A Survey on Vehicular Social Networks

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A Survey on Vehicular Social Networks

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Abstract

This article surveys recent literature on Vehicular Social Networks that are a particular class of vehicular ad hoc networks, characterized by social aspects and features. Starting from this pillar, we investigate perspectives of next generation vehicles under the assumption of *social networking* for vehicular applications (*i.e.*, safety and entertainment applications). This paper plays a role as a starting point about socially-inspired vehicles, and main related applications, as well as communication techniques.

Vehicular communications can be considered as the "first social network for automobiles", since each driver can share data with other neighbors. As an instance, heavy traffic is a common occurrence in some areas on the roads (*e.g.*, at intersections, taxi loading/unloading areas, and so on); as a consequence, roads become a popular social place for vehicles to connect to each other. Human factors are then involved in vehicular ad hoc networks, not only due to the safety related applications, but also for entertainment purpose. Social characteristics and human behavior largely impact on vehicular ad hoc networks, and this arises to the vehicular social networks, which are formed when vehicles (individuals) "socialize" and share common interests.

In this paper, we provide a survey on main features of vehicular social networks, from novel emerging technologies to social aspects used for mobile applications, as well as main issues and challenges. Vehicular social networks are described as decentralized opportunistic communication networks formed among vehicles. They exploit *mobility* aspects, and basics of traditional *social networks*, in order to create novel approaches of message exchange through the detection of dynamic social structures. An overview of the main state-of-the-art on safety and entertainment applications relying on social networking solutions is also provided.

Index Terms

Vehicular social networks, next generation vehicles, vehicular ad hoc networks, social-based applications.

I. Introduction

Nowadays, several automotive manufacturers are looking forward to reach the goals envisioned by Vision 2020 action plan [1]. Particularly, in Europe in 2012 the European Commission tabled the CARS 2020 Action Plan, aimed at reinforcing this industry's competitiveness and sustainability heading towards 2020 [2].

The CAR 2020 Action Plan is supported by CARS 21 (Competitive Automotive Regulatory System for the 21st century) Group, which provides recommendations to help car industry reaching new focuses, particularly those ones addressed to road safety. Indeed, it is known that worldwide more than one million people are killed, or injured in traffic accidents every year, mainly due to drivers' misbehavior and bad road conditions. The CARS 21 group has presented its final report calling for (*i*) a rapid progress and concrete actions about electro-mobility, road safety and Intelligent Transport Systems (ITS), (*ii*) a market access strategy, as well as (*iii*) reviews of the regulations on the CO2 emissions from cars and vans.

Cars have changed significantly over the last years, and will do so in the near future. Especially the integration of more and more sensors, such as camera or radar, and communication technologies opens up a whole new design space for in-vehicle applications. In order to have a look at what *future cars* [3] will be, we can refer to the "visions" from many automotive industries, such as Volvo [4], General Motors (GM) [5], Ford [6], Audi, and many others. It is expected a different kind of automotive experience, where city streets will teem with small, driverless cars whose wireless capabilities direct traffic flow smoothly, so that to make traffic lights unnecessary. Furthermore, the use of *cloud computing* technology will enable passengers to work or play games during their commutes, while listening to their favorite music, as chosen by the car based on user profile.

The National Highway Traffic Safety Administration (NHTSA) promotes that advances in technology could help reduce thousands of road victims and save millions of gallons of fuel in reduced congestion through *self-driving cars*. Indeed, the driver error is a key factor in 90% of crashes, and advanced technologies could help prevent many crashes. Driverless cars exploit video cameras, radar sensors, laser rangefinders and detailed maps to monitor road and driving conditions. Automated systems make corrections to keep the car in the lane, brake and accelerate to avoid accidents, and navigate. The concept of *autonomous vehicles* is almost a reality in California, Florida and Nevada, where legislation on autonomous (self-driving) vehicles has passed successfully. Furthermore, Google, Mercedes-Benz and GM are collaborating to further develop and define

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[1] Vision 2020, http://europa.eu/rapid/press-releaseIP-12-572en.htm.

[2] Car 2020, http://ec.europa.eu/enterprise/sectors/automotive/cars-2020/indexen.htm.

[3] In this paper, the terms car and vehicle are interchanged.

[4] Volvo, http://www.volvocars.com/.../vision-2020.aspx.

[5] General motor?s future car vision, http://www.gm.com/vision/designtechnology/emergingtechnology.html.

[6] Ford's vision, http://corporate.ford.com/innovation/innovation-detail/pr-cars-talking-to-traffic-lights-and-3419.

robo-driving: the capability to control the motion and location of autonomous (unmanned) vehicles provides endless possibilities for the improvement of vehicular safety applications.

The concept of next generation vehicles does not represent only a vision, but a viable reality due to a new class of emerging wireless ad hoc networks for vehicular environment *i.e.*, the Vehicular Ad hoc NETworks (VANETs) [1]. VANETs are a particular class of Mobile Ad hoc NETworks (MANETs), characterized by high (variable) vehicle speed, hostile propagation environment, and quickly changing network topologies [1]. Opportunistic routing has been extended to VANETs in order to disseminate information and improve connectivity among vehicles. Message propagation occurs through (*i*) Vehicle-to-Vehicle (V2V) links built dynamically, where any vehicle can be used as next hop, so to form an end-to-end path toward a final destination, and (*ii*) Vehicle-to-Infrastructure (V2I) links, assuming ubiquitous deployment of fixed road-side units [1]. The idea of employing wireless communications among vehicles arises in $'80$, and only recently the wireless spectrum has been allocated for vehicular communications, along with the adoption of standards like the Dedicated Short Range Communications (DSRC), or the IEEE 802.11 technologies (*i.e.*, $802.11p$). Just to give an example of vehicular communications, we can consider Ford "smart intersection" that communicates with specially-equipped test vehicles, warning drivers of potentially dangerous traffic situations, such as when a vehicle is about to run through a red light. The smart intersection is outfitted with technology that can monitor traffic signal status, GPS (Global Positioning System) data and digital maps to assess potential hazards, and then transmit the information to vehicles. Once the information is received, the vehicle's collision avoidance system is able to determine whether the car will safely cross the intersection or if it needs to stop before reaching it. Notice that many challenges related to road traffic management are investigated by researchers from both industry and academia. Approaches based on sensing, communication and dynamic adaptive technologies are largely exploited. A detailed description about these techniques is presented in [2].

In this paper, we provide an overview of main features and possible applications of *future car* [7]. Particular interest will be given to social aspects that are exploited in vehicular communications for both safety and entertainment applications. Indeed, vehicular communications can be considered as the "first social network for automobiles", since each driver can share data with other neighbors.

Due to the inseparable relationship between a mobile device and its user, social-based relationships and mobility aspects of users have been exploited in many research fields, such as VANETs [1], DTNs (Delay Tolerant Networks) [3], OppNets (Opportunistic Networks) [4], and Pocket Switched Networks (PSNs) [5].

The basic idea of PSNs is to exploit both human mobility and local/global connectivity in order to transfer data among mobile users' devices, focusing on the use of opportunistic networking. Then, one key problem in PSNs is the design of forwarding algorithms by means of human mobility patterns [6]. In [7] Tse *et al.* combine vehicular sensor networks with social networks, in order to provide more advanced and innovative applications.

Opportunistic networking applications are naturally related to social networking (*i.e.*, introduction services, friend finders, job recommendations, content sharing, gaming, etc.), as well as human factors (*i.e.*, human mobility, selfish and user preferences) are involved in VANET applications. This emerging networking paradigm is called Socially-Aware Networking [8], and takes advantage of mobile device users' social relationships to build mobile (ad hoc) social networks. It follows that social characteristics and human behavior largely impact on VANETs, and this arises to the Vehicular Social Networks (VSNs), which are formed when vehicles (individuals) "socialize". A VSN is assumed as a group of individuals who may have common interests, preferences or needs in a context of temporal, and spatial proximity on the roads. More in detail, a VSN is a VANET, including traditional V2V and V2I communication protocols, as well as human factors *i.e.*, mostly human mobility, selfish and user preferences, affecting vehicular connectivity [9]. As an instance, social-based protocols are able to identify *socially-similar* nodes to share common interests with *e.g.*, a group of people all driving to a football game can experience traffic on the route to the stadium, and are also highly expected to encounter others with similar interests. Generally, there is a lot of valuable information that can be posted and shared by vehicles with other users, like personal information (*i.e.*, location, destination, voice notes, pictures, etc.), traffic information (*i.e.*, accidents, roadwork, congestion, etc.), and vehicle information gathered through on-board sensors (*i.e.*, icy/slippery roads, heavy rain/snow, fog, vehicle failures, etc.). As an instance, there are many vehicular social-based applications exploiting traditional online social networking services, like Facebook and Twitter, providing a foundation of social relations among users with common interests. Recently, Ford has developed Twittermobile car [10], which is able to send and receive Twitter messages, containing information ranging from driver's mood (status) to real-time traffic warnings. Similarly, NaviTweet [11] is used to post or listen to traffic related voice tweets, so that the driver's preferences can be incorporated into the navigator's route calculation. Finally, RoadSpeak [12] is a voice chatting system used by daily driving commuters or a group of people who are on a commuter bus or train.

This paper is organized as follows. In Section II, we provide the definition and main features of Next Generation Vehicles (NGVs) according to several automotive industries. In Section III we present VSNs as decentralized opportunistic communication networks formed among vehicles, which take advantage of *mobility* and *social networking*, in order to create novel approaches of message exchange through the detection of dynamic social structures. This is also referred as *mobile ad hoc*

[7] With the term "future car" we mean a vehicle equipped with advanced on-board technology and sensors, with communication and connectivity skills oriented to road safety and entertainment, as well as social features.

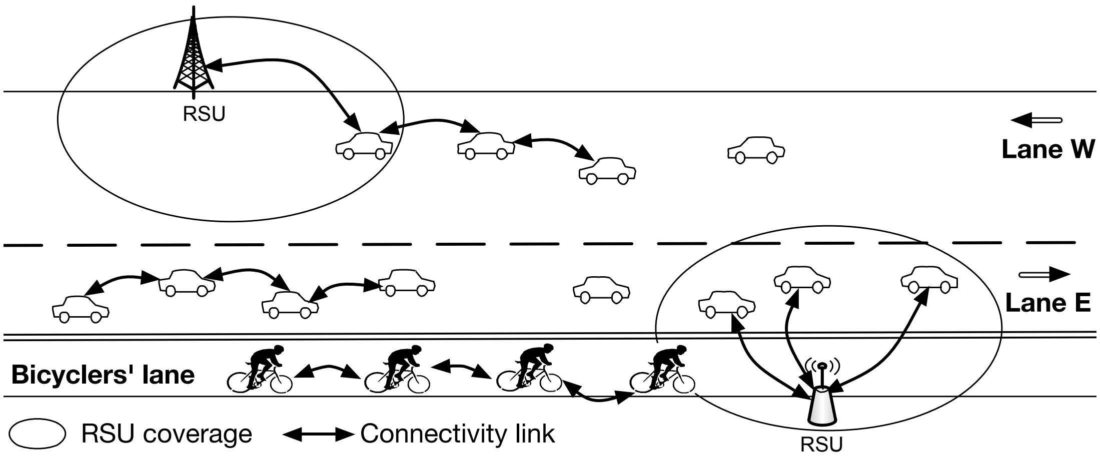

Fig. 1. Schematic of a vehicular ad hoc network with an overlapping wireless network infrastructure. Vehicles (*i.e.*, cars and bicycles) are mobile nodes, which communicate via V2V, as well as V2I, forming *on-the-fly* social networks.

social networking, and such definition is exploited in order to investigate the features of social cars, intended as mobile nodes with sociability skills, apart existing abilities of communicating, positioning, navigation and sensing. Then, Section IV provides an overview of the main state-of-the-art of safety and entertainment applications relying on social networking solutions *e.g.*, approaches based on *crowdsourcing* for social-based data dissemination, and mobility improvement. Finally, conclusions are drawn at the end of the paper.

II. Next Generation Vehicles

In this section, we briefly introduce the concept of VANETs, as a pillar to describe new technologies and features of Next Generation Vehicles, with particular attention to social aspects. Moreover, we try to fill the existing gap between social networks and vehicular networking.

As previously introduced, VANETs belong to the family of MANETs, with the particular feature that mobile nodes are vehicles able to communicate each other via opportunistic wireless links [1]. Vehicles travel on constrained paths (*i.e.*, roads and highways) and exchange safety and entertainment messages among neighboring vehicles. Vehicular networking enables diverse applications associated with traffic safety, traffic efficiency and infotainment, requiring timely and reliable message delivery [13]. As a consequence, VANETs well fit into the class of opportunistic networks, since messages are forwarded according to the *store-carry-and-forward* approach, where messages are stored in a vehicle and quickly forwarded over an available wireless link. Connectivity links are then *opportunistically* exploited to forward messages within the network, through different communication modes. For example, a vehicle can transmit traffic information messages to its neighbors via V2V mode, while it can receive data from a traffic light *i.e.*, a Road Side Unit (RSU), via V2I links.

