Critical Review of Vehicle-to-Everything (V2X) Topologies: Communication, Power Flow Characteristics, Challenges, and Opportunities

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***Abstract*—The rise in demand for energy storage solutions and the widespread adoption of electric vehicles (EVs) have given rise to the creation of vehicle-to-everything (V2X) topologies. V2X technology enables communication and power flow between EVs, the grid, homes, buildings, and other loads. This paper provides an acute review of V2X topologies, including the communication and power flow between EVs and the grid, homes, vehicles, and loads. The different types of V2X communication, including IEEE standards, the 3rd Generation Partnership Project (3GPP), ISO standards, Wi-Fi, and Internet of Things (IoT)-based protocols, are discussed, along with their advantages and disadvantages. Finally, the challenges and opportunities for the adoption of V2X topologies are presented.**

***Index Terms*—5G, C-V2X, DSRC, internet of things, vehicle to grid, vehicle to home, vehicle to vehicle.**

I. INTRODUCTION

THE advent of electric vehicles (EVs) has caused a substantial shift in the transportation industry, offering the possibility to mitigate greenhouse gas emanations and lessen reliance on non-renewable energy sources. However, the integration of EVs into the power grid offers new challenges and opportunities for the power system. vehicle-to-everything (V2X) technology is one of the promising solutions that allows bi-directional power flow between EVs and the grid, enabling EVs to integrate and support the grid's stability and reliability. This technology includes several topologies that can provide various services, including vehicle-to-grid (V2G), vehicle-to-home (V2H), vehicle to building (V2B), vehicle to load (V2L), and vehicle to vehicle (V2V) [1].

V2G provides EVs with the ability to store and supply energy to the grid during high energy demand hours, while V2B and V2H allow EVs to power buildings and homes during power outages or reduce energy consumption during peak hours. Therefore, the integration of V2X topology is likely to diminish the environmental impact of transportation and increase the efficiency and resilience of the power system. In this review paper, our purpose is to provide an outline of this technology and its potential applications, benefits, opportunities, and challenges.

V2X communication systems are a key enabler of connected and autonomous vehicles. Dedicated Short-Range Communications (DSRC) is one of the communication protocols. The allocation of 75 MHz on the 5.9 GHz band to Intelligent Transportation Systems (ITS) uses by the United States FCC in 1999 aimed to enhance road safety, optimize rush-hour traffic flow, provide passenger infotainment, and enhance producer services [2]–[7]. V2X communications protocols include various types of communication, such as vehicle to network (V2N), vehicle-to-infrastructure (V2I), vehicle-to-grid (V2G), and vehicle-to-pedestrian (V2P), each with its own applications and Quality of Service (QoS) requirements [3].

DSRC, a recognized Radio Access Technology (RAT), is specifically crafted for use in automotive and Intelligent Transportation Systems (ITS). It enables units to share status data via short-distance communication. The shared data, referred to as Basic Safety Messages (BSMs), encompasses crucial vehicle details such as velocity, location, and direction. The DSRC system is created based on a sequence of IEEE and Society of Automotive Engineers (SAE) standards, which describe the network design and security protocols. The physical and MAC layer architecture of DSRC is defined by the IEEE 802.11p protocol. This simplifies the verification related processes and data communication before sending information, enabling vehicles to broadcast relevant security information directly to nearby units. The IEEE 1609/Wireless Access in Vehicular Environments (WAVE) protocol is used to describe the network design and safety protocols [4]. Moreover, the SAE J2735 standard is employed to develop the application layer of the DSRC-based EV network. In addition to standardized BSMs, European Telecommunications Standards Institute (ETSI) has defined Cooperative Awareness Messages (CAMs) and distributed Environmental Notification Messages (DENMs) at the European level to upkeep the employment and utilization of Cooperative Intelligent

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TABLE I
Recent Research on the V2X Topologies

Ref.	Year	Remarks
[1]	2022	The hybrid AC/DC-coupled design shows excellent control on power flow and power quality advantage, while the hybrid series-parallel microgrid group balances difficulty, cost, severance, and reliability. The study paves the way for future research in the integration of EV and utility grid.
[11]	2021	The case study of Shenzhen, China, demonstrates that a user-friendly V2G technique can significantly cut peak period power demand compared to traditional EV charging. By using global and divided planning optimization models, the V2G strategy decreased peak demand by 0.93 GW, or 5.89%, in a modest scenario.
[12]	2020	Six PEV charging scenarios are investigated, yielding promising results: compared to uncoordinated charging, peak-shaving improved by 17.54%, valley-filling by 12.42%, and self-consumption of photovoltaic energy increased by 258.74%.

TABLE II
Recent Research on V2X Communications

Ref.	Year	Remarks
[13]	2023	Introduces enhancements to 5G New Radio side link technology, crucial for V2X applications and automated driving. The current design doesn't account for the directionality of high-frequency transmissions, leading to hidden node interference. The proposed method pairs the transmission and sensing of control information in opposite directions, reducing interference and improving the packet reception ratio by 27%. Additional power control strategies further increase performance, reaching a 95% average packet reception ratio in all scenarios. The study also includes a validated critical prototypical for a single-lane V2X system, offering valuable understandings into the dependability and ability of high-frequency side-link networks.
[14]	2023	A novel approach to V2X motion planning that boosts safety and efficiency in autonomous driving considering communication delays, the authors propose an adaptive policy that regulates between competitive and conservative driving and uses power control to ensure minimal delays. It was revealed that this strategy significantly reduces the collision ratio, demonstrating its potential to improve V2X motion planning.
[15]	2023	A two-timescale optimization approach for cellular-based V2X networks reduces signaling overhead and latency. The hierarchical system includes long-span vehicle association, resource control, a matching-auction-based algorithm, and short-timescale power control. The proposed scheme notably enhances the system sum rate, fulfills users' quality-of-service requirements, and minimizes system overhead, offering a promising solution for resource management in dense vehicular networks.
[16]	2022	A V2X network focuses on joint power control and resource allocation. The network includes V2I and V2V links. The research approach involves dividing the resource allocation problem into two sub problems: power control and pairing. The power control issue is transformed into a convex problem, while a fuzzy decision-making method is used for pairing. The technique is tested on a simulated highway and proves to be more stable than other similar pairing algorithms.

Transport Systems (C-ITS) [5]. The DSRC technology has several advantages, including efficient data transmission with low latency, reliable communication, and real time information exchange between vehicles and surrounding infrastructure. It facilitates the development of various vehicular applications, including collision avoidance, intersection safety, and traffic management. However, DSRC has some limitations, such as limited bandwidth width susceptibility and susceptibility to interference, making it challenging to support high-bandwidth applications.

V2X communication facilitates the exchange of data between V2I. C-V2X uses 5G's features like high bandwidth, low latency, and multiple connections to enable real-time data exchange between EVs and different connections. It has excellent prospects for development and is the subject of current research [2], [6]. The Uu interface in C-V2X supports long-range communication between Evolved NodeB (eNB) and user equipment, while the sideline (PC5) interface enables direct V2V/V2I short-range communication [7]. 3GPP plays a crucial role in setting the technical standards for telecommunication technologies, including V2X systems [8], [9]. The 3GPP Release 15 standard introduced the 5G Phase 1 or New Radio (NR) air interface technology, while the 3GPP Version 16, also known as the 5G second stage, specifies the requirements for the next generation of C-V2X called NR-V2X [10]. Unlike C-V2X, NR-V2X supports broadcast, group cast, and unicast transmissions. There have been several efforts to emulate the functions of NR-V2X in various research projects. Table I shows the recent research on the V2X topologies. Table II shows the recent research on V2X communications. The third column explains the motive of the research paper.

