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A comprehensive survey on data dissemination in Vehicular Ad Hoc Networks

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ABSTRACT

Vehicular Ad Hoc Networks (VANET) are self-organized wireless network for Intelligent Transportation Systems (ITS) that allow vehicles to collaborate with each other, to improve driving efficiency and enhance traffic safety without centralized infrastructure. Vehicles are equipped with sensors, global positioning systems (GPS) and communication systems to perform the tasks related to safety, efficiency, and comfort on the road. Data dissemination strategies in VANET help in improving safety, efficiency and comfort by reducing the delivery delay time and ensuring the reliability of message delivery. The available literature papers contain a number of proposed techniques for data dissemination in VANET. This paper presents a systematic literature review for existing data dissemination techniques in VANET in the viewpoint of the data related characteristics and applications such as safety and infotainment. The motivation behind this work is to provide the audience with the required understanding of the data dissemination in VANET, highlight potential opportunities and challenges, and also investigate the recent studies available in reputed resources directed towards the domain of data dissemination in VANET. Especially, this paper provides the audience with a comparative analysis of delay-tolerant and delay-sensitive data dissemination in VANET.

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1. Introduction

The evolution of Vehicular Ad Hoc Networks (VANET) influences a great deal for improving the Intelligent Transportation Systems (ITS). Vehicles are equipped with sensors, global positioning systems (GPS), and communication capabilities that make transportation more secure and efficient, and also passengers and drivers get convenient infotainment services [1]. VANET consists of a large number of vehicles that cooperatively communicate with each other for information exchange. This cooperation of vehicles helps the improvement of traffic safety [2,3]. Vehicles, which gather information from sensors and detect accidents or hurdles on their paths, disseminate warning messages to their neighboring vehicles to prevent further accident risk [4]. Traffic and road information sharing, such as cooperative collision warning [5], pre-crash warning, speed warning, lane change warning [6], traffic signal violation warning [7], accident prevention [8], road obstacle detection [9], traffic jam notifications, accidents notifications, and possible detour guidance [10], increases safety in transportation infrastructure. These warning messages are also important to make the rescue process faster and more effective [11].

Data dissemination in VANET is carried out via vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), or infrastructure-to-vehicle (I2V) communications, as shown in Fig. 1. In this figure, V2V, V2I, and I2V communications within the range of communication of Road-Side Unit (RSU) and Base Station (BS) are represented by different line types and colors. Modern vehicles equipped with hundreds of sensors that are generating a massive amount of data. The data needs to be collected and appropriately analyzed for various innovative and smart traffic management applications [12,13]. These sensors also need to communicate among themselves and this communication is carried out through Bluetooth, ZigBee, radio-frequency identification (RFID), ultra-wide band (UWB), and millimeter wave. IEEE has standardized a suite

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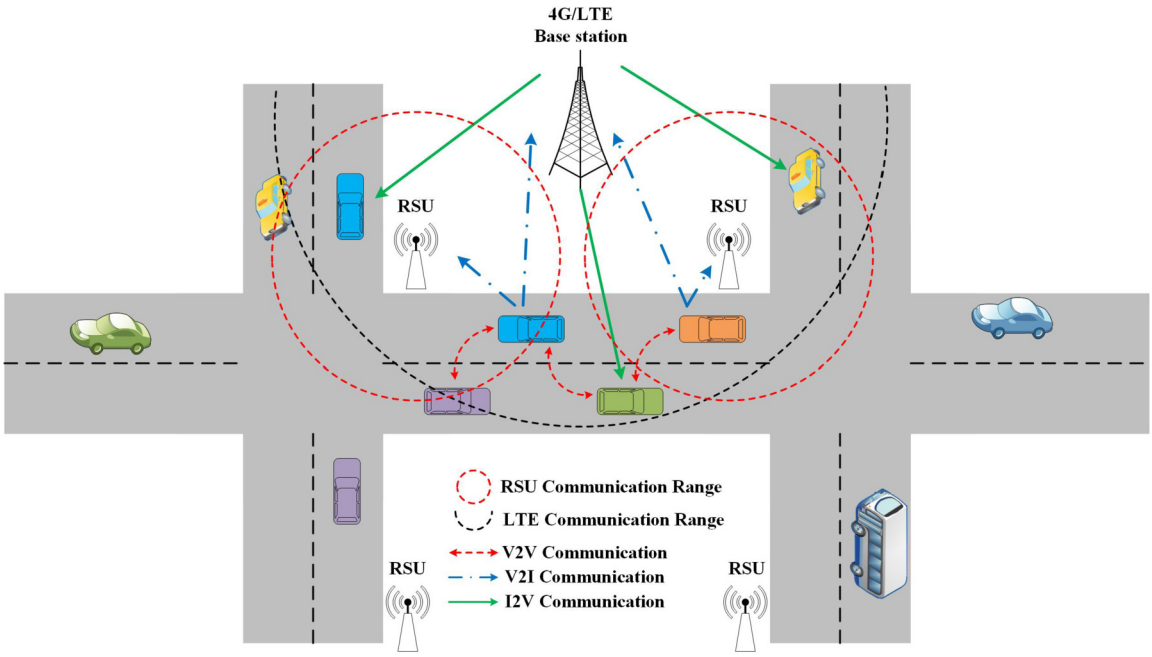

Fig. 1. A general illustration of a vehicular network architecture.

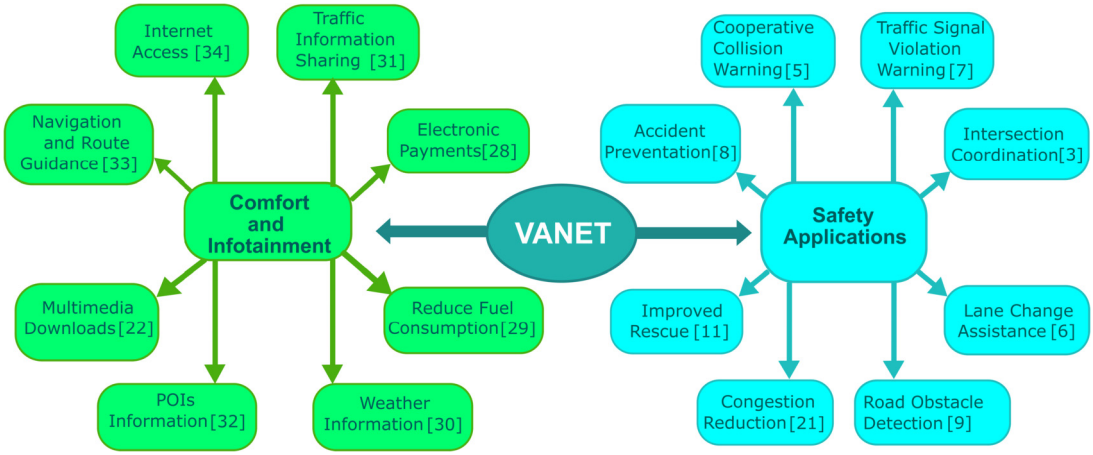

Fig. 2. Taxonomy for VANET applications (safety, comfort, and infotainment).

of Wireless Access in Vehicular Environments (WAVE) for Dedicated Short-Range Communication (DSRC) for vehicles in VANET [14–16]. DSRC supports wireless communication among vehicles or from vehicles to infrastructure with a short delay. As inter-vehicle connectivity, data collected by sensors in a vehicle are disseminated to other vehicles for driving safety through DSRC.

There are numerous applications of VANET that are mainly categorized into two types i.e., (i) Safety applications and (ii) Comfort and infotainment applications. Fig. 2 shows the major two types of VANET applications which are further categorized as a taxonomy into many specific types. In VANET, safety applications are widely recognized to considerably lower the rate of transportation accidents [17–19]. For example, in a traffic signal violation warning case, a vehicle takes an advantage of the warning traffic signal violation for safe driving. A warning message is sent to the relevant neighboring vehicles on the basis of vehicle speed and traffic signal timing. Vehicles moving towards an intersection are informed of a dangerous situation to prevent any further accident. Lane change assistance [20], road obstacle detection, and congestion reduction [21], can also utilize such a warning message to be disseminated timely to the relevant vehicles.

For crash prevention application, VANET should be designed in such a way that it warns the drivers of a possible accident. Vehicles in cooperation with a Road-Side Unit (RSU) share information of an already occurred accident with other vehicles that are coming towards the accident area to prevent further accidents. For autonomous vehicles, applying a brake of a vehicle on time or changing its lane are performed after getting a timely pre-crash warning. In cooperative collision warning, vehicles and an RSU cooperate with each other to detect the probability of collisions among vehicles. All the information is collected and shared among vehicles and an RSU, and is further disseminated to the vehicles that are supposed to have a collision in a blinded or curved point. Moreover, the arrival of emergency vehicles (e.g., ambulance and fire engine) on time to an accident spot is also as important as warning message dissemination. Once a mishap happens, the navigation path of a rescue team obtains a higher priority than other vehicles such that it can reach the accident spot to save people. SAINT+ [22] proposes an efficient navigation method for letting emergency vehicles to reach the accident area by detouring other vehicles out of the navigation paths taken by the emergency vehicles. Also, SAINT+ makes vehicles approach the accident area

quickly by letting other vehicles make detours in advance so as not to increase traffic congestion around the accident spot.

VANET today also provides comfort and infotainment services to the drivers and passengers in various categories [23–27], as shown in Fig. 2. Applications such as electronic payment [28], fuel consumption reduction by selecting an appropriate route [29], weather condition sharing [30], traffic information sharing [31], point of interest (POI) sharing [32], and navigation route guidance [33], are used to increase the comfort of drivers and passengers. Infotainment services are also provided to the drivers and passengers such as the access to the Internet and multimedia data downloading [34].

Even though VANET is improving such vehicular services over time, there are still a lot of challenges as follows: (i) The first is network disconnection, which is due to high mobility of vehicles. Connectivity is sometimes lost because of different speeds of a source and a destination. (ii) The second is traffic condition, e.g., the number of vehicles that can affect the data dissemination in VANET. (iii) The third is heterogeneous applications in VANET such as a safety application that needs a short delay and high reliability, and an infotainment application that does not need a short message delivery delay, but a high throughput. For the purpose of safe driving, safety messages have a higher priority than infotainment messages. (iv) The last is data dissemination that needs to be fast and reliable in VANET.

