Chapter 8

From Vehicular Networks to Vehicular Clouds in Smart Cities

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Abstract: Vehicular networks are inseparable components of a smart city environment due to several applications that improve life quality, safety and security. Applications of vehicular networks vary from safety applications such as blind spot warning and traffic light violations to non-safety applications such as entertainment, optimal speed advisory and/or congestion/accident information. Recently established standards such as IEEE 802.11p and IEEE 1609 help achieve effective communications between vehicles and the infrastructure. However, vehicular ad-hoc networks (VANETs) are still considered as one of the challenging forms of wireless communication technologies that complement Intelligent Transportation Systems (ITS) that aim at the betterment of the transportation in cooperation with the Information and Communication Technologies (ICTs). VANETs are specialized form of mobile ad hoc networks (MANETs) where protocols performed well in MANETs may not be ideal for VANETs due to high mobility, intermittent connectivity and heterogeneity. With the advent of cloud computing paradigm, offloading local resources to a shared pool of resources has been an ideal solution for compute-intensive and memory-intensive applications. Hence, the concept of vehicular clouds has been introduced to facilitate VANET applications in a resource efficient way with rapid elasticity and on the pay-as-you go business model. This chapter presents a comprehensive survey of VANET applications in smart cities along with challenges, solutions and existing implementations. Furthermore, it introduces the state of the art in vehicular clouds for smart cities following an introduction of various vehicular cloud architectures. Moreover open issues and future directions are presented and discussed to help stimulate future studies in this emerging research field.

Keywords: **Smart cities, vehicular cloud, vehicular networks, clustering, ...,**

1. INTRODUCTION

Smart city or ubiquitous city retrieves information in collaborative environment and store it to the internet cloud. According to Yovanof et al [1] a smart and digital city provides connected infrastructure to ensure appropriate service quality standard for the inhabitants of the society. Smart city can also be described as an ICT-centered information city where technical infrastructure, diverse people and good governance are combined in action [2]. Giffinger et al also included the importance of characteristics e.g. economy, mobility and lifestyle [3]. The study in [4] presents the role of smart city applications on government administration, modern health service, intelligent transportation, efficient utility and secure environment for public services.

These applications of smart city advert the role of vehicular ad hoc networks (VANETs), cloud computing and intelligent transportation systems in modern computing era.

As an inseparable component of smart cities, Vehicular Ad Hoc Networks (VANET) is a research area expanding very rapidly where the research community and the industry are working in a collaborative manner. The main aim is offering new and novel communication technologies and building infrastructures for the vehicles to communicate among themselves. There are already recently established standards, e.g. IEEE 802.11p and IEEE 1609, to achieve this goal after works on several years in this area.

Vehicular ad-hoc networks (VANETs) are considered to be one of the challenging forms of wireless communication technologies which facilitate road efficiency and safety applications through Intelligent Transportation Systems (ITS). Intelligent transportation systems aim at the betterment of the transportation in cooperation with the Information and Communication Technologies (ICTs). Furthermore cyber-physical solutions in smart cities have enabled interaction between the physical and computational components of systems. VANETs are specialized forms of MANETs where protocols performed well in MANET may not be suitable for VANET. This is due to VANETs' experiencing significant constraints in terms of node mobility, frequent topology change and varying speed of the nodes. Due to its intrinsic characteristics, enabling Quality of Service (QoS), reliability and security in addition to the well-known network operations e.g. scalable routing has become much more challenging in VANETs. Clustering appears as a promising solution to cope with all these kind of issues as it is proven to be in MANET.

A VANET is a useful platform for intelligent transportation systems. Through peer to peer ad-hoc based communication, VANETs provide collaborative infrastructure to construct a robust information network. The real time status of a particular vehicle is retrieved through its on-board units and eventually transferred to the peers. Thus the network is not particularly dependent on road side unit or sensors for information propagation.

With the advent of cloud computing concept, computing, communications and storage resources are being provided as services within a shared pool of resources with rapid elasticity and pay-as-you-go fashion. Furthermore, the advancements in mobile communications reveal the potential of mobile devices to form a mobile cloud environment. Vehicular networks combined with mobile cloud computing introduces the vehicular cloud concept which enables connected vehicles to share their resources through a cloud platform. Several smart city applications can be empowered by the vehicular clouds. These applications can be listed as highway/downtown traffic monitoring, environmental monitoring, emergency assistance, disaster management, multimedia content delivery and so on. Cloud computing can facilitate a scalable system with optimum cost through on demand access to the shared infrastructure. Vehicular cloud is a unique idea to combine information from mobile nodes and various RSUs, and store it in the cloud.

