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REVIEW ARTICLE

Vehicle-to-Vehicle Communication: A Review of Efficiency, Communication Medium and Action Signal

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ABSTRACT – In an era marked by rapid advancement in technology, transportation systems are experiencing a revolutionary transformation. Vehicle-to-Vehicle (V2V) communication stands at the forefront of this transformative movement, with the potential to significantly change the ways how vehicles interact with one another and their surrounding environment. This newly developed technology has the capacity to significantly improve road safety, traffic efficiency, and every aspect of the driving experience. Thus, a review of V2V communication based on its safety, efficiency of traffic on the road, the medium of communication and the action signal have been made. The purpose of the review on this technology is to examine the possibility of enhancing safety measures that may include walking, motorcyclists, cyclists, and drivers on the road. A comprehensive review of publications about safety, technology for communication, and signal reception in vehicles was conducted, along with an analysis of the articles that followed. Notably, the quest encompassed three prominent databases – IEEE Xplore, ScienceDirect, and Web of Science – covering the period from 2002 to 2023. These repositories were deemed adequately comprehensive to envelop our literature review. Through the application of predefined criteria for inclusion and exclusion, a total of 125 articles were curated. Among this compilation, a majority (63 out of 125) were dedicated to studies centered around V2V communication systems. Furthermore, a significant subset (44 out of 125) revolved around tangible endeavors directed at the advancement of V2V communications. The remaining fraction (18 out of 125) comprised articles offering comprehensive assessments and survey analyses. Multiple investigations were conducted with a focus on automating the detection of V2V communications and their respective subcategories, all geared towards the enhancement of detection accuracy. Therefore, this systematic review is intended to provide pathways for researchers and encourage their motivation to address the identified problems and gaps.

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1. INTRODUCTION

In the contemporary period, which is characterized by urbanization and fast technological progress, the transportation sector is now experiencing significant changes. The integration of advanced communication technologies has facilitated the connection between traditional vehicles that previously functioned independently. This development has led to a significant transformation in the form of Vehicle-to-Vehicle (V2V) communication. V2V communication, an essential component of Intelligent Transportation Systems (ITS), provides an innovative strategy for tackling the issues of traffic congestion, road safety, and environmental sustainability [1], [2], [3]. V2V refers to vehicle communication between vehicles [4], also known as V2V communication. Wireless technology [5] enables the real-time transmission of information between vehicles [6]. Consequently, the data provided may include several aspects of the vehicle's operation, such as its velocity, geographical coordinates, orientation, braking condition, and other safety-relevant information.

The introduction of V2V communication holds promise in mitigating accidents by providing drivers with timely notifications on possible risks [7]. For example, if a vehicle ahead were to come to a stop suddenly, its V2V system could alert the driver about the imminent hazard. This notification would provide the driver with the chance to promptly engage the brakes, potentially lowering the risk of a rear-end collision incident.[8]. This technological advancement facilitates the ability of cars to engage in interactions, exchange vital information, and cooperate instantaneously, introducing a new phase characterized by synchronized and enhanced traffic movement.

As the global population progressively relocates to metropolitan areas, the challenges that posed by the current transportation infrastructure become more apparent. Traffic congestion is a persistent problem in thriving urban areas, which has negative consequences such as economic losses, longer trip durations, higher emissions, and decreased road safety [9], [10]. Considering the issues, the emergence of V2V communication presents a promising solution since it can address these obstacles by facilitating inter-vehicle communication. The interchange of data pertaining to the locations, velocities, and intents of vehicles is made possible by modern wireless technologies, hence enabling effective communication. These interactions serve as the basis for cooperative decision-making and immediate coordination, enabling cars to function collectively, adjust to dynamic traffic circumstances, and eventually mitigate congestion [11], [12].

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In this paper, a review of V2V communication was conducted by previous researchers. Several perspectives were discussed on the communication medium during the process and the signals that were applied to inform the driver on the topic. This research contributes to researchers and practitioners in V2V by presenting a clear review of the safety, traffic, and medium explored when analyzing the topic. The rest of this paper is organized as follows. Section II elaborates on enhancing safety, and Section III details the traffic efficiency when applying V2V system performance. Meanwhile, Section IV will discuss the medium of communication that was used in previous research. Section V indicates the action signal that is obtained by the receiver. Finally, the conclusion of the paper is shown in section VI.

2. ENHANCED SAFETY

When addressing traffic safety, particularly in relation to Cooperative Collision Avoidance (CCA) systems, short-range communications such as V2V or Vehicle-to-Infrastructure (V2I) are often used [13]. Nevertheless, the communication connection represents only one of the several processes that might potentially cause delays in the supply of traffic management information. Additional operations that might be considered include retrieving dynamic characteristics from vehicles, such as location, speed, heading, and headroom. Furthermore, the time required for calculating safety conditions and the potential delay created by protocols for distributing relevant information to all drivers participating in the vehicles should also be taken into consideration [14], [15].

