Social Structure Analysis in Internet of Vehicles

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***Abstract*—Internet, in its most recent evolution, is going to be the playground where a multitude of heterogeneous interconnected "things" autonomously exchange information to accomplish some tasks or to provide a service. Recently, the idea of giving to those smart devices the capability to organize themselves according to a social structure, gave birth to the so-called paradigm of the Social Internet of Things. The expected benefits of SIoT range from the enhanced effectiveness, scalability and speed of the navigability of the network of interconnected objects, to the provision of a level of trustworthiness that can be established by averaging the social relationships among things that are "friends". Bearing in mind the beneficial effects of social components in IoT, we consider a social structure in a vehicular context i.e., Social Internet of Vehicles (SIoV). In SIoV, smart vehicles build social relationships with other social objects they might come into contact, with the intent of creating an overlay social network to be exploited for information search and dissemination for vehicular applications. In this paper, we aim to investigate the social behavior of vehicles in SIoV and how it is affected by mobility patterns. Specifically, through the analysis of simulated traffic traces, we distinguish friendly and acquaintance vehicles based on the encounter time and connection maintenance.**

I. Introduction

The term Internet of Vehicles (IoV) has emerged to indicate an interconnected set of vehicles providing information for common services, such as traffic management and road safety. As the technologies advances vehicles are becoming more and more connected and, in the next future, they will be able both to communicate on a short range with nearby vehicles (i.e., V2V links) and infrastructure (i.e., V2I links) by means of IEEE 802.11and to remotely access to the Internet by using cellular systems. Vehicular communications are a key enabler for many automotive applications. As an instance, we may enumerate safety related operations, predictive maintenance, crowdsourcing, and many others [1].

Recently the idea of Social Internet of Things (SIoT) brought out in the academic community receiving a great consensus [2], thanks to its benefits deriving from the convergence of typical technologies and solutions of the IoT and the Social Networks domains. Applying social networking principles to the IoT definitely leads to advantages that span (i) from the enhanced effectiveness, scalability and speed of the navigability of the network of the future billions of objects that will populate the IoT (ii) to the provision of a level of trustworthiness that can be established by leveraging the social relationships among things that are "friends", (iii) to the interoperability between objects that are very heterogeneous from one another.

Following the framework of SIoT [3], also IoV networks are moving towards a social networking structure, where vehicles can share data information based on social ties that can be built everyday during the own journey. This has led to the concept of Social Internet of Vehicles (SIoV), aiming to create an overlay social network to be exploited for information search and dissemination for vehicular applications [4]. In SIoV a group of vehicles may have common interests, preferences or needs in a context of temporal, and spatial proximity on the roads. In this context, 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.

In this paper, we aim to investigate the SIoV framework in a real traffic scenario. Specifically, we analyse the ability of vehicles to form a vehicular social networks, based on SIoT social relationships. We assume that a pair of vehicles will form a social tie (e.g., they are friends) if the encounter time will last a given threshold. The paper is organized as follows. Section II gives an overview of SIoT and how it can influence SIoV framework, and describes some relevant use cases in the IoV domain. In Section III present a simulation framework specifically tailored to evaluate SIoT in the context of IoV. In section IV we will present some preliminary simulation results, expressed in terms of number of social vehicles connected, obtained in a real traffic simulation framework. We assess that in a SIoV scenario, vehicles (and more in general, objects) can form social ties in a reliable manner, based on the encounter time. Finally, conclusions are drawn at the end of this paper.

II. Background and motivations

According to SIoT "social-like" relationships mimicking humans, friendship ties are built between the objects in the IoT [2] and are used to (i) limit the search only to those nodes with mutual social relations and to (ii) increase the trustworthiness in the exchange of each piece of information provided by the devices in the network. So far, five relationship types have been defined in SIoT [2]:

1) *Ownership object relationship (OOR)*: relation bounding heterogeneous objects belonging to the same user;
2) *Parental objects relationship (POR)*: relation established between homogeneous devices produced by the same manufacturer and belonging to the same production batch;
3) *Co-work objects relationship (C-WOR)*: relation set up between objects cooperating towards the provision of the same IoT application;
4) *Co-location objects relationship (C-LOR)*: relation bounding devices that are always used in the same place;
5) *Social object relationship (SOR)*: relationship established between objects that come into contact, either sporadically or continuously, because their owners come in touch each other.