Vehicular cloud is formed by a cluster of vehicles which can enhance unified communication and are able to self-organize as per network demand. The VANET technology proposed in [5, 6] has discussed the concept of Vehicular communication through vehicular cloud computing (VCC) and information centric networking (ICN). VCC provides a method of network service provisioning and ICN ensures the process of cloud centric data routing and dissemination. Through peer to peer connection, the nodes are internetworked for resource sharing directly in a decentralized manner. However, for the sake of computing efficieny, one vehicle might be elected as the broker based on some metrics. Thus vehicular cloud computing can provide resource monitoring, efficiency in routing, securing the inter vehicle privacy issues and virtualization among vehicles. Based on the network, it is easier to create new application on vehicular cloud. ICN provides the scope to spread the cloud contents efficiently among the vehicles. Hu et al [7] introduced a service centric contextualized vehicular cloud (SCCV) which is efficient and can mitigate the network overhead.

Two important issues of VCN are addressed in [6]: the process to quantify the value of resources and process of preventing vehicles moving freely. The corresponding paper also introduces the design principles of VCN services: data storage, sensing services and computing services.

Figure 1 illustrates a sample smart city scenario where connected vehicles collaboratively share the traffic condition to assist paramedics to hospitalize the patients who need urgent medical care as early as possible. According to this application, alternate destination medical centers are crowdsourced, and alternate route-trees towards those destinations are computed through collaboratively collected road and traffic condition data. The mobile end-user device sends an inquiry to the vehicular network which reports the traffic profile to the alternate route-tree selection module along with a number of possible medical centers that the patient may be taken to. Due to the possible sudden changes of the traffic profile in an urban area, it is crucial to determine the alternate routes to pre-determined destinations. Moreover, in case of a sudden change in the traffic profile, the ambulance driver should be able to switch to an alternate route towards an alternate medical center.

Besides their benefits, connected vehicle systems denoting both vehicular networks and vehicular clouds introduce several challenges. These challenges vary from clustering problems related to spatial and temporal properties of the communication medium, Quality of Service assurance, vehicle-to-infrastructure/infrastructure-to-vehicle communication challenges in VANETS

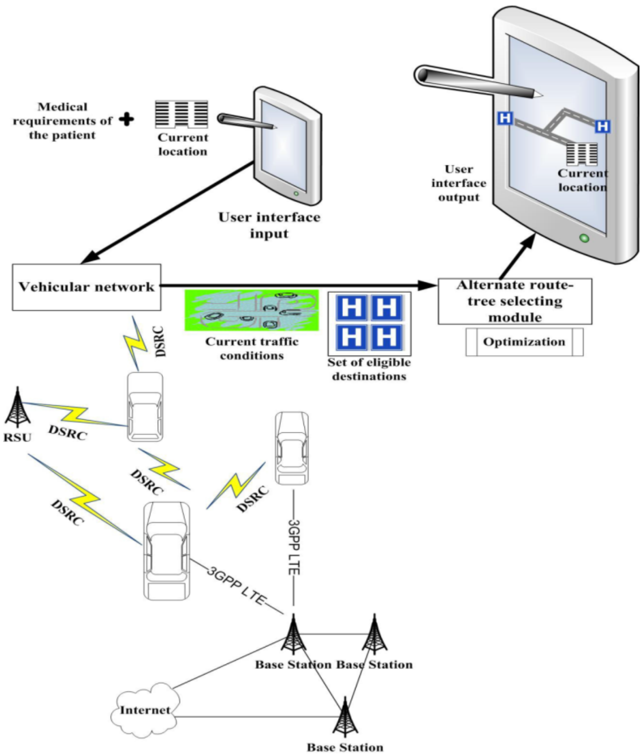

Figure 1: Sample smart city application in an urban area aiming at emergency assistance for paramedics (Kantarci, 2015)

to virtualization and security/privacy/trust problems in vehicular clouds. This chapter presents a comprehensive survey of the current state of the art in VANETS and vehicular clouds for smart cities. The chapter starts with a definition of the VANET and vehicular cloud architectures by surveying the existing solutions, as well as identifying research and application challenges. Then a thorough study of the existing solutions for VANET challenges in smart cities are presented and compared to each other by using several criteria. This section is followed by a section where vehicular cloud solutions under dynamic and static scenarios are presented along with the challenges that are mentioned above. The studies in this section will be grouped under the following categories: Virtualization for computation and storage services, security challenges, privacy and user experience issues ad context-aware solutions for all services in vehicular cloud environments. In these two survey sections, comparisons of the surveyed solutions are presented along with relevant arguments. The chapter is wrapped up with a thorough discussion of open issues, challenges and possible directions for the researchers who would like to pursue solutions for vehicular communications in smart cities..