Subsequently, the cooperative collision warning service assists the driver in reducing or preventing collisions with the rear end of vehicles by providing notifications or warnings of oncoming accidents [16]. Based on the work in [17] [18], this study focuses on investigating the anti-collision warning system in both urban road (low speed) and highway (high speed) situations. It aims to examine the simulation impacts of anti-collision braking using onboard sensors and V2V technology. Note that the simulations were conducted utilizing combination tools in Prescan. This experiment demonstrated that V2V technology is more effective in implementing an anti-collision warning system for forward vehicles than sensor technology. The findings suggested that these algorithms can serve as a universal approach to decrease the time and cost associated with the implementation of safety services in the context of IEEE 802.11p/Wireless Access in Vehicular Environments (WAVE) wireless networks [19]. As indicated by the Road Traffic Rules, the act of braking serves as the fundamental measure to mitigate the occurrence of hazardous circumstances. Lowering the speed to the suggested level, or below, facilitates the safe traversal of the intersection [18]. Therefore, the analytical method for calculating the minimum safe distance can precisely determine the initial distance needed to execute lane changes without compromising safety. [20].

V2V communication systems provide inter-vehicle communication, allowing cars to exchange information and use such shared data to make informed choices pertaining to safety. Nevertheless, enhancing safety in the existing V2V systems only provides advantages to V2V-enabled entities inside the V2V network [21]. Moreover, the primary emphasis of the V2V communications system is in the domain of automobiles and trucks, with comparatively little attention given to Vulnerable Road Users such as pedestrians, motorcyclists, and cyclists. To further improve the safety of Vulnerable Road Users, some researchers have introduced the concept of Advanced Driver Assistance Systems (ADAS) to prevent accidents involving motorcyclists and cyclists by utilizing V2V communications and the integration of V2V capabilities with the Pedestrian Automatic Emergency Braking System (V2V-PAEB) [22], [23]. The suggested technique was evaluated by conducting tests in both real vehicle and simulation environments, specifically focusing on vehicle speeds below 50km/h. The findings indicated that the V2V-PAEB system, as proposed, exhibited the capability to detect pedestrians at an earlier stage compared to scenarios where V2V communication was absent [24], [25]. Consequently, collisions with pedestrians were successfully averted. Additionally, the system demonstrated the ability to detect motorcycles within a range of less than 30 meters, aligning with anticipated outcomes in terms of safety and efficiency [26]. These outcomes represent an initial stride towards enhancing the safety of both cyclists and motorists.

Therefore, with the introduction of the V2V-PAEB system, vehicles equipped with V2V technology can share relevant information on the presence of pedestrians, cyclists, and motorcyclists in their immediate surroundings, even in cases when these road users may not be immediately observable by the driver. The use of this technology has the potential to enhance cars' ability to foresee and effectively react to impending risks, hence reducing the likelihood of accidents.

3. TRAFFIC EFFICIENCY

V2V communication has the capacity to effectively mitigate traffic congestion by facilitating vehicles to coordinate and optimize traffic flow using several methodologies. Moreover, road traffic safety is one of the priorities in the development of ITS [27], [28]. With the increasing integration of sensors in vehicles, it is anticipated that incorporating V2V modules would facilitate the implementation of advanced vehicle platooning [4]. These articles [5] and [29] present a study that examines the implementation of a platoon run of trucks on the highway, emphasizing V2V distance optimization. The objective of this study is to investigate the potential fuel efficiency improvements and traffic congestion this approach may achieve. Furthermore, analysis and field measurements of V2V communication using several diversity schemes are described in [30]. Receive diversity (Rx) and transmit diversity (Tx) are the two communication diversity strategies that were evaluated. The comparison between these schemes and communication without diversity is based on actual measured data. It has been demonstrated that vertical diversity is effective in the context of the meeting scenario, whereas it is not as applicable in the joining from behind or leaving from ahead scenarios [31]. This is primarily attributed to the meeting scenario involving vehicles with a significantly greater speed differential, at least ten times higher, compared to the other scenarios where all vehicles travel in the same direction. It has been shown that in cases involving vehicles, the recommendation of "placing the antenna as high as possible" is not always applicable [32]. However, the experimental data suggest that the communicated designed acceleration of the leading truck may identify between safe and risky situations, therefore maintaining stability and safety in dangerous scenarios within a vehicle platoon. [32], [33].

