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Heterogeneous Vehicular Networks for Social Networks: Requirements and Challenges

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Abstract

Heterogeneous vehicular networks (HetVNETs) are regarded as a promising technique for meeting various requirements of intelligent transportation system (ITS) services. With the rapid development of mobile Internet in the past decade, social networks (SNs) have become an indispensable part of human life. Based on this indivisible relationship between vehicles and users, social characteristics and human behaviors can significantly affect vehicular network performance. Hence, we firstly present two architectures for SNs by introducing social characteristics into the HetVNETs. Then, several user cases are also given in this paper, in which service requirements are analyzed simultaneously. At last, we briefly discuss potential challenges raised by the HetVNETs for SNs.

Keywords

social network (SN); heterogeneous vehicular network (HetVNET); intelligent transportation system (ITS)

1 Introduction

Over the past decade, traffic congestion and accidents, as well as environmental pollution have become important global issues in the transportation industry. In order to overcome these common issues, intelligent transportation systems (ITSs) and vehicular networks have been widely studied in recent years. Not long ago, the United States Department of Transportation (USDOT) has published the *ITS Strategic Plan 2015-2019*, where two primary strategic priorities are defined. These are: realizing connected vehicle (CV) implementation and advancing automation. The first means the substantial progress about design, test, and plan for CVs. The second shapes the ITS Program around research, development, and adoption of automation-related technologies as they emerge [1].

It is well known that vehicular networks generally adopt dedicated short range communication (DSRC) systems [2] and mobile cellular networks to provide various services for vehicles on road. However, both DSRC and cellular networks have their corresponding limitations when used in vehicular networks. For instance, the lack of deployment of roadside infrastructures leads to DSRC not being widely used. On the other hand, although mobile cellular networks can provide wide coverage and high data rate, they cannot satisfy latency-sensitive services in high speed scenario. Hence, a heterogeneous vehicular network (HetVNET) framework takes along heterogeneous link layer (HLL) is proposed in [3]. It integrates DSRC with cellular networks, and may well support the communication requirements of ITSs. Furthermore, the novel layer, namely HLL, operates on the top of the medium access control (MAC) layer in each radio access network and provides a unified interface to the higher layers.

Nowadays, social networks (SNs) have become an indispensable part of human life, more and more people acquire happiness and enjoyment through SNs. One of the well-known SNs is online social networks, i.e., Facebook, Twitter, Weibo, etc. These kinds of websites offer platforms and services to people, and also let people utilize them to share and discuss common interests and topics. Thanks to the rapid development of mobile social software, SNs shift from "online" to "mobile", which supports people to engage in social interactions among interconnected mobile users [4]. On account of the rapid growth of mobile social networks, some networks (i.e., sensor networks, vehicular networks, etc.) address how to include social aspects into them. Based on the indivisible relationship between vehicles and users, social characteristics and human behaviors significantly affect vehicular networks. Hence, it is necessary to introduce social characteristics into the HetVNETs.

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Generally speaking, users on road create a novel type of social networks, namely vehicular social network (VSNs). By mining and exploiting the nature characteristics of VSNs, the innovative social applications and services such as social location, navigation and personal feeling dissemination can be well supported. On the other hand, users also can exchange some useful and interesting information via VSNs to improve the pleasure of journey. However, with regard to content dissemination in VSNs, several challenges lie behind resource and communication network constrains. For example, due to the high mobility of vehicles, the links between vehicles are unstable and easy to be broken, which means there only has short periods for information sharing.

The remainder of this paper is organized as follows. Firstly, a brief introduction on the HetVNETs and two VSN architectures are presented in Section 2. Then, several user cases are discussed in Section 3, where service requirements are analyzed simultaneously. In Section 4, we discuss a few potential challenges and solutions for SNs utilizing the HetVNETs. Finally, conclusions are drawn in Section 5.