2. VANET ARCHITECTURE

Intelligent Transportation Systems (ITS) utilize the communication technologies to connect vehicles, people and any facility for more secure, safer, and highly mobile transportation in an urban environment [8]. Vehicular Networks constitute the key and major component of the ITSs by enabling and integrating the use of various technologies, communication standards and the infrastructures [9, 10, 11]. The city is turned into a smart connected city by the intelligent transportation systems with the use of vehicular networks and its infrastructure. Every region, facility, driver, passenger and even any pedestrian is envisioned to be connected to the ITS and be aware of local, or region of interest (ROI), or city-wide events and updates/changes on the transportation system even in real-time. Within that architecture, real-time and non-real time information will be used and provided by the ITS and vehicular networks for safety and efficiency [12].

Since 80's, modern vehicles are being able to gather massive amount of data from the electronic control units placed within the vehicle. These data have been stored on board by the vehicles but have been processed only by the manufacturers. However, there is a great demand in the industry to utilize these data for various purposes, e.g. safety, efficiency, and comfort driving. Data collected by the vehicles can be used to identify and quickly locate the available parking spaces or to reduce traffic congestion. VANETs can be used to increase the efficiency and the utilization of resources, e.g. saving time and reducing fuel consumption. It could be used to create smart cities for a better quality of life. Moreover, such kind of data and networking infrastructure have a great commercial value which can be used to improve competition in the market. Building such kind of cost-effective (considering cost of the radios in vehicles), distributed and decentralized networking system is the common aim of both the industry and the research community.

Vehicular networks are composed of vehicles and infrastructure units. Communication takes place between the vehicles which is named as Vehicle-to-Vehicle (V2V) communication and between the vehicles and infrastructure points (road side units –RSU) which is named as vehicle-to-infrastructure (V2I) communication. Vehicles use on-board units (OBU) for V2V and V2I communication.

[FIGURE VANET ARCHITECTURE]

Although VANETs are specialized forms of Mobile Ad Hoc Networks (MANETs), compared to MANET and other wireless and mobile networks, VANETs show unique characteristics. These are [13, 14, 15]:

- **Intermittent connectivity:** Due to the high and variable speed of vehicles, the connectivity of the vehicles doesn't last for a long time but vehicles get connected instantly and frequently.
- **Dense vs. Sparse Topology:** Density may vary in time and space. In urban areas,

density is high and variable during the daytime and becomes very crowded in rush hours, but is sparse after midnight. On the other hand, the topology is sparse in rural areas.

- **Predictable Mobility Pattern:** Since the vehicles are mobile and usually follow each other, it is easier to predict the mobility of the vehicles. Drivers who use the same path in their daily life make the route and mobility patterns more predictable.
- **Broadcasting & Controlled Flooding:** Due to the characteristics mentioned above, constructing and maintaining routes between the communicating pairs are not feasible solutions. For the safety and non-safety applications, beaconing and controlled flooding are accepted approaches for information dissemination.

VANETs integrate several networking technologies such as Dedicated Short Range Communications (DSRC) [16], IEEE 802.11p [17], WAVE IEEE 1609 [STD1609], WIMAX IEEE 802.16 [STD 802.16], and even ZigBee IEEE 802.15.4 [STD802.15.4] are amongst these technologies.

WAVE Standard	Usage	Description
IEEE P1609.0	Architecture	Describes the architecture and service necessary for multi-channel WAVE devices
IEEE P1609.2	Security Services for Applications and Management Messages	Covers methods for securing WAVE management messages and application messages, It also describes administrative functions necessary to support the core security functions
IEEE 1609.3–2010	Networking Service	Describes standard messages that support higher layer communication stacks, including TCP/IP
IEEE 1609.4–2010	Multi-Channel Operation	Describes various standard message formats for DSRC applications at 5.9 GHz
IEEE P1609.5	Communication Manager	Defines communication management services in support of wireless connectivity among vehicle-based devices, and between fixed roadside devices and vehicle-based devices
IEEE 1609.11–2010	Over-the-Air Electronic Payment Data Exchange Protocol	Defines a basic level of technical interoperability for electronic payment equipment, i.e. On board unit (OBU) and roadside equipment (RSE) using DSRC
IEEE P1609.12	Identifier Allocations	Specifies allocations of WAVE identifiers defined in the IEEE 1609 series of standards

