IEEE Access
Multidisciplinary ⋮ Rapid Review ⋮ Open Access Journal

Received October 4, 2019, accepted October 18, 2019, date of publication October 23, 2019, date of current version November 12, 2019.

Digital Object Identifier 10.1109/ACCESS.2019.2949130

A Deep Review and Analysis of Data Exchange in Vehicle-to-Vehicle Communications Systems: Coherent Taxonomy, Challenges, Motivations, Recommendations, Substantial Analysis and Future Directions

HUSSEIN ALI AMEEN[1,2], ABD KADIR MAHAMAD[1], (Senior Member, IEEE), BILAL BAHAA ZAIDAN[3], AWS ALAA ZAIDAN[3], SHARIFAH SAON[1], DANIAL MD NOR[1], RAMI QAYS MALIK[1,2], ZAHRAA HASHIM KAREEM[1,2], SALEM GARFAN[3], RUQAYAH ALAA ZAIDAN[3], AND ALI MOHAMMED[4]

[1]Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia, Parit Raja 86400, Malaysia
[2]Department of Computer Engineering Techniques, Al-Mustaqbal University College, Babil 51001, Iraq
[3]Department of Computing, Faculty of Arts, Computing and Creative Industry, Universiti Pendidikan Sultan Idris, Perak 35900, Malaysia
[4]Faculty of Engineering and Built Environment, Department of Civil Engineering, Universiti Kebangsaan Malaysia, Selangor 43600, Malaysia

Corresponding author: Abd Kadir Mahamad (kadir@uthm.edu.my)

This work was supported in part by the TIER 1 RESEARCH GRANT: Vot U856, Office for Research, Innovation, Commercialization and Consultancy Management (ORICC), Universiti Tun Hussein Onn Malaysia.

ABSTRACT Data exchange in Vehicle-to-vehicle (V2V) communications systems is a field that requires automated solutions, tools and methods and the capability to facilitate early detection and even a prediction. Many studies have focused on V2V system and its classification to improve road safety, reduce traffic congestion and help streamline the vehicle flow on the road. This study aims to review and analyse literature related to data exchange in V2V communications systems. The factors considered to improve the understanding of the field's various contextual aspects were derived from published studies. We systematically searched all articles about the classification and detection of data exchange in vehicles, as well as their evaluation. Three main databases, namely, ScienceDirect, Web of Science and IEEE Xplore from 2008 to 2018, were used. These indices were considered sufficiently extensive to encompass our literature. On the basis of our inclusion and exclusion criteria, 140 articles were selected. Most articles (53/140) are studies conducted in a V2V communication system; a number of papers (51/140) covered the actual attempts to develop V2V communications; and few papers (18/140) comprised framework proposals and architectures. The last portion (18/140) of articles presented review and survey articles. V2V collision avoidance system, which is a field requiring automated solutions, tools and methods, entails the capability to facilitate early detection. Several studies have been performed on the automatic detection of V2V and their subtypes to promote accurate detection. The basic characteristics of this emerging field are identified from the aspects of motivations, open challenges that impede the technology's utility, authors' recommendations and substantial analysis of the previous studies are discussed based on seven aspect (devices, number of scenario, test location, types of sensors, number of vehicle, evaluation techniques used and types of software). A propose research methodology as new direction is provided to solve the gaps identified in the analysis. This methodology consists of four phases; investigation, develop a hardware system, study and analysis, and evaluation phases. However, research areas on V2V communication with the scope of data exchange are varied. This systematic review is expected to open opportunities for researchers and encourage them to work on the identified gaps.

INDEX TERMS Data exchange, vehicle to vehicle, vehicular ad hoc network, safety, collision avoidance, driving behaviors.

ABBREVIATIONS

V2V	Vehicle to Vehicle
VANET	Vehicular Ad Hoc Network
DSRC	Dedicated Short Range Communication
ITS	Intelligent Transportation Systems
DSRC	Dedicated Short Range Communication
GPS	Global Positioning System
IoV	Internet of Vehicles

The associate editor coordinating the review of this manuscript and approving it for publication was Chao Yang.

I. INTRODUCTION

Exploring the literature demonstrates an observable number of research articles in the area of vehicle-to-vehicle (V2V) communication systems. Over the past years, data exchange techniques among vehicles have been developed. Moreover, traffic congestion has become an ever-increasing problem worldwide. Congestion reduces the efficiency of transportation infrastructure and increases travel time, air pollution and fuel consumption. In Europe alone, around 40000 people die, and 1.7 million are injured annually in traffic accidents [1]. Traffic safety has become a serious problem in transportation systems. The growing number of vehicles significantly increased the level of traffic accidents. The safety of vehicles and pedestrians is threatened by traffic accidents [2]. Traffic crashes on highways not only induce delays, but also additional safety issues in terms of secondary crashes (SCs) [3]. The new generation of wireless network should be designed to offer a solution with a high degree of reliability and availability in terms of data rate, latency or other quality of service parameters [1] With the rapid development of wireless communication technologies, V2V networks are increasingly becoming common. Such networks possess enormous potential in improving driving safety and traffic conditions by sharing road and traffic information among vehicles in real-time [4]. Data exchange in V2V communications and ranging systems enable communication and measuring between two moving vehicles at a distance [5] Enabling vehicles and additional communication infrastructure with "smart" algorithms may solve some major safety problems in vehicular networks [6]. The perception of vehicles may be improved beyond the capabilities of traditional sensors by the exchange of location data (i.e. time, position, heading and speed), vehicle dimensions, vehicle type, yaw rate, acceleration and many other parameters [7], [8]. The objectives of the current research are to present researchers' accomplishments, summarise the previous results interaction to the crucial need for identification and classification of data exchange in V2V system, determine evaluation criteria and methods, suggest taxonomic literature on this topic and differentiate aspects in this field of studies. The remainder of this paper is organised as follows. Section 1 introduces the research. Section 2 describes the systematic review protocol and analysis. Section 3 presents the distribution results. Section 4 discusses the challenges, motivations and recommendations extracted from the reviewed papers. Section 5 shows the substantial analysis of the reviewed articles. Section 6 provides the proposed approach. Section 7 describes research limitations. Section 8 concludes the research.

II. SYSTEMATIC REVIEW PROTOCOL AND ANALYSIS

The most important keyword in this work is 'vehicle-to-vehicle (V2V) communications.' This keyword excludes any non-V2V communications, such as in vehicle-to-infrastructure or vehicle-to-pedestrian systems, and limited the scope to English literature but considered all data exchanges in V2V communications in all scenarios. Three digital databases were explored to search for target articles. (1) IEEE Xplore is a scholarly research database that provides the most reliable and wide ranging articles in the fields of computer science, electronic technologies and electrical engineering. (2) Web of Science (WoS) offers indexing of cross-disciplinary research in sciences, electronic technologies, social sciences, arts and humanities. (3) ScienceDirect is a large database of scientific techniques and medical research. These three databases sufficiently cover V2V and all communication types in this area and provide a broad view of existing research in a wide but relevant range of disciplines. Study selection involved the search for literature sources and three iterations of screening and filtering. In the first iteration of screening and filtering, all unrelated articles were removed. In the second iteration, duplicates and irrelevant articles were removed by scanning the titles and abstracts. In the last iteration, the full-text articles screened from the second iteration were carefully reviewed. All iteration steps applied the same eligibility criteria followed by the authors. The search was conducted in January 2018 and used the search boxes of ScienceDirect, IEEE Xplore and WoS. To identify the studies related to this area, the query comprises mixed keywords and includes 'vehicle-to-vehicle', 'V2V', 'car-to-car', 'C2C' in different variations and combined by the operator 'OR'; and 'information exchange', 'exchanging information', 'data exchange', 'exchanging data', 'data integration', 'information integration' in different variations and combined by the operator 'AND'. The query text shown in Figure 1.

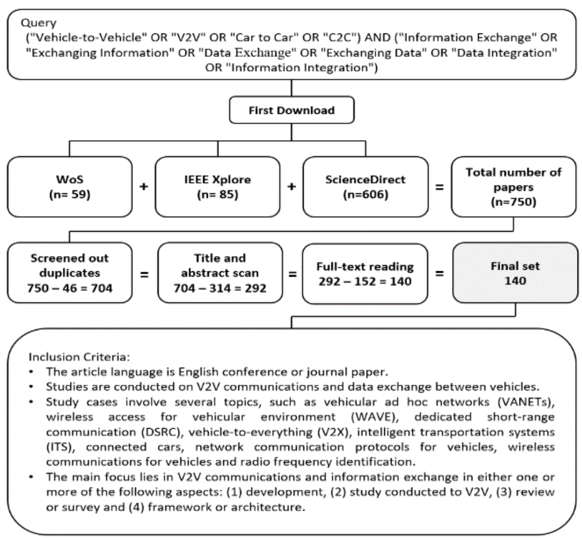


FIGURE 1. Selection of studies, search query and inclusion criteria.

Advanced search options in the search engines were used to exclude book chapters, short communication, correspondences and letters and gain access to recent scientific works that are relevant to our survey on this emergent trend of data exchange in V2V communications systems. Table 1 presents the settings used to run the search query.

TABLE 1. Settings of search query.

Digital Library	IEEE	Web of Science	Science Direct
Year	Last 10 years	Last 10 years	
Language	Only English	Only English	
Search type	Conference, journal and magazine	Conference, journal and magazine	
Subject area	Metadata only	Full text	
Date of running search string	2018	2018	

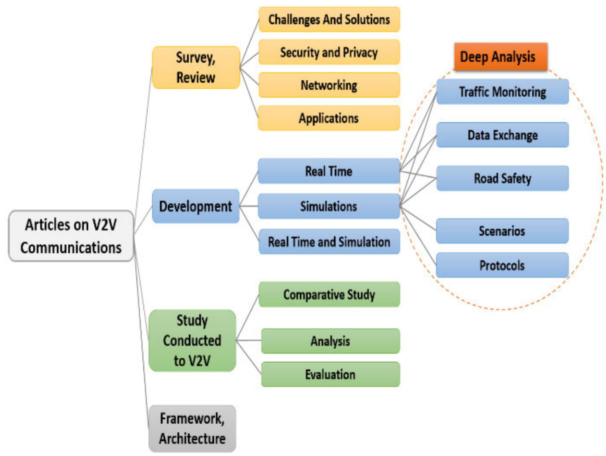


FIGURE 2. Taxonomy of research literature on V2V communications.

Every article that met the criteria listed in Figure 1 was included. These categories were derived from a presurvey of the literature. After the initial removal of duplicates, articles were excluded in two iterations of screening and filtering if they did not fulfil the eligibility criteria. The exclusion criteria included the following: (1) article is non-English; (2) article is focused on a specific aspect of smart cities and customer-to-customer, which represents car-to-car in other articles; and (3) subject is limited to communication of vehicles with pedestrians and infrastructure.

To simplify the steps, we read and analysed the final set of articles in Word format. Moreover, the articles were classified in detail using taxonomy and a large collection of highlights and comments. The taxonomy suggested different classes and subclasses, including four main categories, namely, development, framework/architecture, study conducted to V2V and survey/review. Texts were categorised depending on authors' preferred style. The collected data and relevant information were saved in Word files. All the articles from various sources were analysed in depth to provide a comprehensive overview of the subject.

A. RESULT OF LITERATURE TAXONOMY

The initial query resulted in 750 papers (59, 606 and 85 from the WoS, ScienceDirect and IEEE Explore databases, respectively). We filtered articles published from 2008 to 2018 and grouped into three categories. In the three databases, 46 out 750 papers were duplicates. After scanning the titles and abstracts, 314 papers were excluded further, which narrowed down the total to 292 papers. The final full-text review excluded 152 papers, and only 140 papers made the final set. All these papers are related to V2V technology through different topics. The taxonomy presented in Figure 2 was used to review the main streams of research focusing on data exchange in V2V communications systems. This taxonomy shows the comprehensive development of various studies and applications. The classification suggests different classes and subclasses. The first class includes a review and survey articles related to data exchange in V2V communications systems (18/140 papers). The second class includes studies with actual attempts to develop V2V communication systems using real time or simulation or both (51/140 papers). The third class includes studies conducted using V2V communication systems (53/140 papers). The final class comprises framework proposals and architectures related to V2V communications (18/140 papers). The observed categories are listed in the following sections for statistical analysis.

1) SURVEY AND REVIEW ARTICLES

This category included the survey and review articles (18/140) that summarized the current state of understanding data exchange in V2V communications systems and their challenges, security, networking and applications. The first group (4/18) categorises security and privacy issues by proposing an autonomous privacy-preserving authentication scheme; reviews recent research in vehicular communication [9], [10]; discusses security features, attacks of VANETs and some security requirements; and proposes certain architectures to solve security problems [11], [12].

The second group (7/18) includes survey and review articles related to V2V challenges and corresponding solutions. In [13] discuss the protocol stack with open research problems in developing efficient cross-layer protocols; expand the horizon of drivers and provide alerts of possible dangerous situations ahead of time, as well as comfortable, safe and efficient traffic flow [14], [15]. Various challenges and existing solutions used for clustering in VANETs are analysed [16]. Some works present a survey of the manner in which data fusion is used in different areas of ITS with the most significant applications of data fusion techniques [17] while in [18] a comprehensive survey on heterogeneous vehicular networks (HetVNETs). A survey presents VANET security frameworks in three parts [19].

The third group (4/18) includes survey and review articles related to network types related to V2V communications systems. Work in this category presents aspects related to this field to aid researchers and developers understand and distinguish the main features surrounding VANET [20]. Another work analyzes the topic of vehicular networks in the context of a comprehensive review on existing cooperation mechanisms [21]. A study provides a comprehensive overview of various radio channel access protocols and resource management approach [22]. In [23] a review of dissemination protocols on the basis of network coding strategy.

The final group (3/18) of survey and review articles focus on types of application provided by the vehicular communication system. Work in this category presents reviews on several existing VANET safety applications, revises disseminating methods for safety messages between vehicles and the benefits of avoiding accidents and high driving efficiencies [24], [25]. Reference [26] present an applications of wireless sensor networks for urban areas and discuss problems related to traffic light projects and solutions.

2) DEVELOPMENT

This section reviews the studies (51/140) that proposed a development system in which V2V communications were used as a mean contribution or a tool. Selected works were classified into three groups depending on the types of the development. The first group was real-time developments (10/51), which contained articles in which real-time field tests were used, and the second group was simulation developments (33/51), which contained articles in which some type of simulator was used to evaluate the work and final group was real-time and simulation developments (8/51), which contained articles that use real-time field tests and some type of simulator. The first of the two groups were further classified into five subgroups according to the purpose of the study. In the real-time development group, the V2V communications were further classified into three subgroups, namely, traffic monitoring, data exchange between vehicles and road safety detection system for collision avoidance. This section introduces these three classifications.

Firstly, a V2V-based architecture for communication to improve traffic flow by using cooperative adaptive cruise control system [27]. Secondly, A perception system is developed for urban situations [28]. In addition, [7], [29] proposed a prototype for VANETs, multisensor data fusion for exchange of short safety messages and multiple object tracking are validated using real-world scenarios. Furthermore, [30] proposed vehicle control, such as efficient and reliable maneuvering negotiations and interactions vehicles. Moreover, [31] developed V2V millimetre wave radio channel characterisation and modelling for 5G V2V communications. A modular vehicle sensor technology hardware based on an Arduino board using cellular and DSRC connectivity [32]. Reference [8] developed two test vehicles to transmit and receive data on the basis of IEEE 802.11p standard and European Telecommunications Standards Institute (ETSI) ITS-G5. Another type of articles includes real-time safety for roads and a collision avoidance and detection system. A road safety system is developed in [33] based on WAVE communication V2V using GPS to warn drivers of collisions, and a system that relies on VANET technology solution is presented in [34] to provide controlled and privacy-preserving dissemination through the roads.

Simulation developments in V2V communications in the second group was further classified into two subgroups, namely, scenario and protocols. This section introduces these two classifications. Firstly, authors presented two strategies provide each vehicle with relevant information about its surroundings and allow drivers to be aware of undesirable events and road conditions [35]. Reference [36] introduced the effect of the beacon rate on the network performance of safety message scenarios. A development of scenarios to maintain stable and safe work under a wide range of network conditions using V2V communications systems is discussed in [37].

Other authors focus on simulation development for protocols used in V2V communications systems. References [38], [39] developed a scheme to improve mobility and stability clustering scheme and cluster-based beacon dissemination process. In addition, other works focus on cross-layer protocol for traffic management, calculation of the desired vehicles' speed necessary to cross and distribution of data-gathering protocol for the collection of delay tolerant to make the congestion control efficient [40]–[43]. The problem of routing guidance in nonrecurring congestion caused by temporary loss of capacity is also addressed in [44]. The authors in [45]–[49] focus on new Geocast approaches, forwarding protocols for mitigating the interest broadcast storm and the disconnected link problems in a car-following control scheme and sampling-based estimation schemes (SESs). Other authors focused on types of data exchanging used in V2V communications systems. A self-configuring protocol for enhancing vehicle safety with DSRC-based on data exchange in V2V communications systems is presented in [50], [51], which uses the heterogeneous network provided by DSRC and Long-Term Evolution (LTE). A development of a visible light (VL) for V2V communication channel is used in [52]. Furthermore, [53] presented a decision-making module for accident situations. References [54]–[57] introduced a handling aspects of safety and reliable time efficiency. Authors in [58], [59] presented techniques for detecting incidents early by using incident detection node by calculating time to collision for unconstrained vehicle motion. References [3] work on assess the influence of connectivity on the risk of Secondary Crashes (SCs). A new scheme for warnings spreading between vehicles without any dependence on road foundation is discussed in [60]. Moreover, [61]–[63] used a distributed cooperative approach and distribute information interaction. The likelihood of the accuracy of V2V incident reports based on trustworthiness is presented in [4]. The authors in [64], [65] work to enhance a cooperative microscopic car following and enable efficient V2V traffic.

The third group presents the types of V2V communication article on the basis of real time and simulation. Works under this category comprise road safety and traffic management systems for vehicles and pedestrians [2], [66]–[69]. A service for vehicles stuck in tunnels with limited resources is provided in [70]. Other works focus on data exchange between connected vehicles using wireless communications [71], [72].

3) STUDY CONDUCTED TO V2V COMMUNICATIONS

This category included numerous studies (53/140) related to V2V communication system. These articles were further classified into three groups. The first group (7/53) comprises comparative studies. Works under this category articles to investigate different conditions, scenarios, number of tests and types of drivers [5], [73]–[75] to evaluate whether a given assignment method corresponds to the observed reality. Reference [76] introduced a hybrid routing protocol for VANET based on the application of two most widely accepted mobile technologies and their combination. Furthermore, [77] try to study incorporates different techniques of localization along with data fusion in V2V communication. Moreover, [78] explores the possibility of using a single node to emulate a set of nodes to overcome or facilitate the logistic issues during measurement campaigns.

