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Advancements in V2X Communication: Enhancing Vehicle-to-Vehicle, Vehicle-to-Pedestrian, and Vehicle-to-Infrastructure Connectivity

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Abstract

The automotive industry is transforming rapidly with the evolution of 5G, cloud computing, connected and autonomous vehicles, and artificial intelligence. Wireless communication plays a significant role in this industry transformation with continuously evolving V2X (Vehicle-to-everything) communication technologies. V2X in general is referred to as Vehicle-to-Vehicle (V2V), Vehicle-to-Pedestrian (V2P), V2I (Vehicle-to-Infrastructure), V2N (Vehicle-to-Network) communication and so on. Safety and congestion, two of the major issues in transport, are the best examples, to which the vehicular communication has started to have an influence. These V2Xcommunications provide traffic efficiency, driving safety, and road information in real-time. This paper briefly highlights the evolution of V2X communications, starting from DSRC to 5G NR V2X, and compares different types of wireless communication for vehicle communications. It also provides a list of applications that use V2X. It also briefly highlights the security concerns involved with these V2X communications and the mitigation plans being studied by academia and industry.

Keywords: V2X (Vehicle-to-Everything), V2P, Cellular-V2X(C-V2X), Connected and Autonomous Vehicles (CAV), Connectivity, Artificial Intelligence

Introduction

In the modern world, especially in urban areas, vehicle crashes and traffic jams have constantly risen. Technical advancements in the auto industry with progressive goals in developing intelligent and autonomous vehicles are trying to address this concern through V2X(Vehicle-to-everything) communications. These intelligent and autonomous vehicles may also be called connected vehicles in the United States and Cooperative intelligent transport systems (C-ITS) in EU countries. Over wireless networks, the vehicle can communicate with other vehicles (V2V), infrastructure(V2I) and pedestrians(V2P), etc.

Initially, two significant standards developed for information exchange in V2X communications were DSRC (Dedicated Short Range communication) in the US and ITS (Intelligent Transport System) in Europe. They were derived from the IEEE 802.11p, which stemmed from IEEE 802.11a (WLAN – Wireless local area network). The specifications for VANET (Vehicular Adhoc NETwork) were developed based on this standard. However, it has been found that this standard has several limitations. The DSRC performance was adequate for most vehicle safety applications, requiring end-to-end latency of around 100 msif the vehicle density is low. The global adoption of DSRC has been delayed due to the communication challenges introduced by dynamic mobility and poor scalability. Meanwhile, the 3GPP (Third Generation Partnership Project) was developing standards for V2X based on 3G and LTE as an alternative to DSRC, called C-V2X (Cellular V2X). LTE for vehicles (LTE-V) was introduced in 2016. However, it still could not meet the ultra-low latency, ultra-high reliability, and ultra-high bandwidth requirements of V2X applications, such as critical messages and platooning. Since then, NR V2X (New Radio V2X) has been introduced to support all V2X applications. The crucial feature of NR V2X is side link node 2, which will provide improved scheduling mechanisms, different transmission mechanisms, various side link modes, etc.**[1].**The emerging 5G will further help C-V2X and, at the same time, increase security. The evolution of C-V2X towards 5G NR V2X provides adequate requirements and new possibilities for current and future intelligent and autonomous driving industries. In contrast to IEEE 802.11, C-V2X can provide better QoS(Quality of Service) and massive coverage with higher data flow rate for vehicles. The Device-to-Device(D2D), a feature of LTE-Advance, allows the UEs (User equipment) to communicate with each other directly instead of hopping through the eNodeB. The channel structure used in the air interface to realize the D2D communication is referred to as sidelink (SL), and it can ensure low latency and high reliability. Thus, the D2D sidelink (SL) has been specially adopted as the basis for C-V2X standards**[2].**Meanwhile, edge computing has emerged as an expansion of cloud computing, and it is considered to enable technology to drive 5G ecosystems forward. It delivers computing facilities at the edge of the network to nearby vehicles or other devices, allowing for even shorter communication delays in processing and storage. The rapid and explosive growth in 5G V2X traffic data generated by high-density vehicles has led to intense demands for network defense systems against various cyber-attacks. Blockchain is expected to offer a range of security services for 5G V2X and edge computing with powerful security properties to enhance the overall performance of future V2X networks. This paper mainly highlights the (1) different V2X modes and (2) compares different types of wireless communication for vehicle communications. (3) Provides a list of applications that use V2X. It also briefly highlights the security concerns involved with these V2X communications and the mitigation plans being studied by academia and industry.

