A Survey of Next-Generation Vehicle-to-X

Xingjian Ding (A paper written under the guidance of Prof. Raj Jain) Download

Abstract

Vehicular communications have played a more critical role in daily life, especially nowadays. As gas prices keep increasing and for some other reasons, many people choose electric or hybrid vehicles as their subsequent transportation rather than traditional fuel vehicles, which caused the rapid development of vehicular communications. In many cities, Vehicle-to-everything(V2x) has been implemented successfully and helped improve the transportation system in different ways, such as roadworks warning, intersection movement assistance, and forward collision warning. These other V2x systems intend to increase the public safety and efficiency of traffic. This document provides some basic information about Next-Gen V2x. This paper will introduce 802.11bd, Cellular Vehicle-to-everything (C-V2x), New Radio Cellular Vehicle-to-everything (NR V2x), Vehicle Named Data Networking (Vehicle Named Data Networking), Internet of vehicles (IoV), and Cognitive Internet of vehicles (CIoV) in Next-Gen V2x. After briefly introducing different features, it will discuss challenges and potential future directions in the existing Next-Gen V2x.

Keywords: Next-Gen Vehicle-to-everything, 802.11bd, NR C-Vehicle-to-everything, Vehicular Named Data Networking, Cognitive Internet of Vehicles, millimeter wave (mmWave), Internet of Things (IoT)

Table of Contents:

1. Introduction

The V2x has successfully launched in different cities. The positive influence promotes the development of Next-Gen V2x. This generation of V2x primarily uses 802.11p or C-V2x to implement vehicular communications. However, some existing limitations in 802.11p and C-V2x, like high latency, low data rate, and instability, restrict the development of advanced vehicle applications. To make V2x improve faster, we need the Next-Gen V2x urgently. The following paper will introduce some features and challenges in Next-Gen V2x.

The structure of this paper is as follows: the first section will introduce the background of this generation V2x. Then, section 2 will discuss some issues in V2x nowadays and some features that obstruct V2x development. Based on these problems, sections 3, 4 and 5 will introduce new techniques arising in Next-Gen V2x. Those new features include 802.11bd, 5G New Radio(), Vehicular Named Data Networking(V-NDN), Urban Vehicular ad hoc network (Urban-VANET), IoV, and CIoV. In these new techniques, sections 3 and 4 will focus on 802.11bd and 5GBR. These two techniques are the most significant improvements of Next-Gen V2x. After discussing those features of Next-Gen V2x, the final section will proffer the challenges and potential future directions of the Next-Gen V2x.

2. Why Next-Gen V2x

This section will introduce the background of V2x, problems in this generation of V2x and what next-gen V2x is.

2.1 V2x Background

This paper will not discuss basic knowledge about V2x. To find more information about these techniques, please see the reference page. Vehicular wireless networks already have a long history. The oldest vehicular communications project is a national project from the U.S. Department of Transportation administered in the Land Transport Efficiency Act in 1991. This project set up the base purposes of V2x, which include several targets, the efficiency of road improvement, energy savings, protection of the environment, and traffic safety [Zhou20]. In this project, the essential things to V2x history are the basic proposal and the set of a specialized spectrum to support the DSRC-based Incompatible Timesharing System (ITS), which is the 75 MHz spectrum in the 5.9

GHz band. This conference became the beginning of nowadays' V2x. Throughout the development of vehicular communications, the traditional V2x is halved into 802.11 V2x and Cellular V2x. This section will mainly discuss the issues in V2x nowadays and how Next-Gen V2x is trying to fix them.

2.2 Problems in this Generation V2x

A. 802.11 V2x

IEEE first published the specification of WLAN-based V2x in 2010 in the standard IEEE 802.11p. It supports directly communicating between vehicle and vehicle and between vehicle and infrastructure. In the past ten years of development, 802.11 V2x has achieved some success in different areas. The main 802.11 V2x has been categorized into three types based on the spectrum access and utilization approaches. The three types are DSRC, Industrial, Scientific and Medical (ISM) Band Wi-Fi with Opportunistic Access, and TV White Space (TVWS) With Cognitive Spectrum Access. [Table1] compared these three 802.11 primary techniques in different features including access spectrum, coverage, penetration, link capacity and cost.