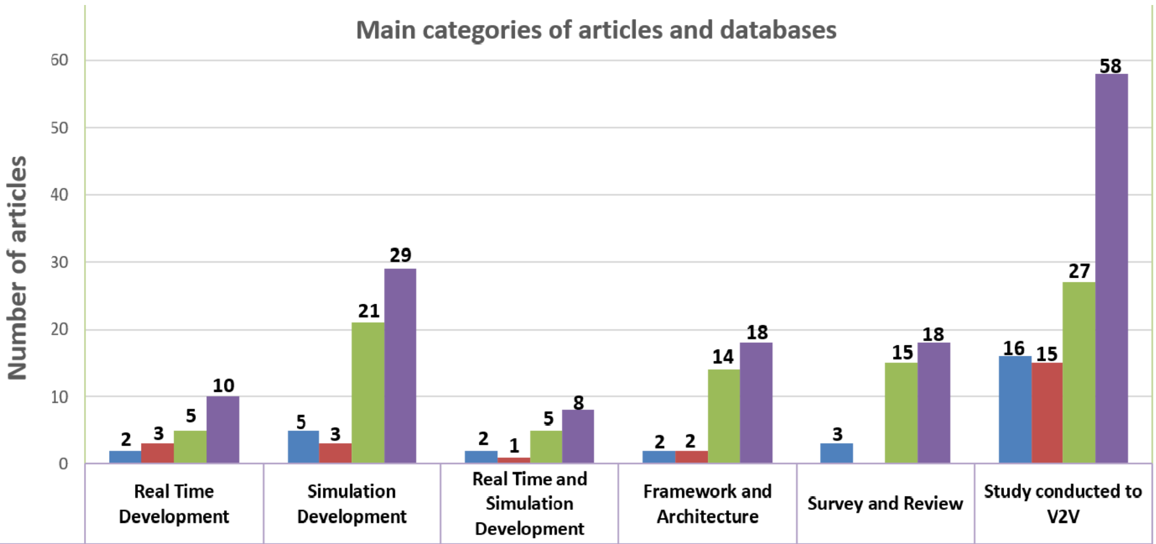
The second group (10/53) comprises analytical studies. An analysis of the possible V2V wireless connectivity by considering the effect of headway distance, acceleration, association time, relative speed of vehicles, transmission range is presented in [79] and [80]. Reference [81] analyse the timing of events and how they influence software-based collision avoidance strategies by define two collision avoidance timings: critical time to avoid collision and preferred time to avoid collision. The stochastic broadcast range in VANET and numerical estimation algorithm of it based on generalized vehicle distribution and V2V packet loss models was studied in [82]. Furthermore, [83] analyzed a method to extend the information sharing network's coverage by adding long-range connections between targeted vehicle clusters. The author in [84] investigated and focused on exploring the effect of the air density on the performance of a V2V with DSCR based communication system in a foggy environment. An analysis of communication and navigation issues in collision avoidance support and detect oncoming collisions systems is presented in [85]. Other works focus on message coverage distance and delivery delay [86], [87], determine the performance of the V2V dynamic anchor position-based routing protocols [88].

The last group (36/53) of study related to V2V comprises evaluation studies to investigate traffic safety and smoothness depending on various parameters, e.g., configurations of traffic lights, communication time interval length to prevent road traffic accidents at such intersections [56], [89]–[91]. Reference [92] introduced a microscopic traffic simulation used to determine the extent to which inter-vehicle communication and change in the driving strategy after the recognition of a shockwave on freeways. In addition, [93] introduced an evaluation method for describing the emergency degree of ongoing collisions by using particle swarm optimization to calculate the target acceleration and control the vehicle to prevent unexpected collisions. The authors in [94]–[97] evaluated how vehicles can exchange information with each other by V2V communications integrated in the vehicular architecture to get more information about oncoming road, arranges appropriate vehicle routes based on queuing theory. The performance of short range vehicular communications by using real world personal portable devices (smartphones, tablets, and laptops), two different PHY standards (IEEE 802.11g and IEEE 802.11a), and vehicles is evaluated in [98].

Reference [99] demonstrated the potential of communication between vehicles in a complex roundabout and test the connection strength of that network. The authors in [100] and [101] investigated the data collection problem in VANETs under rapid evolving traffic conditions using grouping models over different propagation environments. Reference [102] investigated the Vertical Relative Angle (VRA) scheme to improve the forwarding decision, especially in the three-dimensional case within a large city environment. In [103]–[105] and [106] a coordinated online in-vehicle routing mechanism for smart vehicles with real-time information exchange and portable computation capabilities to determine optimal route choice decision and enable diverse applications is studied. The author in [107] works to enhance the positioning accuracy and line of sight systems multiple forms of the Kalman filter derivatives to estimate the vehicles' nonlinear model vector state, named local fusion node, while in [108] proposed Bayesian data fusion relying on Particle Filtering (PF). Furthermore, [109], [110] focused on Internet of Vehicles (IoV) and content sharing among different vehicles. In addition, [111] presented how different parameters (e.g., sensing time, association time, number for vehicles, relative speed of vehicles, overlap transmission range) affect communication in smart transportation. Moreover, [112]–[120] focused on the evaluation of safety messages, safety and non safety application for drivers and handling multiple data sources in unreliable vehicular networks that can be used for designing applications for advanced detection of dangerous events [6]. In [121] provide mobile healthcare and medical data exchange from ambulances or rural healthcare centers to hospitals. Maximizing the number of successfully transmitted packets in ideal and non-ideal channels in V2V scenario using effective heuristic algorithm is presented in [122].

4) FRAMEWORK AND ARCHITECTURE

This section defines the framework, modules and architecture (18/140) related to V2V communication system to provide transportation management, security and privacy for vehicular communication systems. Firstly, [1] presented a work to consider a network control for direct data exchange among vehicles; and provide a model structure and the operation of the information management issues with new telematics-based, shared, demand-responsive transportation mode [123]. Secondly, A system that relies on video streaming technology solution that provides controlled and privacy-preserving dissemination is discussed in [124]. A study proposes a flexible,



	Real Time Development	Simulation Development	Real Time and Simulation Development	Framework and Architecture	Survey and Review	Study conducted to V2V
Web of Science	2	5	2	2	3	16
IEEE	3	3	1	2	0	15
Sicence Direct	5	21	5	14	15	27
Total	10	29	8	18	18	58

FIGURE 3. Number of included articles based on main categories and database source.

secure and decentralised attribute based on security key management framework and security data access control policy in VANET to provide reliability is presented in [125]. Other authors focused on safety, traffic light controller, smart city and driver assistance frameworks and architectures. Reference [126] described a new approach on VANET architecture for ITS that intends to open up the development process of ITS applications and services to a larger community of software makers. The underlying strategy is to adapt. The authors in [127] proposed a Context-Aware Driver Assistance System architecture that links drivers with the physical environment surrounding them to reduce the number of car accidents and improve drivers' decisions. Novel Architecture for Improving vehicular safety message delivery through the implementation of a cognitive vehicular network is presented in [128]. Reference [129] proposed a possible architecture for V2X communication-centric traffic light controller systems, a solution that easily implementable and deployable, uses standardized C-ITS messaging techniques. A novel trust establishment architecture fully compliant with the ETSI ITS standard which takes advantage of the periodically exchanged beacons and event triggered messages is described in [130]. In addition, [131] described a framework development validated through simulations of both vehicular micro-mobility and communications for collecting vehicular traffic measurements. A framework that can act as a generalized firewall and work interactively in a smart city to protect the respective operations from a variety of cyber threat is studied in [132]. The authors also focused on the road management, such as tracking system and provides localization through vehicular networks. Reference [133] developed a framework to provide a better understanding of road security by studying the impact of V2V communications, thereby improving the quality of perception systems and adding new features for Advanced driver assistance systems. Authors in [134] and [135] presented a concept for traffic homogenization where flow and density are decoupled for testing and evaluation of C-ITS applications. In [136] an ontology model framework development contains classes, objects, their properties/relations as well as some functions and query templates to represent and update the information of dynamic vehicles, inter-vehicle interactions and behavior. Moreover, [137] presented hybrid modules and architecture related to V2V communication system and hybrid electric vehicles in urban road conditions. A hybrid architecture for collaborative exchanges is proposed in [138], and a module for the new V2V elastic network is presented in [139].

III. DISTRIBUTION RESULTS

The three digital databases that store numerous research works is shown in Figure 3. The results of the review are divided into six main categories, namely real-time development, simulation development, real-time and simulation development, framework and architecture, survey and review and studies conducted on V2V papers. The total number of selected published articles from the WoS database is 30, consisting of 2 articles for real time, 5 for simulation, 2 for real time and simulation, 2 for framework, 3 for survey and 16 for studies conducted on V2V papers.

The total number of selected published articles from the IEEE database is 24, consisting of 3 articles for real time, 3 for simulation, 1 for real time and simulation development, 2 for framework and 15 for studies conducted on V2V papers. The total number of selected published articles from

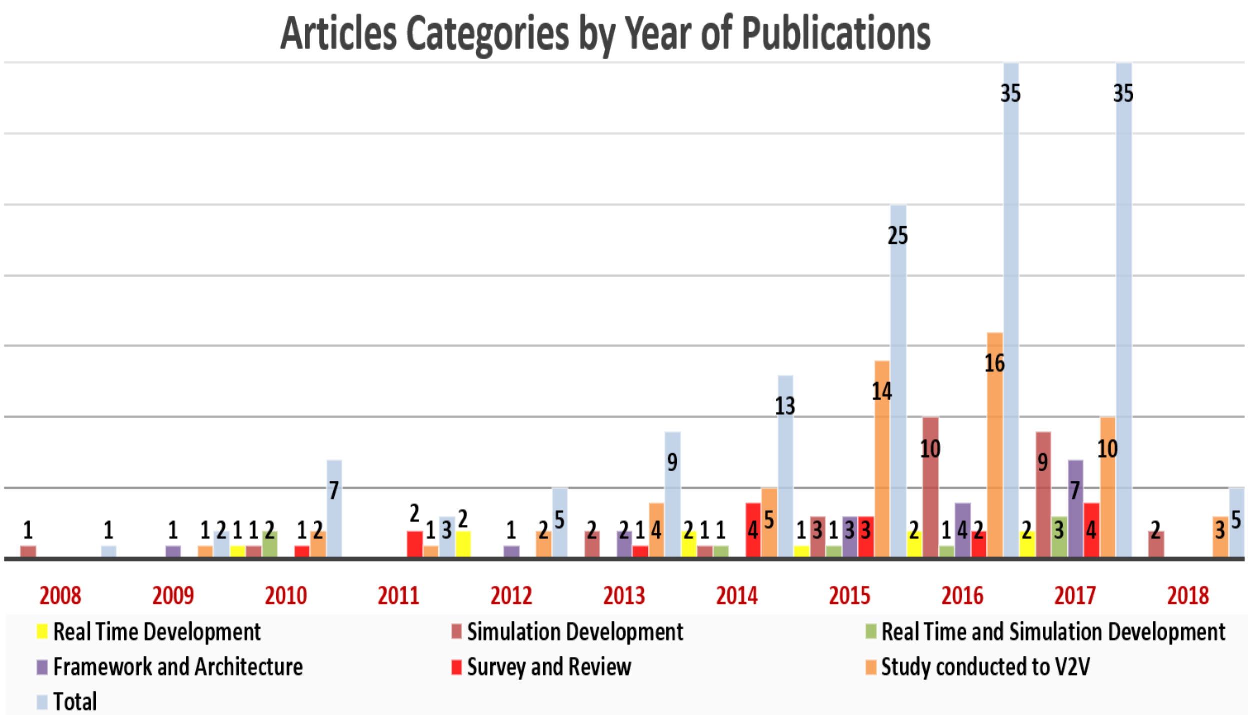


FIGURE 4. Number of included articles in different categories by year of publication.

the ScienceDirect database is 86, consisting of 5 articles for real time, 21 for simulation, 5 for real time and simulation, 14 for framework, 14 for survey and 27 for studies conducted on V2V papers. The number of included articles in the six categories according to the year of publication is shown in Figure 4.

Exactly 35 papers included in this review were published in 2016 and 2017, whereas only 1 paper was published in 2008 and 2 in 2009. Exactly seven and three papers were published in 2010 and 2011, respectively. Exactly 5 and 9 papers were published in 2012 and 2013, respectively. In 2014, exactly 13 papers were published. Among the selected articles, 25 were published in 2015, and 5 in 2018.

IV. DISCUSSION

This review presented the most relevant studies on data exchange in V2V communications systems and applications related to it. The objective of this work was to highlight the research trends in this research area. A taxonomy of the related literature was proposed, which can provide several benefits. Firstly, it organised various publications. A new researcher in this area may be overwhelmed by the large number of papers on the subject and the absence of any kind of structure and thus may fail to obtain an overview in this area. Secondly, various articles addressed the topic from an introductory perspective, whereas others examined existing data exchanging applications in V2V systems. A taxonomy of the related literature can help sort these different works and activities into a clear and comprehensible layout. Finally, the structure introduced by the taxonomy provides researchers with important insights into the subject in several ways.

Firstly, it outlined the potential research directions in the field. For example, the taxonomy of V2V communication systems in the current work demonstrated that researchers are inclined to propose frameworks to develop V2V traffic management systems, thereby providing a possible path in this area. Secondly, the taxonomy could reveal gaps in the research. Mapping the literature on V2V applications into distinct categories highlighted weak and strong features in terms of research coverage. For example, the taxonomy in this work showed how groups of individual applications received significant attention in terms of reviews and evaluations at the expense of integrated solutions and frameworks as well as development efforts. The taxonomy also highlighted the lack of studies on real time deployment efforts of V2V system. Similar to taxonomies in other fields, the proposed taxonomy employed a common language for researchers to communicate and discuss emerging works, such as development papers, comparative studies and reviews. The review conducted revealed seven aspects of the literature content: the description of datasets used in the articles, the measurement criteria used in the reviewed papers, validation techniques adopted, the survey analysis used in previous articles, the motivations behind the development of the V2V system, challenges to the successful utilization of these technologies and recommendations to alleviate these difficulties. This review focuses on the literature on applications rather than on the actual applications. In line with this, we propose a taxonomy of the related literature.

A. DATA SOURCES

In our survey, we depended on the number of types of data sources for V2V communication systems in real-time developments such as devices that provided data between vehicles and types of information. The details of V2V communication data sources in our survey are summarized in Table 2.

TABLE 2. Dataset used in reviewed research.

Ref.	Real time data											
	Types of Data			Main Device					Vehicle information, positioning			
	Vehicle Speed	Distance Between Vehicles	Vehicle Direction	LIDAR	Arduino	Raspberry Pi	Radar	Camera	CAN Bus	OBU	GPS	GNSS
[27]	✓	✓	✓	✓			✓	✓			✓	
[29]	✓	✓	✓		✓							
[30]	✓	✓		✓					✓			✓
[32]	✓	✓			✓					✓	✓	
[7]	✓	✓						✓	✓		✓	
[8]	✓	✓		✓						✓		✓
[33]	✓	✓	✓			✓				✓	✓	
[34]	✓		✓					✓		✓		
[95]	✓	✓										
[129]	✓	✓	✓			✓				✓		
[124]		✓	✓			✓		✓				
[2]	✓	✓	✓						✓	✓		✓
[66]	✓	✓	✓	✓						✓		
[69]	✓	✓	✓					✓				
[71]	✓	✓	✓					✓			✓	
[67]	✓		✓							✓	✓	
[70]	✓		✓					✓		✓	✓	

As shown in Table 2, the researchers generated their own datasets through experiments. Table 2 presents a detailed description of research experiments designed towards developing a hardware-based V2V communication system that consists of numerous factors. Most of the studies used a positioning system (GPS), On Board Unit (OBU) for vehicle information and positioning and using hardware device, such as a LIDAR, Arduino or Raspberry Pi for exchanging data, in their research. Table 2 shows that only a few studies used a real device to generate their dataset. Other works obtained their data from the literature and public datasets.

B. PERFORMANCE MEASUREMENT

The performance of the studies involved in our review was evaluated by using different measures related to time, latency and delay as well as other measurement criteria, including bandwidth, accuracy, signal strength, number of experiments, speed, number of vehicles, the distance between vehicles, data rate, packet delivery, packet error rate, system performance, connectivity, data privacy and cost. All of these parameters are discussed in this section. Table 3 illustrates the measurement criteria used in the reviewed papers.

Table 3 presents various studies on V2V communication systems as well as a comprehensive survey on different criteria for evaluation. The most-used criteria to evaluate V2V system performance were time, system performance, number of packets, delay, accuracy, data rate in 47%, 34%, 30%, 28%, 21%, 21% respectively. Other criteria such as bandwidth, range, packet error rate, packet delivery were used in 18%, 16%, 11%, 11% respectively. The rest of the criteria such as connectivity, data privacy were used only 8%, 5% while the cost criteria used only once (1%). As clearly shown in Table 3, no study has used all types of measurement criteria. The variance in the use of these measurement criteria indicates a challenge in adopting a specific type for the evaluation of the V2V communication systems.

C. EVALUATION TECHNIQUES

This section describes the evaluation process conducted on the use of V2V networking. This phase of the survey consisted of three main evaluation techniques for data exchange in V2V across different vehicular communication systems, namely, actual experiments, simulations experiments and comparisons. Table 4 illustrates the evaluation techniques used in the included articles. Table 4 shows that most of the studies used simulations to evaluate their works, followed by comparisons. However, a small proportion of the research depended on actual experiment evaluation techniques.

D. SURVEY ANALYSIS

This section summarizes of different types of review and survey articles related to V2V communication systems. Table 5 shows that most of the articles were concerned with the VANET and only partly covered V2V systems. In addition, only two articles [23] focused on network coding approach for V2V communication discussing principles, protocols as well as benefits, and [24] focused on broadcasting safety data in V2V discussing weaknesses and requirements no survey or review article discussed all types of measurement criteria. To the best of our knowledge, the present survey offered an overall view and provided directions for future research and development. It created a new classification system for recent works based on data analysis provided by different studies. Moreover, the present survey relied on

TABLE 3. Measurement criteria used in the reviewed papers.

TABLE 3. *(Continued.)* Measurement criteria used in the reviewed papers.

Ref.	Performance Measurement												
	Time Group					Data Rate Group							
	Time	Latency and Delay	Bandwidth	Accuracy	Coverage Area/Range	Data Rate	Packet Delivery	Packet Error Rate	Number of Packets	Performance	Connectivity	Data Privacy	Cost
[90]	✓												
[32]		✓									✓		✓
[124]												✓	
[34]	✓	✓						✓					
[27]									✓				
[29]	✓	✓			✓	✓			✓				
[7]	✓						✓						
[31]	✓	✓	✓		✓								
[28]	✓		✓					✓					
[8]	✓			✓									
[30]							✓		✓				
[33]													
[62]		✓						✓					
[37]		✓	✓						✓				
[48]		✓											
[58]	✓			✓	✓			✓					
[65]				✓						✓			
[52]	✓	✓			✓			✓		✓			
[42]		✓			✓				✓				
[4]	✓			✓		✓							
[36]	✓					✓		✓	✓	✓			
[63]					✓					✓			
[51]		✓						✓			✓		
[55]		✓								✓			
[35]									✓				
[38]		✓	✓							✓			
[53]	✓					✓	✓		✓				
[40]	✓								✓				
[61]				✓				✓		✓			
[43]	✓	✓	✓						✓	✓			
[45]		✓						✓					
[46]		✓			✓			✓	✓				
[39]					✓	✓				✓			
[41]		✓		✓		✓			✓				
[57]	✓									✓			
[49]		✓				✓	✓		✓	✓			
[59]										✓			
[50]	✓	✓								✓			
[3]										✓	✓		
[44]	✓									✓			
[56]					✓					✓			
[64]											✓		
[60]	✓	✓							✓			✓	
[54]	✓												
[67]			✓	✓	✓				✓				
[2]	✓								✓			✓	
[66]	✓			✓		✓		✓			✓		
[69]													
[71]	✓	✓		✓							✓		
[72]	✓					✓			✓				
[70]				✓									
[68]						✓	✓	✓					
[139]				✓									
[134]				✓									
[133]				✓									
[136]				✓									
[126]				✓								✓	
[138]	✓								✓				
[130]		✓				✓	✓		✓	✓			
[131]	✓			✓					✓				
[137]	✓										✓		
[128]	✓	✓				✓	✓	✓	✓				
[123]			✓			✓							
[125]			✓							✓		✓	
[127]	✓												
[135]	✓												
[95]	✓				✓				✓				
[93]				✓						✓			
[79]	✓				✓								
[73]	✓	✓		✓					✓	✓			
[96]	✓									✓			
[89]					✓								
[82]							✓	✓	✓				
[103]		✓											
[94]	✓												
[119]	✓												
[5]								✓					
[113]													
[112]	✓					✓			✓	✓			
[118]	✓						✓						

TABLE 3. *(Continued.)* Measurement criteria used in the reviewed papers.