V2X modes:

According to the 3GPP, the term V2X refers to communication between different entities, Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), Vehicle-to-Network (V2N), and Vehicle-to-Pedestrian (V2P), etc. for both safety and non-safety applications. These four types of communication can be used simultaneously for safety, autonomous vehicle control by using data from nearby sensors, and accident prevention.

Vehicle-to-Vehicle (V2V) communication mode: In this mode, the vehicle nodes communicate with each other at close proximity in an ad hoc domain by forming a mesh network without the help of any infrastructure, such as Road side Units (RSU).

Vehicle-to-pedestrian (V2P) communication mode: in V2P mode, vehicles connect with pedestrians or bikers' phones on the road to prevent accidents.

Vehicles can communicate with pedestrians even if they are not in the line of sight due to night or foggy weather, etc. The sensitivity of pedestrian user equipment (e.g., phones) is lower than vehicular V2P devices because of antenna and battery capacity differences.

Vehicle-to-Infrastructure (V2I) communication mode: V2I communication happens through RSU (Road Side Unit) or locally available application server.RSU receives and transmits the broadcasted message to one or more UE supporting V2I communication modes. V2I typically provides information such as available parking space, traffic congestion, road conditions, etc.

Vehicle-to-Network (V2N) communication mode: In this mode, vehicular nodes communicate with cellular infrastructures (e.g., eNB), evolved packet switching, remote servers providing extended vehicle communication, and cloud-based services through cellular networks. V2N allows broadcast and unicast communications between vehicular nodes and V2X management systems.

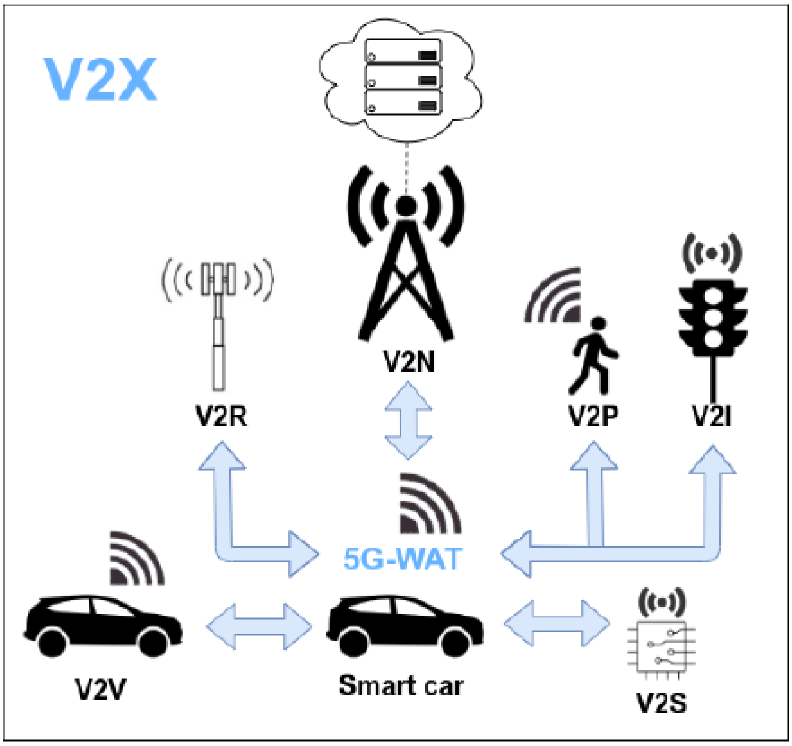

Figure 1: Modes of V2X communication (Courtesy [3])

