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Review

# Vehicular Social Networks: A survey

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ABSTRACT

A Vehicular Social Network (VSN) is an emerging field of communication where relevant concepts are being borrowed from two different disciplines, i.e., vehicular ad-hoc networks (VANETs) and mobile social networks (MSNs). This emerging paradigm presents new research fields for content sharing, data dissemination, and delivery services. Based on social network analysis (SNA) applications and methodologies, interdependencies of network entities can be exploited in VSNs for prospective applications. VSNs involve social interactions of commuters having similar objectives, interests, or mobility patterns in the virtual community of vehicles, passengers, and drivers on the roads. In this paper, considering social networking in a vehicular environment, we investigate the prospective applications of VSNs and communication architecture. VSNs benefit from the social behaviors and mobility of nodes to develop novel recommendation systems and route planning. We present a state-of-the-art literature review on socially-aware applications of VSNs, data dissemination, and mobility modeling. Further, we give an overview of different recommendation systems and path planning protocols based on crowdsourcing and cloud-computing with future research directions.

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## 1. Introduction

With the rapid growth of smart devices and advent of advanced communication and computing capabilities, it is possible for drivers and passengers to communicate and socialize with other commuters on the roads. Not only limited to interest, but these commuters may also interact with other passengers facing similar traffic condition, environmental factors, the same mobility pattern, or belong to the same community. These commuters may share valuable information for different personal-oriented or public-oriented applications. The social interdependencies of these commuters can be exploited for a diverse range of applications. These applications can be mainly categorized into four categories; (a) Safety-based applications, (b) Comfort-based applications, (c) Convenience-based applications, and (d) Entertainment-based applications. Thus, integration of advanced intelligent computing and social networking perspective into the vehicular environment has emerged as a new paradigm of Vehicular Social Networks (VSNs) with high potential for diverse applications; not only for future Intelligent Transportation System (ITS) but also for entertainment and drivers comfort along the roads.

A Vehicular Social Network (VSN) is a mobile communication system formed by the combination of relevant concepts and features from the vehicular ad-hoc networks (VANETs) and social networks [1]. Network entities share data and communicate with each other exploiting the social interdependencies. The inheritance of social features and study of the vehicular system under social perspective have significant potential to improve reliability and efficiency in the vehicular environment. Different from other socially-aware networks, network entities in the VSNs are heterogeneous, including On-Body Units (OBUs), Road Side Units (RSUs), drivers', passengers' and pedestrians' smart devices. Considering different scenarios such as urban and highway, VSNs can be easily deployed either in centralized, distributed, or hybrid fashion resulting in three distinct kinds of communication relationships such as humans-to-humans, humans-to-machines, and machines-to-machines. These communication characteristics, dynamic network topology, density variation, and unique applications distinguish VSNs from other traditional social networks and VANETs. The research community has considered the concepts of social networking to design different possible socially-aware applications [2–4]. However, these efforts are limited to Delay Tolerant Networks (DTNs) and Mobile Social Networks (MSNs). Quite recently, the incorporation of social networks in the vehicular environment has attracted the research community to develop innovative applications for VSNs [5]. For example, the Online Social Networks (OSNs) such as Twitter, Facebook, and WeChat exploit the GPS reading to tag different posts by mobile users. Thus, the knowledge of frequently traveled locations and routes from such kind of social networks may impact many research and development fields including intelligent transportation system, path calculation, recommendation, and urban planning [6]. However, this new trend comes up with some technical challenges that need to be considered. Highly dynamic network topology, vehicular density variation, mobility, and short-term communication contacts in VSNs are some of the basic factors influencing the development of application and protocols design. Besides, mobility modeling, data forwarding, routing, simulation, privacy, and security are the other issues which need to be considered. Unlike traditional V2V communication, VSNs can take advantage of social features along with GPS modules, sensing modules, and various radio communication channels. These features enable VSNs to enhance conventional V2V communication with additional features, such as social-aware location-based communication, socially-aware opportunistic communication, autonomous driving, and social driving among neighbors with common interests, or similar mobility pattern. VSNs involve the social communication of drivers and passengers in the virtual community of vehicles based on social interests, common objectives or mobility pattern [7]. It has been observed from research studies that knowledge of the social interaction of nodes can significantly improve the performance of mobile systems [8]; therefore it is anticipated that VSNs can significantly improve the social-aware communication of commuters for a number of applications. In VSNs heterogeneous communication devices, application environment, unique characteristics and features mentioned above distinguish VSNs from conventional MSNs, as summarized in Table 1.

Recently, Vegni et al., in [9] presented a survey paper to investigate perspective of next generation vehicles under VSNs. The authors have focused on main features and possible applications of next generation vehicles followed by data dissemination and social features in the context of VSNs distinguishing from other social networks. Concerning communication protocols, the authors have compared and discussed some methods and research approaches. Their study is only limited to distributed VSNs and socially-aware applications. The work presented in [9] is application oriented to capture a clear image to show the significance of VSNs in the realization of next generation of vehicles. On the other hand, in our work, we provide a state-of-the-art literature review of various efforts made to realize the concept of VSNs with open research issue and future direction. In other words, their work is to highlight the significance of social aspects and social-aware applications to realize the concept of VSNs whereas our work aims to present state-of-the-art literature review in the field to analyze existing work with possible future directions to provide. Also, to the best of our knowledge, there is no such work exists before which presents a literature review on VSN, socially-aware applications, data dissemination in VSNs, mobility modeling and applications based on mobility modeling and data mining. Considering the issues above, and since VSN is a new communication paradigm of interests in both academic and industrial communities, we go a step forward to present an analysis of recent research work and shed light on different open research issues. Our major contributions are:

- We present an overview of VSNs under social perspective and present a literature review of socially-aware applications for VSNs.
- We survey recent approaches to enhance data dissemination in VSNs and present a comparison of these methods.
- We focus on mobility modeling of VSNs and present a literature review of different approaches based on crowdsourcing and cloud computing to enhance urban life.
- We highlight several open research issues and future research directions.

**Table 1**
Difference between VSNs and MSNs.

| | Mobile social networks | Vehicular social networks |
|---|---|---|
| Mobility | Random | Restricted to roads and streets |
| Network topology | Slow nodes mobility | Highly dynamic due to vehicular speed and mobility requirements |
| Social contribution | Real-life, friends | Human-to-human/machines, machines-to-machines, contact frequency, similarity, etc. |
| Network architecture | Opportunistic and the Internet | Internet and VANETs |
| Time sensitivity | Normal and acceptable | Application dependent, real-time requirements for safety applications |
| Energy constrains | High | Not sensitive |
| Mobility modeling | Random and easy | Complicated and large scale |

The rest of the manuscript is organized as follows. Section 2 presents an overview of VSNs formed by the combination of relevant concepts from two different communication networks, i.e., social networks and vehicular networks. Besides, we also focus on the underlying communication architecture where nodes can communicate in a centralized, distributed manner or hybrid manner. Furthermore, we present the perspective applications of VSNs ranging from safety-based to entertainment based application. In Section 3, we focus on different socially-aware application for VSNs. Data dissemination in VSNs is a key issue attracted by the research community. In Section 4, we present a comparative study of various socially-inspired approaches for data dissemination in VSNs. Besides, VSNs' applications and data dissemination, vehicular mobility plays an important role. We extend our analysis in Section 5 to present a literature review on mobility modeling in VSNs and focus on different applications based on mobility modeling and data mining. Before concluding remarks in Section 7, some important open research issues are presented in Section 6.

## 2. Vehicular social networks

At the different interval of day/week, the commuters along the roads encounter other commuters with the same routine, social behaviors, social interests and facing similar traffic conditions along their routes. People tend to use the same routes to travel to and from specific destinations with predictable and regular patterns and form virtual communities on roads with unique features inherited from social networks, i.e., centrality, similarity, common interests, friendship and professional relationships. However, these relationships are not strong as compared to those in OSNs [10]. Vehicular social networking is the concept of incorporating possible social behavior of these commuters in vehicular environments. VSNs incorporate social networking to communicate based on social properties, similar interests, social behaviors and objectives in the virtual community of vehicles, RSUs, drivers', passengers' and pedestrians' smart devices. Social networking and its applications are being considered by the research community and have shown that social knowledge, gained through the interaction of nodes can help to enhance the performance of mobile communication systems. It is assumed that social behaviors of network entities could be exploited to for a diverse range of applications [3,5,9].