Section II describes the different V2X topologies and their definitions. Section III describes the technical requirements for V2X communication and V2X topologies. Section IV describes the standards used in V2X communication. Section V describes the opportunity and challenges for V2X communication. In [1], it is discussed the different V2X topologies and their benefits, applications, barriers, and measures in the implementation of the V2X topology. V2X topologies provide services like emergency backup, energy sharing, energy arbitrage, voltage regulation, reactive power consumption, and frequency regulation.

In [11], the author discusses the V2G operation and a survey done for Shenzhen, China. In this survey, he discusses the optimization model for the charging of EVs during peak hours.

A. Brief Overview of V2X Topologies and its Applications

V2X topologies state to the ability of EVs to communicate with infrastructure, other vehicles, and the grid. This topology

TABLE III
APPLICATIONS OF V2X TOPOLOGIES

Topology	Charger Used	Ref.	Benefits
V2G	Off-board	[17]–[19]	Maximum demand decline, voltage/frequency balance, DSM, energy storage
V2V	Off-board/On-board	[20], [21]	Energy trading, P2P, power exchange, and off-grid
V2L	On-board	[22]	Energy source, off-grid, storage system
V2H	On-board	[23], [24]	Demand control, energy sources, and energy trading
V2B	On-board/Off-board	[25], [26]	Demand response control, energy source, and electricity price

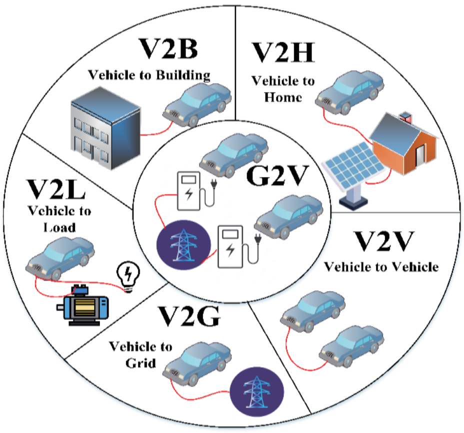

Fig. 1. V2X topology diagram.

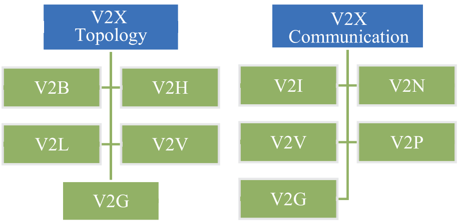

Fig. 2. V2X topology and V2X communication.

enables a widespread range of applications, including but not limited to V2V, V2I, V2G, V2H, and V2L. Each of these V2X applications is designed to provide specific energy services, and therefore, the load demand on the battery pack is different for each of them. Fig. 1 shows the different topologies of power flow from vehicles to other things. Vehicles are charged through the utility grid. It can be used as dynamic energy storage system.

V2X topologies can be divided into two categories: energy-based products and power-based products. Energy-based products include V2G energy arbitrage, spinning reserves, demand response, and emergency backup power. While the occurrence of use and daily utilization rates for each of these services will diverge, they will have a similar load profile.

Power-based products, on the other hand, are designed to respond quickly to fluctuations in the grid. V2G frequency regulation is a prime example of a power-based product where fast response time is essential and there is considerably less energy exchange involved. The inherent energy service for these products is charge/discharge flexibility. Fig. 2 shows the types of V2X topology and V2X communication. The power flows from the vehicle to others are shown in Fig. 3. It shows the complete structure of power flow from G2V and from vehicle to others through communication. It is explained on-board and off-board chargers of an EV. These are explained below.

1) On-Board Charger

An on-board charger is an electronic device that is installed in EVs and plug-in hybrid electric vehicles to convert AC from an external power source to DC to recharge the vehicle's battery pack.

2) Off-Board Charger

An off-board charger is an EV charging device that is not built into the vehicle but is located outside of it. It is designed to charge the electric vehicle by providing electricity from an external source. Table III shows the applications of V2X topologies.

B. Overview of V2X Communication

The field of vehicular communication has been accelerating over the past few years and is anticipated to fundamentally influence the automotive industry and the way vehicles are utilized in society. V2X communication is projected to yield significant benefits. As per a study by the U.S. National Highway Traffic Safety Administration (NHTSA), the implementation of V2V technology could enhance traffic safety by averting 439000 to 614000 accidents, sparing 987 to 1365 lives, and reducing 537000 to 746005 property destruction happenings each year. An article from the European Commission (EC) indicates that the comprehensive advantages of deploying the C-ITS comprise reductions in travel times, enhancements in efficiency, fewer accident rates, and fuel savings.

The initial standardized V2X technology is grounded in IEEE 802.11p (IEEE 802.11 external the Context of Basic Service Set (OCB) mode). In the U.S., the V2X system employing the 802.11 OCB mode is designated as DSRC, and its superior layer is known as WAVE as defined in the IEEE 1609 series and the SAE International (SAE) standard J2735. In Europe, ITS systems predicated on the IEEE 802.11 OCB mode are named ITS-G5, with their upper layer referred to as C-ITS. These standards and their interrelationships are discussed thoroughly in [27]. An overview of the V2X communication system is depicted in Fig. 4. V2X represents

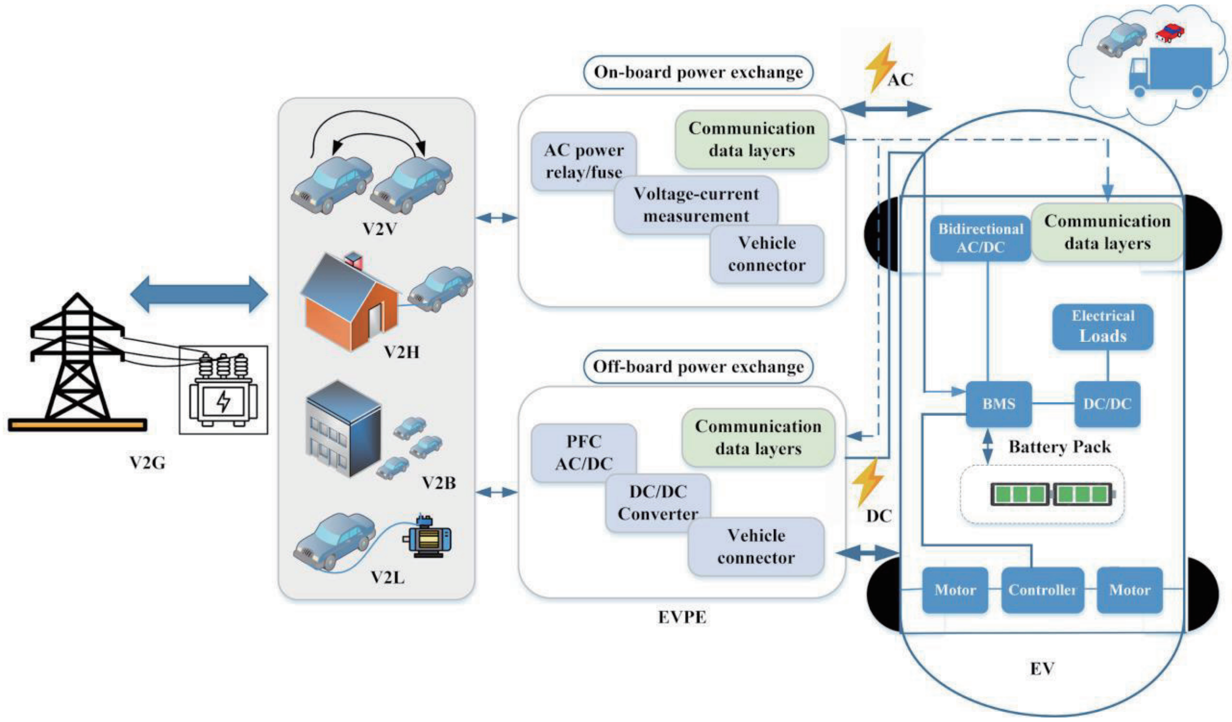

Fig. 3. Power flow from vehicle to others with communication [28].