Table 1. The Comparison of three different types in 802.11 V2x[Naik19]

802.11 V2x type	**DSRC**	**Wi-Fi**	**TVWS**
Access Spectrum	Dedicated	Unlicensed	Cognitive
Coverage	< 1 km	100 -300 m	around 10 km
Penetration	poor	poor	good
Link capacity	less than 10 Mbps	up to 1 Gbps(802.11ac)	10 Mbps
Cost	High	Low	High

Dedicated Short Range Communication (DSRC) is our most familiar technique. It also is known as 802.11p. It is a variation of the IEEE 802.11a 5.8 GHz physical layer. In the MAC layer, the DSRC fixes the contention backoff windows size and uses half of the bandwidth as 802.11.a. DSRC is the final answer for V2x communication. However, there still exist some problems that still need to be fixed. First, because of the limitation of bandwidth and range of communication, sometimes the high data range transmission will fail. At the same time, the DSRC also disconnects when non-line-of-sight and highly dynamic network topology happens. The low efficiency of MAC layer access causes other issues in DSRC. As a result, the channel has some significant delays. Although, some research shows that the significant delay can be reduced to 50-100 milliseconds which can be successfully implemented in some systems today, for example, brake alert [Jiang06].

After Ott Jorg successfully set up Wi-Fi to provide internet access for drive-by vehicles [Ott04], ISM Band Wi-Fi with Opportunistic Access showed its unlicensed spectrum advantage and high performance and became an attractive topic in both the V2x industry and academia. The advantage of Wi-Fi is that it is constantly updated, and the new generation of Wi-Fi can always bring new things that may be used in V2x. However, due to the high mobility, the Wi-Fi technology may still have some issues applying to V2x. Compared with its low cost, high efficiency, and potential for future Wi-Fi, the disadvantage of Wi-Fi becomes surmountable. Most researchers believe that Wi-Fi is also a good choice for Next-Gen V2x.

The third primary technique is TV Whitespace (TVWS) With Cognitive Spectrum Access. From the last two introduction paragraphs to DSRC and Wi-Fi networks, we know both methods have the disadvantage of propagation range and penetration capability. The vacant TV spectrum between 460 MHz and 790 MHz is reused to solve these problems because it is no longer in use. The 802.11af standard to support sharing the TVWS spectrum was published by IEEE for secondary cognitive users in 2013 [Flores13]. The measurements of TVWS show that 802.11af can achieve 9 Mb/s when more than 3.7 miles away. However, like DSRC and Wi-Fi, the TVWS has some unavoidable and critical issues. The first problem is that TVWS uses the TV spectrum, which means the usability of the TV band is not guaranteed. Also, the large number of vehicles may cause severe congestion. Besides this, the expensive cost limits its usage.

[Figure1] shows the different frequency ranges for these three techniques.

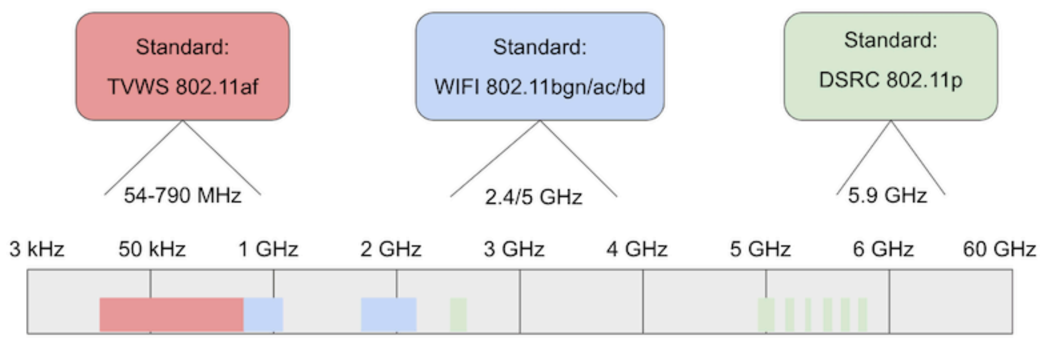

Figure 1. 802.11 V2x spectrum access type [Zhou20]

B. Cellular V2x

This section briefly introduces the overview, the advantages, and disadvantages of C-V2x, and then compares the C-V2x to 802.11 V2x [Costandoiu19].