VSNs consolidate relevant features and concepts from two different fields namely VANETs and social networks. VANETs provide the underlying communication network infrastructure coupled with centralized infrastructure, whereas social networks contribute to the social knowledge of entities. The mobility of nodes is restricted to roads as in VANET, but it does not mean at all that VSNs is a pure ad-hoc network. VSN can be deployed in a centralized, distributed or hybrid fashion. Different from conventional MSNs and VANETs, VSNs are heterogeneous communication systems where multiple devices including onboard devices, RSUs, and smart devices exploit the social behaviors to communicate in virtual communities along the roads. Also, due to distinct features borrowed from VANETs and social networks, the unique characteristics distinguish VSNs from other traditional mobile networks. It is anticipated that VSNs have the capabilities to support a diverse range of applications, not only limited to road safety and traffic management but can also facilitate commuters to share information such as audio, video, and photos on roads. However, this emerging technology encounters several challenges. In the following subsections, we present the communication architecture, the possible applications of VSNs, and socially-aware applications for VSNs.

As already stated, the social-aware interaction of nodes based on human behavior, common interests and similarity can significantly improve the performance of mobile systems. Some of the factors which largely impact the communication of VNSs include, human mobility, user preferences, node selfishness, mobility restrictions, traffic intensity, and dynamic network topology; to mention a few. Human factors, which cannot be ignored in the vehicular environment, play a vital role in the realization of VSNs. As an instance, the vehicular mobility and traffic conditions in the morning and evening rush hours show relatively high density and static behavior. In such scenarios, vehicles can connect to form social groups or individually to share information, based on their social affiliation, interest, and user preferences. Also, the vehicular mobility exhibits social characteristics [11], which can significantly improve the performance of communication protocols design in VSNs.

### 2.1. Architecture

The major components of VSNs are participants, mobile devices, and network infrastructure. In VSNs, not only drivers, but also passengers, pedestrians, and OBUs participate in the communication. The integrated smart devices in vehicles,

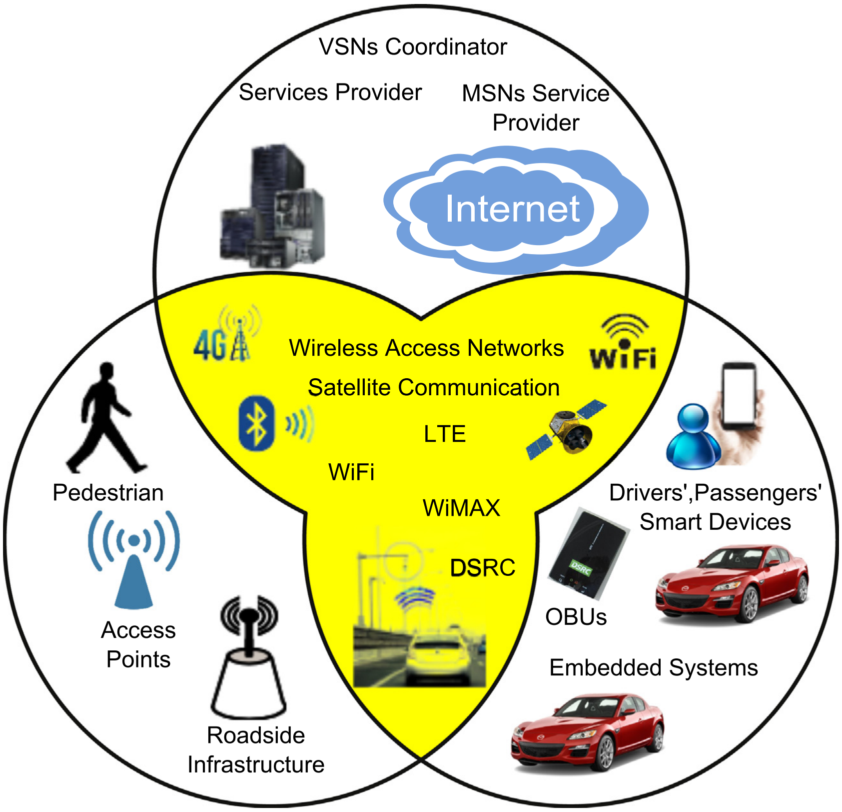

**Fig. 1.** Physical communication architecture of VSNs.

drivers', passengers' and pedestrians' smart devices can detect proximity with other devices and may share contents. Each user can be a publisher, a subscriber or both at the same time. The way in which these devices can communicate depends on the underlying communication architecture. The communication of these devices/users can be classified as humans-to-humans, humans-to-machines, and machines-to-machines. The physical communication architecture of VSNs, shown in Fig. 1, depends on upon the network infrastructure of a vehicular network and software platform. Applications developers can design some applications, platforms, and services for VSNs. These applications or services will facilitate users and devices either in a centralized, distributed or hybrid fashion. Hereafter, VSNs are classified into three types based on communication architecture: centralized VSNs, distribute VSNs, and hybrid VSNs.

In centralized VSNs, all devices/users communicate with centralized services providers such as Intelligent Traffic Control Systems (ITCS), web-based social network services providers, or a centralized server which continuously monitors and manages their interaction. In such a centralized communication architecture, the commuters cannot communicate directly, and all the information concerning the members of VSNs are stored at a remote server. A centralized coordination unit works as a bridge between two users/platforms to communicate. End users/devices communicate with infrastructure units, i.e., RSUs; resulting in Vehicle-to-Infrastructure (V2I) communication. The centralized architecture of VSNs provides an opportunity to each user to maintain his/her profile on the server and may update his/her profile or interest list at any time. This client–server architecture results in relatively stable social ties among users. Also, a centralized system is less sensitive to traffic density on roads and can operate over larger geographic area enabling VSNs user to communicate even they are not close to each other. However, centralized communication cost, in this case, is greater than distributed VSNs. Besides, centralized system architecture may cause inefficient communication between end users, low capacity for content storage in RSUs, and traffic load on RSUs in the highly dense area.

In distributed or decentralized VSNs, vehicles/commuters communicate with each other independently and collaborate in an ad-hoc manner without any centralized server to cooperate or regulate the communication. Vehicles/commuters communicate without any centralized infrastructure to facilitate opportunistic data delivery and forwarding using Vehicle-to-Vehicle (V2V) contact. The intermediate nodes store the contextual and social data packets until the destination node is found. However, this does not mean at all that infrastructure does not exist. Road Side Unites (RSUs), or cellular network can be used to provide connectivity between two nodes. Data dissemination in distributed VSNs is a challenging task since it demands cooperative communication and processing without the aid of a centralized system. Temporary communities are established on roads to share data of common interests based on user proximity. Moreover, data forwarding and dissemination in distributed VSNs is vulnerable to malicious behavior of relay nodes. Interoperability of devices/applications, network protocol design, and communication overhead are other challenges in distributed VSNs. Distributed communication architecture is more efficient than centralize to provide direct communication among vehicles and reduce traffic load on RSUs, however, limited to a geographic area with challenges in communication in sparse situations.

The vehicles can communicate directly using V2V communication or indirectly with V2I communication in a hybrid VSN, enabling a diverse range of applications, such as improved vehicle traffic efficiency and infotainment on the roads. The commuters may communicate using a cellular data connection if the roadside infrastructure is not available. With the advent of advanced wireless communication capabilities of smart devices, a surge has observed in the development of socially-aware applications for vehicular scenarios using cellular data communications. In the following section, we outline the prospective applications of VSNs.

### *2.2. Applications*

This section presents the different possible applications of VSNs. It is perceived that combination of social networking and vehicular networks, in the form VSNs, can help to improve the efficiency and performance of communication systems [12]. Therefore, it is projected that the concept of VSNs can be broadly used to enhance commuters' communication along the roads for different applications. These applications can be widely categorized into four categories: (a) Safety-based applications, (b) Convenience-based applications, (c) Comfort-based applications, and (d) Entertainment-based applications.

The *Safety-based* applications are of great importance and are primarily employed to enhance the safety on roads to decrease the probability of traffic accidents. Every year, a significant number of accidents that occur on the roads are associated with the head, intersection, and rear end vehicles collisions [13]. The safety-based applications can ensure the sharing of information such as vehicle's position, speed, direction, distance heading, and calculated collision position to avoid such accidents. This information can be shared among vehicles or RSUs. Safety-based applications are delay sensitive as the drivers need to be notified promptly to avoid accidents. Some use cases have been presented in the literature that focuses on safety-based applications [14]. These applications include warning for intersection collision, overtaking vehicles, rear end collisions, emergency vehicles, pre-crash sensing, traffic conditions, and signal violation, to mention a few. Social features of nodes, such as node degree, degree centrality, or community acquaintance, can be exploited to enhance data delivery in emergency situation to disseminate the information with possible minimum delay and maximize the bandwidth utilization.