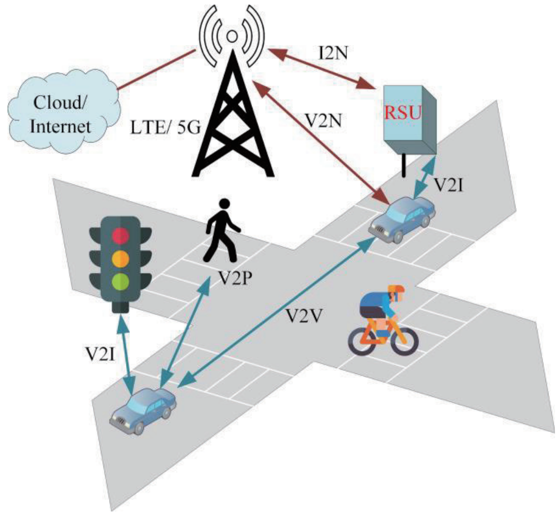

Fig. 4. Overview of V2X communication.

an umbrella term encompassing various communication types (V2V, V2P, V2I, and V2N).

C. Integration of V2X Communication and V2X Topology

V2X communication (V2V, V2P, V2I, and V2N) can be used in the V2X topology (V2G, V2V, V2H, and V2L) for power flow from EV to others. This is the new concept of equipping the EV with V2X communication. V2X communication with EVs will be very useful to enhance safety and enable the vehicles to share information about their speed, direction, and location with each other and infrastructure, helping to prevent accidents by alerting drivers or triggering autonomous systems in advance about potential collisions, road hazards, or other dangerous conditions. For effective integration of V2X communication and V2X topology, a few key factors need to be considered. Fig. 5 shows the major features for the integration of V2X communication with V2X topologies.

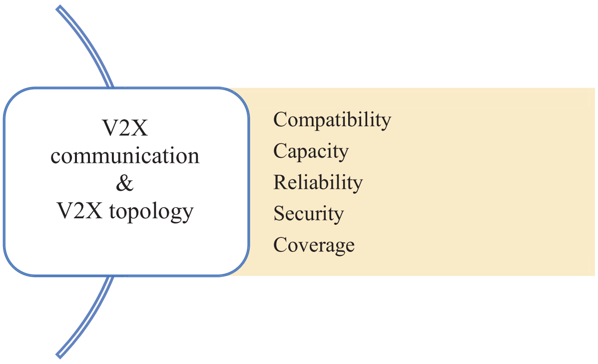

Fig. 5. Major features need to be considered for integration.

II. Different V2X Topologies and Their Definitions

V2X topologies refer to the various modes of connection and interface between EVs and the power grid. V2X is an umbrella term that covers a range of technologies and services that enable EVs to interact with various elements of the power system, such as the grid, buildings, other EVs, and even pedestrians. V2X topologies represent the different ways in which these interactions can occur, depending on the application, location, and energy service being provided.

There are several V2X topologies, including V2G, V2B, V2H,

TABLE IV
Detail of Different Components Required in the Various V2X Topologies

Topology Type	PV Integration	Vehicles	Aggregator Required	DC/DC Rating	DC/AC Rating	AC/DC Rating	Battery
V2G	-	Many	Yes	High	High	-	Bigger size
G2V	-	Single	No	Low	-	Low	-
V2H	Rooftop	Single	No	Low	Low	-	Small
V2H (fleet)	Rooftop	More	Yes	High			Very smal
V2B	Buliding integrantion	More	Yes	High	High	-	Medium

TABLE V
The Advantages and Disadvantages of V2X Topologies

Type	Advantage	Disadvantage
V2G	Provides cheap energy storage Load balancing for grid stability Renewable energy integration Cost savings of installing peak plants	Battery degradation Complexity in the infrastructure Limited availability of the technology Implementation cost
V2H	Backup power when grid is not available Cost savings during peak energy demand Increased energy efficiency Environmental benefits by reducing greenhouse gas emissions	Battery degradation because of frequent charging and discharging of installation is high Compatibility issues, Battery degradation Limited power output from the EV battery
G2V	Grid stabilization during off-peak hours Cost saving Energy security Environmental sustainability by using solar and wind energy	Battery wear and tear Potential security risks of cyberattacks Limited availability because of a lack of infrastructure Grid overload Power grid compatibility
V2H (fleet)	Increased efficiency Environmental sustainability Increased revenue Reduced downtime Improved safety	High initial investment Potential overload of the power grid Limited availability Cybersecurity risks Compatibility issues
H2V	Lower energy costs Convenience Reduced environmental impact Increased energy resiliency Improved energy efficiency	Limited range Technical complexity Initial cost Grid dependence Compatibility
V2B	Peak shaving Increased resiliency Reduced environmental impact Backup power Load balancing	Limited energy capacity Technical complexity Vehicle availability Battery degradation Cost
B2V	Energy storage Enhanced building Improved resilience Cost savings Reduced emissions	Complexity Compatibility Cost Range limitations Security
V2V	Improved safety Increased accessibility Better awareness Enhanced convenience Creased efficiency	Privacy concerns Cybersecurity risks Compatibility Cost Reliance on infrastructure
V2L	Energy storage Convenience Environmental benefits Grid stability Cost savings	Battery degradation Infrastructure requirements Compatibility Cost Cybersecurity

V2L, and V2V [29]. Each topology describes a distinct mode of interaction and energy service that EVs can offer. V2G involves the use of EVs as a source of mobile storage of energy and flexibility for the grid. V2H and V2B refer to the usage of EVs as backup power sources for homes or buildings, respectively. V2L involves using EVs to power various loads, such as lighting or appliances, directly. V2V refers to the use of EVs to transfer energy between vehicles, for example, in the case of a stranded

TABLE VI
WORLDWIDE RECENT PROJECTS ON V2X TOPOLOGY [30]

Time Span	Project Name	Country	Remarks/Services	Technology
2022-ongoing	ABB V2X Trondheim	Norway	-	V2G
2019-ongoing	AirQon	Netherlands	-	V2G
2020-2022	Equigy	Switzerland	Balance the grid, Decarbonize the energy system, Decentralized energy resources like solar and wind, Energy consumers through V2G	V2G
2014-2017	Amsterdam V2G	Netherlands	Time shifting,Two DC, CHAdeMO chargers are used.	V2H
2019-2022	BDL: - Bidirectional charging management	Germany	Frequency response, Arbitrage, Dist. services, Time shifting	V2H, V2G
2019-2022	BloRin	Italy	Frequency response, Time shifting, The primary objective of this project is to incorporate the V2G charger into the BLORIN block chain platform for managing energy resources rather than concentrating on building a fleet of vehicles.	V2G
2021-2022	V2G at home	Netherlands	Time shifting and energy arbitrage	V2H
2018-2022	EV elocity	UK	Peak demand shifting, Energy arbitrage	V2G
2015-2018	Distribution System V2G	USA	Time shifting for energy users, Distribution services	V2G
2017-2020	INVENT - UCSD	USA	Frequency regulation, Peak shifting, Distribution services	V2G