Broadcasting in VANET is considered as a good scheme for data dissemination as it does not require destination information, but can just send data to the neighboring vehicles. However, broadcasting has some issues such as flooding, non-reliability and redundancy of data [35]. Data dissemination techniques in VANET are usually verified through simulation or a few are mathematically analyzed, hence there is no standard method for evaluation of data dissemination in VANET. The two major applications of VANET, i.e., safety and comfort, mainly use three models for data dissemination, i.e., a pull-based model [36], push-based model [37] and hybrid model [38]. In the pull-based model, data dissemination is on demand where as in the push-based model, data dissemination is proactively performed using periodic broadcast. The hybrid model is the combination of the pull-based and push-based models. The pull-based model is usually used for infotainment applications, while the push-based model is used for safety applications.

This study aims to explore the existing methods related to data dissemination and outline the categories of important issues that can be addressed for data collection in the VANET. We investigate the existing performance modeling for delay-tolerant and delay-sensitive data dissemination systems. To the best of our knowledge, this paper is the first study that examines both the delay-tolerant and delay-sensitive data dissemination. Therefore, the main contributions of this paper can be defined as follows:

- A systematic literature review is performed for the existing techniques on data dissemination in VANET.
- The recent research efforts published only in recognized journals with regards to the state-of-the-art data dissemination methods are investigated and the selected data dissemination schemes are assessed through various parameters.
- Identifying the main data dissemination optimization problems and data-related characteristics for applications such as safety and infotainment.
- A detailed comparison of performance modeling approaches in delay-tolerant and delay-sensitive data dissemination within VANET is provided.
- A set of open research challenges that requires to be addressed is identified and discussed.

Table 1
Acronyms and abbreviations.

Acronym	Description
ACK	Acknowledgment
ADDP	Adaptive Data Dissemination Protocol
AP	Access Point
BIFS	Broadcast Inter-Frame Space
BS	Base Station
CCA	Cooperative Collision Avoidance
CMDS	Cloud Assisted Message Downlink Dissemination Scheme
CPB	Clustering and Probabilistic Broadcasting
CRN	Current Rebroadcasting Node
CTS	Clear to Send
DEEP	Density-aware Emergency Message Extension Protocol
DIFS	Distributed Inter-Frame Space
DPDR	Data Packet Delivery Ratio
DPMS	Dissemination Protocol based on Map Splitting
DSRC	Dedicated Short-Range Communications
DTN	Delay-Tolerant Networks
EDD	Expected Delivery Delay
E2E	End-to-End
GPS	Global Positioning Systems
ITS	Intelligent Transportation Systems
I2V	Infrastructure-to-Vehicle
LTE	Long Term Evolution
MAC	Media Access Control
MOVE	Mobility Mode Generator for Vehicles
NS	Network Simulator
OBU	On-Board Unit
PMB	Position-based Multi-hop Broadcast
POI	Point Of Interest
PRN	Previous Rebroadcasting Node
RFID	Radio Frequency Identification
RSU	Road-Side Unit
RTS	Request to Send
SAB	Speed Adaptive Broadcast
SEAD	Simple and Efficient Adaptive Data Dissemination
SIFS	Short Inter-Frame Space
SLR	Systematic Literature Review
SN	Stationary Node
SUMO	Simulation of Urban Mobility
TA	Trusted Authorities
TBD	Trajectory-Based Data forwarding
TSF	Trajectory-based Statistical Forwarding
UMBP	Urban Multi-hop Broadcast Protocol
UWB	Ultra-Wide Band
VANET	Vehicular Ad Hoc Networks
VCPS	Vehicular Cyber-Physical Systems
VMaSC	Vehicular Multi-hop Algorithm for Stable Cluster
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
WAVE	Wireless Access in Vehicular Environments

The rest of this paper is organized as follows. Section 2 outlines the review plan to conduct the systematic literature review. Section 3 presents the related work having the existing surveys available in the literature for data dissemination. Section 4 discusses the data dissemination systems (i.e., delay-tolerant and delay-sensitive data dissemination systems) and highlights their respective performance modeling approaches. Section 5 presents the key research challenges that needs to be tackled for future research undertakings. Finally, Section 6 concludes the paper. Note that the acronyms and abbreviations which are used in this paper for brevity are shown in Table 1.

2. Review plan

The Systematic Literature Review (SLR) conducted in this study is based on the guidelines suggested by Kitchenham et al. [39,40], with the aim to summarize available literature resources and develop the basis for qualitative synthesis and information extraction. SLR is a process of identifying, assessing and understanding the available literature, focusing on a specific research area, research questions or phenomenon of interest [41]. We also followed some

Table 2
The combination of keywords for electronic databases.

"Vehicle Ad hoc Networks" OR "VANET" **AND** (Data Dissemination*) **AND** "Delay-tolerant*" **OR** "Delay-sensitive*"

of the guidelines and policies suggested in [42], which includes the allocation of bibliographic databases, selection of searching keywords and criteria for inclusion and exclusion. The following subsections describe each of the guidelines carried out in this study in the respective order.

2.1. Research question identification

In this work, we systematically classify the body of knowledge, so our study focuses on answering the following five research questions (RQs):

- RQ1: What is the significance of data dissemination in the VANET?
- RQ2: What are the recognized sources for article searching and selecting to evaluate the data dissemination methods in the VANET?
- RQ3: What are the main parameters used by existing schemes to assess data dissemination methods in the VANET?
- RQ4: How can the performance modeling approaches in delay-tolerant and delay-sensitive data dissemination within VANET be investigated?
- RQ5: What are the key challenges associated with data dissemination in the VANET?

2.2. Bibliographic databases

In order to reach the related articles at the maximum level, the selection of precise and up-to-date bibliographic databases is very vital. For this purpose, eight different multidisciplinary electronic bibliographic databases were chosen to extract the required publications, such as (1) Scopus (ScienceDirect, Elsevier), (2) IEEE Xplore, (3) SpringerLink (Springer), (4) ACM Digital Library, (5) Taylor & Francis Online, and (6) Wiley Online Library. The list of the selected electronic databases was prepared to keep in view their relevance to the research area and the related journals and conferences indexed by them.

2.3. Search strings

Selecting the appropriate search strings are very essential to extract accurate and required information from the electronic bibliographic databases. Owing to the contrasting nature of this survey, a set of proper search strings have to be selected that assures the inclusion of VANET and data dissemination within the scope of delay-tolerant and delay-sensitive data dissemination systems. Initially, a set of keywords containing the full form of VANET was used with data dissemination phenomena, describing keywords to acquire additional sources within the research area. With multiple electronic databases, the query string was to be changed accordingly. Logical operators and wildcards were used with these keywords to access the maximum number of relevant articles. Table 2 shows the combination of keywords used for this review.

2.4. Inclusion and exclusion criteria

The following inclusion and exclusion criteria were applied in the planning phase for the overall validity of the literature review.

1. The study is an English written full-text article.
2. The study is published in a scientific journal (preferably impact factor journal).
3. The study has been published since 2010.
4. The study is qualified for inclusion only if it describes the concept of VANET with some data dissemination operations.
5. The study is excluded if it does not consider any data dissemination operations.
6. Identical papers found in different electronic databases are considered once.
7. Publications such as conference proceeding, workshop, dissertation, in-progress research, guest editorial, poster session, and blogs are excluded.

After applying the designated keywords and predefined inclusion and exclusion criteria to the selected bibliographic electronic databases, a total of 686 papers were identified. From these collected papers, 381 papers were excluded on the basis of their titles and abstracts. Some abstracts were not clarifying the research work openly, so a full-text screening was also performed on papers and discussions between the authors so that their significance can be ensured. A total of 204 more papers were excluded on the basis full text screening and keeping in view the inclusion and exclusion criteria. Additionally, during the studies of full text papers a total of 7 relevant papers were included through the application of backward and forward search. As a principle, an effective literature search comprises of querying the scholarly databases using the prescribed keywords, as well as either a backward search or a forward search. Here, on one hand, the backward search means evaluating the references mentioned in the articles acquired through a search with keywords. On the other hand, the forward search means evaluating the sources that have cited a particular article.

Finally, a total of 75 papers were selected for synthesis and analysis. Fig. 3 displays year-wise search results with the number of articles found in journals of various bibliographic databases and the number of selected articles for this paper. Fig. 4 shows the leading research journals in which we found the most number of papers with respect to the research questions and search strings. The overall review plan for the conducted systematic literature review is demonstrated in Fig. 5. Due to the nature of this review, it can be assured that the implemented methods and the selected sample papers are sufficient for making a contribution for survey and drawing a conclusion for the next step towards future work.

3. Related work

Various aspects of VANET have already been covered in different survey papers [43–46], while some researchers focused on survey papers related to data dissemination methods in VANET [47–49]. But to the best of our knowledge, no one has presented a detailed survey on the data dissemination optimization problems and data-related characteristics and applications such as safety and infotainment.

Julio A. Sanguesa et al. present a survey on dissemination schemes for broadcasting messages [50]. The authors mainly focus on one-hop and multi-hop data dissemination schemes for broadcasting messages. They also provide information about the classification of multi-hop dissemination schemes such as flooding, beacon, topology-based scheme, distance-based scheme, store-and-carry broadcast scheme, and stochastic broadcast scheme. They compare existing schemes by evaluation while keeping the same performance metrics and the same simulation parameters in a simulation platform.

