IEEE Access
The journal for rapid open access publishing

Received December 28, 2014, accepted February 2, 2015, date of publication March 25, 2015, date of current version April 27, 2015.

Digital Object Identifier 10.1109/ACCESS.2015.2416657

Toward Social Internet of Vehicles: Concept, Architecture, and Applications

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ABSTRACT The main vision of the Internet of Things (IoT) is to equip real-life physical objects with computing and communication power so that they can interact with each other for the social good. As one of the key members of IoT, Internet of Vehicles (IoV) has seen steep advancement in communication technologies. Now, vehicles can easily exchange safety, efficiency, infotainment, and comfort-related information with other vehicles and infrastructures using vehicular ad hoc networks (VANETs). We leverage on the cloud-based VANETs theme to propose cyber-physical architecture for the Social IoV (SIoV). SIoV is a vehicular instance of the Social IoT (SIoT), where vehicles are the key social entities in the machine-to-machine vehicular social networks. We have identified the social structures of SIoV components, their relationships, and the interaction types. We have mapped VANETs components into IoT-A architecture reference model to offer better integration of SIoV with other IoT domains. We also present a communication message structure based on automotive ontologies, the SAE J2735 message set, and the advanced traveler information system events schema that corresponds to the social graph. Finally, we provide the implementation details and the experimental analysis to demonstrate the efficacy of the proposed system as well as include different application scenarios for various user groups.

INDEX TERMS Social network of vehicles, Cyber-physical systems, Internet of Things, Internet of Vehicles, IoT architecture reference model, Intelligent transport systems, SAE J2735.

I. INTRODUCTION

The growing technological advancements in the field of information technology have made Smart Cities a thing of near future. In a Smart City, all objects would have embedded processors and capability to communicate with each other through wired or wireless connections [3], [38]. These increasingly intelligent objects would provide safe and convenient environment through increased interconnection and interoperability, which is also termed as Internet of Things (IoT). Within the objectives of IoT, vehicles play an important role for safe and convenient travel that leads to Internet of Vehicles (IoV).

The number of vehicles has increased dramatically in recent times [12], [39]. Almost all major cities experience heavy traffic during peak hours. An unfortunate accident or even a small road maintenance task can cause a huge traffic jam and further accidents. In US alone, more than 16,000 crashes take place every day on highways [18]. Driver fatigue and lack of early warning system is responsible for these crashes [28]. Watchful suggestions from the surrounding vehicles could be vital in these cases to provide improved safety to the vehicle users.

State-of-the-art vehicles are equipped with advanced technologies [32], [34] that enable them to communicate with nearby vehicles by forming vehicular ad-hoc networks (VANETs) [25]. There has been growing interest in building vehicular social network (VSN) where passengers can engage into entertainment, utility, and emergency related data exchanges [1], [9], [36]. This type of social network belongs to the mobile social network (MSN) category where mobile users share user centric information with each other using mobile devices [20].

On the other hand, our work is based on emerging Social Internet of Things (SIoT) [6], [7], [31] where *things* become the social entity rather than their owners, which aligns very well with the vision of smart cities. Here, smart *things* establish connection with other smart *things* (e.g. vehicle-vehicle, home-home, home multimedia devices, etc.) and exploit *things* social network relationships to solve various interest groups' necessities. From the IoV perspective, this new paradigm raises a valid question, 'what are the key

TABLE 1. Key differences of *social network of humans* and *social network of vehicles.*

Property	Social Network of Humans	Social Network of Vehicles
Dynamic Nature	Mostly static and grows based on real life relationship.	Highly dynamic and nodes join or leave extremely fast.
Basis of Relation	Connection links are based on real life relations, similar personal interests, career paths, locations, etc.	Connection links are based on travel route, similar configurations, similar owner interests, same manufacturer etc.
Social Interactions	Tweet, comment, like, share, chat, tagging, follow, poke etc.	Message exchange, sensory data consumption, status update subscription, status reputation score.
Anonymity	Mostly not anonymous since connections exist between real life friends, or with people of some common interests.	Mostly anonymous since the identity of the vehicle and the vehicle owner is hidden.
Trust	Social relationship grows through continuous interactions and authenticity. Trust among peers increase with more interactions.	Mostly anonymous relationship unless otherwise specified and there is direct and indirect trust due to high speed topology change.
Topology	Mostly stable. Slowly changes with addition or deletion of friends.	In a vehicular social network topology updates very fast because of the ad-hoc wireless technology range and high speed of vehicles.
Privacy Settings	Privacy is generally maintained or customized by the social network owner.	Some information is publicly shared for the safety issue and others are private to the vehicle owner. Owner should be able to customize privacy.
Activity Concentration	Most activities occur among real life close friends, or in a group of professionals of similar interests.	Interactions occur mostly within anonymous neighbors.
Usage	Online social network is a virtual network which is valued by human interactions and social engagement.	An overlay network on top of the physical vehicular network and mostly used as a knowledge base of vehicle usage and experience.

differences of human social network (HSN) and the social network of vehicles, where human and vehicles are social entities respectively'. In the Table 1, we present the key differences between social network of humans and social network of vehicles. The analysis shows a comprehensive difference in terms of dynamic nature, social interactions, topology, privacy, and the usage. As a result, it is important to describe the social network of vehicles from SIoT perspective too rather than the MSN only, which introduces the SIoV. In this paper, we describe the SIoV where vehicles are the smart and interactive social objects in contrast to the humans.

The proposed SIoV system leverages existing VANETs technologies such as vehicle-to-vehicle, vehicle-to-infrastructure and vehicle-to-internet communications and presents a vehicular social network platform following cyber-physical [23], [33] architecture. The cyber-physical SIoV system uses social relationships among physical components to encourage different types of communications and stores the information (e.g. safety, efficiency, and infotainment messages) as a social graph. The social graph is distributed in various layers of communications and it can provide near real time or offline use cases for the intelligent transport systems (ITS). The near real time applications offer safe and efficient travel of the vehicle users, and the offline data ensures smart behavior of the vehicles or Big data analysis for the transport authorities. We envision that social interactions based IoV would be an integral part of the future ITS. The contributions of this paper are identification of social structures and related interactions of the IoV components, mapping of VANETs components with the IoT architecture reference model, and details of communication message structure that corresponds to the IoV social graph. We also provide implementation details of the proposed system, related experimental analysis and various application scenarios.

The rest of the paper is organized as follows. Section II presents the state-of-the-art works, Section III describes the social internet of vehicles, more specifically, Section III-A provides the vehicular social network structure, relation types, interactions and Section III-B details the system architecture from IoT perspective. Later, Section IV presents the message structure, and Section V details implementation specifics. In Section VI, we describe the application scenarios and finally Section VII concludes the paper with possible future works.

II. RELATED WORKS

Guinard et al. [13] discussed how *Web-of-Things* can share their functionality interfaces using human social network infrastructures such as Facebook, Linkedin, Twitter etc. In their system every object that wants to share its functionality on the web either has a built-in embedded web server, or proxy smart gateways (e.g. RFID tag based devices). The *Smart-Things* of an individual person share their web crawlable public interfaces with the owner's groups and friends through a social network. Smart-Its Friends [15] looked into how qualitative wireless connections can be established between *smart-artifacts*. Their system introduces context proximity based match making and respective connections.

Ning and Wang provided an architecture of future Internet of Things (IoT) using human neural network structure [29]. They define a *Unit IoT* and combine various *Unit IoT*s to form the *Ubiquitous IoT*. Matthias et al. describe a so called socio-technical network for IoT where every physical object is enabled with sensors to detect activity and later synchronizes the status using human readable short texts in the Twitter [22]. They present a proof-of-concept twittering plant application which shares moisture, and temperature information in the twitter. Atzori et al. have introduced

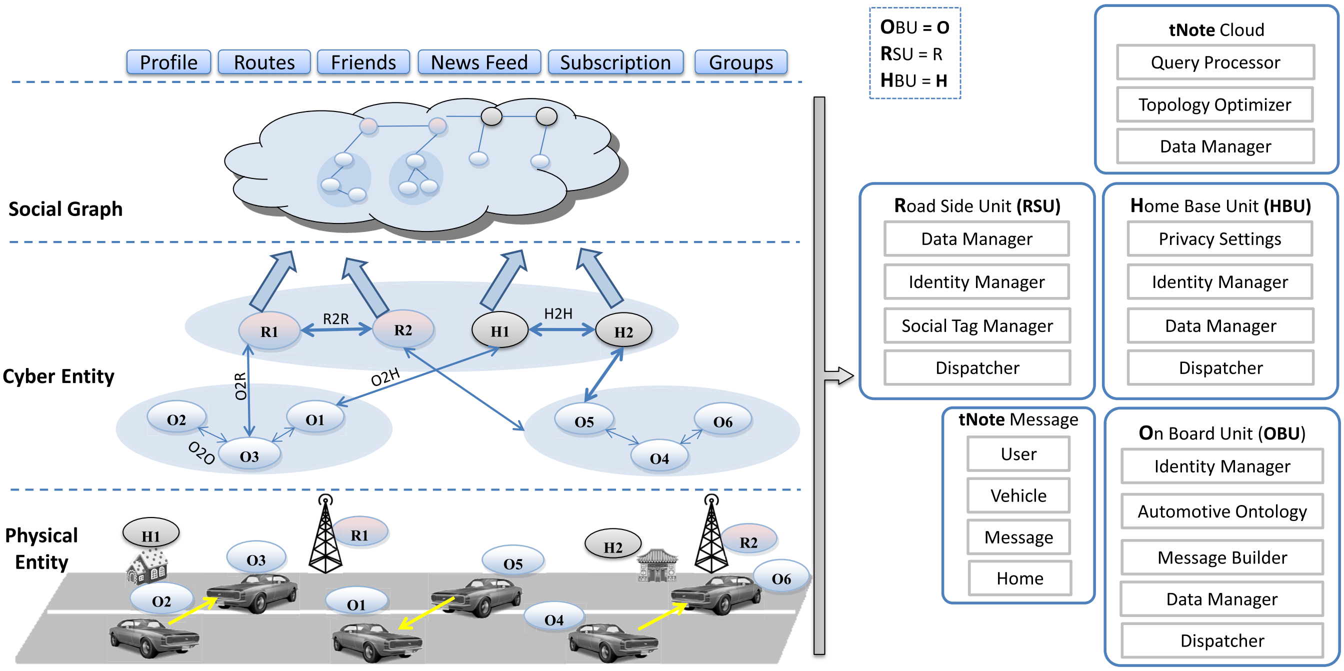

FIGURE 1. Abstract architecture of Social Internet of Vehicles (SIoV).