The Cellular V2x is a 3rd Generation Partnership Project (3GPP) standard for V2x applications, which aims to be the alternative to 802.11p. C-V2x uses the 4G or 5G cellular network to communicate between vehicles, infrastructure, and rode-side units. It exchanges messages at the 5.9 GHz frequency band in most countries. The beginning of C-V2x can trace back to the release of 13 studies to test the application of the current standard to V2x by 3GPP. After release 13, releases 14 and 15 also significantly impacted the development of C-V2x. Europe and the United States leave some forward possibilities for 4G, 5G, and other technologies to be a part of V2x applications and services. For example, in November 2020 United States kept 20 MHz and 30 MHz of the 5.9 GHz band to be allocated to C-V2x. The two main modes for C-V2x include device-to-network and device-to-device. In the device-to-network modes, conventional cellular links are used to communicate between vehicle and network applications. The device-to-device methods use direct communication without networking scheduling for Vehicle-to-vehicle (V2V), Vehicle-to-internet (V2I), and Vehicle-to-pedestrian (V2P)[Triwinarko21].

3GPP published the C-V2x techniques to replace the 802.11 V2x because of higher spectral efficiency, direct communication between vehicles, more extended range, and reliable performance. C-V2x also makes up one of the main disadvantages of DSRC, providing non-line-of-sight propagation (NLOS) awareness for autonomous driving.

The drawbacks of Cellular V2x are most focused on safety and privacy. Because all data is connected to the internet, the security of cars and sensitive information about location and other parts become hard to protect. Also, if any issues happen to the autonomous driving system, it may cause critical accidents. Therefore, how to protect users' safety and privacy has become the biggest problem of C-V2x.

In general, C-V2x is a robust competitive technology of IEEE 802.11p. It integrates LTE 4G cellular communications between device and device. At the same time, the C-V2x is also evolving to 5G New Radio (5G NR) V2x, which is the next stage of cellular V2x.

2.3 What is Next-Gen V2x

The next generation of Vehicles to Everything includes the improvement in different areas, the next stage of 802.11, 802.11bd, and the next stage of C-V2x is 5G NR. At the same time, the Next Gen V2x also includes some new techniques which never been used in V2x before. This paper will introduce those main techniques in sections 3 and 4[Kenney18].

2.4 Summary

In summary, the 802.11p and C-V2x are the most critical roles for this generation of V2x. [Figure2] shows the worldwide forecast for the number of vehicles equipped with V2X from 2018 to 2022. However, the DSRC, Wi-Fi, TVWS and C-V2x have some disadvantages that need to be improved for new applications. The features of these techniques, like delays, data rate, and stability, are good enough for vehicular communication. However, with the increasing interest in advanced V2x applications, latency and reliability requirements are becoming more stringent. 802.11p and C-V2x cannot support the development of those high-requirements applications. Therefore, 802.11p and C-V2x are implementing extensive enhancements to fill the requirements. These evolutions bring us to the next generation of V2x, 802.11bd, and 5G NR [Ansari21].

