

Review

Road to Efficiency: V2V Enabled Intelligent Transportation System

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Abstract: Intelligent Transportation Systems (ITSs) have grown rapidly to accommodate the increasing need for safer, more efficient, and environmentally friendly transportation options. These systems cover a wide range of applications, from transportation control and management to self-driving vehicles to improve mobility while tackling urbanization concerns. This research looks closely at the important infrastructure parts of vehicle-to-vehicle (V2V) communication systems. It focuses on the different types of communication architectures that are out there, including decentralized mesh networks, cloud-integrated hubs, edge computing-based architectures, blockchain-enabled networks, hybrid cellular networks, ad-hoc networks, and AI-driven dynamic networks. This review aims to critically analyze and compare the key components of these architectures with their contributions and limitations. Finally, it outlines open research challenges and future technological advancements, encouraging the development of robust and interconnected V2V communication systems in ITSs.

Keywords: V2V communications; intelligent transportation systems; connected vehicles; autonomous vehicles; cellular vehicle-to-everything

1. Introduction

Intelligent Transportation Systems (ITSs) are revolutionizing the transportation industry by integrating advanced wireless communications systems to improve efficiency, security, and sustainability. These systems aim to reduce traffic congestion, shorten travel times, improve safety, and minimize environmental impacts [1]. An ITS encompasses electronic toll collection, dynamic route planning, autonomous vehicle technology, and real-time public transportation tracking. These developments support daily mobility and contribute to social objectives like emission reduction, energy conservation, and better urban planning [2,3].

The emergence of technologies like IoT and 5G connectivity has accelerated the acceptance of ITSs. Vehicular Ad-hoc Networks (VANETs), vehicle-to-vehicle (V2V), and Mobility Prediction are significant ITS applications designed to enhance vehicle movement and alleviate traffic congestion [4]. V2V communication represents a paradigm shift in vehicular connectivity, enabling real-time information exchange between nearby vehicles [5]. As automotive technology continues to evolve, the integration of V2V communication becomes increasingly crucial for enhancing road safety, traffic efficiency, and the overall driving experience. The fundamental premise of V2V communication revolves around vehicles acting as intelligent entities capable of sharing crucial data, including speed, position, and status, with nearby vehicles [6,7].

This shared information forms the basis for proactive decision-making, contributing to creating a connected and cooperative vehicular ecosystem. This study aims to establish the significance of V2V communication in the broader context of intelligent transportation systems. By providing a contextual framework, we set the stage for a focused exploration of the infrastructure components that play a pivotal role in shaping the effectiveness and reliability of V2V communication. Recently, V2V communication technologies have become



Citation: Naeem, M.A.; Chaudhary, S.; Meng, Y. Road to Efficiency: V2V Enabled Intelligent Transportation System. *Electronics* **2024**, *13*, 2673. <https://doi.org/10.3390/electronics13132673>

Academic Editor: Dongkyun Kim

Received: 22 May 2024

Revised: 28 June 2024

Accepted: 5 July 2024

Published: 8 July 2024



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essential in ITS development, potentially transforming road safety, traffic flow, and the driving experience. The paradigm shift is driven by progress in wireless communication, edge computing, artificial intelligence, and blockchain technologies [8]. These advancements are focused on improving vehicle connections and facilitating real-time data exchange between vehicles [9]. As more connected cars become available, assessing and comparing the effectiveness of different V2V communication protocols in various situations and environments is crucial [10]. This enables stakeholders to make informed decisions and develop strong and adaptable solutions to the complexities of modern transportation conditions.

In the era of smart and connected transportation systems, the effectiveness of V2V communication hinges on the intricate interplay of advanced infrastructure components [11]. It is imperative to recognize the pivotal role that infrastructure components play in realizing the full potential of this paradigm [12]. Moreover, the effectiveness of V2V communication depends on the deployment of specific infrastructures, including roadside units, onboard units, and communication gateways. These components are the backbone of a connected ecosystem, facilitating the seamless transmission and reception of critical data among vehicles. Understanding and optimizing these infrastructure elements are essential for unlocking the full potential of V2V communication, ensuring not only enhanced sustainable road safety but also contributing to the development of ITSs [13,14].

Therefore, V2V communication technology offers several advantages that can help reduce traffic congestion, enhance road safety, and lessen the negative impact on the environment. By providing vehicles with real-time information, V2V communication enables proper traffic flow, increased awareness among drivers regarding potential dangers, and improved traffic flow on the roads [15]. These improvements not only result in safe and efficient roadways but also in other environmentally sustainable development initiatives. V2V is expected to advance even faster in the next few years and be further entwined with the other ITS applications, further unlocking the opportunities V2V has for changing the nature of city transportation systems to be better, safer, cleaner, and more efficient [16,17]. The major contributions of this study are stated as follows:

- We present a review that contributes to this dynamic field by providing a comprehensive synthesis by critically analyzing the state of the art and aiming to identify trends, challenges, and emerging research areas of ITSs;
- Additionally, we seek to offer insights into the transformative potential of intelligent hybrid V2V communication systems in enhancing sustainable road cooperation, safety, and overall transportation efficiency;
- With this contribution, we aim to guide future research and developments in connected and cooperative vehicle systems for the ITS;
- We analyze and deliberate on the most advanced, sustainable V2V communication architectures;
- We thoroughly examine the advantages of V2V communication architectures, their contributions, and their limitations for ITS network environments.

The remaining portions of the article are grouped into the following categories: Section 2 outlines the rationale and motivation behind utilizing multiple V2V communication systems. Section 3 presents a comprehensive comparison of the latest relevant studies. Section 4 focuses solely on V2V communication methods. Section 5 presents a concise overview of the survey on certain communication architectures. Section 6 provides future research prospects and directions. Section 7 finally presents the conclusion.

2. Motivations

V2V is considered one of the potential technologies at the heart of ITSs. It is important to achieve such objectives as road safety, traffic management, and the negative impacts of transportation on the environment. The V2V systems enable the vehicle to acquire information about other vehicles' positions, velocities, and planned paths, which is critical for avoiding accidents and managing traffic flow [18]. This capability is essential as urbanization rises and accidents are likely to occur more frequently, coupled with traffic

congestion. Another advantage of V2V communication is that it can significantly reduce car accidents. Such applications include real-time information sharing so vehicles can warn one another of risks such as sudden braking, objects on the road, or unfavorable weather conditions [19]. This early warning system allows a driver to take preventive action much earlier than relying on the time it takes for a human to react [20]. However, V2V communication empowers Advanced Driver Assistance (ADA) and autonomous control technologies that help to avoid road accidents in a faster and more precise way than the human driver. In addition to safety benefits, the primary purpose of V2V communication is to improve traffic efficiency. Through collaboration with others, the vehicles can employ resourceful path and velocity plans that will prevent traffic density formations and, in turn, shorten the overall transport time. For instance, V2V-equipped cars can develop platoons of vehicles that move nearby at the same speed limit [21]. It maximally expands the area of roads to transport more vehicles simultaneously, contributing to fuel efficiency and decreasing emissions. Thus, V2V communication helps improve traffic flow and is necessary to cater to cities' increasing traffic demands [22]. The environmental aspect is another area closely touched by V2V communication, where many differences are noted. Because they promote traffic flow and decrease density, V2V systems contribute to reducing greenhouse gas emissions and fuel consumption [23]. This is especially noble in the compacted regions where mobility is a chief contributor to smog.