To enhance traffic throughput, the Cooperative Adaptive Cruise Control (CACC) systems have drawn significant attention [34], [35] due to their ability to facilitate communication and collaboration among the automated regulation of inter-vehicle distances within a string of vehicles [36]. These systems enable vehicles to create platoons, whereby one vehicle follows another while maintaining a predetermined spacing or time difference. The use of a linear controller and a Model Predictive Control (MPC) controller is prevalent in longitudinal controllers [37] for CACC systems, primarily to address constraint management. Based on the obtained outcomes, it can be seen that the linear controller exhibits adaptability in promptly addressing substantial faults [38], [39]. Conversely, the MPC controller ensures that the vehicle follows a trajectory in a manner that prioritizes comfort and safety [40], [41].

Furthermore, it might be stated that CACC exhibits superior performance compared to the standard Adaptive Cruise Control (ACC) technique [42]. This statement is supported by evidence suggesting a significant improvement in accuracy [43] as the quantity of surrounding cars and the corresponding information obtained from them increases. Therefore, this demonstrates that the CACC controller has the capability to mitigate the impact of anomalous communication on connected vehicle platoons, maintain string stability, and achieve substantial fuel consumption [34], [44] reduction while assuring driving comfort and safety. Subsequently, V2V technology facilitates inter-vehicle communication and collaboration, hence mitigating the negative effects associated with stop-and-go traffic, irregular driving patterns, and abrupt lane changes, all of which are prevalent factors contributing to traffic congestion. The increasing use of V2V communication has significant promise for mitigating congestion, hence enhancing the efficiency and satisfaction of commuting experiences for all road users [45].

4. MEDIUM OF COMMUNICATION

Within the domain of V2V communication, the term "medium" conventionally denotes the communication channel or physical medium used to transmit information between vehicles. V2V communication is essential in ITS, enabling inter-vehicle communication to exchange vital information to improve safety, traffic control, and overall road efficiency [46], [47]. The role of medium communication in V2V systems encompasses several aspects, including information sharing, collision avoidance, cooperative maneuvers, traffic flow optimization, emergency notification, traffic management, infrastructure interaction, and data fusion [48], [49].

Overall, the purpose of medium communication in V2V is to allow vehicles to communicate essential information, collaborate and contribute collectively to safer and more efficient transportation networks. Wireless technologies, such as Dedicated Short-Range Communications (DSRC) or Cellular Vehicle-to-Everything (C-V2X) communication [50], [51], [52], are often used as the communication channel, allowing cars to broadcast and receive data across a shared frequency band.

4.1 Light Fidelity

Light fidelity, also known as Li-Fi, is used to modulate light at a speed faster than the human eye can perceive. With the recent advancements in light communication via Li-Fi and the pervasive adoption of LED illumination by consumers, the future of light communication is bright [53]. Li-Fi has many benefits over other communication protocols, making it a viable option for V2V communication and this medium's potential increased utilization of effective V2V communications, thus a practical and affordable way to integrate road safety applications [54], [55].

There are several sensors used with Li-Fi to collect specific data such as speed, location, and direction data. The ultrasonic sensor was used in [56 and [57] to collect location data among cars to detect objects in the vehicle's surroundings. These papers [58] [59] propose a concept for a collision detection system for smart cars using light fidelity (Li-Fi) and ultrasonic sensor technologies on the Arduino platform. The design incorporates an ultrasonic sensor, an Arduino microcontroller, and a Li-Fi circuit. Consequently, ultrasonic technology is used to measure the distance between cars [60], with the Arduino microcontroller processing the acquired data and then making decisions based on this information. Data transfer between automobiles is facilitated using a Li-Fi transmitter circuit and a Li-Fi reception circuit. Based on the method proposed, the ultrasonic range sensor can be modified to extend its detection range. The proposed system can be expanded to include Side impact collision detection, Lane-Change assistance, and Blind-Spot detection [61]. In general, integrating ultrasonic sensors with Li-Fi technology offers a more complete and dependable means of vehicular communication. Therefore, implementing this measure may effectively reduce the occurrence of crashes, enhance overall road safety, provide assistance for parking and optimize the efficiency of driving operations [62], [63].

Other than that, Li-Fi in-vehicle communications may be a low-cost method of communication with a simple approach, eco-friendly method, a high data throughput and significant bandwidth efficiency [56], [64], [65]. These studies [64] [66] introduce an innovative approach for avoiding collisions between two cars. The proposed technique involves the integration of LED technology at the front of the vehicles and photodiode technology at the back. This configuration enables the transmission and reception of data to facilitate collision avoidance. The power consumption of the system is minimal, as shown by the technique [67]. This implies that the operational expenses associated with using Li-Fi in V2V applications are comparatively less costly than those of other wireless communication technologies, making it accessible to even the most impoverished segments of the global economy [68]. Although the study verifies the concept, more research is necessary since real implementation may differ, and associated issues must be considered. The work adds to the conceptual understanding of how Li-Fi may be implemented into automobiles and serves as an aspect of inter-vehicle communication [66].