2 Heterogeneous Vehicular Social Networks

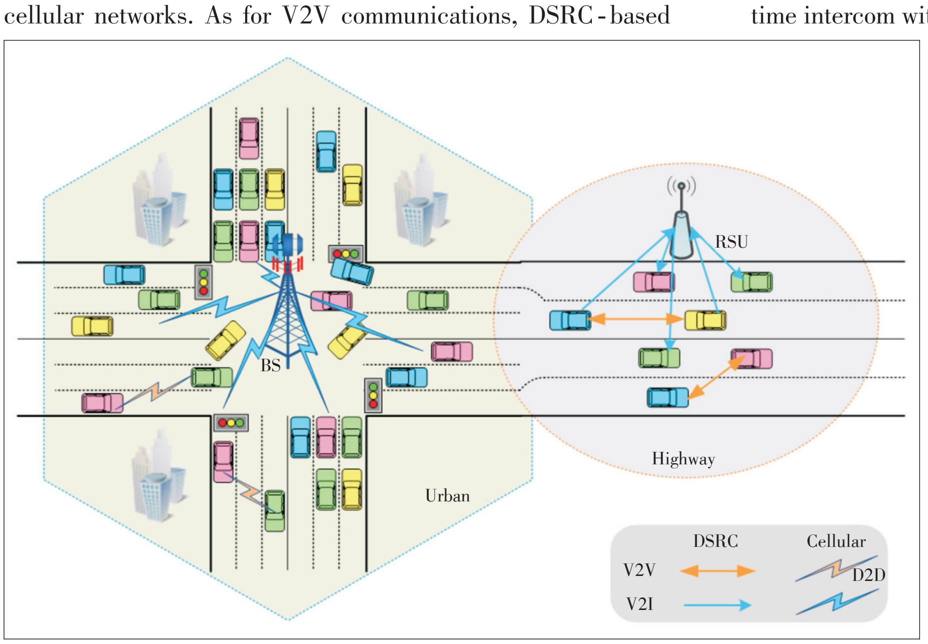
Owing to the mobility of vehicles and the complexity of vehicular network topology, a single wireless network generally cannot offer satisfied services. Integrating DSRC with cellular networks, the HetVNETs proposed in [3] may well support various communication requirements of ITS.

As illustrated in **Fig. 1**, there exist two different communication links in the HetVNETs, namely vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications. Both V2V and V2I communications are composed of DSRC systems and cellular networks. As for V2V communications, DSRC-based pattern can effectively support safety services with low latency, while cellular-D2D-based pattern not only supports safety and non-safety services, but also meets various quality of service (QoS) requirements.

On the other hand, direct connections between vehicles and infrastructures located on the roadside can be provided via V2I communications. Because of the wide deployment of cellular networks, Long Term Evolution (LTE), Wideband Code Division Multiple Access (WCDMA) and the others are regarded as the most promising candidate techniques to support V2I communications [5], [6]. Meanwhile, cellular-based V2I communications also can provide perfect user experiences of non-safety services by utilizing its large bandwidth and high data rate. With regard to safety messages broadcast, DSRC is more effective than cellular networks. Thus, those messages about minimizing traffic accident and improving traffic efficiency can be broadcasted by roadside unit (RSU).

Although the HetVNETs solve the problem by organically combining DSRC with cellular networks, it still has unavoidable issues, i.e.,

- There exist broadcast storms when DSRC is used in V2I and V2V communications. For example, if a large amount of vehicles in a certain coverage want to simultaneously communicate with a RSU, it will cause common broadcast storms.
- Everything has two sides and cellular networks are not an exception, they have both advantages and disadvantages. Wide coverage, large bandwidth and high data rate are their attractive advantages, but high latency is also non-ignorable disadvantages. Furthermore, only some of traditional vehicular non-safety services are provided via cellular networks, which does not meet the demand of Internet Age, especially the most popular over the top (OTT) services such as real-time intercom within a group, live streaming, etc.



▲Figure 1. Illustration of the HetVNETs.

Based on these two issues, we introduce and make use of social characteristics and human behaviors into the previous HetVNETs. Thus, two architectures namely centralized and distributed are discussed in this section.