Furthermore, V2V communication enables the connection of electric and hybrid vehicles by effectively utilizing energy and determining the most efficient route. With transportation being an important area of focus where green innovations are being implemented, V2V communication will be an important avenue that boosts the realization of these environmental objectives [24]. Last but not least, the potential of V2V communication is not limited to the space it occupies in ITSs; it also enhances the other ancillary structures [25]. They allow smooth communication between vehicles and other entities, such as traffic signals and roadway appliances, to create a highly responsive transportation system. This system integration allows continuous flow control, route flexibility, and road incident handling. Besides improving the performance of individual vehicles, V2V communication, which acts as a basis for multiple ITS applications, also helps to optimize the functionality of the transportation system as a whole [26].

V2V communication is the foundation for many new services and applications, from platooning to autonomous driving. Through the lens of real-time data interchange and collaborative decision-making, travelers are promised a pattern of ease, comfort, and accessibility like never before, creating a picture of mobility redefined. From the domains of wireless communication to the frontiers of artificial intelligence and blockchain, V2V communication is a tribute to human creativity [27,28]. These technical breakthroughs establish the framework for communication networks that are safe and dependable, scalable, and prepared to meet the voracious needs of tomorrow's transportation systems [29]. By presenting a comprehensive perspective on the condition of infrastructure components in V2V communication, we lay the groundwork for future advancements. Therefore, V2V communication is a pivotal element in the future of transportation. Hence, it enables a boost in safety, an increase in traffic flow, a decrease in impact on the environment, and the implementation of a strong functional ITS infrastructure, which makes it crucial in the process of transportation systems modernization [30]. Therefore, with a steadily progressing world in terms of technology, its application toward the implementation and further development of V2V communication will be crucial in overcoming the challenges of urbanization and achieving the best and safest means of transport in society [31].

3. Related Studies

Tracing the historical evolution of V2V communication reveals its progression from conceptualization to implementation. A paper by Magboul et al. [32] considers a detailed analysis of existing literature and research papers concerning security protocols and techniques for vehicle-to-vehicle (V2V) communication. These entail a comprehensive review of

some major facets that comprise authorization and authentication, cryptology and ciphers, key management and distribution, and lastly, intrusion and detection systems. The paper is likely to contain changes and advice; however, comparisons with real-life applications and analysis of effectiveness are missing. Another limitation of this type of study is that the improvements that were proposed would have to be implemented and tested in practice. The study by Hussian et al. [33] makes a unique contribution to the field of VANETs because it aims to cover most aspects of VANET applications, networking, and issues in a single survey. However, the paper predominantly considers the strategic and main categories, which is insufficient to explore the details to be implemented at the V2V level. Moreover, while the integration of evolutionary technologies with V2V is described in sufficient detail, more concrete examples and real-life experiments can be useful to support the theoretical analyses and introduced solutions. Ameer et al. [34] survey reviews on P2P applications for VANETs, addressing challenges like broadcast storm problems, network partitioning, and temporal fragmentation. The paper also discusses research issues related to implementing P2P techniques in VANETs but acknowledges the limitations in V2V networks and ITSs. The conceptual frameworks lack implementation details and are not empirically proven or tested in real scenarios, making their applicability in actual V2V networks questionable. Further research is needed for practical, scalable, and reliable solutions. The paper by Zhang et al. [13] proposes the application of the Internet of Vehicles (IoV) as an extension to conventional VANET for the 5G/B5G world. It emphasizes the need for VANETs to accommodate vehicle automatic control and intelligent road information services. The paper presents a literature review on IoV Midlands, discussing VANET technologies, network architectures, and IoV applications. However, the paper has limitations, such as a lack of practical experience, scalability, and security and privacy aspects. Further research is needed to overcome these limitations and advance the understanding of IoV in vehicular communication systems. The study by Narayanan et al. [35] discusses the introduction of MANETs and introduces VANET as the best way through which communication and the flow of traffic on the roads could be achieved. It focuses on the strength that contains low jitter, reduced transmission delay, and proper mobility management of the VANETs, which are, in general, essential for ITSs. However, this document is silent on prospects such as risks such as security threats, V2V implementation challenges, and compatibility of the relatively new V2V communication with established structures that may inhibit its large-scale usage. Moreover, it lacks information about the compatibility of the various communication infrastructures and the effect of several traffic loads on V2V networks. Further elaboration on these limitations would help to give better insight into the issues that must be addressed when considering V2V communications and their integration into VANET structures [36].

A study by Malik et al. [37] provides a distinct trend in the development of automotive V2X technology: the V2P communication system, which has the potential to improve the safety and comfort of vulnerable road use groups, explains Vehicle-to-Pedestrian (V2P) systems in a nutshell, speaking of different communication technologies and interaction modes used to increase pedestrian security. But if the same is considered in the context of V2V networks, then several constraints are observed, as given below. There is no information on the conflict or cooperation of V2P and V2V systems when vehicles and pedestrians use the same channels and frequencies. It also neglects the issues of growing V2P systems for managing the density of vehicles and pedestrians that are characteristic of metropolises and affecting the reliability of V2V networks. However, generic security and privacy requirements customarily applied to V2P communications, which also include V2V systems, are not considered, even though they play crucial roles in ensuring the dependability of the system as a whole.

However, this study provides an in-depth examination of important performance measures for several V2V communication methods. This document aims to offer researchers a comprehensive understanding of the current status of V2V communication technologies and guide future advancement through detailed critical analysis, discussions, and visual-

izations. This paper offers an extensive review of the primary communication components required for the creation of a V2V communication system and pays special attention to the distinct communication structural frameworks. It goes over the area where Artificial Intelligence (AI) affects the allocation of network dynamics and provides insight into the literature as well as performance outcomes in order to understand the challenges in V2V communication schemes. Thus, while evaluating and identifying significant factors, the review also intends to guide further research in V2V communication and technological progress in the sphere to create a stable and closely-knit framework for ITS. This study gives a detailed analysis of various archetypes of V2V communication architectures, thus making valuable input into the field by elaborating on different V2V systems that help boost the V2V network. They also make a very effective analysis of how these architectures contribute to enhancing V2V communication and are relevant to ITSs. Furthermore, this study has provided a useful research agenda for further investigation of new trends and findings based on new technologies, as well as guidelines for improving existing protocol designs under V2V communication that will be beneficial for future and continuous developments. Also, the inclusion of detailed diagrams with some tables describing the architectures of the models, as well as comparative measurements of their performances, will improve readability and understanding of the content.

4. V2V Communication Architectures

Technology is increasing as the economy grows, and development in technology also increases. Transport has developed significantly through factors such as downtown business and globalized transport, which have led to congestion, pollution, and frequent traffic accidents. They pose a security threat to the car user and the pedestrian, who may be a mishap victim. However, the novel innovation of connected vehicle systems has been carefully developed and analyzed over the years and is on the edge of commercial production due to continuous technological innovation. As we observe in modern capital cities, we have sought to make technology a way of probing traffic to improve the transport system and provide a faster, more efficient means of transport [38]. Hence, with proper road networking and the setting up of smart traffic signals, high traffic problems due to the number of vehicles are minor concerns. Current car models are capable of real-time V2V data sharing, incorporating various forms of entertainment and information, security, traffic management, driving, and even smart cities' functionalities [39].

Moreover, the Ethernet standard of IEEE 802.11p [40] is used for VANETs, especially for ITSs. It is particularly suitable for wireless access in vehicular environments [41]. The standard operates in the 5.9 GHz band, built for V2V and vehicle-to-infrastructure (V2I) applications [42]. The most important reference is IEEE 802.11p, which can build low-latency and high-speed data links critical for real-time services such as collision avoidance and synchronized traffic control signals. The fact that it is possible to quickly create a communication channel with the help of the protocol that excludes numerous handshakings can be critical in such high-speed contexts as vehicles [43].