Note that outdoor Li-Fi is still in its early stages of development, hence, the most potential applications envisaged by this technology include urban Li-Fi, VLC- Internet of Things (IoT) and V2X (Vehicle to Everything). With VLC-IoT, a streetlight may communicate with the urban environment around it or provide location-based content to a visitor standing in its path. V2X is designed to communicate with street infrastructure as well as with one another. As a result, VLC might respond to certain areas' lack of connection while also relieving the RF spectrum [69], [70]. Since light can pass through the water more readily than radio waves, Li-Fi may be utilized for underwater communication. Furthermore, Li-fi has the potential to be used in the real of industrial automation because of its enhanced reliability and heightened security in the transmission of data, particularly in challenging environmental conditions [71]. Moreover, Li-Fi can provide high-speed wireless networking in indoor environments, such as offices, colleges, and hospitals. Li-Fi's prospective applications are genuinely limitless. As technology advances, we expect to see even more inventive and ground-breaking uses in the coming years [72].

4.2 Dedicated Short-Range Communications

A wireless standard called Dedicated Short-Range Communications (DSRC) was created specially to accommodate applications for ITS. The US Federal Communications Commission (FCC) allocated 70 MHz in the 5.9 GHz band for the implementation of wireless systems for V2V and V2I communications in accordance with the DSRC standard, thereby limiting the potential for high-speed data transfer [73] [74].

The implementation of DSRC technology for V2V communication heavily relies on two fundamental standards, namely IEEE 802.11p and SAE J2735, to deliver secure and standardized V2I communication for road safety and cooperative driving [75]. These standards have significant importance in facilitating the successful application of DSRC technology. IEEE 802.11p specifies the physical and Medium Access Control (MAC) layers for WAVE investigated in [75], [76]. It is a V2V and V2I-specific Wi-Fi standard (IEEE 802.11) extension. Additionally, it provides the protocol and framework for short-range, high-speed wireless communication between vehicles and infrastructure elements like Roadside Units (RSU) [77]. Thus, specifies the DSRC communication channels and frequency bands, which in the US are 5.9 GHz. On the other hand, the Society of Automotive Engineers (SAE) J2735 defines V2V and V2I DSRC message sets, which specify V2I communication content, structure, and data [78]. It standardizes V2I safety messaging. These communications contain vehicle location, speed, acceleration, direction, and safety data. Nevertheless, the adoption of DSRC technology and the regulatory environment surrounding it vary by country [79]. Some nations have taken significant measures to promote DSRC for V2V communication, while others have explored alternative communication technologies or system combinations. Importantly, the status of DSRC adoption and regulatory considerations can alter over time as technology evolves, new research is conducted, and new communication standards are created [79], [80]. Other than that, regional differences in regulations and technology preferences can affect the deployment direction of V2V communications.

There are numerous technical specifications for DSRC regarding frequency bands used, data rates, and Communication Range. In most regions, including the United States, Europe, and areas of Asia, DSRC operates in the 5.9 GHz frequency band. This frequency band is exclusively allocated for ITS applications, including V2V and V2I communication [74]. These works [81] [82] introduced a revolutionary dual-band V2V receiver architecture that is designed to support both DSRC and 28GHz communications. The structure of the said architecture incorporates optimized antenna gain and the number of components for each band to maximize the range and data throughput of the system. According to the proposed method, the DSRC communication range depends on environmental conditions, antenna design, and output power [83]. DSRC typically has a range between a few hundred meters and one kilometer [84]. This kind of communication, which has a limited range, is very appropriate for applications involving V2V and V2I interactions in situations characterized by high traffic density. Note that DSRC supports variable data rates depending on the specific use case and communication distance. For lesser ranges, it can provide data rates between 6 and 27 Mbps (Megabits per second) for lesser ranges, which is typically sufficient for safety-critical applications [81].

Furthermore, DSRC technology can dramatically improve transportation safety, not only for transit vehicle passengers but also for pedestrians [79], [85]. Based on spectrum parameters, transmission rate, and communication modes, research in [86] DSRC was compared with typical short-range access technologies such as WiMax, Wi-Fi, GPS, and Bluetooth. Each radio system has unique technical performance and application fields, as observed. It delivers high-speed and reliable Internet access but does not support apps that demand high real-time performance [87]. Telecom networks (such as GSM/CDMA) are designed primarily for voice services and so have minimal latency. The original DSRC standards, present in Europe, Japan, and Korea, are more applications, including the whole protocol stack with a physical (PHY), a MAC, and an application layer [88].