Vehicles and RSUs can be used to share the information periodically to enhance road safety. The exchanged information can be utilized to prevent/predict vehicular collisions. The shared information can be used to optimize the vehicular systems/equipments to minimize the effect of an inevitable crash. Similarly, the emergency warning systems will enable vehicles to broadcast the information of emergency vehicles, i.e., police cars and ambulances, to free the corridor in case of urgency. In addition to these use cases, a number of VSNs applications will enable commuters to share their experience and vehicular information to enhance the safety on roads. As an instance, the mobility of vehicles moving between residential areas and commercial/office areas can be temporally and spatially predictable. These vehicles can form some virtual communities on the fly with vehicles passing through the same road, at the same time and facing similar traffic conditions, where they can share the traffic conditions based on user preferences, such as vehicle density, weather updates, speed and road conditions to improve road safety.

The *Convenience-based* applications primarily help to improve traffic flow, avoid congestion, and reduce commuters' travel time. Some Inter-Vehicular Communication (IVC) projects have focused on to enhancing transportation assistance and coordination [15,16] in terms of on-board navigational systems, traffic flow control, cooperative traffic management, congestion and route computations, etc. As an instance, the commuters on the road may form virtual community to share real-time traffic information with user of mutual interests, which can be exploited to select or change the route to avoid traffic congestions.

The *Comfort-based* applications allow commuters to communicate either with other commuters or with Internet hosts so as to improve commuters comfort. For example, VSNs provide Internet connectivity to commuters along the roads so that they can access other networks to share and download information. These communication capabilities can be used to enhance commuters comfort with a diverse range of applications which include payment of tolls for bridges/roads, parking payments, repair and maintenance records of vehicles, finding free space for parking, finding fuel stations and recreation centers along their trajectories.

Last but not least, *Entertainment-based* applications facilitate commuters while driving to share/download music, video, photos or play games. Socially aware data dissemination, sharing or downloading of location-dependent data in various VSNs will facilitate the commuters to gain access to various available information of diverse interests such as advertisements, multimedia contents, and recreational facilities along the roads [17]. Due to road congestion during rush hours, commuters spend more time in comparison to normal traffic conditions; in such a case, these applications of VSNs will play an important role to provide entertainment sources to commuters.

## 3. Socially-aware applications for VSNs

Over the last few years, significant improvement and development have been observed in the field of smart devices regarding their communication, storage, sensing, and computational capabilities. Also, the concept of *ubiquitous computing* and *cloud computing* technology has enabled the end users to stay connected and communicate with other users in their proximity. Social networks, such as Facebook and Twitter have attracted billions of active users facilitating them to communicate, share and discuss topics of mutual interest in the virtual social communities. Recently, the concept of social networking in the vehicular environment has emerged in the form of VSNs, where drivers and passengers can communicate and share in virtual communities along the roads. As an instance, commuters towards a destination city along a highway may share their driving experience or available information about hotels, restaurants and parking space. Some online services can be used to acquire the information above and made a proper plan before visiting a destination. However, authenticity and quality recommendation does matter for commuters. In this case, a person could easily accept information shared by his friends or trusted user in his proximity. Thus vehicles form social groups or communicate directly using V2V communication to share information based on their social affiliation or common interests. As an instance, the vehicles along the roads in morning evening rush hours can form virtual communities or social groups to discuss and share contents of mutual interest, such as weather updates, news, traffic information or entertainment related information sharing. The social features extracted from SNA can be exploited to achieve the goal of social-aware V2V communication, such as popularity of node, activeness of the node, and group or community affiliation. In [1], Smaldone et al. present the concept of VSNs by introducing RoadSpeak to enable users to communicate within virtual communities through voice messages along the roads. This proposed system works in a centralized manner, where the commuters are considered to share voice messages through a central server, called a coordinator or the RoadSpeak server. Similar to RoadSpeak, Knobel et al. present another application, called Clique Trip [18]. This application allows the commuters in different cars to be connected and feel like in the same vehicle. A group of people towards a common destination may interact with each other and exchange voice messages if they are within the communication range. Besides, if the group members tend to lose each other, an automatic navigational system helps the driver to follow the leading car. Some of these socially-aware applications for VSNs are based on online social networking services, such as Facebook and Twitter, which enable users to communicate with no restriction on time, frequency or location. NaviTweet [19] is a centralized socially-aware interactive navigation system allowing users to provide information to the on-board vehicular navigation system. NaviTweet allows drivers to calculate a personalized route and form a VSN group with other commuters on the same path. Every user of the group can send voice tweets, and the NaviTweet server periodically aggregates these tweets into a tweet digest and send to the members of the specific VSN group. Similarly, Xiping et al. present the concept of Social Drive to encourage the user to improve their driving behaviors. Social Drive provides the integration of onboard devices to social networks to share users' trip information and experience. The commuters are encouraged by a novel mechanism of rating about their driving behavior and fuel consumption. Ford's Tweeting [20] car is another socially-aware cloud-based application for VSNs which enables drivers to be connected with other drivers and share vehicle and route information.

In VSNs, the drivers and passengers along the roads can also communicate with each other even if a centralized infrastructure is not available. This feature enables drivers and passengers to share information directly with neighbors based on social similarity or affiliation in the virtual communities of vehicles on the roads. GeoVanet [21] is a position based application using V2V communication allowing users to communicate directly within close spatial proximity. For instance, let us consider a person who is visiting the city center for the first time, and he needs some information about the famous restaurant or scenic spots around the city. Based on the individual's interests, queries are broadcasted to vehicles within the communication range with a delivery address. GeoVanet preserves the senders anonymity and provides a destination address where the replies should be delivered. If the information shared by other users matches the queries of the initiator, the received information will be shared with the initiator. GeoVanet enables users to receive the maximum amount of results matching the queries within a bounded time and does not guarantee instant delivery of contents.

Lequerica et al. present Drive and Share (DaS), another socially-aware application for VSNs where commuters can share personal and traffic information, including voice notes, pictures, and comments. DaS collects real-time traffic information from vehicles moving along the different alternative route to estimate the travel time and inform the drivers automatically if something happens on the road. A new path is calculated and shared with the driver. The personal information shared by users are associated with their traveled routes, similar to the concept of "tagging" allowing users to socialize on the roads.

The *Crowdsourcing* has great potential to overcome a number of issues related to traffic and transportation services. With increasing number of smart devices and integrated on-board sensors, it is possible to share information with neighbors. The concept crowdsourcing allows the commuters to share valuable information, not only limited to entertainment but also to improve traffic management. Waze [23] is a social mobile crowdsourcing application which allows drivers and passengers to publish real-time traffic information using Internet infrastructure. It is now possible for drivers to select a route towards destination using this crowdsourced data collected from thousands of onboard smart devices. However, crowdsourcing applications have the confidentiality issues related with privacy of drivers and passengers.

The traffic congestion on roads and inclement weather are the factors which highly influence the human mobility on the roads. To know about the weather condition and real-time traffic information may help the drivers to plan the trip and avoid possible inconveniences on the roads. Shankar et al. [24] present a RoadSense application to provide real-time areal traffic information. RoadSense collects real-time areal information using smart devices carried by users who belong to a specific VSN group or driving in the same geographical area. Also, RoadSense shares multiple traffic state information, such as velocity, road congestion, and road conditions. The drivers and passengers may not be able to have continuous access to Internet contents and services while traveling on highways. Social on the Roads (SOR) [25] is a VSN application which enables social communication among users in such scenario where access to Internet contents and services are not available.

