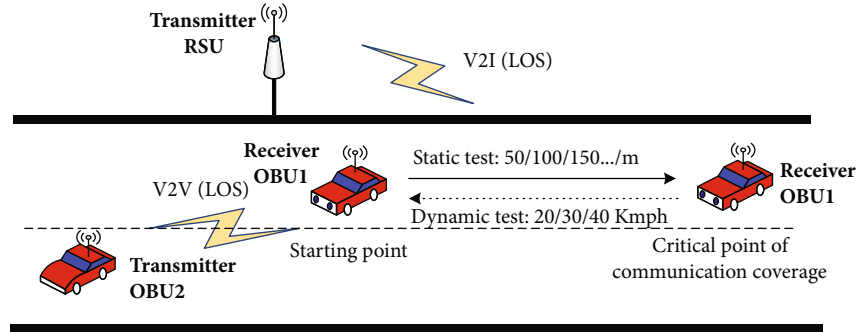
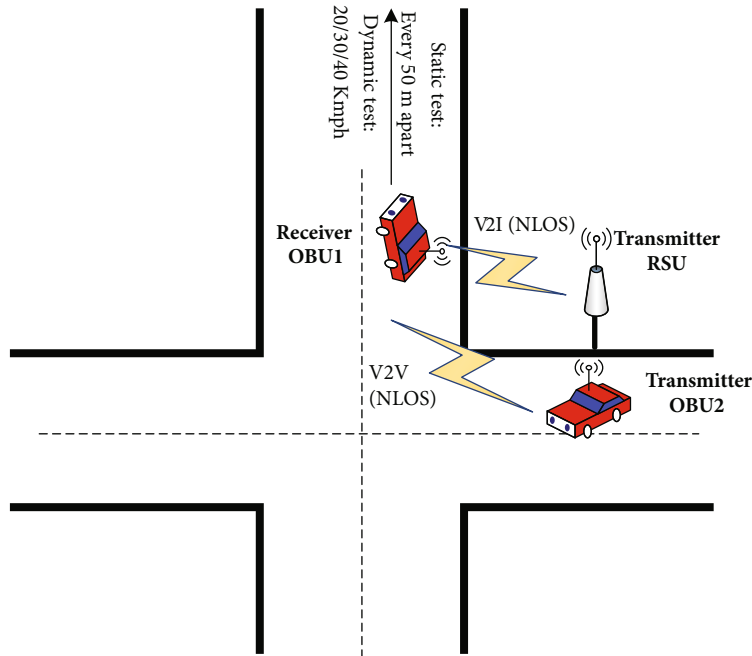FIGURE 6: V2V/V2I performance test of the LOS scenario.

FIGURE 7: V2V/V2I performance test of the NLOS scenario.

synchronization configuration. In other words, eNB can configure to prioritize either GNSS or UE. Moreover, GNSS has higher priority when UE does not detect any cell in any carrier, and UE does not detect any SLSS transmissions that are directly synchronized to eNB.

3. Test Scheme

3.1. Method and Content. In recent years, with the gradual improvement of the LTE-V2X standard, it is particularly important to accelerate the implementation of standard. Therefore, there is an urgent need to test and verify LTE-V2X-related products, which is a necessary stage for the popularization and improvement of each standard and technology [20, 21]. Considerable laboratory evaluations and field tests have been conducted in many places [22]. The test object of laboratory evaluation is module, which mainly investigates communication protocol consistency and interoperability. Conformance testing includes radio frequency consistency (signal transmission, reception, and demodulation performance), radio resource management consistency,

and communication protocol consistency. The radio frequency conformance test mainly examines whether the reception, transmission, and demodulation performance of the LTE-V2X radio frequency meet the national radio management and LTE-V2X communication requirements. The conformance test of the communication protocol includes the conformance test for the underlying layer protocol and the upper layer protocol, which ensures that both parties of the communication have a unified and unambiguous understanding of the protocol and the corresponding implementation. The object of the outfield test is vehicle, mainly from the following aspects. On the one hand, it is necessary to verify whether the designed function meets expectations. The function of the application layer of the LTE-V2X system was tested in the open road of Chongqing Automotive Research Institute in this paper. Specific test contents are exhibited in Table 1, which can be divided into traffic safety, traffic efficiency, and information service.