4.3 Fifth Generation Connection

The next generation of wireless systems should be able to provide a greater variety of services with varying Quality of Service (QoS) requirements than the current Fourth-Generation (4G) wireless communication network. Utilizing cooperative driving to actively prevent accidents and actively increase traffic efficiency is an emergent new service. V2V communication, which requires high reliability and low end-to-end (E2E) latency, is a significant obstacle to cooperative driving. To meet these requirements, Fifth-Generation (5G) should be evaluated using new Key Performance Indicators (KPIs) rather than the traditional metric, which is the throughput of legacy cellular networks. Thus, the development of V2V communication technology is primarily driven by 5G networks, and V2V communication in 5G has recently attracted considerable interest [89], [90].

The implementation of interconnected cars capable of exchanging information has the potential to drastically lower the percentage of traffic accidents. New network technologies are required to enable V2V communication that is reliable and low latency [91]. Thus, the provision of Ultra-Reliable and Low-Latency Communication (URLLC) services has significant importance within the scope of the 5G cellular system [92]. To optimize the energy efficiency of V2V communication and fulfill the demands of URLLC, a novel deep reinforcement learning framework is introduced [93], [94]. This framework employed a centralized training approach coupled with distributed execution. To achieve the desired outcome, a model was trained via the Double Deep Q-Network (DDQN) algorithm. The simulation findings demonstrated that the DDQN-based algorithm exhibited superior performance in terms of computation offloading, energy efficiency, and latency when compared to existing baseline algorithms [95]. In addition, low latency may play a critical role in video to ensure the safe and effective functioning of autonomous cars [96]. Autonomous cars need video feeds because they depend on cameras and other sensors to sense their surroundings and make real-time judgments. Low-latency video processing is even more important when there are complicated driving situations, including heavy traffic or bad weather. It aids the vehicle's safer and more accurate navigation under these circumstances [97].

Besides, within the framework of upcoming 5G technology, millimeter-wave (mm-wave) bands are being employed to provide high data rates and higher bandwidth for V2V communication [98], [99]. Because of the shorter carrier wavelength, mm-wave is particularly sensitive to the environment, and any vibration of the User Equipment (UE) installation will result in the enhanced carrier and waveform alteration; thus, it is critical to thoroughly define the mm-wave channel by characterizing actual channels in various situations [100]. Furthermore, several mm-wave frequencies have been studied internationally, with an emphasis on 28 GHz and higher for up to 60 GHz [101]. Because of the extremely directional character of wireless communications in millimeter spectral bands, continual channel measurements will be required to verify that the transmitter (Tx) and reception (Rx) beams are aligned to offer the greatest performance [102]. Although high directivity beamforming antenna arrays may be used to provide a stable connection between the transmitter and receiver, there is always a Doppler shift associated with mobility in a vehicular channel, which can degrade performance in certain communication settings. However, the directional beam created by a phased array antenna provides spatial filtering of the environment, lessening the influence of the Doppler effect. Nevertheless, a reduced beamwidth may accentuate the effects of vibration and antenna inaccuracy [103].

Despite being in the early development phase in the context of V2V) communication and exhibiting performance degradation when compared to 4G, the widespread use of the 5G connection remains feasible. Consequently, it is essential to conduct comprehensive research to explore the many possible applications envisaged by this technology. The reliability of 5G surpasses that of previous generations of cellular networks. Note that the enhanced signal strength and range of 5G could be attributable to the use of advanced technologies, such as beamforming and mm-wave [104]. Additionally, with greater data rates and bandwidth, networked autonomous vehicles can be supported by the 5G spectrum. The mm-wave spectrum range of the 5G communication channel offers a very high bandwidth, making it appropriate for automotive connection [105].

5. ACTION SIGNAL

In the context of V2V communication, receivers have the capability to create a wide variety of action signals to transmit information to drivers effectively. The purpose of these signals is to efficiently notify drivers of possible risks [106], [107], crucial occurrences, or required tasks. The effectiveness of each form of action signal ultimately depends on variables such as the driving situation, the driver's attention and sensory capacity, and the signal's clarity. Ideally, V2V communication systems should provide a proportional combination of visual, auditory, and haptic signals, considering human factors and the potential impact on driver behavior. However, haptic signals may not be as informative as visual or auditory cues when communicating specific information [108]. User studies, simulations, and real-world testing are essential for evaluating and improving the effectiveness of these signals in informing drivers. Therefore, the significance of visual and auditory warnings has become prominent, finding several uses, particularly in disseminating dangers within transportation and other industrial systems [109].

5.1 Human-Centric Philosophy in V2V Communication for Autonomous Vehicles

The human-centric concept of autonomous vehicle (AV) and V2V communication emphasizes the need to incorporate human drivers into the driving environment as cooperative players rather than obstacles. This conceptual modification is critical for improving the safety, efficiency, and acceptability of AV technology. By incorporating human driving patterns and behaviors into V2V communication protocols, autonomous vehicles may anticipate and react to human drivers' unexpected behavior [110]. For example, when an AV senses a human-driven vehicle approaching an intersection, the V2V system may anticipate whether the driver will stop or proceed. Based on this forecast, the AV may modify its actions [111], either slowing down to enable the human driver to pass or safely speeding through the junction, as shown in Figure 1. This human-centric planning improves the safety and efficiency of autonomous driving. It raises the comfort and confidence of human drivers [112] who share the road with AVs, resulting in a more seamless transition to broad autonomous vehicle adoption.