DSRC-based V2X Vs Cellular V2X

DSRC-based V2X:
DSRC-based V2X (5.9 GHz)offers cooperative awareness applications such as emergency brake lighting, vehicle warning, and vehicle platooning. However, such applications are only applicable for low vehicle-density environments. However,V2X applications need an extremely high capacity, high bandwidth, and very low latency in a densely populated environment where thousands of vehicles drive on the road. In the case of critical and emergency warning notifications, latency plays a vital role in the

security of traffic to prevent collisions. Some of the features and requirements of future V2X are high bandwidth, low delay, high scalability, availability, reliability, and high data speeds. DSRC has limitations in satisfying all the specifications of futureV2X requirements due to weakness in the physical layer (i.e., radio technology) and the absence of collision and interference management. Moreover, intelligent vehicle connectivity requirements and applications are growing exponentially, while DSRC cannot get closer to the ever-increasing needs of such applications. The infrastructure of DSRC needs RSUs, which take a massive amount of time and money for global implementation. DSRC is an asynchronous system based on the CSMA/CA protocol, so many physical layer inadequacies result in reduced performance. DSRC, based on the CSMA system, is more vulnerable to interference, as there is no channel access as long as the activity is sensed on the channel. In addition, CSMA issues are more evident at higher network loads and unsuitable for critical communication scenarios **[4]**. On the other hand, a separate investigation based on cellular networks for V2X connectivity is ongoing, and it promises to address all the above concerns.

Cellular V2X:

3GPP developed the **Cellular Vehicle to Everything** (C-V2X) based on V2X RAT (Radio Access Technology) inRel.14, which gives the highest priority for modifications of radio access suitable for V2X. LTE for vehicles(LTE-V) was introduced in vehicle networks as an alternative technology in addition to DSRC. Telecom companies and the automotive industry approved LTE-V for vehicle connectivity based on LTE. The LTE-V promised low costs, rapid development, and installation by leveraging existing cell towers to make the public transport network more efficient and accessible. Soon, the telecom companies and the automotive industry approved LTE-V for vehicle connectivity based on LTE-A. One study details using unlicensed bands in 5G networks via LTE and WLAN aggregation to alleviate spectrum scarcity **[4,5].** Several vehicles use an onboard system to connect to the cellular network for telematics, GPS systems, infotainment, fleet management, etc.

For commercial applications, such as voice or data access, C-V2X can use V2N mode based on existing licensed cellular networks. The cellular network provides access to the cloud through commercially licensed spectrum using a network slicing architecture for the vertical industry. C-V2Xdescribes transmission modes allowing direct V2X connections over the PC5 interface through the side link channel. The PC5 refers to the point of contact where the vehicular nodes connect with other nodes directly over the same channel, where it does not require connection with the base station.

Based on Rel.14 and Rel.15**[6]**specifications, the 3GPP announced C-V2X technology. The Rel.14included two additional transmission sidelink modes to enable V2X communications with low latency. The two transmission modes are mode 3 and mode 4, as shown in Figure 3 **[7]**. The C-V2X canperform in both within-coverage and outside-of-coverage environments, i.e., C-V2X can work with both the conventional LTE air interface and the sidelink air interface **[1]**.

1. V2X based on PC5 Air Interface: As per 5G Automotive Association (5GAA),the device-to-device communication mode (i.e., PC-5) must be enabled in C-V2X for direct safety message communication assuring privacy. This mode also works well in the ITS 5.9 GHz band without a paid subscription and provides privacy. The PC5 air interface allows direct UE communications without requiring each packet to proceed through the base station. The user nodes can exploit the PC5 interface when eNodeB (base station)is present or absent.