Besides the above mentioned relationships, as in most human social networks, it is also possible to define special groups that include devices bounded by some common features or finalities.

The application of SIoT toward IoV context has been also investigated. In [3], the authors firstly reviewed the relationships which can be established between the vehicles and between the vehicles and the road side units (RSUs) and proposed a middleware that extends the functionalities of the Intelligent Transportation Systems Station Architecture [5] to support the creation of SIoT like relationship between vehicles and the objects surrounding them. This paper goes further w.r.t. to [3] by evaluating how well the original design of SIoT fits with the requirements of automotive services.

Connected vehicles can be used as mobile probes to infer information about the environment where they move such as the average speed on road segments they traverse during their journey, the weather condition they experience (i.e. temperature, humidity, pressure, etc.) and the pollution levels [1]. The information collected, although valuable might be affected by a poor quality or may be maliciously corrupted by rogue vehicles to some purpose. SIoV can offer a framework to assess the trustworthiness of each contributing vehicle [6], [7]. Also, SIoV offers a framework to improve the quality of the shared information, so that vehicles belonging to a given social group can provide a better information to others. As an instance, a traffic information message transmitted by a vehicle that usually travels on a given itinerary is expected being particularly precise due to its familiarity with the itinerary and thus ability to find the quickest path in a congested area.

The types of social relations so far defined for SIoT can hardly be applied to bound vehicles that usually commute in the same path. The closest matching to such a relation is the SOR (Social Object Relation) that is created among objects that frequently meet to each other; also, a SOR can bound vehicles frequently parked in the same parking area, as well as vehicles that frequently travel on the same street at the same time.

A. Data Dissemination in SIoV

In general, the IoV is used to feed the vehicles with constantly updated information to help them during their journey. However, not all the vehicles are interested to all the information provided. In this context, SIoV can offer a framework to group the vehicles according to the information they can be interested to. As an example, the news about the scheduled closure of a road due to maintenance should be firstly sent to vehicles that usually drive that path, as well as heavy vehicles might be interested to a news about a weight restriction on a given road segment. From the latter example, it clearly emerges the need to address all the vehicles belonging to a given category (i.e., the trucks). Again, SIoV might offer a framework to drive the information to the most appropriate recipients. However, once again the types types of social relations so far defined for SIoT fail to to capture some relevant aspects of SIoV and none of them can be used to connect all the vehicles belonging to the same category (i.e the trucks). The the types of social relationship originally defined for SIoT such as POR can be also considered in the SIoV context. Specifically, POR allows vehicles belonging to the same automaker and originated in the same period to be "socially" connected. POR provides useful information about the status of a vehicle for diagnostic services and remote maintenance.

Indeed, vehicles with similar characteristics and common features are usually affected by similar failures. By mining the information about the failures shared by similar vehicles, a predictive maintenance program could be arranged for each vehicle. However, the automotive sector is a little more complicated then IoT. So, it might happen that the same engine might be mounted on several models of different brands. The same applies to many other components. Hence, to fully exploit the benefits of SIoV it is necessary to extend the POR to capture the formerly evidenced peculiarities of the automotive market.

III. The Simulation Framework

In the former section we have discussed the applicability of SIoT to IoV and we have pointed out some pros and cons. However, to get a deeper insight on this issue it is necessary to run some experiments and get some numerical results. This call for the implementation of a simulation environment capable to take in to consideration the peculiarities of both: the IoV and SIoT. Among all the types of social bounds so far defined, the SOR is the hardest to be simulated. PORs, OORs, C-WORs and C-LORs depend on the intrinsic characteristics of the objects or depend on their purpose. Therefore they are static and deterministic. On the contrary, SORs depend on the random meeting among the objects, hence they are stochastic in nature and depend on the mobility pattern of the objects. Although, appropriate mobility models for the smart objects, are still lacking in many applicative scenarios [8], this is not the case of IoV where several mobility models for vehicles have been developed in time [9]. Also, considering only the vehicles is not enough, the environment where they move is always populated by other smart objects which might enter

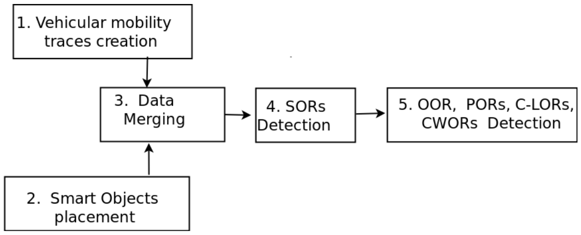

Figure 1. The simulation workflow.

