A social internet of vehicles sharing SIoT relationships

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ABSTRACT

In recent years, the concept of social networking combined with the Internet of Vehicles has brought to the definition of the Social IoV (SIoV) paradigm, *i.e.*, a social network where every vehicle is capable of establishing social relationships in an autonomous way with other vehicles or road infrastructure equipment. In SIoV, social networking is applied to vehicular networks according to how social ties are built upon, *i.e.*, either among vehicles or humans. This creates a twofold nature of SIoV *i.e.*, both based on human social relationships, and as an instance of the Social Internet of Things (SIoT). This twofold nature of SIoV is not in contrast with itself, but allows to distinguish different applications and use-cases.

This paper analyzes the SIoT-based social relations in a vehicular network scenario for establishing a Social Internet of Vehicles and providing insights on this growing research area.

KEYWORDS

Social Internet of Vehicular Things, Social Internet of Things, Connectivity

1 INTRODUCTION

Future Internet (FI) is expected to embody a large number of smart objects providing services to end-users through standard communication protocols.

The Internet of Things (IoT) paradigm is playing a key role in the context of FI. Its main focus is to provide innovative services based on the use of possibly hundreds of millions of smart interacting devices placed in all types of objects. Recently, it has been considered the possibility to integrate social relations among communicating objects and the IoT evolved to the Social Internet of Things (SIoT) whose aim is to provide devices with intelligence and awareness to socialize with each other based on shared context and mutual interests. In parallel, the broader area of vehicular networks [9] and its application to the realm of Intelligent Transportation Systems (ITS), evolved to a concept identified as the Social Internet of Vehicles (SIoV), where SIoT concepts are transferred to the vehicular domain to make far reaching changes to the existing ITS solutions by adding value and intelligence to the vehicles [4, 7, 14].

Human features and behavior are observed to strongly affect the SIoV paradigm, as the presence of humans is still a relevant component. For example, the mobility pattern in SIoV is affected by humans' daily routines, as well as the use of many applications is strongly user-oriented. According to this features, SIoV becomes a paradigm where social relationships can be built among drivers as well, similarly to what happens in traditional Online Social Networks (*e.g.*, Facebook, Instagram, etc.), but affected by the mobility, limited connectivity and high dynamics proper of the vehicular scenarios [23].

Leveraging on the above considerations, it follows that SIoV paradigm presents a twofold nature, *i.e.*, one that derives from SIoT main pillars, where vehicles play the main role as active devices and social ties can built among them, and the latter that focuses on humans (*i.e.*, drivers and passengers) behaviors and daily routines in order to build social ties and communities. As expected, different features distinguish the two natures and specific applications exist accordingly. The coexistence of the two approaches is allowed in an integrated manner as they work according to different sub-architectures. As a result, an integrated framework allows to comprise both two approaches.

In this paper, we will focus on the twofold nature of SIoV. In particular, we will analyze the differences between a Social Internet of Vehicles (SIoV) from a vehicle perspective only and a SIoV where social ties are established according to a SIoT approach. Based on the main actors, we define (*i*) the Vehicle-Oriented SIoV (VO-SIoV), and (*ii*) the Driver-Oriented SIoV (DO-SIoV) behaviors, which coexist in a unified SIoV architecture.

The paper is organized as follows. Section 2 describes the SIoV twofold nature, where vehicles and drivers are the main different actors. The VO-SIoV and DO-SIoV behaviors are detailed in Subsections 2.1 and 2.2, while while Subsection 2.3 highlights the main differences among them. Section 3 shows a preliminary analysis of the insurgence of a DO-SIoV. Finally, conclusions and a discussion on the SIoV behaviors are drawn at the end of this paper.

2 FROM SIOT AND VANETS, TO SIOV

There is an increasing research activity on SIoV, as the next-generation car is expected to be featured with a plethora of sensors, communication technologies, networking and security aspects, autonomous and social features. Internet of Vehicles (IoV) consists of interconnected sets of vehicles that communicate to each others for common services, such as traffic management, road safety and entertainment applications. On one side, the SIoV arises from an extension to the concept of IoV, where the social networking concepts of SIoT are applied to IoV. Social ties are built among neighboring vehicles and other social objects they might come into contact, and can be exploited in vehicular communications for both safety and entertainment applications. As an instance, cowork-object relationship (CWOR) based community services provide information about road conditions or maintenance to vehicles, and social object relationship (SOR) based traffic information is provided to vehicles to obtain from friends updated information about traffic conditions. All these features distinguish the SIoV behavior as a "SIoT-derived", where nodes are social entities that form communities to share common interests and relationships [6]. This first nature can be defined as Vehicle-Oriented SIoV (VO-SIoV).