Xiaomin Ma et al. present an overview of safety related applications and their reliability issues in VANET [51]. They mention three main factors that affect reliability in VANET, i.e., hidden ter-

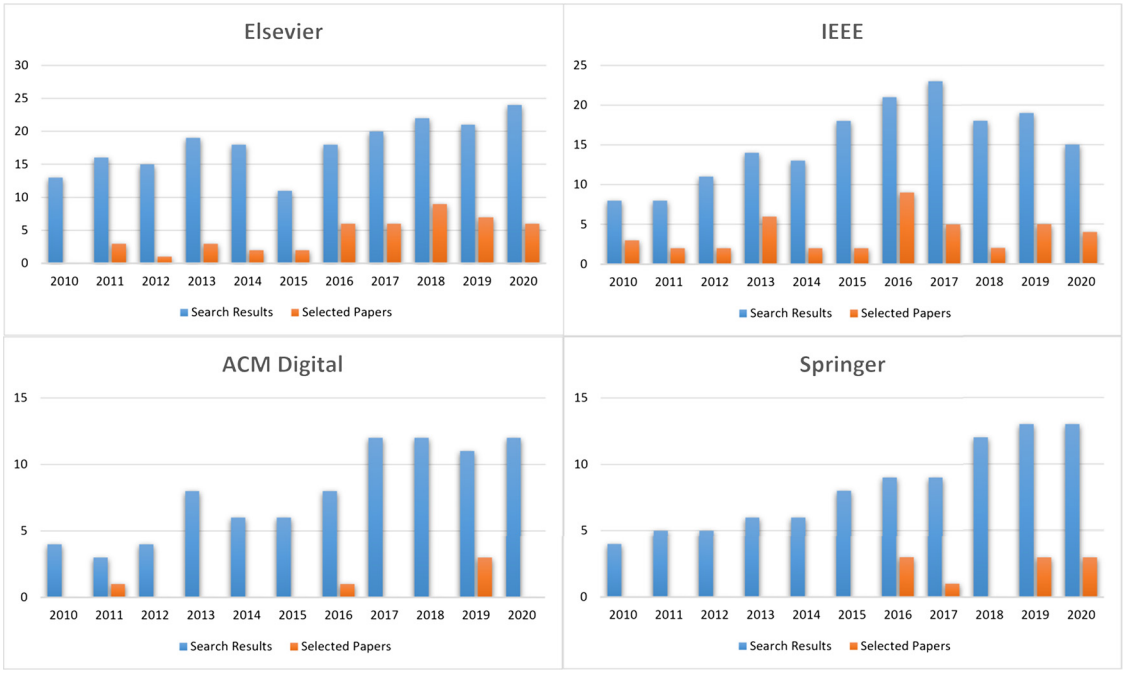

Fig. 3. Year-wise distribution of search results along with the number of selected papers in various bibliographic databases.

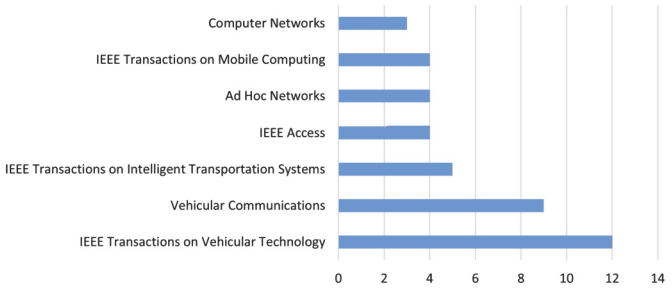

Fig. 4. Research journals with respect to the number of publications acquired regarding the research area.

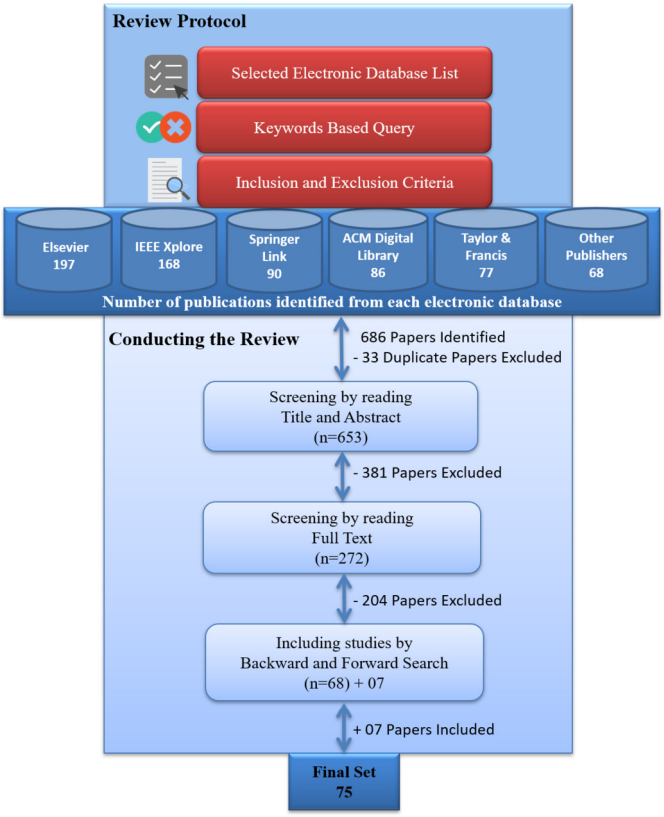

Fig. 5. Review plan for conducted systematic literature review.

minal problem in broadcast, radio channel fading in DSRC and the impact of high mobility. They use four metrics for the performance evaluation of reliability for one-hop safety services such as packet reception ratio, packet delivery ratio, successful packet delivery probability, and effective communication range. Using packet reception ratio, they check the percentage of successful packets reception by the nodes from the tagged node. Packet delivery ratio means the ratio of the number of the successfully received packets by all nodes to the number of the transmitted packets.

Felipe Domingos da Cunha et al. present a survey on VANET in terms of communication and application perspectives [52]. They discuss each layer protocol in VANET. Multi-path fading and Doppler shift are considered for physical layer protocols. Media Access Control (MAC) layer protocols consider reliability and efficiency in channel access such that a safety related application can send its messages to destinations with a short delay. It also deals with the hidden terminal problem. Routing protocols for unicast, multicast and broadcast are considered as network layer protocols. Transport layer protocols are mainly designed for unicast packet delivery among applications.

Ying Zhu et al. present a survey on social-based routing techniques in delay-tolerant networks (DTN) [53]. The authors summarize the social properties in DTN communication in VANET. They mention two approaches for social-based efficient routing considering both positive social characteristics and negative social characteristics. Positive characteristics such as friendship and community help to improve network performance whereas negative characteristics such as selfishness degrade network performance. The important social characteristics mentioned in the paper construct a social graph or contact graph with community, centrality, similarity, friendship, and selfishness. A lot of advantages can be taken from positive characteristics of social routing such as friendship-

based routing, label routing, and other social-based routing. The paper also elaborates the methods of dealing with negative social characteristics in DTN routing such as tit-for-tat and give2get.

Azlan Awang et al. present a survey on single and cross layer design techniques in VANET [54]. The authors utilize the information at physical, MAC and network layers such as parameters for routing. The problems incurred by topology-based routing are discussed. They classify the challenges into safety, public services, driving improvement, and comfort message exchange. Due to unique characteristics of VANET such as mobility, movement patterns, traffic density, and heterogeneity, some great challenges are addressed such as scalability, neighborhood discovery, data forwarding, the use of position information, and the prediction of future position.

Dongyao Jia et al. present a survey on platoon-based Vehicular Cyber-Physical Systems (VCPS) [55]. They introduce a vehicular networking architecture, standards, and traffic dynamics. They also discuss issues related to platoon-based VCPS. They provide detailed analysis on fundamental issues in VCPS including platoon management, cooperative platoon-based driving, and platoon-based vehicular communication.

Sooksan Panichpapiboon et al. provide a review on single-hop and multi-hop broadcasting protocols [56]. The ways of spreading information in networks are different for both broadcasting protocols. In general, information is propagated in the form of flooding in multi-hop broadcasting, where a vehicle having information just sends the information to other vehicles in its vicinity. On the other hand, in single-hop broadcasting, information is broadcasted to other vehicles within one-hop communication range of a source vehicle. They further provide different classification of broadcasting protocols. Multi-hop broadcasting protocols are further classified into delay-based multi-hop broadcasting, probabilistic multi-hop broadcasting, and network-coding-based multi-hop broadcasting. Similarly, single-hop broadcasting protocols are classified into fixed-interval broadcasting protocols and adaptive-interval broadcasting protocols.

Table 3 shows a comparison of this survey and existing related surveys from the aspects of architecture, SLR, Performance modeling for Delay-Tolerant and Delay-Sensitive, and research challenges and opportunities identifications.

4. Data dissemination systems

Data dissemination in VANET is defined as the exchange of information among vehicles. There are different schemes of data dissemination that include opportunistic, vehicle-assisted and cooperative data dissemination schemes. Traffic safety, infotainment, and travel comfort are main applications of data dissemination in VANET. Safety applications are given high priority to secure traffic, therefore the messages of the safety applications require a short delay and high reliability. On the other hand, there is no such time constraint for infotainment and comfort applications. Safety and comfort applications are also known as delay-sensitive and delay-tolerant applications, respectively. Safety messages can be event-driven such as accident information sharing and periodic information sharing (e.g., traffic monitoring). Comfort messages can be delivered following a carry-and-forward method.

Safety messages are generally propagated via broadcast and comfort messages are sent via unicast. Broadcasting in VANET is further divided into two types such as multi-hop and single-hop schemes. In multi-hop broadcasting schemes [62], messages are sent using a flooding method. A source vehicle broadcasts an information message to other vehicles in its vicinity, and the vehicles that receive the message will rebroadcast it. This process continues until the message is received by the destination vehicle. On the other hand, in single-hop broadcasting schemes [63], a flooding method is not used. Instead of flooding, each vehicle keeps information messages after receiving them, and rebroadcasts some of the messages in the next broadcast cycle.

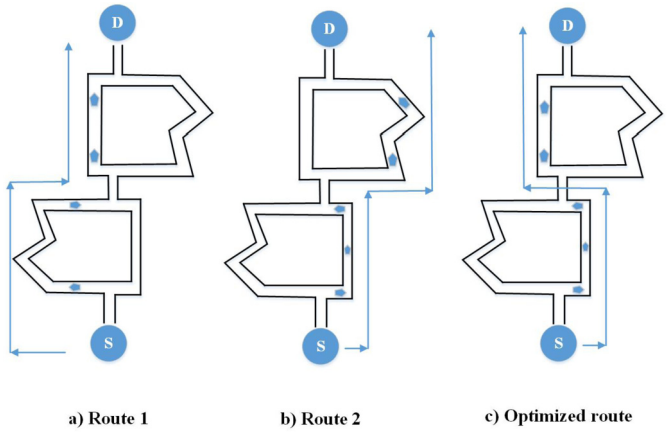

Fig. 6. Ant colony optimization.