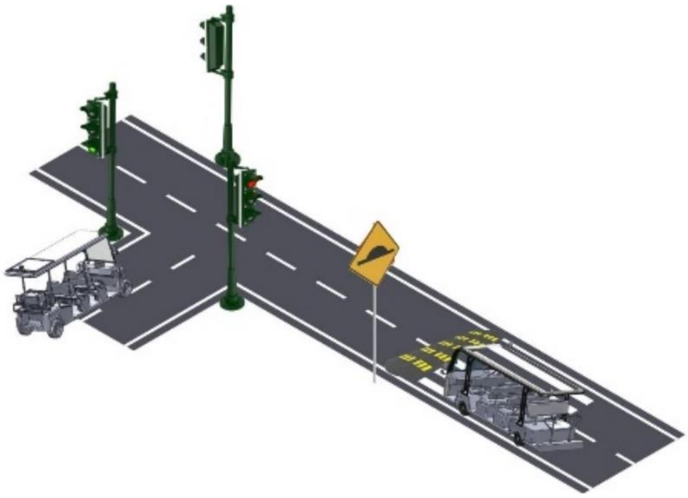

Figure 1. The vehicle approaching the intersection

5.2 Visual Alert

Visual alerts include the transmitting of information to drivers using visual stimuli, often shown on display or by lighting. These signals demonstrate a high level of efficacy in attracting the attention of drivers and effectively delivering urgent information. Next, the visual interface may be equated to text-based or symbolic messages that can be shown on the dashboard or in a heads-up display of a car. Illustrative instances include cautions pertaining to the deceleration of cars in proximity, deviations from the designated lane, or the prospect of an impending accident. According to the SAE J2735 protocol [113], the BSM is the primary message set for sending data between vehicles and ensuring the driver's life. The BSM is currently the most common application layer protocol used for the purpose of transmitting security status information among cars [114], [115]. Vehicles transmit and receive BSM communications to relay their current operational state to other vehicles and to acquire information on the operational state of the surrounding vehicles.

Using Prescan simulations in MATLAB [2], [116] and the Carla Simulator [79], it is seen that when the Following Vehicle (FV) approaches the Leading Vehicle (LV), certain outcomes are observed. Upon the occurrence of a symbol alert, a visual warning in the form of "SLOWDOWN! SUDDEN BRAKE" will be triggered inside the FV [66]. Furthermore, this technology may potentially be developed to aid emergency vehicle drivers in selecting their routes [117]. Additionally, it mitigates the potential risks associated with accidents involving emergency vehicles by promoting safety measures and traffic management protocols for both emergency and non-emergency vehicles [118]. Nevertheless, any deviation from the Line-of-Sight position may also disrupt communication and lead to misunderstanding.

Furthermore, warning lights also function as visual indicators on the dashboard that may be used to illuminate certain lights, so indicating possible hazards. For instance, a luminous entity symbolizing a nearby automobile has the potential to provide information pertaining to its velocity and proximity in relation to the driver's vehicle. The electronic emergency brake light [119] has the capability to transmit an active breaking Li-Fi signal to subsequent vehicles. Therefore, it alerts the drivers when a vehicle is not within their line of sight. However, several cars ahead are braking or coming to a halt due to an emergency. This communication is facilitated by a breaking message, as seen in Figure 2.

Figure 2. Avoidance of light-based cohesion in transport environments [119]

In a moving vehicle, additional light-based activities might serve as warnings to motorists, namely indicating "do not pass" or "do not switch lanes" when it is deemed risky to overtake a slow-moving car [70], [120]. In some situations, warnings encourage drivers to react promptly to prevent potential collisions. For instance, the intersection crossing alert utilizes brake light technology to notify drivers [121] when it is dangerous to go into an intersection on a road with limited visibility. The outcome of the experimental assessments [55],[56] indicated that the prototype has the capability to identify instances of heavy braking from 20 meters. Furthermore, it can promptly alert drivers positioned behind who are traveling approximately 80 kilometers per hour, mitigating the likelihood of road accidents. However, technology may also assist in automating some processes, allowing the driver to have limited control over the vehicle. Although, these visual alerts are highly effective when the driver's attention is focused on the road. They provide immediate information and can convey complex details, such as the position and speed of nearby vehicles. Conversely, their effectiveness can decrease if the driver is visually distracted or if the display is difficult to see.