**Table 2**
Socially-aware applications for VSNs.

| Reference | Centralized | Distributed | Hybrid Architecture | Scenario | Connectivity | Internet Connectivity | Temporal-Proximity | Spatial-Proximity | Interest | Incentive Mechanism | Community Detection | Integration | Services | Limitations |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| [1] | ✓ | ✗ | ✗ | Any | Laptops, 3G Network | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | Personal and traffic information sharing | Privacy and authentication |
| [18] | ✓ | ✗ | ✗ | Any | Mobiles, OBUs | ✓ | ✗ | ✗ | ✓ | ✗ | ✗ | ✗ | Navigation, Voice Chat | Security & privacy, management |
| [19] | ✓ | ✗ | ✗ | Any | Mobiles, cellular | ✓ | ✗ | ✗ | ✓ | ✗ | ✗ | ✗ | Social Navigation | Scalability, Users' selfishness, safety |
| [6] | ✓ | ✗ | ✗ | Any | Smart phones, Cellular | ✓ | ✗ | ✗ | ✓ | ✗ | ✗ | Facebook | Encourage drivers to improve driving and fuel consumption | V2V Communication with neighbors |
| [20] | ✓ | ✗ | ✗ | Any | Mobiles, OBUs, Cellular | ✓ | ✗ | ✗ | ✓ | ✗ | ✗ | ✗ | Local interest points detection and information sharing | Selfish and malicious nodes, security |
| [21] | ✗ | ✓ | ✗ | Any | V2V | ✗ | ✗ | ✗ | ✓ | ✗ | ✗ | ✗ | Information sharing | Limited to geographical area, privacy |
| [22] | ✗ | ✗ | ✓ | Any | Cellular, WiFi, Mobile, OBUs | ✓ | ✗ | ✓ | ✓ | ✗ | ✗ | Facebook and Twitter | Traffic information, route selection, Experience sharing | User Selfishness, Data dissemination, User interface |
| [23] | ✓ | ✗ | ✗ | Any | Smart phones, Cellular | ✓ | ✗ | ✓ | ✗ | ✗ | ✗ | Facebook and Twitter | Traffic, weather and parking information | OBUs communication with smart devices is neglected |
| [24] | ✗ | ✗ | ✓ | Any | V2V, Cellular | ✓ | ✗ | ✓ | ✓ | ✗ | ✗ | ✗ | Inoformation sharing | User interface and Privacy issues |
| [25] | ✗ | ✓ | ✗ | Highway | V2V | ✗ | ✗ | ✗ | ✓ | ✗ | ✗ | ✗ | Personal and traffic information sharing | Limited to geographical area |
| [26] | ✗ | ✗ | ✓ | Any | V2I, V2V, Cellular | ✓ | ✗ | ✗ | ✓ | ✗ | ✗ | ✗ | Social information sharing | Users selfishness, privacy |
| [27] | ✗ | ✓ | ✗ | Any | V2V | ✗ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | Data delivery in socially-aware vehicular networks | Dynamic community detection and security |

SOR exploits the V2V communication architecture to encourage users to interact in the distributed environment. Each user maintains a personal blog on SOR and shares the personal information and interest with users in the neighborhood. SOR uses a proactive mechanism to recommend friends in the dynamic environment by estimating stable inter-vehicle connections. Real-time communication in VSN is a challenging task due to highly dynamic nature of VSNs. Authors present *VeShare* in [26] to enhance inter-vehicle communication in the highly dynamic vehicular scenario and support time-sensitive social behaviors in VSNs. This framework enables the users to register in different VSNs social-groups using cellular infrastructure to guaranty efficient and timely communication.

After reviewing socially-aware applications from literature, we come up with a conclusion that these socially-aware applications have significant potential to improve road experience, road safety, traffic management, and entertainment along the roads. We also observe that application development for socially-aware networking in the vehicular environment is in its infancy and several issues still need more improvement and attention from the research community to overcome the existing problems to encourage the users to adopt such applications. Table 2 presents a summary of the main contributions in this direction. We summarize the contributions based on characteristics and features along with some of the key issues and challenges.

## 4. Data dissemination in VSNs

VSNs enable commuters to socialize and exchange information with other commuters on the roads. The vehicles in VSNs communicate opportunistically in the distributed architecture and information sharing with neighbors merely happens in given circumstances, such as for a particular social relationship and geographic position. VSNs are constructed on-the-fly and have short life resulting in a highly dynamic network. Data dissemination in VSNs presents several challenges. It is hard to understand and exploit the social relationship and behaviors of nodes in VSNs to improve data dissemination in VSNs. Dynamic network topology and intermittent connectivity in the vehicular environment are two of the factors influencing information dissemination in VSNs. The applications of VSNs demand for reliable and efficient mechanism and protocols for data dissemination which may be achieved considering different network parameters and features. Mezghani et al. present an overview of recent achievements to enhance data dissemination in VSNs [5]. This study provides a taxonomy for data dissemination approaches based on information processing, content delivery, and performance. Recently, Social Network Analysis (SNA) [28] and use of inextricable properties of communicating devices have attracted the research community to design protocols and standards for other communication networks such as Delay Tolerant Networks (DTNs) [29], Pocket Switched Networks (PSNs) [30], Opportunistic Networks (OppNets) [31], and Socially Aware networking (SAN) [3]. SNA plays an important role to provide a base for the inheritance of social features in the vehicular environment to enhance data dissemination in VSNs using social properties and mobility pattern of humans and vehicles.

Every day, people traveling along different routes at different time encounter other people along their trajectories with possibly same mobility pattern or interests. The traffic management policy on the roads, speed limitation, traffic conditions, and destination are some of the factors which influence the encounter frequency of the commuters along the roads. Besides, the social similarity of commuters such as social interests, daily routine, and driving behaviors are some of the other factors influencing their mobility. In [11], Cunha et al. present the social analysis of two vehicular mobility traces and infer interesting features. The mobility pattern shows the presence of communities with similar interests and is possible to find social properties in the vehicular environment. Similarly in [32], authors characterize and study the mobility pattern of vehicles under social perspective. Based on the extensive numerical analysis, the authors identify several important social features and present how these social features can improve the network performance. Levering on SNA and its applications, authors studied these traces to observe the social relationships and structures in the vehicular environment. SNA considers several metrics to identify the importance of users (nodes) inside the network and defines their social relationship (ties). Node Degree, Closeness Centrality, Betweenness Centrality, Closeness Centrality, Bridging Centrality, Cluster Coefficient, Community detection, and Distance are some of the key metrics to find the most appealing node in a social network. For details about these metric, we refer the readers to [28]. In VSNs, vehicles/commuters are considered as nodes, and their social relationships define the ties among these nodes. Thus the important component or suitable relay nodes are identified by considering the metrics mentioned above. Indeed, VSNs consist of human, social ties, user preferences, and common interest which can be collectively or individually used to identify suitable relay nodes in the network to enhance data end-to-end data delivery. For example, a node with high degree centrality shows how important a node is inside a network. Degree centrality is the measurement of direct connection of a node with its neighbors. In other words, degree centrality shows the popularity of a node in the network. In the context of VSNs, choosing a node with high degree centrality as next hop forwarder increases the probability of data delivery. Similarly, betweenness centrality of node $v$ is the number of shortest paths passing through node $v$ from a source node to a destination node, which shows the global importance of node $v$. A node with high betweenness centrality plays a significant role in the network connectivity. Not only limited to degree centrality or betweenness centrality, but also the other social metrics play an important role to enhance data dissemination in VSNs. However, efficiently modeling and selection of these parameters in socially-aware networking is still an open issue. These parameters are extensively considered by the research community to design routing and data dissemination protocols in VSNs. In [27], authors present a novel protocol based on a social acquaintance of nodes for data forwarding in VSNs. The proposed method considers community acquaintance, node activeness and degree centrality of a node to identify next suitable relay node for data forwarding opportunistically. The data is forwarded in store-and-carry fashion to the destination node. Authors consider the social interaction and greater probability of nodes to encounter with other nodes of similar interests or belong to the same community. In VSNs, where people can have the opportunities to meet other nodes that belong to the same community or having higher global community acquaintance with respect to others can be the suitable intermediate nodes for information sharing in delay-tolerant applications of VSNs. Results show that End-to-End delay and packet delivery ratio are significantly improved by considering social features as compared to traditional protocols [27].

In [33], Gu et al. present a social-aware routing protocol based on a fuzzy logic algorithm to improve data delivery and reduce end-to-end delay in the vehicular environment. The proposed algorithm adopts a greedy approach to select next hop in the road scenario. A node which is closest to the destination is selected as next hop. However, in the intersection, the proposed protocol considers centrality, similarity, and activeness of a node collectively to choose the next hop. In [34], Xai et al. present artificial BEE-colony-inspired INterest-based FOrwarding (BEEINFO) mechanism for content dissemination in socially-aware vehicular networks. BEEINFO classifies the user into different communities, and mobile nodes record the community information. Based on community density information, BEEINFO selects the next hop. BEEINFO assumes that each user belongs to a single community or VSNs group. However, users can join different communities or VSNs groups while traveling along the roads. As an instance, a user who is interested in weather updates and also needs some information about the scenic spots may join two different VSNs groups and can be a member of two communities at the same time. Interest based community detection in the dense environment may lead to complexity and higher end-to-end delay.