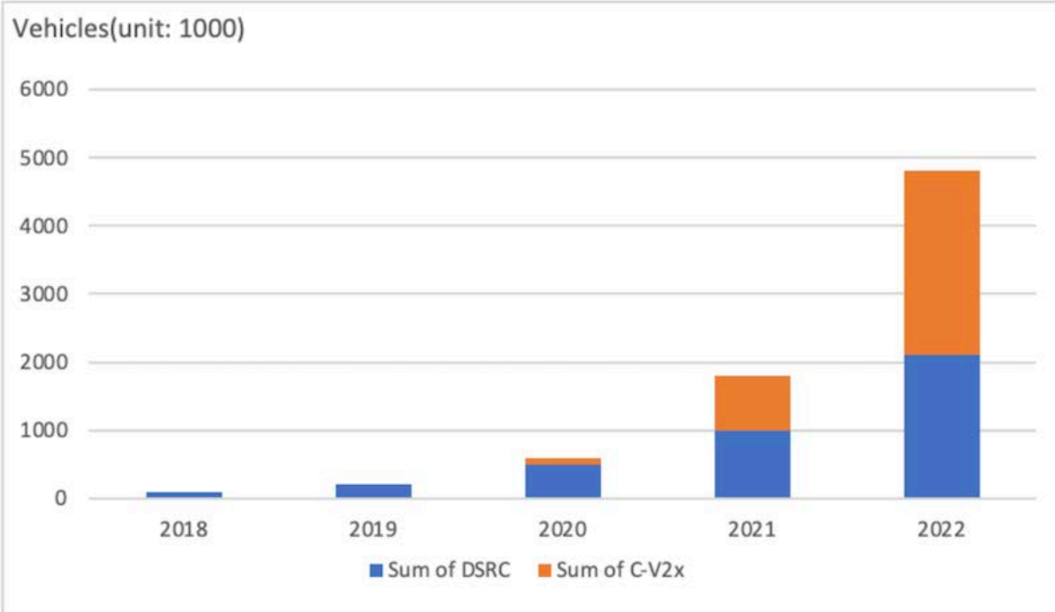

Figure 2. Worldwide forecast for the number of vehicles equipped with V2X technology [Miao21]

3. 802.11bd

Three different objectives are set up when developing the IEEE 802.11bd, safety, traffic management, and filling the requirements of advanced applications. Based on these three objects, 802.11bd was needed to support V2V communication when vehicles are up to 200 km/h, response time needs less than 100 msec, and can communicate when vehicles area at a distance of up to 1 km. This section will introduce the mechanisms and challenges of 802.11bd.

3.1 Midambles

The 802.11 PHY layer is based on Orthogonal frequency-division multiplexing (OFDM) with 64 sub-carries and 312.5 kHz sub-carrier spacing. To solve the reliability at typical vehicle high-speed mobile, finding a balance between multi-path fading and relative Doppler spread can be provided by the 156.25 kHz sub-carrier spacing [Cheng08]. Therefore, the 802.11bd PHY layer is designed based on the 802.11ac PHY layer. However, from some research [Hongyuan18] shows that in some cases, the actual performance is poorer than 802.11p. To solve this problem, IEEE 802.11bd introduces a sort of preambles additionally inserted between OFDM symbols called midambles. The midambles are put between k OFDM symbols to improve the channel estimation. The k is the frequency of midambles depending on different features, including doppler spread and error control. The new midambles can help track the channels and achieve the channel estimates for all data symbols.

3.2 Re-transmission

To improve the reliability of V2x, one of the most important mechanisms is increasing the re-transmission of a packet. Therefore, 802.11bd introduces the adaptive blind re-transmission

[Fischer18] intends to improve reliability and reduce delays. It allows the next-gen V2x station to re-transmit a frame up to 3 times. Each transmission should remain with a time gap with Short Interframe Space (SIFS). Also, based on the channel busy ratio, the station can choose the number of repeat times.

3.3 Dual Carrier Modulation

To increase the reliability of 802.11bd in long-distance transmission, the 802.11bd use the new technique introduced in 802.11ax, Dual Carrier Modulation. In 802.11bd, the modulation order will be double because of the dual carrier. So, for example, if using the BPSK and DCM, the data will translate on a 10 MHz channel, duplicating two 5MHz channels.

3.4 mmWave Frequency

Besides the 5.9 GHz frequency band used in 802.11p, 802.11bd also allows operating in the 60 GHz frequency band. The 60 GHz have an excellent performance in short distance with high throughput. This may solve the problem of some high data throughput requirement V2x applications like video streaming or downloading 3D maps. The only disadvantage of mmWave is low range limitation. Therefore, combining the use case of 60 GHz and 5.9 GHz frequency bands can reduce the negative influence of its drawback.

3.5 Other Improvements

The 802.11bd is more efficient than OFDM. One OFDM symbol includes a cyclic prefix and a tangible data symbol. 802.11bd is trying to narrow the OFDM parameter to increase the ratio of the helpful duration of total duration [Rui18]. Vehicle positioning is another important target for 802.11bd. The 802.11ax provides high location accuracy to 1 meter and may become the next-generation positioning for 802.11bd. To achieve a higher data rate, 802.11bd also introduces Single-User Multiple Input Multiple Output (SU-MIMO) technology, a higher-order Modulation Coding Scheme (MCS) with 256 quadrature amplitude modulation.

In summary, compared with 802.11p, 802.11bd has a vast improvement in different areas and fills the requirements for advanced V2x applications. A details comparison of these two techniques is shown in [Table2].