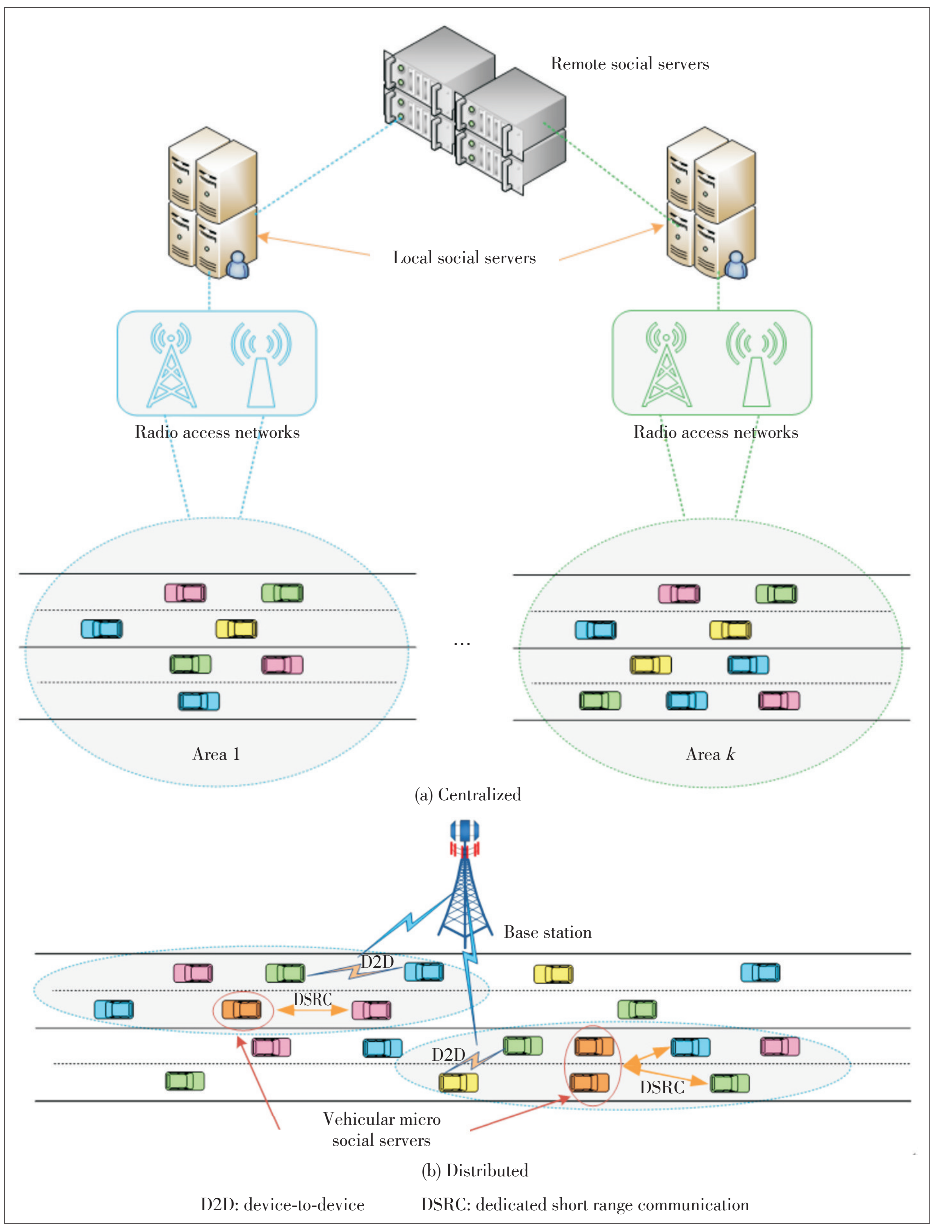
2.1 Centralized

Due to the rapid development of mobile Internet in the past decade, people are no longer content to use high data rate to view news, photos and videos, they prefer sharing and exchanging something with their close friends, and this arises VSNs. The contents shared by people can be interesting topics such as location-related hot issues and messages about improving driving comfort and safety, e.g., real-time road conditions information or notice on road reminder and so on. To effectively utilize these valuable social information in vehicular environments, centralized vehicular social networks (CVSNs) are firstly presented for VSNs.