Fig. 1 depicts a vehicular grid with an overlapping wireless network infrastructure, comprised of two RSUs (*i.e.*, a cellular base station, and a wireless access point). Notice that we do not limit the concept of “vehicle” to cars only, but extend to bicycles, trucks, and buses too. In Fig. 1, cars move along different lanes *i.e.*, lane W (E) is from east (west) to west (east), as well as bicycles drive in a dedicated lane. Connectivity links allow not only packet exchange, but also forming *dynamic social networks* (*e.g.*, the social network of bicyclers provides information on races and available paths). Communications via V2I (*i.e.*, from a vehicle to a RSU) are exploited in order to check for available social networks, corresponding to a given query. For instance, a vehicle should ask a query about “traffic status”, and receives information regarding neighboring social networks talking about this topic. On the other hand, communications via V2V (*i.e.*, among neighboring vehicles) are used to share content among members of the same social network/community. For instance, during a race, bicyclers can share information about time elapsed, missing miles, weather forecast, and so on.

Social-Aware Networking (SAN) [8] is a concept based on a twofold paradigm *i.e.*, (*i*) social relationships are relatively stable, and (*ii*) transmission links among mobile nodes vary more frequently than social ties. Fig. 2 depicts two social levels [14], mapping with each other in the context of SAN in vehicular environment *i.e.*, a route with two lanes along east (Lane E), and west (Lane W) directions. Mobile devices (*i.e.*, smartphones, digital camera, laptop, etc.) form electronic social networks when they are close enough to communicate, and their spatio-temporal properties determine their relationships. Meanwhile, mobile devices construct the virtual social networks based on their inherent social ties. On the other hand, an individual usually drives with fixed routes (*e.g.*, the way from home to workplace, and back). Generally, electronic social networks change rapidly due to the mobility of mobile devices, while people’s relationships change little during a time period.

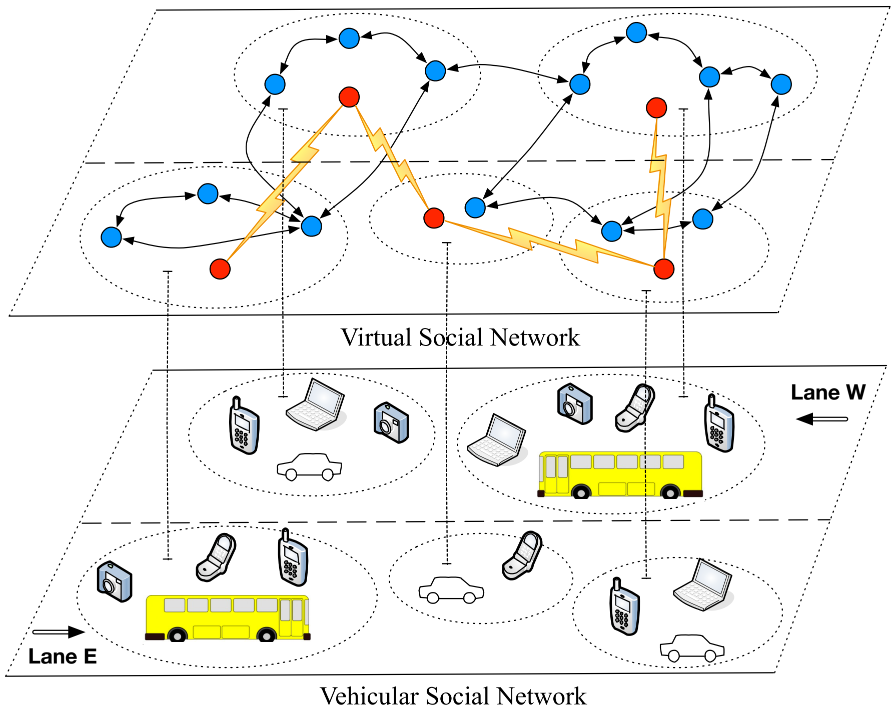

Fig. 2. Vehicular Social Network and Virtual Social Network, overlapping in the context of SAN. Vehicles (*red circles*) establish social ties based on mobility and common interests, while mobile devices (*blue circles*) form an electronic social network, when they are in proximity.

A. Technologies and features of NGVs

There are several wireless access technologies used for vehicular communications. On-board devices are equipped with IEEE 802.11 and Wireless Wide Area Network interface cards, like Long Term Evolution (LTE) and Worldwide Interoperability for Microwave Access (WiMax), as well as Global Navigation Satellite System (GNSS) receiver for vehicle positioning and tracking [15]. Particularly, the IEEE 802.11p standard is intended to operate with the IEEE 1609 protocol suite, which provides the Wireless Access in Vehicular Environments (WAVE) protocol stack [16]. Finally, short-range communications are also guaranteed within Personal Area Networks, through Bluetooth technology.

Based on the above-described aspects, we can enlist the following features for NGVs:

- **Safety driving**: in next decades, vehicles will be safer than today, and will no longer pollute. Existing and emerging technologies inside (*i.e.*, IEEE 802.11p, LTE, Visible Light Communications, etc.) and outside vehicles (*i.e.*, cameras, radar, lidar, etc.) can anticipate brakes in order to avoid collisions, by means of exchanging warning and beacon messages via V2V, as well as V2I communication modes;
- **Autonomous driving**: the aim is to reduce accidents and increase independence cars, which drive themselves with technology for fully autonomous vehicles (no human drivers) capable of navigating the roadways. With the help of the computational power and through security constraints [8], vehicles are expected to operate autonomously with a high degree of reliability in different scenarios (*i.e.*, urban, rural, and highway). As an example, in the DARPA Grand Challenge [9] vehicles were asked to autonomously operate in a dynamic urban environment; vehicles had to navigate a network of paved suburban and dirt roads among other autonomous cars, as well as human-driven vehicles. Notice that vehicular networks with capabilities of decision making and autonomous control can be upgraded to cloud-assisted context-aware vehicular cyber-physical systems (CVCs) [17]. With the support of cloud computing, and by means of the use of context information (*e.g.*, the status of available parking spots), Wan *et al.* in [17] provide a context-aware parking services;
- **Social driving**: vehicles become members of a mobile social network, which is formed *on-the-fly* among neighboring vehicles with common interests, or moving in the same location, or having relationship binding. Social interactions among vehicles occur in specific situations and exist for a limited time, often corresponding to the journey duration. Social communities are also built among classes of vehicles (*e.g.*, the social network of small size cars, sharing information on available parking spots), and drivers (*e.g.*, the social network of bicyclers, sharing information on available paths);
- **Mobile applications**: the aim is to keep drivers and passengers connected with people and information while on-the-go. Internet browsing, online gaming, instant messaging, video streaming and video on-demand are a few of many mobile

[8]Future cars can also make wrong decisions if there are bugs in code or it is under attack. Thus, it is better to give humans the capability to control the car (with a higher priority than the self-driving system) when necessary.

[9]Darpa Grand Challenge, http://www.darpagrandchallenge.com

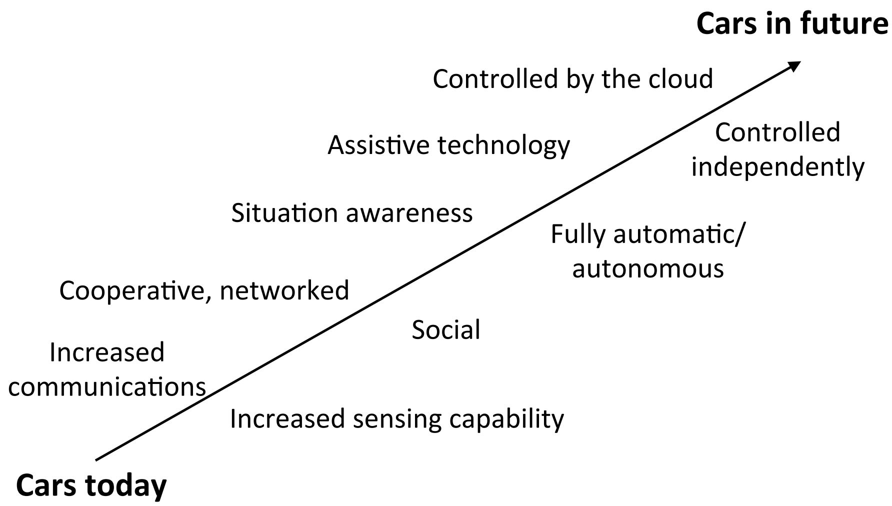

Fig. 3. Vision of NGVs, with main features and challenges.

applications used by passengers in order to enjoy the journey;

- **Electric Vehicles (EV)**: there is a growing customer interest in gas-electric hybrids and fully electric vehicles with emission-free driving. This technology holds a great potential, especially for use in smaller vehicles running at lower speeds for short distances, in highly populated urban areas.

Based on such features, we can consider the *next generation vehicle* as an autonomous vehicle with the following capabilities: (*i*) sensing, (*ii*) communicating, (*iii*) sociability, (*iv*) positioning, and (*v*) navigation. Fig. 3 shows the car evolution from today to the early future, by means of a set of improved technologies and novel capabilities (*i.e.*, autonomous control, sociability, etc.). However, features from Fig. 3 can be extended to any other vehicle, like trains. As an instance, the rail traffic system is regarded as a typical social-infrastructure system [18], and effective Social Network Services are largely exploited to make rail traffic transportation systems more active in the safety, efficiency, and comfort.

Notice that many sensors and communication technologies are already a reality today, as well as many aspects of NGVs are already implemented (*i.e.*, sensing, assistive technology, communication, situation awareness, navigation, etc.). Nowadays, there is a considerable demand from industry and end-users to introduce new forms of computing technology into cars; it is expected that more computing power will help to improve road safety, efficiency and comfort of the driving experience.

As a first step toward NGVs, we find the increase of size of the *safety envelope* around the vehicle. The use of better sensors, like LIDAR, IR, thermal, ultrasound, video, and lane change detection devices, as well as the sensing and deployment of braking and stability control, can provide more safety to the drivers. Vehicular communications are then enhanced through external sensors, so that warning and beacon messages can be sent to neighboring vehicles.

Apart external sensors, in-car computing systems are currently developed for use within vehicles, such as (*i*) control-based systems, directly related to driving tasks *e.g.*, collision avoidance, adaptive cruise control, speed limiters, lane keeping, etc., as well as (*ii*) information-based systems, which provide information and services relevant to components of the driving environment, the vehicle or the driver *e.g.*, traffic and travel information, vision enhancement, route guidance/navigation, driver alertness monitoring, collision warning, etc.

The second step is to take humans out of the control loop. It is expected autonomous vehicles will be introduced widely to be used in normal highways and cities. Many car manufacturers have already embarked on developing autonomous vehicles. BMW has started testing autonomous vehicles since 2005, [19]. In 2011, General Motors created the Electric Networked Vehicle in hopes to have their autonomous vehicle in the market by the year 2018, [20]. In the same year, Audi will be able to send an autonomous vehicle TTS to achieve close to race speeds at Pikes peak [21].

By the year 2040, it is expected vehicle operators will not be required to obtain a driver license due to the vehicles being autonomous [22], as well as they will no longer be involved in the manipulation or in the control of the vehicle speed, location, or direction. Nowadays, as remarked in the event "The Road Ahead: The Future of Transportation and Mobility" [10] in the context of the Forum on Future Cities, hosted by the MIT Senseable City Lab in November 2014, we are moving from the fiction to the reality in the context of automotive. In fact, as reported by Paolo Santi, research scientist at MIT Senseable City Lab where he leads the MIT-Fraunhofer Ambient Mobility initiative, '*Tesla's Autopilot features get that company's offerings to near self-driving to consumers in the coming months, and the State of California has begun offering licenses to "drivers" of autonomous vehicles self-driving cars.*' However, this arises with many open issues and there are several unanswered questions

[10]http://senseable.mit.edu/roadahead/

related to regulation and safety. Just as an example, insurance companies are still self-wondering who is at fault when some accident occurs or something goes wrong.

Many benefits are expected from the wide use of autonomous vehicles. Among those benefits, we recall a reduction of traffic collisions due to the increase reliability of the vehicles in sensing and reacting to environment traffic changes [23], also due to the lack of traffic collisions, and required safety gaps, as well as the development of algorithms that determine the best path selection. Finally, drivers will be no longer required to drive and navigate the vehicle, and hence, will be able to perform other chores while in the vehicle (*e.g.*, to check emails, watch a video, read news on the web, etc.). It also affects a lack of restriction requirements for passengers such as age, vision, impaired or intoxication, and is expected to improve fuel efficiency [24].