Social Internet of Things (SIoT) terminology and focuses on establishing and exploiting social relationships among *things* rather than their owners [6], [7]. They have identified different types of *things* relations based on location, co-work, ownership, etc. The *things* can crawl in their social network to discover other *things* or *services* which can be exploited to build various IoT applications.

Smaldone et al. first used vehicular social network terminology in RoadSpeak [36]. They consider the vehicular network for human socialization from entertainment, utility, and emergency messaging perspective. They describe RoadSpeak voice chat application where vehicle users can dynamically form location, time, route, and interest oriented groups and engage in interactions. Hu et al. proposed a service oriented architecture of VSN named VSSA [17]. VSSA describes many types of services but does not detail how social network of vehicles will be realized and what are the types of interactions, message exchanges occur among different vehicular network nodes. Hu et al. also introduced *Social Drive* system which promotes driver awareness about fuel economy using cloud computing and traditional social networks [16].

The contemporary research about vehicular social network mostly revolves around human as a social entity, whereas in our research, we describe vehicular social network on SIoT philosophy where vehicles are the central social entities. In our previous work *tNote*, we have introduced the preliminary concept of vehicular social network from SIoT perspective [5]. Nitti et al. [30] also described some key aspects of SIoV and the integration of SIoV middleware in the ITS station architecture. In this paper, we detail the SIoV following more compelling cyber-physical [2] architecture and mapped VANETs components using IoT principle, which makes it interoperable with other IoT systems in a smart city. Also, we present the social structures, relationship types, as well as the interactions to form an SIoV. Furthermore, we propose the communication message structure which inhabits both safety and non-safety messages following automotive ontology, SAE J2735 message set and ATIS schema. Finally, we present the implementation details of the message, payload analysis, cyber-physical infrastructure implementation approach, and various applications for different groups of users.

III. SOCIAL INTERNET OF VEHICLES

We describe SIoV using already established acronyms in the VANETs model such as OBU (On Board Unit) and RSU (Road Side Unit) [19]. OBUs represent the vehicles on road and RSUs represent the road side infrastructures that are interconnected using Internet. OBUs use LTE/4G type technology for Internet connections and wireless ad-hoc networking for direct message (safety and non-safety) exchange with the surrounding vehicles or with the RSUs [30]. SIoV is a cyber-physical application on top of the original physical vehicular network of WAVE (IEEE 802.11p) [19] communication model. Every physical entity has its corresponding twin cyber (i.e. virtual) entity and operations can be directed from cyber-to-physical or vice versa while entities are in physical/cyber peer-to-peer (e.g. O2O, R2R, H2H) connections (Figure 1). The one-to-one network connection of physical to virtual entity is pervasive and interactions can ubiquitously travel both physical-physical or physical-cyber-cyber-physical path based on convenience or availability. The interaction data of physical or cyber layer is accumulated in the *Social Graph* cloud, where every entity represents a node and the data exchanges are represented using links. In the following sections, we describe the relationships and the interactions of SIoV components, their detailed architectures and privacy-security issues from the physical end, which will be similar from the cyber end as well.

A. SIoV RELATIONS AND INTERACTIONS

It is assumed that every vehicle belongs to a household and there exists a Home Base Unit (HBU) to which all the vehicles and other household devices are connected to form the Internet of Things (IoT). In the SIoV, there are different classes of social structures along with various types of relationships and interactions which are depicted below.

1) STRUCTURES AND RELATIONSHIPS

SIoV consists of both dynamic (OBU) and static (RSU and HBU) type of nodes and changes the network topology continuously. In the first scenario, a vehicle (OBU) is parked at the owner's residence and forms social network with the respective HBU. Since both OBU and HBU are static in this scenario, we consider it as static SIoV which can extend to neighboring OBUs and HBUs. For example, all the vehicles parked in an apartment's basement or in the parking lot can form SIoV with the building's HBU. In the second scenario, an OBU creates relationships with remote HBUs using HBU-HBU or OBU-HBU communication. For example, a travelling OBU can be in a relationship with the owner's office HBU or an OBU can share usage data with its mechanic's HBU. These are examples of somewhat static relationships. The third scenario is highly dynamic, where an OBU is on the move on a roadway and in dynamic peer-to-peer relations with surrounding OBUs and RSUs to exchange safety and non-safety information. These physical-physical or physical-cyber-cyber-physical communications have short lifespans and are represented as data edges in the social graph.

In order to describe the SIoV relations, we have adopted the social relationships prescribed in SIoT [6]. In SIoV, Parental Object Relationship (POR) exists between a vehicle and its manufacturer and manufacturer has the initial responsibility to enable the vehicle with public settings for the SIoV. Manufacturer can introduce new features to their vehicles and add custom sections to the interaction message (*tNote* [5]). Here, Co-Location Object Relationship (CLOR) applies when two objects are working close in a geographical location. Whereas, Co-Work Object Relationship (CWOR) applies when two objects are working together to achieve a common goal regardless of their locations. Both CLOR and CWOR apply to OBU-OBU type communication, where vehicles work together situated in close geo-locations. Ownership Object Relationship (OOR) represents the OBU-HBU (resident) relationship where owner has the authority to configure the vehicle's privacy settings. Again, Social Object Relationship (SOR) applies to OBU-HBU (remote) when vehicle's owner is willing to share protected information with friends (e.g. vehicle status with the car mechanic). We introduced Guardian Object Relationship (GOR) in order to define the communication of OBU-RSU where OBU is a child node of the RSU super node and RSU changes over time on the roadway. Every vehicle maintains its own set of relationships in both physical and the cyber layer. Vehicles form static or dynamic friendships with other SIoV components through the physical or the cyber layer following these set of relationships.

2) INTERACTIONS

OBU-OBU: When a vehicle (i.e. OBU) comes in contact with another vehicle, then, based on physical layer message exchange, a virtual link of type CLOR and/or CWOR is created between the communicating vehicles. This virtual connection and corresponding physical messages are stored in the OBU's storage. Every time a new vehicle comes in contact with a running vehicle, they exchange messages and store them in their social graph. Only public information are exchanged in this communication though private information are also stored in the social graph. This OBU-OBU social graph continues to grow in every OBU. If an OBU has acted as a platoon leader of an OBU-OBU platoon, then once it comes in the range of an RSU it transfers the bulk OBU-OBU social graph to the RSU. Only public information gets transferred in such case.

OBU-RSU: When an RSU receives OBU-OBU social graph data, the GOR transaction is completed. At this level of physical communication a new virtual social link is created between the participating OBU and RSU. After this step, the network takes a shape where a group of OBU nodes form a small social network with a super node RSU. Every RSU, based on its wireless technology and GPS location, maintains a radius of geo-social space. It is possible to uniquely identify a specific interaction message; hence redundancy is reduced in the OBU as well as in the RSU.

RSU-RSU: Geo-locally neighbor RSUs generally have direct wired connection which is a CLOR and/or CWOR relationship and is represented with a virtual link in the SIoV. If an OBU fails to complete the GOR data handover to the RSU, then the rest of the transaction is completed in the next RSU. The neighbor RSU reports back the incomplete data exchanged with it to the originating RSU.

OBU-HBU: When a vehicle is produced, it is part of the manufacturer plant HBU. Hence, the owner of the vehicle is its manufacturer. The manufacturer has the authority to change the vehicle settings (e.g. choosing public message parts) following the POR relationship. When the vehicle ownership belongs to a vehicle user, he can change the non-public settings of the vehicle message which is part of OOR relationship. SOR relationship applies to OBU-HBU (remote) type of communication.