Figure 2: IEEE 802.11p and IEEE 1609 protocol family for VANET communication

2.1. VANET Protocol Architecture

After several years on standardization efforts, the wireless access in vehicular environments (WAVE) has been accepted as the system architecture for vehicular communication, and several standards have been released for short range communication in VANETs. These standards are described in Fig. 2 [18, 19, 20, 21, 22, 23, 24]. IEEE 802.11p (IEEE Std 802.11p-2010) [17] is the physical layer standard including a set of extensions to the IEEE 802.11 standard. Upper layers include the family of IEEE 1609 standards which relies on IEEE 802.11p (Figure 3). The family of 1609 standards defines the architecture, communications model, protocols, security mechanisms, network services, multichannel operation and the use of Provider Service Identifiers in the vehicular environment. It is aimed to support high speed (up to 27 Mb/s) short range (up to 1000m) low latency wireless communications [25].

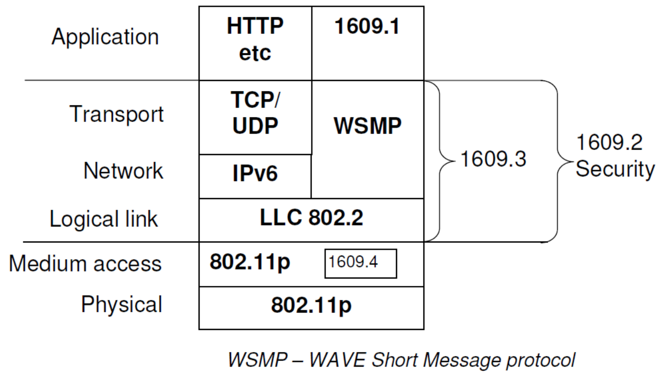

Figure 3: IEEE 802.11p and IEEE 1609 protocol family in the communication protocol stack

Center Frequency	5.860 Ghz	5.870 Ghz	5.880 Ghz	5.890 Ghz	5.900 Ghz	5.910 Ghz	5.920 Ghz
EU regulatory channel number	1	3	4	5	6	7	9
US regulatory channel number	172	174	176	178	180	182	184
IEEE channel number	172	174	176	178	180	182	184
EU Allocation	SCH	SCH	SCH	SCH	CCH & SfCH	SCH	SCH
US Allocation	SfCH	SCH	SCH	CCH	SCH	SCH	SfCH

SCH: Service Channel CCH: Control Channel SfCH: Safety Channel

Figure 4: Frequencies and channels allocated for VANET in the U.S and EU

The 75 MHz of bandwidth in the 5.9 GHz (5850-5925 MHz) has been allocated for Intelligent Transportation Systems (ITS) in the U.S. [26] and 70 MHz bandwidth in the same spectrum has been allocated in E.U. (between 5855-5925 MHz)[27]. Channel allocations vary in US and EU [27, 28, 29]. As shown in Figure 4, allocated bandwidth is divided into seven channels of 10 MHz forming one control and six service channels in U.S. and E.U. regulations [29]. The control channels is located in the middle and is used for control and safety messaging. The service channels are used for messaging by non-safety applications after coordination in the control channel.

2.2. VANET Applications

Applications are categorized or classified in various ways and number of groups in the literature. Willke et al. [30] define four types of applications according to the aim of the application; General Information Services, Vehicle Safety Information Services, Individual Motion Control and Group Motion Control. Karagiannis et al. [31] categorizes into three as 1) Active road safety applications, 2) Traffic efficiency and management applications and 3) Infotainment applications. A more glimpse and catchy classification has been defined in [32] as shown in Figure 5. In [32], applications in VANETs are generally classified as safety or non-safety applications. Safety applications include safety-critical applications sub-categorized as situation awareness applications and safety messaging applications. Non-safety applications include the applications for comfort driving, enhancing the driving process and traffic information systems, which do not present any safety or life-critical requirements.