For entertainment applications, there are several mobile applications aimed to enhance drivers and passengers' travel experience, like Cadillac CUE [11]. The OnStar's RemoteLink [12] creates a secure connection between a mobile device and the OnStar-equipped vehicle. It uses the mobile device to control the own vehicle from anywhere, like the command of remote door lock and remote start. As the same, the Chevrolet MyLink [13] provides connectivity to the vehicle, so that drivers are connected to own friends, family and colleagues safely while driving. This application also provides personalized radio playing preferred music and comedy through the Pandora mobile application on a compatible smartphone [14], as well as favorite news from Internet broadcast or entertainment podcast are always available through the streaming capabilities of Stitcher Smart Radio.

The Next Generation Vehicles will be key actors in the context of the future urban mobility systems. They will play a primary role in the broad spectrum of smart mobility applications and one expects an enormous impact in reduction of emissions and travel times. These aspects are remarked in the seminar taken at the GeorgiaTech in February 2015 by Paolo Santi [15].

In NGVs, *navigation* of unmanned vehicles will be made simple with the ability to search for a destination and send directions directly from a mobile phone to the vehicle (*path planning*). For example, autonomous vehicles can be programmed to drive the path from home to school, and back, to pick the kids at school. Owners can also check vehicle diagnostics like fuel level, remaining oil life, and tire air pressure remotely. With all such innovative features, vehicle operators will no longer be involved in the manipulation or in the control of the vehicle speed, location, or direction. Vehicle operators will only notify the vehicle of the destination they are heading to, and the vehicle will determine the path, speed, and direction to be used in order to reach the destination. Enabling the vehicle to autonomously select these variables opens endless possibilities for the innovation of new algorithms that will provide the best possible journey experience to passengers.

Several researchers have addressed the topic of unmanned vehicles, particularly dealing with novel routing techniques. Collision prediction can be achieved via estimating the trajectory of objects, while collision avoidance is achieved through controlling the speed of the vehicle or through replanning the path of the vehicle [25]. In [26] Xu *et al.* propose an autonomous real-time driving motion planner with trajectory optimization, based on a set of cost functions. In [27], Krogh and Thorpe present a method for vehicle guidance that is based on path relaxation to compute critical points using a priori information and sensor data along a desirable path. The scope of this method is to provide a collision free path for the vehicle.

Finally, the use of approaches based on *human computing interactions* can increase security in NGVs. As largely known, drivers are more likely to be involved in vehicle accidents when using smartphones or other mobile devices. According to the literature, driver's distraction happens when attention is diverted away from the driving task due to an event or an object. As a result, the driver is no longer able to drive adequately or safely, and the reaction times are strongly reduced [28]. As an instance, biomechanical distractions occur when a driver removes one or both hands from the steering wheel to physically manipulate an object instead of focusing on the road (*e.g.*, in order to dialing a call, as well as sending a text message). In-Car Communication Systems (ICCS) have increased noticeably, with the aim to limit road accidents due to the use of a mobile phone whilst driving. ICCS allow drivers to interact with a Bluetooth-enabled phone paired with the system, and perform typical tasks such as recalling names in the address book [29]. Several user interfaces promoting the usage of the hands and eyes solely for the driving task have been proposed, in order to allow the driver to reduce distractions. The Multimodal Interface for Mobile Info-communication (MIMI) [30] is a prototype multimodal ICCS, based on a speech interface, supplemented with steering wheel button input. Current solutions include hierarchical menus and multi-functional control devices, which increase complexity and visual demand. Finally, another approach consists in combining speech control and gestures. By using speech for identification of functions, in [30] Tchankue *et al.* exploit the visibility of objects in the car (*e.g.*, mirror) and simple access to a wide range of functions equaling a very broad menu. Also, with the use of gestures for manipulation, it is possible to provide fine-grained control with immediate feedback and easy undo of actions.

B. Bridging social networks to vehicular networking

Leveraging on the growing popularity of social networks, other works address how to include social aspects into existing networks (*e.g.*, sensor networks [7], and mobile networks [31]). Hereafter, we investigate the gap that exists from social

[11] Cadillac, http://www.cadillac.com/cadillac-cue.html
[12] Onstar, https://www.onstar.com/web/portal/home
[13] Chevrolet, http://www.chevrolet.com/mylink-vehicle-technology.html
[14] Pandora, http://www.pandora.com
[15] http://seminars.gatech.edu/hg_event/377411

networks to vehicular networking, in order to understand how social aspects can coexist into vehicular networks [16].

Social networks (*e.g.*, Facebook, Twitter, MySpace, etc.) not only provide platforms for people to share, and discuss common interests and topics, but implicitly include some useful information. For instance, from the status of logging in, it is possible to extract real-time data on people density located in specific places such as stadiums, malls, theaters, and so on.

The integration of social networks into VANETs provides some novel applications, mainly devoted to safety, and entertainment [12], [32]. As an instance, the *intelligent traffic management* helps people to adjust their behaviors or schedules to reduce the side impacts of traffic on daily life [33]. With real-time data collected from VANETs, it is possible to generate a real-time traffic map that indicates the levels of traffic at different locations; such an information can be shared among people in order to avoid congested roads. On the other side, trusted people sharing the same trip, or neighborhood, can discuss about common interests (*e.g.*, students going to school talk about lectures) [34], [35].

Thus, the main trend to make social networks available for mobile users (*e.g.*, vehicles) is Mobile Social Software (MoSoSo) [36]. MoSoSo is a class of mobile applications connected to the concept of mobile Internet, with the aim to support social interactions among interconnected mobile users, with a particular emphasis on data sharing. Also, the availability of GPS systems and the integration of maps in mobile devices give rise to the concept of Location-based Mobile Social networks (LoMoSo), enabling users to find one another in a particular location and time dimension.

One common assumption for the design of data dissemination protocols in Mobile Social Networks is the *social similarity*, so that two nodes can contact with a higher probability if they have more common interests or common communities. However, members within the same community *i.e.*, with the same interest, usually have different levels of local activity, which will result in a low efficiency of data delivery. In [34], Li *et al.* present an efficient data forwarding scheme based on Local Activity and Social Similarity (LASS). Indeed, a low local activity results in a low efficiency in terms of delivery ratio and latency due to the misalignment on the estimation of nodes' contact probability.

Two fundamental factors are envisaged as main issues related to NGVs *i.e.*, (*i*) the lack of integration of several technologies together with sensors, and (*ii*) the security and privacy aspects that still remain one of the most significant concerns, as shown in [37]. Indeed, security and privacy issues in vehicular social networks have been poorly investigated, and more effort is required from the research community.

Among known approaches, in [38] Lu *et al.* propose a novel Social-based PRivacy-preserving packet forwardING (SPRING) protocol for vehicular networks. SPRING exploits the concept of deploying RSUs at high social intersections, so that RSUs can assist cars in packet forwarding, by temporarily storing packets via V2I communications, whenever next-hop forwarders are not available for retransmissions. This approach also provides a conditional privacy preservation, and resists most attacks existing in vehicular networks. Another work is [39], where a privacy-preserving data dissemination approach for mobile social networks is presented.

Establishing trust among drivers is still a challenge, and security and privacy aspects need to be deeply investigated in VSNs. Abbani *et al.* in [40] propose a model for forming and maintaining VSNs by means of trust principles for admission to social groups, and controlling the interactions among members. Generally, the following aspects should be addressed whenever a VSN is built under security constraints:

1) **Formation of social groups**: each node can become member of several groups, based on common characteristics. In each group, nodes interact with other members;
2) **Trust management and evaluation**: the node's trust levels are updated on the basis of a function of the nodes' behavior, interaction, activity and participation in a community;
3) **Decentralized architecture of VSNs**: group management and update are automatically exchanged among nodes;
4) **Data integrity**: the flexibility in data exchange depends on the mutual trust among nodes.

Establishing *entity trust* by means of well-known Public Key Infrastructure (PKI) certificates is an effective method. However, the use of *social trust* among drivers or passengers can enhance the entity trust method, as well as the trust relationships. As an instance, let us consider a driver receiving a warning message about an accident occurred on a near place: the message can be a fake, as well as the identity of the sender, and information about certified ID is not enough to trust the sender, neither the data content of the message sent. In [41], de Oliveira *et al.* propose the use of certificates to exchange cryptographic material in daily relationships, like meeting with friends. In this way, users in the network establish a trust degree, and reputation can become a reward for users with good behavior in divulgation and forwarding of traffic information.

As it is evident, social trust in vehicular networks is essential [42], [43]. Many vehicular applications not only require cryptographic protections on transmitted data, but also need a level of confidence on accepting data messages from other neighboring nodes. Indeed, each received message should be elected as trustable or not, as well as the identity of the sender should be secured by public key based cryptography. Huang *et al.* [42] propose a trust management solution for VSNs by considering trust models and cryptography-based solutions. Social trust is built among drivers by means of e-mail interactions, due to the e-mail social network paradigm offering a trust level more accurate than that of other social networks. Finally, in [44] Alganas *et al.* present an Efficient Vehicle Social Evaluation (EVSE) scheme, which enables each vehicle to show its authentic social evaluation to neighboring vehicles.

[16] In terms of advanced and innovative applications

Location privacy is one of the most important privacy requirements in VSNs, since the locations of vehicles are tightly related to the drivers. During a path, driver's locations are almost fixed *e.g.*, a driver may often drive to home, school, and shopping mall –that is, known paths–. However, informations about driver's home and school are confidential (*i.e.*, privacy locations), while the shopping mall is a *social spot* (*i.e.*, public location). In [45], Lu *et al.* propose an efficient Social spot-based Packet Forwarding (SPF) protocol, where the social spots are referred to as the locations in a city environment that many vehicles often visit (*i.e.*, shopping malls, restaurants, cinema, museums, etc.). Social spots are then used as relay nodes for packet forwarding, and since many vehicles visit the same social spot, the social spot cannot be used to trace a specific vehicle [45], [46]. In [47], Lin *et al.* present STAP (Social-Tier-Assisted Packet), an efficient packet forwarding protocol for vehicular networks. Under the assumption that vehicles often visit social spots, the authors accordingly deploy RSUs at social spots, in order to form a virtual social tier, where packets are disseminated. Later, once the receiver visits one of social spots, it can successfully receive the packet, and in this way, information about receiver's location is not taken into account. As it is evident, STAP is effective not only in packet dissemination, but also in protection of receiver-location privacy.

III. Vehicular Social Networks

The concept of a *social car* arises from the assumption that each driver can share data with other neighbors based on common interests *e.g.*, Ford concept car Evos can directly form a social network with driver's friends [48].

Starting from basic features of VANETs, our aim is to present how sociability and human social behavior can change the way to drive a car in the next few years. Today, social networking is a reality, and introducing social aspects in VANETs allows vehicles not only communicating, but also selecting similar neighboring based on social metrics.

This section is organized as follows. Subsection III-A describes the main content dissemination approaches for VSNs. Subsection III-B presents the social features adopted in VSNs. In Subsection III-C we will provide the main differences between VSNs and Online Social Networks. Finally, an overview of main research challenges in the context of vehicular social networks is presented in Subsection III-D.

A. Content Dissemination in VSNs

Recent achievements in the context of data dissemination approaches in VSNs are deeply studied in [49], where the authors distinguish three main categories based on (*i*) information processing, (*ii*) content delivery, and (*iii*) performance. Basically, the main idea for the design of content dissemination protocols and routing algorithms in VSNs exploits social properties and mobility behavior of human beings and vehicles. Xia *et al.* in [50] present BEEINFO (Artificial BEE Colony inspired INterest-based FOrwarding), a routing mechanism that classifies communities into specified categories, on the basis of personal interests. The general idea of BEEINFO is that mobile nodes perceive and record information (*e.g.*, vehicular densities) of passing communities, as similar as how bees fly from a flower to another one. The density information indicates the number of nodes belonging to a community: the higher the density is, the more nodes the community has. This information provides a guideline to better select next-hop forwarders.