Table 2. Comparison of IEEE 802.11p & IEEE 802.11bd [Naik19]

Feature	IEEE 802.11p	IEEE 802.11bd
Radio bands of operations	5.9 GHz	5.9 GHz & 60 GHz
Channel coding	BCC	LDPC
Re-transmissions	None	Congestion dependent
Countermeasures against Doppler shift	None	Midambles
Sub-carrier spacing	156.25 kHz	312.5 kHz, 156.25 kHz, 78.125 kHz
Supported relative speeds	252 kmph	500kmph
Spatial Streams	One	Multiple

4. New Radio V2x

NR V2x is designed to support some use cases C-V2x can not support. From the NR V2x Study [Vodafone18], the final target of 5G NR V2x is not to replace the C-V2x. Because C-V2x has already been implemented and standardized, C-V2x and NR V2x may exist in the same area. In this situation, the original C-V2x base applications are still supported by C-V2x. NR V2x only supports the high requirements of advanced applications. However, to ensure NR V2x can support all applications in the future, the design of NR V2x must support advanced applications and all present-day C-V2x applications. This section will introduce the evolution of C-V2x and NR V2x. The comparison between C-V2x, and NR V2x [Table3] are listed below[Lu20].

Table 3. Comparison of C-V2x & NR V2x[Naik19]

Feature	C-V2x	NR V2x
Comm. Types	Broadcast	Broadcast, Groupcast, Unicast
MCS	Rel. 14: QPSK, 16-QAM Rel. 15: 64-QAM	QPSK, 16-QAM, 64-QAM
Waveform	SC-FDMA	OFDM
Re-transmissions	Blind	HARQ
Feedback channel	Not Available	PSFCH
Control & data multiplexing	FDM	TDM
DMRS	Four/sub-frame	Flexible
Sub-carrier spacing	15 kHz	sub-6 GHz: 15, 30, 60 kHz mmWave: 60.120 kHz
Scheduling interval	one sub-frame	slot, mini-slot or multi-slot
Sidelink modes	Modes 3 & 4	Modes 1 & 2
Sidelink sub-modes	N/A	Modes 2(a), 2(d)

4.1 Outline

The several outlines for NR V2x study are re-design for sidelink and (Interface E-UTRAN Uu) LTE-Uu interface to support all advanced applications, Uu interface base sidelink configuration, interface selection, Quality of service (QoS) management, and coexistence. Next, this section will introduce some mechanisms for NR V2x.

4.2 NR Numerologies

The NR numerologies is one of the essential techniques introduced in 3GPP Release 15 of NR V2x. Unlike the fixed sub-carrier spacing in LTE, NR used the sub-carrier spacings. For example, if the LTE sub-carrier spacing is 15 kHz, the NR sub-carrier uses 15, 30, and 60 kHz. The higher sub-carrier spacings can effectively reduce the latency. One slot in NR is defined as 14 OFDM symbols and set one sub-frame to 1 msec. Additionally, the NR numerologies can fix the half-duplex problems. For channel estimation, NR only needs fewer DMSR symbols per slot.

4.3 Slot

In the C-V2x, all user equipment transmits a duration in 1 sub-frame, 1 msec. This shows that all transmission time in C-V2x is coupled tightly. However, this design could perform better when user equipment only has little data to transmit. For example, when transmission data is less than 14 OFDM symbols, the effectiveness of C-V2x is low. Therefore, when designing NR V2x, it still follows this slot-based scheduling. However, at any of the 14 OFDM symbols, it can support mini-slot scheduling to start the transmission and can occupy any number of OFDM symbols within the slot. In addition, NR V2x also supports slot aggregation, combining more than one slot into multiple large spaces to fill the large-sized packet requirements case.

4.4 Other

Besides the NR Numerologies and Slot, NR V2x also has several significant improvements, including multiplexing of the Physical Sidelink Control Channel (PSCCH) and Physical Sidelink Shared Channel (PSSCH) [Butler18], PHY layer enhancements[Anwar19], and new sub-Modes of NR Sidelink Mode 2 [3GPP19]. Due to space limitations, this paper will not discuss in detail about these techniques. If interested, please check the reference page.

5. Other Techniques

This section will introduce other techniques besides 802.11bd and NR V2x, including Vehicular Named Data Networking and CIoV.

5.1 Vehicular Named Data Networking (V-NDN)

In 802.11 and C-V2x, vehicles should be based on the need of the application to choose one of the best interfaces to support the applications. However, with the increasing number of cars connected to the internet, in more and more cases, vehicles will only choose cellular for communication [Wang20] [Saad21] .