TABLE VII
COMMUNICATION PROTOCOLS FOR V2X TOPOLOGIES

Topology	Description	Communication Protocol
V2G	This involves the flow of energy between an EV and the main electrical grid. It's a bidirectional process, with energy going from G2V during charging and from V2G when the vehicle's stored energy is sold back to the utility grid or used to supplement it during peak demand periods.	OCPP (Open charge point protocol), IEC 15118, Wi-Fi, ZigBee and IEEE 802.15.4
V2H	This is a subset of V2G and involves energy flow between the EV and a home's energy system. It enables the EV to power the household, especially during power outages, reducing the home's reliance on the grid.	ISO 15118, ZigBee and IEEE 802.15.4
V2H (fleet)	A fleet of company vehicles or shared vehicles that are charged through a central charging system when not in use. In this scenario, during off-peak hours or times of low demand, these vehicles can be charged from the grid. Conversely, during periods of high demand or during power outages, these vehicles could provide power back to the building or grid.	ISO 15118, ZigBee and/or IEEE 802.15.4
V2B	V2B is a technology that uses EVs to provide power to buildings. Just like in V2G and V2H in V2B, the battery of an EV acts as a temporary energy storage device, which can provide electricity back to the building during peak times or power outages.	ISO 15118, ZigBee and IEEE 802.15.4

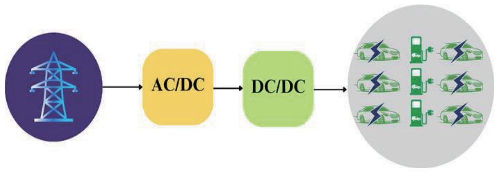

Fig. 6. Power flows from the grid to an electric vehicle.

EV that needs a boost from another EV. Fig. 6 shows the unidirectional power flow from the utility grid to the EVs.

The details of the different components required for V2X topologies are given in Table IV. The advantages and disadvantages of V2X topologies are given in Table V. Table VI shows the recent projects on V2X topology. Table VII shows the communication protocols for V2X topologies. A year-wise analysis of V2X topologies and applications is given in Table VIII. The services, optimization objective, and constraints for V2G are listed in Table IX.

A. Vehicle to Grid

V2G is a topology that allows EVs to discharge electricity from their batteries spinal to the electrical grid during periods of high demand or in emergency situations, in addition to charging from the grid. Fig. 7 indicates the power flow from an EV to the grid with an energy storage system.

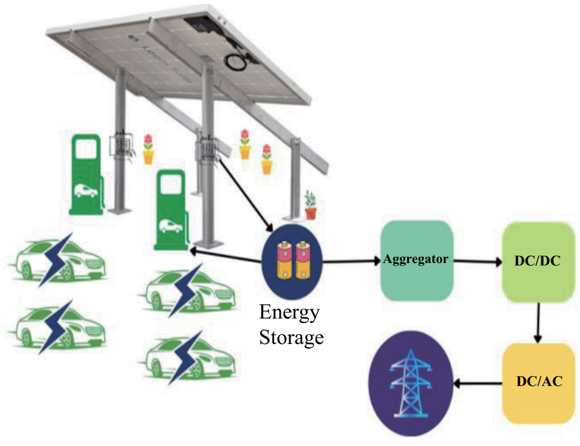

Fig. 7. Electric vehicle to grid with battery storage system.

V2G topology is based on bidirectional charging, which allows EV batteries to be charged or discharged based on the needs of the grid. The technology permits EV owners to sell

TABLE VIII
Year-Wise Analysis of Research on V2X Topologies

Ref.	Year	Type of Connection	Remarks
[31]	2023	V2X	The high-frequency magnetic link (HFML) and Si-C switches used in the DAB bidirectional converter are used to improve efficiency.
[32]	2023	V2G	Bidirectional converter topologies are used for V2G.
[33]	2022	G2V	Discussed charging rectifiers, power trains, DC-DC converters, motor-driving inverters, and control schemes designed for EV applications, the current status, opportunities, challenges, and applications of wireless power transfer in electric vehicles.
[34]	2022	V2G	V2G applications include the regulation of active power demand, reactive power compensation, and power factor correction.
[35]	2022	V2X	V2X, in the form of EVPE, the multi-layer Cyber-Physical Production Systems (CPPS) framework proposed, bidirectional charging, and the impact of e-mobility as emerging digitalization technologies, such as AI, DLT, and IoT, continue to advance.
[36]	2021	V2X	VANETs to ensure efficient and reliable communication among vehicles. V2X communication-based mixed approach for dynamic topology control in VANETs. The proposed approach combines both V2V and V2I communication to achieve efficient and reliable communication.
[37]	2021	G2V	There are several types of transformers that can be used in fast charging stations, depending on the specific requirements and charging rates. High frequency transformer works up to 100 kHz.
[38]	2019	V2X	The integration of V2X and V2X regulatory issues.
[39]	2019	V2V, V2I	The merging of the longitudinal and lateral control algorithms is examined using the Hurwitz stable theorem and the Lyapunov technique. This platoon control system is considered to increase the performance of platooning in terms of stability, safety, and fuel efficiency.
[40]	2019	V2G	This paper describes the issues of integrating renewable energy resources and the utilization of EVs, for efficient, reliable, and uninterruptible power flow are covered.
[41]	2019	V2X	The development efforts related to smart cities, with a particular focus on V2X, I2X, and P2X (pedestrian-to-everything) communication.
[42]	2018	V2X	There are several models that are commonly used to study battery health degradation, including the NREL model, the Knee Region model, the Wang model, and the MOBICUS model.
[43]	2017	V2G	The use of the constant power method for the V2G power exchange profile and the hybrid GA-PSO optimization algorithm for minimizing losses, voltage fluctuations, and costs are notable contributions of the study.
[44]	2015	V2G	It suggests that using solar power generated by office buildings and parking lots for EV charging can maximize the use of renewable energy and reduce carbon emanations. The long parking times at workplaces make them ideal for implementing V2G topology.
[45]	2013	V2G	The system provides a real-time view of the voltage profile, voltage stability, operations of step voltage regulators (SVRs), power, and energy loss parameters and helps in identifying any abnormalities or issues in the power system.
[46]	2013	V2X	V2X architecture that uses both V2V and V2I communication to predict the traffic density on the road using RSU.
[47]	2013	V2G	V2G impact, potential, limitations and RES integration.

TABLE IX
Services, Objectives and Constraints for V2G Topologies [48]

V2G Type	Services	Optimization Objective	Constraints		Ref.
			Power System	Electric Vehicle	
Unidirectional	Voltage regulation	Minimize power loss	Voltage stability	Battery energy exchange rate limit	[29], [48]
	Frequency regulation	Minimize emission	Line thermal limit	Battery SOC limit	
	Load shifting	Minimize operation costs		Battery capacity	
	Spinning reserve	Maximize profit	Generation limit	EV availability	
	Power grid regulation			Energy price	
Bidirectional	Demand response	Minimize operation costs	Power stability	Battery energy exchange rate limit	[48], [49], [50]
	Load leaving	Maximize the generation of renewable energy	Voltage limit	Battery SOC limit	
	Load peak shaving	Minimize error of load curve from target load curve	Generation limit	Battery capacity	
	Voltage regulation	Minimize emission	Line thermal limit	EV availability	
	Improve system reliability	Maximize profit	Load forecasting	System efficiency	
	Spinning reserve	Minimize power loss	Upstream supplier limit	Energy price	
	Power grid regulation		System loading limit		

excess electricity stored in their vehicle batteries back to the grid, either for a profit or as a way to offset the cost of charging. It can also help grid operators manage peak demand periods, provide frequency regulation and spinning reserve services, and improve the overall reliability and stability of the grid. Fig. 8 shows the power flow from an EV to the grid without an energy storage system.

For utilities and grid operators, V2G can help manage peak

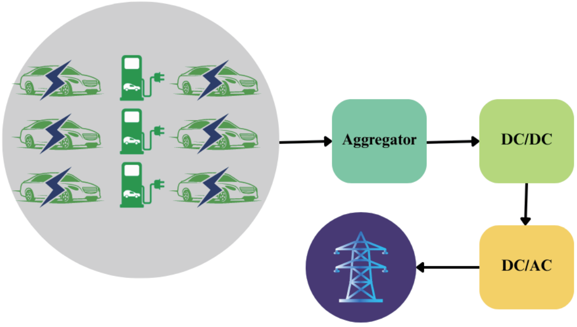

Fig. 8. Power flows from an electric vehicle to grid without an energy storage system.