In Fig. 4 we show how the bees' awareness capability is introduced in VSNs [50]. Let us consider three different communities related to given places *i.e.*, (*i*) shopping mall, (*ii*) school, and (*iii*) hospital, representing different data categories. The bus passes the shopping mall and school (*i.e.*, following the route highlighted by the brown arrows), while the car passes all other three spots (*i.e.*, following the route highlighted by the blue arrows). Notice that the bus and the car both pass the shopping mall and school community (respectively, in position B and C in Fig. 4), but they estimate different densities for the two communities (see the community densities in positions B, and C). Bus estimates higher density value than car in shopping mall community (*i.e.*, $10 > 5$), and lower density in school community (*i.e.*, $8 < 10$). Therefore, if there is a message to be delivered to shopping mall community, bus is the better forwarder. Vice versa, the car is the better one to deliver a message to school community. The same process applies for intra-community communications, where a potential forwarder is selected based on social ties *i.e.*, the more times two nodes that belong to the same community meet, the higher their social tie is.

Basically, a VSN is comprised of two fundamental parts *i.e.*, (*i*) a vehicular ad hoc network that represents the physical layer, and (*ii*) a social network framework running on top of such a physical vehicular network. Therefore, a VSN needs a strong cooperation between social aspects and physical network operational mechanisms. In [51], Fei *et al.* consider a VSN scheme in a urban vehicular scenario, as depicted in Fig. 5.

The IEEE $802.16j$ technology is used to enable vehicular communications and some approaches focused on the distributed scheduler of the 802.16 Standard [52] and [53] to improve the bandwidth resources utilization. A Relay Station (RS) can be assumed as a bus that carries multiple users, while a roadside Base Station (BS) serves multiple moving RSs within the coverage, and then an RS may further service multiple Subscriber Stations (SSs). The BSs are connected to the internet via Internet Service Gateways. The VSN provider is also connected to the Internet, and provides a web-based portal for interested users to register and use its social networking services.

In order to better understand the behavior of social-based vehicular ad hoc networks, we need to refer to main tools of Social Network Analysis (SNA) [54]. SNA takes into account social relationships in terms of nodes (*i.e.*, individuals) and ties (*i.e.*, relationships among nodes), and identifies important components in a social network, such as the centrality metrics

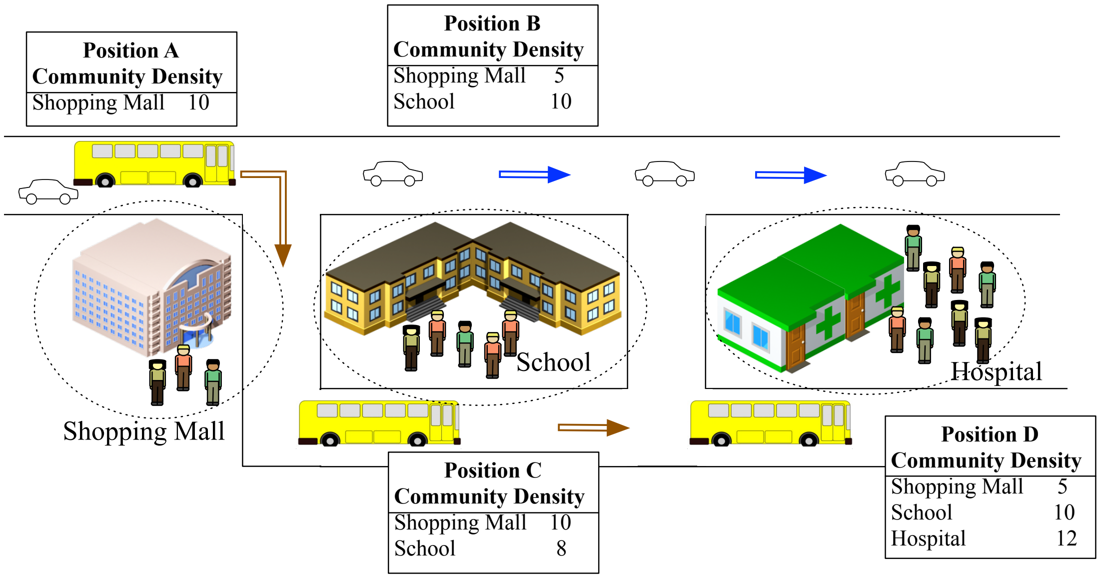

Fig. 4. Imitation of bees' awareness capability applied in VSNs, [50].

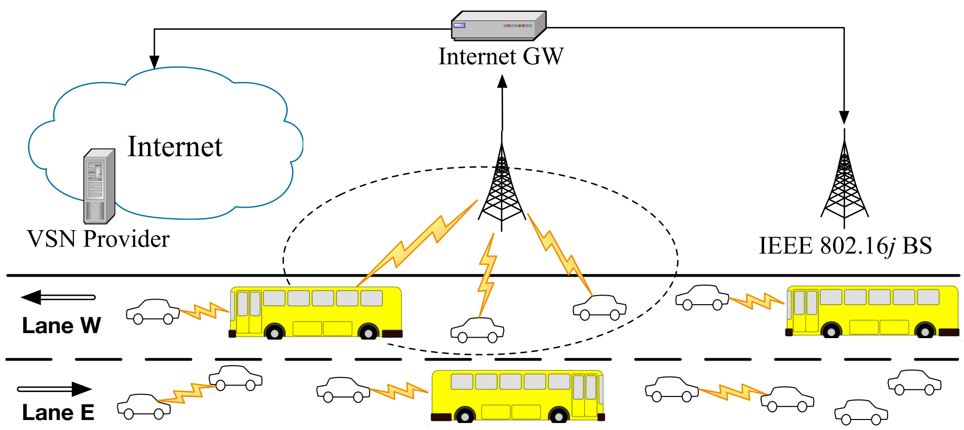

Fig. 5. A schematic example of VSN in urban scenario, plus the underlying network. Vehicles are moving along opposite directions (*i.e.*, lane east, and west). The relay stations (*yellow vehicles*) provide connectivity to the subscriber stations (*white vehicles*).

that are used to denote how "important" a node is inside a network. Indeed, a social network consists of users, social ties or relationships among users, and common interests. All three parts may impact the social influence of users [55]. As known, a VANET is a constantly evolving network, with dynamics that change over time. Thus, one of the main features to examine is the network connectivity over time, assuming that nodes can build opportunistic connectivity links on-the-move. SNA can be used to monitoring the traffic evolution during the day aiming to understand the human routines, the similar trajectories, and the rush times.

Let us assume a generic network expressed in terms of graph $G(V, N)$, where V and N are the sets of nodes, and edges, respectively. Based on the works in [51], [56], [57], [58], [59], and through graph theoretic and functionality models, we can distinguish the following centrality metrics:

1) **Degree Centrality** of a node v *i.e.*, $d(v)$, is the simplest centrality metric that refers to the number of direct connections the node v has to its neighbors. It can be expressed as:

$$d(v) = \sum_{j \in V, j \neq v} l_{vj}, \tag{1}$$

where l_{vj} is the link from node v to its neighbors j (with $j \in V, j \neq v$). The degree centrality identifies a node more popular *i.e.*, with a larger number of neighbors. In the context of VANETs, choosing a "popular" vehicle as next hop forwarder increases the chance of delivering the message to a wider group. In a social-aware data diffusion, in order to disseminate packets, a source selects only those nodes with high social centrality *i.e.*, nodes that have more chances to contact other nodes;

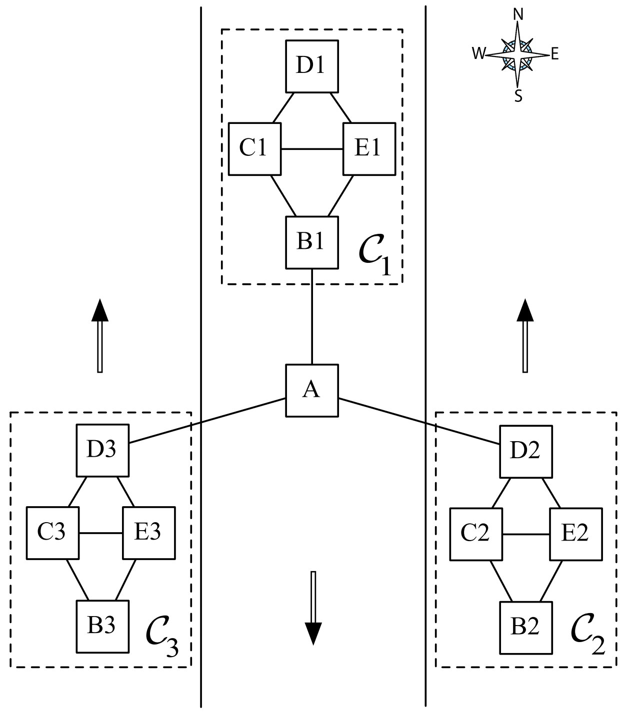

Fig. 6. Graph comprised of three clusters *i.e.*, $\mathcal{C}_{1,2,3}$, connected to each other through node A. The graph depicts a typical scheme of highway scenario where nodes (vehicles) are moving along lanes. Specifically, $\mathcal{C}_1$ is driving from north to south along the lane in the middle, while clusters $\mathcal{C}_2$ and $\mathcal{C}_3$ are moving from south to north along the outer lanes.

2) **Betweenness Centrality** of a node v *i.e.*, $BC\left(v\right)$, considers the number of shortest paths passing through node v, such as:

$$BC\left(v\right) = \sum_{\substack{s\neq v\neq t\\ s,v,t\in V}} \frac{\rho_{st}\left(v\right)}{\rho_{st}}, \tag{2}$$

where ρ_{st} is the number of shortest paths from node s to t, and $\rho_{st}\left(v\right)$ is the number of shortest paths from s to t passing through node v. Notice that $BC\left(v\right)$ is a measure of the global importance of node v that assesses the proportion of the shortest paths between all node pairs passing through node v. As a consequence, a node with high betweenness centrality plays a crucial role in the connectivity of the network, since the higher $BC\left(v\right)$, more the number of shortest paths among all node pairs passing through the node v;

3) **Closeness Centrality** of a node v *i.e.*, $CC\left(v\right)$, considers the inverse of the distance of node v to every other node j in the network *i.e.*, $d_{v,j}$. This means that node v has the shortest paths to all other nodes in the graph. The Closeness Centrality is defined as:

$$CC\left(v\right) = \left[\sum_{j\in V, j\neq v} d_{v,j}\right]^{-1}. \tag{3}$$

This metric describes how central is node v, in terms of the proximity to other nodes j (with $j \in V, j \neq v$). The choice of central nodes can ensure a wider delivery of the message within a network;

4) **BRidging Centrality** of a node v *i.e.*, $BRC\left(v\right)$, identifies if v is a bridging node, that is, v is located in between highly connected regions. It is expressed as the product of $BC\left(v\right)$ and the bridging coefficient $b\left(v\right)$ *i.e.*,

$$BRC\left(v\right) = BC\left(v\right) \cdot b\left(v\right), \tag{4}$$

where $b\left(v\right)$ determines the extent how well the node v is located between high degree nodes *i.e.*,

$$b\left(v\right) = \frac{d^{-1}\left(v\right)}{\sum_{i\in N(v)} d^{-1}\left(i\right)}, \tag{5}$$

with $N\left(v\right)$ as the set of neighbors of node v (*i.e.*, $N \subseteq V$).

Fig. 6 depicts an undirected graph comprised of $V = 13$ nodes, and $E = 18$ edges. Due to specific topology, the graph can represent a portion of vehicular network (*i.e.*, highway scenario) with connected clusters through a relay node. We assume a cluster as a connected group of vehicles *i.e.*, a sub-graph such that there exists a path between any pair of nodes. $\mathcal{C}_1$ is a vehicles' cluster driving from north to south along the lane in the middle, while $\mathcal{C}_2$ and $\mathcal{C}_3$ are moving from south to north along dedicated lanes. We can observe that all clusters are connected to each other through node A *e.g.*, $\mathcal{C}_1$ is connected with $\mathcal{C}_3$, and $\mathcal{C}_2$, via node A. Then, node A acts as relay node, and its presence allows the whole network to be connected.

Table I collects the centrality metrics for the graph in Fig. 6. We observe that node A has the highest value of betweenness (*i.e.*, 0.73), closeness (*i.e.*, 0.5), and bridging (*i.e.*, 0.243) centralities. Again, this means the important role of node A in the graph, and that graphs in VANETs exhibit *small world* properties, that is, most node pairs are connected by at least one short path.