Furthermore, IEEE 802.11p introduces QoS characteristics that allow settings to give a higher priority to safety messages than comparatively less important data [44]. However, Dedicated Short-Range Communications (DSRCs) are a group of protocols and standards that build on the capabilities of IEEE 802.11p for vehicular communication [45]. DSRC works at a similar 5.9 GHz and contains further protection, dependability, and compatibility advancements. It is intended to work in safety- and non-safety-related cases, such as electronic fee collection, traffic control, and information processing. Safe transfer of messages is addressed in DSRC protocols so that communications, including vehicles and infrastructure, are safe from threats and vandalism [46]. Furthermore, channelization in DSRC enables efficient use of the frequency spectrum, allowing simultaneous communications without any hindrance. Because of its high design capacity and ability to support low latency and high reliability in communication, DSRC is considered one of the most critical technologies in modern ITSs [45]. These protocols are essential for developing

smart transportation, which would necessitate the basic implementation of V2V and V2I to improve road safety, reduce traffic density, and increase productivity [35].

In the general communication pattern, Figure 1 depicts direct correspondence between On-Board Units (OBUs) installed on general vehicles and Road Side Units (RSUs) fixed alongside the roads, which form general communication abilities and assist the roadside infrastructure. It oversees the flow of work and operations while managing all traffic to and from the central control and administrative points. The reduced hyper architecture presented below provides a probable solution to explicate V2V communication architecture concerning how the components inter-relate in improving secure and efficient transport. This involves critically presenting the most significant V2V architectures crucial to real-life applications. We explain how these architectures have evolved and how they contribute to improved V2V communication. The categorized architectures are as follows: Decentralized mesh network, V2V-based cloud integrated hub, Edge computing-based V2V, Blockchain-enabled V2V network, V2V over hybrid cellular and ad-hoc networks, Artificial intelligence-assisted dynamic networks for V2V communication, and V2V assistance toward sustainable transport systems. These V2V architectures are different, but at the same time, they provide variety and supplement each other in that they are endowed with unique functions that tackle various areas of vehicle communication and transport management. Thus, critical review and integration of these architectures shall provide reliable and effective V2V systems for safety, efficiency, and environmental gains in practical applications.

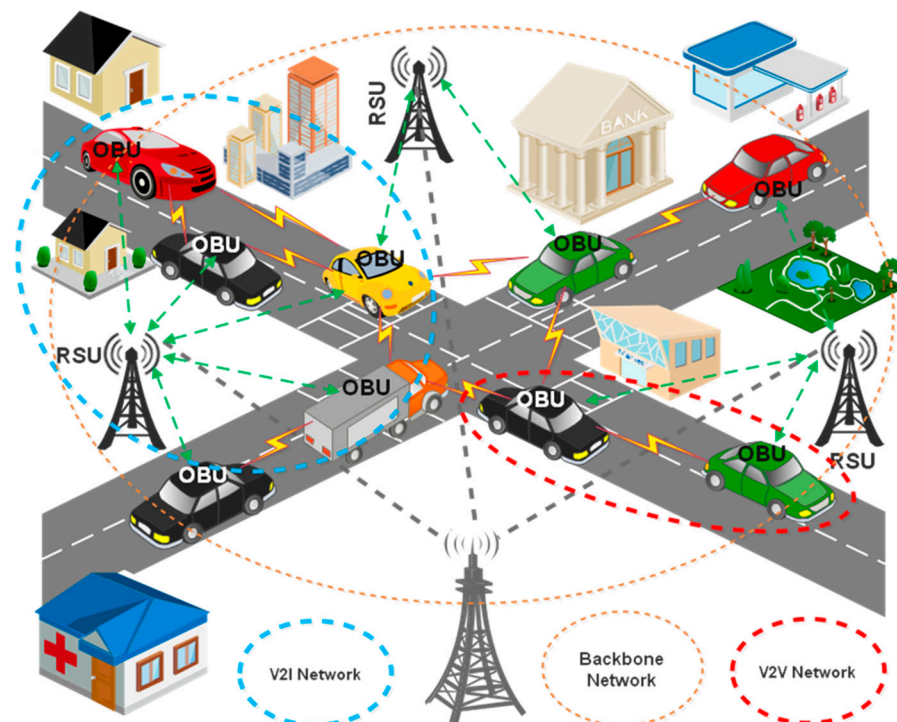


Figure 1. V2V Communication Architecture.

4.1. Decentralized Mesh Network

The Decentralized Mesh Network (DMN) is a connectedness module that develops among vehicular prowess nodes, where each vehicle serves as a guard in the vast range of communication [47]. Through wireless protocols like IEEE 802.11p, cars engage in a web of short-range exchanges, weaving a system of safety-critical information. The network's reach is expanded by intermediate vehicles, ensuring no area is left untouched by the hand of connection [48]. The beauty of decentralization lies in no entity retains authority over the network. Each vehicle in the network contributes to its overall resilience by serving as a key component in a robust, redundant system that can adapt to failures and maintain constant communication [49]. The security threat looms large, but end-to-end encryption

shrouds critical information, keeping it from prying eyes. Trust mechanisms develop within the network, allowing it to verify with a node of recognition and confirm the purity of the received communication, making it resistant to the intrigues of malicious powers. The DMN's complexity and variety associate, weaving resilience, dependability, and security, creating a route toward a future where communication knows no boundaries [50]. The infrastructure is inherently scalable, accommodating varying numbers of vehicles in different scenarios.

A DMN is a self-organizing and resilient architecture that allows peer-to-peer communication without relying on a centralized infrastructure [51]. Figure 2 represents individual nodes within the network, representing equipment with wireless communication capabilities. These nodes are interconnected, creating a web-like structure where communication pathways can be built between any two nodes within range. The mesh topology ensures stability and redundancy in communication pathways, allowing data transmission between neighboring nodes. The flexible configuration of nodes and links demonstrates the network's adaptability, which can autonomously adapt their communication behavior based on network parameters like signal strength, traffic load, or node mobility. This dynamic adaptation provides optimal performance and effective resource utilization, even in demanding conditions. DMN supports real-time communication for collision avoidance, facilitates the dissemination of traffic information, and enables rapid and direct communication between vehicles in case of emergencies, enhancing coordination for emergency services and first responders.

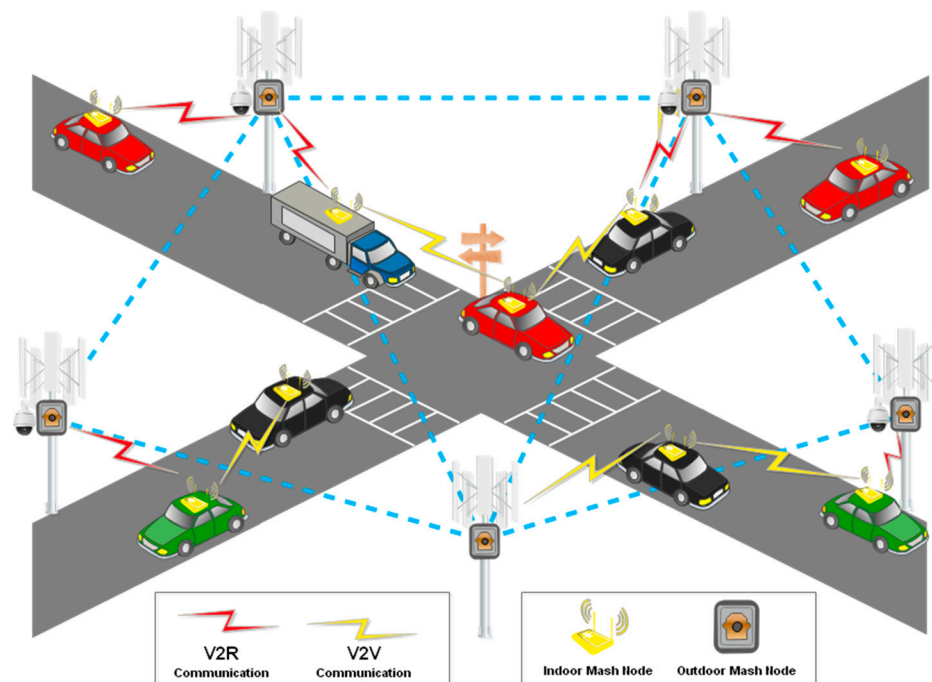


Figure 2. Decentralized Mesh Network for V2V Communication.