On the other hand, the performance of the communication system under diverse environments, road conditions, and vehicle speeds needs to be examined. The verified

(a) BBU

(b) Base station

(c) MEC equipment

Figure 8: Part of the equipment used in the test.

performance indicators include packet reception success probability, communication delay, and coverage. Network measurement methods include active measurement and passive measurement. Active measurement is to send probe data packets to the network and measure the network performance by analyzing the changes that are affected by the data packets. Passive measurement is to capture and analyze data packets by arranging measurement devices in the network to measure network performance. Passive measurement does not send measurement packets and will not affect the normal flow of the network, but its implementation is more complicated and requires higher performance of the measurement device. Therefore, passive measurement is more suitable for network traffic measurement, and active measurement is suitable for network performance measurement [22]. The method of the performance testing is to send probe packets to the network in this paper, and the network performance is measured by analyzing the changes that occur when the packets are affected during transmission, as shown in

Figure 5. Firstly, the GPS information of transmitter and receiver should be read. Then, the OBU/RSU at the transmitter actively sends the detection packets and records the sending logs. The time of each data communication is 1 second. The OBU at the receiving end receives the data packets and records the receiving logs in combination with GPS information, and then the statistical analysis model is used to infer the PLR and average delay of the internal link.

Measurement of one-way end-to-end delay requires clock synchronization, which is more difficult to achieve in actual measurement. Therefore, the measurement of network delay usually requires the use of round-trip time (RTT), which is the time interval required for a packet to travel from the source node to the destination node, so as to avoid the problem of clock synchronization. The specific approach is to calculate the RTT by adding a time stamp to each packet. Before sending a message, the OBU at the transmitting end adds a time stamp to each message and records it as TS1. When receiving the message, the OBU at the receiving end

FIGURE 9: The LTE-V2X test environment.

TABLE 2: Base station/OBU/RSU parameter configuration.

Equipment	Base station				
Parameter	Frequency	Bandwidth	Number of antennas	Uplink power control/HARQ	Rated transmit power
Configuration	2555~2565 MHz	10 MHz	2T×2R	Enable	2×10 W
Equipment	OBU/RSU				
Parameter	Frequency	Bandwidth	Transmit power	Message frequency	Packet size
Configuration	5855~5925 MHz	10 MHz	23 dBm	One packet/100 ms	78 bytes

adds the second timestamp and records it as TS2; then, it replies with an ACK message and marks the third timestamp as TS3. The OBU/RSU at the transmitter receives the ACK message with the fourth timestamp, which is recorded as TS4. Therefore, the RTT is calculated as follows:

$$RTT = (TS4 - TS1) - (TS3 - TS2). \quad (1)$$

In order to test the accuracy of the results, it is necessary to calculate a round-trip time (TS4 − TS1) from the sending end to the receiving end to the sending end and subtract the message processing waiting time (TS3 − TS2) at the receiving end. Hence, the end-to-end delay is half of RTT.

PLR is defined as the ratio of lost packets to all packets in the transmission, which is mainly related to network traffic, and packet loss will be caused by network congestion.

$$L(D, y) = (1 - y)^a y^b, \quad (2)$$

where a is the number of data packets received in a test time window, b is the number of unreceived data packets, $D = (a, b)$ is the set of lost data packets at one time, y is the PLR, and $L(D, y)$ is the maximum likelihood function of the packet loss rate y. Next, we take the logarithm of both

sides of equation (2),

$$lnL(D, y) = a(1 - y) + by. \quad (3)$$

Then, we need to take the derivative of both sides of equation (3) with respect to y and set the value of the derivative to be 0.