HBU-HBU: HBUs are connected through Internet. They know their geographical locations and can be in

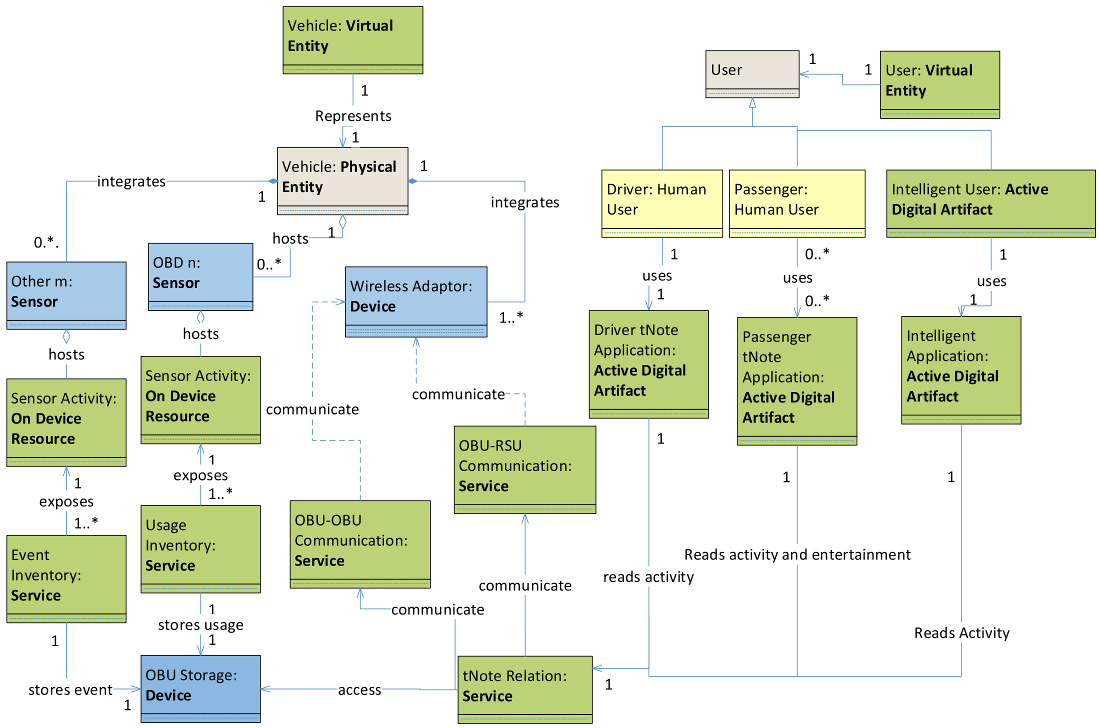

FIGURE 2. **Domain model of On Board Unit (OBU).**

CLOR relationship with neighbor vehicles. Also, HBUs can have remote HBU friends using CWOR relationships.

All these relationship based interactions among the SIoV components dictate the nature of the communication and whether to use physical-physical or physical-cyber-cyber-physical communication path. Wherever physical-physical communication is possible, it is preferred over physical-cyber-cyber-physical communications as it could be efficient.

B. SIoV SYSTEM ARCHITECTURE

In this section, we describe the overall architecture of the proposed system (Figure 1) which consists of six components: *tNote* Message, On Board Unit (OBU), Road Side Unit (RSU), Home Base Unit (HBU), *tNote* Cloud, and User Interface. The key components are designed following IoT Architecture Reference Model (ARM[1]) [14], [35] which promotes a common understanding between the research community and the industry to provide interoperable solutions at the communication and service level, as well as across platforms. Following guidelines are adopted from the IoT-A reference model to design the domain models of the SIoV subsystems. 1) Categorizing abstract concepts as Device, Service, Resource, User or Physical Entity. 2) Defining concepts using UML notations. 3) Using color codes to represent abstract concepts. 4) Active Digital Artifacts are running software applications, agents or services. 5) Passive Digital Artifacts are database entries or digital representations. 6) Every Physical Entity is represented by its corresponding Virtual Entity. 7) Service exposes a functionality of a Device through its hosted Resources.

1) tNOTE MESSAGE

tNote message is a wrapper over user information, vehicular status, and different types of sensory messages. In [5] we have introduced it, which is further detailed in this paper. The user part of the message contains both static administrative user information and dynamic user information such as physiological state, mental state, etc. The static part of the vehicular message contains information such as driver's identity, vehicle's physical attributes, interior, and exterior information. On the other hand, the dynamic part of the vehicular message consists of the sensory messages and observed events. Different layers of privacy are maintained by dividing data into public, private and protected category. Details of the *tNote* message structure are covered in Section IV.

2) ON BOARD UNIT (OBU)

OBU plays the key role in sensing and building the vehicular interaction messages. Every vehicle is represented using a unique number such as IPv6, Universal Product Code (UPC), or Electronic Product Code (EPC). According to IoT-A, every physical *Thing* should have a twin *Virtual Entity* (Figure 2). In SIoV, cyber communications are handled through

[1]Final architectural reference model for the IoT v3.0, http://www.iot-a.eu/public/public-documents/d1.5/at_download/file

this *Virtual Entity*, which is analogous to the physical communication. *Identity Manager* is responsible for the ID update management of OBU. Every vehicle hosts a list of On Board Diagnostic (OBD) sensor devices and it can also integrate other internal sensory devices such as fatigue detector, sleep detector, etc. For every sensor, there is on-device resource to monitor the activities. All these sensory data are accessed through the services; later built into a message by the *Message Builder* and stored on the OBU following the *Automotive Ontology*. Every vehicle is expected to have at least one wireless adaptor to communicate with surrounding OBUs and RSUs. When an OBU comes in contact with another OBU, it exchanges public messages using OBU-OBU communication service through the wireless adaptor.

In an OBU-OBU ad-hoc vehicle platoon (i.e. a group of vehicles that formed ad-hoc network), there exists a platoon leader which receives most of the communication messages and stores them in the OBU-OBU social graph with the help of *Data Manager*. Since OBU-OBU communication is omnidirectional, it is possible that messages are duplicated in the same OBU-OBU topology from different intermediate sources. *Data Manager* filters out stale messages and keeps the local OBU social graph up-to-date. Once, one carrier OBU reaches into the range of an RSU, *Dispatcher* pushes the OBU based *tNote* social graph to the RSU using OBU-RSU communication service. All these data are consumed either by the vehicle operator, on-board passengers or intelligent software agents using respective application clients.

3) ROAD SIDE UNIT (RSU)

In the SIoV, whenever an OBU comes in the range of an RSU, RSU asks the OBU whether it wants to share the OBU-OBU social graph. If an OBU acted as a platoon leader in between the last RSU and current RSU then it should have some OBU-OBU social graph to push to the RSU. The *Identity Manager* of an RSU maintains the physical and virtual identity of the RSU entities. Every RSU has its geographical location, storage device and at least two communication interfaces. OBU-RSU communication occurs through the wireless network interface and uses the OBU-RSU Communication Service. At any specific time, one RSU can receive multiple *tNote* bulk messages from various approaching platoon leaders. RSU collects the *tNote* bulks and *Social Tag Manager* assigns possible tags to the collected data before storing them to the cloud through RSU-Cloud Communication Service (Figure 3). In case an OBU-RSU data exchange renders incomplete, then RSU-RSU Communication Service is used to handle incomplete social data transactions with neighboring RSUs. Social tags generated from the abstract concepts of the ontology facilitate in searching the *tNote* data cloud. *Data Manager* enhances the OBU-RSU social graph by reducing the redundant data. RSU is the super node of the OBU-OBU social graph in the *tNote* cloud. After a predetermined period, the public type RSU-OBU social graph is transferred to the *tNote* data cloud by the *Dispatcher*.

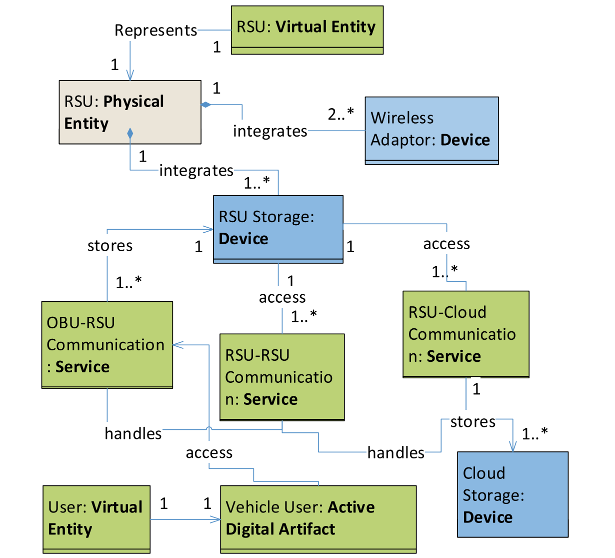

FIGURE 3. Domain model of Road Side Unit (RSU).

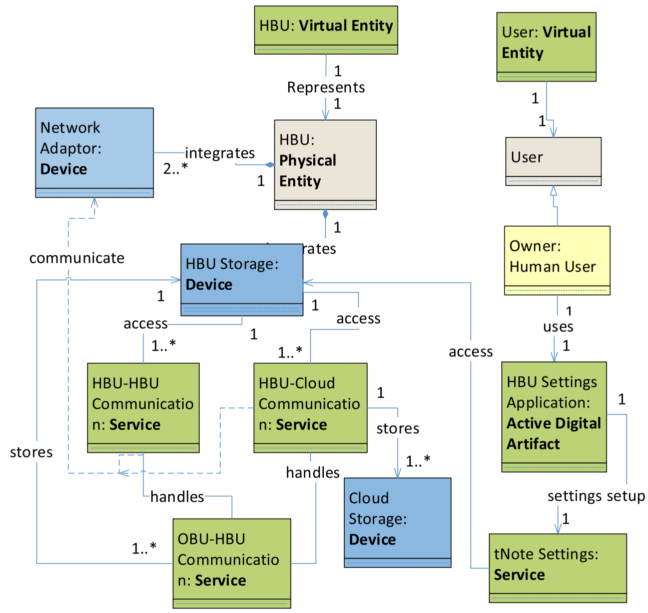

FIGURE 4. Domain model of Home Base Unit (HBU).

4) HOME BASE UNIT (HBU)

HBU plays an important role in the static network building of the SIoV. The home/remote social networks are built based on the data sent from the HBU. Every HBU has an *Identity Manager* to maintain the physical and virtual identity of the component. Geo-local neighboring OBUs are connected to the SIoV through the super node HBU. It is assumed that the home base unit has a storage device where all the social data are stored temporarily (Figure 4). HBU based user data and the corresponding relationship is managed by the *Data Manager*. Every HBU is expected to have network interfaces to exchange data with the OBU and the *tNote* cloud. The owner of the vehicle can change the privacy settings of the vehicle through the *tNote* Settings Service.

