Paper:

Research on Wireless Coverage Performance of LTE-V2X in Urban Scenario

Jiahui Qiu[1], Jiaying Feng[2], Xiaobo Lin[1], Chao Cai[1], Xiangyun Zhang[1]

[1]China United Network Communications Group Co., Ltd., Beijing 100033, China
[2]School of Electronic and Information Engineering, Beihang University, Beijing 100191 China
E-mail: qiujh21@chinaunicom.cn, feng_jiaying@buaa.edu.cn, linxb15@chinaunicom.cn, caichao2@chinaunicom.cn, zhangxy368@chinaunicom.cn
[Received 00/00/00; accepted 00/00/00]

Abstract. As a ubiquitous connection scenario, IoV is the infrastructure and technical path to realize intelligent transportation. With the development of communication technology, more and more entities are added to the communication network and become the elements of the network. How to reasonably deploy the devices according to the scenario characteristics has become the key point of the development of V2X technology. In this paper, comparison between Uu communication and PC5 communication in LTE-V2X as well as the classification of LTE-V2X are first introduced. Moreover, typical scenarios of V2X communication are analyzed. Finally, test and evaluation work for V2X network quality are conducted and recommendations are made for RSU deployment. It can be concluded that in the urban scenario, the effective coverage distance is about 400 to 500 meters. Surrounding trees and buildings have obvious shielding effect on LTE-V2X signals, and therefore, RSUs cannot cover the next intersection. In actual deployment, some roads should supplement more RSUs to satisfy the coverage requirements. Recommendations for deployment scheme in urban scenarios are also presented.

Keywords: LTE-V2X, RSU deployment, network quality

1. INTRODUCTION

V2X is an emerging interdisciplinary technology which crosses information and communication, automobiles, transportation and other fields. V2X realizes all-round connection and communication between vehicles and the surrounding cars, people, transportation infrastructure and the cloud service. As an important catalyst for industrial reform and innovation, V2X is driving profound changes in the model of traffic management, the form of the automobile industry, the way people travel and the structure of energy consumption.

With the rapid development of V2X, market scale is increasing constantly as well. It is estimated that in 2025, the V2X market will exceed 2 trillion yuan and the number of global intelligent-networked vehicles will reach about 76.2 million. Besides, the V2X installation rate of new car is expected to increase to 50% and the penetration rate will also exceed 60% by then [1].

China regards C-V2X as an important infrastructure and key technology for intelligent transportation, and vigorously develops the intelligent transportation and intelligent driving industry. In terms of the technological evolution, C-V2X includes LTE-V2X and NR-V2X. 3GPP completed the standardization of LTE-V2X in R14, enhanced LTE-V2X technology in R15, standardized NR-V2X in R16, and started the enhancement research of NR-V2X in R17. LTE-V2X and NR-V2X technology are not compatible. At present, application deployment and industrialization work are completed mainly on LTE-V2X, and research for NR-V2X spectrum requirements has just started. In terms of industrial development, "the combination of strips and blocks" strategy is adopted, which means promoting network deployment and application demonstration simultaneously on expressways and urban roads. In July 2020, the "No. 1 Expressway" project was launched, which aims to build the first demonstration expressway for pilot application of V2X in China. Additionally, Wuxi, Tianjin, Changsha, and Chongqing have been established as national-level pilot zones for car networking.

The development of LTE-V2X has gradually evolved from technical testing and verification to large-scale commercial application. The industrial chain is basically mature and has the basic conditions for large-scale commercial use. However, there still exists some problems in the development of LTE-V2X, including both policy and technical aspects. Policy difficulties include industrial coordination, imperfect safety supervision system and lack of a reasonable business operation model. While technically, problems such as reasonable network deployment and planning, improvement of communication reliability, and research on channel non-stationary changes also need to be solved, which are also the research hotspots in academic circles.

Some studies focused on the resource allocation scheme for LTE-V2X [2][3][4][5] and some are mainly interested in the performance evaluation of LTE-V2X technologies [6][7][8]. In [9], field test and analysis based on LTE-V2X in the industrial park scenario is conducted with the aim of promoting the formulation of relevant standards and accelerate the implementation of industrialization. In [10], traffic modeling for car-following model is proposed to recover the individual difference of driving behavior corresponding to honk effect under LTE-V2X environment. Numerical simulation indicates that the individual difference of driving behavior plays a different role on traffic flow dynamics under honk environment in car-following model. However, there are no studies on the coverage performance evaluation of LTE-V2X except [11], which presented the downlink coverage with simulation but not with practical test data. Therefore, this paper focuses on the test and analysis of LTE-V2X coverage performance in the urban scenario.