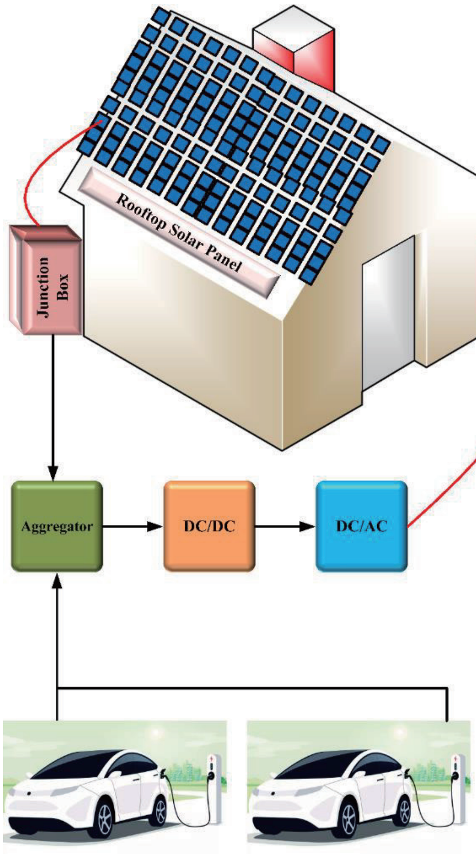

Fig. 9. Power flow from EV and PV to home without grid.

demand and reduce the need for expensive grid infrastructure upgrades. Additionally, it can provide an alternative source of backup power in the result of a grid outage or other emergency.

B. EVs to Building or EV to House

V2B and V2H are two different types of V2X topologies. Both technologies allow EVs to discharge their batteries to provide energy to buildings or homes in peak demand periods or power outages [26].

It can help reduce stress on the power grid and lower energy costs for building owners. In this scenario, the EVs are connected to the building's electrical system via a specialized charging station. Power flow from EV and PV to homes without Grid is given in Fig. 9. Power flow from EV, PV, and utility grids to homes is given in Fig. 10. The aggregator is used to collect the power from all the EVs and send it for further transfer. During a blackout, the EV can be connected to the home's electrical system via a bidirectional charger to provide power. In this scenario, the EV can also be used as a temporary power source during emergency situations or natural disasters.

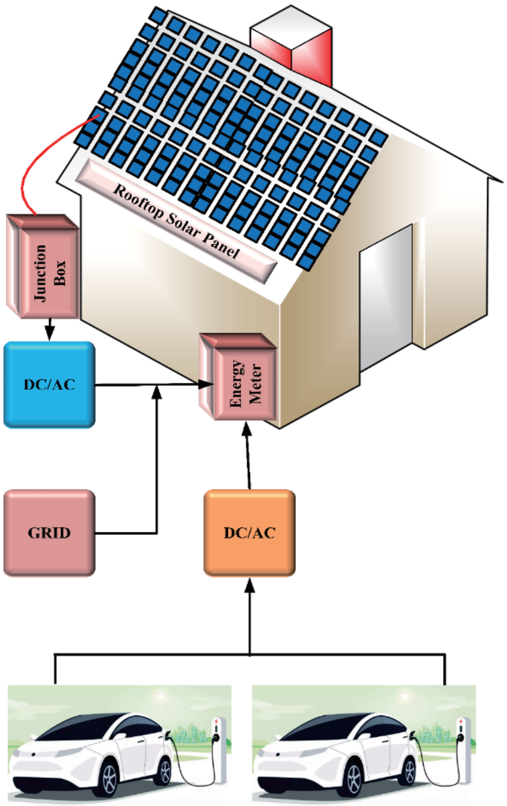

Fig. 10. Power flow from EV, PV and utility grid to home.

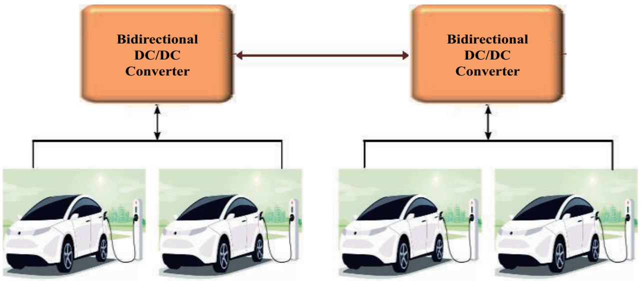

Fig. 11. Power flows from EV to EV.

C. Vehicle to Vehicle

V2V power flow, which refers to the capability of sharing energy with each other. The V2V bidirectional power flow system involves two electric vehicles that are equipped with bidirectional chargers, which can either charge the battery or discharge it. The charger can communicate with the other vehicle and determine the amount of energy required or

TABLE X
STANDARDS USED FOR V2X COMMUNICATION

Communication Standard	Focus	Application
IEEE 802.11p	V2X communication	V2V, V2I
IEEE 802.11 ETSI ITS-G5	V2X communication	V2V, V2I, and V2P
SAE J2735	V2X message sets	Data dictionary for DSRC
ISO 15118	V2G communication interface	Bi-directional charging/discharging
Cellular-V2X (C-V2X)	V2X communication	V2V, V2I, V2P, and V2 roadside unit (RSU)
SAE J2945/x series	V2X safety communications	V2V, V2I, and V2P
IEEE 1609 family	WAVE architecture and services	V2V, V2I
3GPP	LTE, 4G, and 5G	V2P, V2V, V2I, C-V2X, V2 RSU

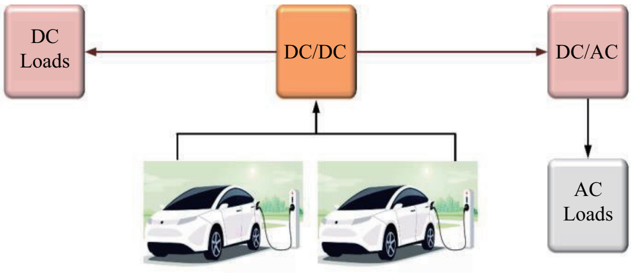

Fig. 12. Power flow from an electric vehicle to AC/DC load.

available for transfer [21]. V2V bidirectional power flow has several potential applications shown in the Fig. 11. For instance, it can enable electric vehicle owners to share energy with each other, reducing their dependence on the electric grid. It can also be used in emergency situations to provide energy to vehicles that are stranded or have run out of battery power. Additionally, it can help balance the grid by allowing excess energy to be transferred to other vehicles or the grid [1].

V2V scenarios rarely happen, but in countries like India where there is a lack of charging stations, if the BEV car is far away and has a shortage of energy, another BEV can supply enough energy to reach the nearest charging station.

D. Vehicle to Load

V2L refers to a technology that allows EVs to transfer energy from their battery to power external loads. This can be done using the vehicle's onboard charging system or with the help of off-board system and can be useful in a variety of situations, such as powering tools at a job site, providing electricity during a power outage, or even serving as a backup power source for a home or for a remote site. V2L topology is becoming increasingly popular as EV adoption continues to grow and as more advanced charging systems are developed. The power flow from an EV to AC or DC Loads is given in Fig. 12.

III. TECHNICAL REQUIREMENTS AND SPECIFICATIONS FOR V2X COMMUNICATION AND V2X TOPOLOGY

Communication protocols: V2X systems require specific communication protocols that enable the transfer of data and information between different devices and systems. Some of the commonly used communication protocols include IEEE 802.11p, 3GPP, Cellular V2X (C-V2X), DSRC, internet of Things, Bluetooth, etc.