Table 4 shows detailed parameters of different data dissemination schemes including topology, mode, focus, technology, type and simulator.

4.1. Delay-tolerant data dissemination systems

Delay-tolerant data dissemination systems usually follow a pull-based mechanism, which means that data dissemination is performed on demand. Delay-tolerant systems have no strict time constraints and require less overhead. Some delay-tolerant systems related to comfort and infotainment applications are explained as follows.

Priyan et al. propose a comfort application for VANET using ant colony optimization algorithm to overcome traffic jam and congestion [76]. An effective system for traffic controlling applies a forward ant procedure and a backward ant procedure to pick out a best optimal route to a destination as shown in Fig. 6. Ant colony optimization is a probabilistic technique for searching for an optimal path based on an ant's behavior. Basically, ants move at random and deposit pheromone on their path. The higher probability of a shortest path can be determined by the intensity of pheromone.

Jianping et al. propose a carry-and-forward idea considering bidirectional vehicle traffic for VANET, so as to use the opposite-direction vehicles to accelerate the message propagation [77]. In carry-and-forward concept, a packet is carried by a vehicle until it finds a new vehicle and transfers the packet to it. An analytical framework is designed to address the issues related to message propagation delay based on a stochastic vehicle traffic model. In Fig. 7, source vehicle S sends a query packet to destination D, and S gets the responsibility to select an optimized route to send the packet to D so that D can receive and process the query packet.

Jeong et al. propose a Trajectory-Based Data (TBD) forwarding scheme [78]. The authors claim that this is the first attempt to use vehicle trajectory information along with traffic statistics in a privacy-preserving manner for better performance. Each vehicle shares its delivery delay information with neighboring vehicles after computing its end-to-end (E2E) expected delivery delay to an Access Point (AP) having the Internet connectivity. Vehicles cannot send their packets directly to the APs connected to the Internet because of their limited coverage, so instead of the direct transmission, it uses a carry-and-forward technique. With the help of neighboring vehicles trajectories, the current packet carrier vehicle selects a best next-hop carrier. The authors use unicast to reduce the amount of data packets. Fig. 8 shows a scenario of a road net-

Table 3
Comparison of this survey with the existing related surveys.

Survey	Focus	Year	Architecture	SLR	Performance modeling for delay-tolerant	Performance modeling for delay-sensitive	Research challenges & opportunities
Mchergui et al. [47]	QoS-aware broadcasting techniques in VANET	2017	✓	×	×	×	✓
Katiyar et al. [48]	Clustering protocol in VANET	2020	×	×	×	×	✓
Tang et al. [49]	Data dissemination service discovery for VANET	2018	×	×	×	×	✓
Sanguesa et al. [50]	Broadcast warning message dissemination	2016	×	×	×	✓	✓
Xiaomin Ma et al. [51]	Reliability of safety applications	2012	×	×	×	✓	✓
Felipe et al. [52]	Data communication and application challenges	2016	✓	×	×	×	✓
Ying Zhu et al. [53]	Summarizes the socila properties in delay tolerant network	2013	×	×	✓	×	✓
Azlan Awang et al. [54]	Single and cross layer design techniques in VANET	2017	✓	×	×	×	✓
Dongyao Jia et al. [55]	Platoon-based vehicular cyber-physical systems	2016	✓	×	×	×	✓
Panichpapiboon et al. [56]	Review of information dissemination protocol for VANET	2012	×	×	✓	✓	✓
Hakima Khelifi et al. [57]	Information-centric named data networking for VANET	2020	✓	×	×	×	✓
Abdul Qayyum et al. [58]	Focuses on adversarial machine learning techniques	2020	×	×	×	×	✓
Jiadai Wang et al. [59]	Networking and communication in autonomous driving	2019	✓	×	×	×	✓
Haixia Peng et al. [60]	Communication techniques for manual and automated driving vehicular networks	2019	✓	×	×	×	✓
Ikram Ali et al. [61]	Authentication and privacy scheme for VANET	2019	×	×	×	×	✓
Our Survey	Safety and infotainment related data dissemination techniques in VANET	2021	✓	✓	✓	✓	✓

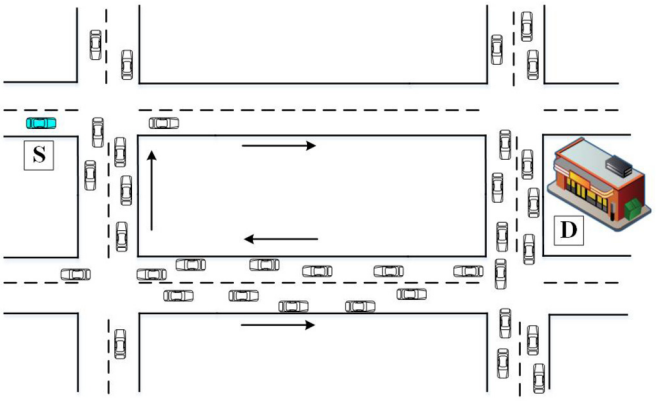

Fig. 7. Carry-and-forward strategy in VANET.

work with different traffic densities. Source vehicle *S* wants to send its packet towards an AP. Having the information of vehicle trajectories and traffic statistics, *S* can select a vehicle between carrier-1 (C-1) and carrier-2 (C-2), which are within its wireless communication range, as a next-hop packet carrier.

Jeong et al. propose a trajectory-based statistical forwarding (TSF) scheme for multi-hop data delivery from infrastructure to vehicle (I2V) [79]. TSF focuses on forwarding packets from infrastructure (i.e., APs) to a moving vehicle with a minimum delay and a certain delivery probability. In TSF, a packet from infrastructure is forwarded to a selected target point through which a destination vehicle is expected to pass. TSF selects an optimal target point

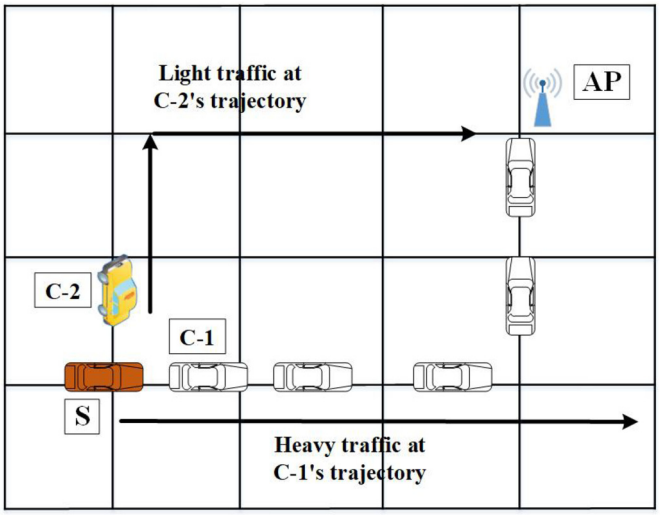

Fig. 8. Road network with different traffic density.

which is achieved by using both a destination vehicle's traveling delay (i.e., vehicle delay) and a packet's delivery delay (i.e., packet delay). TSF presents an architecture for multi-hop I2V data delivery, packet and vehicle delay modeling, and a selection algorithm for an optimal target point.

Rongxing et al. propose a smart parking scheme as a comfort application that provides a real-time navigation system with parking and intelligent anti-theft protection [80]. Smart parking

Table 4
Parameters selected to assess the different data dissemination schemes.

Reference	Objective	Topology & route structure	Mode	Focus	Technology	Type	Simulator
Yangyang Xia et al. [64]	Greedy traffic light and queue aware routing protocol to alleviate the packet loss	24 two-way streets with 16 intersections	Multi-hop	Packet delivery ratio and end-to-end delay	IEEE 802.11p	V2V	NS-2 and SUMO
Boubakeur Moussaoui et al. [65]	Enhanced Ad-hoc On-demand Distance Vector (AODV) protocol to deal with routes instability issue in VANET	Digital Map of 2000 m × 2000 m	Multi-hop	Reducing the overhead generated by control packets and improving end-to-end delay	IEEE 802.11p	V2V	NS-3 and SUMO
Odilbek Urmonov et al. [66]	Introduces a notion of source Lateral Crossing Line (LCL) algorithm for an effective broadcast message dissemination	Manhattan grid (2000 m × 2000 m) comprise 3 × 3 blocks and four-ways intersections	Multi-hop	Reduction in delays and enhancement in propagation distance	IEEE 1609/IEEE 802.11p	V2V	NS-3
Manisha Chahal et al. [67]	Intelligent forwarding–based stable and reliable data dissemination scheme	Open Street Map 4 × 4 km	Multi-hop	Improving latency, throughput and packet delivery ratio	IEEE 802.11p	V2V	NS-2 and SUMO
Mazen Alowish et al. [68]	software-defined networking controlled vehicular named-data networking for trustworthy emergency data dissemination and content retrieval	1000 m × 1000 m	Multi-hop	improving average hop count, and gain of scalability	IEEE 802.11a	V2V	NS-3
Qinglei Kong et al. [69]	A secure querying scheme in vehicular fog data dissemination	Nil	Nil	Achieve the security goals of unlinkability, confidentiality, and verifiability	IEEE 802.11p	V2V and V2I	Java Paillier Library
Nishu Gupta et al. [70]	Presents enhancement to the existing IEEE 802.11p protocol that targets prioritized delivery of safety messages	10000 m × 10000 m	both single-hop and multi-hop	Enhancement and stability of the clustered topology	IEEE 802.11p	V2V	NS-2
Nishu Gupta et al. [71]	Uses hash operations and cryptographic concepts to transfer messages between vehicles to ensure security	Nil	multi-hop	Authentication-Based Secure Data Dissemination	5G	V2V	MATLAB
Saliha Benkerdagh et al. [72]	clustering by using the Fitness parameter	8 km × 6 km	2-hop	Performance of cluster duration and delivery rate	IEEE 802.11p	V2V	VanetSim
Joahannes B. D.da Costa et al. [73]	Efficient data dissemination protocol based on complex networks metrics	1000 m × 1000 m	1-hop and 2-hop	High efficiency in terms of coverage, number of transmitted packets, delay, and packet collisions	IEEE 802.11p	V2V	Veins, OMNeT++ and SUMO
Debanjan Roy Chowdhury et al. [74]	Predicting the relevance of vehicles using a distributed algorithm and heuristically tries to disseminate safety messages	1000 m × 1000 m	Multi-hop	packet loss and dissemination delay	IEEE 1609	V2V	OMNeT++ and SUMO
Guiyang Luo et al. [75]	Propose a software-defined cooperative data sharing architecture in 5G VANET.	1000 m × 1000 m	Multi-hop	packet loss and dissemination delay	802.11p and 5G	V2V and V2I	NS-3 and SUMO

characterizes RSUs in parking areas to manage parking lots via the VANET technology. It helps drivers to find their parking space quickly in a parking lot so that it can help vehicles to reduce gasoline consumption and parking time. It also provides vehicles with an anti-theft protection service. This parking system consists of a trusted authority (TA), on-board units (OBUs), RSUs, and parking space for a parking lot. For smart parking, RSUs at a parking lot record some attributes such as position, reservation, occupancy, pseudo-ID, ticket-ID, ticket key, start time, and last update time.