[88]	✓	✓					✓			✓			
[99]	✓							✓		✓			
[116]	✓					✓	✓			✓			
[74]										✓			
[1]									✓	✓			
[121]		✓						✓					
[122]									✓	✓			
[76]	✓	✓							✓	✓			
[78]	✓												
[114]		✓						✓		✓			
[110]										✓			
[101]								✓	✓				
[111]	✓				✓	✓							
[84]	✓									✓			
[81]	✓				✓								
[98]			✓		✓					✓			
[77]				✓									
[75]				✓					✓		✓		
[117]	✓					✓				✓			
[120]						✓				✓			
[85]		✓								✓			
[107]				✓									
[108]	✓			✓					✓				
[115]	✓												
Total	**48**	**29**	**19**	**22**	**16**	**22**	**12**	**12**	**31**	**36**	**8**	**5**	**1**
%	**46%**	**28%**	**18%**	**21%**	**15%**	**21%**	**11%**	**11%**	**30%**	**34%**	**8%**	**5%**	**1%**

TABLE 4. Validation techniques used in the reviewed papers.

Ref	**Evaluation techniques**		
	Actual Experiments	Simulation Experiments	Comparisons
[27],[28], [29], [7], [30], [31], [32], [8], [33], [34]	✓		
[35], [36], [37], [4], [38], [50], [51], [52], [3], [58], [60], [2], [66], [67], [68], [69], [70], [71], [72], [59]		✓	
[5], [73], [74], [75], [76], [77], [78]			✓

numerous factors such as coherent taxonomy, data sources, performance measurements, evaluation techniques to explore new trend challenges, motivations related to V2V systems, recommendations and methodological aspects to provide a comprehensive analysis for this research area.

E. MOTIVATIONS

The use of V2V communications in VANETs has numerous benefits. This section lists a few of the advantages reported in the literature, which are grouped into categories depending on the similarities. The corresponding references are cited for further discussion, as shown in Figure 5.

1) IMPROVING TRAFFIC MANAGEMENT

V2V communication systems enhance traffic monitoring, management during congestion and adapting the schedule of traffic lights to reduce average delay and travel time. Studies have looked into providing wireless communications to the traffic flow and traffic signals to the drivers, such that drivers can receive adequate information to drive [21], [90], [136] a new concept for traffic flow optimisation [134] using cloud and mobile application [67] and IoV application [40]; and online in-vehicle routing mechanism using real-time traffic information [105]. Other topics include a wide measuring of incoming traffic [69] and full distribution of traffic information systems that enable traffic self-organisation in smart cities [75], [132]. Research has been performed on designing efficient microscopic traffic simulation model for such vehicles, including a robust protocol for exchanging information to improve and reduce traffic congestion, minimise average delay for vehicles [44], [56], [57], [73], [94], [100], simulations and an experimental model pertaining to the performance of IEEE 802.11p communication standard to reduce traffic congestion [66] and robust decision support tool for cooperative traffic simulation [65]. Other benefits related to traffic management support precision, positioning and safety when driving in traffic [5] and high transmission efficiency and validity through traffic flow [62]. Studies have looked into creating an intersection environment for road users and operators [129] to bridge the gap between traffic flow modelling and communication approaches [64].

2) BENEFITS RELATED TO V2V INTEROPERABILITY

V2V interoperability communication systems enable information exchange among vehicles, improve mobility and reliability and enhance routing protocol by providing direction and route optimisation through a network. Connected vehicles can use wireless communication to exchange sensor data, allowing them to enlarge their sensing range and improve automated driving functions [78], [104], thereby maximising information sharing among vehicles [55]. An algorithm can accurately predict the broadcast fail probability and effective broadcast coverage [82], maneuvre negotiations and interactions among vehicles efficiently and reliably [30], operate systems at millimetre wave frequencies where the

TABLE 5. Survey analysis used in reviewed papers.

	Covered Topics	Main Concerned
[24]	Reviews several existing VANET safety applications and revises the disseminating methods for safety messages among vehicles without infrastructure to cover a wide area in a fast reliable approach; includes relevant works that present different methods for broadcasting the warning message among vehicles.	• Disseminating safety data between connecting vehicles is a challenging task due to the quick change in the wireless network topology, and the broad- cast protocol's reliance on many physical parameters (e.g. vehicle's speed, location, roads structures etc.).
[13]	Surveys VANET systems and focuses on their communication and application challenges, discusses the protocol stack of this type of network and provides a qualitative comparison among the most common protocols in the literature.	• Highly heterogeneous vehicular networks • Data management and storage • Localization systems: Critical safety applications in VANETs require more reliable and high accurate localization systems. • Security and privacy: security challenges in VANETs are intrinsic and unique due to the size of the network, frequent topology changes, high mobility, and the different classes of applications and services, with conflicting requirements that will be offered to such networks.
[20]	Presents aspects to help researchers and developers understand and distinguish the main features surrounding VANET in one solid document without the need to go through other relevant papers and articles starting from VANET architecture and ends up with the most appropriate simulation tools to simulate VANET protocols and applications.	• Signal fading • Bandwidth limitations • Connectivity • Small effective diameter • Security and privacy • Routing protocol
[18]	Focuses on recent wireless networks techniques applied to HetVNETs; summarises and compares the requirements and cases of safety and nonsafety services, major challenges and solutions; and outlines open issues to identify new research directions.	• As a candidate technique supporting V2V in HetVNETs, D2D communications in LTE face several challenges. Since D2D communications links share the same radio resources with other links in the LTE network, interference is a major issue when employing D2D in HetVNETs. • The interference from neighboring cells is problem facing D2D communications.
[16]	Discusses and analyses the clustering mechanism of grouping vehicles based on predefined metrics, such as density, velocity and geographical locations of vehicles; motivated from these factors, various challenges and existing solutions used for clustering in VANETs are analysed.	• Due to the high mobility and sparse distribution of the vehicles on the road, itis a challenging task to route the messages to their final destination in VANETs.
[11]	Discusses security features, challenges and attacks of VANETs; and classifies the security attacks of VANETs due to different network layers.	• VANETs have different network concerns and security challenges to get the availability of ubiquitous connectivity, secure communications, and reputation management systems which affect the trust in cooperation and negotiation between mobile networking entities. • Due to the multi-hop transmission in VANETs, routing problems will exist greatly since no figure for a network infrastructure with vehicle entities.
[19]	Focuses on VANET security frameworks in three parts; the first part presents an extensive overview of VANET security characteristics, challenges and requirements; the second focuses on a novel classification of the different attacks known in the VANET literature and their related solutions; and the third compares solutions on the basis of well-known security criteria in VANET.	• In VANET, security must guarantee that the exchanged messages are not inserted or modified by attackers. As well, the liability of the drivers is essential to inform the traffic environment correctly within time constraint. • The Forwarding algorithms: which is challenging concerning the number of transferred packets after finding the best route; is it unicast, broadcast, V2V, V2I or hybrid communication.
[12]	Presents a survey of the security issues and the challenges they generate, the various categories of applications in VANETs and security requirements; proposes threats and certain architectures to solve the security problems; and proposes a global security architecture for VANETs.	• the information transmitted in VANETs is distributed in an open access environment. • Applications require data communication between nodes, this may change the network topology and security may be threatened if a malicious user alters the message. • Users' privacy: drivers will not accept to be tracked by a central system such as a big brother program, yet some security solutions may threaten users' privacy. • Time constraints • The high mobility of nodes: The high mobility of nodes in VANETs causes considerable challenges in VANET research. It is impossible to apply classical authentication techniques for nodes and messages due to the high mobility of nodes.
[9]	Covers the main security and privacy issues, reviews recent research on these issues, summarises	• Authentication • Intellectual Property Protection

TABLE 5. ***(Continued.)*** **Survey analysis used in reviewed papers.**

	the requirements of modern cars and classifies threats and solutions on the basis of underlying technologies.	• Confidentiality • Integrity • Privacy • Availability
[10]	Surveys the most relevant issues while discussing benefits and drawbacks; and explores the newest trends in privacy, anonymity, misbehaving nodes, dissemination of false information and data aggregation security.	• VANETs face many interesting research challenges in multiple areas, from privacy and anonymity to the detection and eviction of misbehaving nodes and many others in between. • VANET is subject to many security threats, which can lead to attacks and service abuses.
[25]	Presents current research efforts on information management techniques used for safety-related applications in VANETs, including gathering, aggregation, validation and dissemination; and provides directions for future research and development on the basis of V2V, V2I, and hybrid architecture.	• The major concerns in safety applications are reliability, security, trust, real time delivery, and latency. • A challenging issue in this context is that if significant number of vehicles upload their GPS data points at the same time, wireless network cannot offer enough network resources for simultaneous network connections.
[17]	Provides a survey of how data fusion is used in different areas of ITS to acquaint readers with the most significant applications of data fusion techniques in intelligent transportation systems and indicate the directions for future research in this area.	• Providing accurate traffic information is becoming a major challenge for the public institutions and private companies leading to the rapid growth of intelligent transportation system (ITS).
[15]	Reviews outstanding proposed V2V MAC schemes, discusses V2V MAC design approaches and provides qualitative comparison; presents a novel classification of V2V MAC schemes and the characteristics of these schemes along with their strengths and weaknesses; And provides comparative summary and opens challenges regarding the design of V2V MAC schemes.	• Challenging issues of V2V (such as synchronization between vehicular nodes, adaption to the mobility of vehicles, variety in the number of vehicles, and QoS-related issues)
[22]	Provides a comprehensive overview of various radio channel access protocols and resource management approaches and discusses their suitability for infotainment and safety service support in VANETs; presents recent research activities and related projects on vehicular communications; and discusses potential challenges and open research issues.	• Frequent link disconnections • Highly dynamic spatial emporal traffic conditions: The vehicle density of a VANET can vary from very small (rural areas) to very large (traffic jam). • Heterogeneity of data dissemination: In light of heterogeneous information services, channel access protocols and network resource allocation strategies should be adaptive to ensure efficient, orderly, and fair communications among all the vehicles on the road.
[23]	Focuses on the review of dissemination protocols based on network coding strategy that is essentially designed for a V2V communication mode.	• Realizing the necessary information exchange among roadside infrastructure and vehicles efficiently and reliably. • Efficient scheduling and coordination of multicast transmissions
[14]	Efficiently enhance information dissemination and successful deployment of VANETs and to promote foresighted driving which aim to provide a comfortable, safer and more efficient traffic flow.	• Beacon messages must be periodically disseminated among vehicles in order to keep track of neighbor's vehicle's mobility characteristics, thus, building their cooperative awareness. • Due to periodic beacon messages among vehicles caused by rapid changes in traffic conditions that ranges from heavy to sparse, the wireless channel can easily become congested. So, this can lead to performance degrading as offered load increased. • Each vehicle disseminates periodic beacon messages at a fixed rate especially in high traffic density scenarios; causing the wireless channel to be overloaded and thus packet loss.
[21]	Exploring the existing challenges in VANET and discuss a taxonomy for existing cooperation mechanisms in VANETs and review the proposed solutions of each cooperation type.	• Communication and transmission protocol issues • Dynamic operating environment: VANET has been dealing with different types of communication environment. • Unrealistic vehicle simulation issues: To validate if a routing protocol is suitable for VANET, a reliable and accurate mobility model must be chosen carefully. • Transmission power constraint: Energy is not a concern for VANET as the power is constantly provided by the car battery. • Security and privacy issues.

needed bandwidth may be available [31] and allow direct data transmission over proximate peer-to-peer links [110]. Studies have investigated benefits to improve mobility, enhance safety, lower latency and reduce greenhouse gas emissions at the network-wide level [47], [91], [113], [114], [119], [138]; enable direct V2V communication [1], [106]; improve telemedicine [121]; and enhance the efficiency and the reliability of data collection [41].

A model of information system architecture is presented by describing the information management activities of the

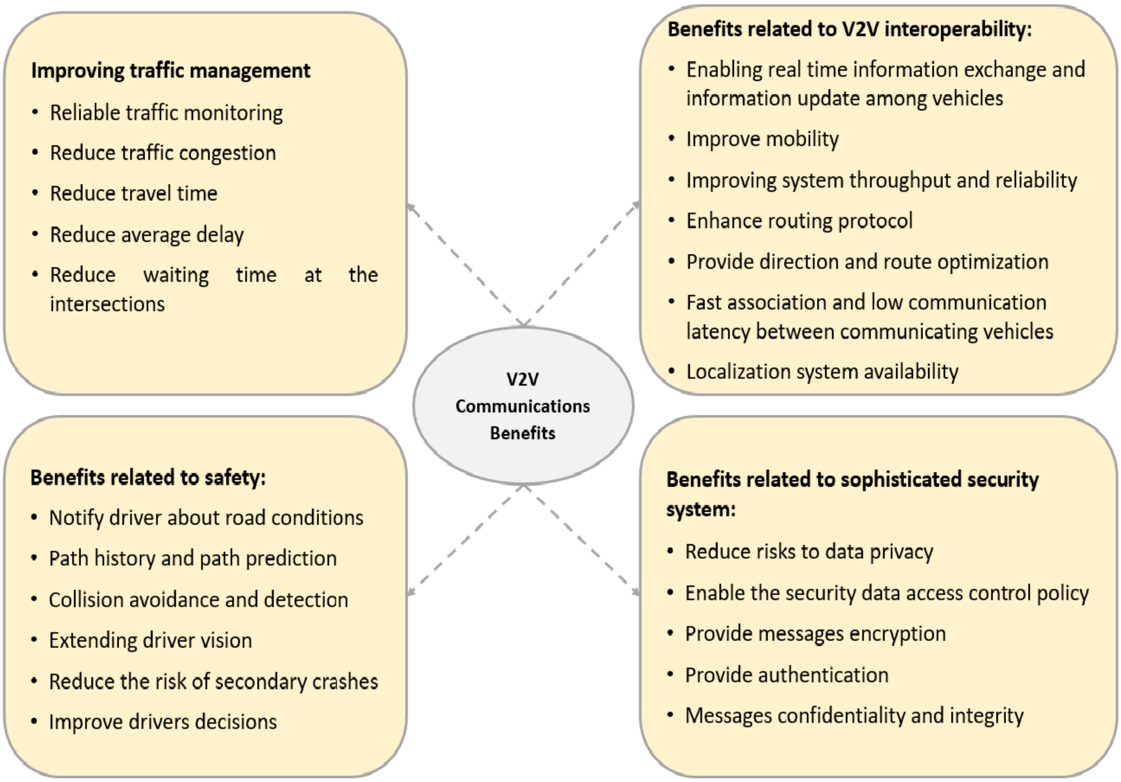


FIGURE 5. Categories of benefits of V2V communication system.

system components [123] and developing new methods on the basis of the notion of update [97]. Studies on performance data obtained from off-the-shelf 801.11p devices [117], checking cellular and DSRC connectivity [32] and investigation of whether DSRC performance persists with respect to air density changes in a foggy environment [84] are lacking. Other benefits include usage of personal mobile devices for deploying VANETs without having to acquire new equipment for vehicles [98], device-to-device (D2D) with V2V pairs for IoV networks [63] and network coding [23], [122]. Furthermore, studies have introduced the advantages of a centralised approach in highly dynamic VANETs [120], which allows exchange of information among moving vehicles [13], [14], [126] using fast association and low communication latency of the uplink channel in cellular systems [68], [79], [103]; these studies have also evaluated the transmission performance of V2X communication on the basis of the variance of speed nodes [101]. Other benefits related to V2V interoperability provide all information required of connected vehicles through vehicular networks. Furthermore, various studies have discussed improving the coverage of the vehicle information sharing network [83]; providing vehicles with a local proximity map of their vicinity [39], service to stuck vehicles in tunnels [70], and localisation system availability and precision improvement by eliminating the restriction of all vehicles having GPS; and using data fusion techniques to estimate vehicle location [7], [77], [107], [108], [139].

Another benefits related to V2V interoperability is the provision of different types of protocols for the vehicular network. Other advantages are the development of routing protocol capable of eliminating broadcasting storm, disconnecting link problems, ensuring that the maximum content packet successfully received by the consumer [46], timer-based dissemination protocols in a highway environment [86] and design of a self-configuring time-division multiple access protocol that is capable of inter-vehicle message delivery with short and deterministic delay bounds [51]. Data dissemination protocol based on map splitting aims to reach a high reachability ratio and a high Geocast precision [45]. Other studies have proposed an SES for routing with probabilistic contacts on overlapped roads [49] and analysing and evaluating various position-based routing protocols [88]. Furthermore, a hybrid networking mechanism under which a VANET based on V2V networking protocol is used [50], and a hierarchical network topology called cluster is provided for VANETs [38].

3) BENEFITS RELATED TO SOPHISTICATED SECURITY SYSTEMS

Security systems are important in V2V communication and a critical point in the development of robust V2V systems. A trust establishment scheme that uses cooperative intelligent transport system messaging services [130] and a new scheme to spread warnings among vehicles without any dependence on road foundation [60] have been discussed. Studies have delved into improving efficiency and safety in transportation networks and opportunities to bridge the physical components and processes with the cyber world, thereby leading to cyber physical systems [111], preventing DDoS attacks and eliminating misbehaving nodes in a distributed, collaborative and instantaneous manner [125].

4) BENEFITS RELATED TO SAFETY

V2V safety systems notify drivers about road conditions and reduces the number of collisions on the road. Such systems are used to prevent road traffic accidents and collision and provide assistance to drivers on the road [3], [4], [24], [29], [33], [34], [58], [71], [74], [81], [85], [89], [124], [127], [131]. V2V communication systems allow vehicles to share state information with one another to improve safety, comfort and efficiency of transportation networks [8], [12], [15], [18], [20], [28], [54], [59], [76], [87], [112]; provide safety-oriented applications for vehicle and pedestrian on tablets and smartphones [2], [35] and IoV [109]; and provide safety assurance strategies for resolving intervehicle conflicts at unsignalised intersections [93], [115] and road intersections [99]. A shockwave system has significant influence on freeway capacity and safety. The main objective of vehicles in a string of a platoon is to ensure constant and safe intervehicle distance along with successful tracking of velocity and acceleration of its predecessors [37] and broadcasting safety and beacon messages to improve road safety and reduce traffic congestion [36].

Other benefits related to the safety of V2V communication systems are focused on urban road conditions and development of control strategies in the presence of congestion where the behavior of one vehicle influences the other [137]; and notification of neighbouring vehicles of hazardous conditions, such that drivers can take actions during and before emergency situations [48], [96]. Other studies provide drivers with relevant information about the environment surrounding their vehicle, which can make driving safe and easy [53]; and solutions that assess the risk of finding ice on the road [6], enable efficient use of existing road infrastructure, reduce road congestion and lower fuel consumption [27], [133], and increase road throughput [52].

F. ISSUES AND CHALLENGES RELATED TO V2V COMMUNICATION SYSTEMS

Although V2V communications offer numerous benefits, these technologies are not the perfect solution in communication network delivery. The surveyed works indicate that researchers are concerned about the challenges associated with V2V applications and their communications system. The main challenges in adopting V2V communications are classified according to their nature along with citations for further discussion, as shown in Figure 6.

1) CONCERNS ON ROAD SAFETY

Potential threats and road accidents have been increasing due to high density of vehicles. Road accidents in congested urban areas are a serious problem of great importance, and changing lanes and reaching out to the next incident node would be complex for vehicles [2], [33], [58], [127], [137]. The need is to understand the relationship between looking ahead toward potential collision detection and when to deploy collision mitigation strategies [81]. The current traffic system lacks in efficiently providing help to people who are stuck in any problem on the road [29], and no individual vehicle can have sufficient view of the other vehicles' behavior to reason out effectively about trustworthiness [4]. The main concern to road users is to demonstrate the possibility of detecting an icy road segment, such as the dangerous spot, before the vehicle actually reaches the spot [6], [92]. The question arises whether such communication system may efficiently improve travel quality while reducing the risk of collisions [56].

Road intersections are considered bottlenecks for urban transportation, thereby requiring the principle to predict trajectory in the absence of intersections and estimating the probability of front and rear collisions [99]. Existing radio communication technologies suffer from poor performance in highly dense road scenarios and not providing sufficient spectrum for reliable exchange of safety information [52], [128]. The next step is to develop precollision systems that can warn the driver and take control of the car to avoid potential collision and ensure interactions among all vehicles, not only a select subset [28], [54], [59]. Road traffic safety applications, infotainment applications and decisions for collision avoidance and SC need to address accurate information because broadcast communication does not allow mechanisms, such as sending request to send/clear to send and acknowledgements that can be considered among the most critical vehicular services [3], [22], [37], [48], [85], [89], [112], [125].