4.2. V2V-Based Cloud-Integrated Hub

The Cloud-Integrated V2V Hub is a modern technology that merges cloud computing and vehicular communication. Each vehicle has communication modules, allowing real-time exchanges and transmitting essential data [52]. The hub uses cloud-based analytics to analyze patterns, predict traffic conditions, and derive insights for intelligent traffic management. This allows for global connectivity, enabling communication between vehicles regardless of their physical proximity [53]. The decentralized communication ensures low-latency interactions for safety-critical applications, while vehicles maintain peer-to-peer communication for instantaneous exchanges. End-to-end encryption safeguards sensitive information, preventing unauthorized access and tampering. Vehicles

authenticate to the hub, ensuring only authorized individuals contribute to and access V2V communication information. Edge computing, where nodes process time-sensitive data quickly, lowers latency for safety-critical applications and allows for predictive analytics from traffic management [54]. Cloud-integrated V2V Hub is a powerful, resourceful, and elegant technology that controls vehicle communications in a broad, organized ecosystem.

Figure 3 illustrates a cloud-integrated V2V hub, a centralized component within a V2V communication architecture. It acts as a bridge between vehicles and cloud infrastructure, facilitating data exchange, processing, and coordination among linked vehicles. The V2V Hub receives data from individual vehicles, processes it, and transmits it to other vehicles within the network. It also allows for connectivity with external organizations such as roadside infrastructure or cloud servers. The V2V Hub's connection to the cloud infrastructure demonstrates the incorporation of cloud computing resources into the V2V communication architecture. By leveraging cloud services, the V2V Hub can offload computationally heavy operations, store and analyze massive volumes of data, and leverage additional processing capabilities that are not available locally. The bi-directional flow of data between vehicles and the V2V Hub and the cloud is illustrated by the bi-directional flow of sensor data, status updates, and safety-related information. The V2V Hub may also relay processed data to the cloud for further analysis or storage.

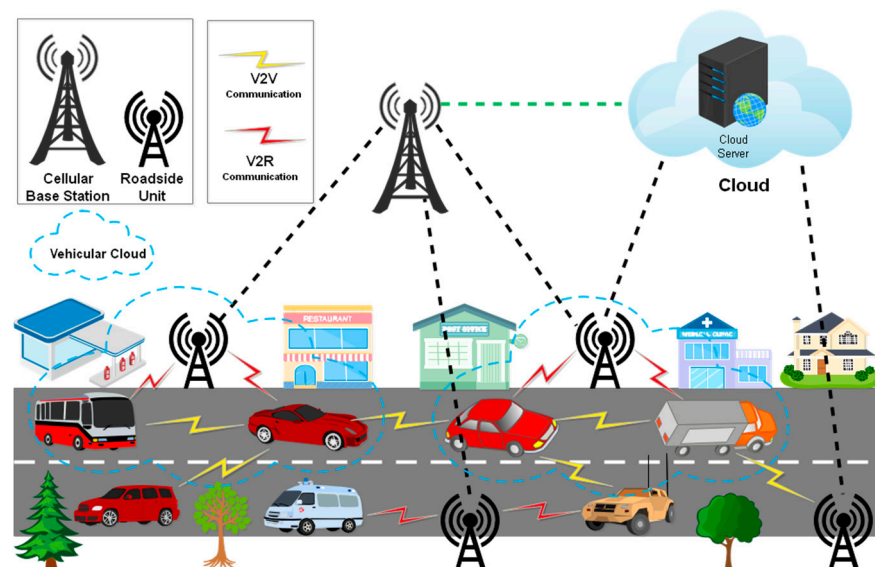


Figure 3. Cloud-Integrated V2V Hub.

4.3. Edge Computing-Based V2V Architecture

This architecture uses edge computing nodes strategically located at the network edge, allowing real-time processing of V2V communication data. These nodes process time-sensitive data at the network edge, reducing latency for safety-critical applications [55]. They analyze incoming V2V communication data in real-time, extracting valuable insights for immediate decision-making. Edge computing distributes processing tasks closer to the data source, enhancing responsiveness and reducing the need to transmit large volumes of data to centralized cloud servers [56,57]. The architecture incorporates dynamic load-balancing mechanisms to ensure the efficient distribution of processing tasks among edge computing nodes. Vehicles in proximity communicate directly using short-range protocols, supporting direct V2V communication without relying solely on centralized cloud resources. The edge computing-based architecture may support the formation of a dynamic mesh network among vehicles, enhancing reliability and allowing communication even in scenarios where direct line-of-sight is limited. Edge computing nodes use encryption and authentication to ensure the confidentiality and integrity of V2V communication data [58]. They also incorporate intrusion detection systems to identify potential security threats. At the edge, real-time processing allows for instantaneous collision warnings and avoidance

strategies based on nearby vehicle proximity and speed. This technology supports quick analysis of V2V data at intersections, facilitating safer navigation and reducing collision risks in complex traffic scenarios. Edge-based insights contribute to traffic signal optimization by adjusting signal timing based on real-time vehicle flow to alleviate congestion. The architecture may incorporate a hybrid model, integrating edge computing with centralized cloud services for a balance between real-time processing, extensive analytics, and historical data storage. This decentralized approach optimizes resource utilization, improves real-time decision-making, and contributes to the overall effectiveness of connected vehicles in the IoT environment [59].

Figure 4 illustrates an edge computing-based architecture for V2V communication, integrating edge computing resources into the communication infrastructure. This design enhances the performance, reliability, and efficiency of V2V communication systems. The network edge is represented by automobile icons with onboard communication devices like DSRC or Cellular Vehicle-to-Everything (C-V2X) units. Edge computer nodes are deployed near the cars, acting as localized sites of computation and data processing, reducing latency and bandwidth consumption. Communication links between vehicles, neighboring edge nodes, and other network components enable data exchange. The edge server, a centralized point for managing edge computing resources, handles tasks like resource allocation, load balancing, and job scheduling to maximize the performance and reliability of edge computing processes.