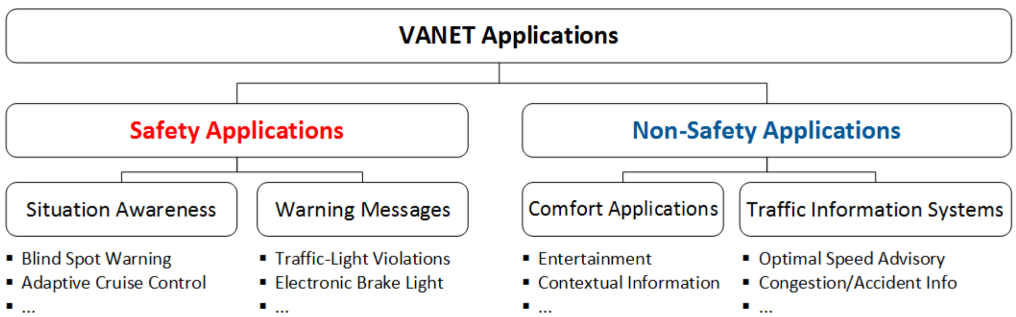

Figure 5: Classification of the VANET Applications [32]

3. VEHICULAR CLOUD INFRASTRUCTURE

Smart cities call for a new business model for vehicular communications where the vehicles can join a pool of resources and/or offer their resources as service. With the advent of cloud computing paradigm, offloading local resources and rapidly accessing to a shared pool of resources have appeared as a feasible solution to accelerate computing and storage services. Basically, a vehicular cloud is formed by incorporating cloud-based services into vehicular networks. Thus, Computing-as-a-Service (CompaaS), Storage-as-a-Service (STaaS), Network-as-a-Service (NaaS) [33], Cooperationas-a-Service, (CaaS) [34], Entertainment-as-a-Service (ENaas), Information-as-a-Service (INaaS) [35], and Traffic Information-as-a-Service (TIaaS) can be received via vehicular clouds. In [36], the authors model a vehicular cloud as a data center with mobile hosts that have limited computing and/or storage capability. Migration from the conventional VANET model towards the vehicular cloud model enables the vehicular divers to access mobile cloud resources rapidly based on the pay as you go fashion.

As shown in Figure 6, vehicular cloud infrastructure can be static or dynamic whereas the applications in a vehicular cloud system are various. Some of these applications can be listed as management of parking lots, real time traffic management, safety, and typical cloud computing applications. In the static implementation of a vehicular cloud, computing resources of a group

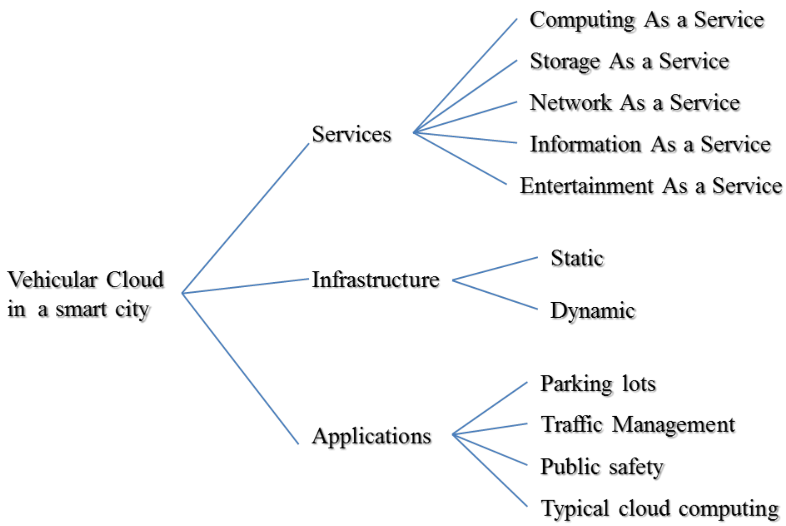

Figure 6: Vehicular Cloud System Design in a smart city

of vehicles that remain fixed at a specific geographic location for a reasonable amount of time are pooled in a data center-like structure. ”Data center in a parking lot” is a typical application of this kind of implementation. Indeed, the parking lot application is very similar to the static cloud data center implementation where servers are always switched on unless they are idle. The only difference between the parking lot implementation and the cloud data center is the limited computing an storage capability of the data center in a parking lot.

Dynamic implementation of a vehicular cloud system can be formed by a pool of computing/storage/communication resources in mobile vehicles, that are interconnected via VANET infrastructure and further linked to the Internet via roadside units. In the dynamic implementation, incorporating the roadside units in the vehicular cloud infrastructure improves the manageability of mobile hosts (i.e., computing resources in vehicles) [37]. As mentioned in [36], a vehicular cloud system should ideally utilize the underlying VANET infrastructure and minimize the involvement of RSUs.