Andrea et al. propose an architecture model for infotainment services based on push-mode dissemination in an integrated VANET and 3G [81]. The authors use a push mechanism to disseminate advertisements and other announcements. Information dissemination and information retrieval are considered to be part of infotainment services. For disseminating infotainment services, only VANET is used while in a retrieval phase both VANET and 3G are used. For the first phase (i.e., information dissemination), simulation is carried out by simulation of urban mobility (SUMO), network simulator-2 (NS-2), and mobility mode generator for vehicular networks (MOVE). Performance metrics such as average delay and information coverage were used. For the second phase (i.e., information retrieval), a testbed was built to prove the feasibility of this phase.

Ozan et al. propose a biologically inspired self-organizing network approach to solve a formidable problem in VANET [82]. The authors propose to use a vehicle as a temporary RSU. A vehicle can make a short stay while traveling and acting as a bridge for other vehicles. Inspired by ant and bee colonies, the authors assume a

vehicle to be used as a temporary RSU for relaying other vehicles' data packets. A candidate vehicle for a temporary RSU is the one at the boundary of the coverage areas.

Changqiao Xu et al. [83] propose a QoE-driven User-centric solution for VoD services in urban vehicular network environments (QUVoD). The efficiency depends on the following four mechanisms: 1) distributed grouping-based video segments storage scheme; 2) video segment seeking scheme; 3) multipath data delivery mechanism; and 4) speculation-based prefetching strategy. In [84], a novel ant-inspired mini-community-based video sharing solution is proposed for on-demand streaming services in wireless mobile networks (AMCV). Based on video contents, AMCV constructs multiple mini-communities and then distributes resource maintenance costs and enhances overall solution scalability. An Ant Colony Optimization (ACO)-based community communication strategy is proposed that reduces both the data traffic and delay of the resource search. A novel community maintenance mechanism is also proposed to balance the load across nodes and enhance resource utilization efficiency. The authors in [85] propose an adaptive carry store forward (ACSF) scheme to reduce the outage time, where a vehicle is selected to send the data to the target vehicle in the uncovered areas. The relaying vehicle stores a sufficient amount of data and then forwards it to the target vehicle. The moving speed of the target vehicle can be adaptively changed according to the relaying vehicle. To minimize the target vehicle's communication outage time, the moving speeds of the target vehicle are optimized, and the best relaying vehicle is selected.

4.1.1. Performance modeling for delay-tolerant data dissemination systems

Mostly performance evaluation of VANET is verified by simulation, or in some cases, it is analyzed using mathematical modeling. There is no standard methodology for performance evaluation of information dissemination algorithms in VANET. Such algorithms are commonly verified via simulations, and are rarely analyzed using mathematical models. This is mainly due to the major challenge of providing a sufficient level of detail to ensure realistic traffic scenarios and driving behaviors. This subsection describes some of the performance modeling for delay-tolerant data dissemination.

Ant Colony Optimization

The authors in [76] apply an ant colony optimization algorithm on street maps to get an optimal route. For modeling heavy traffic, they propose a calculation function for traffic intensity based on fuzzy logic. They classify their method in four steps such as map segmentation, ant colony optimization, computation of traffic intensity, and pheromone update. In map segmentation, the street maps are segmented into several identical parts, and then represented by graphs as follows:

$$G_N = (O_N, L_M), \tag{1}$$

where O_N is the set of nodes and L_M is the set of links. Each segment maintains a routing table, which is updated dynamically as follows:

$$R_{t_i} = G_{N_i} = (O_{N_i}, L_{M_i}), \tag{2}$$

where R_{ti} represents the routing table for the i^{th} segment. The data related to a road segment's length and the number of vehicles are gathered for calculating the maximum number of vehicles and vehicle density. Forward ants are usually used for finding an optimal route and the new position movement is defined as:

$$P_{ij}^{k}(t) \begin{cases} \frac{a(\partial_{ij})+b(1-\eta_{ij})}{\sum_{h \notin tabu_k} a(\partial_{ij})+b(1-\eta_{ij})} \times (\frac{1}{1+\frac{1}{N_j}}), & \text{if } j \notin tabu_k = 0 \\ 0, & \text{otherwise} \end{cases}$$

where ∂_{ij} and η_{ij} represent a pheromone value and instantaneous state of a fuzzy value, respectively. a and b are weights for ∂_{ij} and η_{ij}, respectively. N_j is the number of neighbors for j, whereas $tabu_k$ shows the set of nodes that k has not visited. At the end of pheromone update, the value is increased or decreased by the following function:

$$\tau_{ij}^{new} = (1-\rho)\tau_{ij}^{old} + \sum_{k=1}^{m} \Delta\tau_{ij}^{k}, \tag{3}$$

where $\rho \in A[0, 1]$ represents the value of pheromone evaporation.

Carry-and-Forward Schemes

The authors in [77] present a carry-and-forward scheme where a vehicle carries a packet until it finds a new vehicle in its vicinity to carry and forward the packet. This is different from greedy perimeter stateless routing (GPSR) [86], which selects a next-hop node that is closest to the destination. This type of selection is not suitable for vehicular networks where vehicles are sparsely connected with each other. This paper uses a two-dimensional VANET to select a forwarding path and uses opposite-direction vehicles to carry and forward the packet faster. If a packet-carrier vehicle cannot find any other vehicle as a next-hop packet carrier, the vehicle forwards its packet to the vehicle behind it as a next-hop packet carrier. A packet is supposed to be delivered to another vehicle in the opposite direction. The probability of an event can be estimated as follows:

$$Pr\{Y_{wn}\} = 1 - (1 - P_w^n)^{|c_s|} e^{-(\lambda_{en}+\lambda_{sn})(c_s+R')/v}, \tag{4}$$

where P_w^n is the probability that a vehicle may turn north from west, c_s is the number of vehicles in a cluster, Y_{wn} shows that a cluster coming from west towards an intersection passes the message to a vehicle traveling to north, R' is the effective range of communication between two clusters, v is the speed of a vehicle, λ_{en} shows the traffic from east to north and λ_{sn} shows the traffic from south to north. For delay estimation, the authors consider link propagation delay, link transfer delay, and E2E delay.

TBD is also a carry-and-forward scheme that uses vehicles trajectory information to forward a packet towards a destination [78]. TBD tackles two challenging problems; the first is how to share trajectories in a privacy-sensitive manner, and the second is how to combine vehicle trajectory information with traffic statistics for an E2E delivery delay estimate. The distance where a vehicle carries a packet to a specific distance is called carry distance, denoted by l_c. The carry delay is computed by the carry distance divided by a vehicle's speed. On the other hand, the distance where a packet can be forwarded over VANET is called forwarding distance. The forwarding delay is computed by the forwarding distance divided by a packet delivery speed over VANET. The link delay is the sum of forwarding delay and carry delay. However, since the magnitude of the carry delay is higher than that of the forwarding delay, the forwarding delay can be ignored to compute the link delay. Thus, the link delay (denoted as d_{ij}) for a road segment e_{ij} can be computed as follows:

$$d_{ij} = \frac{l_c}{v}, \tag{5}$$

where v is the speed of a vehicle, and l_c is the length of a road segment e_{ij}.

TBD does not use an algorithm different from Dijkstra's shortest path algorithm, and instead it uses a stochastic model for carry-and-forward data delivery. Unlike a traditional shortest path algorithm such as Dijkstra's, it is not guaranteed that at an intersection,

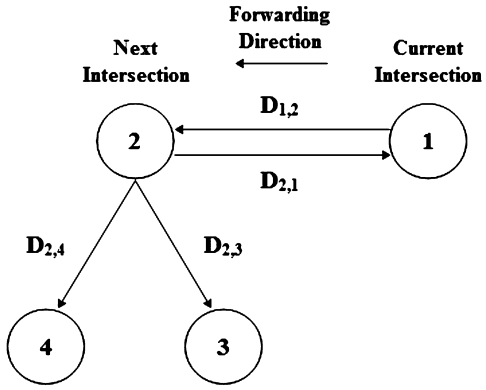

Fig. 9. Expected Delivery Delay (EDD) computation for road segment $e_{1,2}$.

the carrier vehicle can meet another suitable vehicle to forward its packet. A graph model for the computation of an expected delivery delay (EDD) at an intersection toward a packet destination (e.g., AP) is shown in Fig. 9 where a packet is sent from intersection 1 to intersection 2. The E2E EDD from a packet carrier to the AP via the edge $e_{1,2}$ is denoted as $D_{1,2}$. After taking $d_{1,2}$ seconds, the packet arrives at intersection 2, and then the packet around intersection 2 can be sent toward one of the neighboring intersections (i.e., 1, 3, and 4) with an average forwarding probability. The EDD at intersection 1 toward intersection 2 is denoted as D_{ij} as follows:

$$\begin{aligned} D_{ij} &= d_{ij} + E[\text{delivery delay at } j \text{ by forwarding or carry}] \\ &= d_{ij} + \sum_{k \in N(j)} (P_{jk} \times D_{jk}), \end{aligned} \tag{6}$$

where N_j is the set of neighboring intersections and P_{jk} is the probability that the packet is forwarded from intersection j to intersection k, called average forwarding probability. For performance evaluation, TBD uses average delivery delay and packet delivery ratio as performance metrics [78].