The rest of this paper is organized as follows. Section 2 introduces comparison between Uu communication and PC5 communication in LTE-V2X as well as the classification of LTE-V2X. Section 3 describes the analysis of typical V2X wireless scenarios. Test scheme, evaluation results with analysis and deployment scheme are presented in Section 4. Section 5 serves as a conclusion for this paper.

2. CLASSIFICATION OF LTE-V2X

LTE-V2X is currently the mainstream technology of C-V2X, which supports two communication interfaces, V2X-Cellular (Uu interface) and V2X-Direct (PC5 interface)[12]. The differences between the two communication interfaces are described in Table 1.

According to the business model, LTE-V2X can be divided into the following 4 categories[1], as shown in Fig.1.

V2N (Vehicle-to-Network) communication, including dynamic map download, automatic driving related route planning, remote control, etc.

V2V (vehicle-to-vehicle) communication, including anti-collision, congestion avoidance and other security applications. V2V security applications are not limited to network coverage.

V2P (vehicle-to-pedestrian) communication, refers to communication between vehicles and pedestrians and is mainly used for pedestrian safety;

V2I (Vehicle-to-Infrastructure) communication, used to communicate between vehicles and road facilities and transmit or receive local road traffic information.

3. ANALYSIS OF TYPICAL V2X WIRELESS SCENARIOS

According to the survey, V2X communication mainly involves the following 6 scenarios: urban road, highway, tunnel, overpass, roundabout and parking lot (surface & underground). Wireless channel characteristics, RSU deployment locations and service applications are different in different scenarios. For example, in the urban scenario, due to the shielding of buildings, there exists rich

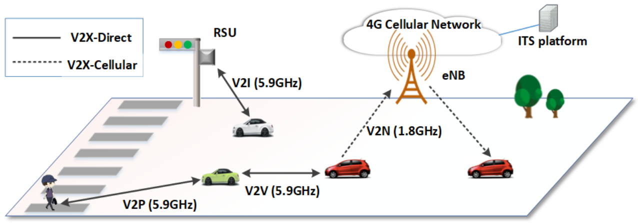


Fig. 1. Classification of LTE-V2X

multipath as well as strong Doppler frequency offset and Doppler spread. In the highway scenario, as there are few obstructions, field of vision is wide and multipath is fewer. The comparison of channel features, RSU deployment locations and service requirements in different scenarios are presented in Table 2. Based on the analysis, it can be seen that RSU deployment schemes vary in different scenarios and need to be comprehensively evaluated. Moreover, research on the coverage performance of RSU in different scenarios is a necessary prerequisite for commercial large-scale deployment.

4. TEST AND EVALUATION OF V2X NETWORK QUALITY

4.1. Test Scheme

4.1.1. Test Parameter Definition

(1)PSSCH-RSRP

PSSCH-RSRP, abbreviated as RSRP, is the linear average power (unit: watt) of all Resource Element (RE) of the demodulation reference signal carried on the shared channel. See 3GPP TS 36.214 for details.

(2)PLR

PLR (package loss rate) refers to the ratio of the number of data packets lost in the test to the data packets sent. LTE-V2X is a broadcast-based communication mode that guarantees service reliability through blind retransmission, which means every data packet is sent twice to reduce the packet loss rate. This paper counts PLR in the application layer, that is, it does not distinguish between initial transmission packets and retransmission packets. There are two statistical methods for PLR: (a) Since the MsgCount number is continuously accumulated, the receiving end accurately calculates the PLR within a certain time period by analyzing the MsgCount field in the RSI / RSM message. (b) RSU is configured to send a certain number of V2X messages, and the receiving end counts the lost packets and divides them.

4.1.2. Test Device Requirements

(1)Transmitting End

The transmitting end of V2X data shall comply with the Technical Requirements in Appendix A.