On the other side, SIoV also considers a group of individuals (*i.e.*, people) who may have common interests, preferences and needs in a context of temporal, and spatial proximity on the roads [23]. SIoV extends the concept of Vehicular Ad-hoc NETworks (VANETs), including traditional V2V and V2I communication protocols, to human factors *i.e.*, mostly human mobility, selfish and user preferences, affecting vehicular connectivity. According to this vision, nodes in a SIoV distinguish based on social features like the centrality/importance of a node and its social habits. This latter behavior represents another SIoV nature, which we can defined as "human/driver-oriented" *i.e.*, Driver-Oriented SIoV (DO-SIoV).

A schematic representation of the SIoV twofold nature is depicted in Figure 1, where we observe how the integration of social networking into VANETs arises to SIoV model. We distinguish the twofold nature of SIoV, as in this context we can differentiate different roles of (*i*) humans (*i.e.*, drivers and passengers) and (*ii*) vehicles (*i.e.*, cars, trucks, etc.). Thus, when social networking is applied directly to humans (vehicles) in VANETs, we derive the DO (VO)-SIoV approach, respectively. Notice that considering vehicles as main actors in VANETs recalls to SIoT framework when applied to vehicular environments. As we can observe, DO/VO-SIoV involve different entities, characterized with different dynamics and social interactions. Since the VO-SIoV and DO-SIoV approaches are inherently different, their design cannot be similar, but must take into account the peculiar characteristics of the two behaviors.

In the following, we will describe the main features of the two behaviors of SIoV, *i.e.*, (*i*) the DO-SIoV and (*ii*) the VO-SIoV. For the readers' convenience teble 1 comparatively summarizes the main main feature of the two approaches that will be described in the following.

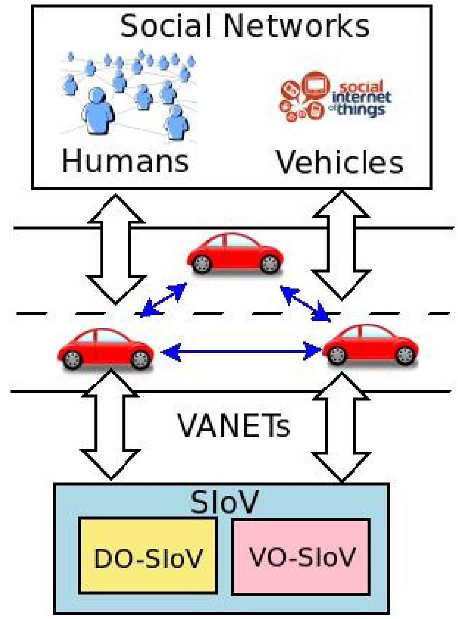


Figure 1: Schematic representation of the SIoV twofold nature.

2.1 Vehicle-Oriented SIoV

The idea that the IoT and the social networks are two worlds not really so far apart from each other as one may think, has led to the definition of several paradigms. Among them, one of the most famous is without a doubt the SIoT model, as proposed in [6]. Another recent solution is the SIoV (VO-SIoV), initially defined as a vehicular instance of the SIoT, where the things are represented by buses, trucks, cars and bicycles in addition to Road Side Units (RSUs). SIoT and VO-SIoV share the root idea of sociality, which enables things and vehicles to establish their own social relationships with other things in an autonomous way. A similar set of social relations as been defined for the two paradigm. In particular, so far, four relationship types have been defined in VO-SIoV [5]: *Ownership object relationship (OOR)*, *Parental objects relationship (POR)*, *Co-work objects relationship (C-WOR)*, *Co-location objects relationship (C-LOR)*, *Social object relationship (SOR)*. All those relationships are usually long lived being based on some inherent property of the vehicles or on their routinary mobility pattern. Furthermore, these relationships are not mutually exclusive so that two nodes can be tied by more than one relation.