5.3 Auditory Alert

Auditory signals use auditory stimuli to inform drivers about possible hazards or necessary actions. Note that auditory stimuli have the potential [122] to be efficacious in scenarios when the driver's visual focus is fragmented. Based on preliminary testing [54], [64] Li-Fi is used as a communication medium when the system detects a forceful braking and activates the alert buzzer. Therefore, an alarm is triggered if the Leading Vehicles (LV) has a sudden deceleration and a buzzer sound is emitted via the Following Vehicle's (FV) speakers [55], [116]. This serves as a warning to the driver that the car is ahead. Moreover, auditory warnings attract a driver's attention effectively, particularly when visual indicators are not immediately visible. Short, distinct noises can convey urgency rapidly. However, an excess of auditory signals or noises that are excessively complex can confuse[123] and reduce effectiveness [120]. According to a survey [124], 70% of drivers switch off warning alarms due to their irritating sound and nuisance.

Furthermore, voice messages may be categorized as auditory alerts, indicating notices that are sent verbally and have the potential to provide detailed information about the current situation, thus aiding the driver in making informed decisions. Previous research has shown a preference for female voices in route guidance systems as compared to male voices [125]. The research demonstrates [114], [126] the use of auditory alerts sent through the automobile's speakers in specific circumstances, including instances when a driver engages in tailgating, abruptly changes lanes, or commits a traffic violation at a junction by disregarding a traffic light. In such scenarios, the system is designed to autonomously transmit a concise vocal message, such as 'watch your front' or 'bi-bi'. Nevertheless, there is currently little understanding of how auditory displays and audio indicators might cause disruption and confusion among drivers in real-world driving scenarios [127].

When comparing sound warnings with voice message warnings [128], it can be seen that the beep sound warning signal provides a direct test stimulus to drivers, specifically targeting their attention toward the car in front of them. This auditory signal has been shown to enhance drivers' performance in steering control. On the other hand, a verbal message has no advantage when the automobile in front stops, showing that the beep sound is more helpful in aiding a driver confronting a car stopping in front and does not cause too much interference. Furthermore, the auditory stimulus of the beep elicited a reduced perception-reaction time compared to the verbal stimulus of speech. The driver would decrease the velocity of the vehicle when it is equipped with a warning system.

5.4 Potential for Future Research

This paper argues that V2V communication has undergone significant progress, but it continues to be an intriguing field for future research and innovation. This analysis identifies many deficiencies and prospects within the current literature that further research might explore to improve the efficacy, scalability, and integration of V2V systems in practical applications. A crucial area for future study is challenging the issues of communication dependability under varying traffic situations. Research may focus on enhancing communication protocols to reduce signal interference resulting from increased vehicle density, obstacles to travel, and fluctuating weather conditions. Furthermore, the use of adaptive algorithms that can dynamically regulate transmission bandwidth and prioritize essential data may greatly enhance system dependability. A crucial aspect requiring study is the integration of VRUs, including walkers, cyclists, and motorcyclists, into V2V ecosystems. Although several studies have investigated V2V-enabled ADAS for the protection of VRUs, further research is required to provide complete frameworks that include these technologies in larger Intelligent Transportation Systems (ITS). Integrating V2V communication with augmented reality (AR) interfaces for the safety of VRUs may provide novel solutions.

The use of new technologies such as 5G and Li-Fi offers more research prospects. The enormous bandwidth and low latency of 5G networks enable real-time data sharing for sophisticated applications like autonomous vehicle platooning and collaborative traffic management. Li-Fi's promise as a cost-effective and environmentally sustainable communication medium requires a thorough investigation of its scalability and compatibility with other wireless technologies. Cybersecurity and data privacy continue to be critical issues in the implementation of V2V communication systems. Future research should investigate resilient encryption techniques and distributed blockchain frameworks to guarantee safe and persistent data exchange. Moreover, creating frameworks that integrate data-sharing efficacy with user privacy may enhance confidence in the public and facilitate the adoption of V2V technology.

The incorporation of artificial intelligence (AI) and machine learning (ML) into V2V communication systems has significant transformational possibilities. Future research may explore the use of AI-driven prediction models to forecast traffic patterns, identify possible risks, and enhance real-time decision-making processes. Machine learning algorithms may improve the flexibility of vehicle-to-vehicle systems, allowing them to learn and grow from past data and fluctuating traffic conditions. A potential research area is the advancement of human-centric V2V communication systems. Comprehending driving behavior and creating technologies that correspond with human decision-making processes may substantially improve safety and usefulness. Research on multimodal communication action signals by integrating auditory, visual, and physical feedback can enhance driver awareness and reaction times. Finally, further research should examine the socio-economic consequences of extensive V2V deployment. Investigating economic deployment techniques, evaluating their effects on urban planning, and examining the advantages for excluded areas might facilitate inclusive and equitable adoption. By solving these deficiencies and using new technology, forthcoming research may facilitate the development of safer, more efficient, and attributed transportation systems, eventually transforming the driving experience.