Data dissemination in VSNs provides a promising solution for various applications; road safety, entertainment, and commercial advertisements are few to mention. Reliable end-to-end data delivery is required for these applications. In [35], authors present another social-based approach for data dissemination in the vehicular environment. This protocol considers the *Probabilistic Control Centrality* to select the next hop. The general idea of this approach is to select multiple relay nodes with high *Probabilistic Control Centrality* to rebroadcast a message on behalf of the sender. Similarly, Bradai et al. in [36] present a novel mechanism for efficient video streaming in the vehicular environment by exploiting the strategic location information of vehicles to achieve high-quality video streaming. Authors define a new metric, called dissemination capacity to measure the ability of node data dissemination in the network. Cunha et al., in [37] present a social-aware data dissemination protocols for the vehicular environment considering the social relationship and mobility pattern. Authors use node degree and clustering coefficient to identify reliable relay nodes for to rebroadcast the message.

In VSNs, heavy network traffic, intermittent connectivity, limited storage, and weak social ties are some of the key factors which make the content delivery more challenging task as compared to static networks. Device-to-Device (D2D) communication infrastructure enables the drivers and passengers to communicate on the fly. In [38], authors present a D2D-Based content delivery mechanism for VSNs. The moving vehicles can communicate directly to share information as well as with the social community of parked vehicles using D2D communication instead of communicating with RSU. The moving vehicles share the interest with parked vehicles in a social spot. For example, the moving vehicles can share the information about the traffic information with parked vehicles in the parking area of a shopping mall, and the parked vehicles can exchange information about shopping, waiting time, and parking space; to mention a few. Not only limited to parked vehicles, but this information can also be shared with vehicles passing near the shopping mall. The main objective of the proposed mechanism is to improve V2V communication, reduce the load in RSUs, and increase storage capability of VSNs by deploying content-centric network (CCN) nodes in the social communities of parked vehicles.

Traditional performance metrics, such as end-to-end delay, data delivery ratio, and bandwidth utilization greatly affect the behavior of VSNs. The performance of VSNs in terms of these metrics depends upon the applications. For examples, applications for road safety and traffic information demand for the short end-to-end delay. On the other side, delay-tolerant applications require improved data delivery ratio, instead of low end-to-end delay. In VSNs, people commute along the same route at the same time encountering other commuters with similar mobility pattern or facing the same traffic conditions. Besides, these commuters may have social similarity or belong to the same community. In [39], authors, present data forwarding mechanism based on community affiliation which shows that delivery ratio can be improved if data packets are forwarded to nodes that belong to the same community as the destination. In VSNs, commuters along the same route traveling at the same time on a regular basis may create virtual communities on the roads which can be exploited to enhance data delivery ratio. Also, people with similar social interests and similar mobility pattern tend to encounter each other frequently. Based on this observation, some work in literature [40,41] exploits social similarity of nodes to enhance data delivery ratio for delay-tolerant applications.

From the literature review, we observe that data dissemination in VSNs can be improved considering mobility pattern, social similarity, communication infrastructure, and user interests for time-critical and delay tolerant applications of VSNs. Table 3 presents summary and comparison of different approaches for data dissemination in the vehicular environment.

## 5. Vehicular mobility in VSNs

In VSNs, the mobility of mobile vehicles is restricted to roads and highways; vehicular networking enables passengers and drivers to exchange information for diverse applications (safety and non-safety). Human behavior, traffic management, social characteristics, and daily routine of the commuters are some of the factors which largely impact the mobility in the vehicular environment. Also, user preferences greatly influence the mobility pattern. For example, moving from a specific source towards a destination, the route selection depends on drivers' preference, such as fastest route or shortest route. Similarly, the social attractiveness of different social spots and time are the other factors which affect the mobility in VSNs. For example, on workdays, people to their offices in morning and back to home in the evening, while on weekends people tend to stay to home or move towards other social spots (e.g., shopping malls, parks, restaurants, theaters, etc.).

Cunha et al., in [11] analyzed two vehicular mobility data set traces: (1) Zurich's Trace, (2) San Francisco's Trace. Zurich's trace is a realistic data set based on mathematical modeling and produced in mobility modeling simulator considering the Zurich's city information. This data set contains the trajectory traces of vehicles over the day. The San Francisco's data set includes real GPS data set of 551 taxi cabs in the city. This data set contains the data captured from GPS device over trajectories at each minute. Authors considered different aspects of vehicular mobility to analyze different metrics at *Macroscopic* and *Microscopic* levels. These parameters include distance, diameter, density, edge persistence, node degree, cluster coefficient, and closeness centrality. Some mobility parameters are being considered with some assumption to analyze the encounter of vehicles. From analysis result, it is shown that vehicular networks exhibit social characteristics that can be exploited to enhance network performance in vehicular networks. Lu et al. in [42,43] investigated the network performance in social proximity vehicular networks. Authors consider that the mobility of vehicles is restricted around specific social sports. From analysis results, authors infer that the network performance in the socialized vehicular environment depends on the mobility pattern.

In addition to mobility pattern and human behavior on network performance, exploiting the advanced communication capabilities of smart devices and onboard services, the vehicles and commuters can share valuable information with their neighbors and stay connected. With the extremely rapid development in the field of communication and computing, the number of connected devices has exceeded the world population [44,45]. Considering these developments and the concept of *crowdsourcing*, we can achieve the dream of Smart and Green City. For example, Liu et al., in [46] present Carbon-Recorder, a mobile social application not only to encourage drivers to improve their behavior but also provide social awareness and a platform for data collection which can be exploited by the research community and traffic authorities for intelligent transportation systems. In [47], Chen et al. present crowdsourcing-based application for smart parking in Smart Cities.

**Table 3**
Socially-aware contribution in VSNs.

| Reference | Objective | Main Idea | Centrality | Similarity | Community | Activness | Location | Cluster coefficient | Issues addressed | Challenges |
|---|---|---|---|---|---|---|---|---|---|---|
| [33] | Efficient data delivery | To select suitable node as relay node | ✓ | ✓ | ✗ | ✓ | ✓ | ✗ | Reduce end-to-end delay & Improve packet delivery ratio | Node selfishness, Realtime scenario or simulation, Security & privacy |
| [34] | Packet forwarding using social properties | Consider social properties and mobility pattern of humans and vehicles | ✗ | ✓ | ✓ | ✗ | ✗ | ✗ | Message delivery ratio, average latency & hop-counts | Limited interest profile, Week community detection, security |
| [35] | Maximize the spreading of messages | Select next hop based on the Probabilistic Control Centrality | ✓ | ✗ | ✗ | ✗ | ✗ | ✗ | Improved broadcast capabilities with lower overhead | Communication channel, Incentive mechanism, security |
| [36] | Data packet forwarding (Video) | Rank the vehicles based on their location and capacity to reach other vehicles | ✓ | ✗ | ✗ | ✗ | ✓ | ✓ | Reduce redundant broadcast, | No incentive mechanism for selfish nodes, small scale simulation, privacy |
| [37] | Rebroadcast data messages based on social metrics | Selection of relay node based on degree centrality and cluster coefficient | ✓ | ✗ | ✗ | ✗ | ✗ | ✓ | Reduce broadcast storm, | Privacy, node selfishness and real time scenario |
| [38] | Reliable Content delivery in VSNs | Improve V2Vccommunication, reduce load in RSUs, deploy CCN in parked vehicles | ✗ | ✗ | ✓ |  | ✓ | ✗ | Reduced traffic load in RSUs, Reduced overhead | No mechanism for community detection, how to deal with nodes' privacy &selfish behavior |
| [39] | Reduce redundant broadcast and improve data delivery | Messages are forwarded to destination or xmarkdes which belong to community of destination node | ✗ | ✗ | ✓ | ✗ | ✗ | ✗ | Improve delivery ratio and reduce cost | Dynamic community detection, Security and node Selfishness |
| [40] | Improve packet forwarding | Individuals with similar interests tend to meet more often | ✗ | ✓ | ✗ | ✗ | ✗ | ✗ | Improved packet delivery | Privacy, node selfishness, and mobility are the key issues |
| [41] | Enhance data dissemination based on Social features | To extract features and made a forwarding decision on similarity | ✗ | ✓ | ✗ | ✗ | ✗ | ✗ | Multipath rout scheme to enhance data delivery | Incentive mechanism, security issues, |

The smart parking application integrates crowdsourcing with traditional road navigation system to collect and share real-time information about parking availability. The crowdsourcing applications in VSNs have great potential for intelligent transportation. For example, a driver can select a suitable route from source to destination, drivers and passengers can find a good restaurant along their route using recommendation systems, drivers can easily find a gas station with a lower price, and taxi drivers can choose a suitable route; are few to mention. The crowdsourcing capabilities of VSNs can significantly overcome traffic congestion problem to share the real time road information. Not only limited to private vehicles but also public transport vehicles such as buses can significantly contribute to crowdsourcing data to overcome such issues. Kong et al. in [48] proposed a long-term traffic anomaly detection scheme to detect traffic anomaly in the city based on crowdsourced mobility data of public transport vehicles. The applications of VSNs based on crowdsourcing do not only provide insights to traffic conditions for city planners but can also be used to inform vehicles in VSNs about traffic anomalies, public events, disasters and road accidents.