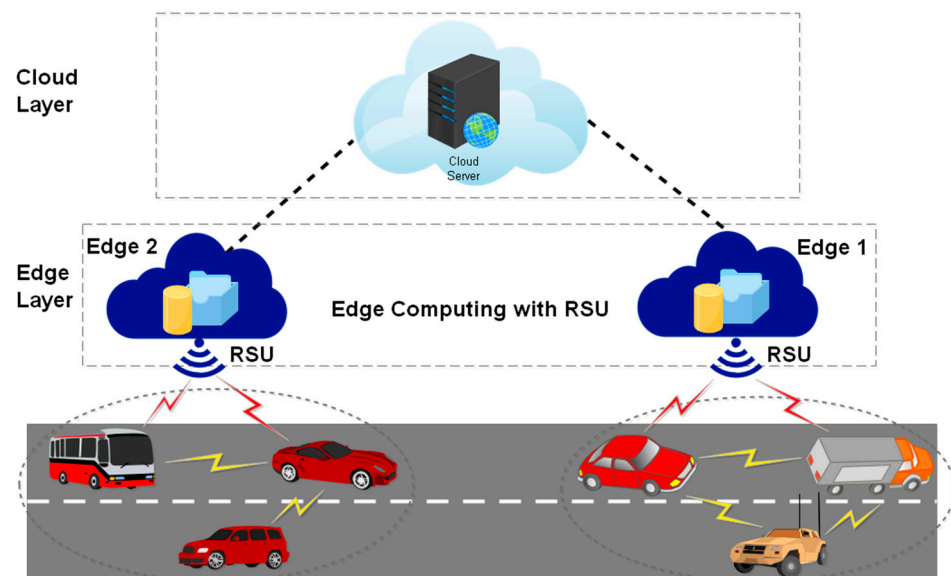


Figure 4. Edge Computing-Based V2V Architecture.

4.4. Blockchain-Enabled V2V Network

The infrastructure uses a decentralized blockchain network, with each connected vehicle acting as a node in the network. This decentralized nature eliminates the need for a central authority and enhances transparency [60,61]. Utilize smart contracts, which are self-executing contracts with the terms of the agreement directly written into code. Smart contracts facilitate automated and trustless interactions between vehicles in the V2V network. Each V2V communication interaction is treated as a transaction. Transactions, such as safety alerts or traffic information, are verified by consensus mechanisms among the nodes in the blockchain network [62]. Once verified, transactions are recorded in an immutable and transparent ledger. The blockchain ledger ensures the integrity of the data exchanged among vehicles, making it resistant to tampering. While the blockchain records the transactions, vehicles engage in direct peer-to-peer communication for real-time data exchange. The blockchain serves as a secure and verifiable record of these interactions [63]. Implement cryptographic techniques for securing transactions and communication between vehicles.

Cryptographic hashes ensure data integrity, while public-key cryptography secures the identity and authenticity of participating vehicles and relies on consensus mechanisms, such as Proof of Work (PoW) or Proof of Stake (PoS), for transaction validation. Consensus ensures that only legitimate transactions are added to the blockchain, enhancing security. It provides options for private transactions using techniques like zero-knowledge proofs [64]. This allows vehicles to exchange information while maintaining the privacy and anonymity of involved parties. Blockchain-enabled V2V networks assign pseudonymous identities to vehicles within the network. While transactions are recorded on the blockchain, the real-world identities of the vehicles remain protected. Blockchain ensures the authenticity of traffic alerts and safety messages exchanged between vehicles [65]. Verified alerts improve road safety by preventing false information propagation. Therefore, the record details of accidents or incidents on the blockchain are in an immutable ledger. This information can be crucial for insurance claims, law enforcement, and post-accident analysis. According to Figure 5, the Blockchain-based Intelligent Internet Vehicles Architecture (BI2V) safely addresses IoV security challenges and a vehicle management communication system using two blockchain networks to safeguard vehicle data security and anonymity. The permissioned blockchain facilitates communication between all vehicle authorities, including the parent zonal office, without exposing all zonal offices to communicate the information, as shown in Figure 5. However, the blockchain ledger, a chain of interconnected blocks, acts as a tamper-evident record of transactions and data exchanges. Smart contracts embedded in the blockchain can automate traffic management, such as coordinating traffic flow at intersections or managing priority lanes. The blockchain-enabled V2V network can integrate seamlessly with smart city initiatives, enhancing collaboration with urban infrastructure for more effective traffic management. A token economy is introduced, where participating vehicles earn tokens to contribute valuable data to the network, which could be used for accessing premium services or incentives within the smart city ecosystem.

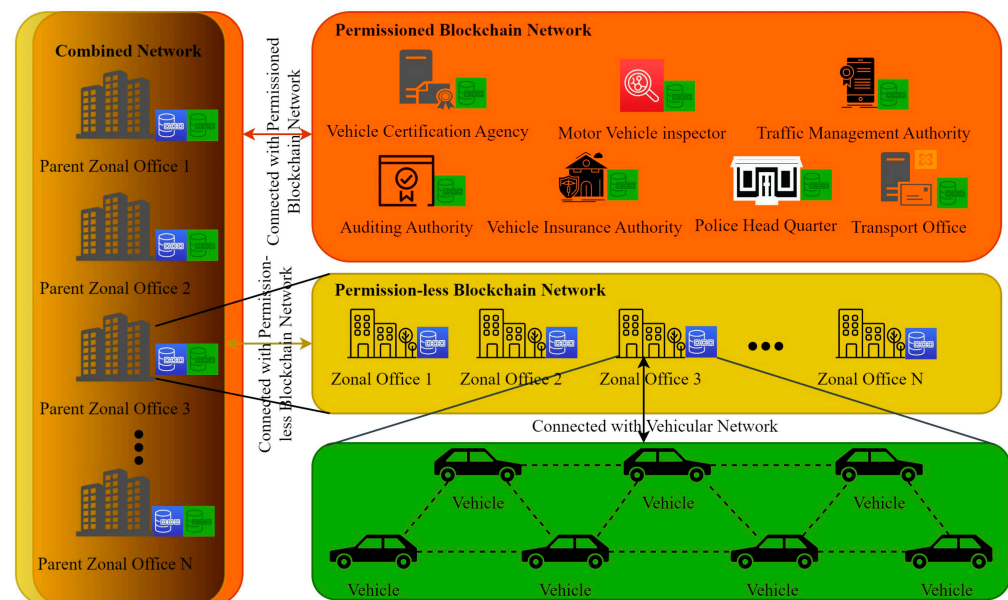


Figure 5. Blockchain-based Intelligent Internet Vehicles Architecture [66].

4.5. Hybrid Cellular and Ad-Hoc Network-Based V2V

C-V2X technology is a hybrid approach to cellular communication that uses existing infrastructure for direct communication between vehicles and roadside infrastructure [4,17]. It enables direct peer-to-peer communication without reliance on cellular infrastructure, allowing high-bandwidth communication for real-time data exchange and low-latency responses. In areas with limited or congested cellular coverage, vehicles switch to ad-hoc mesh networking, providing a decentralized communication infrastructure [67]. This

infrastructure allows for dynamic mode switching between cellular communication and ad-hoc mesh networking based on factors like signal strength, traffic density, and application requirements. The hybrid architecture benefits from wide coverage and high data rates, particularly in urban and suburban areas. It allows smooth handover between cellular and ad-hoc modes, ensuring uninterrupted communication during mode transitions. The ad-hoc mesh network is self-organizing, allowing vehicles to dynamically join and leave the network as they move, ensuring continuous communication even in changing traffic patterns [68].

Mesh routing protocols like Ad-hoc On-demand Distance Vector (AODV) and Dynamic Source Routing (DSR) are used for efficient message routing within a mesh network, enabling quick communication paths. Hybrid cellular and ad-hoc networks use end-to-end encryption for confidentiality and integrity, preventing unauthorized access. Robust authentication mechanisms validate vehicle identities in both modes. In urban areas with dense cellular coverage, cellular communication is used for traffic signal coordination and collision avoidance. In rural or remote areas, ad-hoc mesh networking is used for safety and traffic coordination. The system adapts to dynamic traffic scenarios by selecting the most suitable communication mode based on real-time conditions.