As shown in **Fig. 2a**, CVSNs are composed of three main components, namely radio access networks (RANs), local social servers (LSSs) and remote social servers (RSSs). LSSs connecting to BS and RSU own the relatively complete functions of storage and computing. Therefore, regional social information can be released via LSSs. In particular, the regional social information includes nearby beautiful scenery, social forum and safety messages (i.e., surrounding traffic accident condition or road congestion condition, etc.). Meanwhile, LSSs also offer a fine graphical user interface (GUI) for users. Generally speaking, for a better management for LSSs, RSSs connect to a number of LSSs. Furthermore, RSSs can provide more wide-area social resources such as trans-regional friend making messages, emergency messages and so on.

In the CVSNs, V2I communications through RANs are primary social communication means. A vehicle in a certain area will acquire a social ID when it accesses LSSs via the GUI. The social ID is unique, so it can weaken the influence of broadcast storms. Meanwhile, because of direct connections between RANs and LSSs, the social interaction latency is effectively reduced. Unlike the online social networks, VSN topology is dynamic on account of the high speed of vehicles. Hence, in order to carry out mobility management, RSSs should connect to LSSs.

Heterogeneous RANs bring the possibility of the transmission of different services. Safety-related messages can be sent via DSRC, while social entertainment services can be transmitted via cellular networks. By the way, the jam-free V2V-based social communications also can be provided by the unique social ID.



▲Figure 2. Two types of architectures for VSNs.

2.2 Distributed

Fig. 2b presents distributed vehicular social networks (DVSNs). The RSSs and LSSs are not included in DVSNs, instead of vehicular micro social servers (VMSSs). VMSSs are composed of a vehicle or several vehicles whose social relations are very strong and handling ability are very powerful. VMSSs are spontaneous and they are likely to be produced when a hot topic need to be discussed within a group of vehicles. Vehicles on road can access their surrounding VMSSs by the aid of Global Positioning System (GPS), certainly there cannot be without GUI at the same time.

There also exists the social ID, but this ID is provided by VMSSs and convenient for VMSSs to manage their surrounding vehicles. In the DVSNs, two types of V2V communications are prime social communication means. After obtaining the social ID, vehicles can communicate with everyone among a group via DSRC-based V2V or cellular-based D2D communications. Due to the group social ID, social-based DSRC broadcast storms can be avoided. Furthermore, base station (BS) should be employed to assist D2D communications in DVSNs. What should be paid attention to is that control between BS and vehicles is loose.

2.3 Hybrid

In order to gather the advantages of CVSNs and DVSNs, hybrid vehicular social networks (HVSNs) are proposed here. Thus, vehicles on road can not only enjoy abundant social contents in CVSNs, but also proceed private cluster social conversations in DVSNs. When a vehicle accesses both CVSNs and DVSNs, it will have several social IDs at the same time. Just because of this reason, vehicles must have a powerful GUI to support switching.

At the end of this section, three architectures are summarized in **Table 1**.

3 User Cases and Service Requirements

In order to understand the service requirements of the HetVNETs for VSNs, it is necessary to study several typical user cases with social behaviors. Hence, two categories of user cases, namely centralized-based and distributed-based, are discussed in this section before social service requirements are analyzed.

3.1 Centralized

As previously mentioned, CVSNs own LSSs connecting to RANs, therefore, they can offer users a better quality of experience on the latency-sensitive social contents. In general, user cases existing in CVSNs can be divided into two types, i.e.,

1) Entertainment-related

- Regional social information dissemination. Since LSSs are in charge of the Internet social activities of a certain area, we can utilize RSSs to push area-related social contents (e.g., surrounding scenery, weather forecast, some amusements, etc.) to certain LSSs. Then LSSs release these regional social information to the vehicles in this area via GUI.
- Personal feeling dissemination. Once a vehicle accesses LSSs, it can share the personal feelings of passengers in a social community. Moreover, the passengers can disclose their personal information to find the surrounding friends which have the same interests.

