Wireless Communication Between Vehicles: Exploring the Potential of V2V and V2X Communication for Improved Efficiency, Safety, and Sustainability

Received 16 June 2023; Accepted: 29 June 2023 ***Research Article***

Mohammed Alsudani
Electrical and Electronics Engineering
karabuk university
Karabuk, Turkiye
mode8427@gmail.com
0009-0007-8574-4912

Turgut Öztürk
Electrical and Electronics Engineering
karabuk university
Karabuk, Turkiye
turgut.ozturk@karabuk.edu.tr
0000-0002-0749-5849

***Abstract*— Vehicle-to-Vehicle (V2V) communication is a groundbreaking technology that promises to reshape transportation systems globally. This paper delves into the diverse applications of V2V communication, emphasizing its potential to enhance traffic efficiency, road safety, and environmental sustainability. By facilitating real-time information exchange between vehicles, V2V communication can aid in collision prevention, traffic flow optimization, and emission reduction, thereby fostering a more secure, efficient, and eco-friendly transportation landscape. The analysis presented in this paper encompasses the key components and benefits of V2V communication, along with an exploration of its far-reaching implications for the future of transportation, including the advancement of autonomous vehicles and the establishment of greener, more sustainable transport networks.**

Keywords— Vehicle-to-Vehicle communication, V2V, traffic efficiency, road safety, traffic flow optimization, autonomous vehicles, sustainable transportation.

I. INTRODUCTION

With the rapid growth of smart cities and the Internet of Things (IoT), connectivity has become an essential aspect of modern life. This connectivity extends to the transportation industry, where wireless communication between vehicles is poised to play a vital role in enhancing road safety, optimizing traffic flow, and facilitating the development of autonomous vehicles. This paper provides an overview of the various technologies and applications related to wireless communication between vehicles, addressing both the opportunities and the challenges that lie ahead. [1]

In recent years, the transportation industry has been undergoing a significant transformation, fueled by advancements in communication and information technologies. The growing importance of connectivity in everyday life, combined with the rise of smart cities and the Internet of Things (IoT), has led to an increased focus on enabling wireless communication between vehicles. This enhanced connectivity is expected to bring about a paradigm shift in the way we approach transportation, with implications for road safety, traffic management, and the development of autonomous vehicles. This paper aims to provide an in-depth examination of the technologies, benefits, and challenges associated with wireless communication between vehicles and the methodologies that can be employed to study these topics.[2]

Moreover, V2V communication, or Vehicle-to-Vehicle communication, refers to the exchange of information between vehicles through wireless networks. This technology allows vehicles to share critical data, such as their position, speed, and direction, with nearby vehicles in real-time. V2V communication is a crucial component of connected vehicle systems and plays a significant role in improving road safety, reducing traffic congestion, and supporting the development of autonomous vehicles.

By enabling vehicles to communicate with each other, V2V communication helps drivers or autonomous systems anticipate potential hazards and adjust their actions accordingly. For instance, if a car ahead suddenly brakes, the following vehicles can receive this information and react promptly, minimizing the risk of collisions.

Overall, V2V communication is a vital component of the future of transportation, paving the way for safer, more efficient, and intelligent roadways.[3]

II. TECHNOLOGIES ENABLING WIRELESS COMMUNICATION BETWEEN VEHICLES

Several wireless communication technologies enable the exchange of information between vehicles in V2V communication systems. These technologies provide real-time, low-latency communication, which is essential for ensuring the safety and efficiency of connected vehicles. Here are some of the key technologies enabling wireless communication between vehicles:

A. Dedicated Short-Range Communications (DSRC)

DSRC is a radio communication technology operating in the 5.9 GHz frequency band. It is specifically designed for V2V and Vehicle-to-Infrastructure (V2I) communication, providing low-latency, short-range communication that is well-suited for safety-critical applications.[4] As shown the (DSRC) in the figure 1.

Fig. 1. The Dedicated Short-Range Communications

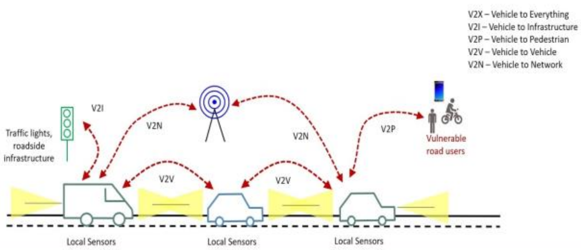

Fig. 2. The *Cellular Vehicle-to-Everything*

Fig. 2. The *5G New Radio (NR)*

B. Cellular Vehicle-to-Everything (C-V2X)

C-V2X technology leverages existing cellular networks (e.g., 4G LTE, 5G) to facilitate communication between vehicles, infrastructure, and other road users. C-V2X offers longer communication ranges and enhanced reliability compared to DSRC, making it suitable for various V2V and V2I applications. [5] As shown the (C-V2X) in figure 2.