Figure 6 illustrates the hybrid cellular and ad-hoc network-based V2V communication system, which demonstrates the integration of both cellular and ad-hoc communication. The V2V contact network in which vehicles fitted with the said high-end communication gear can directly communicate with other similar gadgets is relevant in that it can allow for faster exchange of data that is relevant in real-time matters such as accident occurrence and flow of traffic information. Likewise, the feature of updating from a distance, as well as the cellular networking through the cellular towers, is also used for the networking in the given figure. To depict the integration of these two channels of communication and the direction of data, the figure uses arrows and signal waves.

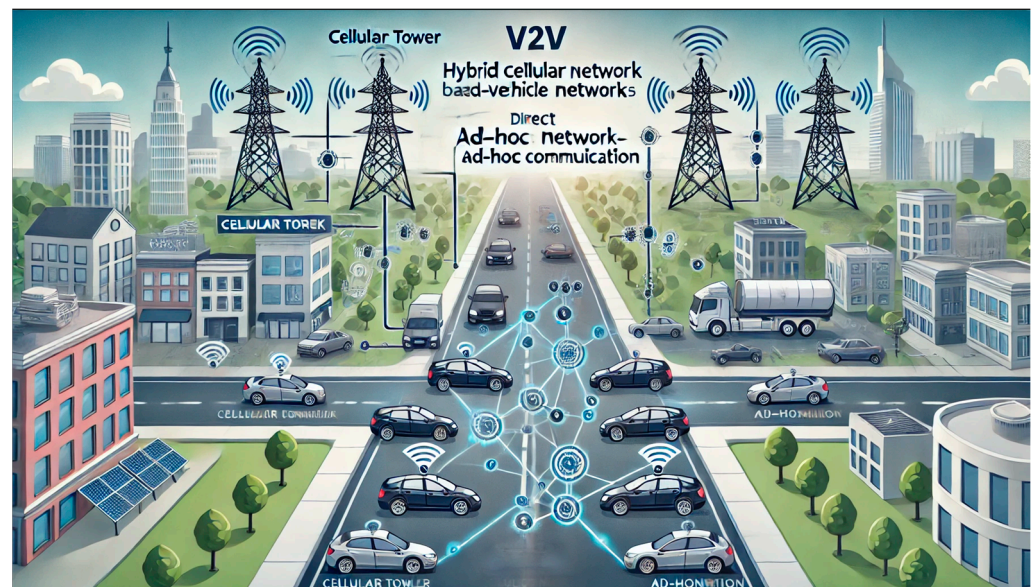


Figure 6. Hybrid Cellular and Ad-Hoc Network-based V2V.

4.6. AI-Driven Dynamic Network for V2V Communication

The infrastructure features an AI controller that dynamically allocates communication resources based on real-time conditions using machine learning algorithms and predictive analytics. Each vehicle is equipped with V2V communication modules, such as Dedicated Short-Range Communication (DSRC) or C-V2X technologies. The AI controller analyzes real-time data, including traffic patterns, vehicle density, and communication requirements, to make informed decisions about network resource allocation. It uses predictive modeling based on historical data to anticipate future communication demands, proactively

allocating resources for upcoming traffic conditions and events. The system dynamically allocates resources like bandwidth, frequency channels, and transmission power based on evolving V2V communication needs and the traffic landscape. Machine learning algorithms identify peak hours, congestion points, and areas with frequent communication demands, guiding resource allocation strategies [69]. The AI controller learns from historical performance and adjusts its strategies to enhance V2V communication efficiency. Decentralized communication ensures low latency and instantaneous data exchange between vehicles.

Figure 7 shows an AI-driven dynamic network allocation system for V2V communication, enhancing efficiency, reliability, and performance. AI algorithms optimize network resources and manage communication paths in real-time, allowing mobile units like cars, trucks, and drones to exchange data, share information, and collaborate on applications like traffic management and collision avoidance. The road infrastructure, including roads, intersections, and traffic signals, affects communication propagation, signal strength, and network topology. The AI controller, a computer or cloud server equipped with AI algorithms and machine learning models, is the core component of the system. The AI controller uses real-time data from the V2V communication network to make intelligent decisions about network resource allocation and communication management. It dynamically adjusts parameters like transmission power, frequency channels, and routing patterns to optimize performance, eliminate interference, and increase network throughput. The controller also uses a feedback loop to monitor and adapt to network conditions, ensuring responsive and adaptive communication management. The infrastructure may support the formation of a dynamic mesh network among vehicles, enhancing reliability even in limited direct line-of-sight scenarios. Security considerations are integrated into the allocation process, ensuring resources adhere to protocols like encryption and authentication. The system incorporates anomaly detection mechanisms to identify unusual patterns or potential security threats in communication behavior, triggering adaptive responses to mitigate risks. The AI-driven system optimizes communication resources to address traffic congestion, prioritizes and allocates resources during emergencies, and adapts to dynamic traffic scenarios. The system dynamically reallocates resources to address emerging communication demands in real-time.

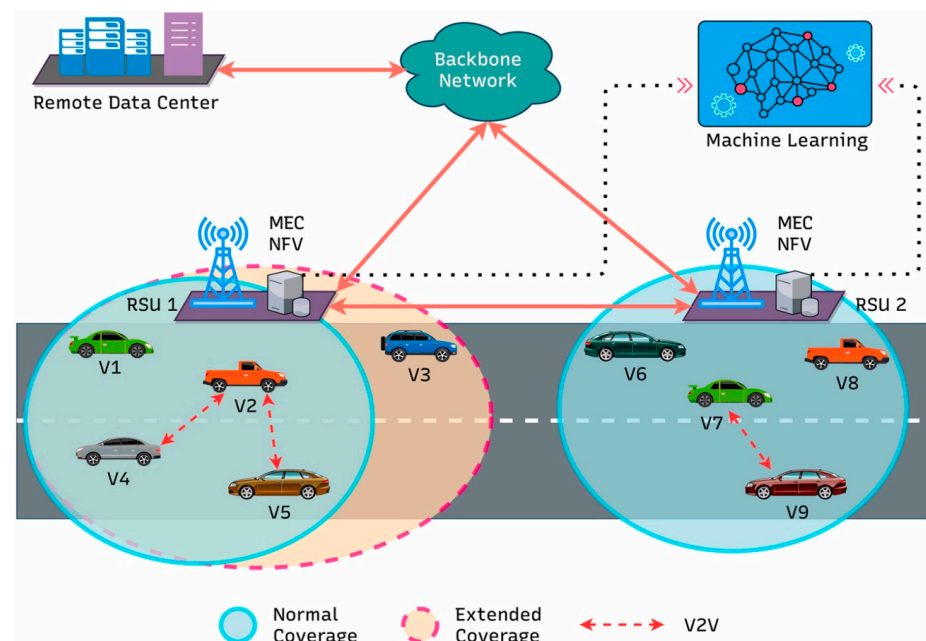


Figure 7. AI-Driven Dynamic Network for V2V Communication [70].

5. V2V Aids toward Sustainable Transportation Systems

The performance evaluations of V2V communication architectures provide valuable insights into their effectiveness in supporting reliable, efficient, sustainable, and intelligent transportation systems. Here, we focused on sustainable transportation and smart cities to evaluate the benefits of V2V communication architectures [67]. The details of the benefits are given below.