$$\frac{-a}{1 - y} + \frac{b}{y} = 0. \quad (4)$$

Referring to the above equation, the maximum likelihood estimation $\hat{y}$ of PLR can be obtained as follows:

$$\hat{y} = \frac{b}{a + b}. \quad (5)$$

The performance test of the outfield can be divided into static test and dynamic test, where the static test and dynamic test of the line-of-sight (LOS) scenario are demonstrated in Figure 6. For the static test of LOS, a fixed-point test is implemented. To put it simply, let the two cars conduct a V2V performance test every 50 meters (straight line distance) apart and record the data at this distance. Similarly, a V2I performance test is performed every 50 meters apart. When the test vehicle is unable to establish communication during movement, it is
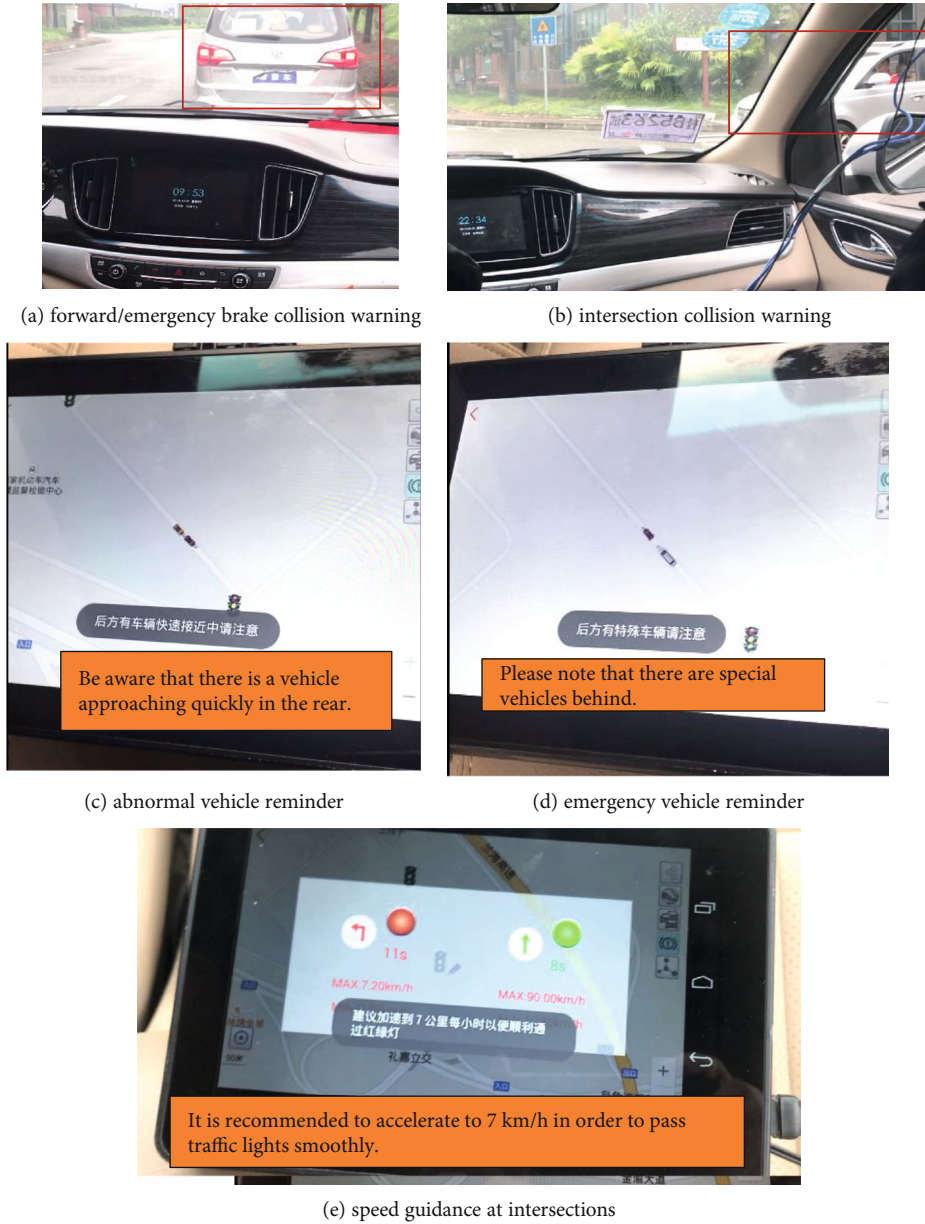
(a) forward/emergency brake collision warning

(b) intersection collision warning

后方有车辆快速接近中请注意

Be aware that there is a vehicle approaching quickly in the rear.