Privacy Settings help in privacy management of all devices connected to the HBU except the vehicles. All the private information of the OBU is transferred to the cloud through HBU. OBU-HBU Communication Service coordinates the functionality of other services: HBU-HBU service for inter HBU data exchange, and HBU-Cloud service for transferring data to the central cloud.

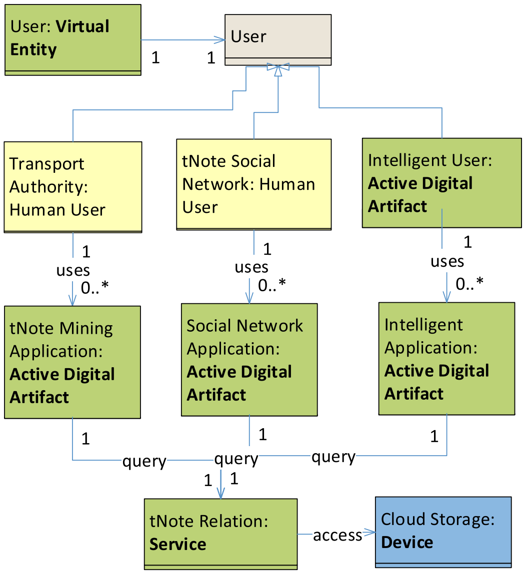

FIGURE 5. **Domain model of *tNote* Cloud.**

5) tNOTE CLOUD

Data cloud is the central infrastructure that retains all the vehicular interactions (i.e. OBU-OBU, OBU-RSU, OBU-HBU) data along with their timestamps. It is hosted in the Internet and allows offline access to the content. *Topology Optimizer* runs on the offline data to remove existing redundancy. Ontology based formatting of the data enables reasoning systems to provide additional insights based on new rules. This is a key aspect for *Intelligent Active Digital Artifacts* (Figure 5). All the queries sent to the cloud from different types of users access the *tNote Relation Service* and they are finally processed by the *Query Processor*. Users of cloud can be intelligent software agents or humans. Human users can be of two types: social network portal user and transport authority. Social network portal users can create static friends, different interest groups (e.g. based on car model, common routes), update vehicle profiles, analyze their usual route data, analyze future travel plans, etc. on the cloud data. The static friendships or groups are managed through the online portal which relate to earlier described relationships. Transport authorities can use the system from BigData perspective and develop various mining applications to solve transport related problems.

6) USER INTERFACE

User Interface is further divided into *Profile, Routes, Friends, Groups, News Feed,* and *Subscription*. The *Profile* presents all the up-to-date vehicle related public, private or protected information. All the public information about the vehicle is easily accessible in its social graph. But, private information is only available for the owner of the vehicle. *Social Graph* of a vehicle is the node-link relationships among OBUs, RSUs, and HBUs involved with that vehicle. The social graph of any vehicle represents the friend structure of any vehicle at a time. *Friends* of a vehicle are different than the friends of a person. Vehicular friends represent the neighbors which participated in the message exchange at any specific time. *Routes* collect all the frequently travelled routes. *Groups* collect different interest groups such as based on owner's interest, manufacturer, vendor, travel interest, etc. Any vehicle or user can subscribe to the important updates of friendly OBUs or RSUs. Updated data are accessible through the *News Feed* interface.

C. PRIVACY AND SECURITY

Privacy is maintained in SIoV by dividing content types to: private, protected, and public. Private type of information is only accessible by the owner of the vehicle (e.g. users personal information, vehicle usage data). Any part of the *tNote* message not determined public is by default private. Owner has the authority to share the private information to the public or to a selected group by making them protected (e.g. vehicle usage data shared with the mechanic). A national or international body (e.g. International Telecommunication Union (ITU)) will decide which part of the message must be public (e.g. Basic Safety Message) that is accessible by anyone (i.e. vehicle, user, authority) participating in a social communication. The sensory data generated in each OBU is stored in various parts of the *tNote* message structure. Only public content is shared among the OBUs, which is later transferred from the platoon leader OBU to the RSU, and finally to the cloud. All the private and protected type of data are shared to the cloud through the HBU of a user.

The proposed SIoV system is data centric and works as an application in the application layer. So, SIoV follows all the security measures such as authentication and access control that are implemented in the VANETs by different service providers to protect the network against all possible types of attacks such as internal, external, active, passive, etc. [26], [27].

IV. tNOTE MESSAGE STRUCTURE

In this section, we describe the detailed structure of the *tNote* message that was introduced in [5]. In order to define the message structure, we consult automotive ontologies [8], [10], [11], SAE J2735 Dedicated Short Range Communications (DSRC[2]) Message Set, and `ITISEventType`[3] of Advanced Traveler Information System (ATIS) schema. Every *tNote* message is transferred as one unit in the communication channel. The *tNote* message

[2] http://www.sae.org/standardsdev/dsrc/
[3] http://www.itsware.net/ITSschemas/ATIS/ATIS-03-00-79/OxDocs/ITIS-Adopted-03-00-02.xsd.html

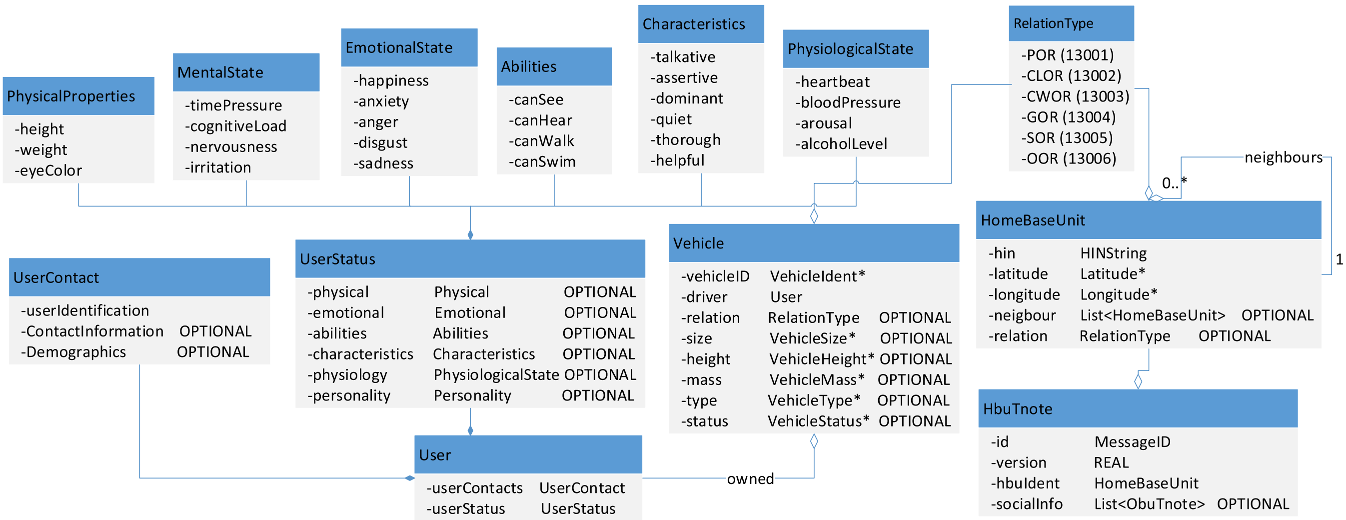

FIGURE 6. User, Vehicle and HBU components of the *tNote* message. Here * comes from SAE J2735.

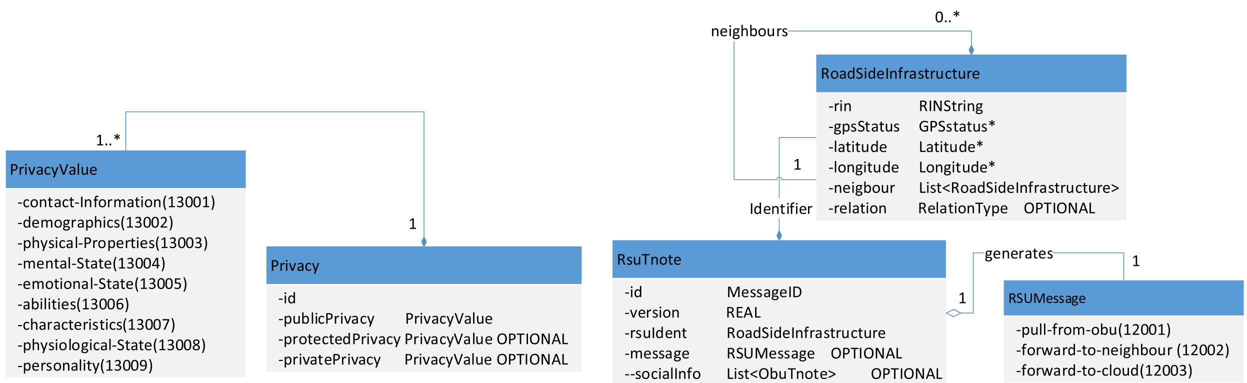

FIGURE 7. RSU and Privacy components of the *tNote* message. Here * comes from SAE J2735.

works as a wrapper or metadata over the other messages. Details of the message parts are described below.

A. USER AND VEHICLE

Figure 6 shows the detailed relationship of user status and vehicle in a *tNote* message. User status consists of physical properties, mental state, emotional state, abilities and characteristics. It is assumed that the sensors inside a smart vehicle will be able to detect and notify these user states. At any given time, abilities, emotional state and mental state are the most important factors for an operator's driving capability. These *tNote* values will help the intelligent vehicle system to be aware of their surrounding vehicle operators' contexts. For the `UserStatus`, most of the corresponding values are `OPTIONAL`, i.e., those values are used when required. `OPTIONAL` values in the message structure ensure flexibility as well as strong handles to reduce the payload if required. `Vehicle` is mostly derived from the SAE J2735 message set. Here `VehicleIdent` refers to the vehicle identification class of SAE J2735 which is consists of VIN, owner code, vehicle type, vehicle class etc. Vehicle class also contains information such as vehicle height, mass, status etc. `VehicleStatus` provides related information about lights, wipers, brake, steering, acceleration, speed, gps etc.