Table 1. Comparison Between Uu Communication and PC5 Communication

Comparison Item	PC5 Interface Communication (V2X-Direct)	Uu Interface Communication (V2X-Cellular)
Features	(1) Low latency, small coverage area, high moving speed; (2) Suitable for traffic safety and local traffic efficiency service; (3) Use V2X special frequency band (5.9GHz);	(1) Wide coverage, transmitted back to the cloud platform, support higher moving speed; (2) Suitable for infotainment and wide-area traffic efficiency service; (3) Use cellular network frequency band (3.5GHz) and transmit through cellular network Uu interface;
Enhancements	(1) Enhanced structure for problems caused by high-speed movement; (2) Multiple information transmission periods for various business needs; (3) Congestion control mechanism for high-density vehicle scenarios; (4) Location-based spectrum pool resource planning and scheduling management; (5) Self-perceived resources and self- organizing communication methods; (6) Multiple synchronization methods for vehicle terminal	(1) Local downlink broadcast to satisfy low delay requirement; (2) QoS settings for V2X applications; (3) Multiple information transmission periods for various business needs

Table 2. Typical scene library classification

Scene	Wireless Environment Characteristic	RSU Deployment	Typical Application
Urban Road	much shielding; rich multipath with LOS and NLOS paths; strong Doppler frequency shift and Doppler spread	on electric police poles /signal light poles /street light poles	FCW[1], ICW[2], LTA[3], BSW/LCW[4], DNPW[5], CLW[6], HLW[7], RLVW[8], VRUCW[9]
Highway	wide field of vision with no shielding and reflection; few multipath with strong LOS path; strong Doppler frequency shift caused by high speed	on the gantry	FCW, ICW, LTA, BSW/LCW, DNPW, SLW[10]
Tunnel	narrow and small space; rich multipath caused by reflections; strong Doppler frequency shift and Doppler spread	on the sidewall and the top of the tunnel	DNPW, EBW[11], AVW[12], CLW, HLW, SLW
Overpass	wide field of vision with no shielding; few multipath with strong LOS path; long propagation distance	around the overpass	EBW, CLW, SLW
Roundabout	wide field of vision with no tall buildings; few multipath with strong LOS path; weak Doppler frequency shift	on electric police poles and signal light poles	ICW, AVW
Surface Parking Lot	wide field of vision with no shielding around; strong LOS path; weak Doppler frequency shift and Doppler spread	on street light poles	ICW, BSW/LCW
Underground Parking Lot	narrow space with wall shielding; rich multipath with LOS and NLOS paths; weak Doppler frequency shift	on the sidewall and the top of the parking lot	ICW, BSW/LCW

Descriptions for the marked typical application abbreviations are present in Appendix C.

The V2X data transmitter should be configured with different RSU IDs. RSU ID, which is used to uniquely identify the RSU in the message body, refers to the ID in the RSI/RSM message body defined in the third requirement in Appendix A.

The V2X data transmitter also supports custom sending parameters, including the content of the package (filler fields, standard message body and transmission timestamp), package size (150 bytes, 400 bytes, 600 bytes, 1000 bytes or 1300 bytes), transmission frequency (10Hz) and the number of packages to be sent (>1000).

(a) Test Route in Shougang Park (b) Real Image of Qunminghu Southbound Intersection

Fig. 2. Real Image of the test area

(2)Receiving End

The receiving end of V2X data shall comply with the Technical Requirements in Appendix A.

Compared with the commercial on-board terminals, the V2X data receiver should additionally provide the output of network performance parameters and statistical information, as shown in Table 3.

4.1.3. Test Method

(1)Coverage Test

Coverage test is a test for the whole target area. RSUs in this area are configured to work regularly and transmit RSM, RSI, SPAT and MAP messages periodically. The receiving end traverses the road surface at a speed of less than 10km/h. The road detector receives the messages transmitted by the RSUs, including RSRP, RSSI and SNR, and imports the results into the platform for analysis and integration.

(2)Dotting Test

Dotting test is the test for a single RSU. Generally, the test starts directly under the RSU, and then the distance gradually extends. At each test point, “MsgCount” in the RSI/RSM message is used to count PLR for the normally working RSU device. Dotting test is used to supplement the coverage test in the under-covered area to observe whether the PLR of the location can meet the business requirements.

