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An Architecture of Cloud-Assisted Information Dissemination in Vehicular Networks

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ABSTRACT Vehicular network technology allows vehicles to exchange real-time information between each other, which plays a vital role in the development of future intelligent transportation systems Existing research on vehicular networks assumes that each vehicle broadcasts collected information to neighboring vehicles, so that information is shared among vehicles. The fundamental problem of what information is delivered with which vehicle(s), however, has not been adequately studied. We propose an innovative cloud-assisted architecture to facilitate intelligent information dissemination among vehicles. Within the novel architecture, virtual social connections between vehicles are created and maintained on the cloud. Vehicles with similar driving histories are considered friends in a vehicular social network (VSN). The closeness of the relation between two vehicles in a VSN is then modeled by the three-valued subjective logic model. Based on the closeness between vehicles, only relevant information will be delivered to vehicles that are likely interested in it. The cloud-assisted architecture coordinates vehicular social connection construction, VSN maintenance, vehicle closeness assessment, and information dissemination.

INDEX TERMS Vehicular ad hoc networks, crowdsourcing, Internet of Things, social computing, information exchange.

I. INTRODUCTION

Emerging wireless technologies enable drivers/vehicles to share information between each other and such information could greatly improve people's driving experience in terms of both safety and efficiency. The U.S. Department of Transportation's National Highway Traffic Safety Administration just announced that it began taking steps to enable vehicle to vehicle communications for light vehicles after the success of the Safety Pilot project [1]. Recently, tremendous efforts have been devoted to accelerating the implementation of vehicular networks, e.g., Mcity and Internet2 of Things University Electric Vehicles Research.

According to the report released by Cisco [16], there will be 400 million gigabytes of data generated by 300 million passenger vehicles that are interconnected via wireless technologies. The data is generated by various types of sensors on vehicles, it includes a vehicle's route, speed, condition of a vehicle, traffic congestion information, and road conditions. Although these 300 million vehicles only contribute 25 percent of the global vehicle population, the huge amount of data may cause significant challenges to existing networking infrastructures. Most importantly, large amount data generated by vehicles will make efficient information dissemination a challenging issue. Drivers may not want to receive irrelevant information from others, so the research challenge is how to intelligently deliver relevant information to drivers. Existing research on information dissemination in vehicular network, however, deals with efficiently delivering data to a vehicle, a group of vehicles, or vehicles in a specified area. They focus on either reducing data delivery delay [37], decreasing packet loss rate [30], or increasing data forwarding opportunity [11]. For most data collected on a vehicle, however, there is no prior knowledge about which vehicle(s) will be interested in it. As a result, the data will be either stored on vehicles (or a server), or broadcast within the network in the hope that other vehicles will be interested in it. The fundamental problem of what information is delivered to which vehicle is an important yet unexplored issue. To address this fundamental issue, we propose an innovative architecture of cloud-assisted information dissemination system in vehicular networks that connects information providers and information consumers on an individual level. The proposed architecture will transform current intelligent transportation systems (ITSs) from providing a one-size-fits-all to a tailored information provision service. Existing techniques in ITS heavily rely on roadside infrastructures (e.g., cameras, radar, invasive sensors), and complex algorithms (e.g., vehicle classification and counting algorithms [28]), to monitor traffic and road conditions. The information is then aggregated on a server and disseminated to vehicles through the Internet. Our solution focuses on a vehicular social network (VSN) that enables drivers to connect and communicate with each other by exchanging information. The closeness of the relation between the information seeker and provider is modeled and computed from the social connections between them. As such, a driver can quickly determine whether a piece of information is relevant based on the closeness between itself and the information source. Because information is ''filtered'' by a vehicular social network, it is unlikely that a driver will receive irrelevant information. Due to the large amount of data exchanged between vehicles, filtering information on the cloud and delivering relevant information to vehicles will be essential in future vehicular networks.