The concept of VO-SIoV has so far been investigated in several researches. As an example, an analytical model to measure the workloads of various subsystem involved in the VO-SIoV process is proposed in [2] whereas the authors in [3] present an overall architecture for the VO-SIoV, which defines the main components and their interactions; a structure of the interaction message is also proposed to support several kinds of applications for the VO-SIoV. The authors of [15] explore the concept of the VO-SIoV and discusses possible issues of security, privacy and trust that are likely to arise. Finally, some studies have used the social part of the VO-SIoV to address common issues of VANET and IoV, such as [19], which focused on the issue of dynamic network access.

In spite of its wide spreading, the VO-SIoV paradigm still requires further investigation. Even if VO-SIoV derives from SIoT, there are some main differences between the two paradigm. The SIoT encompasses objects with heterogeneous capabilities ranging from sensors to smart devices, which communicate with different communication technologies; this has led to the creation of a comprehensive set of relations able to address all the possible type of interactions among the devices. As compared to SIoT paradigm, the VO-SIoV is more homogeneous, where the devices involved in the network are either RSUs or vehicles. Also, the relations for the VO-SIoV are usually derived starting from the SIoT vision. However, we claim that a new set of relations for the VO-SIoV should be elaborated from scratch to reflect the possible service and application typologies available in the VO-SIoV.

The homogeneous set of devices in the VO-SIoV is also reflected in the available resources *i.e.*, both RSUs and vehicles do not have issues related to power supply or to computational capabilities. This factor enables the perspective of a different implementation strategies for the two approaches.

Due to the presence of vehicles, the VO-SIoV scenario is highly dynamic, where we usually have vehicles travelling at sustained speed on the same streets every day, as it is the case of users who go back and forth from work or buses that always do the same route. As a result, the values of inter-contact time and contact duration, which are among the main parameters for the creation of the relations in the SIoT [17], must be revised in order to create a connected and navigable VO-SIoV network. A possible approach could be to introduce the strength of a relation based on how much two devices come into contact with each other or on how much they interact; moreover, if the strength decreases below a certain threshold, it should be possible to terminate a relation that it is not useful anymore.

Finally, being derived from SIoT, VO-SIoV inherits from its predecessor an implementation based on a cloud architecture. Such an approach, implying high latencies, is clearly not optimized for a vehicluar scenario.

2.2 Driver-Oriented SIoV

DO-SIoV is a driver/passenger centric approach, where social ties are built among users according to their behavior (*i.e.*, daily routines) and interests (*i.e.*, content). As an example, Ford concept car Evos can directly form a social network with driver's friends. According to DO-SIoV the communication over traditional VANET are driven by the social relationship occurring between the drivers, thus restricting the communication scope to select similar neighboring vehicles based on social metrics. While in VANETs messages are mainly related to traffic and safety information, and then are disseminated within the network mainly based on broadcast, in DO-SIoV nodes are classified based on social ties, as occurs in OSNs. Actually, in DO-SIoV not all nodes in the network may be interested in a given topic, but there exist clusters (*i.e.*, communities) of nodes that share interests among each other.

Due to its derivation from VANETs, DO-SIoV is also defined as Vehicular Social Networks (VSNs) [22, 23], where users are the main actors for data dissemination. Communities in DO-SIoV are built *on-the-fly* among users that share (*i*) content, (*ii*) position, and (*iii*) relationship, to each other. Communities may exist only in particular areas where exist point of interests (*e.g.*, malls), and groups of vehicles intend to share common information (*e.g.*, sales in a mall). A typical example of a DO-SIoV community is one built among vehicles driving to a football game. Drivers and passengers 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.

Social ties in DO-SIoV are very dynamic and usually short lived being based on the instantaneous position of the vehicles or on transient facts as the temporarily interest of the driver for a particular content or the imminence of a particular event such as a football game. Typical relationships for DO-SIoV are *Content-oriented driver relationship (CDR)*, *Relationship driver ties (RDT)*, *Position-based driver relationship (PDR)*. To cope with its high dynamic nature, DO-SIoV, is usually implemented by following some distributed approach, such as Edge or P2P. Such an implementation approach has the nice side effect to offer short latency usually comparable with Vehicular application.

Table 1: Main differences between DO/VO-SIoV approaches.

Features	DO-SIoV	VO-SIoV
Main actors	Human behavior	Vehicles' behavior and features
Architecture	Edge, P2P	Cloud, Client/Server
Connections	V2V/V2I	Remote
Dynamics	Fast evolving	Slow varying
Lifetime	Limited	Always available
Social ties	Dynamic	Stable/strong
Relationships	CDR, RDT, PDR	SOR, C-LOR, OOR, POR
Latency	Low	High

Recent achievements in the context of data dissemination approaches in VSNs are deeply studied in [18]. where 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 [24] present Artificial BEE Colony inspired INterest-based FOrwarding (BEEINFO), a routing mechanism that classifies communities into specified categories, on the basis of personal interests.