C. 5G New Radio (NR)

The 5G NR technology offers ultra-reliable, low-latency communication, which is critical for V2V applications. With its high data rates and capacity, 5G NR enables advanced applications, such as autonomous driving and high-definition map updates, and supports the massive amounts of data exchanged in V2X communication.[6] As shown the 5G New Radio (NR) in figure 3.

D. Wi-Fi (802.11p)

Wi-Fi-based V2V communication uses the 802.11p standard, which is an amendment to the IEEE 802.11 standard for wireless local area networks (WLANs). It has been specifically designed for automotive environments, providing fast and reliable communication for V2V and V2I applications [7] As shown the Wi-Fi (802.11p) in figure 4.

III. How Does V2V Communication Work

Vehicle-to-Vehicle (V2V) communication works by enabling vehicles to exchange information with each other over wireless networks, typically using Dedicated Short-Range Communications (DSRC)/Cellular Vehicle-to-Everything (C-V2X) technology/C. 5G New Radio (NR)or wi-fi (802.11p) Here is a step-by-step explanation of how V2V communication works:

A. Data Collection

Each vehicle collects data from its onboard sensors, such as GPS, radar, LiDAR, and cameras, which provide information on the vehicle's position, speed, direction, and other dynamic attributes.

B. Data Processing

The vehicle's onboard computer processes this data to generate relevant information, such as potential hazards, traffic updates, or weather conditions. This information is then prepared for transmission to other nearby vehicles.

C. Wireless Transmission

The processed information is broadcasted using wireless communication technology. DSRC operates in the 5.9 GHz frequency band, whereas C-V2X uses cellular networks like LTE or 5G. These technologies provide low-latency, high-reliability communication channels that enable vehicles to communicate over short to medium distances (typically up to 1000 meters)

D. Data Reception

Nearby vehicles receive the broadcasted information through their onboard communication systems. The received data is integrated with the vehicle's existing sensor data to provide a more comprehensive understanding of the surrounding environment.

E. Decision-Making

Based on the received information, the vehicle's onboard computer, Advanced Driver Assistance Systems (ADAS), or autonomous driving systems can make informed decisions to adjust vehicle behavior, such as slowing down, changing lanes, or taking evasive action in response to potential hazards.

F. Action Execution

The vehicle's control systems implement the decisions made by the onboard computer or ADAS, adjusting the vehicle's speed, direction, or other parameters to ensure safe and efficient navigation. In summary, V2V communication works by collecting, processing, and transmitting data between vehicles over wireless networks, allowing them to share critical information in real-time. This exchange of information helps drivers or autonomous systems make informed decisions, improving road safety, reducing traffic congestion, and supporting the development of autonomous vehicles.[8, 9]

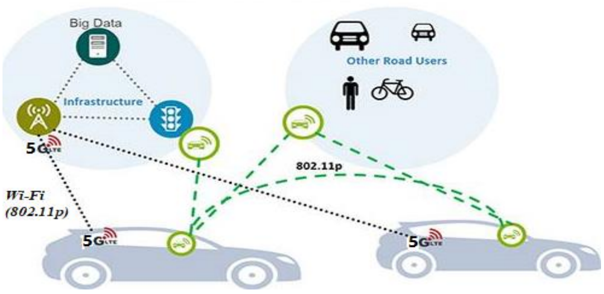

Fig. 4. The Wi-Fi (802.11p)

IV. Components and Applications of V2V Communication

A. Components of V2V Communication

The components of Vehicle-to-Vehicle (V2V) communication play a crucial role in enabling vehicles to exchange information wirelessly. The primary components involved in V2V communication include in the table 1 :Applications of V2V Communication

Vehicle-to-Vehicle (V2V) communication refers to the exchange of information between vehicles using wireless communication technologies. It has gained significant attention in recent years due to its potential to improve road safety, traffic efficiency, and environmental sustainability. Here are some key applications of V2V communication:

1) Traffic Congestion Management: By sharing traffic-related information, vehicles can optimize their routes and avoid congested areas, leading to better traffic flow and reduced travel time.
2) Cooperative Adaptive Cruise Control (CACC): V2V communication enables vehicles to maintain a safe distance from each other while driving at a constant speed, reducing the likelihood of traffic jams and improving overall traffic efficiency.
3) Platooning: V2V communication can be used to form platoons of vehicles driving in close proximity, which can lead to improved fuel efficiency, reduced emissions, and increased road capacity.
4) Autonomous Vehicle Integration: V2V communication plays a crucial role in the development and deployment of autonomous vehicles by providing essential information about the surrounding environment and enabling cooperative behavior among vehicles.
These applications of V2V communication hold the promise of revolutionizing the transportation sector by significantly enhancing road safety, reducing traffic congestion, and contributing to a greener environment.[9, 11, 12]

V. Impacts of V2V Communication

the impacts of V2V communication on traffic efficiency, road safety, and the environment can be significant, providing a range of benefits that can enhance the transportation sector's sustainability and efficiency. As the technology continues to evolve and become more widespread, we can expect to see further improvements in these areas, leading to safer, more efficient, and sustainable transportation solutions. Here we can explain some the impacts of V2V communication.

A. Traffic Efficiency

V2V communication has the potential to significantly enhance traffic efficiency through various means. By enabling vehicles to exchange real-time information with each other, V2V technology can lead to better traffic management, reduced congestion, and optimized travel routes. Here are some of the ways V2V communication impacts traffic efficiency:

1) Real-time Traffic Updates : V2V communication allows vehicles to share real-time traffic data, enabling drivers to make informed decisions about their routes, avoiding congestion, and reducing travel times.
2) Traffic Signal Adjustments: V2V communication can provide information about traffic conditions to traffic management systems, allowing them to optimize signal timings and improve traffic flow.
3) Reduced Traffic Congestion: By facilitating cooperation among vehicles and sharing traffic information, V2V communication helps in reducing traffic congestion and improving overall road efficiency.
4) Improved Fuel Efficiency : V2V communication enables more efficient driving patterns, such as cooperative adaptive cruise control, which can result in reduced fuel consumption and lower emissions.[9, 13]

B. Road Safety

V2V communication has a significant impact on road safety by allowing vehicles to share real-time information about their positions, speeds, and trajectories with each other. This enhanced situational awareness can help prevent accidents, reduce the severity of crashes, and save lives. Here are five ways V2V communication contributes to road safety:
1) Collision Avoidance: V2V communication enables vehicles to predict and avoid potential collisions by sharing data about their positions, speeds, and trajectories with nearby vehicles. This can help reduce the number of accidents and minimize the severity of crashes when they occur.
2) Intersection Safety: V2V communication can improve safety at intersections by allowing vehicles to share information about their intentions to turn, change lanes, or pass through the intersection. This helps prevent crashes resulting from miscommunication or lack of visibility, especially in complex or congested intersections.
3) Emergency Vehicle Notification: V2V communication can alert nearby vehicles to the presence of emergency vehicles, such as ambulances, fire trucks, or police cars. This enables drivers to take appropriate actions to clear a path, ensuring faster and safer emergency response.

TABLE I. COMPONENTS OF V2V COMMUNICATION

Component	Description
1. Onboard Sensors	Collect data on position, speed, direction, etc., from GPS, radar, LiDAR, and cameras.
2. Onboard Computer	Process sensor data, generate information for transmission, and make decisions.
3.V2V Communication Module	Transmit and receive data using DSRC or C-V2X technologies.
4. Antenna	Transmit and receive wireless signals, ensuring reliable connections within range.
5. User Interface	Display V2V information to the driver through infotainment, dashboard, or dedicated devices.
6. Control Systems	Implement decisions made by onboard computer or ADAS for safe and efficient navigation.

Note: Security mechanisms like encryption, authentication, and message signing are essential for maintaining secure and private communication between vehicles.[9, 10]

4) Vulnerable Road User Protection: By integrating V2V communication with other technologies, such as Vehicle-to-Pedestrian (V2P) or Vehicle-to-Bicycle (V2B) communication, the safety of vulnerable road users, like pedestrians and cyclists, can be enhanced. This can help prevent accidents involving these road users, who are often more susceptible to serious injuries or fatalities.

5) Enhanced Driving Assistance Systems: V2V communication can augment Advanced Driver Assistance Systems (ADAS) by providing additional information from surrounding vehicles, enabling more accurate decision-making and improved safety features, such as blind-spot monitoring, lane-keeping assistance, and automatic emergency braking.[14, 15]

C. Environment

2V communication has the potential to positively impact the environment by promoting more efficient driving behavior, reducing traffic congestion, and supporting the integration of eco-friendly technologies. Here are some ways in which V2V communication can contribute to a greener environment:

1) Eco-routing: V2V communication enables vehicles to share real-time traffic information, allowing them to optimize their routes based on traffic conditions and minimize fuel consumption. By reducing the time spent idling in traffic, vehicles can emit fewer greenhouse gases and pollutants.