Cloud computing plays a vital role in setting up a vehicular network [34], [35]. Cloud computing is one of the most important components in the proposed architecture. First, vehicles' interaction data will be uploaded and maintained on the cloud. The information serves as the foundation of building/computing the closeness between vehicles. It is extremely difficult, if not impossible, to keep track of this information by individual vehicles in a distributed manner. Second, information provided by vehicles will be saved in a data repository on the cloud. For each piece of information, its contributor's ID will also be saved on the cloud. When this information is requested by another vehicle, its usefulness will be assessed based on the closeness between the information requester and provider. Third, the social connections derived from a VSN need to be maintained on the cloud, which not only facilitates the closeness assessment between vehicles but also supports intelligent information dissemination.

The rest of this paper is organized as follows. In Section II, we describe the proposed cloud assisted architecture by providing the details for each component in it. Particularly, we propose to construct the initial social connections between vehicles based on the points of interest (POIs) they visited. We then introduce in Section III how to model the closeness between vehicles based on the three-valued subjective logic [14]. In Section IV, we discuss the security and privacy concerns and possible solutions in the proposed architecture. We summarize the related work in V and finally conclude our work in Section VI.

II. CLOUD ASSISTED ARCHITECTURE

Various information will be exchanged between vehicles in future vehicular networks, and it is likely that a vehicle will receive too much irrelevant information. Transmitting irrelevant information among vehicles will waste precious network resources. It may also distract drivers, which should be avoided in a vehicular network. Our aim is to use data exchanged between vehicles/drivers to estimate their closeness, and most importantly, to determine what data should be delivered to which vehicle(s) based on the closeness information.

A. ARCHITECTURE OVERVIEW

With the proposed architecture, initial social connections between vehicles are built by analyzing drivers' movement data. The list of POIs that a vehicle visited is considered the ''genome'' of this vehicle. Vehicles with similar genetic features are considered initially connected in the VSN. These social connections are then cultivated by interactions, in the form of information exchanging, between vehicles. We have demonstrated in our previous work that the closeness between users can be mined based on the quantity and quality of their interactions [13]. A cloud-hosted service will be used to facilitate vehicle genome extraction, vehicle social connections, VSN maintenance, closeness assessment, and data dissemination.

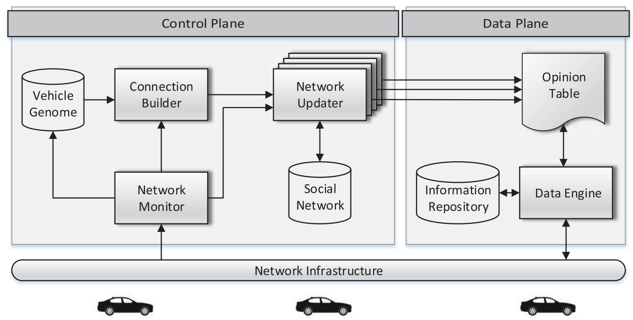

FIGURE 1. System architecture of intelligent information dissemination in vehicular networks.

As shown in Fig. 1, the proposed system architecture consists of vehicles, a cloud service, and a network infrastructure that enables information exchange between them. Inspired by the software defined network technology, the cloud service is further divided into a control plane and a data plane. The control plane deals with network changes and social network maintenance, and the data plane collects/disseminate information from/to vehicles.

B. VEHICULAR NETWORK

In the proposed architecture, vehicles form a wireless vehicular network via either vehicle-to-vehicle (V2V) or vehicle-to-infrastructure (V2I) communications. Every vehicle keeps track of its locations by collecting the POIs it visited. This information is then uploaded to the cloud through the *network infrastructure* that includes but is not limited to cellular, dedicated short range communication (DSRC) and WiFi technologies. Because the historical POIs are not real-time information, a vehicle can upload the information when network traffic is low, e.g., during the night. Then, a ''genome'' consisting of a driver's visited POIs could be defined for each vehicle. For example, the ''genome'' of a university professor's vehicle could be ''Home:[0:00, 8:30];University X:[9:00-12:00];Restaurant

Y:[12:20-14:00];University X:[14:20-16:00];Gym Z:[16:30-17:30];Home:[18:00-23:59].'' The pair of timestamps after each POI provides the time instances at which the professor entered and left a certain POI. A vehicle's ''genome'' information is uploaded to the *network monitor* module that updates the *vehicle genome* database and triggers the *connection builder* module to identify vehicles with similar driving patterns.