How to define which metric efficiently models the activities of members in social networks is still a challenge. Generally, the above social metrics are application-oriented, and are largely exploited in the design of routing protocols in vehicular social networks, while achieving higher delivery ratio, and shorter end-to-end delays than existing routing protocols. Gu *et al.* in [60] present a social-aware routing algorithm based on a fuzzy logic algorithm, with the aim to improve the data packet delivery ratio and reduce end-to-end delay. The basic idea behind the fuzzy logic algorithm is that a node is selected as next hop not only according to traditional greedy approaches (*i.e.*, the closest node to a given destination), but also considering social factors like centrality. Also, Bradai *et al.* in [61] propose a new mechanism for efficient video streaming over VANET, by selecting rebroadcaster vehicles based on their strategic location in the network and their capacity to reach other vehicles, by using a new centrality metric, called dissemination capacity. Cunha *et al.* [62] propose a data dissemination solution for vehicular networks by considering daily road traffic variations and relationships among vehicles. The focus is to select the best vehicles to rebroadcast data messages according to social metrics (*i.e.*, the clustering coefficient and the node degree). In [63], Stagkopoulou *et al*. use social inspired metrics *i.e.*, a Probabilistic Control Centrality (pCoCe) metric, in order to identify potential vehicles for message forwarding and coverage of a wide range of a vehicular network. Esmaeilyfard *et al.* [64] focus on the management of social groups and information dissemination by means of a three layer network architecture. Finally, in [35] Smailovic *et al.* exploit user social relationships by establishing temporary social relationships among users with common interests. The authors propose the Bfriend, a location-aware ad-hoc social networking platform based on the Facebook social graph.

Apart the SNA, since VSNs are a communication network, we can also consider how traditional performance metrics *i.e.*, delivery delay, delivery ratio, and bandwidth usage, affect the behavior of VSNs [49]. As an instance, some applications like safety, traffic, and information dissemination, require a short delivery delay (*i.e.*, time delay for a message to be received at the destination node). On the other side, delay-tolerant applications such as entertainment applications do not require a limited delivery delay, but it is expected an improved delivery ratio (*i.e.*, the ratio of data objects successfully delivered to destinations) for all the nodes that are interested in a given data object (*i.e.*, common interest). Finally, the bandwidth usage should be efficiently limited in order to reduce data exchange in the network.

The example in Fig. 6 describes a simple graph with a very limited number of nodes as compared to real vehicular ad hoc networks, where the number of nodes increases based on time evolution (*i.e.*, the vehicular density changes along position, and time). In order to fully understand the dynamics of a VANET, many researchers [56], [65], [66], [67] have studied the behavior of nodes by means of large scale of vehicle trajectories over real road networks. In [56], Papadimitriou *et al.* study the structure and evolution of a VANET by using realistic vehicular traces from the city of Zurich. Specifically, they assume a 5×5 km^2 road area, covering the centre of Zurich, and containing around 2×10^5 distinct vehicle trajectories in a typical morning rush hour. In such a scenario, the distribution of the centrality metrics is not affected by the communication range, but it depends on the variation in traffic conditions *i.e.*, density and relative positions of the vehicles. Therefore, centrality is not an artifact of the communication range, but a factor of the behavior of the vehicles *i.e.*, road network, and drivers' intentions.

In [65], Cunha *et al.* present a numerical analysis of real and realistic data sets that describe the mobility of vehicles, under a social perspective. The authors demonstrate that the vehicular scenario affects the vehicles' speed, then impacting the encounter ratio. Moreover, also the nature of vehicles affects the sociability aspects in vehicular scenarios *e.g.*, taxis cross the whole city and perform random trajectories, without fixed time and trip duration, while buses transit the same routes under a fixed schedule, as well as common people use their vehicles to perform predetermined trajectories according to their routines. Finally, in [66] the assessment of a simple broadcast data dissemination protocol in VANETs has been provided. The design of an optimal deployment of relay nodes, enhancing system performance, has been investigated for different traffic scenarios (*i.e.*, highway, rural, and urban) in the city of Rome (Italy), assuming the case of (*i*) inter-vehicular communications, as well as (*ii*) availability of fixed network infrastructure for V2I communications. A detailed description of data dissemination protocols for VANETs is presented in [68].

Leveraging on previous works, the connectivity behavior in VANETs can be enhanced on the basis of key factors, such as (*i*) vehicles' mobility pattern, (*ii*) transmission range, (*iii*) the existence of network infrastructure, and (*iv*) market penetration [69]. The driver's behavior produces great influences in vehicular mobility *e.g.*, people tend to go to the same places, at the same day period, through the same trajectories. Then, vehicles encounter others vehicles, pass in the same streets, and suffers the same traffic conditions. All these features suggest (*i*) the study of the vehicular mobility under a social perspective, and (*ii*) to apply the social concepts to improve the services and the connectivity in VANETs.

TABLE I
CENTRALITY METRICS FOR THE GRAPH IN FIG. 6. NODE A ACTS AS RELAY NODE, PROVIDING CONNECTIVITY IN THE WHOLE GRAPH.

Nodes	d	BC	CC	BRC
A	3	0.73	0.5	0.243
B1	3	0.41	0.41	0.136
C1	3	0.076	0.32	0.021
D1	2	0	0.26	0
E1	3	0.076	0.32	0.021
B2	2	0	0.26	0
C2	3	0.076	0.32	0.0304
D2	3	0.41	0.41	0.205
E2	3	0.076	0.32	0.030
B3	2	0	0.26	0
C3	3	0.076	0.32	0.030
D3	3	0.41	0.41	0.205
E3	3	0.076	0.32	0.021

B. Social features in VSNs

As already stated, social characteristics and human behavior largely impact on vehicular networks, thus arising to the VSNs [9]. The influence of human factors *i.e.*, mostly human mobility, selfish and user preferences, largely impacts on vehicular connectivity.

In [58] Cunha *et al.* present the characterization and evaluation of a realistic vehicular trace in order to study the vehicles' mobility in the context of social behaviors. Through numerical analysis, the authors identify peculiar social characteristics in vehicular networks, and how the use of these metrics can improve the network performance of communication protocols and services. Indeed, human factors are involved in vehicular networks, not only due to safety related applications, but also for non-safety related applications *i.e.*, entertainment. From the nature of vehicular ad hoc networks, traffic patterns can provide social interactions. As an instance, in heavy traffic scenarios (*e.g.*, during morning rush hours), the vehicular density is very high and traffic pattern is relatively static. Such scenario becomes a popular social place for vehicles to connect to each other, and share information (*e.g.*, traffic information, weather news, and so on).

In [70], [71], [72] the issue of stable vehicle clustering are investigated, in order to limit the broadcast storm problem. Indeed, due to the rapidly changing network topology, vehicle clusters are built dynamically, and data packets can be forwarded multiple times. As a solution, Maglaras *et al.* [70] develop a Sociological Pattern Clustering (SPC), and Route Stability Clustering (RSC) algorithm, exploiting the social behavior of vehicles *i.e.*, their tendency to share the same/similar routes.

Mobility models for VSNs are affected by (*i*) the human mobility model, (*ii*) the human selfish status, and (*iii*) human preferences. In VSNs, vehicles are driven by people with own decision capability and driving style (*i.e.*, smooth deceleration and acceleration, and intelligent driving patterns [17]). For example, drivers use to select the shortest path toward a destination instead of traveling along the longest path.

Other mobility models follow collective human behavior (*i.e.*, community). In the community-based mobility model, it is assumed that there exist several points of interest with high social attractivity (*e.g.*, restaurants, malls, theaters, etc.). Finally,

[17]Drivers interact with the environment, not only with respect to static obstacles, but also to dynamic obstacles, such as neighboring cars and pedestrians.

mobility in VSNs is also affected by a time-variant model, such as a vehicle moves toward a given spot in a given time of a day *e.g.*, people go to the office in the morning, and back home in the evening, while on Sunday people prefer to relax at home, and then traffic is very low in urban area.

An example of mobility model for social-based vehicular networks is presented by Lu *et al.* in [73], [74]. The authors investigate VANETs in terms of social-proximity feature, since many vehicular scenarios are involved in the proximity-related applications, such as safety message dissemination and localized social content sharing. Lu *et al.* present a mobility model called Restricted Mobility Region With Social Spot, where the urban area is assumed as a scalable grid with a set of social spots, so that the mobility region of each vehicle is restricted and associated with a fixed social spot.

Recently, new open-source tools are available for the generation of vehicular mobility patterns, such as IMPORTANT [75], GEMM [76], and BONNMOTION [18]. The IMPORTANT tool [75] implements several random mobility models, included the Manhattan model and the Car Following Model, which is a basic car-to-car inter-distance control scheme. The GEMM tool [76] introduces the concepts of Attraction Points (AP), activity, and role. The APs reflect a destination interest for several people, activities are the process of moving to an AP, while roles characterize the mobility tendencies of different classes of people. Finally, a most realistic mobility model for VANETs is provided by the Street Random Waypoint (STRAW) tool [77], which implements a complex intersection management using traffic lights and traffic signs. An extended description of mobility models for vehicular networks is given in [78].

In VSNs, the design of novel non-safety applications should consider not only these realistic mobility models, but also human behavior *i.e.*, the *human selfish status* and *preferences*. For the first factor, not all drivers are nonselfish, but some people will behave selfishly, and decide not to participate in some non-safety applications. As an instance, for some reasons [19], a selfish vehicle may be reluctant in the cooperation with other neighboring vehicles, if this is not directly beneficial to it. Therefore, the selfishness is a very challenging issue for non-safety related applications in VSNs, since selfish behaviors of nodes degrade network performance. As a solution, specific strategies like routing protocols based on reputation criterium [79], [80], and tit-for-tat (TFT) schemes [81] for selfish ad-hoc networks, aim to fix this issue. In reputation-based schemes, forwarding task is assigned to nodes depending on their reputation level (*i.e.*, when a node provides services for other nodes, it obtains a good-reputation score). Then, nodes with good reputations can receive services from other nodes, while misbehaving nodes get bad reputations and are not allowed to take part of the network. Similarly, in TFT-based schemes, every node forwards messages to a neighbor, based on how many messages the neighbor forwards to it. In this way, the task of message forwarding is based on nodes' misbehavior. In [82] Gong *et al.* propose a Social Contribution-based Routing (SCR) protocol, exploiting (*i*) the message delivery probability to a destination node according to social relations among vehicles, and (*ii*) the social contributions of a relay node. Notice that the social contribution is used as key factor to stimulate selfish vehicles to be more cooperative within the vehicular network. Based on these two metrics, the vehicle with higher delivery probability and lower social contributions is selected as next hop forwarder.

Social aspects can be also integrated with Internet of Things (IoT) features, always in the context of vehicular environment [33]. Specifically, starting from the integration of the concept of IoT into VANETs, Nitti *et al.* [33] consider a novel paradigm, namely the Internet of Vehicles (IoV) *i.e.*, an interconnected set of vehicles providing information for common services such as traffic management and road safety. Then, the integration of social networking concepts into the IoV brings to the Social Internet of Vehicles (SIoV) paradigm, as an extension of the Social Internet of Things (SIoT) concept, as introduced in [83]. As a remind, the SIoT is a social network where every node is an object capable of establishing social relationships with other things in an autonomous way.

In [84] Alam *et al.* propose *VeDi*, a crowd-sourced video VSN, where users share a video with neighboring vehicles interested in such a multimedia content. *VeDi* system results as a viable option to create video social networks such as youtube, by exploiting vehicular crowd. In the framework of SIoV [33], vehicles and RSUs can create their own relationships to efficiently look for services and exchange information in an autonomous way, with the intent of creating an overlay social network that can be exploited for information search and dissemination for vehicular applications. They identify different social interactions in the SIoV scenario, that is:

- **Parental Object Relationship (POR)**, established among vehicles belonging to the same automaker and originated in the same period. POR provides useful information about the status of a vehicle for diagnostic services and remote maintenance;
- **Social Object Relationship (SOR)**, established among vehicles that come into contact through V2V links. SORs take into account common vehicles paths and locations, thus forming social networks among vehicles strictly related to determined areas;
- **Co-Work Object Relationship (CWOR)**, established among vehicles that meet continuously with RSUs through V2I links. These relationships can be useful to provide traffic information or to guide the drivers in less congestionated routes.

Leveraging on the social relationships highlighted in [33], several applications can be developed, such as (*i*) POR-based diagnostic services, where vehicles contact friends in order to know if they have fixed a similar issue, (*ii*) SOR-based traffic

[18]Bonnmotion, http://web.informatik.uni-bonn.de/IV/BonnMotion
[19]As an instance, the need to conserve buffer and computing resources.

information, where vehicles obtain from friends updated information about traffic conditions, and (*iii*) CWOR-based community services, where RSUs communicate with vehicles to provide information about road conditions or maintenance.