2. V2X based on LTE-Uu Air Interface: LTE-Uu is the standard air interface for connecting User Equipment (UE) and a base station. Each UE that supports the LTE-Uu protocol relays its signal on the uplink to the base station, and the base station transmits the signal to the destination UE on the downlink. The base station will use semi-persistent scheduling to lower the scheduling overhead that is involved with V2X uplink transmission. In semi-persistent scheduling, the base station allocates resources to a user over several subsequent transmissions, as most traffic is periodic and has similar packet sizes [16].
3. C-V2X sidelink mode 3: in C-V2X side-link mode 3, the scheduled mode functions only in the presence of a base station or an eNB. The allocation of resources is carried out in a centralized manner by the cellular network. Some of the mode 3 mechanisms are semi-persistent scheduling, UE reports based scheduling, and cross carrier scheduling. However, this mode has an issue in high mobility highway scenarios, where the vehicles should be connected with the eNB.
4: C-V2X side-link mode 4 functions independently in the absence of eNB or base station support for directly interacting using the PC5 side-link radio interface using a 5.9 GHz frequency band similar to the DSRC. It is also known as autonomous mode. It can interact with other nearby vehicles in a decentralized manner without depending on central cellular network connections. The Mode 4 in C-V2X showed better performance compared to the IEEE 802.11p protocol in several situations during an initial comparison. Moreover, it provides high security for different operating modes.

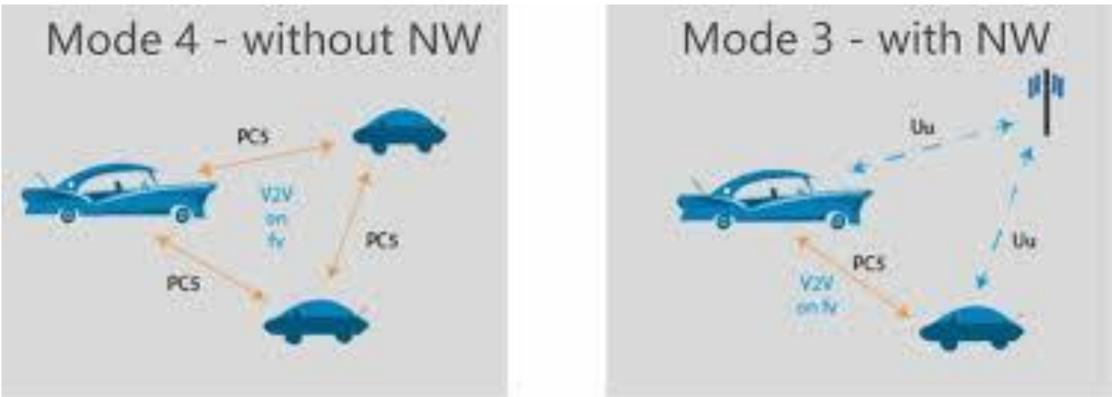

Figure 2: Mode 3 and Mode 4 (Source[6])

Comparison of DSRC and Cellular based communications:

Components	**DSRC V2X**	**Cellular V2X**
Technology	Wi-Fi	LTE/4G
Evolution Path	Towards 802.11bd	Compatible with Rel -14/15
Modulation	OFDM	SC-FDM
N/W Communication	Limited	Full Support
Range	Good for short radio range	Good for extended communication
Security and Privacy on (V2V, V2P, V2I)	Yes	Yes

High density support	Packet loss at high density	No packet loss guaranteed at high density
Resource selection	CSMA-CA	Semi persistent Tx with comparative energy-based selection.
Connectivity	Hybrid mode (Connects with cellular network for non-safety services)	Hybrid model (Connects with peer vehicles based on PC5)

Applications of V2X:

V2X can be used for various purposes. Their application can make mobility safe and smoother.

The major types of V2X applications are as follows.

1. Safety Application: It notifies drivers and pedestrians about road conditions. Drivers and pedestrians are periodically updated about their surroundings. Vehicles are warned about the complexities they might face in an intersection, thus helping them make decisions**[8].** From the information shared by different vehicles, RSUs broadcast it throughout the UEs (User Equipment) for better deliberations and maneuvers.

- Forward Collision Warning: Forward Collision Warning (FCW) application serves by alerting a Host Vehicle (HV) about a possible collision with a Remote Vehicle (RV). With V2V service, FCW helps drivers to mitigate or avoid rear-end collisions.