Table I
PARAMETER SETTINGS USED IN SIMULATION RESULTS.

Parameter	Value
Simulation Area	City of Reggio Calabria
Number of Vehicles	3000
Number of fixed Access Points	100
Time to establish a SOR T	10 [m]
Sensing Distance D	100 [m]
Simulation Time	9 [h]

in their social network and exchange information with them. Therefore the simulation framework should take in to account at least the most relevant object surrounding the vehicles such as Road Side Units (RSU) and whatever other device that may produce or consume information related to the vehicles. To implement our simulation framework we followed the flowchart shown in Figure 1.

The ***first step*** consists in producing accurate mobility traces to take in to account the mobility pattern of vehicles. A plethora of vehicular mobility simulator are available. Among those simulator we chose "Simulation of Urban MObility" (SUMO) which is an open source, highly portable, microscopic and continuous road traffic simulation package designed to handle road networks on a city scale [10]. Sumo takes in to account several parameters ranging from real road maps, speed limits, traffic signals and vehicle characteristics thus producing very accurate mobility traces. SUMO might produce the output in many formats, we chose the FCD (floating car data) format that reports the position of each vehicle in time.

The ***second step*** of our flowchart consists in determining the number and the position of the smart object to be included in the simulation. Depending on the objective of the simulation many kind of smart objects can be considered. Accordingly many strategies might be followed to identify and positioning them. If we restrict our attention to Wi-Fi access points located along the road, then there are many option. the first one is to use one of the many open data repository such as [11], [12]. A second option would be to randomly positioning them by using some realistic distribution. If this latter approach is followed, a random topology generator such as NPart [13] might be used.

Once the positions of the smart objects has been determined, the ***third step*** in our flowchart consists in integrating those positions in the SUMO output file. Smart Object are inserted in the output file at the beginning of it by using the same syntax SUMO uses for parked vehicles and their positions is never changed. To accomplish this step we used a custom software written in *Phyton*.

The ***fourth step*** consists in processing the merged file containing the position of both the objects and the vehicles. During this phase the rule of SIoT are applied [8] to seek out the insurgence of SOR relationships. Specifically, two entities (either vehicles or smart objects) establish a *SOR* relationship after having experienced one or more contacts for a cumulative contact time of at least T [min] [8]. To determine the reciprocal contact between two entities we have assumed that they enter into contact whenever they are closer then $D[m]$. Where $D[m]$ is the sensing range of their IEEE802.11 wireless cards. In our framework the social network connecting N objects is represented by a symmetric, $N-by-N$ binary adjacency matrix where the elements (i,j) and (j,i) are set to 1 if a social relationship exists between object i ad object j. Hence, the output of the fourth step consists in a binary matrix where the elements have been set to 1 according to the SORs that have been discovered. To carry out this phased we used a custom software written in *phyton*.

The adjacency matrix is finally amended in the ***fifth step*** by including all the other types of social relationship (i.e., OOR, POR, C-LOR, C-WOR) that deterministically bind the objects according their characteristics. Of course this step might be accomplished only if additional information concerning the objects and vehicle are available. As an example, if a group of vehicle is assumed to belong to the same fleet, then a OOR relationship is created between them. If a group of smart devices is supposed to cooperating to the same task then a C-WOR relationship is created among them.

The adjacency matrix obtained at the end of the fifth step fully represents the social network connecting all the object in the simulation scenario.

IV. SOME PRELIMINARY SIMULATION RESULTS

To test our framework we carried out a simulation campaign whose setting are summarized in Table I. Specifically, we downloaded the map of the city of Reggio Calabria (Italy) from [14], represented in Figure 2, and we used it as an input to SUMO. We considered 3000 vehicles and 100 access points randomly deployed. Since, we assumed that all the access points belong to the municipality we considered all of them bounded by an OOR while we hourly monitored the creation of SOR relationship between objects and vehicles for a cumulative observation time of 9 [h]. Finally, we considered a sensing range $D = 100$ [m] and a cumulative time T required to create a SOR of 10 [min].