(c) abnormal vehicle reminder

后方有特殊车辆请注意

Please note that there are special vehicles behind.

(d) emergency vehicle reminder

建议加速到7公里每小时以便顺利通过红绿灯

It is recommended to accelerate to 7 km/h in order to pass traffic lights smoothly.

(e) speed guidance at intersections

FIGURE 10: Results of functional tests.

TABLE 3: Static test results of the LOS scenario.

Distance/m	Average delay/ms		Maximum delay/ms		Packet loss rate	
	V2V	V2I	V2V	V2I	V2V	V2I
50	7	7.5	7	7.5	0.66%	0%
100	7.5	7	7.5	9	0%	0%
150	7	7.5	7	7.5	0%	0%
200	7	7.5	8	7.5	0%	0%
250	7	7	7.5	7	0%	0.15%
285	7	7	8	8	1.43%	1.10%

considered to have exceeded the communication coverage of V2V/V2I. For the dynamic test of the LOS, in the initial state, one vehicle (at transmitter) keeps stationary, and the other vehicle (at receiver) moves away from the stationary vehicle at 20/30/40kmph, respectively. When the relative distance between the two vehicles exceeds their communication range, the vehicle at the transmitter moves towards the vehicle at the receiver. The above process needs to be repeated several times, and the complete test logs are recorded in order to test the network performance of LTE-V2X at different speeds.

The test of non-line-of-sight (NLOS) is similar to the it of LOS, except that the two test vehicles are located perpendicular to each other at the intersection. In Figure 7, for the static test of V2V under NLOS, the fixed-point test is also implemented, which means that two vehicles are tested for the network performance of V2V every 50 meters in a straight-line

TABLE 4: Static test results of the NLOS.

Distance/m	Average delay/ms		Maximum delay/ms		PLR	
	V2V	V2I	V2V	V2I	V2V	V2I
50	8	7	8.5	7.5	0.91%	0%
75	8	7.5	8	7.5	6.97%	0%

TABLE 5: Average and maximum delay of V2V/V2I dynamic test.

Speed km/h	Average delay /ms				Maximum delay /ms			
	LOS		NLOS		LOS		NLOS	
	V2V	V2I	V2V	V2I	V2V	V2I	V2V	V2I
20	7.25	7.5	7.5	7.17	8	8.5	9	7.5
30	8.125	8	7.83	7.17	9	9	9	8.5
40	7.5	7.5	8	7.17	8.5	8.5	9	7.5

distance. Dynamic testing, in which one vehicle stays at rest while the other moves away from the stationary vehicle at 20/30/40kmph in the communication range (in this case, the vehicle do not need to return), also requires repeated recording of delays and PLR. The V2I test method is resemblance to that of V2V, which also requires the movement of the vehicle at the receiving end. In addition, it is necessary to evaluate the interoperability between the same equipment of different manufacturers and different equipment of the same manufacturer under various working conditions and environments.

3.2. Environment and Equipment. This test took place in the open road of industrial park in China. The OBU and its display equipment were installed inside the test vehicles, and two antennas were installed on the roof of each vehicle. In order to better perceive the environment, the RSU and the camera were deployed alongside the traffic lights at the intersection. The equipment based on multiaccess edge computing (MEC) was deployed in the indoor baseband processing unit (BBU) room as seen in Figure 8(c). The actual test environment is shown in Figure 9.

The whole test system was divided into three parts: "terminal," "edge equipment," and "V2X service platform." The terminal contained OBU, person, and vehicle. The edge equipment included RSU and MEC-based device. The RSU received messages from the V2X platform or edge device and multicast to the terminal device in the area through the PC5 interface [23–25]. Moreover, RSU could collect the message from OSU to the upper layer through the PC5 or Uu interface. The equipment based upon MEC received message from RSU and distributed the processed message to RSU. It is possible to reduce the end-to-end network delay in the Uu mode by decreasing routing nodes for data transmission through the construction of an LTE network architecture based on MEC. The V2X cloud service platform was used to process information from terminals and MEC-based device, implement comprehensive scheduling and optimization, and improve driving safety and traffic efficiency. So far, the construction of seven LTE base stations based upon

the 2600 MHz frequency band, one set of MEC equipment, and a set of evolved packet core (EPC) network equipment have been completed inside the industrial park [26].