Hardware components: V2X systems require specific hardware components to facilitate communication and power transfer. These components may include antennas, power electronics, batteries, inverters, and voltage converters.

Safety standards: V2X systems must comply with strict safety standards to ensure that they do not pose any risks to drivers, passengers, or pedestrians. Safety standards may include crash testing, Electromagnetic compatibility (EMC) testing, and environmental testing.

Power requirements: V2X systems require a reliable power source to operate effectively. The power source may be a battery, a fuel cell, or a direct connection to the grid. The power source must provide enough energy to support the V2X system's power requirements.

Data security: V2X systems must confirm the security and privacy of the data and information being transferred between different devices and systems. This may involve using encryption techniques, digital signatures, and secure communication protocols.

Interoperability: V2X systems must be interoperable, meaning they can communicate and exchange information with other systems regardless of the manufacturer or technology used.

IV. STANDARDS FOR V2X COMMUNICATION

V2X communication technology enables vehicles to communicate with other vehicles, infrastructure, and devices. It provides a range of aids, including enhanced safety, abridged traffic congestion, and increased energy efficiency[51], [52]. It uses various communication protocols and topologies, including V2V, V2I, V2P, and V2G [52], [53]. These topologies have different advantages and disadvantages, and technical requirements and specifications need to be met for successful implementation. This technology can also be applied to CAVs [54] to improve safety and efficiency. A few communication technologies are given below. Fig. 13 shows V2V, V2P, V2I, and V2N wireless communication. It has two types of communication ranges: long and short distance. Short communication is done with DSRC and Wi-Fi. For long-distance communication, C-V2X is required. GPS can also be used to detect the location of vehicles and send data to other

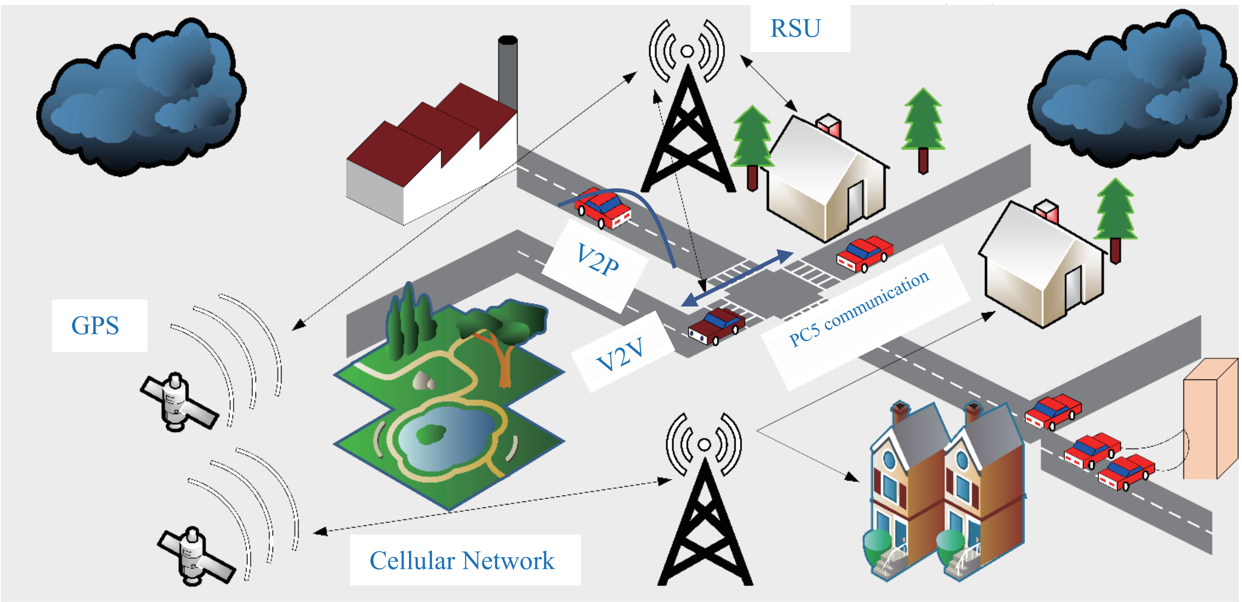

Fig. 13. V2V, V2I, V2P, and V2N wireless communication.

TABLE XI
REVIEW OF STANDARD FOR V2X COMMUNICATION

Ref.	Year	Communication Standards
[55]	2023	V2X communication standards like IEEE 802.11p., ITS G5 (DSRC), 3GPP (C-V2X)
[56]	2022	ETSI ITS-G5, 3GPP LTE-V2X, SAE J2735, IEEE 1609, (ETSI TS 103 097) including block chain technology
[57]	2020	IEEE 802.11p, 3GPP PC5, IETF IPWAVE, IEEE 1609 and ETSI ITS
[58]	2009	SAE J2735
[59]	2020	LTE and 5G-based C-V2X, 3GPP
[60]	2020	DSRC/WAVE and 3GPP-based LTE and 5G C-V2X
[61]	2019	3GPP
[62]	2009	DSRC

TABLE XII
INDUSTRIAL APPLICATION PROJECT REGARDING V2X COMMUNICATION [31]

Year	Project Name	Country	Brief Description	Technology
2012	Safety pilot model deployment	USA	Project involving 2800 vehicles equipped with V2X technology to study its impact on traffic safety.	DSRC
2013	Crocodile	Europe	Data management end-user services.	IoT based
2014	Ann arbor connected vehicle test environment	USA	One of the largest real-world deployments of connected vehicles and infrastructure.	DSRC
2014	Cooperative ITS corridor	Germany-Netherlands-Austria	Joint project testing and demonstrating cooperative intelligent transportation systems, including V2X.	ETSI ITS G5
2013-2015	COMPASS4D	Europe	Launched in seven European cities to improve road safety, energy efficiency, and comfort in city traffic using V2X.	ETSI ITS G5
2015-2020	Connected vehicle pilot deployment program	USA	Includes projects in Wyoming, Tampa, and New York City. Focused on implementing V2X technology to improve safety and reduce traffic congestion.	DSRC, C-V2X
2014-2019	SCOOP@F	France	Pilot program focusing on testing cooperative intelligent transport systems on French roads, involving 3000 connected vehicles and a 2000 km road network.	hybrid cellular/ITS G5
2017-2020	SAFER-LC project	Europe	EU-funded project to improve safety at level crossings by integrating V2X technology.	-
2016-2020	Queensland C-ITS pilot project	Australia	Launched by Queensland's Department of Transport and Main Roads, this project aimed to test a range of cooperative intelligent transport system technologies.	C-V2X
2017-2019	K-City	South Korea	A test bed for autonomous vehicle technologies, including V2X communication, was developed by South Korea's Ministry of Land, Infrastructure, and Transport.	C-V2X

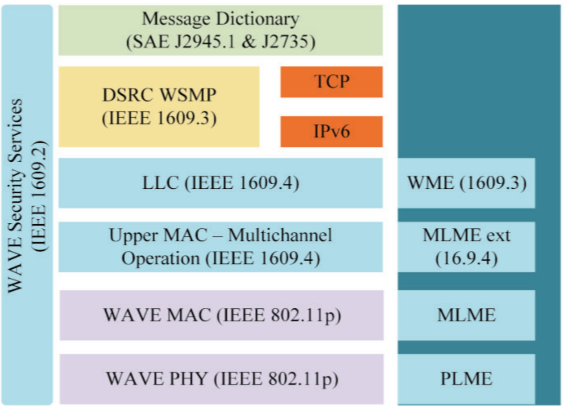

Fig. 14. Protocol stack of WAVE-DSRC.