5.1. V2V DMN Contributions in ITS

V2V mesh networks are bound to present various advantages to durable ITSs and, as a result, will greatly improve traffic, safety, and sustainability. These networks facilitate real-time V2V communication, which in turn eases traffic and facilitates maintaining order. As a result, fuel consumption and emissions are reduced, and improving air pollution and urban contamination are the main objectives for any eco-city. Safety also receives a massive increase. Vehicle data, including information about road conditions, posted risks, and traffic data, can be quickly received, thereby reducing accident rates [71]. In emergencies, it also speeds up the response. But that is not all. V2V networks will not only allow many advances in ADAS and driverless cars that tune traffic management and decrease brick-and-mortar infrastructure requirements, coupled with the fact that they have a decentralized structure, but they are also swift and resilient [31]. Not only do some cars fall out of the network, but the system works proficiently all the time, ensuring smooth transport. Therefore, V2V mesh networks are the real foundation of ITSs, with extremely efficient communication between vehicles and the integration of technology in smart cities, which, in turn, alters the way people travel and breathe in the cities [72].

5.2. Cloud-Integrated V2V Network Contributions in ITS

ITSs are the next game changer because V2V cloud computing presents multiple advantages along the way, shifting the ecosystem of vehicle communication and performance [55]. Employing cloud computing, vehicles can transfer significant amounts of computationally intensive data to remote machines; subsequently, they can obtain access to intensified computational resources and execute massive amounts of data. With this ability, V2V systems can be scaled and become more flexible, allowing complex algorithms and applications that are impossible to implement locally on individual vehicles to run [73]. On the other hand, cloud computing makes data sharing between vehicles and their collaboration possible, which in turn makes the description of traffic and occurrences on the road so precise and current. Furthermore, cloud-based V2V frameworks benefit from these technologies, as they can redesign route maps, reduce traffic, and increase overall traffic management efficiency. In addition, cloud computing underlies the centralized monitoring and regulation of V2V networks, which effectively promotes security and allows for rapid response to emerging dangers or mild conditions [74]. Therefore, V2V cloud computing is likely to redesign the way transport functions in smart cities and give vehicles access to powerful computing resources, which in turn aim to improve safety, efficiency, and sustainability in ITSs.

5.3. V2V Edge Computing Contributions in ITSs

There are many benefits to V2V edge computing; therefore, there is an evolution in how cars communicate together in smart ITSs [74]. Taking advantage of edge computing, vehicles can analyze and determine data locally, thus reducing the time lag and enabling real-time decision-making without the central server as the standard. Specifically, this characteristic allows for quick reaction times and reliability, which is important in cases like collision avoidance and traffic management, which are crucial for safety. Also, edge computing allows the processing of the data coming from different sensors of the vehicles, from the cameras to Light Detection and Ranging (LiDARs), without using too much Internet capacity. This has the advantage of increasing the expansiveness of V2V networks while at the same time preserving privacy by reducing the necessity to send data by beating rounds

on extra links [68]. Furthermore, edge computing creates the possibility of performing the AI algorithms directly on vehicles' boards, which eventually will enable functions such as predictive maintenance and personalized services [75]. In conclusion, V2V edge computing offers the prospect of safer, more effective, and smarter transportation systems, paving the way for ITSs, like smart cities, to evolve into an era of interconnectedness and sustainability.

5.4. Blockchain-Enabled V2V Network Contributions in ITSs

V2V blockchain networks configure real scalable values to make ITSs smarter with backless solutions for transportation systems, as well as other benefits that come with secure, transparent, and efficient infrastructures. Because blockchain is the power behind these networks, users can enjoy the notion that hosted data on them cannot be faked or manipulated, so the protection against hackers and unauthorized personnel access is very feasible [76]. These high levels of security not only protect the city from data theft but also deter citizens who no longer trust the authorities. It also makes it easier to keep modern and accurate records of transactions, interactions, and the movement of other objects. This lets you do more in-depth analysis, which keeps traffic from building up and leads to better performance in the end. Each Blockchain network divides decision-making capabilities among several nodes, so network activity continues even if some nodes are down [77]. Therefore, during the pandemic, uncertainty and obstacles drove company inventiveness during lockdown. However, cars and public transport vehicles may interact with V2V blockchain networks to provide greener traffic solutions, lowering the usage of fuel. Therefore, these network constitutions are the cause; they are identified as essential elements in the design of reliable, scalable, and green transport systems, which are the basics of ITSs.

5.5. V2V Enabled Hybrid Cellular and Ad-Hoc Network Contributions in ITSs

V2V cellular networks with ad-hoc networking are multifunctional, improving ITS sustainability by optimizing communication and combining the strengths of cellular infrastructure and peer-to-peer functionality [78]. Cellular networking is combined with ad-hoc networking to be able to switch automatically from a cellular network to a peer-to-peer one depending on factors such as network availability, bandwidth needs, and the distance to another vehicle. This flexibility guarantees reliable and resilient communication regardless of the nature of the network, whether it covers the entire cellular area or has high network congestion. Thus, the hybrid approach encompasses bigger data offloading capabilities, which allows vehicles to develop high-transport bandwidth applications such as software updates or video by utilizing the cellular network, and low latency, peer-to-peer real-time communication, which is primarily important to the issue of avoiding road collisions, are developed within the ad-hoc network. Furthermore, the inherent ad-hoc characteristic of ad-hoc networking ensures that the scalability and suitability of vehicles can be easily satisfied through the formation of communication links and data sharing between the vehicles, with no need for centralized infrastructure [44]. Besides that, V2V hybrid cellular networks, including ad-hoc networking, aid in the integration of advanced technologies such as edge computing and AI, which allow the vehicles to process and analyze the data on the vector itself for faster decision-making and recovery from external server failure. However, these networks form an integral part of ITSs, which boosts safety, mobility, and environmental sustainability by serving as a backbone for efficient and reliable vehicular communication.

5.6. V2V AI-Driven Dynamic Network Contributions in ITSs

V2V AI installations in cutting-edge, dynamic networks represent decisive progress in urban traffic and completely change the way vehicles relate to and interact in the ITSs. Through AI deployment, the network can self-learn and dynamically adjust transmission lines and protocols in real-time based on information such as traffic flow, weather, and network load [79]. With such dynamic automation, not only does the V2V communication system become more efficient and reliable, but it can also provide emergency response faster

and quicker, as the V2V system can help coordinate collision avoidance and emergency response. Furthermore, AI-dependent networks are capable of intelligently routing bandwidth resources, which are then prioritized for important data transmissions by minimizing network congestion and latency [80]. Concurrently, the AI algorithms access the data from the vehicles and the sensors that are used for traffic management, for example, to provide actionable insights. These insights include urban planning, environmental monitoring, and environmental monitoring, all of which lead to efficient and sustainable urban transport systems. In addition, intelligent AI-based networks are inherently dynamic, which implies they can constantly learn and improve as they keep up with the shifting needs of smart cities. In a nutshell, AI-driven V2V dynamic networks are playing a key role in the safe, smart, and sustainable urban mobility of ITSs.