The test equipment can monitor the communication status of V2X in real time and has the recording function of sending logs or receiving logs. During the test, the antenna was installed vertically at the center of the roof of the vehicle. Single antenna transmission and dual antenna reception modes were used throughout the communication. This test network and V2X equipment were provided by Datang [3, 11]. The parameter configuration of base station and OBU/RSU are demonstrated in Table 2.

4. Evaluation Results and Analysis

The security class business, efficient traffic, and video playback business-based MEC in Table 1 were tested. Figure 10 shows the test vehicle and display device during test. It is verified that all business functions are normal. Figure 10(a) indicates that when the host vehicle (HV) and the vehicle in front of the same lane are in danger of rear-end collision or the vehicle in front is in emergency braking, the on-board device will send an early warning message to remind the rear host vehicle to avoid collision. When the HV is driving to the intersection and there is a danger of collision with a faraway vehicle traveling sideways, the driver is alerted by warning to avoid the collision, as shown in Figure 10(b). When the far vehicle rapidly approaches the host vehicle from the rear, the driver of the HV is alerted, as exhibited in Figure 10(c). While the HV is running, the emergency vehicle in the rear issues a reminder to alert the host vehicle in front, as demonstrated in Figure 10(d). As shown in Figure 10(e), the RSU multicasts real-time information to the vehicle and then the OBU reminds the driver to perform operations such as accelerating through or decelerating through the current vehicle speed, position, and remaining time of signal phase.

In the performance test, the static test results of V2V and V2I at LOS are demonstrated in Table 3 and Table 4. Table 3 indicates that different distances and LOS/NLOS have little effect on the change of delay, and the delay is about 7 ~ 8 ms. In the performance test of LOS, phenomenon of packet loss in V2V and V2I is rare when the distance is less than 250 meters, but obvious packet loss occurs when the distance is higher than 250 meters. (the site is limited to 290 meters, so the PLR at a longer distance cannot be tested.)

During the test, it is found that the NLOS has a greater impact on the communication distance, seen as Table 4. When the distance between V2I and V2V is larger than 70 and 75 in meters, respectively, communication cannot be established, but there is no phenomenon of communication failure when reaching the end of the road in the LOS. In other words, the communication distance between V2I and V2V is 70 m and 75 m, respectively, in the NLOS. Besides that, it is not difficult to find that the PLR of V2V in NLOS has increased significantly.

After undergoing multiple dynamic tests, the test results demonstrated in Table 5 can be obtained, which contains the average delay and maximum delay of V2V and V2I in the LOS and NLOS. As can be seen from Table 5, different

(a) Average packet loss rate of the V2V/V2I dynamic test

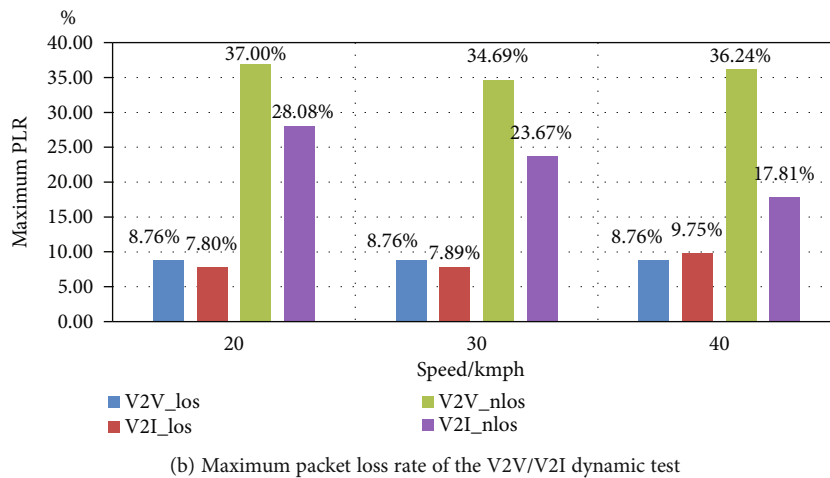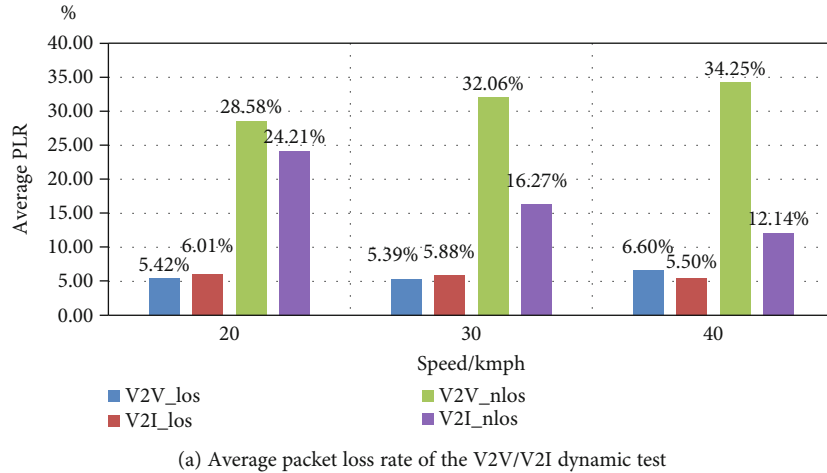(b) Maximum packet loss rate of the V2V/V2I dynamic test