- Control Loss Warning: Control Loss Warning (CLW) works by broadcasting a message about the loss of self-generated control. Surrounding vehicles are notified about the host vehicles's condition; thus, they perform maneuvers to avoid collisions. V2V Use for Emergency vehicle: An emergency vehicle like an ambulance or fire brigade broadcasts messages, asking other vehicles to make a gap for fast mobility.

- Wrong Way Driving Warning: This use case enables communication between two vehicles moving in opposite directions. In this scenario, the wrong-sided vehicle is warned about its wrong heading, and a safety behavior is triggered for nearby cars.

- Pre-Crash Sensing Warning: Alerts are generated, and onboard safety measures are activated in this case. The moment when a crash cannot be omitted, the application warns the driver about the imminent contact and activates all the available safety measures.

- Pedestrian Warning: Pedestrians are periodically warned about their surroundings. Alerts are sent to road users to avoid collision with a moving vehicle.

2. Non-Safety Application: Non-safety-based applications mainly focus on increasing traffic efficiency, reducing traffic, improving traffic flow, ensuring improved traffic coordination, and assisting drivers **[9], [10].** Moreover, they supply updated information, maps, and real-time data to each other.

- V2N Traffic Flow Optimization: V2N traffic flow works by managing the speed of the vehicles for smooth driving. The priority of vehicles can be taken into consideration to ensure a harmonious surrounding.
- Co-operative Adaptive Cruise Control (CACC): This application focuses on improving traffic efficiency by controlling navigation vehicles, where a vehicle with V2V capability can leave and join a group of CACC vehicles. This application can provide safety and convenience for CACC vehicles. This application also helps in reducing traffic congestion, thus improving traffic efficiency. Latency-tolerant applications also fall under this category. These applications include discovering unoccupied parking slots, traffic flow control, and cloud-based sensor sharing.

Security and Privacy Challenges in V2X Communications:

V2X communications face significant security and privacy challenges due to their wireless nature, making them vulnerable to various attacks such as bogus messages, message modification, Sybil attacks, DoS, eavesdropping, impersonation, replay attacks, black hole attacks, grey hole attacks, and location tracking. To address these challenges, one study proposed cryptography-based schemes (including group signature, identity-based, and hybrid schemes) and trust-based schemes **[11]**. Cryptography-based schemes focus on robust authentication and message integrity, while trust-based schemes manage reputation scores to prevent inside attacks and specific threats like DoS and black hole attacks.

Privacy in V2X communications is crucial, focusing on identity privacy and location privacy. Pseudonyms are used to protect identity privacy, while strategies like pseudonym changing at social spots and using dummy locations or caching are employed to preserve location privacy.

5G-V2X is expected to play a significant role in future V2X services. Cellular technologies like LTE and 5G offer advantages over DSRC, such as a more extensive communication range and better QoS. Security architectures for LTE-V2X and 5G-V2X include mutual authentication, key management, and protection against DoS attacks.

Critical areas for future research include improving the efficiency of authentication schemes, developing efficient revocation mechanisms, integrating cryptography and trust management, enhancing privacy preservation, ensuring compatibility with heterogeneous networks, implementing effective intrusion detection mechanisms, securing autonomous driving systems, establishing a standardized simulation platform, and exploring the use of UAVs for enhanced security and privacy.

Conclusion:

This article details the evolution of V2X communication, and the different modes of V2X communications are discussed. Comparison and the benefits of CV2X over DSRC V2X communicationare highlighted. Also, the different applications of V2X communications were listed. For security, cryptography-based schemes and trust-based schemes are suggested. For privacy, general solutions for preserving identity privacy and location privacy were discussed.
One study**[3]** highlights the future of 5G V2X involving the integration of C-V2X and DSRC, using Software-Defined Networking for IoV (SDIoV) to manage heterogeneous networks and deploying mm

Wave technology for high data rates and low latency. These advancements will support autonomous driving, enhance traffic management, and improve vehicular communication systems.

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