Several social-based applications exist, such as Clique Trip [10] that allows connecting drivers and passengers in different cars, when traveling as a group to a common destination. SocialDrive [8, 13] 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 aware manner towards a green transportation behavior. Finally, Caravan Track [21] -namely, the tweeting car- has been designed to allow drivers to share vehicle and route information among neighboring cars. However, other vehicular social-based applications are based on traditional online social networking services, like Facebook, Google+ and so on. As an instance, NaviTweet [20] is a social vehicles navigation system that integrates driver-provided information into a vehicle navigation system and compute personalized routing.

2.3 VO/DO-SIoV Comparison

SIoV represents a key concept in the vehicular context for revolutionising ITS. Fundamentally, SIoV systems enable social interactions both among vehicles and drivers. This twofold nature of SIoV interacts to each other, and can be highlighted as in Figure 2, where the two overlays overlap. Let us consider a vehicular network, comprised of groups of vehicles driving along different lanes

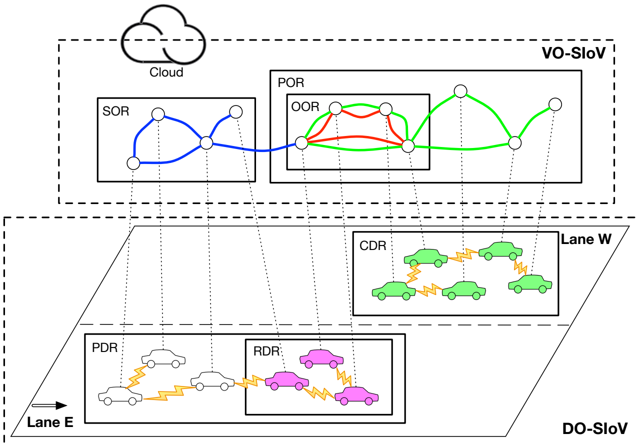


Figure 2: SIoV paradigm comprised of (*i*) the DO-SIoV and (*ii*) the VO-SIoV network layers. In DO-SIoV, communities among vehicles are built on-the-fly based on PDR (*white vehicles*), RDT (*pink vehicles*), and CDR (*green vehicles*). Overlapping among communities can occur. In VO-SIoV, social ties among vehicles are stronger and slow varying, built based on SOR (*blue edges*), CDR (*red edges*), and POR (*green edges*). Vehicles form a connected network, without isolated clusters. Vehicles can exhibit multiple social relationships.

(*i.e.*, Lane east and west). Differently from traditional VANETs, the DO-SIoV allows vehicular communications among neighboring vehicles that share common interests, position or social ties. Vehicles can form communities on-the-fly, based on the encounters among vehicles (*i.e.*, opportunistic networking). However, based on daily routines and mobility patterns of vehicles, vehicular encounters can be foreseen.

Communities can be built based on the social relationships that exist among vehicles (*i.e.*, CDR, RDT, PDR). For instance, vehicles that use to drive along the same path during workdays (*e.g.*, from position A to position B) are expected of being interested in sharing common interests (*e.g.*, information about real-time traffic or what-to-do in that particular neighborhood). Then, the community will be formed based on PDR. Similarly, a community among vehicles that share a common content (*e.g.*, music and video file sharing) is formed based on CDR.

When a vehicle drives near an area of interest, it can check for available social communities to share interests. Through the exchange of query and reply messages about a given topic related to the same interest or experiences (*e.g.*, traffic information, shopping experience, what-to-do in a given area, etc.), a vehicle can enter a community and stay for a limited time depending on vehicle journey duration. Moreover, a vehicle can take part of a known community *e.g.*, the 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. A centralized approach such as V2I occurs for scanning available social networks, while V2V connections are exploited for communications among members of a community. 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" communities), and the vehicle will access one or both the communities.

Figure 3: Map of the simulation area [1].