Every vehicle also needs to sense the environments it traverses and to measure the information, such as ice on road, fog, potholes, traffic conditions, and parking lot occupancy. Data collected on each vehicle can be divided into two categories: objective and subjective. Objective information includes such things as traffic condition and parking space availability, while subjective information contains such things as rating of a restaurant and the quality of service provided by an automobile dealer. For subjective information, a driver would prefer to trust those provided by his/her close friends in the VSN. Information is uploaded to the cloud via the *data engine* module that pushes data into the *information repository* database. Although frequent information saving and searching will happen, we believe advanced cloud storage technique [20] will make this an efficient system.

C. SOCIAL CONNECTION CONSTRUCTION

Drivers with similar ''genomes'' are likely to share information between each other. For example, given two drivers who frequently visited University X, the parking information of X may be of interest to both of them. Based on this assumption, we speculate there exists a hidden social network among vehicles. Because two vehicles with similar ''genomes'' have the potential to exchange information, the *connection builder* module will build a social connection between them. In this way, a vehicular social network is constructed on the cloud and saved in the *social network* database. If a vehicle is willing to join this system, it only needs to upload its recent POIs history. The *connection builder* module will match this record to existing ones and connect this vehicle to the VSN.

Let L_i be the list of POIs visited by a vehicle on the the i-th weekday. Ignoring the order information, let S_i be the corresponding set of locations in L_i. After m days, m sets of POIs are collected on this vehicle. We use $\mathcal{S} = \{S_1, S_2, \ldots, S_m\}$ to denote the set containing all possible POIs visited by this vehicle. The problem is to identify a set T of minimum size such that at least d number of POIs from S_i are in T, for every $i = 1 \cdots m$. After identifying the genome of every vehicle, the next problem is to compute the genetic similarity between vehicles. Two vehicles with a genome similarity score greater than a certain threshold will be connected in the VSN.

The problem of comparing two vehicles' genome sequences A' and B' is different from comparing genomes with gene repetitions. First, the contents contained in A', B' might not be identical. For example, vehicle v_1 may visit some POIs that never appears in v_2's genome. Second, the duration that a vehicle stays in a POI is also important in comparing the similarity between two vehicles. For example, a vehicle visiting a POI for eight hours will be significantly different from those visiting the POI for 30 minutes. We first convert a POI $x \in A'$ that appears for t units of time into a substring containing t copies of x. The same procedure is performed on B', and the resulting sequences are A and B, respectively. Then, we can use adjacency number between two vehicles' genomes to quality their similarity.

D. NETWORK MAINTENANCE

Vehicles with similar ''genomes'' may also provide irrelevant information to each other. Besides, a vehicle may provide false information due to defective sensors, infection of computer viruses, or even selfish purposes, e.g., a driver reports wrong parking information to ensure he/she can park in the desired parking lot. It is essential to design a mechanism to quantify drivers' closeness based on the interactions between them. For example, if vehicle v_1 believes the information provided by v_2 is relevant and useful, i.e., a positive interaction occurs, the edge from v_1 to v_2 in *social network* database is strengthened. Otherwise, a negative interaction is recorded, and the edge from v_1 to v_2 is weakened. If a driver forgets or intends not to evaluate received information, we determine that an uncertain interaction happened.

With positive, negative, and uncertain interactions, the closeness between vehicles can be modeled as an opinion, according to the three-valued subjective logic (3VSL) [14]. This model will be detained in the next section. In the rest of this article, we will interchangeably use opinion and closeness. The *network updater* module is triggered by either the *network monitor* (e.g., an edge weight update) or *connection builder* modules (e.g., an edge addition). If a network change is detected, *network updater* changes the *social network* database accordingly and updates the *opinion table* that stores the opinion between any two vehicles in the VSN. The *opinion table* is updated if and only if a network change occurs. It will be frequently queried by the *data engine* module. Due to the dynamic nature of information exchange between vehicles, the *social network* and *opinion table* are updated frequently. Here, the technical challenge is to quickly update *social network* and *opinion table* to offer a real-time service.