A breakthrough is found in improving safety messages and resending relevant accident messages periodically and continuing the messages to make other vehicles aware of the accident and for accurate network knowledge [35], [36], [53], [54]. Safety-based V2V applications have to fulfill quality requirements to help drivers in critical situations on rural and motorway roads, as well as in urban and inner-city areas [74], [115]. Furthermore, such applications should effectively extend the coverage and improve the efficiency, comfort and safety of drivers [83]. Several researchers are concerned about the delay of data due to high traffic mobility among vehicles during communication, which represents a huge challenge [64]. Thus, providing a low propagation network delay still poses significant challenges for telematics applications and data delivery that affect communication links and loss of information [42], [61], [62], [85]. Even a few hundred milliseconds of delay through a highway section can limit the sustainable throughput of messages, thereby making high throughput communications critical [86]. Communication technology should have least delay to provide feedback for information, threeby stabilising the system in a timely manner to broadcast traffic [22], [111].

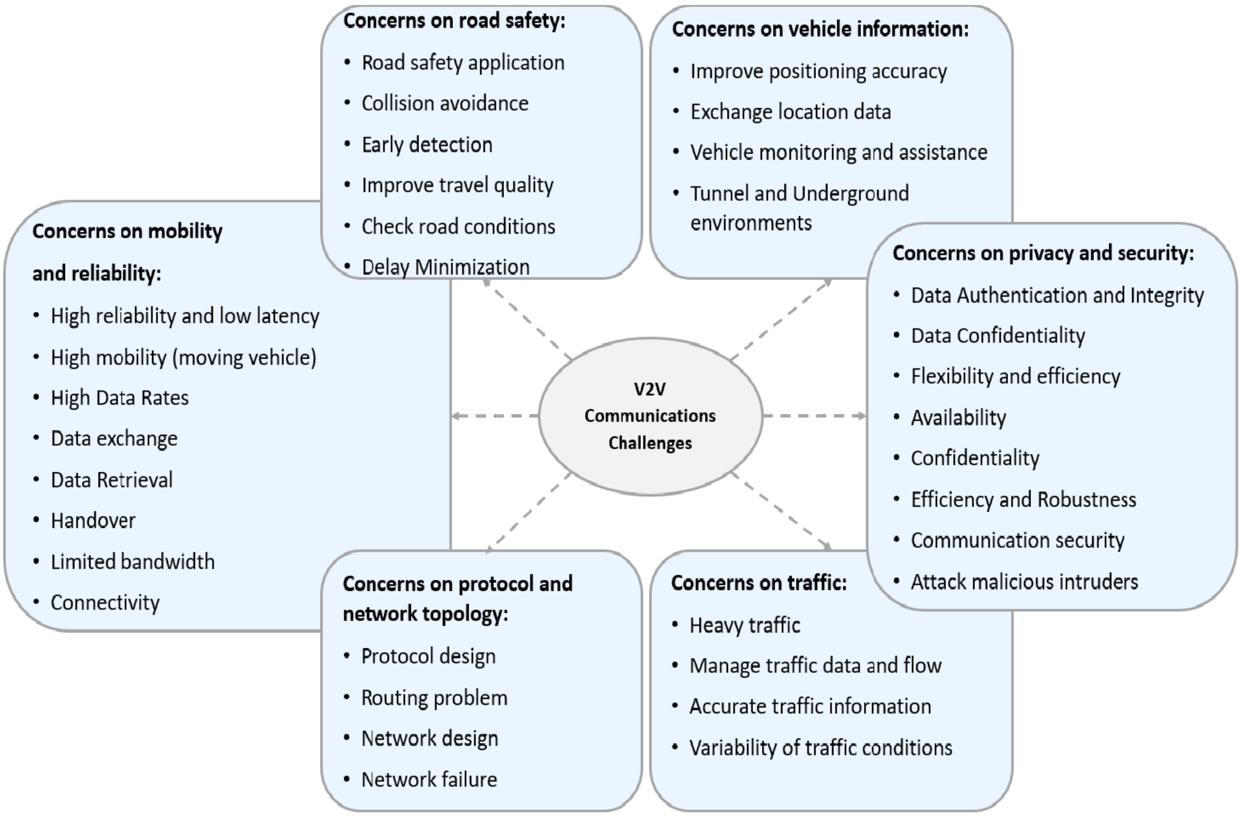


FIGURE 6. Categories of challenges related to V2V communication systems.

2) CONCERNS ON VEHICLE INFORMATION

The increasing automation of driving functions places high demands in which each vehicle information must be updated periodically to exchange location data (time, position, heading and speed), detect nearby vehicles and geographical address and track a target [7], [8], [13], [26], [50], [68], which are vital issues in trusting data prior to their use. The majority of VANET applications require the availability of real-time position information [39]. As GPS, Global Navigation Satellite System (GNSS) requires a clear line of sight for moving vehicles to have accurate services of positioning and localisation of applications, which represent drawbacks and bottlenecks when vehicles are stuck in a long tunnel, urban canyons or a place where GPS data are unavailable or severely poor [67], [70], [85], [107], [108], [136], [139], which remain an open issue [77]. Therefore, assistance from additional inertial sensors is important [93]. A significant portion of message transmissions will be susceptible to recurrent signal attenuation caused by buildings or vegetation due to the presence of radio shadowing [74]. Few technologies can be implemented to control car-following behaviors of human-driven vehicles [47]. To address the issue, major problems must be resolved, such as the distributed control of autonomous vehicles, coordination between each vehicle and the complex environment and the lack of available neighborhood information [14].

3) CONCERNS ON PRIVACY AND SECURITY

Wherever wireless network or vehicular network are applied, security vulnerabilities for cyber physical systems present risks to privacy of sensitive data; and when people are involved, privacy and security are major concerns [22], [111], [124]. Finding a balanced tradeoff among security, efficiency and network requirements during fast movements of vehicles remain an open challenge [13], [130]. The security system requirements must improve and ensure message confidentiality, integrity, access control and availability for all packets sent and received [9], [11], [96], which should be guaranteed that these messages come from actual vehicles and contain original information [56]. The benefits offered by VANETs and ITS cannot be fully realised unless a mechanism can effectively defend against false and erroneous information exchange from malicious or dysfunctional nodes to other vehicles; thus, flexibility in the security architecture and the system design is a significant issue [19]. Keeping a reasonable balance between security and privacy is one of the main challenges in VANET [20], [21] because transmitted information is distributed in an open access environment [12], and disseminating safety data between connecting vehicles [24] is vital.

4) CONCERNS ON TRAFFIC

Efficient traffic control and management for highway and urban area must maximise roadway capacity usage, balance traffic flows, decrease emission and improve traffic safety and travel time prediction [22], [44], [66], [69], [129], [131], [132], [134], which pose a fundamental and urgent challenge in ever-growing cities and cooperative systems to ease heavy traffic [5], [65], [90], [129]. Realistic and efficient traffic simulation models do not consider independent and autonomous traffic participants other than different types of car and conflicts between user optimality and system optimality to explore introduced measurement errors [56], [64]. High traffic volume and variability of traffic conditions on the road results in large queue length, which causes long waiting time for cars. Under heavy traffic conditions, fixed signals can cause congestion due to their inability to adapt according to the dynamic requirements of the real-time density of vehicles [73], [94]; thus, up-to-date traffic data must be collected to control traffic lights before vehicles pass by them [75], [100]. Providing accurate traffic information is becoming a major challenge for public institutions and private companies, which result in the rapid growth of intelligent transportation systems [17]. Frequent traffic congestion can hinder a nation's progress as its citizens are crippled by transportation, which leads to increased chances of road accidents [26] and expectations to have drivers and passengers in a VANET to interact with people, applications and services in other networks, thereby posing new challenges [13].

5) CONCERNS ON PROTOCOL AND NETWORK TOPOLOGY

Conventional routing and forwarding protocols strategies in such environments are challenging goals for VANET because of its strict requirements of high-speed mobility and rapidly changing topology [21], [43], [60] and definition problems of the zone of relevance in Geocast protocols [45]. Another challenge in protocols is the information available for decision making [105] and the absence of infrastructure nodes in communication [88]. VANETs comprise different types of vehicle and should communicate using the same protocol [13]. However, future deployment raises many issues and challenges in modelling, network management and control, which should be anticipated because of the high mobility of nodes and rapid changes of topology; hence, designing an efficient routing protocol and high heterogeneity that can deliver a packet in a short period with few dropped packets is a critical challenge in VANET [20], [41]. Routing protocols that integrate information gathering requires the accurate collection of geographic information of vehicles that pose problems when evaluated for urban scenarios because the existence of obstacles in city environments may interrupt communication [25]. The problem of increasing the physical/medium access control protocol overhead to ensure efficient use of the communication channel usage [14], [101] and very poor dense networks [116] is another issue tackled in research.

6) CONCERNS ON MOBILITY AND RELIABILITY

Data exchange in V2V communications systems faces many challenges, such as high mobility and intermittent connectivity between vehicles due to changing their velocity and direction constantly and unpredictable network topology [12], [15], [16], [46], [51], [79], [104], [110], moving in opposite direction [79], amount of time needed to establish connection links with other vehicles [95] and high speed, which require fast data transmission [31], [80], [113], [118]. Stochastic V2V communication with frequent information exchange, low latency and high reliability among vehicles poses a great challenge on communication systems [1], [55], [78], [82], [117], [119], [138], packet loss and transmission delay [97], [121] and transmission range degradation [14] when supporting real-time services due to deep fading and co-channel interference [122]. Vehicular communication networks represent an opportunity and a challenge for providing smart mobility services by using a hybrid solution, model of VANET link connectivity, architecture to provide cellular connectivity and short-range communications [76], [87], [98], [106], [123], efficient radio resource management [114] and effective information dissemination [84]. One of the greatest issues of the distributed channel access scheme of 802.11p is the absence of guaranteed bandwidth and access delay [120]. The gap between the limited network bandwidth and the rapidly growing demands of data rate has become prominent [14]. Other challenges are related to variable network density and network fragmentation [13], which motivate researchers to look at new technological solutions for limited bandwidth [109]. A new type of communication networks and scenarios for modern cities is needed to develop local, low-latency data exchange among direct neighbouring vehicles, which implies the need for dedicated short-range communication based on the IEEE802.11p standard or VANETs [30], [63] where vehicles cam communicate and exchange information, such as traffic conditions or safety warnings [91], [126]. The system design for rapid detection of neighbouring vehicles with fast recognition [71] should provide data sharing and line-of-sight communication through DSRC [32], [103] and is one of the key challenges in V2V communication. Vehicle mobility varies within traffic condition variation, such as during traffic congestion, accidents, traffic lights, rush hours [23], fading signal [20], problem of using high data rates [14] and IEEE 802.11p exhibiting poor performance in the event of a large number of vehicles [18]. Other concerns related to mobility are frequent link disconnections [22], disruptive tolerant communications [13] and unreliable error recovery techniques [21].

G. RECOMMENDATION

This section summarises the most important recommendations in the literature to mitigate the challenges and facilitate the safe and effective use of data exchanging in V2V communications systems, as shown in Figure 7.

1) NEW STANDARD RECOMMENDATION FOR V2V SYSTEMS

This section presents important recommendations related to the new standard and communications aspects for V2V

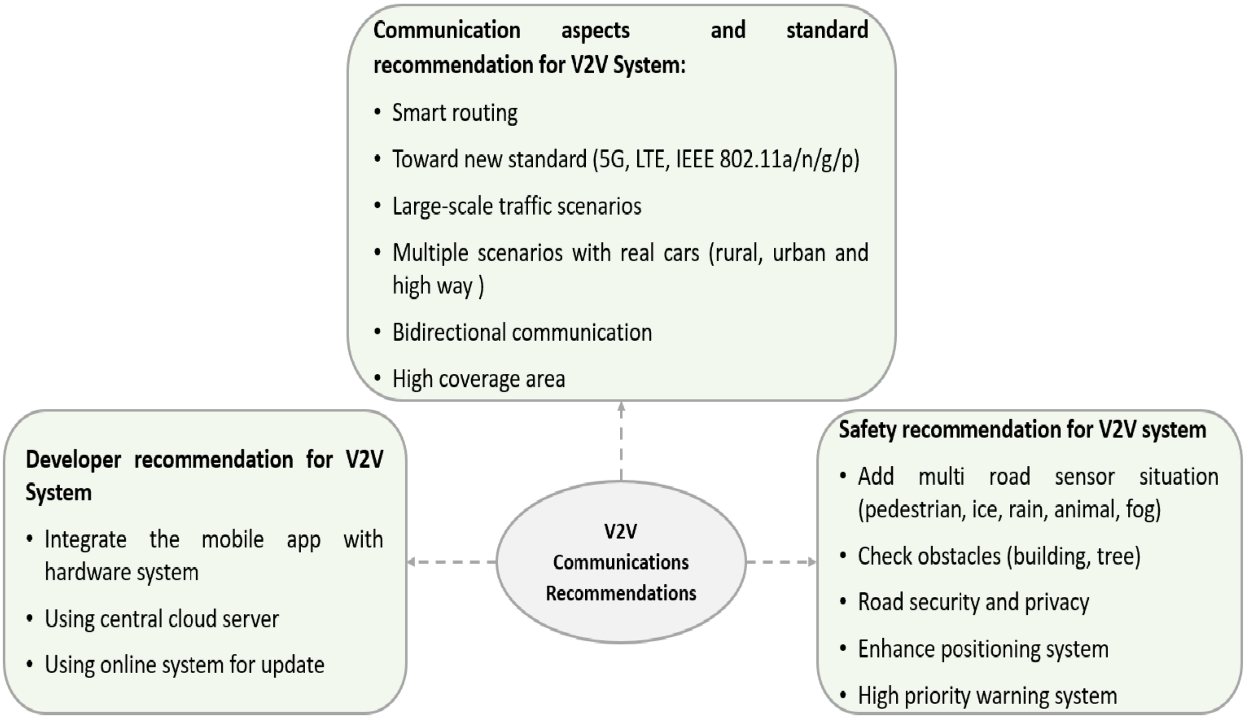


FIGURE 7. Categories of recommendations for V2V communication systems.

communication systems. Introducing the new technology DSRC/WAVE and develop one of the two applications, namely, dilemma zone avoidance, which had an actual trial in Michigan, US [90]. The test took advantage of DSRC and LTE [18] and LTE D2D communications, WiFi and VL communication and 5G technologies [50], [68], [76], [109], which enable flexibility to optimise vehicular communication systems. In a hybrid channel allocation scheme, beacon messages are exchanges based on cluster-based MAC, whereas event-driven messages are exchanges based on DSRC [39]. The differences between DSRC and cellular network performance motivate future work on creating a V2V communication model that uses both channels to implement such applications by leveraging them together [32]. In addition to IEEE 802.11a/n/g, the IEEE 802.11p technology is used in simulations to cope with the frequent topology changes in VANET [102] by conducting field experiments to evaluate the capacity of a contact among mobile vehicles with 801.11p interfaces [106]. A technology-independent sensor over DSRC link that supports V2V and monitors the DSRC performance in response to the sensor location placement of the vehicle system is presented in [84].

Further studies might focus on designing a smarter routing protocol that combines vehicle velocity, position, direction, density and distance from destination nodes for existing protocols [88] and communication aspects (e.g. efficient protocol design for packet exchanges and influence of packet error rate) on localised performance [108]. A robust set of protocols for information dissemination and collection that is adaptive to vehicular traffic density and equipment deployment rate is defined in [131]. Securing the main phases of a protocol, especially the data collection and aggregation phases [41] can reduce the cost of packet routing [21] and provide an Adaptively Intelligent Routing System (AIRS) for future target with routing path to make a realistic simulation [94]. A forward topology to meet the requirement of vehicle and perform further experimentation with combinations of routing protocols and other wireless technologies is provided in [121]. Optimising standards based on intelligent and dynamic solutions using an assisted decision method [66] can improve the robustness of a model against perturbations introduced by unreliable sensors [65]. Model platooning of vehicles that are connected via a V2V communication network to analyse how a platoon can improve movement of vehicles is discussed in [43].

Future studies might focus on implementing models in a large-scale agent-based traffic simulation software and traffic simulation framework. In this manner, realistic road networks taken from the OpenStreetMap project can be further examined [56] and large-scale scenarios with flash crowd effect can be designed [44]. Extending the architecture into a comprehensive framework for HetVNETs and focusing on large-scale deployment [129] consider heterogeneous traffic scenarios, where combinations of connected, not connected, automated, and nonautomated vehicles share a road space [135]. Further studies might focus on experiments with actual cars and testing environments [28, 122], apply algorithms for moving cars [89] and integrate floating car observer modules into customary cars in rural areas and highway sites [3], [51], [69]. Increased ranging accuracy can enable detailed bidirectional data exchange for ITS precision [5], [51]. Multiple lane scenarios will be evaluated in depth to increase the understanding of scenarios involving vertical relative angle and derive applicable observations for actual traffic and map for Jakarta [102]. Vehicle speed will be further analysed by considering highway tests and increased speeds at urban locations [85], and coverage and efficiency of vehicle information sharing networks are of significant importance for future IoV [83].

2) SAFETY RECOMMENDATION FOR V2V SYSTEMS

A future research direction is to provide systems with the capability of detecting emergency situations by using sensors to gather additional information on accidents to make appropriate decisions in various situations [53], such as the detection of other hazards. Specifically, traffic bottleneck and heavy rain alerts can potentially affect vehicle safety state [6], [25] by giving high priority to warning messages over other types to ensure human safety by avoiding message collision, and guaranteeing message delivery to the goal [24] and due to hidden terminals and preserving channel reservation [120]. Trajectories of two vehicles and collision must be defined in advance by combining with actual running trajectories of vehicles, such as turning left, going straight and turning right, thereby providing a dynamic collision avoidance strategy [115]. Human–machine interface is essential in implementing an adaptable and accurate CAS [81]. Another future extension is to provide misbehavior detection and revocation, which need to be further explored [19]. Anti-malware, intrusion detection system and security mechanisms of protocols should be studied for future works to enhance network security [19]. Other issues are testing for malicious nodes [97] and addressing privacy issues [60]. Advances in information and communication technologies allow the transportation community to foresee relevant improvements for the incoming years in terms of efficient, environmentally friendly and safe traffic management [1], [48]. By combining the usage of loop detectors and traffic cameras, the regional traffic management authority can achieve near real-time detection of potential incidents in practice, which is ideal for detecting situations, such as icy roads or animals on the road [4]. Other recommendations related to avoid road obstacles and building shadowing clearly have a substantial influence on packet delivery rate and thus on the communication performance of VANETs [74], [78] by performing experiments with two or more moving vehicles to analyse the effects of these factors on communication performance among 802.11p devices [117]. The inclusion of maps and linking algorithms with a common GPS path planning system can improve projects, thereby fixing many problems [33]. Using TIGER maps that provide realistic road network [42] and general packet radio service technique for the traffic data collection system can provide all-time connectivity and achieve 'close to real-time' data transmission [103] as well as local information among neighbouring vehicles to provide safety [47]. Future vehicles will undoubtedly feature advanced decision-making modules that can take complex maneuvers in the event that a driver becomes incapacitated or simply to drive the vehicle in autonomous mode [53], ranging from seamless intervehicle video streaming to road traffic monitoring to collision warning/avoidance [22]; moreover, blind-spot warning systems can complement its functionality [34]. The integration of improved intelligent computing methods into the original algorithm can also enhance the performance and completeness of collision prediction and conflict resolution [93].