3 SIMULATION BASED ANALYSIS

In order to get a deeper insight on the VO-SIoV paradigm, we provide a preliminary analysis of the vehicular social network structure in a context of urban mobility. We consider an urban environment and apply the SOR concept defined for SIoT [6] to the vehicles roaming in that area to determine (*i*) the influence of the peculiar movement pattern of the vehicles on the insurgence of such social social relation, and (*ii*) the capability of SORs to selectively connect vehicles connecting vehicles commuting on a partially overlapping path. We based our analysis on the simulation framework described in [12]. Firstly, we used the well-known vehicular mobility simulator SUMO [11] to generate a set of accurate mobility traces. We subsequently processed those traces by using customary written Matlab scripts to seek the insurgence of SOR relationships. Specifically, we supposed that vehicles have established a SOR relationship after having experienced one or more contacts for a cumulative interval of at least T_{SOR} minutes [6]. We have assumed that a contact between two vehicles exists whenever they are closer than $D[m]$. The mobility traces have been generated by considering an urban environment, more precisely we considered the portion of the city of Reggio Calabria (Italy) represented in Figure 3. We structured our simulation to cover the same 2 hour period on 10 consecutive days, and we considered the following two classes of vehicles:

- **Commuting Vehicles:** Each i-th vehicle belonging to this class follows every day the same route between a starting and a destination point and it departs from its starting point at time $T^i_{depart} \pm T_{Jitter}$, where T_{Jitter} is uniformly distributed in $\left[0,\ T^{Max}_{Jitter}\right]$;

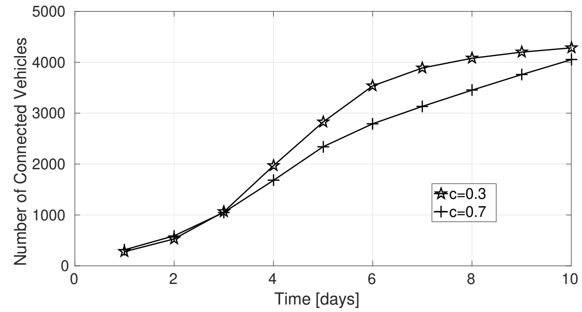
Table 2: Parameter settings used in simulation results.

Parameter	Value
Simulation Area	City of Reggio Calabria
Total Number of Vehicles	7200
Percentage commuting vehicles	$c = [0.7,\ 0.3]$
Time to establish a SOR T_{SOR}	5 [m]
Sensing Distance D	300 [min]
T^{Max}_{Jitter}	10 [m]
Single day analysis	2 [h]
Number of Days	30 [Days]

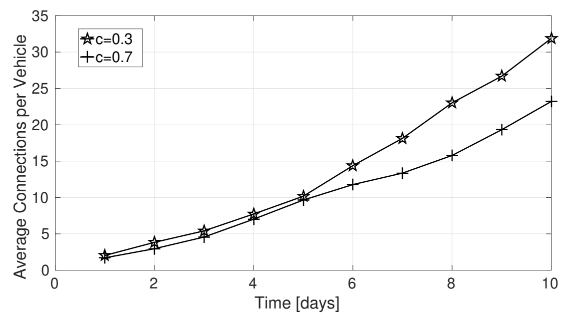
- **Randomly moving Vehicles:** Each i-th vehicle belonging to this class changes everyday its destination and departs from its starting point at a random time.

The first class includes public transportation or vehicles belonging to people moving every day from their home to their office. The second class includes vehicles not following a daily routine such as cabs and vehicles delivering goods around the city. It is worth to be noted that, in some cases, the mobility pattern of a vehicles is not related to the mobility pattern of any human. As an example this is the case of public transportation or cabs or commercial vehicles that might be driven by different professional drivers. In our simulation we considered a fraction c of commuting vehicles and a fraction $(1 - c)$ of randomly moving vehicles. The speed of each vehicle and the time it spends to go from its starting and destination points is automatically determined by SUMO according to the speed limits along the route and the traffic conditions. The main setting of our simulation campaign are summarized in Table 2.