As a result of the survey, the following features make different V2V communication architectures and their uses in ITSs different from one another: For example, it was determined that decentralized mesh networks proved optimal for disruption tolerance and adaptability in large, complex environments but struggled with issues of connectivity and interference in rural settings. On the other hand, V2V infrastructures developed under edge computing-based models offer low-latency communication that is essential to real-time business operations while also providing voluminous infrastructure support. Based on the system characterization results, we identified several valuable findings concerning the functionality and connectivity of V2V communications [81]. One such insight is the reliability that the implemented Blockchain-based V2V network can provide in terms of security and transparency of data exchange, which goes a long way in achieving the goals of safety and security in communication streams for the self-driving car fleet. Furthermore, the analysis of AI-enabled dynamic networks demonstrated their ability to address traffic congestion problems and improve the prospects for smart city development [82]. Thus, the applied significance of our results is significant for the further advancement and usage of V2V communication systems. In this way, by applying different patterns of architecture, it is possible to understand their strengths and weaknesses and choose which of the technologies would be suitable for implementation in conditions affected by specific tasks or characteristics of the environment. For example, it is possible for city planners and transportation authorities to implement dynamic networks through artificial intelligence with the goal of augmenting traffic control systems, thereby increasing mobility levels in urban areas and decreasing emission levels. Furthermore, the identification of security threats and suggested improvements to the protocols, such as IEEE 802.11p and DSRC, provide beneficial directions to developers and policymakers on how to create secure and reliable V2V communication structures [83]. The incorporation of blockchain presents a strategy for protected and confirmable exchanges of data that are beneficial for autonomous vehicle frameworks and their dependability.

By adding these distinct findings, some interesting facts, and the practical contribution within the result discussion and conclusion sections, the current status and future development of V2V communication systems can be elaborated and analyzed more thoroughly and beneficially. This enhanced analysis will not only benefit the academic perspective on V2V technologies but also benefit practitioners such as engineers, policymakers, standards developers, ITS application developers, and managers, among others, who may implement or oversee ITS projects to obtain valuable insights into the technologies that can be used for the improvement of ITSs.

Table 1 shows the summary of the above-mentioned V2V architectures with aims and contributions to enhance the ITSs. This table gives a comparative analysis of various V2V architectures, their correctness, promptness, expansiveness, security, data management, independence, applicability to use cases, implementation cost, and compatibility. Each of these architectures has its advantages and possible limitations, depending on the kind of service that needs to be implemented in V2V communications.

Table 1. V2V Architecture and their Contributions for ITSs.

Aspects	DMS	CI-V2V Hub	V2V-EC	V2V BEN	V2V HCAN	V2V AI-DN
Latency	Low	Moderate	Low	Moderate	Moderate	Low
Reliability	High	Moderate	High	High	High	High
Data Processing	Decentralized	Centralized	Decentralized	Decentralized	Hybrid	AI-driven
Scalability	High	High	High	Moderate	High	High
Implementation Cost	Low	High	Moderate	High	Moderate	Moderate
Interoperability	Moderate	High	High	Moderate	High	High
Infrastructure Dependency	Low	High	Moderate	Moderate	High	Low
Use Case Suitability	Ideal for rural and sparse urban areas	Suitable for urban areas	Ideal for latency-sensitive applications	Suitable for high-security applications	Suitable for mixed urban and rural environments	Ideal for complex and dynamic urban environments

6. Open Research Challenges and Future Research Directions

6.1. Frequent Topological Changes

DMNs face challenges in V2V communication due to mobility and frequent topological changes. To maintain dependable connections, complex algorithms must learn from the environment's conditions. Sophisticated cryptography and intrusion detection are necessary to maintain secure connections in such environments.

6.2. Coherence

The hybrid of cellular and ad-hoc-based V2V architectures is effective, but integration and coherence remain the main issues. Issues include synchronization and data transfer, network coverage and performance differences, high implementation costs, and cumbersome processes.

6.3. Accuracy

Intelligent Vehicle-to-Vehicle Communication Networks use AI to improve network configuration and responsiveness but face challenges in data accuracy and algorithms. Large amounts of quality data are needed for training and consolidating knowledge, and real-time communication is crucial.

6.4. Security and Privacy Challenges

Ensuring the security and privacy of V2V communication remains a critical challenge. Future research should focus on developing robust encryption, authentication, and access control mechanisms to protect sensitive data transmitted between vehicles. Additionally, addressing privacy concerns related to the collection and sharing of vehicle telemetry data is essential for fostering user trust and adoption of V2V communication technologies.

6.5. Integration of 5G and Beyond

As next-generation cellular networks continue to evolve, integrating 5G and beyond into V2V communication systems presents significant opportunities for improving performance, reliability, and scalability. Research efforts should focus on optimizing V2V communication protocols to leverage the capabilities of 5G networks, such as low latency, high bandwidth, and network slicing.

6.6. Edge Intelligence and Edge Computing

With the proliferation of edge computing resources in vehicular networks, future research should explore the integration of edge intelligence and machine learning algorithms to enable real-time decision-making and data analytics at the network edge. This approach can enhance V2V communication by enabling dynamic resource allocation, adaptive routing, and context-aware data processing.

6.7. Scalability and Reliability

As the number of connected vehicles continues to increase, ensuring the scalability and reliability of V2V communication systems becomes paramount. Future research should explore novel approaches for managing network congestion, optimizing resource utilization, and mitigating communication delays in large-scale vehicular networks. Additionally, developing resilient communication protocols capable of tolerating network failures and disruptions is essential for ensuring continuous and reliable V2V communication.

6.8. Autonomous and Cooperative Driving

The advent of autonomous and cooperative driving technologies presents new opportunities and challenges for V2V communication. Future research should focus on developing advanced cooperative driving algorithms and communication protocols to enable safe and efficient coordination between autonomous vehicles and human-driven vehicles. Additionally, exploring the integration of V2V communication with other sensing modalities, such as LiDAR and radar, can further enhance situational awareness and collision avoidance capabilities in autonomous driving scenarios.

6.9. Dynamic Spectrum Access and Resource Management

With the increasing demand for spectrum resources in vehicular networks, future research should explore dynamic spectrum access and resource management techniques to optimize spectrum utilization and mitigate interference. Cognitive radio and spectrum-sharing approaches can enable intelligent spectrum allocation and adaptive modulation schemes, enhancing the efficiency and reliability of V2V communication in dynamic and congested environments.

In conclusion, addressing these future directions and open research challenges is essential for advancing the state-of-the-art in V2V communication and realizing the full potential of connected and autonomous vehicles. By leveraging emerging technologies, interdisciplinary collaborations, and innovative research methodologies, researchers can pave the way for safer, more efficient, and more Intelligent Transportation Systems of the future.

7. Conclusions

V2V communication holds immense promise for revolutionizing the ITS by enabling safer, more efficient, and more connected vehicles. Firstly, it is evident that V2V communication technologies, including mesh networks, edge computing, blockchain, and AI dynamic allocation, offer significant improvements. The strengths and limitations of V2V-enabled communication architectures are thoroughly discussed. The hybridization and integration of multiple technologies present opportunities for achieving optimal performance and resilience in dynamic vehicular environments. Future research efforts should focus on exploring synergies between different technologies and developing hybrid solutions that leverage the strengths of each approach. Moreover, addressing key challenges such as security, privacy, interoperability, scalability, and reliability is essential for realizing the full potential of V2V sustainable communication. By investing in research and development initiatives aimed at overcoming these challenges, stakeholders can accelerate the adoption and deployment of V2V communication technologies on a global scale.

Author Contributions: Conceptualization, S.C. and M.A.N.; methodology, M.A.N.; software, S.C.; validation, S.C., M.A.N. and Y.M.; formal analysis, M.A.N.; investigation, S.C.; resources, S.C.; data curation, S.C.; writing—original draft preparation, M.A.N.; writing—review and editing, M.A.N.; visualization, M.A.N.; supervision, S.C.; project administration, S.C.; funding acquisition, M.A.N. All authors have read and agreed to the published version of the manuscript.

Funding: The research grants given to Muhammad Ali Naeem from the Projects of Talents Recruitment of GDUPT (NO. 2022rcyj2015), in Guangdong Province, China.

Data Availability Statement: No new data were created or analyzed in this study. Data sharing is not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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