4.2. Urban Scenario Test

4.2.1. Scenario Description

The test site is located in Beijing Shougang Winter Olympic Park, No.68, Shijingshan Road, Shijingshan District, Beijing. Several RSU devices are distributed inside Shougang Park. This test is performed with an RSU device deployed at the intersection of Qunming Lake, which is deployed on the traffic light pole at the south side of the intersection, about 5 meters from the ground, with a transmission power of 23dBm and antenna gain of about 6-7dBi.

4.2.2. Test Analysis

(1)Dotting Test

Dotting test is carried out along the south and the west directions separately, the route of which is indicated by the red arrow in Fig.2(a) and the step length is about 30-50 meters. At each test point, the size of test package is 400 bytes and a total of 1000 packages are sent. The test terminal receives and counts the number of packages received. The main purpose of this test is to find out the trends of V2X network performance with the change of distance and with the influence of the surrounding environment in the urban scenario.

In the southward spotting test, the result in Fig.3(a) shows that RSRP generally decreases with the distance. In the process of gradually moving away, there are several sharp declines in the network indicators and also exists a certain rebound afterwards. The obvious declines occur before the intersection and the rebound occurs after the intersection. The main reason is that when the vehicle approaches the intersection, in order to facilitate the rear vehicles to pass, it temporarily enters the right-turn dedicated lane for parking, as indicated by the red arrow in Fig.2(b). In this process, the trees around the road will have a certain shielding effect on the LTE-V2X signal, which results in the decline of network indicators. After passing the intersection, the vehicle returns to the straight road and there is no other shelter between the vehicle and the RSU, as a result, the network signal quality improves.

Besides RSRP, the test also calculates PLR from the application level. As can be seen from Fig.3(a), the overall trend of the package loss rate is not completely consistent with the above network indicators. The relationship between package loss rate and RSRP is not a simple linear one and there may exist a specific threshold value. When the value of RSRP is larger than the threshold, package loss rate is not obvious, but when the value of RSRP is smaller than the certain threshold, package loss rate will rise sharply. Therefore, it can be seen from the application layer that package loss rate can remain relatively small on the north-south road within a distance of 500 meters.

In the westward dotting test, from the corresponding relationship between RSRP and distance in Fig.3(b), it can be seen that, in the process of gradually moving away, the downward trend of RSRP is relatively smooth and uniform without abrupt change or counter-trend node. In addition, it is almost impossible to receive a signal at the north end of the road. The package loss rate curve has an obvious inflection point at the distance of 350 meters westward, which is basically consistent with the result of the southward test.

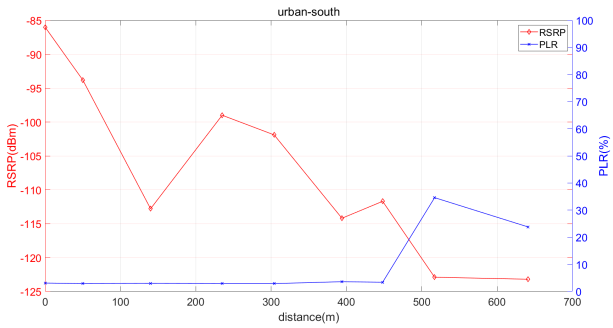
(2)Coverage Test

In this section, coverage test is carried out in the park.

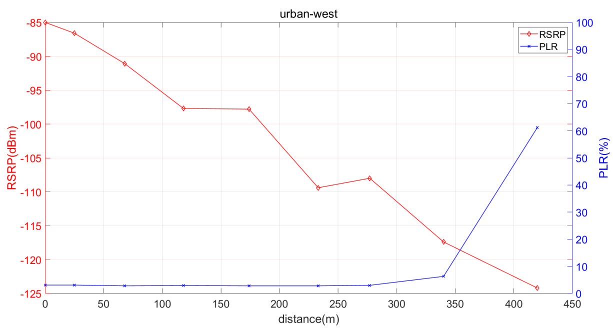
For the tested RSUs in Shougang Park, its single station coverage can be visually displayed through the heatmap in Fig.4. The left figure shows the complete coverage area which includes many extreme coverage points, while the right figure excludes these extreme coverage points and only keeps the points with RSRP>-120dBm. Therefore, from the right figure we can preliminarily determine the effective coverage range of the station.