In VSNs, the design of such interesting environment and user-friendly applications should consider the underlying mobility model and human behavior. Complexity and cost of large-scale scenario for performance evaluation of these novel applications in vehicular networks make the preliminary assessments impractical. In such cases, simulations become the only possible choice to validate newly designed architectures and network protocols. However, simulation analysis of vehicular networks is often biased due to the limitation on mobility modeling. The mobility of nodes greatly affects the performance of different protocols especially routing and data forwarding. So, inappropriate mobility model of vehicles for performance evaluation of protocols using a flawless network simulator can predict misleading results and conclusions. Therefore, to achieve credible findings and results, it is acknowledged that mobility modeling should be capable of capturing all the unique possible microscopic and macroscopic dynamics of the vehicular environment. Publicly available data sets do not capture both the microscopic and macroscopic dynamics of vehicular mobility over a large urban area [49]. However, over the last decade, efforts have been made to analyze these available data sets and propose different application/protocols to facilitate passengers and drivers along their trajectories.

After reviewing many works in the literature about mobility modeling and applications based on mobility modeling and vehicular trajectories, we classify the existing work into three categories: *mobility modeling*, *recommendation systems* and *route discovery & planning*.

### 5.1. Mobility modeling

Mobility modeling is one of the most challenging issues in VSNs. The mobility traces or collected mobility information from the onboard device and personal devices can be used to support different applications in VSNs as well as to evaluate the performance of the various applications. The social interaction of nodes depends upon the density, mobility pattern, connectivity, and speed, which are the key elements to consider for mobility modeling for VSNs. As already stated, vehicular mobility exhibits social features observed from real traces of vehicular mobility. So, it is of great importance to consider the possible social features for mobility modeling in VSNs. Analyzing the existing work, the connectivity of vehicles in VSNs mobility models can be achieved by considering mobility pattern, contact frequency, inter-contact interval, and clustering. After a few years of research, a large number of mobility models have been presented, varying from most trivial to the most realistic ones. Some of these are freely available while some are commercial based traffic simulators. Most of these efforts made in this direction are uncoordinated, and individual interests are targeted rather than considering a global, reliable, reconfigurable, dynamic, and freely available data set for vehicular scenarios. Different approaches are being followed by the research community to develop these models. These efforts can be categorized into three basic categories: *Synthetic Mobility Models*, *Real World Mobility Models* and *Simulators-based Mobility Models*.

Synthetic mobility models are either based on stochastic models or traffic stream models. Stochastic models are based on random mobility of vehicles while traffic stream models are based on different models borrowed from transportation research, i.e., Car-following models, Queue models, and Behavioral models. For more details about these models in details, we refer the readers to [50]. The major limitation of such models are the complexity to model human behaviors as these vehicles are controlled by drivers and cannot be programmed to follow a specific pattern in all cases. Also, the complex nature of large scale scenarios or interaction of vehicles makes the synthetic modeling too complex or impossible.

Real-world mobility models are based on the real-time mobility traces of vehicles. Recently, mobility modeling based on real traces has attracted the research community, however, resulting in some challenges. One of these challenges is the process of extrapolation of patterns that are not observed in the traces. If the mobility traces are recorded from buses, an extrapolated model achieved through complex mathematical modeling cannot be applied to personal vehicular mobility scenarios. The second limitation is the availability of data traces. However, this approach has attracted the research community and the information gained through real traces may help us to configure the synthetic models, making them more realistic. Besides, Some research communities have developed some realistic simulators for research in transportation such as SUMO [51], TRANSIMS [52], and CORSIM [53]. However, these simulators are quite complex and cannot be used for network level analysis directly. Besides, mobility modeling is attracted by the research community resulting in a number of synthetic, real world, and simulator based data sets. These efforts are not synchronized, as well as none of them is accepted as a standard so far.

In the last few years, a surge in demand for generic, accurate and realistic mobility has been observed, and several efforts have been made in this regard. However, mobility model with accurate macroscopic aspects has been the topic of interest for the research community. As mentioned in above section, trace based models are more realistic. However, these trace based models have some limitations in terms of extrapolation and large scale mobility modeling. One of the important macroscopic aspects for a vehicular mobility model is Origin–Destination model [50], however, being ignored by the majority of efforts made for mobility modeling [54]. Recently, Uppoor et al. in [49] used the vehicular mobility simulator to optimize the trajectories of social vehicles in the city of Cologne. In this model, authors considered Gawron algorithm for routes assignment to achieve dynamic balance. Authors generated a mobility data set for 24 h based on social vehicular data in Cologne city. As the underlying network is imported from OSM, authors observed the wrong road restrictions on road segments and modified wherever it was required. However, improving road network data in highly dense urban areas may be a difficult task to overcome wrong restrictions in the road data. A false representation of road data and resulting data set may result in unrealistic results; even a credible network simulator is used. Similarly, Pign et al., in [55] used the microscopic simulation tool to generate vehicular mobility data set considering the city of Luxembourg. Authors used the data from traffic inductors. However, inductors are only installed in few specific areas of the city, and the whole area of the city was not covered. So, this data set is not suitable for credible simulation as it does not cover the entire city and available for the shorter duration. Ferreira et al., in [56] used road image data to construct a vehicular mobility model. Authors used three-dimensional imaging technology to capture the macroscopic data. The images were captured using aircraft in the city of Porto with a frequency of 5 s. The total duration of the captured data is one week. This approach is not only expensive in terms of resources utilization but also lack the global impact of vehicular mobility. Similarly, Cetin et al., in [57] generated a vehicular mobility trajectories using a large-scale multi-tasking microscopic simulation tool. However, authors did not consider the variation of vehicular density. The efforts and progress in this direction are not synchronized, and some of the models are biased. Considering the application requirements, challenging environment, choice of mobility model, and simulation tools, mobility modeling in VSNs is still an open issue and efforts are needed to overcome the problems related to vehicular mobility, such as mobility pattern, clustering, transmission range, connectivity, and network infrastructure. Besides, inter-contact interval, contact frequency, contact duration, vehicular density, node degree, and clustering are the key factors to be considered in vehicular mobility modeling [58–61]. These factors greatly impact the communication V2V communication and data delivery in VSNs.

Another direction which has shown improvement in mobility modeling is to characterize, and mine existing real world traces and extract meaningful information that can improve mobility modeling or network performance in VSNs. Mobility models play a vital role in the evaluation process of different algorithms, applications, and protocols for the vehicular environment. Considering the mobility characteristic of real traces may help to model a realistic synthetic mobility model. There are some studies in the literature that focused on characterization of mobility traces. However, authors did not consider the macroscopic attributes of mobility in these studies. Recently, authors in [54] characterized a realistic trace to model a generic mobility model. According to their proposed model and consideration, they extracted some meaningful information, i.e., departures and arrivals, distance and time for mobility modeling. It is shown that departures and arrival follow geometric and zero differential geometric distribution. Based on this analysis, the authors proposed a generic mobility model. However, this model might not be accurate in other cities. Leveraging on crowdsourcing, the information shared by passengers and drivers along their routes enable us to mine collected data for a number of applications related to road safety and intelligent transportation. In [6], Comito et al. present a novel mechanism to mine efficient route from geo-tagged posts. The proposed mechanism not only help to select a popular route considering the number of trips on the specific road but also predicts the social spots in the city. Yuan et al., in [62] mine the real-world data set collected from 33,000 taxis equipped with GPS devices and propose a mechanism for fastest route recommendation. The proposed model considers time, weather conditions, and individual driving behavior observed from different sources. It is acknowledged that characterization and analysis of large scale vehicular mobility models can be efficiently exploited to improve VSNs' applications. In [63], authors present a cloud-based mechanism to discover mobility pattern from large-scale trajectory data which can be used to enhance different applications in the vehicular environment, such as location prediction, intelligent transportation, social similarity, path planning, and recommendations. In the following subsections, we present different applications based on mobility data for recommendation and path planning.