For V2V communication, most research uses different patches to overcome the limitations of TCP/IP, which need a basic framework for V2V communication. The V-NDN is introduced to solve this problem. Most NDN networks contain three different major structures: Content Store (CS), Pending Interest Table (PIT), and Forwarding Information Base (FIB). In the NDN, applications name the data, and these named applications' data will be directly transmitted through the network [Grassi14]. In a V-NDN, vehicles may play four roles: a data consumer, data producer, data forward, and data mule. The data mule happens when the cars do not connect to anyone else. Vehicles are different from other devices. It can consider the computational, storage, and power. Therefore, the NDN is an excellent choice to overcome the limitations of TCP/IP. However, some modifications are necessary for basic NDN when implemented in a vehicular network.

In general, the V-NDN is not naming the host like I.P. networking. Instead, it directly calls the data, which can bring several benefits to vehicle communication.

5.2 CIoV

Nowadays, vehicles not only require a variety of data but also produce a large amount of data. Therefore, the IoV has become more and more critical in-vehicle communications. This section will introduce the IoV and CIoV in the Next-Gen V2x.

With the development of the internet, more and more vehicles can access the internet. However, the need for vehicle network applications has become one of the biggest obstructs to developing vehicle networks. With the development of cloud technology, this situation could be changed. Huawei, Microsoft, and many other technology companies vigorously promote could computationally service their customers, including the considerable potential of vehicular services. The CIoV is to make a massive change in Next-Gen V2x.

6. Challenge and potential future directions

Although the Next-Gen V2x already offers huge improvement, it still has some issues and challenges in these new techniques. This section will introduce some challenges and potential future directions[Rahim22] for Next-Gen V2x. The comparison of IEEE 802.11bd & NR V2x are in [Table4]

Table 4. Comparison of IEEE 802.11bd & NR V2x[Naik19]

Feature	IEEE 802.11bd	NR V2x
Base Technology	IEEE 802.11n/ac	5G NR
PHY layer	OFDM	SC-FDMA, OFDM
Mac layer	CSMA	Mode 1: gNodeB scheduling Mode 2: Flexible sub-modes
Interoperability	Yes	Non co-channel
Backward compatibility	Co-channel	Not backward compatible
mmWave support	Yes	Yes

6.1 802.11bd

802.11bd is the evolution of 802.11p. This new technique standard has made significant progress in fulfilling the high requirements of advanced V2x applications. However, it still has some problems and points that could improve. For example, there is a marked adjacent channel interference that may result due to the coexistence of DSRC and C-V2x [nasrallah16], some C-V2x and 5G NR may affect the performance of some techniques in 802.11bd. Furthermore, given that 802.11p is already used in some real-world cases, it cannot communicate with the new 802.11bd, which does not have interoperability and is backward. This is unacceptable and still an open question. The PHY and MAC layers need to be modified to solve this problem.

6.2 NR V2x

One of the most significant issues for NR V2x is the coexistence of C-V2x and NR V2x. A vehicle with C-V2x has already hit the roads, considering the average car can be used for more than ten years. This means NR V2x needs to coexist with C-V2x for about ten more years. However, the NR V2x can not be backward compatible with C-V2x causing new vehicles new to both the C-V2x model and the NR V2x model. This not only results in the increasing of cost but also may cause some mutual interference which was mentioned before. Frequency Division Multiplexing and Time Division Multiplexing are used to make the coexistence possible.

7. Conclusion

This paper first introduces two mainly used techniques in V2x nowadays. Then, sections 3 and 4 elaborate two most significant evolutionary processes in Next-Generation V2x 802.11bd and NR V2x, which have a massive overhaul of their previous predecessors. These two techniques improve many features in V2x to support high requirements and advance applications like autonomous driving. Although 802.11bd and NR V2x share some design targets, the basic principles and design structures differ. After discussing 802.11bd and NR V2x, section 5 studies some other vital techniques in Next-Generation V2x, which include V-NDN and CIoV. Finally, section 6 briefly explains Next-Generation V2x and analyses the challenge and potential future directions. After reading this paper, hope readers can have a brief understanding of the next-generation V2x, especially 802.11bd and NR V2x.