Finally, based on human preferences, it is possible arising novel non-safety applications. Especially in urban scenario, a great number of vehicles move between home and office every day, so their mobility pattern is spatially and temporally predictable. Groups of vehicles moving along the same road and at the same time can form some virtual communities. In [85], Ying *et al.* consider clustering as a robust technique to form groups of vehicles that are in geographical vicinity together. The clustering approach could be considered to "regulate" the time-variability of a social network by assuming both measurable parameters (*i.e.*, radio propagation, and vehicle density), information such as movement direction and speed, and also sociological factors (*i.e.* the context where the drive is taking place, or the reasons the driver is on-the-go, etc.). This approach can be a very effective solution for many open issues, such as the extreme time and space variability of a social network. Hu *et al.* [86] present S-Aframe, an agent based multi-layer framework with context-aware semantic service, to support the development of context-aware applications for VSNs. In [87] the authors develop a social Ubiquitous-Help-System (UHS) for vehicular networks, based on context-awareness. Through social relations, like Friend-Of-A-Friend (FOAF), only relevant and reliable information has to be shared between the nodes. Content- and relevance-aware routing protocols are emerged as a viable solutions for data sharing in Mobile Social Networks (MSNs) [88]. MSNs combine techniques related to social science and wireless communications for mobile networking. A comprehensive survey on MSNs is presented in [89], where aspects related to platforms, solutions, and designs of the overall system architecture are discussed. A special type of MSNs are the event-based MSNs [90], allowing mobile users to create events to share group messaging, locations, and multimedia data among participants. Finally, from MSNs we distinguish the Mobile Ad-hoc Social Networks (MASNs), which are emerging as a self-configuring and self-organizing social networking paradigm. In [91], Zhang *et al.* propose a detailed solution called BASA (Building Mobile Ad-hoc Social Networks on Top of Android) that is intended to fast build MASNs on demand with minimal infrastructure support.

C. *Differences between VSNs and OSNs*

After reviewing many works in the literature, we can define a *social car* as a mobile node equipped with advanced technology (*i.e.*, multi wireless network interface cards and a GNSS receiver) that belongs to one or more dynamic vehicular social networks. As told before, in vehicular environments, where vehicle speed is neither constant or homogeneous, VSNs can form *on-the-fly*, through available connectivity links. Indeed, due to the length and the regularity of people's trips on private cars and/or public transport, vehicle encounters exhibit social structure and behavior [92].

Vehicular social networks based on the "encounter" metric connect users sharing a location at the same time [93], as opposed to the traditional social network paradigm of linking users having offline friendships. The concept of On-line Social Networks (OSNs) [20] assumes members of a social network are people with social interactions, such as friendship. Social web communities (*e.g.*, Facebook or LinkedIn), as well as content-sharing sites that also offer social networking functionality (*e.g.*, YouTube), have captured the attention of millions of users [94], [95], and online social networks have proliferated everywhere (*e.g.*, at school and workplace, as well as within families and other social groups). On the other side, in VSNs, social networks are more *dynamic* because members (*i.e.*, vehicle drivers and passengers) are intended to access only when they are in mobility. For this reason, connectivity in a VSN is affected by mobility, causing limited access to members. Also, notice that many of security issues in VSNs are common with classical OSNs [96]. A detailed survey on security threats and issues in OSNs is provided in [97].

To summarize, a vehicular social network exists based on one or more of the following criteria [21]:

- **Position**: a vehicle is moving in a neighborhood where one or more social networks are available to access. When the vehicle exits the neighborhood, it will decide if to maintain the membership to the social network or not, although it can no longer communicate with other members of the network, since it is out of transmission range;
- **Content**: a vehicle can access a social network based on relevant content discussed among members (*e.g.*, social networks talking about traffic, on-the-road sport activity like jogging, places with fuel discounts, and so on);
- **Relationship**: a vehicle discovers and accesses a social network whose members are people with common interests (*e.g.*, co-workers, school alumni or gym attendants). The access is limited to people with existing commonalities.

In order to provide a classic example of VSNs based on *position*, *content* and *relationship* criteria, let us consider a vehicle (*i.e.*, a driver) moving every day from home to office. During the journey, the vehicle can access different social networks, such as that network where members are other vehicles talking about and sharing traffic information (*i.e.*, *content-based social network*). In the case the vehicle crosses a particular area of interest (*i.e.*, a Zone-of-Relevance), the driver and passengers can access the associated social network, whose members are other users crossing such area and talking about relevant topics (*e.g.*, traffic monitoring in that neighborhood). This well depicts the case of a *position-based social network*. Finally, when the

[20]Typical examples of OSNs are Facebook, Tweeter, Google+, LinkedIn and so on.

[21]Notice that due to mobility during a trip, a vehicle can access one or more social networks encountered, based on the above criteria (*i.e.*, position, content, and relationship).

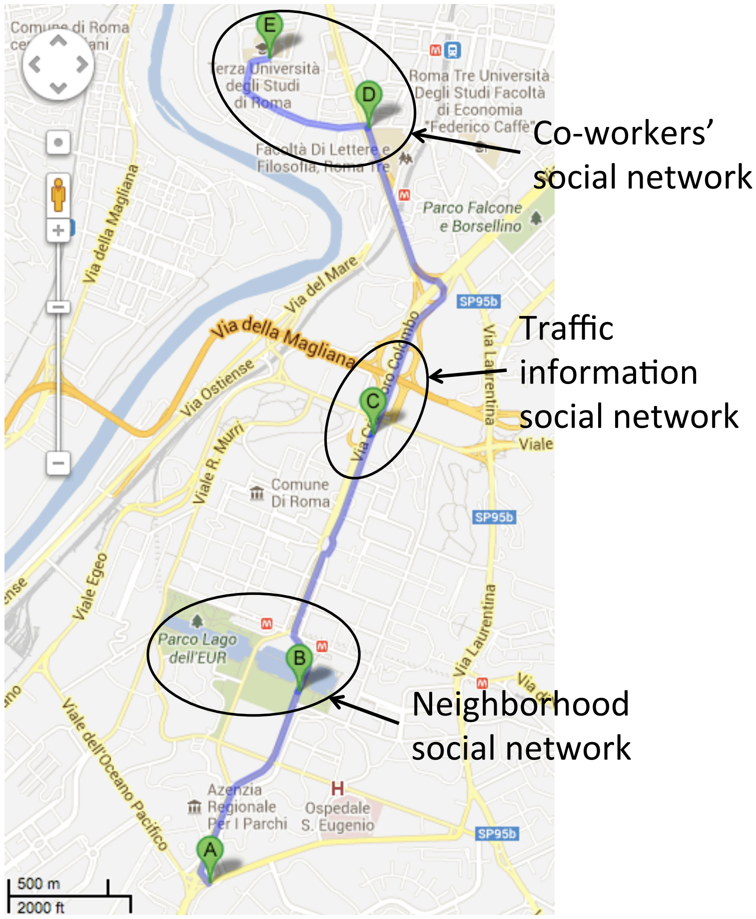

Fig. 7. Everyday path of a vehicle from home (position A) to office (position E). Intermediate positions (*i.e.*, B, C, and D) represent areas where a vehicle can access a given social network based on position, content information, or social relationships.

vehicle approaches the area near the office, people in the vehicle will access the network of co-workers; this represents the case of a *relationship-based social network*.

Fig. 7 illustrates the path of a vehicle from home (position A) to office (position E); other positions from B to D are places where the vehicle can experience social interactions with other vehicles. For example, in the area near position B the vehicle can connect with other vehicles driving along the same area, and then share relevant information with them (*e.g*, cultural information of next opening museum or special discounts at a neighboring mall). Then, in position C the vehicle can experience a traffic congestion and then communicates with other vehicles such content (*e.g.*, sending warning messages of an accident). Finally, when approaching to the office in position D, the vehicle can access the network of co-workers to share common information (*e.g.*, planning a meeting with colleagues). We can notice that during the journey there is not a single social network, but a multiplicity of social networks that are built *on-the-fly*, whenever a car enters a specific area *i.e.*, *position-based social networks*, encounters other vehicles with common interests *i.e.*, *content-based social networks*, or relationship binding *i.e.*, *relationship-based social networks*. *On-the-fly* vehicular social networks represent a *dynamic* process, where vehicles can connect each other for short time periods (*e.g.*, during the travel time). Interactions and data sharing with neighbors occur only in given scenarios *i.e.*, for a given position, content and social relationship. As an instance, in Fig. 7 position C represents a high traffic area. When a vehicle drives there, people in the vehicle can find, and then, enter the traffic information social network, in order to receive warning messages about traffic congestions. However, it is likely that in such position a vehicle will not encounter the own colleagues, because the distance from position C to E is still far. Moreover, vehicles near position B can take part of the neighborhood's social network, and will leave this network when outside the neighborhood; this social network can exist only in that area. As a result, during the whole path from position A to E, the vehicle has connected to at least three social networks.

When a vehicle drives near an area of interest, it can check for available social networks. Through the exchange of *query* and *reply* messages about a given topic related to the same interest or experiences (*e.g.*, music and video file sharing, traffic information, shopping experience, and so on), a vehicle can enter a social network and stay for a limited time depending on vehicle journey duration. Moreover, a vehicle can take part of a known [22] social network (*e.g.*, co-workers' social network), whenever approaching a specific area of interest.

Connections to a vehicular social network can occur via V2V, as well as V2I communication protocols. Basically, a *centralized* approach such as V2I occurs for scanning available social networks. For instance, a vehicle driving in downtown checks for neighboring social networks talking about art expositions and other cultural events. Query results will provide all the available social networks with "art and culture" tag (*e.g.*, "*Churches in Rome*", and "*Vatican Museums*" social networks). The vehicle can access one or both the social networks.

The way to disseminate data information in a very useful and undisturbing way represents the key factor of several infomobility and infotainment frameworks, such as the platform presented in the project "Knowledge Management 4 info Telematic in Mobility Environment" (KOM4T me) [98]. Specifically, this platform can support the information delivery on many different transmission channels, and to many different on-board devices. For example, a final user can decide to download a specific application on the proper own smartphone, that will allow to be "advertised" about some specific entertainment services geographically close to the current position of the user.

On the other hand, the *distributed* V2V approach is used for data exchange among vehicles belonging to the same social network. For example, once the vehicle has discovered "*Churches in Rome*" VSN, the driver and other passengers will enter and talk with other members in order to get information about which church to visit in the neighborhood.

Notice that most of the contents provided by the vehicles are related to certain areas and to limited times, as for example the communication of road incidents to vehicles proceeding toward the crashed areas or the sharing of useful information about traffic conditions or petrol stations. For this reason, a VSN is built *on-the-fly* and has short life, whenever the community members are neighbors to each other. Also, vehicles meet randomly *e.g.*, when drivers go to work and then drive the same road. More often two vehicles meet, the stronger the relationship that links each other, and the higher the value it provides in service discovery and trustworthiness evaluation. Thus, vehicular social networks can be called also as "sporadic social networks" [99]. In [99] Bravo-Torres *et al.* present the potential of automatically establishing sporadic social networks among people occurring to be physically close to one another at a certain moment, and in a given place. The authors present a cross-layer platform, called SPORANGIUM (SPORAdic social networks in the Next-Generation Information services for Users on the Move), aiming to create sporadic (short-lived) social networks, where each individual communicates with the surrounding people at a given moment, considering the information that may be relevant to them in different contexts. In [93] Mohaien *et al.* present MeetUp application that allows users to find other nearby members by means of Bluetooth connections. User ID information *i.e.*, pictures and certificates signed by a trusted certificate authority, is shared in order to connect users to each other.

Another solution for social networks among vehicles is Drive and Share (DaS), presented by Lequerica *et al*. in [100]. DaS is a social network service that offers relevant information (*i.e.*, traffic and personal information, including pictures, voice notes, and recommended places) to vehicles. As an instance, DaS can estimate the travel time of different route alternatives calculated with real-time data gathered from vehicles that are currently moving along those roads. In [101], Luan *et al.* present Verse a distributed vehicular social network allowing vehicle passengers to spontaneously create and share contents, such as travel blogs with pictures, and to explore potential friends on the road. Notice that while DaS exploits an ubiquitous cellular networks to assist passengers to exchange the location-based information, Verse is an infrastructure-less community with the self-organized content/message creation and distribution, and exploits V2V communications only. Moreover, among main features, Verse implements a "friend recommendation" function, which helps passengers efficiently identify potential social friends with both shared interests and relatively reliable wireless connections.

Leveraging on such features, we can enlist the following main differences from traditional online social networks: (*i*) a vehicular social network is built mostly dynamically, and at the same time, when users leave the social network, it will be no longer active, (*ii*) social connections among members occur even if they do not know each other, and (*iii*) members are not strong friends, but only contacts that can become acquaintances and eventually friends (*e.g.*, members of a vehicular social network are mostly people with common interests, not friends or family members). Finally, unlike traditional online social networks, which are built upon the reliable IP networks, VSNs face fundamental challenges, such as (*i*) users are anonymous and strangers to each other and hard to identify potential friends of shared interests, and (*ii*) users communicate through intermittent and unreliable inter-vehicle connections.