FIGURE 11: Packet loss rate of the V2V/V2I dynamic test.

scenarios and speeds have a relatively small impact on the change of delay. The average delay is maintained at 7 ~ 8 ms, and the maximum delay is 9 ms.

The average and maximum PLR of dynamic tests are exhibited in Figure 11. It can be seen from Figure 11 that the maximum PLR of V2V and V2I in the LOS is not more than 10%, and the average PLR remains around 5%~6%. The maximum PLR of V2I and V2V in the NLOS was 28.08% and 37.00%, respectively. The average PLR of V2I was around 17.5%, and the average PLR of V2V was above 30%.

As can be seen from Table 5 and Figure 11, the performance of V2I in NLOS is significantly better than V2V, the reason of which may be the difference between RSU equipment and OBU equipment, which means the former has higher antenna gain. Furthermore, by comparing dynamic test and static test results, the PLR of the dynamic test has an obvious increase compared with the static test, while the change of delay is not obvious.

5. Conclusions and Future Work

On account of the LTE-V2X networking solution, this paper conducted field testing and verification on the open road of Chongqing Automobile Research Institute in China. Firstly,

the key technologies applied in LTE-V2X are introduced. In the physical layer, four DMRS signals are introduced in each subframe to counter the Doppler effect caused by high-speed movement, and two methods of resource reuse (FDM and TDM) and resource allocation (nonadjacent PSSCH and PSCCH) are adopted. In terms of resource scheduling, LTE-V2X proposes a distributed scheduling method based on the PC5 interface. In terms of the synchronization mechanism, three synchronization sources including base station, GNSS, and UE autonomy are selected. Then, it introduces the framework of IoV testing and provides the specific methods and contents of the test from the functions and network performance that IoV needs to have. Specifically, the function of the system is tested from three aspects of traffic safety, traffic efficiency and information service, and end-to-end delay and packet loss rate that are used as evaluation indexes of the performance test. The results verify the effectiveness and reliability of the application layer communication performance. We hope the overall test scheme and test results can lay a foundation for future research.

Due to space and equipment constraints, we only conducted tests on open road sections and just selected delay and packet loss rate as indicators for evaluating network performance. Therefore, in future work, we hope to carry out

tests on a variety of classic scenarios, such as viaducts, tunnels, multivehicles, and mines, and design appropriate test methods according to specific scenarios. What is more, evaluation indicators can also be expanded from multiple dimensions, such as signal-to-noise rate, signal receiving power, and data transmission rate. Certainly, it is also necessary to implement reasonable equipment deployment on the basis of particular scenarios. How to deploy RSU to make the network performance better requires the combination of testing in typical scenarios, semiphysical simulation in the laboratory, and rigorous theoretical analysis.

Data Availability

The data used to support the findings of this study are currently under embargo, so cannot be made freely available.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

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