2) Driving-related

- Parking. Parking problem has been an important traffic issue. Since CVSNs can release the real-time regional information about parking spaces, it is one of the most promising candidate solutions to work out this problem.
- Optimal route selection. A vehicle on road can acquire the surrounding road conditions issued by the other vehicles via CVSNs. Hence, the vehicle can select an optimal route based on these information to reduce the travel time and improve the traffic efficiency.
- Emergency message broadcast. Emergency message broadcast is a common service in the traditional vehicular networks. Utilizing CVSNs to do this can alleviate the latency and broadcast storms. For instance, when a vehicles is traveling on road, it may encounter some emergency vehicles such as ambulances or police cars. At this situation, CVSNs broadcast these messages to vehicles beforehand, and then the normal vehicles can slow down and give the emergency vehicles a way.

▼Table 1. Summary of three architectures

Category	Component	Communication mode	Social feature
CVSNs	RANs, LSSs and RSSs	V2I Primarily	• Possess regional characteristics • Abundant social contents • Have the unique social ID
DVSNs	VMSSs, BS for D2D control	V2V Primarily	• Be spontaneous • Private social contents • May have multiple IDs to access different DVSNs
HVSNs	RANs, LSSs, RSSs and VMSSs	Both V2I and V2V	Take into account the needs of above

BS: base station
CVSN: centralized vehicular social network
D2D: device-to-device
DVSN: distributed vehicular social network
HVSN: hybrid vehicular social network
LSS: local social server
RAN: radio access network
RSS: remote social server
V2I: vehicle-to-infrastructure
V2V: vehicle-to-vehicle
VMSS: vehicular micro social server

3.2 Distributed

On the contrary to CVSNs, DVSNs are usually self-organized. Therefore, there are more flexible user cases. Here, we give several representative user cases, i.e.,

1) Entertainment-related

- Group voice. Voice communication is always effective than words. Voice chats are getting increasing attention, thus, it is necessary to introduce voice chat into VSNs. As a consequence, group voice chats become a typical user case in DVSNs. For example, a group of vehicles having intimate relationships can set up a private voice chat room to share and talk their feelings by utilizing VMSSs. Another example about group voice is the public chat. It is likely to be existed in the urban where a bus acts as VMSS to provide social services for the passengers or other cars.
- Group video. Following the above ideas, we can easily extend social way from voice to video. Similarly, group video can also be divided into private and public. A typical private example is group video meeting. A video meeting can be held in a fleet of company cars traveling on road via DVSNs. Group video indeed achieves success in handling official business whenever and wherever we are. As for public one, the most famous case probably is live streaming like Twitch and Panda.TV, etc. For instance, an anchor traveling on road can bring a funny live streaming about what he sees, and the surrounding vehicles can access his VMSSs to watch his live. Compared to group voice, group video needs a higher data rate and safer privacy protection, hence, more powerful VMSSs are needed here.

2) Driving-related

- Social navigation. Although there exist lots of navigation software on the market, they do not give the best route at certain time. In such a case, a vehicle can ask for navigation assistance in the social community. After that, the surrounding vehicles whose destination is the same as help seekers will guide it based on the empirical experience. In addition, the users can share some interesting topics on the way.

- Cooperative driving. The main purpose of cooperative driving is to guarantee traffic safety and efficiency. For instance, users can find some companies with the same destination through DVSNs. Then they can organize a motorcade that has one head vehicle and the other followers. Through the cooperation of the motorcade, headway control and collision avoidance can be realized easily among them, which significantly improves traffic safety and efficiency as well as the joy of journey [7].

3.3 Service Requirements

Each user case has its specific service requirements in order to achieve the corresponding QoE. Based on the above centralized-based and distributed-based user cases, we can get several categories of service requirements from them.

Firstly, the low latency and high reliability transmission at the physical layer is a basic and important service requirement. Due to the high speed of vehicles on road, the fast fading propagation effects of the radio channels are quite serious, which significantly deteriorates the quality of transmission links [8]. Meanwhile, the explosive growth of social vehicles and users also becomes a challenge to network load. Hence, in order to guarantee reliable communication in such user cases, VSNs should utilize some new physical layer techniques.

However, only physical layer technique is not enough to support VSNs. No matter CVSNs, DVSNs or HVSNs require some advanced scheduling algorithms to allocate resources efficiently. Since there exist a large number of vehicles and users in VSNs, contention-based scheduling-free algorithms are one of the most promising candidate techniques to support MAC layer scheduling. On the other hand, a good design of the social ID in the MAC layer also can reduce the effect of broadcast storm.