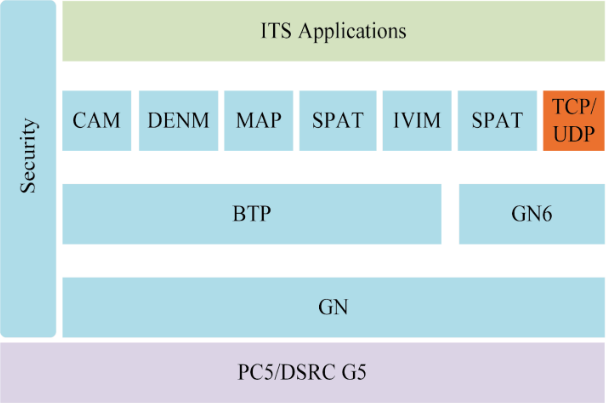

Fig. 15. Protocol stack of ETSI ITS-G5.

infrastructure using different communication protocols. Table X shows the standards used for V2X communication. Table XI contains the details of the review of standards for V2X communication. Table XII shows the industrial application project regarding V2X communication throughout the world.

A. IEEE Standard

In 2010, IEEE accepted the revision IEEE 802.11p, aimed at standardizing vehicular communication systems. Subsequently, in 2016, this amendment was incorporated into the IEEE 802.11 standard [63]. It introduced a new operation mode called OCB mode for 802.11p-compliant devices, which does not require authentication or association. Instead, only the central channel frequency and channel bandwidth need to be set for communication. This amendment primarily focuses on the PHY and MAC layers for WLAN-based V2X communications. Fig. 14 shows the protocol stack of WAVE-DSRC.

To extend this standard to the application layer, the IEEE developed the IEEE 1609 standard, also known as WAVE. In Europe, the ETSI ITS worked on standardizing applications and a security outline on top of IEEE 802.11p. Two initiatives that benefited from this work are SAE [64], known as DSRC, and ETSI ITS-G5. Both define upper layer protocols operating on top of the 802.11 OCB mode. These initiatives enable short-range communication for direct interactions, including V2V between vehicles and V2I between vehicles and RSUs.

B. 3GPP Standard

Since 2014, the 3GPP has been focusing on the standardization of vehicular communication based on the already standardized 4G LTE and later incorporating 5G mobile cellular connectivity. The initiative commenced with the introduction of Proximity Services (ProSe) functionality in Release 12, originally developed for public safety communication. Support for direct vehicle-to-vehicle communication was later added in Release 13.

To extend ProSe abilities to D2D communications within a cellular environment, a new interface known as PC5 was established in 3GPP TS 23.285 [65] for the LTE system. A corresponding functionality for the 5G system exists in 3GPP TS 23.287 [66]. The PC5 interface, also known as side link, provides an additional communication path to the existing Uu interface between the user equipment and the base station (referred to as eNodeB in LTE and gNodeB in 5G in standard specifications). This integrated approach of short-range side link (PC5) and long-range (Uu) communications within the same system is seen as corresponding, facilitating a variety of new use cases or services. This technology, leveraging 4G LTE or 5G for V2X communications, is incorporated under the 3GPP standard for C-V2X. Fig. 15 shows the protocol stack of ETSI ITS-G5.

C. ISO Standard

The International Standard Organization (ISO) has formulated numerous standards relevant to vehicles. ISO 26262 [64] provides a definition for the functional safety of electrical and electronic devices used in the automotive industry. This standard is adapted from IEC 61508, a universally applicable safety standard that prescribes the safety lifecycle for electronic systems and products. As a risk-based safety standard, it enables vehicles to evaluate and mitigate the risk of potential hazardous situations to prevent systematic vehicle failure. This standard was initially published in 2011 and underwent revision in 2018 [64], wherein aspects of cybersecurity were included to a limited extent.

ISO/SAE 21434 [67] outlines the cybersecurity standard for road vehicles, initiated as a joint venture between ISO and SAE in 2016. Grounded in SAE J2735 [68], ISO/SAE 21434 establishes a process and sets minimum criteria for cybersecurity engineering across all stages of the product lifecycle to avert cyberattacks on vehicles. Compliance with this standard ensures a uniform cybersecurity development process throughout the vehicle development lifecycle across the entire automotive industry. However, as noted in an analysis by Macher et al. [69], ISO/SAE 21434 doesn't provide solutions for specific execution details or best practices, nor does it offer a "silver bullet". It also doesn't cover cybersecurity for

TABLE XIII
YEAR-WISE ANALYSIS OF V2X COMMUNICATION AND THEIR APPLICATIONS

Ref.	Year	Communication Type	Remarks	Communication Protocol
[71]	2023	V2X	The proposed taxonomy enables systematic analysis of V2X network slicing to provide tailored connectivity services with varying requirements, optimizing network performance.	-
[72]	2023	V2X	A traffic management approach using C-V2X to improve intersection throughput by integrating networked control platooning and computation-centralized platooning.	C-V2X
[73]	2022	V2X	PCACC is a platooning mechanism that uses prediction assistance to optimize performance. Vehicles broadcast their status to build a local platoon model, reducing information latency and improving overall performance.	C-V2X
[74]	2022	V2X	A simulation framework is developed to study the performance of a VoIP uplink application over V2N communication in two different NR-V2X communication scenarios: NRCar and Lumsden. The study uses the 5G simulator OMNeT++ with INET, Simu5G, and Veins modules.	C-V2X
[75]	2021	V2X	A literature review discussing the integration of Software-Defined Networking (SDN) in the context of V2V and V2X communication, covering routing, location management, and patch scheduling.	C-V2X
[76]–[78]	2021	V2X	RSUs play a crucial role in the V2X ecosystem by enabling communication between vehicles and infrastructure, and their performance affects overall V2X system performance. A comprehensive V2X testing framework involves scenarios, equipment, and methodologies.	DSRC
[79]	2021	V2V	This survey provides an overview of the technical specifications, features, and limitations of DSRC and LTE-V2X technologies for V2X communication. It evaluates their performance through field tests and summarizes related works that have compared and analyzed the two technologies.	5G
[80]	2021	V2X	A proposed approach uses unmanned aerial vehicles (UAVs) as flying base stations equipped with caching capability for efficient data dissemination in V2X networks. The proposed scheduling protocol integrates proactive caching and file sharing strategies, optimized with a UAV dynamic trajectory scheduling (DTS) algorithm, a file sharing cycle framework, and a channel prediction algorithm. A relay ordering algorithm is also suggested to enhance the file sharing process.	DSRC
[81]	2020	V2X	To predict the future traffic flow and density using a combination of the Topological Graph Convolutional Network (ToGCN) and the sequence-to-sequence (Seq2Seq) outline. The Seq2Seq model then captures the temporal correlations and predicts future traffic, density, and traffic management and control.	LTE and 5G
[82]	2019	V2X	A new key distribution scheme for authentication in V2X networks is proposed. The scheme distributes key pairs based on the position information of the vehicles and RSUs, which can pre-distribute keys according to the future locations of the vehicles.	DSRC and C-V2X
[83]	2016	V2X	This article reviews potential hybrid architectures that combine DSRC and cellular technologies to improve V2X communication. The focus is on discussing the challenges of interworking causing from vehicle motion, such as perpendicular handover and network range matters.	DSRC and C-V2X

autonomous vehicles or non-vehicle entities like RSUs.

ISO 39001 [70], published in 2012, serves as a management system standard for Road Traffic Safety (RTS). Aimed at improving traffic safety, this standard is geared towards organizations striving to enhance traffic safety. Those organizations in compliance with ISO 39001 can earn certification of compliance.