TSF supports a reverse data forwarding, that is, a multi-hop data forwarding from an infrastructure node (i.e., AP) to a moving vehicle [79]. The accurate delay estimation determines the successful delivery ratio of reverse data forwarding. A packet should arrive earlier than a destination vehicle at a target point in order to ensure reliable and successful data delivery. An optimal target point is selected with minimum delivery delay given as follows:

$$i^* \leftarrow \arg\min_{i \in I} E[V_i] \text{ subject to } P[P_i \le V_i] \ge \alpha, \tag{7}$$

where $P[P_i \le V_i]$ is the probability that a packet will arrive earlier than a destination vehicle at the target point i and α is a delivery ratio threshold.

Link delay model is given as follows:

$$d \begin{cases} \frac{l - l_f - R}{v}, & \text{for immediate forward} \\ \frac{1}{\lambda} + \frac{(l-R)}{v}, & \text{for wait and carry} \end{cases}$$

where λ is a vehicle arrival rate, R is DSRC communication range, l_f is forwarding distance, l is link distance (i.e., road segment length), and v is vehicle speed. Note that $\frac{1}{\lambda}$ is waiting time for a new vehicle arrival at an intersection.

E2E packet delay distribution is computed as follows:

$$E[P] = \sum_{i=1}^{N} E[d_i] = \sum_{i=1}^{N} \mu_i. \tag{8}$$

A TSF packet's header contains a forwarding path and vehicle trajectory. TSF uses a unicast data forwarding protocol where a relay node at an intersection as a packet holder deletes its packet just after delivering the packet to a next-hop vehicle. Data packets can also be forwarded from multiple APs toward multiple target points such that a destination vehicle can get some of the data packets from one AP and the rest of them from other APs. For performance evaluation, performance metrics of TSF are packet delivery delay, packet delivery ratio, and packet delivery cost.

Comfort Applications

The proposed scheme by [80] is explained in detail in the aspects of four different parts such as system setting, real-time parking navigation, intelligent anti-theft protection, and friendly parking information dissemination.

In real-time parking navigation, a vehicle's OBU communicates with an RSU at a parking lot while a vehicle enters the parking lot to get the ID and key for ticket. After entering the parking lot, the RSU chooses appropriate space for the vehicle on the basis of the shortest path distance.

Vehicle theft is nowadays one of the major public concerns. This parking scheme gives an anti-theft protection scheme that is based on beacon messages sent by a vehicle to an RSU in order to protect the vehicle. A driver locks and sets his vehicle's OBU to sleep mode. When he comes back, the driver enters his password to unlock the OBU. If there is any exception in this procedure, the RSU regards this activity as theft.

If a vehicle enters a parking lot and the parking lot is already full, it has to go around the parking lot to find parking space. To overcome such an issue, this paper proposes a friendly parking information dissemination for the comfort of drivers that provides parking information to the drivers before entering the parking lot.

Table 5 shows a comparison of delay-tolerant data dissemination performance modeling approaches in VANET from aspects of routing protocol, simulation platform, evaluation mode, and performance metrics.

4.2. Delay-sensitive data dissemination systems

Delay-sensitive data dissemination systems usually follow a push-based mechanism, which is known as event-driven data dissemination. Strict time constraints are used in delay-sensitive data dissemination. Several delay-sensitive data dissemination systems for safety applications are developed as follows.

Celimuge Wu et al. propose a mechanism that uses path diversity for reliability where a message is disseminated by two different paths, that is, from a relay vehicle and an auxiliary vehicle [87]. Broadcast message dissemination with a short delay and high reliability is ensured by the cooperation of these two paths. In the proposed mechanism, the sender vehicle selects a relay vehicle and an auxiliary vehicle to rebroadcast the message. Both selected vehicles will rebroadcast the received message, but only the relay vehicle selects the next relay vehicle and auxiliary vehicle. The auxiliary vehicle rebroadcasts the message only once. This mechanism works to provide a high probability of receiving the message with a low delay.

Tarik Taleb et al. present a detailed overview of cooperative collision avoidance (CCA) on highways and intersections, that is considered to be an emerging vehicular safety application [88]. The authors design a cluster-based risk-aware medium-access control (MAC) protocol to increase the responsiveness of CCA. Vehicles are allowed to join or depart from a cluster via specific mechanism. The performance of CCA is evaluated via NS-2 and the evaluation is conducted in two scenarios with naive CCA and no-CCA.

Table 5
Comparison of delay-tolerant data dissemination performance modeling approaches in VANET.

Delay-tolerant						
Performance modeling idea	Description	Routing protocol	Simulation platform	Evaluation mode	Performance metrics	Future scope
Ant colony optimization [76]	Map segmentation, ant colony optimization, traffic intensity computation and pherome update Fuzzy logic based traffic intensity calculation	Unicast (V2V)	Not specified	Not mentioned	Average travel time, Average waiting time	Continuous health monitoring system
Carry and forward [77]	Bidirectional propagation strategy considering two dimensional VANET Shortest path algorithm is used to select path with least delay Analytical framework	Unicast (V2V) and broadcast	not specified	Simulation + Analysis	Link propagation delay, End-to-end delay	Recalculates the optimal path using MDRA
Carry and forward, TBD [78]	Vehicles' trajectories are used to forward data Vehicles share their position and trajectory to the access point to compute end-to-end delivery delay	Unicast (V2I)	C	Simulation + Analysis	Average delivery delay, Packet delivery ratio	Link delay model for two-way vehicular traffic
Carry and forward, TSF [79]	Trajectoy based statistical forwarding Packets are forwarded to a selected target point where the vehicle is expected to pass by	Unicast (I2V)	C	Simulation + Analysis	Packet delivery ratio, Packet delivery delay, Packet delivery cost	Deploy infrastructure nodes
Smart parking [80]	Privacy-preserving parking scheme Real-time parking navigation services Intelligent anti-theft protection	Unicast (V2I, I2V)	Java	Simulation	Searching time delay, coverage	Intelligent parking IoTs
Infotainment Services [81]	An integration of VANET and Cellular network A push mode mechanism is used to disseminate service announcements	Broadcast and unicast	NS-2, SUMO, MOVE	Simulation + Test-bed	Average message delay, Information coverage	4G in VANET
Infotainment Services (video-on-demand), QUVoD [83]	User-centric video on demand services Grouping based storage strategy Segment seeking and multipath delivery scheme	Broadcast and P2P	NS-2	Simulation	Average lookup success rate, Average segment seeking latency, Average hit ratio	Load balancing on nodes
Infotainment Services (Ant-inspired based video sharing), AMCV [84]	Mini-community-based solution for video-on-demand Pherome trails are used to discover shortest path	P2P	NS-2	Simulation	Average lookup success rate, Average hops, Average delay	High efficiency in infotainment services
Adaptive carry-store forward scheme, ACSF [85]	To make communication possible in uncovered area To minimize the communication delay by optimized speed of the target vehicle	Unicast (I2V, V2V)	Not specified	Numerical analysis	Average outage time	Extended to multiple target vehicles

Guann-Long Chiou et al. propose trajectory-based I2V group message delivery over VANET [89]. With in two phases of existing trajectory-based I2V schemes, the first phase identifies an appropriate rendezvous point of a group message, and the second phase delivers the message to the multicast group via a multicast tree. An algorithm for trajectory-based I2V group message delivery (eTGMD) is proposed that selects a stationary node (SN) and constructs a multicast tree to solve the trajectory-based group message delivery problem. This paper simulates their model in NS-2 with three performance metrics such as delivery ratio, delivery delay, and the number of consumed packet transmissions.

Seyhan Ucar et al. propose a multihop-cluster-based IEEE 802.11p and LTE hybrid architecture for VANET-based safety message dissemination [90]. The proposed architecture uses IEEE 802.11p in collaboration with LTE to perform both clustering and message delivery. Clusters are formed with a vehicular multi-hop algorithm for stable clustering (VMaSC) approach where cluster heads are selected on the basis of average relative speed with respect to neighboring vehicles and are responsible for communicating with either an eNodeB or RSU. The authors make an extensive performance analysis with a wide range of performance metrics (e.g., data packet delivery ratio (DPDR), control overhead, stability of cluster, and delay) using NS-3.

Allani et al. present the idea of utilizing Dissemination Protocol based on Map Splitting (DPMS) to transfer information about ongoing events in a VANET [91]. Their protocol effectively uses data disseminated messages zones to achieve both a high delivery ratio and geocast precision. Bingyi Liu et al. propose a rapid safety message dissemination framework that includes cloud computing and diverse communication technologies [92]. A three-tier architecture is proposed where a high-tier node (i.e., cloud server) delivers safety messages to the mid-tier nodes (i.e., buses) with cellular and VANET interfaces, and the messages are finally delivered to low-tier nodes (i.e., vehicles) via V2V communication. The dissemination delay of the proposed safety message dissemination scheme is analyzed mathematically, and the performance is evaluated via OMNeT++.

Rene Oliveira et al. propose an adaptive data dissemination protocol (ADDP) which provides efficient and reliable message dissemination [93]. ADDP aims to adjust the periodicity of beacons and reduce the total number of messages. ADDP claims to disseminate safety messages with the minimum delay to the maximum number of vehicles and also address the problems such as disconnection, the broadcast storm and the hidden node problem. ADDP uses a success ratio, collision ratio and dissemination efficiency as performance metrics and is evaluated by OMNeT++.

Lei Liu et al. propose a clustering and probabilistic broadcasting (CPB) scheme for stable and reliable data dissemination in VANET [36]. In CPB, a probabilistic forwarding scheme is presented in which each cluster member first calculates the probability that the same packet is received during one interval, and then forwards the packet to its cluster head. Performance metrics in CPB are average transmission delay, information coverage and packet delivery ratio, and CPB is evaluated by NS-2.