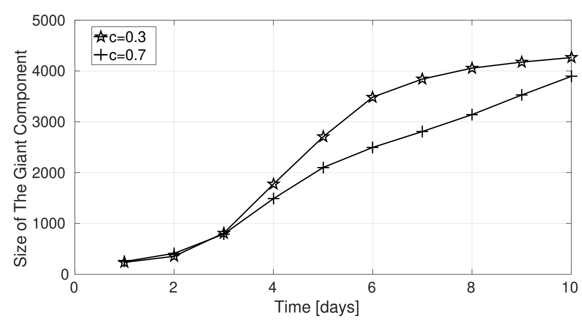
Figure 4(a) shows how many vehicles have joined the VO-SIoV by creating a SOR relation varying the simulation time and the fraction c of commuting vehicles. As it can be argued from Figure 4(a) the fraction of c of commuting vehicles greatly influences the growth rate of the social network. When the percentage of commuting vehicles is high the growth rate of the social network is low and tends to increase as the number of commuting vehicles decreases. This is due to the peculiar movement pattern of commuting vehicles. By following a fixed route at a fixed time commuting vehicles enter in contact with a reduced number of other vehicles, those following a path partially overlapping with their own. Hence, they have few opportunities to create a SOR. On the other end, randomly moving vehicles tend to get in contact with a larger number of other vehicles and thus they tend to create a larger number of SORs allowing a faster grow of the social network. The randomly moving vehicles also tend to became the point of connection between different groups of commuting vehicles. Furthermore, no matter the percentage of commuting vehicles, after 10 days (the end of our simulation), about the half of the vehicles we considered, were connected to the social network. Figure 4(b), shows the average number of social connection created by each vehicle in the scenario. This number is steadily increasing in time whatever the fraction of commuting vehicles is and, more in detail, the lower is c the higher is the increasing rate. At the end of the simulation, after 10 days, the average number of connections created by each vehicle reached about 31 for $c = 0.3$ and 23 for $c = 0.7$. Such an high



(a) Number of Connected Vehicles



(b) Average number of Connection per Vehicles



(c) Average size of the Giant componet of the Social Netwrok

Figure 4: Time evolution of Social Connected Vehicles in the SIoV network.

number of connections assures a well connected social network. This latter observation is further confirmed by average size of the Giant, shown in Figure 4(c), that is very close to the number of the connected vehicles for all values of c. Specifically, after 4 days the size of the Giant component equals the 90% of the connected vehicles and steadily remains above that value. At the end of the simulation, after 10 days, it climbs to the 99% of the connected vehicles for $c = 0.3$ and to the 96% for $c = 0.7$.

4 DISCUSSION AND CONCLUSIONS

In this paper we have discussed the evolutionary steps of Vehicular Ad-hoc Networks into the Social Internet of Vehicles. Even if the SIoV makes use of the same basic idea of the SIoT, the two paradigms have their own distinctive characteristics. By analysing these characteristics, we outlined the main research directions the SIoV has to face in order to make fully use of the advantages of the social approach.

In our opinion, SIoV is beyond the systems exclusively based on a specific entity, but could exploit all its potentialities when different and heterogeneous entities are involved in the network formation. An important evolution we envisage is a system based on entities such as drivers, vehicles, passengers and RSUs to extend the SIoV towards a pervasive interconnected system. This novel vision of SIoV is potentially much more powerful than a system based on homogeneous entities in terms of new services and applications that can be figured out.

The counterpart is represented by the new challenges that need to be firstly identified and then addressed. Just as an instance, privacy and trust issues are different for drivers and vehicles as standalone entities. When we consider them as interconnecting entities of a social system, we believe that new privacy and security issues can be present, issues that need to be clearly identified and solved.

Another important aspect of IoV is to make the vehicles context-aware, namely vehicles must have the capability to adapt their behavior based on the contextual environment. Whether context awareness for vehicles is mostly based on three subsystems [16], namely a sensing subsystem, a reasoning subsystem and an acting subsystem, we believe that for an heterogeneous SIoV it is necessary to conceive new and more flexible context-awareness architectures in order to enable the awareness of the different entities involved in the social network. Nevertheless, context-awareness is a primary requirement for SIoV, since the integration of social components allow the exploitation of evolutionary dynamics related to the specific context. *Identification of the main components for enabling effective context-awareness* in an heterogeneous SIoV constitutes, in our opinion, another important open research direction.

Finally, we must remember that the vehicular scenario involves the safety of people, so the reliability in the communication and the information provided by the peers are of utmost importance. The presence of malicious vehicles can greatly impact the network as a whole, putting at risk human lives. A social approach has the potentiality to build a trustworthy system based on the relations among the entities involved in the network: however, with respect to the SIoT paradigm, the management of trust is quite difficult in this scenario due to the mobility of vehicles. Indeed, the opportunities for two vehicles to interact with each other are rather scarce and then it is difficult for them to construct solid opinions towards other entities.

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