D. Wi-Fi Protocols

There are several Wi-Fi-based protocols that can be used for V2X communication, including IEEE 802.11p and ITS-G5. IEEE 802.11p, also known as WAVE, is a standard developed specifically for vehicular communication. ITS-G5, developed by the ETSI, is another Wi-Fi-based protocol designed for use in ITS. Both IEEE 802.11p and ITS-G5 operate in the 5.9 GHz frequency band and can support communication between vehicles as well as between vehicles and roadside infrastructure. Fi-based protocols have the advantage of being widely used and relatively low-cost, but they may not offer the same level of reliability and security as dedicated V2X communication technologies like DSRC or C-V2X.

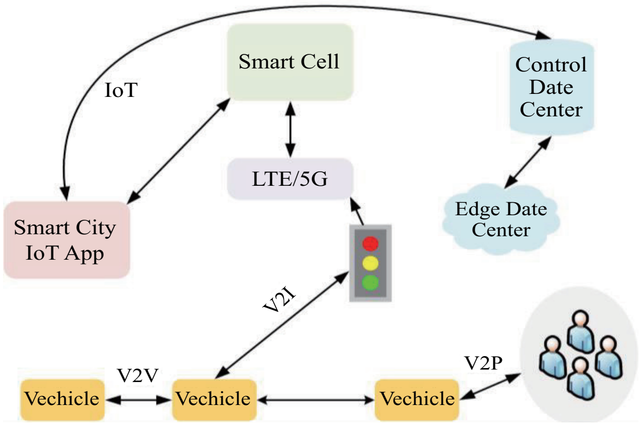

Fig. 16. IoT application in V2X.

E. Internet of Things

IoT is a rapidly growing technology that is increasingly

TABLE XIV
ADVANTAGES AND DISADVANTAGES OF DIFFERENT COMMUNICATION PROTOCOLS

Communication Type	Bandwidth	Advantage	Disadvantage	Complexity	Cost	Efficiency
DSRC	5.9 GHz	Low latency Dedicated frequency band Secure communication Mature technology Low cost	Limited bandwidth Limited range Limited coverage Spectrum allocation for other communication also so there may be interference issue Obsolescence with the emergence of new wireless communication	Less	Cheap	Depends on the traffic data
C-V2X	(1.4-100) MHz	Greater range Better coverage Lower latency Better reliability Supports multiple communication modes like broadcast, multicast, and unicast, while DSRC supports only broadcast and unicast.	Cost Data security Security Dependence on network coverage Standardization	Medium	Expensive	More compare to DSRC
Wi-Fi	2.4 and 5 GHz	High-speed connectivity Cost-effective Easy to use Flexibility Convenience Better coverage Lower latency Better reliability Supports multiple communication modes like broadcast, multicast, and unicast while DSRC supports only broadcast and unicast. Cost-effective Easy to use Flexibility Convenience	Limited range Security concerns Interference Bandwidth limitations Not so reliable Data security Security Dependence on network coverage Standardization Security concerns Interference Bandwidth limitations Not so reliable	Low	Less expensive	Medium

being integrated into V2X communication systems. It refers to the network of physical objects, vehicles, and devices that are connected to the internet and able to communicate with each other, as shown in Fig. 16. It can enable vehicles and other devices to share data and information with each other in real-time, enhancing the overall efficiency and safety of the transportation system. For example, IoT sensors can be used to monitor traffic conditions, weather patterns, and other factors that can affect traffic flow, and this information can be shared with connected vehicles to optimize routing and reduce congestion. It can also enable V2X communication systems to gather and analyze huge amounts of information, allowing for more precise predictions and better decision-making. IoT is very useful in V2X communication because it enables the vehicle to connect to the internet. It is the most trending technology for industrial applications to control and monitor processes. Charging stations for EVs can be connected to the internet through IoT.

A year-wise analysis of V2X communication protocols and their applications is given in Table XIII. A comparison of different Communication protocols, advantages, and disadvantages is given in Table XIV.

V. OPPORTUNITIES AND CHALLENGES OF V2X COMMUNICATION

In this section, we discuss the challenges and opportunities for V2X communication.

A. Opportunities for V2X Communication

1) Improved safety: It can deliver real-time data to vehicles about potential hazards, accidents, and traffic congestion, enabling drivers to make informed decisions and avoid accidents.
2) Increased Efficiency: It can help optimize traffic flow, reduce congestion, and improve fuel efficiency, leading to reduced travel times and fuel consumption.
3) Enhanced mobility: It can improve the accessibility and efficiency of public transportation, making it more attractive to users.
4) Reduced Environmental Impact: It can help reduce emissions by enabling more efficient routing and reducing congestion.
5) New Business Opportunities: V2X technology presents new opportunities for service providers and technology

companies to develop and offer innovative services and applications.

B. Challenges for V2X Communication

1) Standardization: In the context of V2X topologies, standardization is crucial to ensure the compatibility and interoperability of different V2X systems and components and to enable seamless communication among vehicles, infrastructure, and other devices. Standardization also helps to reduce costs and risks related to the development, deployment, and operation of the systems, and to facilitate the adoption and diffusion of these topologies [35].
   There are several organizations and bodies involved in the standardization of this technology, including the ISO, SAE, ETSI, and IEEE, among others. These organizations develop and publish standards, guidelines, and technical specifications for various aspects of this technology, such as communication protocols, network architecture, security, and testing and certification procedures.
2) Security: Security is a crucial aspect of V2X technology since it involves communication between vehicles and the infrastructure, and any vulnerability in the communication network can result in potential threats to the safety of the passengers and the vehicles. The security challenges of V2X technology includes the need for secure communication channels, authentication and authorization of the devices, secure storage of sensitive data, and protection against cyberattacks. To report these security, challenges, various security mechanisms, such as encryption, digital signatures, and secure booting, have been projected and implemented in V2X systems.
3) Cost: One of the major challenges in the deployment of this technology is the cost associated with it. The development and installation of V2X infrastructure involve a significant investment, including the cost of sensors, communication equipment, and other hardware and software components. Additionally, the cost of maintaining and upgrading the infrastructure over time is also a consideration. This can be a barrier to adoption, particularly for smaller municipalities or organizations that may not have the resources to invest in such technology. However, as the technology becomes more widespread and economies of scale are achieved, the cost is expected to decrease, making V2X more accessible to a wider range of users.
4) Reliability: Reliability is an important challenge for this technology. The communication system must be highly reliable to ensure that safety-critical messages are delivered in a timely manner. This is especially important for applications such as collision avoidance and emergency warning systems. The system must be designed to minimize the risk of message loss, delays, and interference. Numerous variables, such as the caliber of the communication link, the environment, and the dependability of the communication equipment, affect the reliability of the V2X system. The use of redundant communication channels and error correction codes can help improve reliability. Additionally, regular maintenance and testing of The V2X equipment can help ensure that the system is operating reliably.
5) Integration: V2X technology needs to be integrated with other technologies, such as autonomous driving and smart cities, to realize its full potential. Therefore, there is a need for collaboration between different industries and sectors to achieve this integration.

VI. CONCLUSION

V2X topologies and communication protocols with definitions, advantages, and disadvantages, along with the worldwide status of the projects on V2X topologies and V2X communications, are discussed in this paper. Further, comparisons of different communication protocols and power flows between different topologies are discussed. At last, the challenges and opportunities of V2X communications are discussed. By integrating both the technologies, EV can be upgraded with safety and communication.

These topologies have the potential to brighten the transportation industry by providing the facility so that vehicles and infrastructure can communicate with each other, leading to improved road safety, transportation efficiency, and sustainability. 3GPP, DSRC, C-V2X, Wi-Fi, and IoT are the prominent technologies that enable V2X communication, each with its own advantages and disadvantages.

As for future trends, this communication technology is likely to continue evolving and improving in the coming years. The development of 5G networks and the introduction of cellular V2X technology are expected to enhance this communication performance and enable new applications. Additionally, the incorporation of artificial intelligence and machine learning techniques can enable intelligent decision-making and optimization in V2X networks.

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