Moumena Chaqfeh et al. propose a multi-hop data dissemination approach to provide scalable broadcast with minimum overhead [94]. The authors aim to achieve scalability and reliability, and to minimize overhead. A broadcasting storm problem is addressed to achieve scalability. For reliability, the goal is to reach full network coverage. Finally, to minimize overhead, data redundancy is reduced. Amoroso et al. propose a design for broadcasting warning messages in the time of danger [95]. The idea uses the concept of a relay mechanism to transfer an alert message. Multiple broadcast cycles are generated to guarantee a vehicular safety across the danger points.

Table 6 shows a comparison of delay-sensitive data dissemination performance modeling approaches in VANET from aspects of routing protocol, simulation platform, evaluation mode, and performance metrics.

4.2.1. Performance modeling for delay-sensitive data dissemination systems

Delay-sensitive data dissemination in VANET can be carried out by a push-based mechanism. This subsection describes some performance modelings for delay-Sensitive data dissemination as follows.

Cloud-assisted Message Downlink Dissemination Scheme (CMDS)

CMDS is a method proposed to achieve effective and fast dissemination of traffic information [92]. In CMDS framework, cloud as a top-tier collects traffic information, selects gateways (i.e., buses), and disseminates the traffic information to the gateways. Gateways further disseminate the traffic information to the vehicles. A cloud-based approach is used to select gateways. Cloud having real-time traffic density information chooses the gateways which can disseminate the information to the maximum number of vehicles in its transmission range. Gateways then select forward and backward delegators that are farthest from the gateway to disseminate the traffic information further to the vehicles. The time interval is defined between the formation time of a safety message in a cloud server and the time at which all vehicles receive the message. This time interval is called safety message dissemination delay T_A and shown as follows:

$$T_A = max\{T_1, T_2, ..., T_s\}, \tag{9}$$

where T_i (i = 1, 2,...,s) is the time point when all the vehicles on the road network receive the message.

Urban Multi-hop Broadcast Protocol

Urban Multi-hop Broadcast Protocol (UMBP) is proposed for an urban transportation environment where emergency messages are disseminated via multi-hop V2V. UMBP is used to reduce message redundancy and minimize a transmission delay. By using an iterative partition, mini-slot, black-burst, and asynchronous contention mechanism, UMBP proposes a scheme for selecting efficient forwarding nodes [45]. In the first step, forwarding nodes are selected in each direction via bi-directional or multi-directional broadcast. In the second step, the directional broadcast is used to select relaying nodes with different handshaking protocols such as request-to-send (RTS), clear-to-send (CTS), and acknowledgment (ACK). While creating emergency messages, a sender must sense the idle channel for broadcast interframe space (BIFS) satisfying the following condition:

$T_{SIFS} < T_{BIFS} < T_{DIFS}$, where T_{DIFS} is a distributed interframe space interval, and T_{SIFS} is a short interframe space interval. A mini contention window calculated in the following equation is used to avoid emergency message collisions:

$$mini_CW = \left[\frac{T_{DIFS} - T_{BIFS}}{\tau}\right], \tag{10}$$

where τ is a mini-slot length and calculated as $\tau = 2\delta + t_{switch}$, δ is the max delay, and t_{switch} represents the radio switch delay.

Position-based Multi-hop Broadcast

Position-based Multi-hop Broadcast (PMB) is proposed to ensure the consistency of emergency warning message dissemination by utilizing either implicit or explicit acknowledgment [96]. PMB selects a set of nodes from bi-directional lanes that would be responsible for rebroadcasting a message. For that purpose, it is assumed that each node has a similar sensitivity of receiving messages, though with diverse transmission power. Rebroadcasting node selection is based on waiting time given by the following equation:

$$T_{defer} = \left| T_{max} \cdot \left(1 - \frac{ACA_{ij}}{ACA_{max}}\right) \cdot \alpha + T_{rand} \right|, \tag{11}$$

where T_{max} = 100 ms, ACA_{max} is the upper limit of additional coverage area (ACA), α is a multiplier factor, T_{rand} is a short random delay, and $ACA_{ij} = S_j - S_{i \cap j}$, where S_j is the coverage area of j and $S_{i \cap j}$ is the intersecting coverage area of i and j. ACA and waiting time are inversely proportional, so the nodes having the highest ACA will have the shortest waiting time. Nodes with the shortest waiting time are chosen to rebroadcast a message while others will stop their timer. In that way, redundant messages are reduced. While receiving the message from the previous rebroadcasting node (PRN), the current rebroadcasting node (CRN) determines the direction of PRN. If CRN and PRN are in the same direction, an implicit ACK is adopted and PRN will halt its rebroadcasting timer. However, if they are in differing paths, an explicit ACK is adopted where it shows that PRN has not received the ACK which is then retransmitted to PRN using an intermediate node.

Simple and Efficient Adaptive Data Dissemination (SEAD)

Simple and Efficient Adaptive Data Dissemination (SEAD) protocol is used to achieve fast and reliable data dissemination within limited bandwidth. SEAD aims to overcome a broadcast storm problem, minimize an E2E delay, and maximize a packet delivery ratio [97]. A redundancy ratio metric (r) is inversely proportional to the probability of rebroadcasting. r is calculated as follows:

$$r = \frac{\text{The number of received messages } (original + duplicate)}{\text{The number of new messages } (original)}. \tag{12}$$

The redundancy ratio metric is updated after receiving a new message. The messages from a front vehicle are treated as new messages and stored in a vehicle's data buffer, and then they are further retransmitted. On the other hand, the messages from behind are considered as ACK. Waiting time W_t for a message in SEAD is calculated as:

$$W_t = \left[N_t \cdot \left(1 - \frac{min(D_{ij}, R)}{R}\right)\right] \cdot \delta, \tag{13}$$

where N_t is the fixed number of slots, R is the average transition rate, $\delta > 1$, and D_{ij} is the distance between a transmitter i and a receiver j. Rebroadcasting probability P is calculated as follows:

Table 6
Comparison of delay-sensitive data dissemination performance modeling approaches in VANET.

Delay-sensitive						
Performance modeling idea	Description	Routing protocol	Simulation platform	Evaluation mode	Performance metrics	Future scope
Cloud-assisted Message Downlink dissemination Scheme (CMDS) [92]	Rapid message dissemination using cloud computing technologies Safety messages are delivered from cloud to gateway and then to vehicles	Broadcast (I2V)	OMNeT++	Simulation + Analysis	Data dissemination delay Communication overhead	4G and 5G implementation
Urban Multi-hop Broadcast Protocol (UMBP) [45]	Lowering emergency message dissemination delay and reducing redundancy For selecting neighboring nodes, it uses iterative partition, mini-slot and black-burst Bi-directional, multi-directional and directional broadcasting is used	Broadcast (I2V, V2V)	NS-2	Simulation + Analysis	Data dissemination delay Message propagation speed	More complex road structure in ITS
Position-based Multi-hop Broadcast (PMB) [96]	Disseminate warning messages only in one-way lane Calculates waiting time to select the rebroadcast nodes	Broadcast (I2V)	NS-2	Simulation + Analysis	End-to-End delay Reachability Packet collision Saved rebroadcast	4G and 5G implementation
Simple and Efficient Adaptive Data Dissemination (SEAD) [97]	Reducing excessive re transmission messages Hybrid broadcast protocol (delay and probability)	Broadcast (I2V)	NS-3	Simulation	Packet delivery ration Forwarding ratio End-to-End delay Packet drop ratio	Accommodate SEAD to sparse networks
Speed Adaptive Broadcast (SAB) [94]	Scalable data dissemination Probabilistic speed adaptive broadcast	Broadcast (I2V)	OMNeT++	Simulation	Data dissemination delay Communication overhead Data delivery ratio	Supports sparsely connected networks
Density-aware Emergency message Extension Protocol (DEEP) [98]	Resolve broadcast storm problem Delivers emergency messages in specific area	Broadcast (I2V)	NS-2	Simulation	Propagation delay Successful delivery ratio	Heterogeneous message dissemination
A vehicle-assisted computing framework for delay-sensitive application, VFog [99]	Provide computing facilities from fog vehicles IoT in vehicular network	Broadcast and unicast (V2V)	OMNeT++	Simulation	Transmission delay, Packet delivery ratio, efficiency	Users incorporate own task scheduling algorithms
End-to-end backlog and delay bound analysis [100]	Consider stochastic network traffic Adopts scheduling policies such as static priority, first in first out and earliest deadline first	Unicast (V2V)	Not specified	Simulation	End-to-end delay	Investigated for dense network
Mobility-aware and collision-avoidance MAC, MoMAC [101]	TDMA-based medium access control protocol Assign every vehicle a time slot according to a road topology and lane distribution	Broadcast (V2V)	SUMO	Simulation	Rate of collision, Rate of safety message transmission, Rate of safety message reception	Utilizes RSUs to act as coordinators

$$P_i = \frac{(2\alpha)^{i+1}}{\prod_{k=0}^{i} r_k}, \tag{14}$$

where α is a fixed valued parameter.

Speed Adaptive Broadcast

Speed Adaptive Broadcast (SAB) is proposed as a scalable data dissemination scheme to minimize extra communication overhead in multi-hop V2V. It aims to achieve scalability and reliability, and to minimize overhead [94]. Probabilistic SAB (P-SAB) is based on a broadcasting method that uses speed in VANET broadcasting. It reduces the number of redundant data packets to overcome a broadcast storm problem. Slotted SAB (S-SAB) suppresses unnecessary broadcasts to minimize broadcasting overhead. It estimates traffic regime dynamically at each hop so that a lesser number of vehicles can forward the data. Speed ratio V_r is calculated as:

$$V_r = \frac{V}{V_f}, \tag{15}$$

where V is the current vehicle speed and V_f is the maximum vehicle speed as a speed limit. The road is under high congestion if V_r approaches zero. On the other hand, the road is under light traffic condition if V_r approaches one. V_r in S-SAB is used for delay calculation.