B. HBU MESSAGE

Every HBU can host a list of *tNote* messages which are received from the owner vehicle or from other friends. The physical location of the HBU is known from the latitude and longitude values. The relationships of the HBU with other HBUs are maintained through `RelationType`.

C. PRIVACY

Privacy is an important part of the *tNote* message. From Figure 7, we see that `PrivacyValue` can be easily extended and represented in binary form and each *tNote* message can mention which part of the message belongs to what privacy: private/protected/public. As mentioned before, public information are shared in the OBU-OBU and OBU-RSU communication. Private and

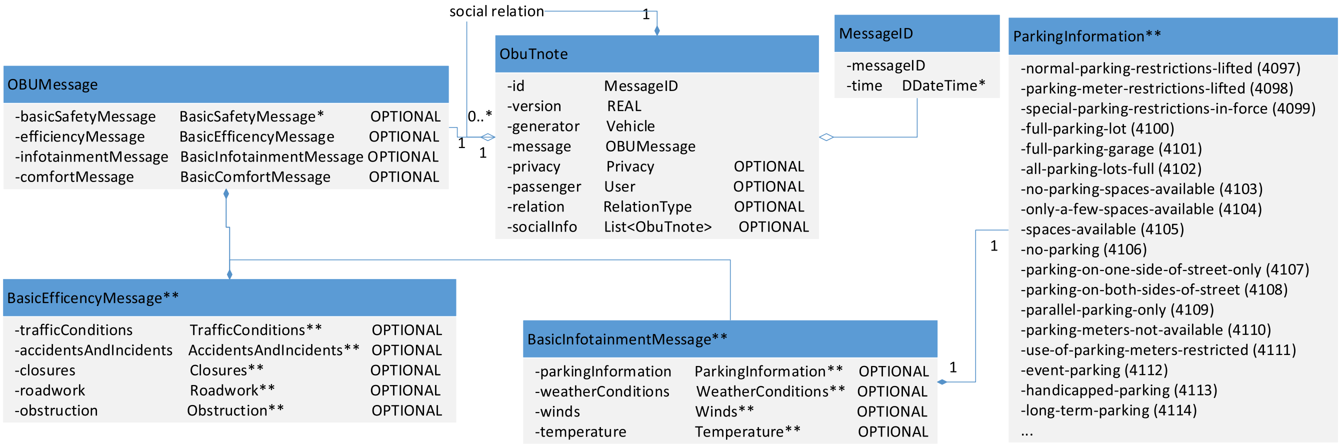

FIGURE 8. OBU components of the *tNote* message. Here * comes from SAE J2735 and ** comes from ATIS schema.

protected information are shared through the OBU-HBU communication to the cloud.

D. RSU MESSAGE

Every *tNote* message is generated in the vehicle and at some point transferred to its closest RSU. An RSU is expected to receive bulk *tNote* messages from platoon leader OBUs. Bulk message consists of *tNote* messages structured in a graph, which represents the OBU-OBU social graph. In Figure 7, we find that `RsuTnote` consists of a list of `ObuTnote` messages. Every RSU is represented using a identifier such as `RoadSideInfrastructure` which recognizes its neighbors, their relation types and the geolocation. The job of RSU is to pull data from OBU, forward incomplete transactions to neighbors, and forward complete transactions to the *tNote Cloud* as described in `RSUMessage`. These functions can easily be extended by adding new RSU functionalities.

E. OBU MESSAGE

An OBU generated message, `ObuTnote`, can be composed of message id, information about the vehicle that created it, privacy segment list, original message part and list of social information in a tree structure. Original message contains the safety, efficiency, infotainment and comfort related metadata (Figure 8). Most `BasicSafetyMessage` message `Part I` are only transmitted in the VANETs control channel and few selected `Part I` and important `Part II` events are stored in the platoon leader OBU, wrapped in the `ObuTnote`. Other types of messages are also stored in the platoon leader OBU. `socialInfo` is a graph like data structure to store the `ObuTnote` list received from the neighbors. `BasicSafetyMessage` is collected from the SAE J2735 message set. `BasicEfficiencyMessage` is a special case of safety message that cannot be described in the original safety message and `BasicInfotainment Message` are derived from the Advanced Traveller Information System (ATIS) schema. As can be seen from the `ParkingInformation`, all these messages are already defined in the ATIS schema. We can select the important fields for infotainment applications or add them to our needs. `BasicComfortMessage` is applicable for video or audio media shared among the OBUs while on the roadway [4].

V. IMPLEMENTATION AND EVALUATION

In this section, we describe the implementation details of the proposed SIoV system. The objective of the implementation is to share the lessons learned in the process. For this purpose, we divide the implementation into three phases: 1) *tNote* message structure is developed using Abstract Syntax Notation One (ASN.1) [37] following the SAE J2735 DSRC[4] footsteps, 2) Cyber-Physical SIoV system infrastructure is developed using Android and Java technology where vehicles are represented as Android Tablets and RSU is represented using laptop, and 3) Internet of Vehicles simulator is built by fusing SUMO[5] trace, Open Street Map[6] and OBD2 codes or situational events.

A. tNOTE MESSAGE

We have used OSS Nokalva ASN.1/java Studio[7] to represent *tNote* message using ASN.1. We have selected ASN.1 for message representation since SAE J2735 message set is defined in ASN.1 and is selected for ITU-T X.680 series of standards [21]. According to ITU, ASN.1 is used in every aspect of our digital life from cellular communication, ATM cash, NetMeeting, RFID, VoIP to biometrics as well as works very well with the XML. We conducted empirical study to see the impact of payload for various encoding rules. The Basic Encoding Rules (BER)/Distinguished Encoding Rules (DER)/Canonical Encoding Rules (CER) type

[4]http://www.sae.org/standardsdev/dsrc/DSRC_R36_Source.ASN
[5]http://sumo-sim.org/
[6]https://www.openstreetmap.org/export#map=13/45.4997/-75.3902
[7]http://www.oss.com/asn1/products/asn1-java/asn1-java.html

encodings follow Tag-Length-Value approach for describing any content where Tag represents an ID, Length is the length of the value, and Value contains the value part. For example, in a given code if `MessageID 12001` corresponds to `80 0A 03 31 32 30 30 31 2E 45 2B 30` hexadecimal bytes, then Tag: `80`, Length: `0A`, and Value: `03 31 32 30 30 31 2E 45 2B 30`. In our implementation of OBU and RSU messages, `RsuTnote` contains a list of `ObuTnote` messages representing OBU-RSU social graph. OBU social graph representing OBU-OBU relationship is implemented using `ASN.1 recursion`, that is `ObuTnote` can be composed of a list of references to other `ObuTnotes`. The above mentioned encodings go very well with the recursive design of *tNote*.

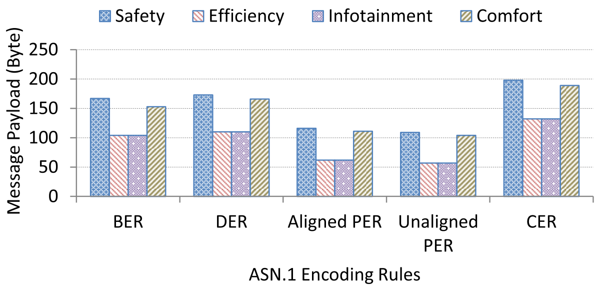

FIGURE 9. Payload size of various *tNote* messages following ASN.1 byte encoding rules.

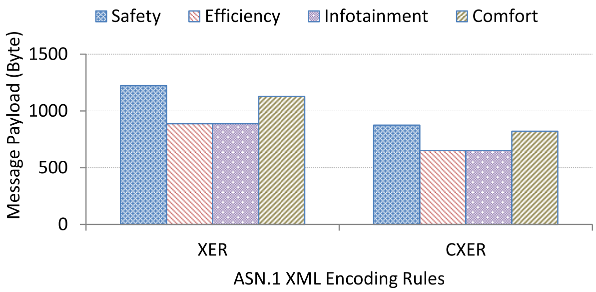

FIGURE 10. Payload size of various *tNote* messages following ASN.1 XML encoding rules.

In the Figure 9 and 10, we present comparative payload size of simpler message for safety, efficiency, infotainment, and comfort applications using variety of X.690 encoding rules for the proposed SIoV. This payload represents the size of one OBU message stored in the OBU storage. The analysis shows that the Packed Encoding Rules (PER) offers the smallest payload whereas BER and DER are larger than PER but almost of similar size. From [21], we come to know that DER[8] type encoding is recommended in the VANETs communication standards. The XML encoding rules XER and CXER present the same information in a text based format which is easy to process but consume high bandwidth.

With the social interactions among OBUs, OBU-OBU social graph grows, which makes the social graph heavier.

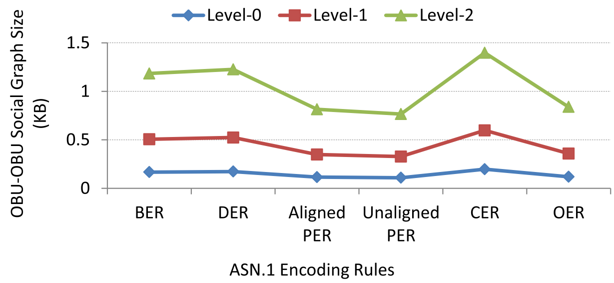

FIGURE 11. ASN.1 data encoding size for OBU-OBU social graph at different friend depths for safety application.