E. INFORMATION DISSEMINATION

Information dissemination in the VSN can be realized in two different ways: (1) a requester pulls data from the cloud, and (2) an information provider pushes data to its friends through the cloud. In the first approach, a vehicle sends a request to the cloud to search for certain information, e.g., ''the rating of restaurant X.'' The *data engine* searches the *information repository* database to check if such information is available. If so, it queries the *opinion table* to get the closeness between the information requester and provider. The *data engine* then returns the information along with closeness score(s) to the information requester. The requester either selects the information provided by the closest friend or take a weighted average of the information. In the second approach, a vehicle is able to collect and push information to its top K close friends through the cloud.

When a vehicle receives a piece of information, it can vote up, vote down, ignore, or re-push this information to its close friends. If a vehicle votes up/down the information, the connection between the vehicle and the information provider is strengthen/weakened. The voting action is recorded by the *network monitor* that calls the *network updater* to update the *social network* and *opinion table* accordingly. Information is then quickly delivered to vehicles that are likely interested. Because a receiver provides evaluations of information providers, it is unlikely that a vehicle will keep pushing unwanted information. Even though a group of malicious vehicles may collude to vote up each other, they will not become close friends to other vehicles. That is the main reason to have the *opinion table* available to record the closeness between two vehicles, rather than the reputation of one vehicle. Delivering information to vehicles through their social networks can significantly reduce the chance of mismatching between information providers and consumers. In additions, our system enables an information requester to easily select information based on closeness scores.

F. CENTRALIZED VS DISTRIBUTED SERVICES

One limitation of the proposed architecture is that information needs to be first uploaded to the cloud and then disseminated to vehicles. The central cloud service could be the bottleneck of the entire system. To address this issue, one possible solution is to store the *opinion table* on vehicles. Based on this table, a vehicle can quickly determine whether to accept information based on the closeness between itself and the information provider. We argue that the existence of a central cloud server is still necessary in building and maintaining the *opinion table*. Although it is possible to let vehicles construct their social networks in a distributed manner [32], the system's real-time performance will be significantly degraded. To realize a feasible system, we focus on the architecture with a centralized cloud service in place.

III. ASSESSMENT OF CLOSENESS

The closeness between vehicles is modeled by our previous work, the three-valued subjective logic model. In this section, we provide a brief introduction of 3VSL, more details can be found at [14].

A. SUBJECTIVE LOGIC

To understand the 3VSL model, we first need to introduce the subjective logic model [9]. It is a type of probabilistic logic based on the Dempster-Shafer belief theory. It explicitly takes uncertainty and belief ownership into account while computing trustworthiness. It treats trustworthiness as opinions and introduces an algebra for opinion operations, e.g. discounting and consensus (or combining) operations. In subjective logic, a binomial opinion applies to a single proposition, and can be represented as a Beta distribution. A multinomial opinion applies to a collection of propositions, and can be represented as a Dirichlet distribution.

Considering two users A and B, the trustworthiness of B to A in subjective logic can be formally described as an opinion vector ω_B^A:

$$\omega_B^A = (b_B^A, d_B^A, u_B^A, a_B^A) \tag{1}$$

where b_B^A, d_B^A, u_B^A and a_B^A denote the belief, distrust, uncertainty, and base rate. a_B^A is a constant derived from impressions without solid evidences, e.g. prejudice and preference. Based on the Beta distribution, two opinions $\omega_1 = (b_1, d_1, u_1, a_1)$ and $\omega_2 = (b_2, d_2, u_2, a_2)$ can be combined to generate a new opinion.