Density-aware Emergency Message Extension Protocol (DEEP)

Density-aware Emergency Message Extension Protocol (DEEP) aims to resolve the broadcasting storm and attains high reliability and low dissemination delay. DEEP uses a multi-lane freeway scenario which is divided into three segments. Segment 'A' is supposed to be an accident area. Segment 'B' comes right after 'A' and segment 'C' is the hot-spot area where vehicles can exit the accident area if a data packet is disseminated to them on time [98]. In Source Vehicle Adaptive Algorithm (SVAA), the vehicle that receives the message ensures that the message is new and it is broadcasted by a vehicle ahead of it. The vehicle then forwards it according to a fast forwarding protocol. Following Vehicle Adaptive Algorithm (FVAA), it is ensured that every vehicle in a hot-spot area should receive a message and change the message's route towards its destination. For a fast forwarding mechanism, a vehicle's coverage area is divided into blocks of different sizes. Smaller block sizes are selected for high-density traffic while larger block sizes

Table 7
Pros and cons of selected performance models for data dissemination in VANET.

Models	Pros	Cons
Ant colony optimization [76]	• Search can be conducted in parallel among a population. • It can adapt to changes such as novel distances. • It discovers reasonable solutions rapidly.	• There is a probability of change in each iteration. • Difficulty in theoretical analysis and has more experimental basis than theoretical research. • Uncertain convergence time.
Carry and forward [77]	• In the carry and forward strategy, when a node cannot contact other nodes, it stores the packet, and forwarding is done based on some metric of neighbor node.	• Due to the change of topology and traffic density, it causes considerable delay.
Multi-Hop Broadcast [45]	• It offers Bidirectional broadcast, multi-directional broadcast, and directional broadcast. • Lower emergency message transmission delay and reduce message redundancy.	• The hidden terminal problem is alleviated when vehicle density goes up.
Cloud-Assisted Safety Message [92]	• Operates with various communication and cloud computing technologies. • Design a parallel multipoint message dissemination approach to reduce packet loss, delay, and message redundancy.	• Prearranged bus routes and schedules may vary in different urban scenarios, which, to some degree, may have an impact on the performance.
Novel Position-based [96]	• Guarantees to use fewer nodes to rebroadcast warning packets. • Uses two way lane mode.	• Causes delay due to hidden terminal problem and change of topology.
SEAD [97]	• Efficiency is achieved by reducing excessive re-transmitted messages by considering three parameters, i.e., distance, traffic density, and message direction for data broadcast decisions.	• SEAD does not consider the vehicle's position, speed, and direction for data dissemination, which may cause delay and packet loss.
Speed Adaptive Broadcast [94]	• Considers the vehicle's speed to provide scalable broadcast without extra overhead as it does not require neighbor information.	• It does not consider traffic density which may affect the efficiency of the network.
DEEP [98]	• DEEP considers traffic density to resolve the broadcast storm problem, achieves low dissemination delay, and provides high reliability by delivering an emergency message to a specific area.	• DEEP does not consider the heterogeneity of message dissemination, vehicle speed, and network complexity.

are selected for low-density traffic. The information of a block size in a relay node is forwarded by a source with a flag to a receiving node. But if a relay node does not receive another message within a deferral timeout TO, it is assumed that collision has happened between messages. TO is calculated as follows:

$$TO = T_{slot} \cdot \frac{Area}{O_x\ Oy}, \tag{16}$$

where $\frac{Area}{O_x\ Oy}$ is the total number of blocks in a transmission area.

The summarized advantages and disadvantage of each identified performance model for data dissemination in VANET are presented in Table 7. Syed Sarmad Shah et al. [99] propose a vehicular Fog framework (vFog) that is designed to provide a computing facility from nearby fog vehicles without any support from RSUs. vFog framework supports two types of vehicles: 1) fog vehicles that provide computation to user vehicles; and 2) user vehicles that can only request resources. The authors in [100] propose an End-to-End Backlog and Delay Bound Analysis for Multi-Hop Vehicular Ad Hoc Networks. For such analysis, the authors consider the traffic characteristics of the stochastic network and the highly dynamic channel environment by using the martingale theory. Feng Lyu et al. [101] propose a Mobility-aware and collision-avoidance MAC for safety applications in VANETs (MoMAC), that assigns a time slot to every vehicle according to the mobility of vehicles, depending on road topology and lane distribution. In MoMAC, lanes and road segments are associated with disjoint time slot sets. Each vehicle broadcasts safety messages along with the time slot having information of neighboring vehicles. Time slot collision detection and accessing a vacant time slot in a fully distributed way is done by updating two-hop neighbors' time slot occupying information.

5. Challenges in data dissemination for VANET

This section presents the main challenges in data dissemination and their implications for VANET applications. The following are the primary data dissemination's research challenges to be addressed with VANET applications.

5.1. Security

In general, the most critical problem for data dissemination in VANET is security. The secure message processing and sharing in VANET will require effective security frameworks. Several network protection challenges in VANET are similar to those encountered in conventional wireless networks. However, due to the unbounded network's scale, high mobility, regular topology changes, and frequent exchange of information, the security problems in VANET are inherent and particular. Apart from these issues, privacy concerns are hard to accommodate with authentication and non-repudiation apprehensions [102]. Moreover, due to some characteristics of VANET, such as low overhead requirement because of time constraint, nodes communication with minimal hops, routing nodes' information storage, and adjusted data dissemination solutions, there is a high demand for new security protocols [103–105]. Regardless of the available solutions addressing the security issues in VANET, there is a high demand for new reliable communication protocols to be examined that consider heterogeneous vehicular networks' unique characteristics. An additional concern is preventing attackers from intruding on the confidentiality of exchanged messages and affecting the system's availability. Apart from standard security specifications such as anonymity, authentication, confidentiality, and DDoS protection, VANET is highly vulnerable to brutal attacks, i.e., disable the steering or braking systems. Integrating security mechanisms is critical within a VANET when it comes to safety data dissemination [106,107]. Customers

will not consider warning systems unless they are given confidence, protection, and dependability. The most important security concern within a VANET is the establishment of trust [108]. Integrating protection schemes into VANET applications, on the other hand, would lengthen the time it takes for messages to reach their destination.

5.2. Ensuring effective information dissemination

The challenge of disseminating traffic information effectively and accurately in VANET is essential to tackle. In traditional network infrastructures, such as the Internet, data is usually unicasted, while in VANET, traffic information necessitates broadcasting since knowledge about traffic is intended for the public usage, not for an individual entity [109]. As a result, disseminating traffic information using a broadcasting scheme is preferable to a unicasting-based routing method and is widely used. The benefit of the broadcasting scheme is to enable a vehicle to not require or be aware of the destination address or the path to a particular location. Consequently, it alleviates numerous VANET issues such as predictive mobility, address resolution, route discovery, and dynamic topology. In the case where the VANET infrastructure is unavailable, two transmission mechanisms, i.e., relaying and flooding, should be considered for information dissemination. The flooding strategy, however, usually results in a lot of contact traffic. Thus, avoiding the transmission storm issue is a significant challenge for the flooding approach [110].

5.3. Inconstant network density

The density of VANET can be very high in urban scenarios with hundreds of vehicles in a relatively small area due to traffic jam or can be very low due to low traffic on some faraway routes. Medium access control protocols must be designed accordingly to prevent transmission errors and confrontations [111]. Moreover, protocols that are more informed of possible disconnections in highway scenarios, where the topology can be thinner, and connectivity is more fragmental, should be deployed [112]. In order to have a good data transfer, vehicles traveling in both situations, i.e., high and low traffic density, must be able to adjust their behavior to network density variations.

5.4. Repeated link disconnections

Owing to the enormous mobility characteristic of vehicles in a VANET, the network's topology changes rapidly and causes intermittent connectivity between a source and its destination [113]. Furthermore, due to repeated link disconnections, network resources allocated to vehicles are wasted [114]. There are various routing protocols proposed for high mobility and high packet loss in VANET; however, the fast change in network topology owing to vehicles' mobility speed still presents challenges that are hard to tackle, so this paper proposes an efficient and effective solution. Therefore, constant connectivity analysis and management of mobility-aware resources are critical.

5.5. Heterogeneity of applications

As VANET offers a variety of infotainment and road safety applications, it is important to develop an effective and efficient communication strategy to ensure vehicle safety while also providing high-quality infotainment services in a heterogeneous applications environment. Infotainment application generally necessitates higher throughput, lower packet loss, and higher resource utilization than road safety applications which requires high reliability. It is obvious that a high priority should be given to road safety applications. Hence, network resource allocation approaches and access protocols should be managed in a way to guarantee effective, timely, and reliable communications between all the vehicles on the network [115].

5.6. Node collaboration

The assumption that every node in data dissemination protocols in VANET is prepared to collaborate and share its resources to connect other nodes is not always valid [116,117]. In some cases, certain nodes may engage in making services available to other nodes while refusing to allow the same nodes to use their resources, showing selfish behavior. Protocols and processes will need to implement efficient incentive, penalty, debt, and credit schemes for VANET to ensure that selfish nodes are identified and managed accordingly.

5.7. Implementation complications

The major hurdles towards implementing VANET data dissemination models are the cost, credibility, scalability, and performance issues. These issues are being tackled in numerous ways, including standardization of the modeling approaches, communication protocols, and network security. Moreover, with the constant demand and generation of multimedia contents, such as video, audio, and pictures on VANETs, the requirement of more extensive network capabilities for transmission is highly in demand. The contents of such kinds of multimedia are transmitted into numerous packets. However, various network limitations make the reliable delivery of the contents more challenging.

6. Conclusion

VANET has attracted a greater attention of researchers due to its higher mobility, dynamic connectivity, and non-centralized administration. However, most of the traditional data dissemination techniques are inefficient on VANET due to its limited degree of connection. This paper firstly presents the existing methods related to data dissemination and outlines the categories of important issues that can be addressed for data collection in VANET. This paper outlines the existing surveys that are available in the literature for data dissemination in VANET. This paper performs a systematic literature review of the existing techniques on data dissemination. Moreover, this paper presents a detailed comparison of performance modeling approaches in delay-tolerant and delay-sensitive data dissemination in VANET. The main goal of this paper is to provide an enhanced understanding of the state-of-the-art developments with regards to data dissemination in VANET. Therefore, it is believed that this paper helps the researchers to get a clear view and understand the recent and well-reputed data dissemination approaches in VANET.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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