We know that a complete binary tree of level n has total number of nodes $2^{n+1} - 1$. For simplicity, our experimental social graphs are represented as complete binary tree. In level 2 OBU-OBU social graph there are 7 vehicles in a platoon, where message size is around 1.2 KB for DER and 0.8 KB for PER type encodings (Figure 11). An OBU-OBU social graph is transferred from a platoon leader OBU to an RSU, where the OBU-RSU social graph continues to grow for a while before getting transferred to the cloud. In Figure 12, the payload size of OBU-RSU social graph considers binary tree of levels 4-8, which corresponds to 31-511 vehicles. Every RSU receives OBU-OBU social graphs from multiple platoons. For an OBU-RSU social graph of 511 vehicles, safety type payload can be of 88 * 8 Kb. So considering each service channel is allocated 10 Mbps, an RSU can easily handle multiple social graph transactions. In real life, the platoon size depends upon the communication range of the platoon leader, the vehicle speed and the traffic density [24], [40].

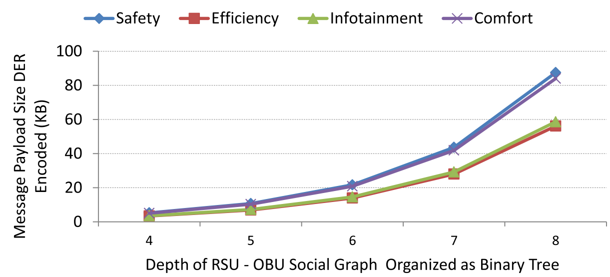

FIGURE 12. ASN.1 data encoding size for RSU-OBU social graph at different friend depths for variety of applications.

Observations: In general, a service advertisement goes through the control channel of VANETs and once a service channel is selected for data communication between the provider and consumer vehicle, then the data exchange starts through the service channel. Hence, from the above analysis, we conclude that established OBU-OBU communication and DER encoding can handle *tNote* OBU-OBU social graph handover to the RSU. Since XML based organization helps in post-processing, RSU can convert the social graphs to an XML format before transferring to the cloud. So, we can say that SIoV application is viable using the VANETs communications and also manageable in the cloud.

[8]http://www.itu.int/ITU-T/studygroups/com17/languages/X.690-0207.pdf

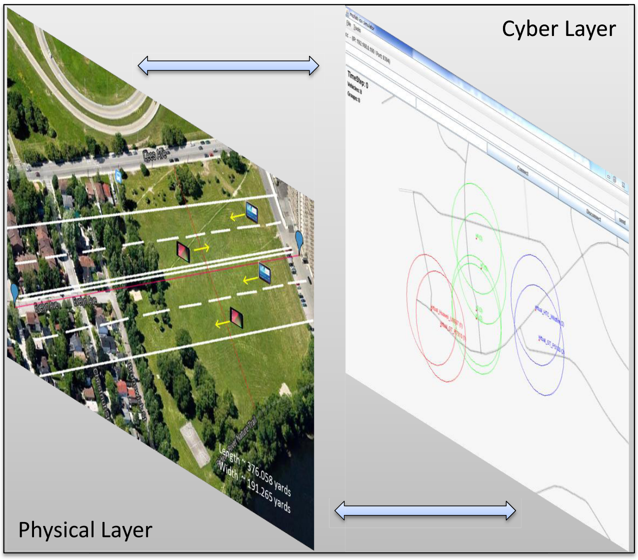

FIGURE 13. Cyber-physical implementation of Social Inter of Vehicles, where each physical element has its representative twin virtual element and operations in physical layer affects cyber computing or vice versa.

B. CYBER-PHYSICAL SIoV SYSTEM INFRASTRUCTURE

The cyber-physical SIoV system has two layers of implementations (Figure 13). First, a mock setup for the physical components of VANETs: OBUs, RSU, and Cloud respectively by Android tablets, laptop computer and desktop computer (motivated by [17]). This open space Wi-Fi communication is conducted in a geographical location *[45.412912, −75.675279], [45.414537, −75.671613], [45.414673, −75.673155], and [45.413377, −75.671917]* of length ∼ 376 yards and width ∼ 191 yards. We simulate multi lane, same direction and opposite direction vehicular traffic in this setup. Second, a Java based connectivity platform for the *Things*, which can be used as an IoV simulator or as a middleware for vehicular communications.

We have created two OBU-OBU platoons of 8 Android based tablets, where the platoon leader of each OBU-OBU network is selected manually. Every tablet is equipped with 802.11n wireless network module that can use *WiFi-Direct* (Software based network access point) technology to establish peer-to-peer connection with the platoon leader and the RSU. RSU is represented by a Windows laptop, and the *tNote* cloud is represented using a Windows desktop server. Additionally, all the devices are connected with an wireless router using LAN or WLAN. Every physical entity maintains a one-to-one connection with its twin cyber entity that is running as an independent JAVA based process in the desktop server.

The Android based communication and messaging platform can use `WifiP2pManager`[9] class for direct peer-to-peer communication in addition to router based server-client operation. When an OBU tablet comes into the wireless range of another OBU tablet and willing to share *tNote* messages, they establish IP networking based socket connection to exchange data. Simultaneously, the virtual processes also establish socket connections. As a result, both physical-physical and physical-cyber-cyber-physical data path is available. Vehicles leaving and joining a platoon is mocked by taking the tablets away from connected peer's wireless range and bringing them inside the wireless range respectively.

For operation simplicity, we represent the *tNote* messages in XML format. We have created an XML database of OBU related messages considering the generic type OBD2 Diagnostic Trouble Codes (DTC[10]). Every virtual OBU has its corresponding MySQL database that stores the communications as well as the DTC codes. Additionally, OBU tablets can read their built-in sensors. All the OBU databases are hosted in the desktop server whereas the RSU database is hosted in the laptop.

The OBU-OBU, OBU-RSU and RSU-Cloud communication services are implemented using RESTful style web services. RESTful architecture requires object identification through Uniform Resource Identifier (URI). In our implementation, RSU sends GET, PUT, POST, and DELETE request to the *tNote* cloud using HTTP protocol, where message payload is of XML type. Complete details of the entire connectivity platform are out of scope for this article. Detailed architecture and connectivity analysis will be reported in a future dissemination.

Observations: In the *WiFi-Direct* peer-to-peer connections, every tablet works as a network access point, hence quick battery drainage is a significant problem. As speed is a key factor in vehicular communication, tablet based OBU presentation may not fully replicate the real life. A vehicle can travel in the speed of 60-100 kilometers/hour and foot based walking or running ensures speed of 9-25 kilometers/hour for any tablet [17]. Hence, the physical-physical connection life may not be appropriate. But, the physical-cyber-cyber-physical data path can offset this issue with some added delay.

C. INTERNET OF VEHICLES SIMULATOR

The SIoV simulator is an extension of the above described connectivity platform (Figure 14); where Simulation of Urban Mobility (SUMO) vehicle traces, road network file (generated from the Open Street Map) and customizable communication properties are the inputs. Only the cyber layer of the earlier described system is used for the simulation purpose. We employ SUMO to generate mobility trace data of the vehicles on different areas of Ottawa, Canada. We follow every time-step of the SUMO trace file and form platoons of the vehicles according to their given communication range. We build random sensory data from generic OBD2 DTC information, vehicle model information and random roadway

[9]http://developer.android.com/reference/android/net/wifi/p2p/WifiP2pManager.html

[10]http://www.dmv.de.gov/services/Vehicle_Services/dtc_list.pdf

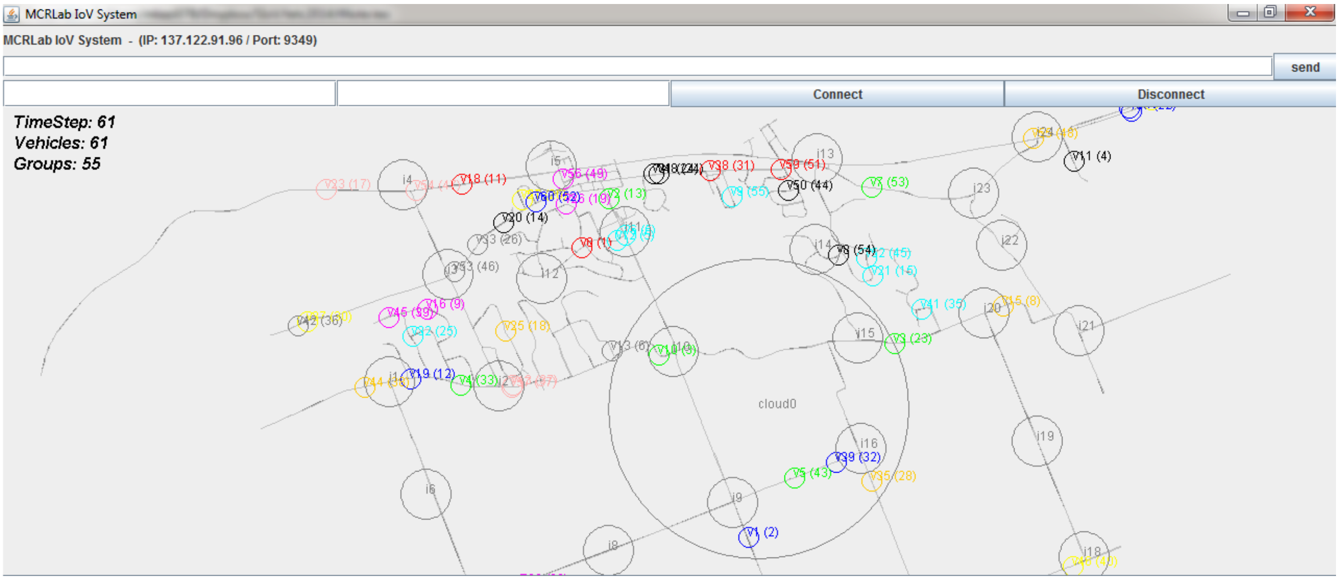

FIGURE 14. IP networking based custom Internet of Vehicles simulator that takes Open Street Map, SUMO vehicle trace as inputs and adds communication properties to exchange information following the SIoV architecture.

situations such as accident, road block, slow vehicle, construction, etc. The messages are then stored in the vehicles, shared with the platoons and finally transferred to the cloud following earlier descriptions.