In order to help users deal with social activities better, a friendly GUI must be designed. Since both the passengers and drivers use the GUI, it should be more simple and intuitive in vehicular environments. Generally speaking, the GUI should provide intelligent voice for the drivers so that they can drive more safely. On the other hand, a fully functional GUI also needs the powerful background data processing. Since there exist a lot of social data in VSNs, various social servers should process and classify them according to the interests of the users so as to push highly correlated information into the users as quickly as possible.

Another requirement in DVSNs is privacy protection. Since group voice and video are very intimate, we have a security requirement in order to protect the contents. Similarly, there also exists privacy protection in CVSNs, but the demand is lower than that of DVSNs, because of its public feature.

The service requirements of different user cases are summarized in **Table 2**.

4 Potential Challenges and Solutions

With the rapid development of vehicular network and social network services, many key techniques enabling the functionality of VSNs already appear. However, since VSNs are a very new and hot topic, many open issues and challenges remain to be addressed. Based on the previous analyses, we not only obtain some important conclusions but also introduce some possible challenges in this field. In this section, we discuss these challenges and future research directions for VSNs.

4.1 RAN Design

It can be predicted that there must be a large number of vehicles and users in future VSNs, hence, sporadic social services will occupy a large proportion in VSNs. As we all know, synchronization procedures introduce the extra latency, so sporadic social services should not be integrated into the complex synchronization procedures such as LTE/LTE-A physical layer random access, which is deliberately designed to satisfy orthogonal constraints [9]. In order to maximize bandwidth utilization and reduce latency in VSNs, guaranteeing reliable communication under such a scenario becomes a challenge.

A straightforward solution to reduce latency is short frame design. Both DSRC and cellular networks have more than 10 ms frames, thus end-to-end latency certainly will be large. In

Table 2. Summary of service requirements

	User cases	Low latency and high reliability	High data rate	MAC layer resources scheduling and allocation	Good design of social ID	GUI and social data processing	Privacy protection
Centralized							
Entertainment	Regional social information dissemination	Medium	High	High	Medium	High	Medium
	Personal feeling dissemination	Medium	High	High	Medium	High	Medium
Driving	Parking	High	Medium	Low	Medium	High	Medium
	Optimal route selection	High	Medium	Low	Medium	High	Medium
	Emergency messages broadcast	High	Medium	High	High	High	Highs
Distributed							
Entertainment	Group voice	Medium	Medium	High	High	Low	High
	Group video	Medium	High	High	High	Low	High
Driving	Social navigation	Medium	High	High	High	High	Medium
	Cooperative driving	High	Medium	High	High	Medium	Medium

order to meet the requirement of low latency, we must redesign the frame structure to shorten the length of that, which raises many new research directions [10], [11].

Another solution to reduce latency is that RANs cut down synchronization costs. filtered-orthogonal frequency division multiplexing (F-OFDM) applies sub-band filter to shape the spectrum of sub-band OFDM signals, which has the good out-of-band leakage rejection and thus supports asynchronous access transmission [12]. Furthermore, F-OFDM is capable of utilizing the fragmented spectrum resources and shaping flexible bandwidth for different kinds of services. Besides, F-OFDM keeps the good backward compatibility to existing LTE/LTE-A systems, it provides a feasible evolutional roadmap to the HetVNETs for VSNs.

Since DSRC adopts the broadcast mechanism, there inevitably exist broadcast storms. Moreover, the carrier sense multiple access/collision avoidance (CSMA/CA) access method is not suitable for sporadic social services, because of its low access efficiency and network capacity. Thus, some new contention-based access mechanisms should be studied to improve system capacity and efficiency.

In the recent research, contention-based spares code multiple access (SCMA) mechanisms is one of the competitive substitutes to CSMA [13]. Through joint optimization of multi-dimension quadrature amplitude modulation (QAM) and non-orthogonal sparse codewords, SCMA is capable of multiplexing more users and improving system reliability.