Table 3. Custom Output Information at V2X Receiver End

Parameters	Explanations
Time	Receiving time of each C-V2X message in network layer
Location	longitude, latitude and altitude of the receiver end when receiving each C-V2X message
Speed	Instantaneous speed of the receiver end when each C-V2X message is received
Transmission Period	If the data packet is periodic data, the V2X receiver will display the value of the package transmission period. If the data packet is trigger data, the receiver will display N/A
Network Indicators	RSRP and RSSI of received C-V2X messages
Initial/Retransmitted Indicator	Indicating whether the received package is initial transmitted or retransmitted
Parsing of V2X message	Parse the content of the message to obtain the message type (RSM, RSI, JR, MAP) and the device ID of the transmitter; Achieve the transmission timestamp and calculate the transmission time.



(a) Results of Southward Dotting Test



(b) Results of Westward Dotting Test

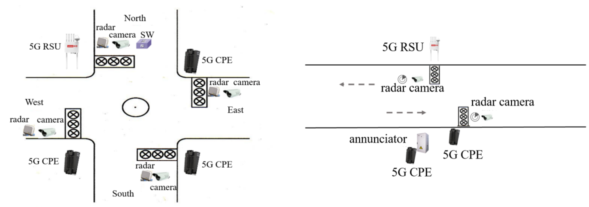
Fig. 3. Results of Dotting Test in the urban scenario

4.2.3. Deployment scheme for typical urban scenarios based on 5G + C-V2X

In order to reduce the complexity and cost caused by optical fiber deployment, this paper proposes a 5G network backhaul scheme. With the help of the large bandwidth and low latency ability of 5G network, roadside sensing information can be sent to the MEC platform for real-time processing, which greatly reduces the construction cost brought by optical fiber deployment. The V2X Cooperative Vehicle Infrastructure System includes RSU, camera, millimeter-wave radar, lidar and other equipment, which uses 5G RSU/CPE to collect data and sends it back through the 5G network. In order to avoid signal interference, one 5G RSU is usually deployed at a single point to realize PC5 communication in the intersection area, and the remaining rod equipment and annunciator realize the 5G backhaul function through 5G CPE instead.

(a) coverage area with extreme coverage points (b) coverage area without extreme coverage points

Fig. 4. Heatmap of RSU single station coverage



(a) Typical deployment at intersections (b) Typical deployment at straight road

Fig. 5. Typical deployment in urban scenarios

(1)Typical deployment scheme for intersection section

As shown in Fig.5(a), in order to achieve full-element perception of target objects in four directions, four sets of vehicle-road cooperative sensing devices are usually deployed in the intersection scenario. Radars and cameras should be installed in the direction of incoming vehicles based on the actual situation.

(2)Typical deployment scheme for straight road section

In the straight road section, to achieve full-element perception of target objects in two directions, it is necessary to deploy at least two sets of vehicle-road cooperative sensing equipment. According to the actual situation, two sets of radars, cameras and other equipment are selected to be installed in the direction of coming vehicle. As shown in Fig.5(b), for targets in the north and south directions, it only needs to deploy one set of sensing equipment on the north side of the road.

5. Summary

Starting from the development trend of V2X industry, this paper first introduces the classification, industry progress, coverage deployment as well as the existing problems of LTE-V2X. Then test and evaluation results of V2X network quality in the urban scenario are presented in detail. Finally, ideas for device deployment and future work are offered.

Preliminary conclusions are as follows:

1. Since the RSU is deployed on the south side of the road, it has better coverage in the south direction, and the effective coverage distance is about 500 meters. The coverage in the west is slightly weaker than that in the south, with a coverage distance of about 400 meters.

2. In the urban scenario, surrounding trees and buildings have obvious shielding effect on LTE-V2X signals, and therefore, RSUs cannot cover the next intersection. In actual deployment, some roads should supplement more RSUs to satisfy the coverage requirements.

3. Network deployment scheme of 5G + C-V2X can greatly reduce the difficulty and cost of construction. In order to meet the business requirements of global perception for intelligent transportation, it is recommended to deploy sensing devices in four directions at key intersections in urban scenarios, and in both directions on key roads.