The communications of the messages follow the same model described in the earlier section. All the messages are stored in the MySQL database. Data analysis based on data count, message type can be applied on the MySQL database. The simulator can house real vehicles or simulated vehicles together and let them communicate as well. We can also install RSUs and HBUs as fixed elements in the simulator and create static relationships among them. It is fully scalable and the scalability only depends on the capacity of the host server. Details about the simulator will be described in a future article.

VI. APPLICATION SCENARIOS

As mentioned earlier, there are five different types of users of SIoV system: driver, passengers, social network portal user, transport authority and intelligent vehicle system. In this section, we present few application scenarios for these users.

A. EARLY WARNING SYSTEM

Early warning system for the vehicle driver is a key real time safety application of the *tNote* OBU-OBU social graph. Critical safety information such as unexpected vehicle movements, sudden break of front vehicle, dangerous road conditions, etc. play important role in early warning systems. These events can be detected by analyzing the OBD and tablet sensors in SIoV. At any time, this information can be shared with the platoon members either by physical-physical or physical-cyber-cyber-physical data path of SIoV implementation. Early warning system can also use a warning ontology to categorize and prioritize sensory information to provide color coded symbolic warnings to reduce cognitive pressure on the driver. Such applications belong to the *Active Digital Artifact* category and should maintain certain level of trust.

B. DETOUR APPLICATION

A near real time efficiency application of OBU-OBU and RSU-OBU social graph is a detour application on board which can benefit the operator as well as the passengers. The RSU-RSU communication path can fast forward the social graph data on request to find an alternate route for any travel. These requests can be initiated to avoid road blockage, slow vehicle, accidents, and construction works. Also, the intelligent vehicle, or web users can log into the social network portal and see the ongoing status or forecast of vehicular situations to any selected route (a region of RSUs) in any time period.

C. SOCIAL WEB PORTAL

A popular social network like web navigation provides vehicle owners deep access to the system. Intelligent vehicle agents can also access the cloud data through APIs. For example, Figure 15(a) shows the *Home* view of an individual `Toyota Prius` status page, which presents time specific vehicular events and observations while on the roadway. The *Groups* feature allows the vehicles to create static relations with other VANETs elements to follow-up inside these groups. Figure 15(b) shows a list of vehicles the `Toyota Prius` is following who are grouped based on their manufacturer `Toyota` company. One can also create other types of groups. Also, Figure 15(c) shows the list of

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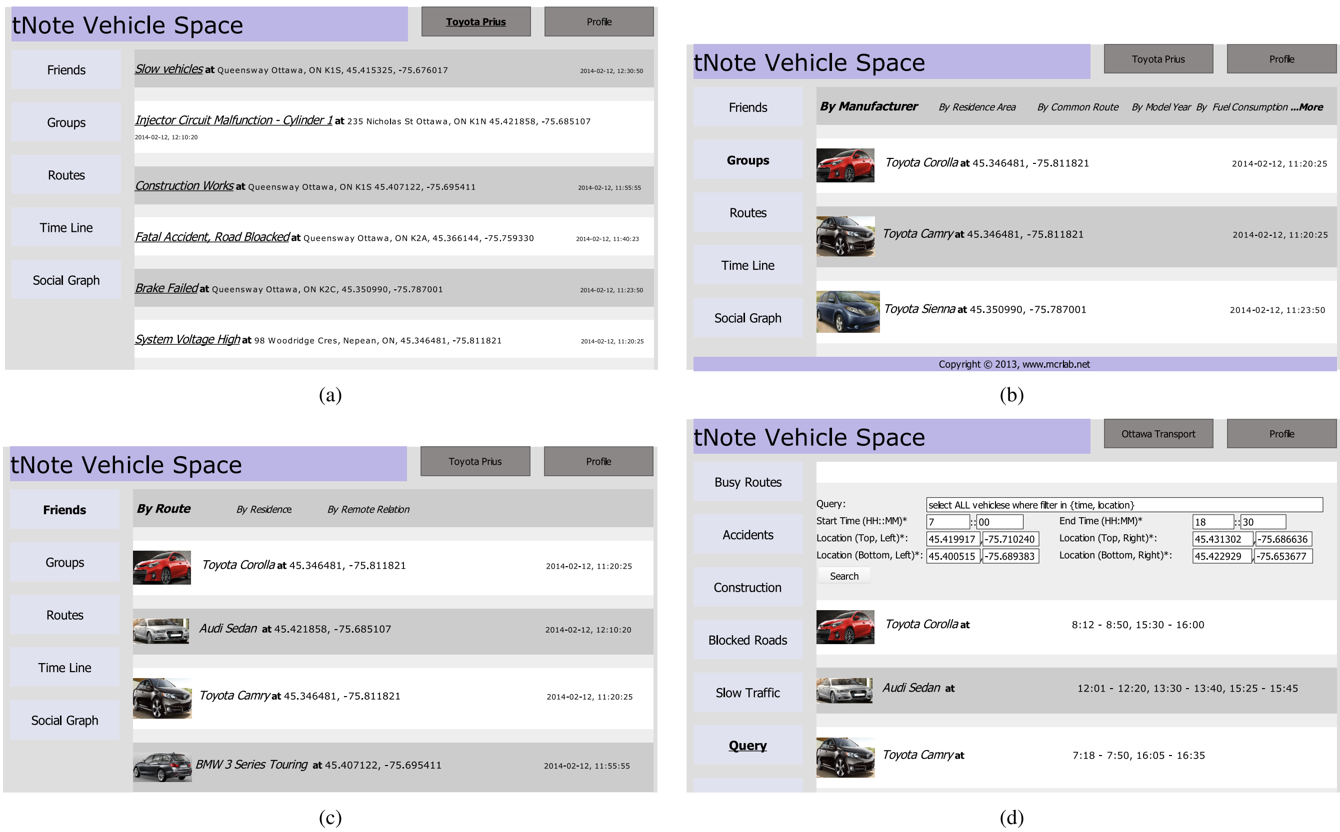

FIGURE 15. **Example social web portal view of the SIoV. (a) Home view for vehicle** `Toyota Prius`**. (b) Groups view based on manufacturer category. (c) Friends view based on routes category. (d) Transport authority query view.**

Friends according to `Toyota Prius` common travel route experience.

D. ANALYSIS APPLICATION FOR TRANSPORT AUTHORITY

Transport authorities can also develop variety of data mining and monitoring applications to improve the efficiency of the roadway movement and other management requirements. In the Figure 15(d), we see a prototype system for `Ottawa Transport` authority which provides features such as *Busy Routes, Accidents, Construction, Blocked Roads, Slow Traffic, Query*, etc. The *Busy Routes* feature provides a list of routes according to the traffic density at any time period of a particular region. Similarly, using *Query* interface, authorities can make raw queries such as '*select All vehicles where time* = - *and location* = -'. For example, all the vehicles that were present in a certain time period in a certain region can be listed for crime investigation purpose.

E. INFOTAINMENT AND COMFORT APPLICATIONS

Different infotainment applications can be built by employing the rich data from the `BasicInfotainmentMessage`. For example, `ParkingInformation` class of ATIS schema is useful for parking status related applications such as *full parking lot, spaces available, overnight parking available, parallel parking only*, etc. This infotainment data is generated in the OBU and will be temporarily stored in the RSU. Any request from an OBU will retrieve this RSU based data for the up-to-date information. Similarly, weather, wind, temperature and other `ITISEventType` information class can be a rich data structure for many infotainment applications. Another infotainment application is the location based advertisement deals moving vehicles can receive from local stores or restaurants. Comfort applications are mostly audio and video sharing application. A detailed video sharing application based on vehicular crowd is discussed in [4].

VII. CONCLUSION AND FUTURE WORKS

The paper details Social Internet of Vehicles as a compelling use case of Social Internet of Things. The proposed architecture defines important components, their interactions, and interrelations, which are inspired from the SIoT, IoT-A reference model and the cyber-physical systems. A structure of the interaction message is provided that can support safety, efficiency, infotainment and comfort applications for the SIoV. Implementation details of the message structure, analysis of the payload size, cyber-physical infrastructure implementation approach and the IoV simulator using SUMO trace, Open Street Map and OBD2 is also explained in this paper. Additionally, prototype application scenarios are included for different user groups such as drivers, passengers, social web users and transport authorities. We envision that the SIoV would be an integral part of intelligent transport systems in the future smart cities.

In order to realize SIoV, we need to consider some important issues such as scalability, data redundancy, and synchronization. Detailed workload characterization of SIoV is important to understand the impact of payload on VANETs infrastructure. The workload model can be used to dynamically adapt the loads on different subsystems of the SIoV. A domain ontology tailored to support the SIoV can be an important work to inject intelligence in the cyber entities. Strategies to handle the smart connections in cyber-physical SIoV is also a viable future work. Additionally, practical deployment of the proposed system and using it to collect real life IoV related multi-modal sensory data in city or urban areas can be another interesting direction.

ACKNOWLEDGMENTS

The authors would like to thank Alejandro Sopeña González-Aller for his involvement in developing the cyber-physical SIoV simulator. Also, they would like to thank the anonymous reviewers for their kind suggestions to improve the quality of this manuscript.