To summarize, the main differences between VSNs and OSNs are collected in TABLE II. We can notice that some issues can arise, specially due to the fact that members of a vehicular social network are mobile users, and then can change all the time *e.g.*, they can access a social network, and then leave after a short period due to mobility. Obviously, this can affect the life-time duration of a vehicular social network.

D. Research challenges

We identify the following research challenges, which should be addressed by researchers in the field of VSNs:

[22] A social network previously visited.

1) **Message dissemination in VSNs**: how data are forwarded in a VSN? Researchers should consider not only existing constraints in vehicular ad hoc networks (*i.e.*, mobility, and connectivity issues), but also social aspects (*i.e.*, messages are forwarded among trusted users, which are sharing same interests and move in a common place at the same time). Indeed, a (mobile) member of a community can communicate with other (neighboring) members only if available and for a limited time interval. As an instance, in the social network of bicyclers moving towards a common destination, a member can obtain information on the race and available paths from other members, only during the lifetime of the mobile social network.
2) **The treatment of the data**: data represents an important issue not only in terms of dissemination, but also related to the way the enormous amount of data is handled *i.e.*, data collection, consolidation and aggregation. There exist specific solutions regarding the "treatment" of data for both the contexts *i.e.*, vehicular networks and OSNs, but separately.
3) **Incentive Mechanism of User Involvement**: without lack of generality, we can absolutely claim that VSNs are really close to the User Centric paradigm. In fact, an effective way to collect a sufficient amount of data that can circulate in the VSN is, for example, through the handheld devices as smartphones [7]. Without data there is no network. On the other hand, the design of intelligent incentive mechanisms to motivate the members in VSNs to be involved with their devices is a key challenging issue to make this method successful.
4) **Effectively Model VSNs**: as remarked in [102] the connection ways can be classified into different categories, such as friends, colleagues, family members and so on. Based on that, it is clear that different applications require different metrics both to model the social networks, and also to evaluate the performance. VSNs can be considered as a kind of macro-application, where different and specific connection ways can be identified. This kind of connections are very specifics since very specific sub-applications can be individuated, such as the forming of a group to detect specific warning on specific roads, or users that share specific interests (*e.g.*, concert events, shopping, etc.).
5) **Migration from Centralized to Distributed**: the most popular OSNs are based on a centralized architecture. As in any central approach there are inherent advantages such as a single control point, availability, etc. On the other hand, we cannot imagine a VSN based on a centralized architecture. Handled devices (*e.g.* smartphones/tablets) are really used as substitute of the traditional computers. Smartphones and tablets can be used either to collect personal data such as locations, pictures, etc. or social environmental information such as compass, temperature, etc. Of course, the mobile devices are resources-constrained and the design of VSN must take into consideration these aspects.
6) **Security in VSNs**: how to guarantee security aspects in VSNs? In VANETs, a variety of applications ranging from the safety related (*e.g.* emergence report, collision warning) to the non-safety related (*e.g.*, delay tolerant network, infotainment sharing) are enabled by V2V and V2I communications. However, the flourish of VANETs still hinges on fully understanding and managing the challenging issues over which the public show concern, particularly, security and privacy preservation issues. If the traffic related messages are not authenticated and integrity-protected in VANETs, a single bogus and/or malicious message can potentially incur a terrible traffic accident. In addition, considering VANET is usually implemented in civilian scenarios where locations of vehicles are closely related to drivers, VANET cannot be widely accepted by the public if VANET discloses the privacy information of the drivers, *i.e.*, identity privacy and location privacy. Therefore, security and privacy preservation must be well addressed prior to its wide acceptance.
7) **Connectivity modeling in VSNs**: how connectivity can be modeled in a VSN, in order to mitigate disconnections and provide coverage in the most part of the network? Apart mobility issues that limit connectivity links among nodes, in a VSN members can communicate not only if within the same transmission range, but also if share the same interests.

From the above mentioned research challenges, we highlight that social aspects should be taken into account in order to face future directions in VSNs. Questions like "*how to exploit social and behavioral data in vehicular networks?*" and also "*could these aspects be leveraged to optimize wireless network designs?*" are of vital importance for researchers in the field of VSNs. As an instance, in crowded areas the probability that people meet and socialize is highest, and this can guarantee connectivity and data propagation. Also, another questionable point is how to apply social network theories (*i.e.*, social metrics) in routing protocols, and how to enhance network security protocols using trust/prestige metrics obtained from social network data. On the other hand, there is a need to develop protocols for social media content distribution in vehicular networks, under the constraints of dynamic social networks with limited access and short life time.

IV. Social-based Vehicular Applications

In VSNs, novel routing algorithms for message forwarding can exploit the *cooperative behavior* among multiple communities of vehicles. Vehicles belonging to the same communities may share common interests and information. As an instance, a group of people all driving (or walking or cycling) to a football game can experience traffic on the route to the stadium, and they are highly expected to encounter others with common interests (*i.e.*, supporters of the same team) or will otherwise be enjoying the same shared experience.

In such a scenario, applications like Clique Trip [103] allow connecting drivers and passengers in different cars, when traveling as a group to a common destination. In order to establish the feeling of connectedness, the system automatically switches to an alternative navigation system when the cars tend to loose each other. Other vehicular social-based applications

TABLE II
MAIN DIFFERENCES BETWEEN VSNS AND OSNS, WITH A SHORT DESCRIPTION.

	Features and description		
VSN	*Dynamic*	*Limited access*	*Limited life time*
	Members change anytime, based on interests and positions. Anonymous users.	Users access only in given positions, when available.	Social networks formed on-the-fly among vehicles with common interests and features.
OSN	*Static*	*Extended access*	*Unlimited life time*
	Members mostly the same, based on the friendship contacts, and other relationships.	User access anytime and anywhere.	Social network formed among users with known relationships.

are based on traditional online social networking services, like Facebook and Twitter [10], [11]. NaviTweet [11] is a Social Vehicle Navigation system that integrates driver-provided information into a vehicle navigation system, in order to calculate personalized routing. As a result, drivers belonging to a certain community can share driving experiences with other drivers, by using voice tweets. All these tweets are automatically aggregated into tweet digests for each social group based on position information. In [12], Smaldone *et al.* present RoadSpeak, a framework for VSNs where neighboring people can construct a periodic virtual social relation, through Internet infrastructure.

SocialDrive [104], [105] is an online social aware publish/subscribe application that helps drivers to learn about their driving behaviors and share real-time trip information through social networks. SocialDrive also aims to stimulate and improve driving habits in a fuel economic way towards a green transportation behavior. Finally, Caravan Track [106] –namely, the *tweeting car*– has been designed to allow drivers to share vehicle and route information among neighboring cars.

GeoVanet [107] is a typical query/reply protocol, where mobile users spread queries in the VSN, and the answers are expected in a bounded time, with a minimum delay. For instance, let us consider a tourist driving a car in a city, and searching for information about the most interesting places to see. Queries about what to see are broadcasted to neighboring vehicles. Selected vehicles (*e.g.*, vehicles of tourists sharing information about the sites they have already visited) send answers to the tourist, and if the shared information matches the user's needs, it will be delivered to her. As opposed to traditional query processing techniques, whose objective is to deliver the query result as quickly as possible, in GeoVanet the goal is to guarantee that the maximum amount of results will be delivered in a bounded time.

Finally, in [108] Hu *et al.* present a semantic-based framework for the development of vehicular social network applications by means of a multi-agent approach. Moreover, in [109] the authors present VSSA a service-oriented vehicular social networking platform, aiming at improving transportation efficiency by means of dynamic and automatic service collaboration support. VSSA enables people to easily collaborate and help each other in transportation situations, as well as it provides a context-awareness mechanism to predict potential incoming traffic congestions.

Many techniques for VSNs are also used for *smart city* applications [110]. Nowadays, cities are addressing simultaneously the challenge of combining competitiveness and sustainable urban development. This challenge reflects the impact on issues of urban quality, such as housing, economy, culture, social and environmental conditions. As a practical example of smart city applications, let us suppose a business man traveling to unfamiliar city needs to find his way to a meeting, and have lunch in an Italian restaurant. Navigating to the meeting can be easily accomplished by means of GPS technology, while finding a good Italian restaurant in a new town could be fixed in several ways. As an instance, the traveler could rely on commercial information about Italian restaurants, which is context-free. However, this solution is not necessarily trustworthy, and not much better than pure advertising. A good solution could relay on accessing information provided by trusted friends, which can recommend good Italian restaurant that they already visited. As a result, with a sufficient amount of comments, and recommendations, the traveler is able to experience the city within a *social context*.

Notice that in addition to reading social content *e.g.*, restaurant recommendations, and the social relevance of a given place, the user would need to create such information, while driving. This arises to the idea of "tagging", which has been already exploited in several map-based applications. A tagging system is intended to give an alert to the driver when a friend is along the way, as well as the driver is near locations relevant to his friends. The knowledge about socially important locations and people (*e.g.*, a bar where friends use to have lunch), allows the user to socialize with other users on the road (*e.g.*, the user could arrange a spontaneous meal with a person who was coincidentally driving the same route).

Another interesting example of smart city's challenge is the parking problem. Studies show that an average of 30% of the traffic in busy areas is caused by vehicles cruising for vacant parking spots [111]. This is additional traffic that causes significant problems, from traffic congestion, to air pollution and energy waste. For limitation of such problems, in [112] Liu *et al.* present Carbon-Recorder, a mobile-social application designed to enable drivers to track their daily vehicular carbon emission, and share the scores on social networks. Carbon-Recorder is then intended to (*i*) take awareness of vehicular carbon emission, (*ii*) encourage a more efficient driving behavior, and (*iii*) act as a platform for data collection for research in vehicular traffic management, carbon emission, and user behavior analysis in VSNs.

The huge demand for transportation-related services to simplify daily life is the pillar for mobile *crowdsourcing* applications. By assuming each citizen is equipped with a mobile device with sensing capability, it is possible to share information with own neighbors. This represents the concept of crowdsourcing, which considers a variety of online activities that exploit collective contribution and intelligence to solve complex problems [23]. The desired effect is to save time and the fuel spent in cruising, to reduce unnecessary walking, and traffic congestion, as well as to improve the quality of information necessary for a given request (*e.g.*, what restaurants to go to, which low price fuel station around, etc.).

In [113] Chen *et al.* describe a real scenario for smart parking that is a system employing information and communication technologies to collect and distribute real-time data about parking availability. Information collected through a coordinated crowdsourcing is integrated into traditional road navigation system; through the use of a GPS navigator, the vehicle can receive recommendations from a central server about potential free parking slots, whenever approaching a given destination.

Finally, another example of crowdsourcing service is Waze [24], a social mobile application available on smartphones, that allow users to publish traffic information via real-time maps by means of a mobile telephony network. Waze "*outsmarts traffic*", since it exploits crowdsourcing information to provide vehicles with updated traffic information. Thanks to data crowdsourced through thousands of mobile devices, drivers are able to pick a better route to avoid a road segment that was detected as congested by Waze users. However, this approach can cause confidentiality issues, since a driver may not accept to send own location that will be stored by an untrusted peer.

Similar to Waze, Moovit is a mobile GPS application for public transport information and navigation [25]. Moovit is a community-driven application that integrates static public transit data with updated real-time data generated by people that anonymously share the own public transport vehicle location and speed, as well as any other relevant contents (*e.g.*, overcrowding on the bus, accidents that cause delays, etc.). As an instance, at the bus station people can be informed about the expected arrival time of next bus via real-time updates, and track the arriving bus on the live map. With Moovit, people can (*i*) *save time* by avoiding jammed and delayed routes, and choosing route based on all public transport methods available, and (*ii*) *comfortably ride* by avoiding overcrowded buses or trains. Finally, a very simple application of social networks applied to vehicular environments is Aha Mobile, whose aim is to deliver an "always-on" connected lifestyle experience via dynamic audio content that originates from existing social networks.

Generally, crowdsourcing applications in vehicular environments are related to many fields. For example, drivers can refill at a gas station with a lower price by GasBuddy application [26], and also find a parking place using applications like Open Spot [114]. Similarly, taxi drivers can select routes on the basis of colleagues' trajectory in order to improve their moves [115]. A dedicated application for commuters is Roadify, which provides real-time transit information and updates from other commuters [27]. Finally, CrowdPark [116] assumes a seller-buyer relationship among drivers, to help other users find parking spots.