6. CONCLUSION

This paper provided a comprehensive assessment of V2V communication, focusing on its capacity to enhance safety, traffic efficiency, communication medium, and action signals received by the recipient. The significance of CCA systems, specifically V2V and V2I communications, in advancing traffic safety was described. In this review, we highlighted the pivotal role of V2V technology in collision warning systems for both urban and highway settings, showcasing its effectiveness in preventing accidents. Additionally, the concept of ADAS was learned, and V2V capabilities were incorporated to bolster the safety of Vulnerable Road Users. Ultimately, the adoption of V2V technology holds the potential to substantially reduce accidents by enabling vehicles to exchange critical information and respond proactively to impending risks. Furthermore, V2V communication offers a versatile solution to address traffic congestion and road safety concerns within ITS. As can be seen, we have examined the potential of V2V communication in optimizing traffic flow, especially through advanced vehicle platooning and CACC systems. It underscores the effectiveness of communication diversity strategies, including Rx and Tx diversity, in diverse traffic scenarios and their influence on stability and safety in vehicle platoons. The comparison between CACC and standard ACC highlights the superior performance and potential for significant fuel consumption reduction offered by CACC. Other than that, V2V technology emerges as a promising tool to alleviate congestion, enhance efficiency, and improve the overall commuting experience for all road users. Despite the significant efforts being dedicated to enhancing safety in V2V mobility, issues regarding safety persist.

Moreover, we deeply delve into the crucial role of communication medium in V2V systems, emphasizing its importance in elevating safety, traffic control, and overall road efficiency within ITS. The utilization of wireless technologies like DSRC and C-V2X was discovered for V2V communication, underscoring the potential of Li-Fi as a practical and cost-effective solution to enhance road safety. Hence, integrating ultrasonic sensors with Li-Fi technology presents a comprehensive approach to vehicular communication, potentially reducing accidents and optimizing driving operations. The emergence of 5G cellular networks and mm-wave bands is presented as a promising avenue for reliable and low-latency V2V communication, with potential applications in autonomous vehicles and high-bandwidth scenarios. The wide range of applications offered by V2V technology has several opportunities for further exploration and investigation. These unexplored avenues may be effectively employed to assess the efficacy of communication technology.

Generally, we discovered the evolving landscape of V2V communication technologies and their potential to revolutionize transportation systems. In addition, effective V2V communication hinges on transmitting action signals to drivers, with visual, auditory, and haptic cues playing pivotal roles in conveying information and ensuring road safety. The choice of signal type depends on various factors, including driving conditions, driver attention, and signal clarity. Other than that, visual alerts, presented through displays, lighting, and symbols, effectively capture drivers' attention and deliver critical information. Warning lights on dashboards, electronic brake lights, and light-based actions contribute to safer driving by informing drivers about nearby vehicles and potential hazards. Auditory signals, such as alarms and voice messages, are valuable when drivers' visual attention is divided and offer swift alerts. Consequently, beep sound warnings have demonstrated effectiveness in steering control and reaction times. Meanwhile, audio alerts are useful in capturing individuals' attention, and others argue that they may be seen as bothersome due to their loudness. Therefore, it would be beneficial to explore a signal type that has the potential to elicit favorable feelings and enhance user consciousness. Thus, the choice of signal type should consider driver preferences and the context in which they are used, ultimately contributing to improved driver awareness and road safety.

While V2V communication has great potential for improving road safety and traffic efficiency, some obstacles have to be solved. One key issue is ensuring reliable communication in a variety of traffic conditions and environments. Factors such as signal interference, vehicle density, and geographical constraints can impact the reliability of V2V transmissions. Furthermore, securing the privacy of vehicle data and avoiding unauthorized access is critical. V2V systems gather and send sensitive data, including vehicle location, speed, and driver behavior. Protecting this data is critical for maintaining user confidence and preventing any kind of misuse. Another issue is the security of V2V systems. Cyber risks, such as hacking and data manipulation, may compromise the integrity of V2V connections, possibly resulting in accidents.

Implementing strong security mechanisms, such as encryption and authentication procedures, is critical for protecting V2V systems from these risks. Finally, the creation of effective and user-friendly signals for V2V communication is essential. Signals must be clear, attention-grabbing, and easy for drivers to understand. Developing signal types that can successfully communicate vital information, especially in complicated driving scenarios, is an important concern.

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CONFLICT OF INTEREST

The authors declare that they do not have any conflict of interest.

AUTHORS CONTRIBUTION

N.I.A. Anizan (Conceptualization, Methodology, Data Collection, Writing – Original Draft)

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