Let A and B be two persons where $\omega_B^A = (b_1, d_1, u_1, a_1)$ is A's opinion about B's trustworthiness. Let C be another person where $\omega_C^B = (b_2, d_2, u_2, a_2)$ is B's opinion about C. The subjective logic model applies the discounting operation to compute A's opinion on C, i.e. ω_C^A. Finally, the expected belief of an opinion ω_B^A is computed from $E(\omega_B^A) = b_B^A + u_B^A a_B^A$. It was shown in [9] that subjective logic is capable of modeling trustworthiness with conflicting evidences, propagative trustworthiness, and composable trustworthiness in small-scale recommendation networks.

B. THREE-VALUED SUBJECTIVE LOGIC

There are two well-known problems in subjective logic. First, subjective logic does not work in complex networks. This problem is addressed in 3VSL [14] by distinguishing distorting opinions from original opinions. The second issue of subjective logic is that it has difficulty defining the discounting operator. This is because there are arguments on whether trust is transitive in OSNs. Some believe trust is transitive [10] while others do not [3], [33]. In other words, if A trusts B and B trusts C, this does not always imply that A trusts C. We believe 3VSL is more appropriate in modeling closeness rather than trust between vehicles in a VSN.

Formally, we model A's closeness to X as

$$\omega_X^A = (b_X^A, d_X^A, n_X^A, e_X^A)|a_X^A \tag{2}$$

where b_X^A refer to the probability that A and X are close friends, and d_X^A is the probability that they are not. n_X^A indicates that A is uncertain about whether X is a close friends or not. We have $b_X^A + d_X^A + n_X^A + e_X^A = 1$. The difference between d_X^A and n_X^A lies in whether there exist interactions between A and X. In the context of a VSN, if A receives the messages generated from X and it believes the information is irrelevant, then d_X^A can be derived from these negative interactions. If A has no idea about the relevance of received messages, n_X^A can be computed. e_X^A is an indicator about the numbers of evidences used to compute b_X^A, d_X^A, and n_X^A. The definition of a_X^A is similar to that in the subjective logic. Considering a ternary value, the closeness between two vehicles can be modeled by a Dirichlet distribution, characterized by three parameters r, s and o. r, s and o represent the numbers of positive, negative, and uncertain interactions between them.

C. DISCOUNTING OPERATION

Let A and B be two vehicles where $\omega_B^A = (b_1, d_1, n_1, e_1)$ is A's opinion about its closeness to B, and let C be another vehicle where $\omega_C^B = (b_2, d_2, n_2, e_2)$ is B's opinion about its closeness to C. The discounting operation $\Delta(\omega_B^A, \omega_C^B)$ is defined as follows.

$$\Delta(\omega_B^A, \omega_C^B) = \begin{cases} b_{12} = b_1 b_2 \\ d_{12} = b_1 d_2 \\ n_{12} = 1 - b_{12} - d_{12} - e_2 \\ e_{12} = e_2 \end{cases} \tag{3}$$

where $\Delta(\omega_B^A, \omega_C^B)$ provides A's opinion about its closeness to C as a result of B's recommendation. With the discounting operation, closeness between vehicles can be "propagated" within a vehicular social network, thus making it possible to compute the closeness between two vehicles that have no direct interactions.

D. COMBINING OPERATION

Let $\omega_1 = (b_1, d_1, n_1, e_1)$ and $\omega_2 = (b_2, d_2, n_2, e_2)$ be the closeness between two vehicle that is generated from two parallel paths between them, then the combining operation $\Theta(\omega_1, \omega_2)$ is defined as follows.

$$\Theta(\omega_1, \omega_2) = \begin{cases} b_{12} = \dfrac{e_2 b_1 + e_1 b_2}{e_1 + e_2 - e_1 e_2} \\ d_{12} = \dfrac{e_2 d_1 + e_1 d_2}{e_1 + e_2 - e_1 e_2} \\ n_{12} = \dfrac{e_2 n_1 + e_1 n_2}{e_1 + e_2 - e_1 e_2} \\ e_{12} = \dfrac{e_1 e_2}{e_1 + e_2 - e_1 e_2} \end{cases} \tag{4}$$