Through the use of smartphones and real-time applications, novel smart transportation systems are emerging, mainly based on the concept of sharing cars or taxi service (*i.e.*, ride sharing or carpooling), which are expected to effectively replace public transportation due to the on-demand quality of individual mobility [117]. MobiliNet [118] is a user-oriented approach for optimizing mobility chains, providing innovative mobility across different types of mobility providers, from public transports (*e.g.* buses, short distance train networks) to personal mobility means (*e.g.* car sharing). MobiliNet is based on the concept of social networks, not limited to human participants, but it extends to objects (*i.e.*, vehicles, parking spaces, public transport stations, and so on). Due to the integration of "things" into Internet-services, MobiliNet platform represents a service for the "Internet of Mobility". As an instance, people with a mobility handicap can get a nearer parking space, and people with babies or toddlers could get assigned a broader parking space so that the getting in and out would be more comfortable.

In [119], Shankar *et al.* discuss the challenges related with the opportunity of automatic sharing. In order to face with these challenges, they present a novel architecture (namely, SBone), that allows the devices to automatically share several types of information. The authors of [120] present ICNoW, a totally distributed framework that exploits local information to implement

[23] Crowdsourcing, http://www.crowdsourcing.org
[24] Waze, http://www.waze.com
[25] Moovit, http://www.moovitapp.com
[26] GasBuddy, "Find Low Gas Prices in the USA and Canada", http://gasbuddy.com
[27] Roadify, http://www.roadify.com

protocols for VSN applications. Other preferences, such as the preferred mode of transportation (*e.g.* with the private vehicle), can be used to refine the system's behavior. In this way, users can also connect to friends and other known people, and based on the degree of confidence, they can share their profile information.

So far, based on the remarks about VSNs, we can state that this topic is still in its infancy, and more improvements need to be addressed. Without pretending to be exhaustive, in Table III we summarize the main contributions in VSNs, by characterizing them in respect of specific features and characteristics, as well as research challenges associated. Furthermore, in Table IV we describe the main research studies in VSNs presented in this paper. We distinguish the goal of each technique and how it is accomplished.

TABLE III: Comparison of main contributions in VSNs.

Contributions	**Type of Infrastructure**	**Connectivity**	**Scenario**	**Services/ Applications**	**Research challenges**
Drive and Share (DaS) [100]	Distributed, Infrastructured	Cellular infrastructure, Smartphone, but can easily work with different networking solutions with some changes	Any type of routes, but cannot work without Internet connection	Social community, choice of the best path based on exchange of traffic and personal information. Able to estimate the travel time of different alternatives calculated with real-time data gathered from the vehicles.	Message dissemination, treatment of the data, incentive mechanism of user involvement, migration from centralized to distributed
Verse [101]	Totally Distributed, Infrastructureless	V2V among vehicles only	Highway	Advanced social application (*i.e.*, chatting room, social gaming, etc.)	Message dissemination, treatment of the data, migration from centralized to distributed
Waze	Centralized, Infrastructured	Cellular infrastructure, smartphone.	Urban scenario, or any other scenario where vehicular density is higher	Social community, where users publish and consume real-time maps and traffic information.	Message dissemination, treatment of the data, incentive mechanism of user involvement
Moovit	Centralized, Infrastructured	Cellular infrastructure, smartphone (*i.e.*, iOS, Android, and Windows Phone)	Urban scenario, or any other scenario where vehicular density is higher	Community-driven application for real-time public transit information and GPS navigation. Users plan trips across transportation modes based on real-time data.	Message dissemination, incentive mechanism of user involvement, effectively model VSN

TABLE III: Comparison of main contributions in VSNs.

Contributions	**Type of Infrastructure**	**Connectivity**	**Scenario**	**Services/ Applications**	**Research challenges**
GasBuddy	Centralized, Infrastructured	Cellular infrastructure, smartphone	Urban scenario, or any other scenario where vehicular density is higher.	Crowdsourcing application providing real-time localization information about cheap gas stations and updates from other commuters.	Message dissemination, incentive mechanism of user involvement
MobiliNet [118]	Centralized, Infrastructured	Cellular infrastructure, personal portable device, such as smartphones or tablets, with mobile Internet access	Urban scenario, or any other scenario where vehicular density is higher	Platform interlinking not only people with each other, but also vehicles.	Message dissemination, connectivity modeling
SBone [119]	Distributed, Infrastructureless	Personal devices used by the users to connect to social networks	Any type of routes, but cannot work without Internet connection	SmartDial, RoadSense	Message dissemination, connectivity modeling, migration from centralized to distributed
ICNow [120]	Distributed, Infrastructureless	Integrated system on IP protocol stack and cellular infrastructure	Any type of routes mostly focused on city areas	Social communications, safety applications, location-based services, city-wide alerts, interactive services	Migration from centralized to distributed, connectivity modeling, effectively model VSN
RoadSpeak [121]	Centralized, Infrastructured	Laptops with Verizon EVDO PC Cards (with 3G connectivity)	Any type of routes, but cannot work without Internet connection	Voice Chat Group	Connectivity modeling, effectively model VSN
SocialDrive [122]	Distributed, Infrastructureless	Android mobile devices	Any type of routes, but cannot work without Internet connection	Real time driving status. Feedbacks to improve driving behaviors (*i.e.*, to reduce fuel consumption)	Migration from centralized to distributed, connectivity modeling, incentive mechanism of user involvement

TABLE IV: Comparison of main research studies in VSNs.

Approach	Goal	Issues addressed	Connectivity	Scenario	Pros	Cons
LASS [34]	Packet forwarding based on local activity and social similarity	Message dissemination, incentive mechanism of user involvement	V2V	Any scenario	Heterogeneity of different members in the same community. Awareness of different levels of local activity	Only unicast data forwarding experiments. Lack of direction of social relationship
SPRING [38]	Packet forwarding protocol	Security and privacy, incentive mechanism of user involvement	V2I through RSUs deployed at high social intersections	Any scenario	SPRING protocol has been identified to be not only capable of significant improvement of reliability with V2V and V2I communications. Achievement of privacy preservation, resistant to black (grey) hole attacks in packet forwarding. High efficiency in terms of delivery ratio	Limited improvement of the forwarding efficiency. Location of destination is assumed as stationary and known.
EVSE [44]	Packet forwarding protocol	Social trust, incentive mechanism of user involvement	V2I	Any scenario	Location privacy preservation. Avoidance of double-count in social evaluations	Presence of a centralized trusted super-entity (centralized mechanisms)
SPF [45]	Packet forwarding protocol	Location and privacy, incentive mechanism of user involvement, treatment of data	V2I by means of social spots as relay nodes	City environment	Relies on realistic mobility models, protection of receiver location privacy	No fully protection against active global adversaries (*i.e.*, the source and vehicles who helped carrying the packets know the receiver's non-sensitive location)

TABLE IV: Comparison of main research studies in VSNs.

Approach	Goal	Issues addressed	Connectivity	Scenario	Pros	Cons
STAP [47]	Packet forwarding protocol	Location and privacy, treatment of data	V2I through RSUs deployed at social spots	City environment	The receiver's location privacy is fully protected against an active global adversary	No use of heterogeneous wireless network environment effectively, simplified adoption of inter vehicular network environment model
BEEINFO [50]	Packet forwarding protocol	Message dissemination, treatment of data	V2V	Urban scenario, or any other scenario where vehicular density is higher	Biologically inspired networking and SAN	Privacy issue not addressed. No realistic scenarios
ReViV [61]	Packet (video) forwarding based on location and centrality metric	Message dissemination, incentive mechanism of user involvement, migration from centralized to distributed	V2V	Dense traffic and high streaming rate scenarios	New centrality metric called dissemination capacity. Good end-to-end delivery. ReViV does not rely on the RSU support	Absence of a realistic physical model
SPC/RSC [70]	Packet forwarding protocol	Message dissemination	V2V	Any scenario	Cluster stability, mobility prediction, social aspects of mobility	The use of centrality metrics only. Absence of application-driven methods
SCR [82]	Next hop forwarder protocol based on social relations	Message dissemination, incentive mechanism of user involvement	V2V	Any scenario	Social contribution used as the incentive to stimulate selfish nodes	No privacy neither security aspects addressed

V. Lesson learnt and future directions

Vehicular Social Networks are a very recent and hot topic, and many open issues and challenges have yet to be addressed. Based on the analysis dealt previously, we can not only draw some important conclusions but also present some future research directions in this field.

The **message dissemination**, and generally the **treatment of the data**, need to be carefully considered in the context of VSNs as we already outlined. There exist specific solutions regarding the treatment of data for both the contexts, vehicular networks and OSNs, but separately. Certainly, the consideration of the handling data methods for vehicular networks and OSNs can be not only a valid starting point but is also obliged. In fact, it will give a viable direction to individuate the specific features of VSN context that do not allow the assumption of one of the two categories. For sure, this will represent a challenging and interesting future direction.

The necessity of specific **incentive mechanisms of user involvement** is a key factor but also a very "delicat" point that deserves to be deeply studied in the context of VSN. This kind of mechanisms can not be separated from the selfish users. In the context of VSN, two different types of selfishness need to be considered: individual and social. The individual selfishness is peculiarity of a node that looks out for its own interests. From a social point of view, a selfish user is willing to cooperate with other users with whom it share some common interests. This type of analysis and research, cannot be "handled" only from a technical perspective (*e.g.* telecommunication engineers, computer science people, etc.) but require a very strictly and strong collaboration among economics and sociologist people, in order to formulate strategies that can be successful.

Another interesting aspect is related with the **effectively modeling of VSNs**. An effective modeling of social networks in the context of the vehicular networks, namely an effective modeling of the connections ways in VSNs is critical to fulfill the various potential applications deriving form the VSN. A future direction in terms of research would be to focus on the individuation of specific metrics that represent correctly the VSNs.

Last but not least, the mechanisms developed in the context of VSNs have to take into account that the interaction among the driver and on-board devices have to be minimized for safety reasons. The architectures developed for VSNs, have to enable the vehicle to automatically share information detected autonomously by the devices/sensors in the vehicles.

Finally, regarding future directions, we also envision a specific attention to the user driving experience, as well as satisfy infrastructure and service providers. Among the main issues that need to be addressed in this context, we summarize the following aspects:

- **Assessment**: researchers shall test existing (or not yet developed) prototypes with a larger number of cars, by means of more case studies with a larger number of participants, as well as recently new applications (*e.g.*, Waze, Moovit, GasBuddy, and so on) need to be improved. As an instance, Verse is expected to be implemented in the real-world environment;
- **Development**: researchers shall investigate advanced social applications, such as video conferencing and online gaming among social friends, social information broadcast, etc;
- **Security**: researchers shall provide solutions for privacy and trust issues, in order to provide a more elaborate mathematical model for trusted VSNs;
- **Enhancement**: researchers shall provide an improvement of existing models to react dynamically to network characteristics and changes;
- **Design**: researchers shall improve positive experiences in the automotive context, by means of target experiences to further study experience design.

Based on the analysis we have dealt so far, we can conclude that in despite of the fact that both, OSNs and Vehicular Networks are subject well studied in literature from several aspects, the combination/integration of them, namely the VSNs present many interesting and open research directions, that need to be addressed. Moreover, many aspects need an interdisciplinary analysis in order to take into account the specific features and the sociological implications.

VI. Conclusions

In this paper, we have presented a survey of the main features and perspectives of Vehicular Social Networks, with particular attention to the aspects of *sociability*, *security*, and *applicability*. VSNs are a novel communication paradigm exploiting opportunistic encounters among vehicles, for mobile social networking and collaborative content dissemination. Social Networks are expected to definitely emerge in vehicular scenarios, due to novel interesting services based on social networking data sharing. As an instance, sharing traffic information through VSNs can lead to new business models, novel applications and services.

We first described VSNs through the main features, which distinguish from traditional OSNs. From such characteristics, it has emerged that opportunistic vehicular social networks exploit user mobility to establish communications and content exchange among mobile devices in pervasive and mobile computing environments. The existing gap between social networks and vehicular networking has been addressed, since it constitutes the very first issue to be fixed in order to make the VSNs a concrete reality.

Concerning the communication protocols in VSNs, we discussed data dissemination methods and compared different research approaches. Furthermore, we presented VSN applications, that are strictly driven by social networking, as well as the human mobility is directly related to the social behavior of people (e.g. vehicles move according to real-life human mobility and social interactions). In VSNs, vehicles can benefit from the user social networks, and many forwarding schemes can rely on social information for efficient packet forwarding decisions. Finally, applications based on *crowdsourcing* have been addressed as one of the most significative solutions for vehicular social networking. Open issues and future directions have also been highlighted.

We can conclude that VSNs are still in their infancy but there is a concrete interest by the research community, automotive industry and social application providers to develop them, as witnessed by the several $R\&D$ events related to this topic.

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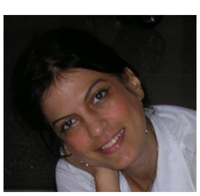

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