Figure 3 shows how many entities (either vehicles or smart objects) have joined the SIoT network varying the simulation time. At the beginning of the simulation only the access points are connected by means of OOR relations. As time evolves, an increased number of entities is included due to the SOR created following their frequent reciprocal meetings. At the end of simulation, after 9 [h], the SIoV network includes about 220 objects out of the 3100 considered in the simulation. Such a relatively small number of connected objects can be

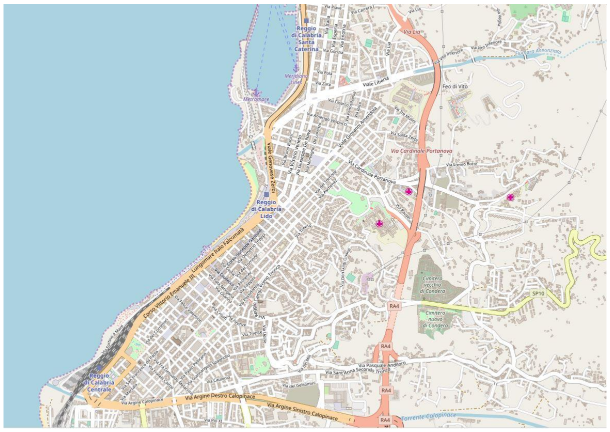

Figure 2. The simulation area.

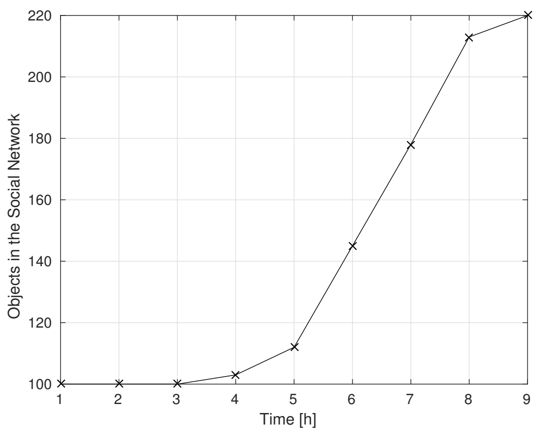

Figure 3. Time Evolution of Social Connected Objects (Vehicles and Access Points) in the SiOV network.

justified by considering the short simulation time and the highly dynamic environment.

The Diameter of a SIoV network is defined as the longest chain of acquaintances connecting two objects. Figure 4 shows how this value evolves in time in our experiment. At the beginning of our simulation the only objects included in the SIoV network are the access points that are directly connected by OOR and hence 1 hop each other. This corresponds to a network diameter of 1. Along time, more and more objects are connected to the SIoV network creating longer chains of acquaintances. At the end of simulation, the network diameter increases to about 9.

V. Conclusions

In this paper, we focused on the SIoV paradigm and evaluated the temporal dynamics that govern the SIoV network, in a real context of the city of Reggio Calabria. We assumed the OOR and SOR relationships in order to build social ties among vehicles. This type of analysis is of paramount importance in order to give an insight of the specific features characterizing an highly evolving scenario like SIoV.

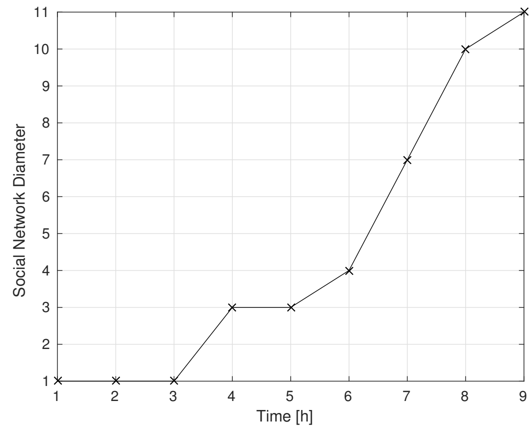

Figure 4. SiOV Network Diameter.

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