According to the mapping relationship between an opinion and a Dirichlet distribution, ω_1 and ω_2 can be represented as $f(P_b, P_d|\alpha_1, \beta_1, \gamma_1)$ and $f(P_b, P_d|\alpha_2, \beta_2, \gamma_2)$, respectively. If observed interactions (or evidences) between vehicles are independent, these two Dirichlet distributions can be aggregated into

$$f(P_b, P_d\,|\alpha_1 + \alpha_2 - 1, \beta_1 + \beta_2 - 1, \gamma_1 + \gamma_2 - 1)$$

Therefore, the closeness can be computed from the expected probability

$$\begin{aligned} E(P_b) &= \frac{r_1 + r_2 + 1}{r_1 + r_2 + s_1 + s_2 + o_1 + o_2 + 3} \\ &= \frac{\alpha_1 + \alpha_2 - 1}{\alpha_1 + \alpha_2 + \beta_1 + \beta_2 + \gamma_1 + \gamma_2 - 3} \end{aligned}$$

We can see the number of interactions between these two vehicles are increased to $r_1 + r_2$, $s_1 + s_2$, and $o_1 + o_2$. Then, we have

$$\begin{aligned} b_1 &= \frac{r_1}{r_1 + s_1 + o_1 + 3} \\ &= \frac{b_1}{(1 - e_1) + e_1} = \frac{\frac{e_2}{e_1} b_1}{(1 - e_1)\frac{e_2}{e_1} + e_2} \\ b_2 &= \frac{r_2}{r_2 + s_2 + o_2 + 3} = \frac{b_2}{(1 - e_2) + e_2} \end{aligned}$$

where e_1 and e_2 are defined as the reciprocals of evidences, so they are different if $r_1 + s_1 + o_1 \neq r_2 + s_2 + o_2$. We normalize them and combine these two opinions to get

$$b_{12} = \frac{\frac{e_2}{e_1} b_1 + b_2}{(1 - e_1)\frac{e_2}{e_1} + (1 - e_2) + e_2} = \frac{e_2 b_1 + e_1 b_2}{e_1 + e_2 - e_1 e_2}$$

Similarly, other components of the resulting opinion can be calculated as follows

$$\begin{aligned} d_{12} &= \frac{e_2 d_1 + e_1 d_2}{e_1 + e_2 - e_1 e_2} \\ n_{12} &= \frac{e_2 n_1 + e_1 n_2}{e_1 + e_2 - e_1 e_2} \\ e_{12} &= \frac{e_1 e_2}{e_1 + e_2 - e_1 e_2} \end{aligned}$$

With the discounting and combining operations, the closeness between any two vehicles in a VSN can be computed based upon the social interactions and/or connections between them. The recursive algorithm proposed in [14] can be used to assess the closeness between two vehicles that have no direct interactions, i.e., no information exchanging between them.

Closeness assessment will be frequently executed on the cloud, we propose to use an opinion table to store the closeness information. The closeness information will be used by the system to deliver relevant information to vehicles. Here, the relevance of information is measured by the closeness between the information provider and consumer. The opinion table is updated in parallel on the cloud when new interactions occur between vehicles or new connections are constructed between vehicles.

IV. PRIVACY AND SECURITY CONSIDERATIONS

It is worthwhile to mention that it seems inevitable that vehicles must exchange data with others. To realized collision avoidance, for example, each vehicle needs to periodically broadcast a beacon message containing at least its ID, location, and a time stamp. Although the information exchanged in a vehicular social network is not as sensitive as that in an OSN, e.g., personal and professional OSNs, privacy protection in vehicular network is very essential. Identity thieves and corporations may dig into the information to gather information about drivers. A lot of personal behaviors can be derived by simply analyzing the data generated from a VSN. For example, insurance companies may want to use these data to analyze and understand the driving habits of a driver. Fortunately, there are some solutions to privacy protection in vehicular networks, e.g., location privacy protection [21], [31], identity privacy protection [17]. Existing privacy protection solutions in vehicular network are still network-oriented, i.e., there are not enough works on privacy protection of the information itself. In the proposed architecture, information protection can be done on the cloud by data encryption and anonymization techniques (e.g., [4], [5]).