References:

[1] G. WJ, "Research on industrialization path and schedule of cv2x," *Intelligent Connected Vehicles*, vol. 000, no. 001, pp. P.78–81, 2020.

[2] Y. Jeon and H. Kim, "An explicit reservation-augmented resource allocation scheme for c-v2x sidelink mode 4," *IEEE Access*, vol. PP, no. 99, pp. 1–1, 2020.

[3] S. Sabeeh and K. Wesoowski, "C-v2x mode 4 resource allocation in high mobility vehicle communication," in *IEEE PIMRC 2020*, 2020.

[4] F. Pervez, C. Yang, and L. Zhao, "Dynamic resource management to enhance video streaming experience in a c-v2x network," in *2020 IEEE 92nd Vehicular Technology Conference (VTC2020-Fall)*, 2020.

[5] X. He, J. Lv, J. Zhao, X. Hou, and T. Luo, "Design and analysis of a short term sensing based resource selection scheme for c-v2x networks," *IEEE Internet of Things Journal*, vol. PP, no. 99, pp. 1–1, 2020.

[6] A. Nabil, V. Marojevic, K. Kaur, and C. Dietrich, "Performance analysis of sensing-based semi-persistent scheduling in c-v2x networks," *IEEE*, 2018.

[7] F. Eckermann, M. Kahlert, and C. Wietfeld, "Performance analysis of c-v2x mode 4 communication introducing an open-source c-v2x simulator," *2019 IEEE 90th Vehicular Technology Conference (VTC2019-Fall)*, pp. 1–5, 2019.

[8] Q. Wu, S. Zhou, C. Pan, G. Tan, and J. Zhan, "Performance analysis of cooperative intersection collision avoidance with c-v2x communications," in *2020 IEEE 20th International Conference on Communication Technology (ICCT)*, 2020.

[9] Y. Fan, L. Liu, S. Dong, L. Zhuang, and M. Song, "Network performance test and analysis of lte-v2x in industrial park scenario," *Wireless Communications and Mobile Computing*, vol. 2020, no. 1, pp. 1–12, 2020.

[10] G. Peng and Q. Li, "Nonlinear analysis of the individual difference corresponding to honk effect for car-following theory under v2x environment," *International Journal of Modern Physics C*, 2020.

[11] V. V. Ch Etlur and H. S. Dhillon, "Coverage and rate analysis of downlink cellular vehicle-to-everything (c-v2x) communication," *IEEE Transactions on Wireless Communications*, vol. 19, no. 3, pp. 1738–1753, 2020.

[12] S. Chen, J. Hu, S. Yan, and Z. Li, "Technologies,standards and applications of ltev2x for vehicular networks," *Telecommunication Science*, vol. v.34, no. 04, pp. 7–17, 2018.

Appendix A. Industrial Standard

1. "Technical requirement of sidelink-enabled road side unit for LTE-based vehicular communication" (018-0175T-YD)

2. "Technical requirements of message layer of LTE-based vehicular communication" (YD/T3709-2020)

3. "Technical requirements of network layer of LTE-based vehicular communication" (YD/T 3707-2020)

Appendix B. Terms and Abbreviations

Abbreviation	Description
IoV	Internet of Vehicles
RSU	Road Side Unit
V2X	Vehicle to Everything
C-V2X	Cellular-V2X
SR	scheduling request
BSR	buffer status report
eNB	eNodeB
RRC	Radio Resource Control
RSI	Road Side Information
RSM	Road Safety Message
SPAT	Signal phase timing message
RSSI	Received Signal Strength Indication
MEC	Mobile Edge Computing
CPE	Customer Premise Equipment

Appendix C. Abbreviations for Typical Application

	Abbreviation	Description
1	FCW	Forward Collision Warning
2	ICW	Intersection Collision Warning
3	LTA	Left Turn Assist
4	BSW/LCW	Blind Spot Warning/ Lane Change Warning
5	DNPWL	Do Not Pass Warning
6	CLW	Control Loss Warning
7	HLW	Hazardous Location Warning
8	RLVW	Red Light Violation Warning
9	VRUCW	Vulnerable Road User Collision Warning
10	SLW	Speed Limit Warning
11	EBW	Emergency Brake Warning
12	AVW	Abnormal Vehicle Warning