3) DEVELOPER RECOMMENDATION FOR V2V SYSTEMS

Connected vehicle technology, such as V2V, will generate a huge sensor platform. These technological enhancements will require strong research effort in the development of new models to anticipate user intentions and capture and simulate a new driving environment accurately [91]. Extending the systems can include added features into, integration of mobile applications and the hardware system with the central cloud server and implementation of security algorithms, thereby making the system efficient, wide, reliable and fast [2], [70], [100], given the rapid and widespread deployment of new smart city applications in metropolitan areas [132]. A development of higher-level algorithms can take the predictions of the method presented here and turn the signals into meaningful warnings to the driver to avert collisions [59]. A real-time decision-making process for a transmission device based on vehicular dynamic spectrum access that can select an appropriate channel when provided with multiple choices can be developed [104]. A Step forward on the concrete hardware implementation of node operation system and establishing a hardware emulation platform of the information interaction system are also possible [62]. Future works will include building different stages such as (situation–options–choose–act–evaluate) decision-making process for vehicles to maximise the potential for resolving various situations [136] and developing higher-level controller strategies in a driver-in-the-loop framework [137]. Moreover, future works will include V2X simulation runtime infrastructure with a Network Simulator (NS) to develop applications, such as rerouting congestion avoidance. A simulation framework may need further development to cover other C-ITS scenarios [135] by using a dissemination scheme [35]. Communication techniques should also be enhanced and negotiation strategies should be developed with machine learning methods to reach quick agreements and resolve any conflicts in traffic [56], [127]. Delay tolerant strategies should also be developed [75] and applied to models to develop a reliable routing algorithm [79]. A feedback channel is important to increase the awareness and speed up the discovery process without incurring large control overhead [114] and make the system statistics available online [7].

V. SUBSTANTIAL ANALYSIS

This section describes the substantial analysis performed on the related work. This analysis is categorised into six parts, as illustrated in Figure 8. It comprises the types of device, number of scenarios used, location of the experiments, types of sensor, number of vehicles and vehicle speed during the test, evaluation technique and strategies used and the types of simulation used in literature, as shown in Figure 8.

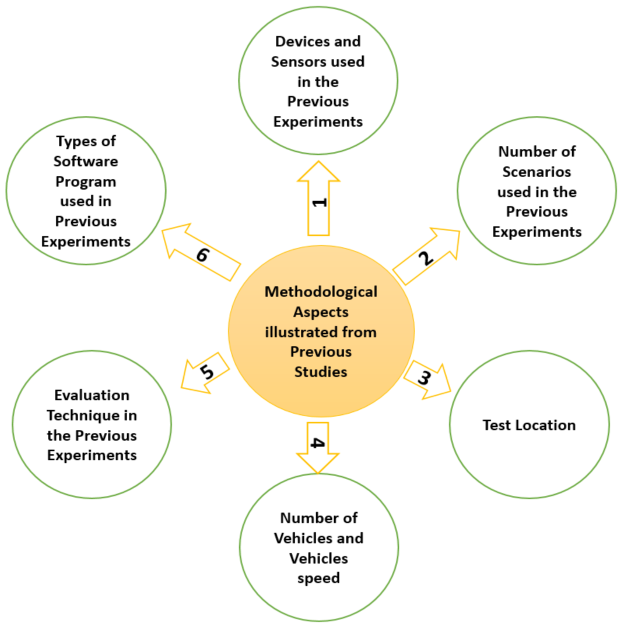


FIGURE 8. Methodological aspects illustrated from previous studies.

A. DEVICES AND SENSORS USED IN PREVIOUS EXPERIMENTS

This section briefly describes the devices used in previous experiments of methodological aspects. Vehicles are equipped with the IEEE 802.11p DSRC [2], [3], [8], [32], [34], [48], [90], [98] or LTE [50] to provide V2V communication using Bluetooth [95], Raspberry Pi board [33], [124], [129] and standard ETSI with ITS-G5 [8], [30]. An implementation of V2V communication paradigm using Arduino Mega board is performed by connecting WiFi to Arduino using Wiznet W5100 Ethernet to SPI converter [29], using the Mono-camera of MobilEye mounted behind the windshield to provide relative measurements (distance, angle and relative speed) [7] and equipping with a WLANp MK5 OBU module from Cohda Wireless [8], [32]. The absolute position of a car is obtained through a GNSS receiver [30], [76] or GPS receiver [34], [67], [89], [107] to detect the position and movement of other vehicles up to 200 m away. Information is derived from accurate differential global positioning system/inertial measurement unit (IMU) fusion, and data are received through the controller area network (CAN) bus [28].

The on-board unit to be designed is a PIC16F877A microcontroller-based system with a 9600 bps, 433 MHz radio transceiver and serial JPEG camera interfaced to it [67]. The communication system is designed on an ALIX3D3 main-board using the Voyage Linux system [2]. A VARON prototype is implemented in an Asus WL-500 g Premium router, a low cost device equipped with a 266 MHz CPU and 32 MB of RAM [72], and a prototype system is implemented on a Xilinx Virtex-5 XC5VLX110T2 platform [96]. A prototype vehicle enhanced with odometry captors, a gyroscope, an accelerometer, two GPS receivers, an SBAS-capable Trimble Ag 132 GPS and an Ashtech GG24 GPS/GLONASS receiver are installed in the car [85]. Two laptops run on a Linux distribution and is equipped with DCMA86-P2 cards, which implement the IEEE 802.11p standard. The DCMA86-P2 is based on Atheros chipset AR5414A-B2B [117] and consists of a microcontroller interfaced with a GPS module, a camera, a radio module (433 MHz), a speaker alarm and liquid-crystal Display [70]. Each e-platoon vehicle is equipped with two radio transceivers with omnidirectional antennas [1]. Each vehicle is equipped with an electronic map, has a unique MAC-ID and every frame has a randomly selected ID [112]. Vehicles are equipped with sensors that capture and report vehicles' surrounding traffic conditions and environment [65], assume to be equipped with a GPS sensor [46], [59], [75] and equipp with wireless transceiver/receiver sensors that update the vehicle location on the road [57] or Xbee [6], [62], [79] and fog sensors [84].

Data from the sensors are divided into two groups according to their latency demands. Information with direct impact on safety and relevant awareness messages is generated and sent to other vehicles using DSRC [113]. In the first experiment, 100 measurements are made with the motionless sensors and no obstacles are found. In the second experiment, the sensor is placed on a vehicle moving towards and away from another parked vehicle, and the distance is measured 100 times [28].

B. NUMBER OF SCENARIOS USED IN PREVIOUS EXPERIMENTS

This section presents a brief description about the scenarios performed in previous experiments to provide a V2V communication. Works mainly focus on two types of scenarios in highway and urban roads [27], [36], [39], [44], [52], [71]. Other works focus on two types of scenarios for V2V communications, that is, when vehicles travel in opposite and in the same direction [6], [79], [80], [111]. Other works provide V2V communication scenarios where two vehicle nodes aim to establish a communication link using WiFi ad hoc connection [58] and a scenario that highlights the potential of DSRC in supporting a fast moving ambulance and an emergency scenario [136]. Other scenarios focus on two vehicles moving at different speeds in opposite directions [66], [81]. Other works focus on three types of scenarios, that is, when an accident occurs at the beginning of each simulation [97], when a V2X PHY layer model is involved and assessing the real performance of the IEEE 802.11p system [66] and implementing simulation tool to depict a wireless transmission environment for vehicular networks operating under highway conditions and randomly generate highway incidents [104].

C. TEST LOCATION

This section presents a brief description of the test location for the experiments and area size made in previous studies to provide V2V communication. Twenty drivers are recruited at the Faculty of Sciences of the University of Porto with ages between 20 and 65. The experiment consists of driving during the given road scenario and attempting to arrive as soon as possible at the destination, respecting all traffic regulations [34]. Field experiments and corresponding simulations are performed in a scenario derived from an actual unsignalised intersection on the campus of Beijing Jiaotong University [93] and a road network of highway 401 in Ontario, Canada. The scale of these regions in the simulation is approximately 4 km $\times$ 4 km [53], The real-world map of the Seventh Street in Shangdi Area, Beijing, China is used as the evaluation scenario [63]. The road–network layout of the scenario consists of a portion of the medium-sized Italian city of Bologna with a size of1.8 $\times$ 1.6 km^2 [109]. Another experiment is performed in an area of approximately 1 km^2. The cars move very slowly in three different conditions, namely, (i) both vehicles are static, (ii) one vehicle is static and the other is moving and (iii) both vehicles are moving [29].

D. NUMBER OF VEHICLES AND SPEED

This section presents a brief description about the number of vehicles included in the vehicle speed tests used in previous experiments in V2V communication systems. Several experiments are conducted by setting the speed at different values from 40 km/h to 70 km/h and the distance to fixed values between 27 m and 150 m. Up to 30 measurements are performed with each sounder [31]. Other works randomly place 440 vehicles over the entire road network, such that each street has a vehicle density of approximately 15 vehicles/km/lane. The vehicle speed is selected randomly from a Gaussian distribution with a mean of 36 km/h and standard deviation of 5 km/h [42]. To obtain a realistic speed of vehicles in a large city environment, the average speed of vehicles is set between 40 km/h and 70 km/h, high and sparse denisities are noted and various types of obstacle are set [102]. Other works consider average vehicle speed of 80 km/h, number of vehicles from 100 to 1000 and density of vehicles comprising 20–200 vehicles/km^2, as well as using IEEE 802.11p DSRC [45] and consider a road segment in which 50 vehicles transmit data to a cluster head vehicle [41]. The simulation setup consists of a span of a six-lane, bi-directional highway. The target velocities of vehicles are 70, 90 and 120 km/h from the slowest to the fastest lane for each direction [86]. Other works provide trafic scenarios for stable trafic flow where all vehicles drive at the same constant speed of 25 m/s [64]. In an urban scenario, 150 vehicles are deployed, whereas a highway scenario comprises six highway lanes and three for each direction. The length of the highway is 8 km. A combination of different types of 150 vehicles with a mean speed of 120 km/h is simulated [120].

E. EVALUATION TECHNIQUES IN PREVIOUS EXPERIMENTS

This section presents a brief description of the evaluation technique for V2V communication used in previous experiments. A protocol that offers remarkable collision avoidance vehicle crash [51], dissemination strategy for mapping rules of ant colony communication system to VANETs [35], decentralised platooning control strategy [37], [61], [135], car-following model using MAC protocol IEEE802.11p [38] and Floating Car Data (FCD) are generated by on-board vehicle equipment [131]. Other works provide architecture that includes a communication module that implements direct inter-agent communications for flexibility and efficiency [138], new hybrid trust establishment scheme for reliable data delivery and DoS defense in VANETs [125], context-aware driver assistance system and hazard detection control [127]. Other works focus on AIRS [94], algorithm using generalised model for traffic distribution and V2V communication packet loss [82] and usage of VL time-hopping spread spectrum techniques [5]. The road is divided into geographical zones, and the network provides mapping between zone(s) and V2V link transmission resource pools [114]; data fusion and radio-ranging distance measurement techniques are combined along with V2V communication [77]; and distributed algorithm are adopted [105].

F. TYPES OF SOFTWARE PROGRAM USED IN PREVIOUS EXPERIMENTS

This section presents a brief description about the types of software used in previous experiments to provide a V2V system, as summarised in Table 6.

A total of 55 articles use a software program for V2V communication system. The first group of studies (18 articles (32%)) uses MATLAB. The second group (13 articles (24%)) uses NS software. The third group (9 articles (16%)) uses a combination of two famous programs, OMNet++ (wireless network simulation tool) that is linked to SUMO (road network simulation tool). The fourth group (7 articles (13%)) uses a combination of two programs, NS and SUMO simulation software. The last group (8 articles (15%)) uses various types of software, such as hybrid NS known as GrooveNet [4], Manhattan [41], MovSim [65], NetLogo [116], Qualnet NS [56], Visual Studio [73], PLEXE [61] and OPNET [72].

VI. RESULT ANALYSIS MAPPING FOR NEW DIRECTIONS

From Section 2.1, the development taxonomy section is classified into two main groups: real time and simulations. A deep analysis of the accuracy of both sections is conducted and focused on the data exchange from previous articles to define the gap in future directions that target data exchange in V2V system with different types of scenarios, vehicles

TABLE 6. Software programs used in previous experiments.

Ref.	Software										
	MATLAB	Network Simulation	SUMO	OMNET++	GrooveNet	Manhattan	MovSim	NetLogo	Qualnet Network	Visual Studio	PLEXE
[27, 36, 37, 40, 43, 47, 52, 63, 66, 87, 92, 97, 105, 107, 108, 115, 128, 137]	✓										
[35, 36, 42, 46, 51, 60, 62, 68, 100, 102, 112, 120, 125]		✓									
[45, 50, 53, 57, 64, 67, 74, 99, 135]			✓	✓							
[44, 49, 70, 76, 118, 121, 130]		✓	✓								
[4]					✓						
[41]						✓					
[65]							✓				
[116]								✓			
[56]									✓		
[73]										✓	
[61]											✓

speed, vehicles number to provide a system that can be used in exchanging information between moving vehicles based on the driving behavior to build a collision avoidance system, which achieved a higher accuracy rate than the other methods used as shown in Figure 9. According to the searching and scanning through the literatures, work has been divided into two groups mention in section 2.2.2. titled development. The first group related to all types of articles in the term of simulation which dealing with collision avoidance and warning systems mentioned in [36], [53] [33], [74], [78], report accident situations mentioned in [4], prevent secondary crash presented in [3] data exchange between moving vehicles mentioned in [59], [62].

The second group is related to all articles based on hardware devices (7% of total articles) to provide V2V connection which dealing with data exchange, platooning and convoy driving, sharing vehicle information, video streaming between vehicles and vision sensing. Firstly, [32] made a comparative study by using two vehicles to check the connectivity for V2V by using laptop for network measurement, only two vehicles and try to create datasets of vehicle sensors readings correlated with measurements of cellular and DSRC connectivity. Secondly, [29] evaluated an experiment for V2V data transfer system based on WiFi to communicate with other vehicles. The authors mention that the limitations are data rate, the system cannot achieve data rate of more than 5.7 KB/s. The experiments performed on cars with very slow speeds with maximum range of 100 ft. Reference [30] present an AutoNet2030 system used for convoy driving. Authors in this article did not mention accuracy, data rate, number of vehicles used, vehicle speed and maximum range provided in their result. According to reference [8] an investigation of V2V communication based on commercial On-Board-Units (OBU) and Light Detection and Ranging (LiDAR) integrated in two tests-vehicles. In this article the relative distance between two vehicles V1 and V2 has to be known for every situation, vehicles need a line of sight connection and assuming 100 % reflectivity, good weather conditions and an even road surface, objects with a size of a car to provide maximum range with 100 m. The results obtained from [27] reveal that the use of low data rate is preferred for better performances in the case of long-range communications. Furthermore, in [66] mention that the major insight obtained from this work suggests that communications at high data rate are required in potential applications of the system under investigation and that further efforts are needed to improve the performance of communications taken at high mobility to provide an intelligent and dynamic solutions using an assisted decision method.

The authors in [71] didn't mention the number of vehicles used, vehicle speed, maximum range provided in their results. The authors focus on the problems of the danger in driving drowsy and imprecise collision warning due to perturbed input signal when processing the pre-crash warning. Moreover, [140] proposed a study of driving behavior-based Collision Warning System (CWS) to determine the collision risk level, according to the driver's driving behavior. The radar used in this experiment was the ESR 1.0 model (Delphi), capacity to output up to 174 m. The speed, acceleration pedal, and brake pedal values of the driving vehicle were collected through the OBD inside the vehicle. The information output from the radar and OBD, through the VN5610 network interface via the Vector and the CANoe programs. The authors in [140] mention that the performance of the driving behavior-based CWS was only evaluated at the laboratory scale using experimental results from actual vehicles. Therefore, additional research is required to evaluate the performance with diverse driving data and warnings that occur while driving in an actual vehicle.

From this Point of view, a clear vision can be seen about the large number of articles for development collision avoidance and warning system related to simulation development while, in the other side real time development experiments for providing data exchange in V2V communications systems are very rare especially in developing a real time collision warning system. The practical aspect was chosen due to the lack of studies that were developed based on hardware on the first side. The second aspect was the focus

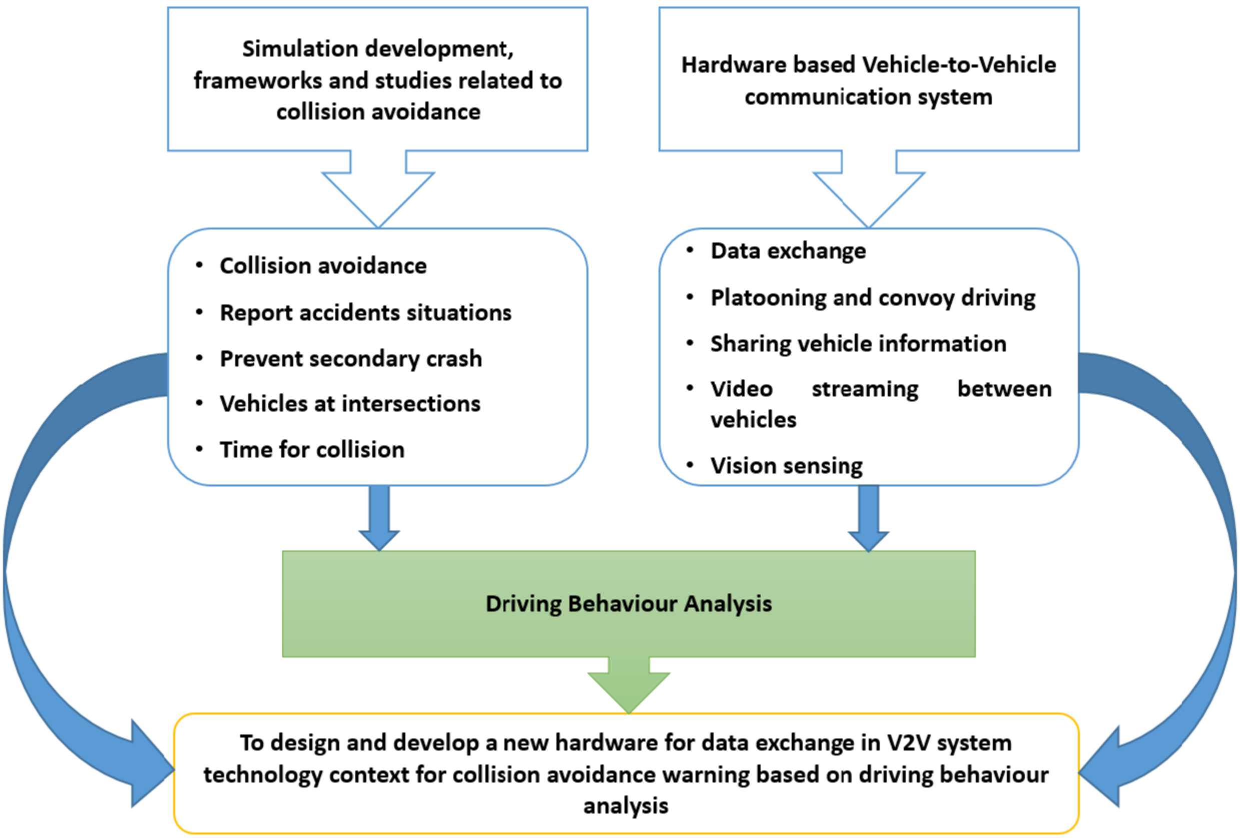


FIGURE 9. Study of gap from several articles related to data exhange in V2V system.

on the field of motivation presented by articles and focus on the most important side which is collision avoidance and detection systems, extending driver vision and reduce the risk of secondary crashes. The most important challenges faced by former researchers to design and develop a collision warning system, taking into consideration the recommendations made by them and try to connect hardware-based collision warning system with the mobile application. The last part to highlight the methods used by previous researchers. In this context, it has been relying on a number of experiments of previous researchers to reach the final design, such as the type of devices, number of the test, number of cars, speed, place of implementation and the type of sensors must be used. According to these results, a hardware system will be developed. This system will take the advantages of simulation such as scenarios, speed, number of vehicles, types of sensors and take the weak points of hardware based and the points that are neglected by the previous researchers during the development, particularly the range of communication, vehicle speed and number of vehicles included in the test and scenarios. The use of wireless technology for information exchange can influence the drivers' behavior towards improving driving performance and reducing road accidents. In this system, we will focus on new factor during the development phase which is the driving behaviour or driving style since the primary cause of road injuries is related to the drivers' behaviors. Based on the literature review, it can be seen that the assessment of drivers' behaviours using their trajectory data is a fresh and open research field. Identifying unsafe driving is a significant step in order to take action and change this situation. In this system we will try to understand drivers' behavior by evaluating and analyzing their movement data which is recorded using gathering devices to identify aggressive behavior in order to reduce the risk of accidents and prevent collisions. As a result, drivers are anticipated to became more aware of their driving and it can also notify transport and insurance companies about the driver's way of driving. The data distribution is usually done using the broadcast method resulting in inefficient use of network resources. Therefore, to avoid the broadcast storm and efficiently use network resources, Next Forwarder Vehicle (NFV) will be selected to forward data to nearby vehicles. The NFV selection is based on certain parameters like direction, distance, and position of vehicles. Accordingly, four main phases have been designed to meet the demands of exchanging data between moving vehicles to develop a collision warning system based on V2V communications systems with a high accuracy rate. The details of the architectural phases of this research are provided in the block diagram in Figure 10 and described in the following subsections.