There is more research on security than privacy in both generic wireless networks and vehicular networks. In wireless mesh networks, for example, authentication has been intensively studied [6]. In a wireless vehicular network, several adversary models are already identified, e.g., greedy drivers, snoops, pranksters, industrial insiders and malicious attackers [18]. Various types of attacks in a vehicular network are studied, including denial of service (DoS) attack, message suppression attacks, authentication attacks, fabrication attacks, and alternation attacks [19]. Unlike other wireless networks, a vehicular network is more challenging to deal with, due to its dynamic nature.

To secure a vehicular network, several measures have been proposed in [19]. To meet the security requirements of a vehicular network, public key infrastructure (PKI) plays an important role. Under the PKI, a vehicle must digitally sign a message with its private key before the message is sent. When another vehicle receives this message, it first checks the authenticity of the sender by verifying the digital signature appended in the message. The key component of successfully applying PKI in a vehicular network is the certificate authority (CA). A CA will issue and revoke certificates used on vehicles. PKI based security solutions perfectly fit the proposed architecture because the cloud component can be used to offer the CA service. Although there are distributed security protection solutions, we believe the centralized one provides a better security protection and system performance.

V. RELATED WORK

A few information dissemination systems for VSNs have been proposed in the literature. Vehicular social network can be considered a mobile social network [24], [25] where drivers in the same social group share information via V2V communications. In the RoadSpeak [23] and Verse [15] systems, vehicles in proximity to each other form a short-lived social network. In the SocialDrive system [8], a standard on-board diagnostics (OBD) port reader is used to connect a vehicle to commercial online social networks. A user interface is provided to drivers to share their driving experience and trip information via online social networks, e.g., Facebook.com. A similar idea is applied in the Social Vehicle Navigation [22] system where drivers share their driving experience using voice tweets over Twitter.com. These tweets are aggregated into tweet digests that are forwarded to corresponding social groups. Several commercial software programs, e.g., WAZE and Inrix, consider VSN a crowdsensing platform where vehicles share information with each other through a central server. Various information including accidents, traffic jams, and police traps, are collected by vehicles and stored on the server. Although all of these systems rely on social networks to provide better information collection and dissemination, as far as we know, there is no previous work that considers the closeness between vehicles to facilitate efficient information dissemination.

Using people's location history information, some systems such as Geowhiz [7] and CityVoyager [26] have been designed to recommend shops or restaurants to users. In GeoWhiz, the collaborative filtering technique [2] is used to recommend restaurants to users based on their moving history. In CityVoyager, users' preferences and their location history are used in recommending shops. Considering user's mobility and the hierarchical property of a geographic area, user similarity can be mined from location history data [12]. Together with the popularity of a geographic region, it is possible to recommend users with unvisited locations that match their tastes well [38]. Finally, privacy protections in vehicular networks, online social networks, and the cloud have been intensively studied [21], [27], [29], [31], [36]. We view all these works as complementary to the proposed work.

VI. CONCLUSION

In this paper, we proposed a novel cloud-assisted architecture for intelligent information dissemination in a vehicular network. Based on the characteristics of information sharing among vehicles, we proposed a new concept of building social connections between vehicles based on the quantity and quality of interactions occurred between them. We also discussed the importance of modeling and assessing the closeness between vehicles and proposed to model closeness based on the 3VSL model. This paper serves as the first step to develop a cloud-assisted information dissemination architecture for future vehicular networks. In the future, we will make efforts to implement the proposed architecture with the design principles discussed. We will examine the system performance given practical circumstances.

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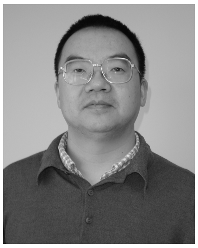

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