2) Fuel-efficient driving: V2V communication can facilitate cooperative driving behaviors, such as platooning and Cooperative Adaptive Cruise Control (CACC), which help maintain constant speeds and minimize sudden braking or acceleration. These behaviors lead to more efficient fuel consumption and reduced emissions.

3) Reduced traffic congestion: By enhancing traffic flow and reducing congestion through improved route planning and traffic management, V2V communication can contribute to lower overall fuel consumption and emissions, as vehicles spend less time idling or moving at inefficient speeds.

4) Support for electric vehicles (EVs): V2V communication can help improve EV infrastructure by sharing information about charging station locations, availability, and charging times, encouraging EV adoption and reducing dependence on fossil fuels.

5) Integration of renewable energy: V2V communication can support the integration of renewable energy sources into the transportation sector by enabling vehicles to communicate with smart grids and optimize energy consumption based on the availability of renewable energy.

6) Smarter urban planning: Data collected through V2V communication can be used by city planners and transportation authorities to identify areas with high traffic congestion or poor air quality, enabling the development of more sustainable and environmentally friendly urban designs.[16]

VI. Challenges and Future Prospects

A. Challenges

Despite the numerous benefits and applications of V2V communication, several challenges must be addressed to realize its full potential. Here are some key challenges and future prospects in the field of V2V communication.

1) Security and Privacy: Ensuring secure and private communication between vehicles is crucial to prevent cyberattacks, data breaches, and unauthorized access. Developing robust security protocols, encryption methods, and authentication techniques will be essential for safeguarding V2V communication systems.

2) Interoperability: As multiple wireless communication technologies exist for V2V communication, ensuring seamless interoperability between different vehicles and infrastructure systems is vital. Establishing common communication standards and protocols will help achieve better integration and coordination among various V2X technologies.

3) Scalability: As the number of connected vehicles increases, V2V communication systems must be able to scale efficiently to handle the massive amounts of data exchanged between vehicles. Advances in network infrastructure, data management, and edge computing will be crucial to ensure the scalability of V2V communication systems.

4) Spectrum Allocation: With the increasing demand for wireless communication technologies, competition for available radio spectrum is intensifying. Efficient spectrum allocation and management will be necessary to avoid interference and ensure the reliable performance of V2V communication systems.

5) Legal and Regulatory Frameworks: The development of comprehensive legal and regulatory frameworks is essential for the widespread adoption of V2V communication. These frameworks should address issues such as liability, data ownership, and privacy while facilitating the integration of V2V technologies into existing transportation systems.

6) Public Acceptance: Gaining public trust and acceptance of V2V communication technologies is vital for their successful implementation. Public awareness campaigns, education, and transparency about the benefits and potential risks associated with V2V communication will be crucial in building public confidence. *[17-20]*

B. Future Prospects

As these challenges are addressed, the future of V2V communication holds significant promise. The development of advanced communication technologies, such as 5G and 6G, will further enhance the capabilities of V2V systems, enabling new applications like fully autonomous driving and smart city integration. Additionally, the increasing adoption of electric and hybrid vehicles will drive the demand for advanced V2V communication systems to optimize energy consumption, route planning, and charging infrastructure.

CONCLUSION

In conclusion, V2V communication offers immense potential to transform the transportation landscape by facilitating real-time information exchange between vehicles, resulting in improved road safety, traffic efficiency, and environmental sustainability. The development and integration of wireless communication technologies, such as DSRC, C-V2X, and 5G NR, have enabled a wide range of V2V applications, from collision avoidance to autonomous vehicle integration. However, challenges such as security and privacy, interoperability, and regulatory frameworks must be addressed to fully realize the potential of V2V communication. As the technology continues to advance and overcome these challenges, V2V communication is expected to become a key enabler of intelligent transportation systems and autonomous driving, ultimately leading to safer, more efficient, and greener transportation solutions for future generations.

CONTRUBITION OF THE AUTHORS

The contributions of the authors to the article are equal.

CONFLICT OF INTEREST

There is no conflict of interest between the authors.

STATEMENT OF RESEARCH AND PUBLICATION ETHICS

Research and publication ethics were observed in this study.

REFERENCES

[1] A. Rejeb, K. Rejeb, S. Simske, H. Treiblmaier, and S. Zailani, "The big picture on the internet of things and the smart city: a review of what we know and what we need to know," *Internet of Things,* vol. 19, p. 100565, 2022.