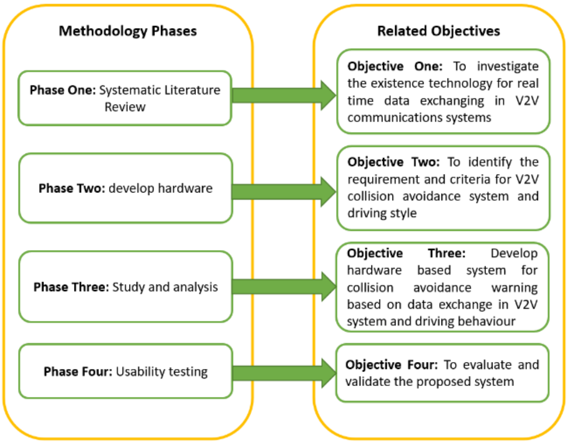


FIGURE 10. Relation between methodology phases, research objectives and the chapters.

A. INVESTIGATION PHASE

This section provides a brief review about the articles related to data exchange in V2V communication system and the steps taken to reach the proposed system as shown in Figure 11.

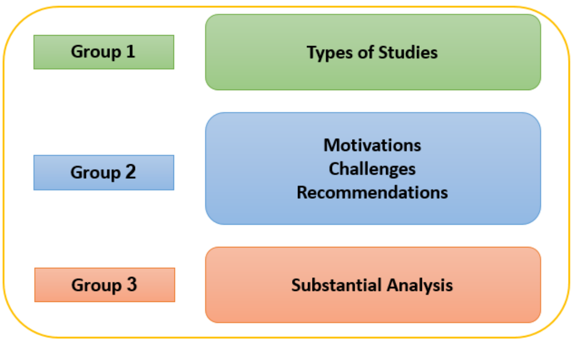


FIGURE 11. Investigation phase related to the vehicle-to-vehicle system.

All the information and the other thing that associated with the main problems are identified. Study selection involved a search for literature sources and then three iterations of screening and filtering applied at the same eligibility criteria followed by the authors. The primary goal is located for mapping the space of research on data exchange in V2V communication into a general taxonomy of four categories. The first group derived from a pre-survey of the literature review. The second group of investigation phase presents the most relevant studies on data exchange in V2V communication system. The objective of this group is to highlight the research trends in this area by focusing on three aspects of the literature content: the motivations behind developing applications based on V2V, the challenges to the successful utilization of these technologies and the recommendations to alleviate these difficulties. The third group of investigation phase presents the substantial analysis, which review the most methodologies used in previous articles to get a clear idea about the proposed system structure that should be implemented.

B. HARDWARE DEVELOPMENT PHASE

This phase presents a detail description of the research experiment design towards developing a real time collision warning system based on driving behaviours. After reviewing through the articles and information regarding to the collision warning system, some points should be noted regarding the selection of the optimal model. A number of standards and measurements have been extracted from previous methodologies and attempts to develop it and increase their efficiency. The appearance and hardware components of the proposed system are shown in Figure 12.

The proposed collision avoidance and warning based on driving behavior is composed of a pre-processor, a driver behavior model analysis, and a collision potential identifier. The communication system is designed on an Arduino UNO board. The main components are described as follows: The OBD-II kit is based on Freematics Esprit is used for driving behaviours analysis, the Arduino compatible ESP32 development board, together with 1.3″ OLED display and Freematics OBD-II UART Adapter. In the proposed system a nRF24L01 device is used to perform the connection between vehicles. The nRF24L01 is a single chip radio transceiver for the world wide which use the 2.4 GHz band and it can operate with baud rates from 250 kbps up to 2 Mbps if used in open space and with a lower baud rate its range can reach up to 1km. An Adafruit Ultimate GPS Breakout - 66 channel w/10 Hz update version 3 used which is built around the MTK3339 chipset, a no-nonsense, high-quality GPS module that can track up to 22 satellites on 66 channels, has an excellent high-sensitivity receiver (−165 dBm tracking), and a built in antenna. It can make up to 10 location updates a second for high speed, high sensitivity logging or tracking. Power usage is incredibly low, only 20 mA during navigation. For data logging we used Micro SD TF card reader module SPI interface with chip level conversion. The SIM800L GSM Module is used for sending and receiving SMS from different drivers in case of a collision to prevent secondary crash. For displaying the warning to the driver inside the vehicles a Arducam 1602 16 × 2 LCD display module based on hd44780 controller character white and blue is used. At the second stage, we combined all the information from the first stage. This phase is done to verify the requirement of the research, limitation and the time required to complete the research, then develop a process to select the destination vehicle for broadcasting information collected by the proposed system using mobile application to share the information between vehicles and notify driver about the aggressive drivers in the road.

The proposed collision avoidance and warning based on driving behavior is composed of a pre-processor, a driver behavior model analysis, and a collision potential identifier. The communication system is designed on an Arduino UNO board. The main components are described as follows: The

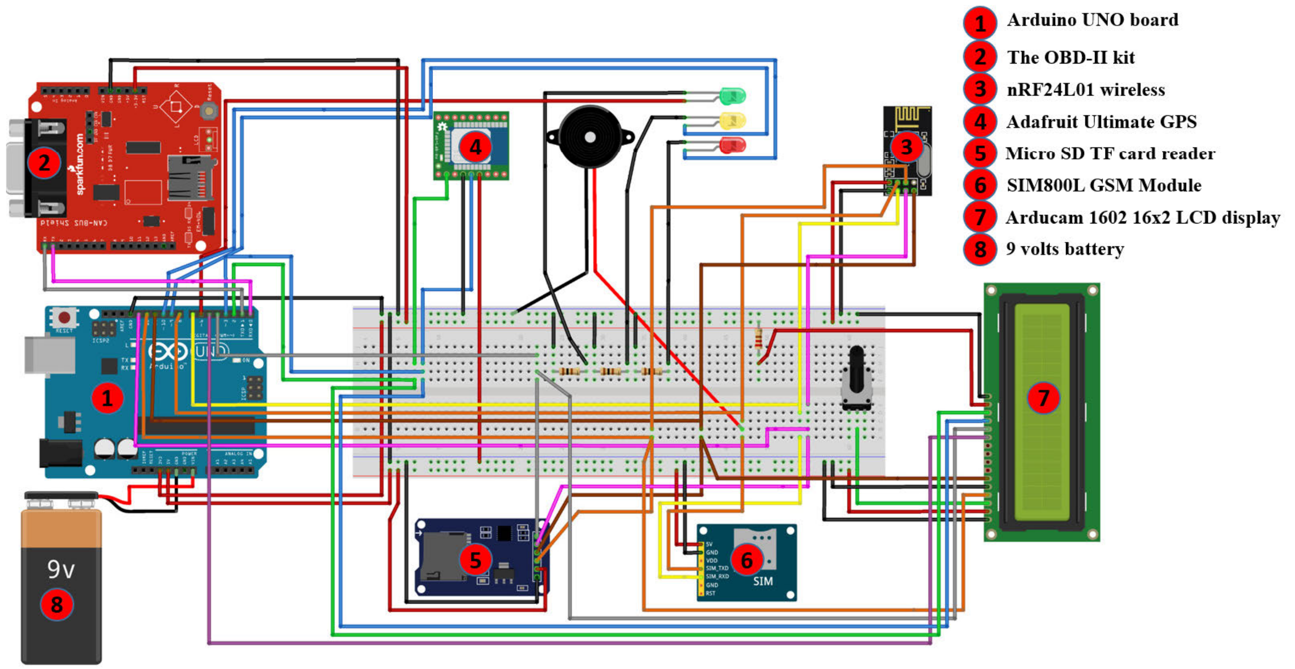


FIGURE 12. Schematic diagram of the propsed data exchange in vehicle-to-vehicle system.

OBD-II kit is based on Freematics Esprit is used for driving behaviours analysis, the Arduino compatible ESP32 development board, together with 1.3″ OLED display and Freematics OBD-II UART Adapter. In the proposed system a nRF24L01 device is used to perform the connection between vehicles. The nRF24L01 is a single chip radio transceiver for the world wide which use the 2.4 GHz band and it can operate with baud rates from 250 kbps up to 2 Mbps if used in open space and with a lower baud rate its range can reach up to 1km. An Adafruit Ultimate GPS Breakout - 66 channel w/10 Hz update version 3 used which is built around the MTK3339 chipset, a no-nonsense, high-quality GPS module that can track up to 22 satellites on 66 channels, has an excellent high-sensitivity receiver (−165 dBm tracking), and a built in antenna. It can make up to 10 location updates a second for high speed, high sensitivity logging or tracking. Power usage is incredibly low, only 20 mA during navigation. For data logging we used Micro SD TF card reader module SPI interface with chip level conversion. The SIM800L GSM Module is used for sending and receiving SMS from different drivers in case of a collision to prevent secondary crash. For displaying the warning to the driver inside the vehicles a Arducam 1602 16 × 2 LCD display module based on hd44780 controller character white and blue is used. At the second stage, we combined all the information from the first stage. This phase is done to verify the requirement of the research, limitation and the time required to complete the research, then develop a process to select the destination vehicle for broadcasting information collected by the proposed system using mobile application to share the information between vehicles and notify driver about the aggressive drivers in the road. The next stage involves circuit construction for the sensor and microcontroller. Finally, in the last stage, the hardware will go through some troubleshooting to identify the efficiency. Any failure will be solved by adjusting the circuit and coding until the system working at maximum capacity. Debugging is done to improve the system. Both the software and hardware should be implemented to make sure everything is running smoothly into one complete system.

C. STUDY AND ANALYSIS PHASE

This phase provides details about the main problem that facing V2V systems in sending warning message after the proposed system detect an event of possible collision risk to alert drivers.

1) DATA COLLECTION

Driving behaviours understanding is a key ingredient for intelligent transportation systems. In order to achieve systems that can operate in a complex physical and social environment, we need to understand driving styles in real-life environments and interact with traffic scenes. The method enriches and evaluate a trajectory trough a set of a experiments done in about 5.2 km long at Universiti Tun Hussein Onn Malaysia (UTHM), Parit Raja, Johor, Malaysia. The aggressive behavior is evaluated considering speed and acceleration maneuvers using an experimental testbed used in the actual vehicle environment, which collected information on the driver's driving behaviors to evaluate the performance of the driver behavior. In this scenario three types of experiments are done, first one is done by using the OBD-II kit is based on Freematics Esprit connected to SD card to record drivers' trips and the second experiment is done by using ELM327 OBD-II Bluetooth adapter connected to Torque Pro application which is a cutting-edge vehicle diagnostic and performance scanner for Android smartphone. In these experiments we should use OBD II port located in the car, but we face a problem since not all Malaysian cars support OBD-II port. In this case we made third the experiment based on cardAdafruit Ultimate GPS Breakout which is connected to the Arduino and stat data logging inside the SD card for further analysis.

Identifying risky or ''accident prone'' drivers could facilitate more effective traffic safety work and allow measures to be tailored for a specific driver group. Jerkiness in driving may be an indication of a more risky driving style and a higher probability of accident involvement. A risky driving style in terms of jerkiness is defined as the amount of critical jerks a driver causes while driving [141]. Several researchers addressed causality-related acceleration limits and high risk of accident involvement. The risk of collision start from $-4.0 m/s^2$ according to [141] while in [140], [142] a simalr conclusions obtained with a risk of accident involvement around $-5.0 m/s^2$. [143] presented a severity stratification of acceleration/deceleration based on different articles to provide an overview about the driving styles. In case of acceleration present the following parameters (dangerous ($7.0\ m/s^2$ - $12.0\ m/s^2$), aggressive ($3.5\ m/s^2$ - $7.0\ m/s^2$), normal ($1.5\ m/s^2$ - $3.5\ m/s^2$) and safe ($0\ m/s^2$ - $1.5\ m/s^2$)) and for deceleration (dangerous (($-9.0\ m/s^2$) - ($-14.0\ m/s^2$)), aggressive (($-5.5\ m/s^2$) – ($-9.0\ m/s^2$)), normal (($-3.0\ m/s^2$) – ($-5.5\ m/s^2$)) and safe ($0\ m/s^2$ – ($-3.0\ m/s^2$)). Considering the mentioned works, we try to propose a stratification of acceleration consist of a number of groups to evaluate driver speeding up and braking based on our experiments to build driving style table in order to activate the warning system of V2V based on driving behaviours.

2) DATA DISSEMINATION

The data dissemination in V2V system is a broadcast oriented message distribution process, where information is required to be sent to group of vehicles instead of individual vehicle. The broadcast-oriented data dissemination leads to several critical problems such as broadcast storm, network partitions, and inefficient use of energy resources. The broadcast storm could be arises during high traffic densities where every vehicle has the authority to retransmit the data packet inside a network simultaneously as shown in Figure 13. Therefore, such Flooding-based data dissemination techniques lead to redundant transmissions, contention, delivery delay, high data packet loss ratio, and immense traffic load [144]. To cope up the problem of broadcast storm, a process is required to select the optimal next forwarder vehicle to ensure effective transmission between vehicles by eliminating the broadcast.

The proposed method uses local information about neighbouring vehicle obtained via the GPS system. It mainly uses a number of information factor regarding neighbouring vehicles to make a decision and a number of steps throughout

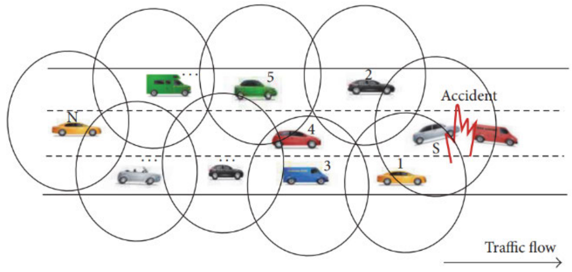


FIGURE 13. **Broadcast message problem [144].**

the selection of the packet for data dissemination in the proposed system and these factors are: direction since the proposed method consider opposite direction vehicles become significant for data dissemination process only during low traffic densities. Moreover, vehicles moving away from the source/transmitting vehicle are also considered less significant than the vehicles moving towards a source/transmitting vehicle. The second factor is position, according to the proposed method categorizes vehicles inside the transmission range in groups called (safe distance, critical distance and collision distance) and assigns highest forwarding probability to the vehicles positioned in ideal segment. The vehicles positioned in normal segment are assigned with low priorities while vehicles positioned inside the ahead segment are assigned with lowest forwarding probabilities. The third factor is distance, in the proposed method, the farthest vehicle inside transmission range is assigned the highest forwarding probability. The fourth factor named as acceleration, the proposed method should studied if vehicle shows decreasing or increasing velocity and get the information needed to prevent a false warning. Final factor is stopping since in the proposed method if the information obtained through the GPS system which, if it not contains a pre-processing then considered false such as when there is no movement, ie, a situation of stop at a stop sign, red light, walkway, parking, etc.

D. EVALUATION PHASE

This phase represents the evaluation of the proposed system for providing V2V collision warning system using driving behaviours analysis to assure quality of a product, system, capability. To be effective, testing cannot occur only at the end of a development. It must be addressed continuously throughout the entire life cycle and predict system performance, identify expected results and determining suitability to test it which is a key decision that can substantially affect the overall success of the proposed system.

VII. LIMITATIONS

Although the database sources that are used in this review are reliable and cover a wide group, identification is difficult. A limitation on the timeliness of the review is caused by increasing the progress in this area. Moreover, studies at a specific period on this vital field do not necessarily reflect the actual usage or influence. Instead, the information merely shows the response of the research community to the field, which is the objective of this review.

VIII. CONCLUSION

This study reviewed and analysed the literature for data exchange in V2V communications systems into a coherent taxonomy. The V2V communication system is an emerging technology. Research efforts in this direction are still ongoing, as relevant descriptions and boundaries remain ambiguous. Obtaining understanding and insights into this research direction is important. This paper aims to contribute to such understanding and insights by surveying and classifying relevant research efforts. It discussed the method, followed by a systematic literature review of related articles selected using the keywords'vehicle to vehicle' and'data exchang'. We studied the related work, classified the taxonomy and then explained the classes and subclasses in different parts on the basis of the final set. The research efforts in this field can provide specific patterns and are classified into four distinct classes, namely, proposals for systems development, survey and review, evaluation and comparative study. We discussed the challenges, motivations, recommendations and substantial analysis of the related work. The result analysis that mapped new directions and a discussion of the data exchange in V2V in hardware and software techniques were presented to identify the gap in future directions that focused on driving behaviour, which achieved a higher accuracy rate than the other techniques used. Accordingly, three phases were designed to meet the demands for detecting and notifying drivers from collisions with a high accuracy rate. Our proposed methodology contains four phases: investigation phase, develop a hardware system for V2V, study and analysis, and evaluation phase. In our future studies, the results of our proposed methodology will be presented, and a dataset will be provided and made available for other researchers.

REFERENCES

[1] J. Lianghai, M. Liu, A. Weinand, and H. D. Schotten, ''Direct vehicle-to-vehicle communication with infrastructure assistance in 5G network,'' in *Proc. 16th Annu. Medit. Ad Hoc Netw. Workshop (Med-Hoc-Net)*, Jun. 2017, pp. 1–5.

[2] L. Zhenyu, P. Lin, Z. Konglin, and Z. Lin, ''Design and evaluation of V2X communication system for vehicle and pedestrian safety,'' *J. China Univ. Posts Telecommun.*, vol. 22, no. 6, pp. 18–26, Dec. 2015.

[3] H. Yang, Z. Wang, and K. Xie, ''Impact of connected vehicles on mitigating secondary crash risk,'' *Int. J. Transp. Sci. Technol.*, vol. 6, no. 3, pp. 196–207, Sep. 2017.

[4] C. Liao, J. Chang, I. Lee, and K. K. Venkatasubramanian, ''A trust model for vehicular network-based incident reports,'' presented at the IEEE 5th Int. Symp. Wireless Veh. Commun. (WiVeC), Jun. 2013.

[5] A. J. Suzuki and K. Mizui, ''Bidirectional vehicle-to-vehicle communication and ranging systems with spread spectrum techniques using laser radar and visible light,'' *IEICE Trans. Fundam. Electron. Commun. Comput. Sci.*, vol. E100-A, no. 5, pp. 1206–1214, May 2017.

[6] J. Radak, B. Ducourthial, V. Cherfaoui, and S. Bonnet, ''Detecting road events using distributed data fusion: Experimental evaluation for the icy roads case,'' *IEEE Trans. Intell. Transp. Syst.*, vol. 17, no. 1, pp. 184–194, Jan. 2016.

[7] M. Obst, L. Hobert, and P. Reisdorf, ''Multi-sensor data fusion for checking plausibility of V2V communications by vision-based multiple-object tracking,'' in *Proc. IEEE Veh. Netw. Conf. (VNC)*, Dec. 2014, pp. 143–150.

[8] S. Eckelmann, T. Trautmann, H. Ußler, B. Reichelt, and O. Michler, ''V2V-communication, LiDAR system and positioning sensors for future fusion algorithms in connected vehicles,'' *Transp. Res. Procedia*, vol. 27, pp. 69–76, Sep. 2017.