### 5.2. Recommendation systems

VSNs applications are based on social networking in vehicular environment considering human behavior and preferences. The individuals share contents of common interests with another individual in the temporal and spatial proximity. Lequerica et al., in [22] presented a framework, Drive and Share (DaS), to enable commuters to share information for a number of services including traffic information, photos, and voice notes and recommend a place. DaS can recommend several points of interest to the drivers, such as restaurants, parking areas, or gasoline station calculated with real time data gathered from vehicles in the same geographical location. Similarly, these social-aware applications of VSNs enable the commuters to share contents and recommend potential friends or points of interest to the commuters on the road. Leveraging on these capabilities of VSNs, the taxi drivers can explore potential points of interest to yield high income by serving a maximum number of passengers.

Exploring reliable and efficient strategies for passengers to find a taxi or for taxi drivers to find a new passenger and avoid idle cruising is a problem that has extensively been investigated by the research community. The aim of these efforts is to find hotspots for drivers to pick up a new passenger or for a passenger to find a vacant taxi with minimum wait along the streets. Chang et al., in [64] used spatial statistical analysis, a clustering algorithm, and data mining on historical data collected from taxi drivers of Taiwan taxi company. The data set contains the taxi request information. Authors extracted the environmental and time context from available data set of taxi request to find hotspots for taxi drivers to pick up a new passenger. Authors used hierarchical clustering to cluster taxi requests and then finally ranked them based on high density. Authors exploit different metrics to define hotspots which include cluster geometry, hotness index, and semantic road segments. However, drivers can set their strategies. Idle taxi cruising not only leads to environmental pollution but also causes extra fuel consumption which is not cost effective. To avoid idle cruising of taxis to get a new passenger, Yamamoto et al., in [65] proposed an adaptive routing mechanism to recommend pathways to drivers where they can get more passengers. This pathways recommendation system is based on fuzzy clustering mechanism which changes dynamically based on taxis' position in a specific geographic area. Lee et al., in [66] analyzed pickup pattern of service of taxis based on data set collected from taxis. Authors proposed a recommendation system for empty taxis using k-means clustering approach to discover clusters with high demands to pick up a new passenger. Temporal analyses were performed to create time-dependent pickup pattern within each cluster. The proposed approach suggests nearby cluster with high demand for a taxi to reduce empty taxi ratio.

In the approaches above, authors used either pickup or drop-off pattern to propose taxi recommendation systems. However, Palma et al. [67] used a different approach as an alternative solution to find "interesting places" based on vehicular speed. Authors used clustering mechanism to find regions with low vehicular speed based on trajectories information. Trajectories analysis is used either for user scenario analysis or traffic analysis. Yue et al. [68] used taxi trajectories data to find attractive places that are visited by people more frequently such as shopping malls, residential areas, and work areas, etc. Authors used level of activeness (LOA) based on the number of visitors in a specific geographic area and spatiotemporally similar pickup and drop-off location information to recommend attractive areas. In addition to finding a vacant taxi, Ge et al., in [69] analyzed vehicular location traces to propose an energy-efficient transportation system to guide drivers to pick up points with high demand or potential parking points.

To find a vacant taxi at a specific location and a given moment is of considerable interest for a passenger to plan his/her daily schedule. To facilitate passenger to predict vacant taxis, Phithakkitnukoon et al., in [70] proposed a predictive scheme for vacant taxis in a specific geographic area. Also, this proposed model also helps to guide the drivers to specific areas with high demands for a taxi. Similarly, Veloso et al., in [71] used extensive analysis of GPS traces collected from taxis to visualize the services of taxis in a specific area within a given moment. Authors explored pickup and drop-off pattern to propose a predictive scheme for next trip of a taxi from a pickup area. Further, authors extended their analysis [72] to predict next pickup area.

Most papers in this direction have focused on finding suitable hotspots where drivers can get a new passenger, or a passenger can catch a taxi. The performance and accuracy of such kind of recommendation systems depend on various variables. Li et al., in [73] analyzed large-scale taxis GPS traces to evaluate/identify both inefficient and efficient passenger-finding mechanisms. Authors categorized the proposed passengers finding mechanism based on location, time, status (“hunting” or “waiting”) and position. Authors propose a performance predictor for taxis built on selected features determine whether a driver should wait, hunt, travel a long distance to find a passenger, or stay locally. Similarly, Yuan et al. [74] exploit passenger mobility pattern and pickup behavior of taxi drivers based on location and time to propose a novel recommendation system for drivers and passengers. The aim of this recommendation system is to reduce the idle cruising of taxicabs and to help people expecting to take a taxi in the specific geographic area. Hu et al. [75] applied clustering approach to GPS traces to predict potential pickup points. Pickup points are recommended for next passenger based on estimated gasoline consumption. Finally, Yang et al. [76] proposed a data-driven strategy for taxi operation to maximize taxis’ drivers’ profit. Authors introduce a time-location-sociality model to predict some passengers in a social functional region. The proposed system recommends a top-N number of hotspots to the driver to pick up a new passenger. In addition, several applications of VSNs, as presented in Section 3, enable the commuters to share real-time traffic information, which can be exploited for a number of recommendation services, such as parking, refueling, restaurants, and route.

### *5.3. Route discovery & planning*

Route discovery, planning, and maintenance have been studied extensively for the last few decades. Most of the efforts made to discover a path from source to destination are mainly based on Dijkstra’s algorithm. This algorithm is primarily used to find the shortest path from source to destination based on the weight of the edges (road segments in vehicular scenarios). Travel-time or the distance is used to assign weights to road segments. Planner and hierarchal algorithms are the most common algorithms applied for path planning based on Dijikstra’s algorithm. Li et at. [77] used statistical analysis to design a hierarchy of roads based on the frequency of use. Authors analyzed taxi GPS trajectories data to plan a route from source to destination to travel along the highest hierarchy of roads. Lou et al. [78] proposed a novel scheme for map-matching of GPS trajectories with low sampling rate. The matching algorithm is exploited to build a candidate graph to identify the best matching path from source to destination. Onboard devices with GPS sensing capabilities are used to provide driving direction to a driver after he/she specifies a desired destination. In literature, historical GPS traces of vehicular mobility are being analyzed to predict a route/destination. Monreale et al. [79] analyzed trajectories patterns to predict next location of a moving entity based on a decision tree which mainly focuses on all previously available trajectories information within a particular region. Similarly, Lim et al. [80] used stochastic modeling of travel delay on road networks to propose a stochastic motion-planning algorithm to find routes that maximize the probability of reaching a specific destination within a particular time interval.

In VSNs, the route discovery should consider not only the models above but also the human behavior and human mobility. As an instance, the experience of taxi drivers cannot be neglected in the search for a quick route from source to destination. Similarly, DaS enables the commuters to share real-time traffic condition and estimate the travel time of different possible alternative routes calculated with real-time traffic data. Also, the drivers behavior can significantly influence the traffic condition. Yuan et al. in [81] analyzed the trajectories information to extract drivers’ behavior in a particular geographic area. Mining historical GPS trajectories data of a large number of taxis, authors proposed a mechanism to predict a possible fastest path based on drivers’ experience from a specific source to a specific destination. Proposed algorithm first predicts an initial path on a landmark graph generated from taxis’ trajectories and then a refined path is calculated on the underlying road network. In [82], Bastani proposed clustering algorithm to define new transportation routes using flexi route discovery algorithm based on mining through multiple taxi trajectories. The proposed algorithm extracts information of routes frequently traveled to reduce mileage from source to destination. Finding a fast route will not only reduce travel time but will also reduce energy consumption. Yuae et al. [62] analyzed a real-world data set of GPS traces and proposed a cloud computing mechanism to find an optimal route from source to destination exploiting drivers’ behavior and traffic conditioned extracted by mining historical trajectories data. This mechanism can predict future traffic, and self-adaptive mechanism facilitates the end user to find new driving direction.

Observed from literature review, the majority of the researchers have used the available trajectories information captured from GPS device of taxicabs in a specific city/duration. These trajectories data have only information of routes traveled by taxis and are difficult to cover all possible trajectories with such limited data set. Xue et al. [83] identified this problem, called “data sparsity problem”. To overcome this problem, authors proposed a novel mechanism to construct “synthesized” trajectories followed by an algorithm to predict future destination.

Recently, Chen et al. [84] studied the crowdsourced GPS traces and proposed a novel approach for route planning. Authors used clustering mechanism to identify hot areas exploiting pick up/drop off pattern available through mining GPS traces. For an efficient path planning, this mechanism uses some parameters including operation time, origin, destination, bus stops, etc. A road with expected high number of passengers is selected as the best route. Not only limited to path planning or destination prediction, but GPS traces analysis can also be broadened and deepened in several directions to enhance and develop applications for VSNs. Also, route selection could relay on traffic information provided by trusted neighbors in VSNs, which can recommend suitable routes that already traveled.