[2] K. Jones, "How the internet of things is building smarter cities," in *World Economic Forum in a cooperation with Visual Capitalist. Retrieved April*, 2020, vol. 10, p. 2020.

[3] E. Smith, "The Future of Intelligent Transportation Systems (ITS): Applying Lessons Learned From 30 Years of Innovation," *Public Roads,* vol. 86, no. 1, 2022.

[4] J. B. Kenney, "Dedicated short-range communications (DSRC) standards in the United States," *Proceedings of the IEEE,* vol. 99, no. 7, pp. 1162-1182, 2011.

[5] S. Chen *et al.*, *Cellular Vehicle-to-Everything (C-V2X).* Springer Nature, 2023.

[6] K. Serizawa, M. Mikami, K. Moto, and H. Yoshino, "Field trial activities on 5G NR V2V direct communication towards application to truck platooning," in *2019 IEEE 90th Vehicular Technology Conference (VTC2019-Fall)*, 2019, pp. 1-5: IEEE.

[7] G. Cecchini, A. Bazzi, B. M. Masini, and A. Zanella, "Performance comparison between IEEE 802.11 p and LTE-V2V in-coverage and out-of-coverage for cooperative awareness," in *2017 IEEE Vehicular Networking Conference (VNC)*, 2017, pp. 109-114: IEEE.

[8] J. Harding *et al.*, "Vehicle-to-vehicle communications: readiness of V2V technology for application," United States. National Highway Traffic Safety Administration2014.

[9] M. El Zorkany, A. Yasser, and A. I. Galal, "Vehicle to vehicle “V2V” communication: scope, importance, challenges, research directions and future," *The Open Transportation Journal,* vol. 14, no. 1, 2020.

[10] A. Demba and D. P. Möller, "Vehicle-to-vehicle communication technology," in *2018 IEEE international conference on electro/information technology (EIT)*, 2018, pp. 0459-0464: IEEE.

[11] J. E. Siegel, D. C. Erb, and S. E. Sarma, "A survey of the connected vehicle landscape—Architectures, enabling technologies, applications, and development areas," *IEEE Transactions on Intelligent Transportation Systems,* vol. 19, no. 8, pp. 2391-2406, 2017.

[12] A. Muza, S. Kamarulzaman, M. Rahman, S. Murad, M. Kamal, and A. Alenezi, "Multiple Vehicle Cooperation and Collision Avoidance in Automated Vehicles: Survey and an AI-Enabled Conceptual Framework," 2022.

[13] S. Wong, L. Jiang, R. Walters, T. G. Molnár, G. Orosz, and R. Yu, "Traffic forecasting using vehicle-to-vehicle communication," in *Learning for Dynamics and Control*, 2021, pp. 917-929: PMLR.

[14] A. Metzner and T. Wickramarathne, "Exploiting Vehicle-to-Vehicle Communications for Enhanced Situational Awareness," in *2019 IEEE Conference on Cognitive and Computational Aspects of Situation Management (CogSIMA)*, 2019, pp. 88-92: IEEE.

[15] M. Mostaed, K. Aldabas, and C. Olaverri-Monreal, "V2V Communication System to Increase Driver Awareness of Emergency Vehicles," in *Computer Aided Systems Theory–EUROCAST 2017: 16th International Conference, Las Palmas de Gran Canaria, Spain, February 19-24, 2017, Revised Selected Papers, Part II 16*, 2018, pp. 413-418: Springer.

[16] F. I. Rahman, "Impact of V2V Communication on Eco-Route Choice," *LOGI–Scientific Journal on Transport and Logistics,* vol. 11, no. 1, pp. 37-45, 2020.

[17] M. A. Habib *et al.*, "Security and privacy based access control model for internet of connected vehicles," *Future Generation Computer Systems,* vol. 97, pp. 687-696, 2019.

[18] L. Jin and P. Slowik, "Literature review of electric vehicle consumer awareness and outreach activities," *International Council on Clean Transportation. Available frominternet: https://www. theicct. org/sites/default/files/publications/Consumer-EV-Awareness_ICCT_Working-Paper_23032017_vF. pdf,* 2017.

[19] L. C. Ezenwa, "Wireless V2V Communication with DSRC Technology in Comparison to C-V2X," *ATZ worldwide,* vol. 124, no. 6, pp. 40-43, 2022.

[20] P. Wang, W. Wu, J. Liu, G. Chai, and L. Feng, "Joint Spectrum and Power Allocation for V2X Communications with Imperfect CSI," *arXiv preprint arXiv:2302.14704,* 2023.