[9] C. Bernardini, M. R. Asghar, and B. Crispo, ''Security and privacy in vehicular communications: Challenges and opportunities,'' *Veh. Commun.*, vol. 10, pp. 13–28, Oct. 2017.

[10] D. A. Rivas, J. M. Barceló-Ordinas, M. G. Zapata, and J. D. Morillo-Pozo, ''Security on VANETs: Privacy, misbehaving nodes, false information and secure data aggregation,'' *J. Netw. Comput. Appl.*, vol. 34, no. 6, pp. 1942–1955, Nov. 2011.

[11] B. Mokhtar and M. Azab, ''Survey on security issues in vehicular ad hoc networks,'' *Alexandria Eng. J.*, vol. 54, no. 4, pp. 1115–1126, Dec. 2015.

[12] R. G. Engoulou, M. Bellaïche, S. Pierre, and A. Quintero, ''VANET security surveys,'' *Comput. Commun.*, vol. 44, pp. 1–13, May 2014.

[13] F. Cunha, L. Villas, A. Boukerche, G. Maia, A. Viana, R. A. F. Mini, and A. A. F. Loureiro, ''Data communication in VANETs: Protocols, applications and challenges,'' *Ad Hoc Netw.*, vol. 44, pp. 90–103, Jul. 2016.

[14] S. A. B. Mussa, M. Manaf, and K. Z. Ghafoor, ''Beaconing and transmission range adaptation approaches in vehicular ad hoc networks: Trends & research challenges,'' in *Proc. Int. Conf. Comput. Sci. Technol.*, Aug. 2014, pp. 1–6.

[15] N. Torabi and B. S. Ghahfarokhi, ''Survey of medium access control schemes for inter-vehicle communications,'' *Comput. Electr. Eng.*, vol. 64, pp. 450–472, Nov. 2017.

[16] R. S. Bali, N. Kumar, and J. J. P. C. Rodrigues, ''Clustering in vehicular ad hoc networks: Taxonomy, challenges and solutions,'' *Veh. Commun.*, vol. 1, no. 3, pp. 134–152, Mar. 2014.

[17] N.-E. El Faouzi, H. Leung, and A. Kurian, ''Data fusion in intelligent transportation systems: Progress and challenges—A survey,'' *Inf. Fusion*, vol. 12, no. 1, pp. 4–10, Jan. 2011.

[18] K. Zheng, Q. Zheng, P. Chatzimisios, W. Xiang, and Y. Zhou, ''Heterogeneous vehicular networking: A survey on architecture, challenges, and solutions,'' *IEEE Commun. Surveys Tuts.*, vol. 17, no. 4, pp. 2377–2396, 4th Quart., 2015.

[19] H. Hasrouny, A. E. Samhat, C. Bassil, and A. Laouiti, ''VANet security challenges and solutions: A survey,'' *Veh. Commun.*, vol. 7, pp. 7–20, Jan. 2017.

[20] S. Al-Sultan, M. M. Al-Doori, A. H. Al-Bayatti, and H. Zedan, ''A comprehensive survey on vehicular ad hoc network,'' *J. Netw. Comput. Appl.*, vol. 37, pp. 380–392, Jan. 2014.

[21] L. C. Hua, M. H. Anisi, P. L. Yee, and M. Alam, ''Social networking-based cooperation mechanisms in vehicular ad-hoc network—A survey,'' *Veh. Commun.*, vol. 10, pp. 57–73, Oct. 2017.

[22] H. T. Cheng, H. Shan, and W. Zhuang, ''Infotainment and road safety service support in vehicular networking: From a communication perspective,'' *Mech. Syst. Signal Process.*, vol. 25, no. 6, pp. 2020–2038, Aug. 2011.

[23] I. Achour, T. Bejaoui, and S. Tabbane, ''Network coding approach for vehicle-to-vehicle communication: Principles, protocols and benefits,'' in *Proc. 22nd Int. Conf. Softw., Telecommun. Comput. Netw.*, Sep. 2014, pp. 154–159.

[24] H. S. Basheer and C. Bassil, ''A review of broadcasting safety data in V2V: Weaknesses and requirements,'' *Ad Hoc Netw.*, vol. 65, pp. 13–25, Oct. 2017.

[25] M. S. Kakkasageri and S. S. Manvi, ''Information management in vehicular ad hoc networks: A review,'' *J. Netw. Comput. Appl.*, vol. 39, pp. 334–350, Mar. 2014.

[26] B. Rashid and M. H. Rehmani, ''Applications of wireless sensor networks for urban areas: A survey,'' *J. Netw. Comput. Appl.*, vol. 60, pp. 192–219, Jan. 2016.

[27] K. Lidström, K. Sjöberg, U. Holmberg, J. Andersson, F. Bergh, M. Bjäde, and S. Mak, ''A modular CACC system integration and design,'' *IEEE Trans. Intell. Transp. Syst.*, vol. 13, no. 3, pp. 1050–1061, Sep. 2012.

[28] V. Milanés, L. Alonso, J. Villagrá, J. Godoy, T. de Pedro, and J. P. Oria, ''Traffic jam driving with NMV avoidance,'' *Mech. Syst. Signal Process.*, vol. 31, pp. 332–344, Aug. 2012.

[29] A. Memon, F. K. Shaikh, and E. Felemban, ''Experimental evaluation of vehicle-to-vehicle based data transfer,'' in *Proc. Int. Conf. Inf. Commun. Technol. Res. (ICTRC)*, May 2015, pp. 274–277.

[30] F. Visintainer, L. Altomare, A. Toffetti, A. Kovacs, and A. Amditis, ''Towards manoeuver negotiation: Autonet2030 project from a car maker perspective,'' *Transp. Res. Procedia*, vol. 14, pp. 2237–2244, Jan. 2016.

[31] M. G. Sánchez, M. P. Táboas, and E. L. Cid, "Millimeter wave radio channel characterization for 5G vehicle-to-vehicle communications," *Measurement*, vol. 95, pp. 223–229, Jan. 2017.
[32] Q. Chen, B. Bellows, M. P. Wittie, S. Patterson, and Q. Yang, "MOVESET: MOdular VEhicle SEnsor technology," in *Proc. IEEE Veh. Netw. Conf.*, O. Altintas, E. Ekici, M. Tsai, M. Sepulcre, B. Bloessl, and Y. L. Wei, Eds., Dec. 2016, pp. 1–4.
[33] F. Cardoso, A. Serrador, and T. Canas, "Algorithms for road safety based on GPS and communications systems WAVE," *Procedia Technol.*, vol. 17, pp. 640–649, Jan. 2014.
[34] C. Olaverri-Monreal, P. Gomes, R. Fernandes, F. Vieira, and M. Ferreira, "The see-through system: A VANET-enabled assistant for overtaking maneuvers," in *Proc. IEEE Intell. Vehicles Symp.*, Jun. 2010, pp. 123–128.
[35] S. Medetov, M. Bakhouya, J. Gaber, K. Zinedine, M. Wack, and P. Lorenz, "A decentralized approach for information dissemination in vehicular ad hoc networks," *J. Netw. Comput. Appl.*, vol. 46, pp. 154–165, Nov. 2014.
[36] H. P. Luong, M. Panda, H. L. Vu, and B. Q. Vo, "Beacon rate optimization for vehicular safety applications in highway scenarios," *IEEE Trans. Veh. Technol.*, vol. 67, no. 1, pp. 524–536, Aug. 2017.
[37] A. Saxena, H. Li, D. Goswami, and C. B. Math, "Design and analysis of control strategies for vehicle platooning," in *Proc. IEEE 19th Int. Conf. Intell. Transp. Syst.*, Nov. 2016, pp. 1805–1812.
[38] M. Ren, L. Khoukhi, H. Labiod, J. Zhang, and V. Véque, "A mobility-based scheme for dynamic clustering in vehicular ad-hoc networks (VANETs)," *Veh. Commun.*, vol. 9, pp. 233–241, Jul. 2017.
[39] Y. Allouche and M. Segal, "Cluster-based beaconing process for VANET," *Veh. Commun.*, vol. 2, no. 2, pp. 80–94, Apr. 2015.
[40] B. Jain, G. Brar, J. Malhotra, S. Rani, and S. H. Ahmed, "A cross layer protocol for traffic management in social Internet of vehicles," *Future Gener. Comput. Syst.*, vol. 82, pp. 707–714, May 2018.
[41] B. Brik, N. Lagraa, A. Lakas, and A. Cheddad, "DDGP: Distributed data gathering protocol for vehicular networks," *Veh. Commun.*, vol. 4, pp. 15–29, Apr. 2016.
[42] B. Jarupan and E. Ekici, "PROMPT: A cross-layer position-based communication protocol for delay-aware vehicular access networks," *Ad Hoc Netw.*, vol. 8, no. 5, pp. 489–505, Jul. 2010.
[43] A. Choudhury, T. Maszczyk, C. B. Math, H. Li, and J. Dauwels, "An integrated simulation environment for testing V2X protocols and applications," *Procedia Comput. Sci.*, vol. 80, pp. 2042–2052, Jan. 2016.
[44] A. Grzybek, G. Danoy, P. Bouvry, and M. Seredynski, "Mitigating flash crowd effect using connected vehicle technology," *Veh. Commun.*, vol. 2, no. 4, pp. 238–250, Oct. 2015.
[45] S. Allani, T. Yeferny, and R. Chbeir, "A scalable data dissemination protocol based on vehicles trajectories analysis," *Ad Hoc Netw.*, vol. 71, pp. 31–44, Mar. 2018.
[46] A. Wahid, M. A. Shah, F. F. Qureshi, H. Maryam, R. Iqbal, and V. Chang, "Big data analytics for mitigating broadcast storm in vehicular content centric networks," *Future Gener. Comput. Syst.*, vol. 86, pp. 1301–1320, Sep. 2017.
[47] S. Gong, J. Shen, and L. Du, "Constrained optimization and distributed computation based car following control of a connected and autonomous vehicle platoon," *Transp. Res. B, Methodol.*, vol. 94, pp. 314–334, Dec. 2016.
[48] A. M. Orozco, S. Céspedes, R. Michoud, and G. Llano, "Design and simulation of a collision notification application with geocast routing for car-to-car communications," *Eur. Transp. Res. Rev.*, vol. 7, no. 4, Dec. 2015, Art. no. 36.
[49] C. Song, J. Wu, M. Liu, and H. Zheng, "Efficient routing through discretization of overlapped road segments in VANETs," *J. Parallel Distrib. Comput.*, vol. 102, pp. 57–70, Apr. 2017.
[50] P. Salvo, I. Turcanu, F. Cuomo, A. Baiocchi, and I. Rubin, "Heterogeneous cellular and DSRC networking for floating car data collection in urban areas," *Veh. Commun.*, vol. 8, pp. 21–34, Apr. 2017.
[51] F. Yu and S. Biswas, "Self-configuring TDMA protocols for enhancing vehicle safety with DSRC based vehicle-to-vehicle communications," *IEEE J. Sel. Areas Commun.*, vol. 25, no. 8, pp. 1526–1537, Oct. 2007.
[52] M. Y. Abualhoul, M. Marouf, O. Shagdar, and F. Nashashibi, "Platooning control using visible light communications: A feasibility study," in *Proc. 16th Int. IEEE Conf. Intell. Transp. Syst. (ITSC)*, Oct. 2013, pp. 1535–1540.
[53] B. Zardosht, S. S. Beauchemin, and M. A. Bauer, "A predictive accident-duration based decision-making module for rerouting in environments with V2V communication," *J. Traffic Transp. Eng.*, vol. 4, no. 6, pp. 535–544, Dec. 2017.
[54] F. Jiménez, J. E. Naranjo, J. J. Anaya, F. García, A. Ponz, and J. M. Armingol, "Advanced driver assistance system for road environments to improve safety and efficiency," *Transp. Res. Procedia*, vol. 14, pp. 2245–2254, Jan. 2016.
[55] M. I. Ashraf, C.-F. Liu, M. Bennis, and W. Saad, "Towards low-latency and ultra-reliable vehicle-to-vehicle communication," in *Proc. Eur. Conf. Netw. Commun. (EuCNC)*, Jun. 2017, pp. 1–5.
[56] P. Gora and I. Rüb, "Traffic models for self-driving connected cars," *Transp. Res. Procedia*, vol. 14, pp. 2207–2216, Apr. 2016.
[57] M. S. Rayeni, A. Hafid, and P. K. Sahu, "Dynamic spatial partition density-based emergency message dissemination in VANETs," *Veh. Commun.*, vol. 2, no. 4, pp. 208–222, Oct. 2015.
[58] B. Singh, M. Y. Nayan, H. Hasbullah, and B. Tahlan, "Early detection of incident using vehicular ad-hoc network," in *Proc. Int. Conf. Comput. Inf. Sci.*, Jun. 2014, pp. 1–6.
[59] J. R. Ward, G. Agamennoni, S. Worrall, A. Bender, and E. Nebot, "Extending time to collision for probabilistic reasoning in general traffic scenarios," *Transp. Res. C, Emerg. Technol.*, vol. 51, pp. 66–82, Feb. 2015.
[60] A. Ltifi, A. Zouinkhi, and M. S. Bouhlel, "Trust-based scheme for alert spreading in VANET," *Procedia Comput. Sci.*, vol. 73, pp. 282–289, Jan. 2015.
[61] A. Petrillo, A. Salvi, S. Santini, and A. S. Valente, "Adaptive multi-agents synchronization for collaborative driving of autonomous vehicles with multiple communication delays," *Transp. Res. C, Emerg. Technol.*, vol. 86, pp. 372–392, Jan. 2018.
[62] S. Zhang, Y. Wu, and Y. Wang, "An embedded node operating system for real-time information interaction in vehicle-to-vehicle communication," in *Proc. IEEE 19th Int. Conf. Intell. Transp. Syst.*, Nov. 2016, pp. 887–892.
[63] Z. Zhou, H. Yu, C. Xu, F. Xiong, Y. Jia, and G. Li, "Joint relay selection and spectrum allocation in D2D-based cooperative vehicular networks," in *Proc. Int. Conf. Inf. Commun. Technol. Converg. (ICTC)*, Oct. 2017, pp. 241–246.
[64] D. Jia and D. Ngoduy, "Enhanced cooperative car-following traffic model with the combination of V2V and V2I communication," *Transp. Res. B, Methodol.*, vol. 90, pp. 172–191, Aug. 2016.
[65] M. Guériau, R. Billot, N.-E. El Faouzi, J. Monteil, F. Armetta, and S. Hassas, "How to assess the benefits of connected vehicles? A simulation framework for the design of cooperative traffic management strategies," *Transp. Res. C, Emerg. Technol.*, vol. 67, pp. 266–279, Jun. 2016.
[66] A. Sassi, Y. Elhillali, and F. Charfi, "Evaluating experimental measurements of the IEEE 802.11p communication using ARADA LocoMate OBU device compared to the theoretical simulation results," *Wireless Pers. Commun.*, vol. 97, no. 3, pp. 3861–3874, Dec. 2017.
[67] Y. Agarwal, K. Jain, and O. Karabasoglu, "Smart vehicle monitoring and assistance using cloud computing in vehicular ad hoc networks," *Int. J. Transp. Sci. Technol.*, vol. 7, no. 1, pp. 60–73, 2017.
[68] M. Sepulcre, J. Gozalvez, and B. Coll-Perales, "Why 6 Mbps is not (always) the optimum data rate for beaconing in vehicular networks," *IEEE Trans. Mobile Comput.*, vol. 16, no. 12, pp. 3568–3579, Apr. 2017.
[69] S. Naumann, F. Wolf, and R. Schönrock, "Floating Car Observer—An innovative vehicle-sensor for urban and highway scenarios," *IFAC Proc. Volumes*, vol. 43, no. 23, pp. 19–24, 2010.
[70] Y. Agarwal, K. Jain, S. Kumar, and G. N. Bhardwaj, "TLST: Time of arrival based localization and smart tunnel concept in VANETs," in *Proc. 3rd Int. Conf. Signal Process. Integr. Netw.*, Feb. 2016, pp. 763–768.
[71] B. R. Chang, H. F. Tsai, and C.-P. Young, "Intelligent data fusion system for predicting vehicle collision warning using vision/GPS sensing," *Expert Syst. Appl.*, vol. 37, no. 3, pp. 2439–2450, Mar. 2010.
[72] M. I. Sanchez, M. Gramaglia, C. J. Bernardos, A. de la Oliva, and M. Calderon, "On the implementation, deployment and evaluation of a networking protocol for VANETs: The VARON case," *Ad Hoc Netw.*, vol. 19, pp. 9–27, Aug. 2014.
[73] V. Jindal and P. Bedi, "Reducing waiting time with parallel preemptive algorithm in VANETs," *Veh. Commun.*, vol. 7, pp. 58–65, Jan. 2017.
[74] H. Tchouankem, "Characterization of intersection topologies in urban areas for vehicle-to-vehicle communication," in *Proc. IEEE 84th Veh. Technol. Conf. (VTC-Fall)*, Sep. 2016, pp. 1–5.