4.2 Intelligent GUI

GUI is generally a kind of interfaces that allows users to interact with devices through graphical icons and visual indicators. GUI plays an important role in acquiring the better user experiences. Unlike other social networks, the GUI in VSNs should give more consideration to drivers that generally focus on driving. Hence, there is no time to report or share information manually while driving. This leads to a challenging requirement for intelligent GUI. In general, we assume that a fully functional intelligent GUI should include the following elements:

- Graphical icons and visual indicators being distinct and clear
- Pushing the information according to the size of the screen
- Avoiding as much as possible touching the screen
- Trying to use intelligent voice system for command recognition and interaction.

Social data processing is one of the most important parts behind the GUI. Data mining techniques can provide high quality, useful and real-time social information to VSNs. The advanced mining algorithms can improve user satisfaction on VSN services [14], [15].

4.3 Privacy and Security

User privacy is emphasized carefully in many fields since it involves the rights of person, especially in VSNs. As a novel kind of social networks, VSNs usually serve as the information exchanging platforms for vehicle users. The information may include user profiles, state of vehicles, instant messages, or even personal data of users. Data packages that are generated by users or vehicles can be shared and spread on VSNs with friends or strangers. However, these packages can be obtained by all the vehicles inside the coverage of V2V communications, because vehicles always broadcast messages to the surroundings. Once privacy information is retrieved and manipulated by malicious people, enormous losses may be incurred.

Privacy issues in VSNs usually reflect on several aspects. First of all, vehicle users are not aware of how much of their privacy can be revealed or distorted during social processes. As a result, users are unable to determine how much information they can share in VSNs. Besides, the communication environment is not knowable by users since it is changing fast due to the high moving speed of vehicles. Therefore, it is difficult to record where the privacy information is leaked. In all, the special way of communication of VSNs contributes to harder protection of user privacy than conventional social networks [16], [17].

In order to solve this problem, privacy protection needs to be considered in every part of the VSN systems. For example, the personal information need to be encrypted and imposed by access restrictions. In terms of VSN systems, efficient authentication is required to prohibit unauthorized users. Firewalls may be helpful to protect vehicle users from hostile attack. Furthermore, necessary repair mechanism and anti-hacking techniques are also demanded for VSNs. In addition, alarms that remind users the risk of privacy leakage are supposed to be put forward by VSN systems.

4.4 Mobile Cloud Computing

Cloud computing (CC) is a kind of emerging Internet-based computation model that provides shared software processing resources and hardware computing facilities to users on demand. With the rapid development of communication technologies, CC has seen a phenomenal growth in the past few years. CC generally provides three types services, namely, Infrastructure as a Service (IaaS), Platform as a Service (PaaS) and Software as a Service (SaaS). The underlying service mode of CC is the familiar pay-as-you-go mode, where a user pays for the resources and his additional demand for these resources can be met in real time. Moreover, CC facilitates to reduce deployment cost and provides flexibility in terms of resource provision.

In recent years, CC has shifted from personal computers to mobile devices, which raises mobile cloud computing (MCC). MCC brings new types of services and facilities for mobile users to make full advantages of cloud computing [18], [19]. It is estimated that both CVSNs and DVSNs generate a lot of social data, which mainly comes from various users and vehicles. Hence, in order to process these data efficiently, we not only need the advanced algorithms, but also the powerful computing ability. In particular, it becomes extraordinarily important in DVSNs. Mobile clouds can provide a good platform for the coordinated deployment of the social data sharing applications required by VMSSs.

5 Conclusions

After introducing social characteristics into the HetVNETs, we not only improve traffic efficiency and reliability, but also upgrade the joy of driving. In this paper, we propose two architectures by means of the HetVNETs to support all kinds of social services. Then, several user cases containing centralized-based and distributed-based are discussed. Each case puts forward its specific service requirements which raise potential challenges for SNs utilizing HetVNETs. In order to tackle these challenges, some solutions such as RAN design, intelligent GUI, privacy protection and MCC are proposed to facilitate the VSNs implementation. Although we have presented the preliminary study on the HetVNETs for SNs, more investigation is needed in order to make them into practice.

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