8. Reference

[Zhou20] H. Zhou, W. Xu, J. Chen and W. Wang, "Evolutionary V2X Technologies Toward the Internet of Vehicles: Challenges and Opportunities," in Proceedings of the IEEE, vol. 108, no. 2, Feb. 2020, pp. 308 - 323. https://ieeexplore.ieee.org/document/8967260

[Jiang06] D. Jiang, V. Taliwal, A. Meier, W. Holfelder, and R. Herrtwich, "Design of 5.9 GHz DSRC-based vehicular safety communication," IEEE Wireless Commun., vol. 13, no. 5, Oct. 2006, pp. 36 - 43. https://ieeexplore.ieee.org/abstract/document/4015707

[Ott04] J. Ott and D. Kutscher, "Drive-thru Internet: IEEE 802.11b for "automobile" users." IEEE INFOCOM 2004 1, 2004, pp. 0 - 373. https://ieeexplore.ieee.org/document/1354509

[Flores13] A. B. Flores, R. E. Guerra, E. W. Knightly, P. Ecclesine, and S. Pandey, "IEEE 802.11 af: A standard for TV white space spectrum sharing," IEEE Commun. Mag., vol. 51, no. 10, Oct. 2013, pp. 92 - 100. https://ieeexplore.ieee.org/document/6619571

[Miao21] L. Miao; J.J. Virtusio; K.-L. Hua, "PC5-Based Cellular-V2X Evolution and Deployment." Sensors 2021, 2021, 843. https://doi.org/10.3390/s21030843

[Naik19] G. Naik, B. Choudhury, and J. Park, "IEEE 802.11bd & 5G NR V2X: Evolution of Radio Access Technologies for V2X Communications." IEEE Access 7, 2019, 70169 - 70184. https://ieeexplore.ieee.org/document/8723326

[Cheng08] L. Cheng, B. E. Henty, R. Cooper, D. D. Stancil, and F. Bai, "A measurement study of time-scaled 802.11a waveforms over the mobile-to-mobile vehicular channel at 5.9 GHz," IEEE Commun. Mag., vol. 46, no. 5, May 2008, pp. 84 - 91. https://ieeexplore.ieee.org/document/4511654

[Hongyuan18] Z. Hongyuan, C. Rui, Z. Yan, C. Liwen, J. Jinjing, L. Hui-Ling, K. Manish, S. Sudhir, J. Lepp, M. Montemurro, and H. Amer, "IEEE 802.11-18/0513r2: 802.11 for next generation V2X communication," in Proc. IEEE NGV Meeting, Mar. 2018, pp. 1 - 29. https://www.ieee802.org/11/Reports/tgbd_update.htm

[Fischer18] M. Fischer, A. Filippi, and V. Martinez, "Interoperable NGV PHY Improvements," document IEEE 802.11-18/1186r0, Jul. 2018. https://mentor.ieee.org/802.11/dcn/18/11-18-1186-00-0ngv-interoperable-ngv-phy-improvements.pptx

[Rui18] C. Rui, H. Zhang and P. Sharma, "IEEE 802.11-18/1553r0: Doppler impact on OFDM numerology for NGV," presented at the IEEE 802.11 NGV Meeting, Sep. 2018. https://mentor.ieee.org/802.11/dcn/18/11-18-1553-00-0ngv-doppler-impact-on-ofdm-numerology-for-ngv.pptx

[Nasrallah16] Y. Y. Nasrallah, I. Al-Anbagi, and H. T. Mouftah, "Adaptive backoff algorithm for EDCA in the IEEE 802.11 p protocol," in Proc. Int. Wireless Commun. Mobile Comput. Conf. (IWCMC), Paphos, Cyprus, Sep. 2016, pp. 800 - 805. https://ieeexplore.ieee.org/document/7577160

[Vodafone18] Vodafone Group Plc, "RP-181480: New SID: Study on NR V2X" in Proc. 3GPP Planery Meeting, vol. 80, San Diego, CA, USA, Jun. 2018, pp. 1 - 10. https://portal.3gpp.org/ngppapp/TdocList.aspx?meetingId=18663

[Butler18] D. Butler, "Final Report of 3GPP TSG RAN WG1 94 v1.0.0," document R1-1810051, Oct. 2018. https://www.3gpp.org/dynareport?code=TDocExMtg--R1-95--18807.htm

[3GPP19] Feature Lead Summary for NR V2X Resource Allocation Mechanism, document R1-1903397, 3GPP RAN WG1 96, Intel, Athens, Greece, Feb. 2019. https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_96/Docs