[75] A. Gibaud and P. Thomin, "Message forwarding based on vehicle trajectory history in fully distributed traffic information systems," *Comput. Commun.*, vol. 60, pp. 40–52, Apr. 2015.
[76] M. Srotyr, T. Zelinka, and Z. Lokaj, "Hybrid communication solution for C-ITS and its evaluation," in *Proc. Smart City Symp. Prague (SCSP)*, May 2017, pp. 1–7.
[77] K. Golestan, F. Sattar, F. Karray, M. Kamel, and S. Seifzadeh, "Localization in vehicular ad hoc networks using data fusion and V2V communication," *Comput. Commun.*, vol. 71, pp. 61–72, Nov. 2015.
[78] H. Tchouankem and T. Lorenzen, "Measurement-based evaluation of interference in vehicular ad-hoc networks at urban intersections," in *Proc. IEEE Int. Conf. Commun. Workshop (ICCW)*, Jun. 2015, pp. 2381–2386.
[79] G. Yan and D. B. Rawat, "Vehicle-to-vehicle connectivity analysis for vehicular ad-hoc networks," *Ad Hoc Netw.*, vol. 58, pp. 25–35, Apr. 2017.
[80] P. Karadimas and D. Matolak, "Generic stochastic modeling of vehicle-to-vehicle wireless channels," *Veh. Commun.*, vol. 1, no. 4, pp. 153–167, Oct. 2014.
[81] A. Tang and A. Yip, "Collision avoidance timing analysis of DSRC-based vehicles," *Accident Anal. Prevention*, vol. 42, no. 1, pp. 182–195, Jan. 2010.
[82] Y. Wang, Y. Zhang, J. Hu, and X. Pei, "An analysis on stochastic broadcast range in VANET based on generalized packet loss model," in *Proc. IEEE 18th Int. Conf. Intell. Transp. Syst.*, Sep. 2015, pp. 1055–1060.
[83] H. Gong, K. He, Y. Qu, and P. Wang, "Analysis and improvement of vehicle information sharing networks," *Phys. A, Stat. Mech. Appl.*, vol. 452, pp. 106–112, Jun. 2016.
[84] M. El-Said, V. Bhuse, and A. Arendsen, "An empirical study to investigate the effect of air density changes on the DSRC performance," *Procedia Comput. Sci.*, vol. 114, pp. 523–530, Jan. 2017.
[85] J. Santa, R. Toledo-Moreo, M. A. Zamora-Izquierdo, B. Úbeda, and A. F. Gómez-Skarmeta, "An analysis of communication and navigation issues in collision avoidance support systems," *Transp. Res. C, Emerg. Technol.*, vol. 18, no. 3, pp. 351–366, Jun. 2010.
[86] A. Baiocchi, "Analysis of timer-based message dissemination protocols for inter-vehicle communications," *Transp. Res. B, Methodol.*, vol. 90, pp. 105–134, Aug. 2016.
[87] A. M. Said, M. Marot, A. W. Ibrahim, and H. Afifi, "Modeling interactive real-time applications in VANETs with performance evaluation," *Comput. Netw.*, vol. 104, pp. 66–78, Jul. 2016.
[88] M. R. Jabbarpour, A. Marefat, A. Jalooli, R. M. Noor, R. H. Khokhar, and J. Lloret, "Performance analysis of V2V dynamic anchor position-based routing protocols," *Wireless Netw.*, vol. 21, no. 3, pp. 911–929, Apr. 2015.
[89] J. Ahrems, "Appraisal of feasibility of using vehicle-to-vehicle communications for safe passage of unsignalled road intersection under varying conditions," *IFAC Proc.*, vol. 46, no. 28, pp. 84–89, 2013.
[90] H. Su, C.-H. Cho, Y.-H. Chu, and W.-Y. Chang, "A traffic information dissemination mechanism based on DSRC/WAVE and its applications," in *Proc. 12th Int. Conf. Telecommun.*, Nov. 2012, pp. 635–638.
[91] S. Carrese, E. Cipriani, L. Mannini, and M. Nigro, "Dynamic demand estimation and prediction for traffic urban networks adopting new data sources," *Transp. Res. C, Emerg. Technol.*, vol. 81, pp. 83–98, Aug. 2017.
[92] N. Motamedidehkordi, M. Margreiter, and T. Benz, "Shockwave suppression by vehicle-to-vehicle communication," *Transp. Res. Procedia*, vol. 15, pp. 471–482, Jan. 2016.
[93] J. Liu, B. Cai, Y. Wang, and J. Wang, "A lane level positioning-based cooperative vehicle conflict resolution algorithm for unsignalized intersection collisions," *Comput. Electr. Eng.*, vol. 39, no. 5, pp. 1381–1398, Jul. 2013.
[94] T.-Y. Wu, N. Guizani, and C.-Y. Hsieh, "An efficient adaptive intelligent routing system for multi-intersections," *Wireless Commun. Mobile Comput.*, vol. 16, no. 17, pp. 3175–3186, Dec. 2016.
[95] D. Perez-Diaz de Cerio and J. L. Valenzuela, "Provisioning vehicular services and communications based on a Bluetooth sensor network deployment," *Sensors*, vol. 15, no. 6, pp. 12765–12781, Jun. 2015.
[96] B. Glas, O. Sander, V. Stuckert, K. D. Müller-Glaser, and J. Becker, "Car-to-car communication security on reconfigurable hardware," in *Proc. IEEE Veh. Technol. Conf.*, Apr. 2009, pp. 1–5.
[97] M. B. Farah, D. Mercier, F. Delmotte, and É. Lefèvre, "Methods using belief functions to manage imperfect information concerning events on the road in VANETs," *Transp. Res. C, Emerg. Technol.*, vol. 67, pp. 299–320, Jun. 2016.
[98] J. Toutouh and E. Alba, "Light commodity devices for building vehicular ad hoc networks: An experimental study," *Ad Hoc Netw.*, vol. 37, no. 1, pp. 499–511, Feb. 2016.
[99] M.-A. Lebre, F. Le Mouel, and E. Menard, "Resilient, decentralized V2V online stop-free strategy in a complex roundabout," in *Proc. IEEE 83rd Veh. Technol. Conf.*, May 2016, pp. 1–5.
[100] Z. He and D. Zhang, "Cost-efficient traffic-aware data collection protocol in VANET," *Ad Hoc Netw.*, vol. 55, pp. 28–39, Feb. 2017.
[101] A. Sassi, F. Charfi, L. Kamoun, Y. Elhillali, and A. Rivenq, "The impact of mobility on the performance of V2X communication," in *Proc. 4th Int. Conf. Logistics*, May/Jun. 2011, pp. 434–438.
[102] L. Kristiana, C. Schmitt, and B. Stiller, "A filtering concept for improving the angle-based forwarding scheme in vehicular ad-hoc network communications," in *Proc. 22nd Asia–Pacific Conf. Commun. (APCC)*, Aug. 2016, pp. 545–551.
[103] B. C. Dhas and P. P. E. Winston, "Efficient vehicular communication using random access channels in UMTS based network," in *Proc. Int. Conf. Electron. Commun. Syst.*, Feb. 2014, pp. 1–4.
[104] S. Pagadarai, B. A. Lessard, A. M. Wyglinski, R. Vuyyuru, and O. Altintas, "Vehicular communication: Enhanced networking through dynamic spectrum access," *IEEE Veh. Technol. Mag.*, vol. 8, no. 3, pp. 93–103, Sep. 2013.
[105] L. Du, L. Han, and X.-Y. Li, "Distributed coordinated in-vehicle online routing using mixed-strategy congestion game," *Transp. Res. B, Methodol.*, vol. 67, pp. 1–17, Sep. 2014.
[106] B. Baron, M. Campista, P. Spathis, L. H. M. K. Costa, M. D. de Amorim, O. C. M. B. Duarte, G. Pujolle, and Y. Viniotis, "Virtualizing vehicular node resources: Feasibility study of virtual machine migration," *Veh. Commun.*, vol. 4, pp. 39–46, Apr. 2016.
[107] F. Bounini, D. Gingras, H. Pollart, and D. Gruyer, "Real time cooperative localization for autonomous vehicles," in *Proc. IEEE 19th Int. Conf. Intell. Transp. Syst. (ITSC)*, Nov. 2016, pp. 1186–1191.
[108] G.-M. Hoang, B. Denis, J. Härri, and D. T. M. Slock, "Robust data fusion for cooperative vehicular localization in tunnels," in *Proc. IEEE Intell. Vehicles Symp. (IV)*, Jun. 2017, pp. 1372–1377.
[109] A. Bazzi, B. M. Masini, A. Zanella, and A. Calisti, "Visible light communications as a complementary technology for the Internet of vehicles," *Comput. Commun.*, vol. 93, pp. 39–51, Nov. 2016.
[110] Z. Zhou, C. Gao, C. Xu, Y. Zhang, and D. Zhang, "Reliable content dissemination in Internet of vehicles using social big data," in *Proc. IEEE Global Commun. Conf. (GLOBECOM)*, Dec. 2017, pp. 1–6.
[111] D. B. Rawat, C. Bajracharya, and G. Yan, "Towards intelligent transportation cyber-physical systems: Real-time computing and communications perspectives," in *Proc. SoutheastCon*, Apr. 2015, pp. 1–6.
[112] M. Barradi, A. S. Hafid, and S. Aljahdali, "Highway multihop broadcast protocols for vehicular networks," in *Proc. IEEE Int. Conf. Commun.*, Jun. 2012, pp. 5296–5300.
[113] T. Petrov, M. Dado, K. E. Ambrosch, and P. Holečko, "Experimental topology for V2V communication based on Internet of Things," in *Proc. 11th Int. Conf. Elektro*, May 2016, pp. 72–76.
[114] B. Soret, M. G. Sarret, I. Z. Kovacs, F. J. Martin-Vega, G. Berardinelli, and N. H. Mahmood, "Radio resource management for V2V discovery," in *Proc. IEEE 85th Veh. Technol. Conf. (VTC Spring)*, Jun. 2017, pp. 1–6.
[115] Z. Wu, J. Yang, and L. Huang, "Study on the collision avoidance strategy at unsignalized intersection based on prescan simulation," *Procedia Social Behav. Sci.*, vol. 96, pp. 1315–1321, Nov. 2013.
[116] O. Shagdar and P. Muhlethaler, "Study on merging control supported by IEEE 802.11p systems for highway environments," in *Proc. IFIP Wireless Days*, Nov. 2013, pp. 1–4.
[117] F. A. Teixeira, V. F. Silva, J. L. Leoni, D. F. Macedo, and J. M. S. Nogueira, "Vehicular networks using the IEEE 802.11p standard: An experimental analysis," *Veh. Commun.*, vol. 1, no. 2, pp. 91–96, Apr. 2014.
[118] T. Acarman, C. Yaman, Y. Peksen, and A. U. Peker, "Intersection based routing in urban VANETs," in *Proc. IEEE 18th Int. Conf. Intell. Transp. Syst. (ITSC)*, Sep. 2015, pp. 1087–1092.
[119] A. Olia, H. Abdelgawad, B. Abdulhai, and S. N. Razavi, "Assessing the potential impacts of connected vehicles: Mobility, environmental, and safety perspectives," *J. Intell. Transp. Syst.*, vol. 20, no. 3, pp. 229–243, 2016.
[120] M. Amadeo, C. Campolo, and A. Molinaro, "Enhancing IEEE 802.11p/WAVE to provide infotainment applications in VANETs," *Ad Hoc Netw.*, vol. 10, no. 2, pp. 253–269, Mar. 2012.
[121] A. Mukhopadhyay, S. Raghunath, and M. Kruti, "Feasibility and performance evaluation of VANET techniques to enhance real-time emergency healthcare services," in *Proc. Int. Conf. Adv. Comput., Commun. Inform. (ICACCI)*, Sep. 2016, pp. 2597–2603.

[122] Y. Lu, Q. Cui, Y. Hou, Z. Gao, and B. Zhang, "Graph-based time-critical cooperative data exchange in V2V via network coding strategy," in *Proc. IEEE 18th Int. Workshop Signal Process. Adv. Wireless Commun. (SPAWC)*, Jul. 2017, pp. 1–5.
[123] S. Szigeti, C. Csiszár, and D. Földes, "Information management of demand-responsive mobility service based on autonomous vehicles," *Procedia Eng.*, vol. 187, pp. 483–491, Jan. 2017.
[124] C. Qu, D. A. Ulybyshev, B. K. Bhargava, R. Ranchal, and L. T. Lilien, "Secure dissemination of video data in vehicle-to-vehicle systems," in *Proc. IEEE 34th Symp. Reliable Distrib. Syst. Workshop*, Sep./Oct. 2015, pp. 47–51.
[125] C. A. Kerrache, N. Lagraa, C. T. Calafate, and A. Lakas, "TFDD: A trust-based framework for reliable data delivery and DoS defense in VANETs," *Veh. Commun.*, vol. 9, pp. 254–267, Jul. 2017.
[126] S. Sousa, A. Santos, A. Costa, B. Dias, B. Ribeiro, F. Gonçalves, J. Macedo, M. J. Nicolau, and Ó. Gama, "A new approach on communications architectures for intelligent transportation systems," *Procedia Comput. Sci.*, vol. 110, pp. 320–327, Jan. 2017.
[127] W. Alghamdi, E. Shakshuki, and T. R. Sheltami, "Context-aware driver assistance system," *Procedia Comput. Sci.*, vol. 10, pp. 785–794, Jan. 2012.
[128] A. J. Ghandour, K. Fawaz, H. Artail, M. Di Felice, and L. Bononi, "Improving vehicular safety message delivery through the implementation of a cognitive vehicular network," *Ad Hoc Netw. J.*, vol. 11, no. 8, pp. 2408–2422, Nov. 2013.
[129] N. Varga, L. Bokor, A. Takács, J. Kovács, and L. Virág, "An architecture proposal for V2X communication-centric traffic light controller systems," in *Proc. 15th Int. Conf. ITS Telecommun. (ITST)*, May 2017, pp. 1–7.
[130] C. A. Kerrache, N. Lagraa, C. T. Calafate, J. C. Cano, and P. Manzoni, "T-VNets: A novel trust architecture for vehicular networks using the standardized messaging services of ETSI ITS," *Comput. Commun.*, vol. 93, pp. 68–83, Nov. 2016.
[131] A. Baiocchi, F. Cuomo, M. De Felice, and G. Fusco, "Vehicular ad-hoc networks sampling protocols for traffic monitoring and incident detection in intelligent transportation systems," *Transp. Res. C, Emerg. Technol.*, vol. 56, pp. 177–194, Jul. 2015.
[132] Z. Li and M. Shahidehpour, "Deployment of cybersecurity for managing traffic efficiency and safety in smart cities," *Electr. J.*, vol. 30, no. 4, pp. 52–61, May 2017.
[133] N. Salameh, G. Challita, S. Mousset, A. Bensrhair, and S. Ramaswamy, "Collaborative positioning and embedded multi-sensors fusion cooperation in advanced driver assistance system," *Transp. Res. C, Emerg. Technol.*, vol. 29, pp. 197–213, Apr. 2013.
[134] M. Hübner, T. Lück, and E. Schnieder, "Cooperative control of multi-vehicle-formations in road traffic by means of consensus algorithm and Petri nets," *IFAC Proc.*, vol. 42, no. 15, pp. 328–333, 2009.
[135] M. Aramrattana, T. Larsson, J. Jansson, and A. Nåbo, "A simulation framework for cooperative intelligent transport systems testing and evaluation," *Transp. Res. F, Traffic Psychol. Behav.*, vol. 61, pp. 268–280, Feb. 2017.
[136] S. K. Choi, "An ontological model to support communications of situation-aware vehicles," *Transp. Res. C, Emerg. Technol.*, vol. 53, pp. 112–133, Apr. 2015.
[137] B. HomChaudhuri, R. Lin, and P. Pisu, "Hierarchical control strategies for energy management of connected hybrid electric vehicles in urban roads," *Transp. Res. C, Emerg. Technol.*, vol. 62, pp. 70–86, Jan. 2016.
[138] L. Lucien, C. Lang, N. Marilleau, and L. Philippe, "Multiagent hybrid architecture for collaborative exchanges between communicating vehicles in an urban context," *Procedia Comput. Sci.*, vol. 83, pp. 695–699, Jan. 2016.
[139] W. Balzano, A. Murano, and F. Vitale, "V2V-EN—Vehicle-2-vehicle elastic network," *Procedia Comput. Sci.*, vol. 98, pp. 497–502, Jan. 2016.
[140] S. H. Lee, S. Lee, and M. H. Kim, "Development of a driving behavior-based collision warning system using a neural network," *Int. J. Automot. Technol.*, vol. 19, no. 5, pp. 837–844, Oct. 2018.
[141] O. Bagdadi and A. Várhelyi, "Jerky driving—An indicator of accident proneness?" *Accident Anal. Prevention*, vol. 43, no. 4, pp. 1359–1363, Jul. 2011.
[142] S. G. Klauer, T. A. Dingus, V. L. Neale, J. D. Sudweeks, and D. J. Ramsey, "The impact of driver inattention on near-crash/crash risk: An analysis using the 100-car naturalistic driving study data," U.S. Dept. Transp., Nat. Highway Traffic Saf. Admin., Washington, DC, USA, Tech. Rep. DOT HS 810 594, Apr. 2006.
[143] M. G. Jasinski and F. Baldo, "A method to identify aggressive driver behaviour based on enriched GPS data analysis," presented at the GEO Process., 9th Int. Conf. Adv. Geograph. Inf. Syst., Appl., Services, 2017.
[144] S. Latif, S. Mahfooz, B. Jan, N. Ahmad, H. Farman, M. Khan, and H. Javed, "Multicriteria based next forwarder selection for data dissemination in vehicular ad hoc networks using analytical network process," *Math. Problems Eng.*, vol. 2017, Oct. 2017, Art. no. 4671892. [Online]. Available: https://www.hindawi.com/journals/mpe/2017/4671892/

HUSSEIN ALI AMEEN received the B.Eng. degree (Hons.) and the M.Sc. degree from Al-Nahrain University, Baghdad, Iraq, in 2011 and 2015, respectively, all in computer engineering. He is currently pursuing the Ph.D. degree in computer engineering with University Tun Hussein Onn Malaysia, Parit Raja, Johor, Malaysia. His research interests include RFID, computer networks, wireless communications, and vehicle to vehicle (V2V) communication systems.

ABD KADIR MAHAMAD received the B.S. and master's degree from University Tun Hussein Onn Malaysia, in 2002 and 2005, respectively, all in electrical engineering, and the D.Phil. degree in computer science and electrical engineering from Kumamoto University, Japan, in 2010. He is currently an Associate Professor with the Faculty of Electrical and Electronic Engineering, UTHM, and registered as a Professional Engineer. His research interests include deep learning, smart city, intelligent system applications, and embedded systems. He is also a member of the Institute of Engineering Malaysia (IEM) and the Board of Engineering Malaysia (BEM).

BILAL BAHAA ZAIDAN received the B.Sc. degree in applied mathematics from Al-Nahrain University, Baghdad, Iraq, in 2004, the M.Sc. degree in data communications and information security from the University of Malaya, Malaysia, in 2009. He is currently a Senior Lecturer with the Department of computing, University Pendidikan Sultan Idris. He led or member for many funded research projects. He has published more than 150 articles at various international conferences and journals. His research interests include data communication and networks, ad-hoc networks, and vehicle-to-vehicle.

AWS ALAA ZAIDAN received the B.Eng. degree (Hons.) in computer engineering from the University of Technology, Baghdad, Iraq, in 2004, the M.Sc. degree in data communications and computer network from the University of Malaya, Malaysia, in 2009, and the Ph.D. degree in artificial intelligence from Multimedia University, Malaysia, in 2013. He is currently a Senior Lecturer with the Department of Computing, University Pendidikan Sultan Idris. He led or member for many funded research projects. He has published more than 150 articles at various international conferences and journals. His research interests include data communication and networks, ad-hoc networks, and vehicle-to-vehicle.

SHARIFAH SAON received the B.S. and master's degrees from Universiti Teknologi Malaysia and Kolej Universiti Tun Hussein Onn Malaysia, Malaysia, in 2001, and 2004, respectively, all in electrical engineering. She is currently a Senior Lecturer with the Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia, and registered professional technologies. Her research interests include theoretical digital signal processing, visible light communication, digital and data communication, application to Internet of Things (IoT), and bigdata analysis.

DANIAL MD NOR received the B.Tech. degree in electrical engineering with education from the University of Technology Malaysia (UTM), Malaysia, in 1998, the M.Sc. degree in information technology from the University of Science Malaysia (USM), Penang, Malaysia, in 2001, and the Ph.D. degree from the Electrical joint Ph.D. programme between the University of La Rochelle (ULR), France, and University Tun Hussein Onn Malaysia (UTHM), Malaysia, in July 2016. In 2002, he joined the Department of Electrical Engineering Technology, UTHM, as a Lecturer, and a Senior Lecturer, in 2009. Since December 2004, he has been with the Department of Computer Engineering, UTHM. He was a recipient of the Technical Teacher Certificate (Electrical) from MPTKL, in 1991.

RAMI QAYS MALIK received the B.S. degree in communication engineering from Al-Furat Al-Awsat Technical University/Engineering Technical College of Al-Najaf, in 2011, and the M.S. degree in electronic and communication engineering from the Sam Higginbottom Institute of Agriculture, Technology and Sciences (SHIATS), Allahabad, India, in 2014, where he is currently pursuing the Ph.D. degree in communication engineering with University Tun Hussein Onn Malaysia, Parit Raja, Johor, Malaysia. His research interests include data communication and networks, ad-hoc networks, and vehicle-to-infrastructure.

ZAHRAA HASHIM KAREEM received the B.S. degree in electrical engineering and the M.S. degree in electronic and communication engineering from Babylon University, Hillah, Iraq, in 2012 and 2016, respectively, where she is currently pursuing the Ph.D. degree in communication engineering with University Tun Hussein Onn Malaysia, Parit Raja, Johor, Malaysia. Her research interests include data communication and networks, ad-hoc networks, and vehicle-to-pedestrian communication.

SALEM GARFAN received the B.Sc. degree in software engineering with multimedia and the M.Sc. degree in software management from the Limkokwing University of Creative Technology, Cyberjaya, Malaysia, in 2015 and 2017, respectively. He is currently pursuing the D.Phil. (Ph.D.) degree with Universiti Pendidikan Sultan Idris (UPSI), Tanjung Malim, Malaysia. His research interests include driver behavior analysis, artificial intelligence, and machine learning.

RUQAYAH ALAA ZAIDAN received the B.IT. degree in networking and data communication from IUKL University, Malaysia, in 2014. She is currently pursuing the master's degree in computer and M.Ph. degree in artificial intelligent with University Pendidikan Sultan Idris (UPSI), Tanjong, Malim, Malaysia. Her research interests include AI and driver behavior analysis.

ALI MOHAMMED received the B.Eng. degree (Hons.) from Al-Mustansiriya University, Baghdad, Iraq, in 2013, and the M.Sc. degree from the International University of Malaysia (UKM), Malaysia, in 2016, all in civil engineering. He is currently pursuing the Ph.D. degree in civil engineering with the International University of Malaysia (UKM), Malaysia. His research interest includes driver behavior analysis.