## 6. Future research direction

VSN is one of the recently emerged communication networks exploiting social behaviors of nodes which has attracted not only the academia but also the industry for different applications ranging from non-safety related applications to safety based applications including collision warning, emergency messages delivery, and entertainment. However, inheritance of social and behavioral aspects of nodes into vehicular environments results in a number of questions to be answered. *How to exploit these social aspects to enhance QoS in vehicular networks? How to apply social theories to design optimal protocols? How to strengthen security mechanism based on trust levels of individuals? How to design or motivate individuals to participate in data dissemination in a fully cooperative manner?* After reviewing currently efforts made in this direction, we observe several issues which need the attention of research community. Based on our analysis, we highlight a few of these issues for future research.

**From social networks to VSNs:** Integration of social networking into VSNs have great potential for safety and entertainment in the vehicular environment. As an instance, mining the social similarity of commuters and geo-tagged tweets of commuters can be exploited to enhance traffic management. However, different from the traditional social networks, where the friendships of users are online or offline, vehicles connect each other by "encounter" in VSNs. Since information sharing with neighbors merely happens in given circumstances, such as for a specific social relationship and geographic position, VSNs are constructed on-the-fly and have a short life. Therefore, the construction of VSNs is widely affected by the spatiotemporal properties. The social relationships in VSNs are weaker than those in traditional social networks. Drivers and passengers are people with similar driving histories or common interests, instead of friends or family members in traditional social networks. Research should consider not only the strong social similarity of nodes, such as spatial proximity but also focus on week ties between the users to enhance data dissemination in VSNs.

**Communication protocols design:** SNA and its applications have gained much attention from the research community in the context of Information and Communication Technologies (ICT) to facilitate reliable and efficient data communication. In VSNs, where the participants share a lot of information with restricted mobility patterns, traveling along the same roads, traveling towards the same destination at the same time, and having similar interests; interdependencies of network nodes and social behaviors can be exploited to improve network performance. Also, the mobility of vehicles is controlled by people so the social ties among these people lead to social relationships which can be utilized for making a data forwarding decision. A number of routing and data dissemination protocols for vehicular networks have been proposed so far which do not consider the social behaviors of commuters. Similarly, keeping in mind, the intermittent connectivity in vehicular environments, the store-carry-and-forward methodology of DTNs has been utilized to design protocols for vehicular networks which also lack the social contribution of nodes. Social behaviors and interdependencies of nodes have been utilized to design protocols for Mobile Social Networks (MSNs); however, either these proposed protocols are simulated in non-vehicular environments or compared with other protocols which are not specifically designed for vehicular environments. On the other hand, VSN can be deployed in centralized, distributed, or hybrid fashion, where a number of devices can participate, such as onboard sensor, OBUs, RSUs, and passengers' and drivers smart devices. Research should consider all these scenarios to design efficient communication protocol limited to not only V2V or V2I communication, but also in-vehicle communication and interaction between the users, users devices, and on-board devices. Of course, the smart devices carried out by people, such as mobile phones, are resources-constrained and that must also be considered for designing applications in VSNs.

**Selfishness:** It is assumed that all nodes in a network work in a cooperative manner, however, in reality, some of these nodes exhibits non-cooperative behaviors to conserve their limited resources or increase their benefits. Li et al., in [85] present the concept of social selfishness, where nodes only cooperate with other nodes with whom they have a social relationship, i.e., coworkers, classmates, friends, etc. In social perspective, the degree of cooperation of socially selfish nodes depends on social ties, i.e., provide better services and support for those with whom having stronger social ties and vice versa. The social selfishness of user can be either *individual selfishness* or *social selfishness*. In the former one, users only replicate their messages without considering social ties with others. In the latter one, selfishness of nodes depends on the social ties with other users. Effective incentive mechanism in the vehicular environment is a highly challenging task due to spontaneous nodes connectively and dynamic network topology. In VSNs, both *individual selfishness* or *social selfishness* need to be considered based on the interdisciplinary collaboration of engineers and sociologists.

**Security and Privacy:** In our daily lives, security is one of the main issues over which individuals in our society show great concern. Different applications of VSNs, ranging from safety to entertainment, rely on drivers' information, i.e., location, interest, trajectories, identities, etc. If VSNs disclose personal information of drivers to other commuters, it cannot be widely accepted by the public. Similarly, privacy and security preservation issues include data integrity and authentication in VSNs. For example, if a malicious node in the network injects a message to the network without any authentication and integrity protection, a single malicious message can potentially lead to adverse events such as car accidents on the roads. Finally, efforts have been made to design different recommendation systems to help the commuters along the roads to find a suitable route to desired destinations or passengers pick-up/drop-off POI. However, false recommendation systems may result in resources wastage, i.e., fuel and time. Therefore, privacy, authentication, data integrity, and security are the key issues in VSNs to be handled before its acceptance in civilian scenarios. Another issue is the trust among drivers and passengers on the roads, and it should be addressed before VSNs are publicly accepted. Social trust in VSNs is required to encourage the participants to cooperate in virtual and dynamic communities for different applications. Similarly, location privacy is also an important privacy measurement required to be addressed. For instance, location of vehicles and mobile devices are directly linked to people and people always seem reluctant about sharing their location. Therefor, security and privacy issues must be well addressed in VSNs.

**Simulation and mobility modeling:** In [32] Cunha et al. characterize and evaluate the realistic mobility traces of vehicular mobility in the context of social dynamics. Authors used extensive numerical analysis to identify the importance of social characteristic found to enhance network performance in VSNs. These captured social characteristics not only help to improve safety related applications but will also have a significant impact on protocols designed for non-safety related applications. Mobility modeling for VSNs poses more challenges as compared to other types of ad-hoc networks. Harri et al., in [50] presented an in-depth analysis of possible vehicular mobility modeling and available platforms. The available mobility generation or networks simulation platforms do not take the social characteristics of commuters into consideration. Integration of social characteristics into these platforms is one of the challenging issues to be considered by the research community to achieve the goal of credible analysis and evaluation of new protocols and architectures. Research should consider the mobility pattern, contact frequent, contact duration, clustering and spatial distribution of social spots for mobility modeling.

**Middleware design:** VSNs' applications are infrastructure dependent. A software layer which provides an interaction between the underlying network infrastructure and applications is termed as middleware. Using a middleware to provide a common set of services for VSNs can simplify the application development process. However, highly heterogeneous and ubiquitous services of VSNs make the application development process more challenging. On the other hand, existing middleware designed for traditional mobile networks are closely coupled with specific applications which may hardly meet the requirements of a diverse range of VSNs' applications. Consequently, efforts are needed to overcome these challenges to develop software platforms to support application development and deployment in VSNs.

**Routing and Forwarding:** In VSNs, cooperative behaviors of nodes can be exploited to design novel algorithms for data forwarding among the communities. Commuters belonging to the same community may share valuable information of common interests. Some specific issues related to VSNs such as mobility patterns, network topology, demographics, rapid changes in vehicles arriving and leaving, the density of vehicles at different times of the day, make the existing routing protocols less suitable in VSNs. First, based on the unique characteristics of VSNs, it is extremely hard to design some protocols to support all kind of VSNs' applications. However, efforts are needed to design application-specific routing protocols. Second, life critical information sharing in VSNs demands secure routing and forwarding algorithms. Finally, reliability and efficiency are other factors to be considered while designing protocols for VSNs.

## 7. Conclusion

VSNs being a bridge between vehicular networks and social networks have attracted the research community due to its diverse range of applications. In this paper, we have presented a literature review of the main features, applications, communication architecture, socially-aware applications, data dissemination with particular attention to social aspects and mobility patterns. VSNs exploit social behaviors of nodes, opportunistic encounters among the commuters and mobility patterns for collaborative data dissemination and socially aware networking along the roads. This new communication paradigm supports not only intelligent traffic control systems but provides a direction for new business models, novel applications, and services ranging from safety-related application to entertainment related applications.

First, we presented the novel applications of VSNs and its communication architecture. Vehicular mobility is directly related to human behavior. VSNs exploit the mobility pattern for different applications in a pervasive and socially aware computing environment. We present mobility modeling for VSNs focusing on socially aware recommendation systems and route planning in VSNs. Further, we discussed the different communication protocols design and data dissemination techniques to address the existing gap between VSNs and traditional ad-hoc networks which is the very first issue to be considered by the research community to realize the concept of VSNs publicly accepted. Finally, we presented some open research issue for future direction. From the intensive literature review, we can conclude that VSNs are still in their infancy level. However, a diverse range of novel applications, socializing vehicular networks, exploiting mobility pattern, socially aware recommendation systems along the roads are some of the factors towards whom the research community has shown concrete interest.

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