[Wang20] X. Wang and Y. Li, "Vehicular Named Data Networking Framework," in IEEE Transactions on Intelligent Transportation Systems, vol. 21, no. 11, Nov. 2020, pp. 4705 - 4714, doi: 10.1109/TITS.2019.2945784. https://ieeexplore.ieee.org/document/8868115

[Grassi14] G. Grassi, D. Pesavento, G. Pau, R. Vuyyuru, R. Wakikawa and L. Zhang, "VANET via Named Data Networking," 2014 IEEE Conference on Computer Communications Workshops (INFOCOM WKSHPS), 2014, pp. 410 - 415, doi: 10.1109/INFCOMW.2014.6849267. https://ieeexplore.ieee.org/document/6849267

[Triwinarko21] A. Triwinarko, I. Dayoub, S. Cherkaoui, "PHY layer enhancements for next generation V2X communication", Vehicular Communications vol.: 32, Issue: 1, December 2021, pp. 1 - 9. https://www.sciencedirect.com/science/article/abs/pii/S2214209621000541

[Lu20] M. Lu, J. Ferragut; M. Kutila; T. Chen, "Next-generation wireless networks for V2X", 2020 IEEE 23rd International Conference on Intelligent Transportation Systems (ITSC), 2020, pp. 1 - 5. https://ieeexplore.ieee.org/document/9294243

[Costandoiu19] A. Costandoiu and M. Leba, "Convergence of V2X communication systems and next generation networks", IOP Conference Series: Materials Science and Engineering vol.: 477, Issue: 1, May 2018. https://iopscience.iop.org/article/10.1088/1757-899X/477/1/012052

[Ansari21] K. Ansari, "Joint use of DSRC and C-V2X for V2X communications in the 5.9 GHz ITS band", IET Intelligent Transport Systems vol.15, Issue2, February 2021, Pages 213-224. https://ietresearch.onlinelibrary.wiley.com/doi/10.1049/itr2.12015

[Saad21] M. Saad, Next Generation V2X Technology, Next Generation V2X Technology, the slides include the introduction to vehicular technology, two radio access vehicular technology DSRC & C-V2X. Also, Vehicular Named Data Networking (V-NDN) along with research challenges and future research directions is presented. https://www.slideshare.net/MalikSaad2/next-generation-v2x-technology

[Kenney18] J. B. Kenney, "An Update on V2X in the United States." https://www.sip-adus.go.jp/evt/workshop2018/file/new01_An_Update_on_V2X_in_the_United_States-Kenney-SIPadus-Nov.2018.pdf

[Rahim22] M. Noor-A-Rahim, Z. Liu, H. Lee, M. O. Khyam, J. He, D. Pesch, K. Moessner, W. Saad and H. V. Poor, "6G for Vehicle-to-Everything (V2X) Communications: Enabling Technologies, Challenges, and Opportunities," in Proceedings of the IEEE, vol. 110, no. 6, June 2022, pp. 712 - 734. https://ieeexplore.ieee.org/document/9779322

[Anwar19] W. Anwar, N. Franchi and G. Fettweis, "Physical Layer Evaluation of V2X Communications Technologies: 5G NR V2X, LTE-V2X, IEEE 802.11bd, and IEEE 802.11p," 2019 IEEE 90th Vehicular Technology Conference (VTC2019-Fall), 2019, pp. 1 - 7. https://ieeexplore.ieee.org/document/8891313

8. Acronyms

- V2x - Vehicle-to-everything
- C-V2x - Cellular Vehicle-to-everything
- NR V2X - New Radio Vehicle-to-everything
- V-NDN - Vehicle Named Data Networking
- IoV - Internet of vehicles
- CIoV - Cognitive Internet of vehicles
- VANET - Vehicular ad hoc network
- DSRC - Dedicated Short Range Communication
- TVWS - TV Whitespace
- 3GPP - 3rd Generation Partnership Project
- V2V - Vehicle-to-vehicle
- V2I - Vehicle-to-internet

- V2P - Vehicle-to-pedestrian
- 5G NR - 5G New Radio
- OFDM - Orthogonal frequency-division multiplexing
- mmWAVE - millimeter wave

Last modified on December 7, 2022
This and other papers on recent advances in Wireless and Mobile Networking are available online at http://www.cse.wustl.edu/~jain/cse574-22/index.html
Back to Raj Jain's Home Page