REFERENCES

[1] N. Abbani, M. Jomaa, T. Tarhini, H. Artail, and W. El-Hajj, "Managing social networks in vehicular networks using trust rules," in *Proc. IEEE Symp. Wireless Technol. Appl.*, Sep. 2011, pp. 168–173.

[2] H. Abid, L. T. T. Phuong, J. Wang, S. Lee, and S. Qaisar, "V-Cloud: Vehicular cyber-physical systems and cloud computing," in *Proc. 4th Int. Symp. Appl. Sci. Biomed. Commun. Technol.*, 2011, p. 165.

[3] M. Al-Hader, A. Rodzi, A. R. Sharif, and N. Ahmad, "Smart city components architecture," in *Proc. Int. Conf. Comput. Intell., Modelling Simulation*, Sep. 2009, pp. 93–97.

[4] K. M. Alam, M. Saini, D. T. Ahmed, and A. El Saddik, "VeDi: A vehicular crowd-sourced video social network for VANETs," in *Proc. IEEE 39th Conf. Local Comput. Netw. (LCN)*, Sep. 2014, pp. 738–745.

[5] K. M. Alam, M. Saini, and A. El Saddik, "*tNote:* A social network of vehicles under Internet of Things," in *Internet of Vehicles—Technologies and Services*. Berlin, Germany: Springer-Verlag, 2014, pp. 227–236.

[6] L. Atzori, A. Iera, and G. Morabito, "SIoT: Giving a social structure to the Internet of Things," *IEEE Commun. Lett.*, vol. 15, no. 11, pp. 1193–1195, Nov. 2011.

[7] L. Atzori, A. Iera, G. Morabito, and M. Nitti, "The social Internet of Things (SIoT)—When social networks meet the Internet of Things: Concept, architecture and network characterization," *Comput. Netw.*, vol. 56, no. 16, pp. 3594–3608, Nov. 2012.

[8] J. Barrachina *et al.*, "CAOVA: A car accident ontology for VANETs," in *Proc. IEEE Wireless Commun. Netw. Conf.*, Apr. 2012, pp. 1864–1869.

[9] R. Fei, K. Yang, and X. Cheng, "A cooperative social and vehicular network and its dynamic bandwidth allocation algorithms," in *Proc. IEEE Conf. Comput. Commun. Workshops*, Apr. 2011, pp. 63–67.

[10] M. Feld and C. Müller, "The automotive ontology: Managing knowledge inside the vehicle and sharing it between cars," in *Proc. 3rd Int. Conf. Automotive User Inter. Interact. Veh. Appl.*, 2011, pp. 79–86.

[11] J. Ferreira, F. Furini, and N. Silva, "VCO–vehicle corporate ontology," in *Proc. 2nd Conf. Ibérica Sistemas Tecnol. Informação*, Porto, Portugal, Jun. 2007.

[12] E. L. George. (2013). *The U.S. Economy and Monetary Policy*, Federal Reserve Bank of Kansas City. [Online]. Available: http://www.kc.frb.org/publicat/speeches/2013-George-KansasCity-CentralExchange-01-10.pdf

[13] D. Guinard, M. Fischer, and V. Trifa, "Sharing using social networks in a composable Web of Things," in *Proc. IEEE Int. Conf. Pervasive Comput. Commun. Workshops*, Mar./Apr. 2010, pp. 702–707.

[14] S. Haller, "The things in the Internet of Things," in *Proc. Internet Things Conf.*, 2010, pp. 1–3.

[15] L. E. Holmquist, F. Mattern, B. Schiele, P. Alahuhta, M. Beigl, and H.-W. Gellersen, "Smart-its friends: A technique for users to easily establish connections between smart artefacts," in *Ubicomp 2001: Ubiquitous Computing*. Berlin, Germany: Springer-Verlag, 2001, pp. 116–122.

[16] X. Hu *et al.*, "Social drive: A crowdsourcing-based vehicular social networking system for green transportation," in *Proc. 3rd ACM Int. Symp. Design Anal. Intell. Veh. Netw. Appl.*, 2013, pp. 85–92.

[17] X. Hu, W. Wang, and V. C. M. Leung, "VSSA: A service-oriented vehicular social-networking platform for transportation efficiency," in *Proc. 2nd ACM Int. Symp. Design Anal. Intell. Veh. Netw. Appl.*, 2012, pp. 31–38.

[18] K. Hartman and J. Strasser. Saving lives through advanced vehicle safety technology: Intelligent vehicle initiative final report. *Federal Highway Administration, FHWA-JPO-05-057*, 2005.

[19] G. Karagiannis *et al.*, "Vehicular networking: A survey and tutorial on requirements, architectures, challenges, standards and solutions," *IEEE Commun. Surveys Tuts.*, vol. 13, no. 4, pp. 584–616, Nov. 2011.

[20] N. Kayastha, D. Niyato, P. Wang, and E. Hossain, "Applications, architectures, and protocol design issues for mobile social networks: A survey," *Proc. IEEE*, vol. 99, no. 12, pp. 2130–2158, Dec. 2011.

[21] J. B. Kenney, "Dedicated short-range communications (DSRC) standards in the United States," *Proc. IEEE*, vol. 99, no. 7, pp. 1162–1182, Jul. 2011.

[22] M. Kranz, L. Roalter, and F. Michahelles, "Things that Twitter: Social networks and the Internet of Things," in *Proc. What Can Internet Things Citizen (CIoT) Workshop 8th Int. Conf. Pervasive Comput. (Pervasive)*, 2010, pp. 1–10.

[23] J. Lee, B. Bagheri, and H.-A. Kao, "A cyber-physical systems architecture for industry 4.0-based manufacturing systems," *Manuf. Lett.*, vol. 3, pp. 18–23, Jan. 2015.

[24] Y. L. Morgan, "Managing DSRC and WAVE standards operations in a V2V scenario," *Int. J. Veh. Technol.*, vol. 2010, Apr. 2010, Art. ID 797405.

[25] Y. L. Morgan, "Notes on DSRC & WAVE standards suite: Its architecture, design, and characteristics," *IEEE Commun. Surveys Tuts.*, vol. 12, no. 4, pp. 504–518, Nov. 2010.

[26] H. Moustafa, G. Bourdon, and Y. Gourhant, "Providing authentication and access control in vehicular network environment," in *Security and Privacy in Dynamic Environments*. Berlin, Germany: Springer-Verlag, 2006, pp. 62–73.

[27] H. Moustafa and Y. Zhang, *Vehicular Networks: Techniques, Standards, and Applications*. New York, NY, USA: Auerbach, 2009.

[28] NHTSA. Traffic Safety Facts 2007. Tech. Rep. National Traffic Safety Administration, U.S. Department of Transportation, Washington, DC 20590, 2008.

[29] H. Ning and Z. Wang, "Future Internet of Things architecture: Like mankind neural system or social organization framework?" *IEEE Commun. Lett.*, vol. 15, no. 4, pp. 461–463, Apr. 2011.

[30] M. Nitti, R. Girau, A. Floris, and L. Atzori, "On adding the social dimension to the Internet of Vehicles: Friendship and middleware," in *Proc. IEEE Int. Black Sea Conf. Commun. Netw. (BlackSeaCom)*, May 2014, pp. 134–138.

[31] A. M. Ortiz, D. Hussein, S. Park, S. N. Han, and N. Crespi, "The cluster between Internet of Things and social networks: Review and research challenges," *IEEE Internet Things J.*, vol. 1, no. 3, pp. 206–215, Jun. 2014.

[32] S. Plotkin, T. Stephens, and W. McManus, "Vehicle technology deployment pathways: An examination of timing and investment constraints," Transportation Energy Futures Series, Prepared for the U.S. Department of Energy by Argonne National Laboratory, Argonne, IL, USA, Tech. Rep. DOE/GO-102013-3708, 2013, vol. 3.

[33] R. Rajkumar, I. Lee, L. Sha, and J. Stankovic, "Cyber-physical systems: The next computing revolution," in *Proc. 47th ACM/IEEE Design Autom. Conf. (DAC)*, Jun. 2010, pp. 731–736.

[34] M. Schütz and K. Dietmayer, "A flexible environment perception framework for advanced driver assistance systems," in *Advanced Microsystems for Automotive Applications*. Berlin, Germany: Springer-Verlag, 2013, pp. 21–29.

[35] A. Serbanati, C. M. Medaglia, and U. B. Ceipidor, "Building blocks of the Internet of Things: State of the art and beyond," in *Deploying RFID—Challenges, Solutions, and Open Issues*, C. Turcu, Ed. Rijeka, Croatia: InTech, 2011.

[36] S. Smaldone, L. Han, P. Shankar, and L. Iftode, "RoadSpeak: Enabling voice chat on roadways using vehicular social networks," in *Proc. 1st Workshop Social Netw. Syst.*, 2008, pp. 43–48.

[37] D. Steedman, *Abstract Syntax Notation One (ASN. 1): The Tutorial and Reference*. Twickenham, U.K.: Technology Appraisals, 1993.

[38] K. Su, J. Li, and H. Fu, "Smart city and the applications," in *Proc. Int. Conf. Electron., Commun. Control (ICECC)*, Sep. 2011, pp. 1028–1031.
[39] M. Warner. (2013). *General Motors Sales Up in December*, Fox Business. [Online]. Available: http://www.foxbusiness.com/industries/2013/01/03/general-motors-sales-up-in-december/
[40] S. Yousefi, E. Altman, R. El-Azouzi, and M. Fathy, "Analytical model for connectivity in vehicular ad hoc networks," *IEEE Trans. Veh. Technol.*, vol. 57, no. 6, pp. 3341–3356, Nov. 2008.

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