Vehicular cloud computing architectures consists three segments vehicle-unit, communication and cloud (see Figure 7). The vehicle-unit segment retrieve the vehicle information through various sensors to monitor vehicle pressure, temperature and driver characteristics [38]. These information are transmitted to cloud for storage purpose. Communication segment of Vehicular cloud operates with Vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) systems. V2V uses DSRC protocol [39, 40] and uses Emergency Warning Messages (EWMs) to monitor abnormal behavior of road, sudden direction change, speed limit or major problem inside vehicle and eventually propagates to store in cloud and neighbor vehicles. V2I exchange information through 3G, Internet or satellite and improve the safety standards and performance of the vehicular network [41].

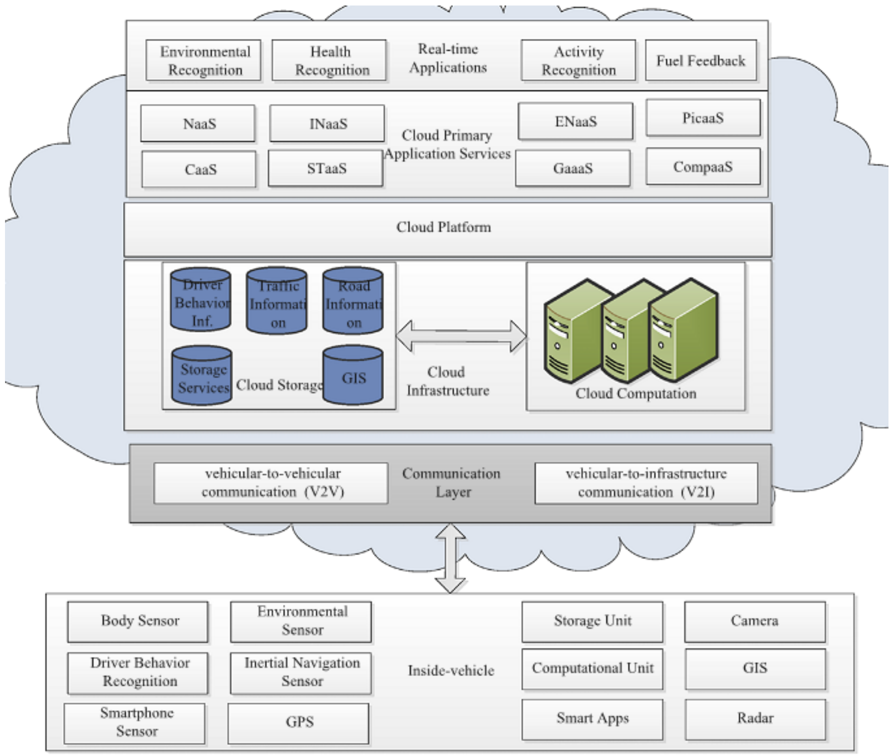

Figure 7: Vehicular cloud computing architecture [40]

The cloud layer ensures data aggregation and data mining techniques in cloud storage. The storage information is used on various research study to meet safety and quality demand of smart city. Cloud primary services are applications in real-time as Network as a services (NAAS), Entertainment (ENAAS) and Storage services (SNAAS). Cloud storage and cloud computation segments are infrastructure for vehicular cloud. Information which is retrieved through vehicle-unit is stored in Cloud storage. Cloud computation part is used to compute data based on storage and real-time data.

In [42], VANET-based clouds are classified in three groups as shown below:

- *Vehicular clouds* are formed by the VANET infrastructure, gateways and brokers. This architecture is similar to the dynamic vehicular clouds mentioned above. The brokers are called authorized entities, and they are elected by the vehicles which join the cloud. Election of the authorized entities also forms the boundary of the cloud as the elected authorized entities send invitation messages to other vehicular nodes within the boundary to join the cloud. The higher authorities (i.e., broker cum gateway) authorize the brokers to pool resources for the cloud in case the number of participating vehicular nodes is higher than a certain threshold.

- *VANETs using clouds* is the vehicular cloud architecture where VANETs access the Internet cloud via gateways on the move. Services provided by this type of cloud are real time traffic information, roadside help and infotainment.

-*Hybrid vehicular clouds* combine the two approaches above. Thus, a vehicular node can join a vehicular cloud as a service provider while at the same time, they can access the Internet cloud via gateways. P2P file sharing and/or IaaS are good examples of hybrid vehicular clouds where vehicles rent their resources intermittently. A specific type of hybrid vehicular clouds, namely the service centric contextualized vehicular cloud is illustrated in Figure 8 along with the corresponding system architecture.

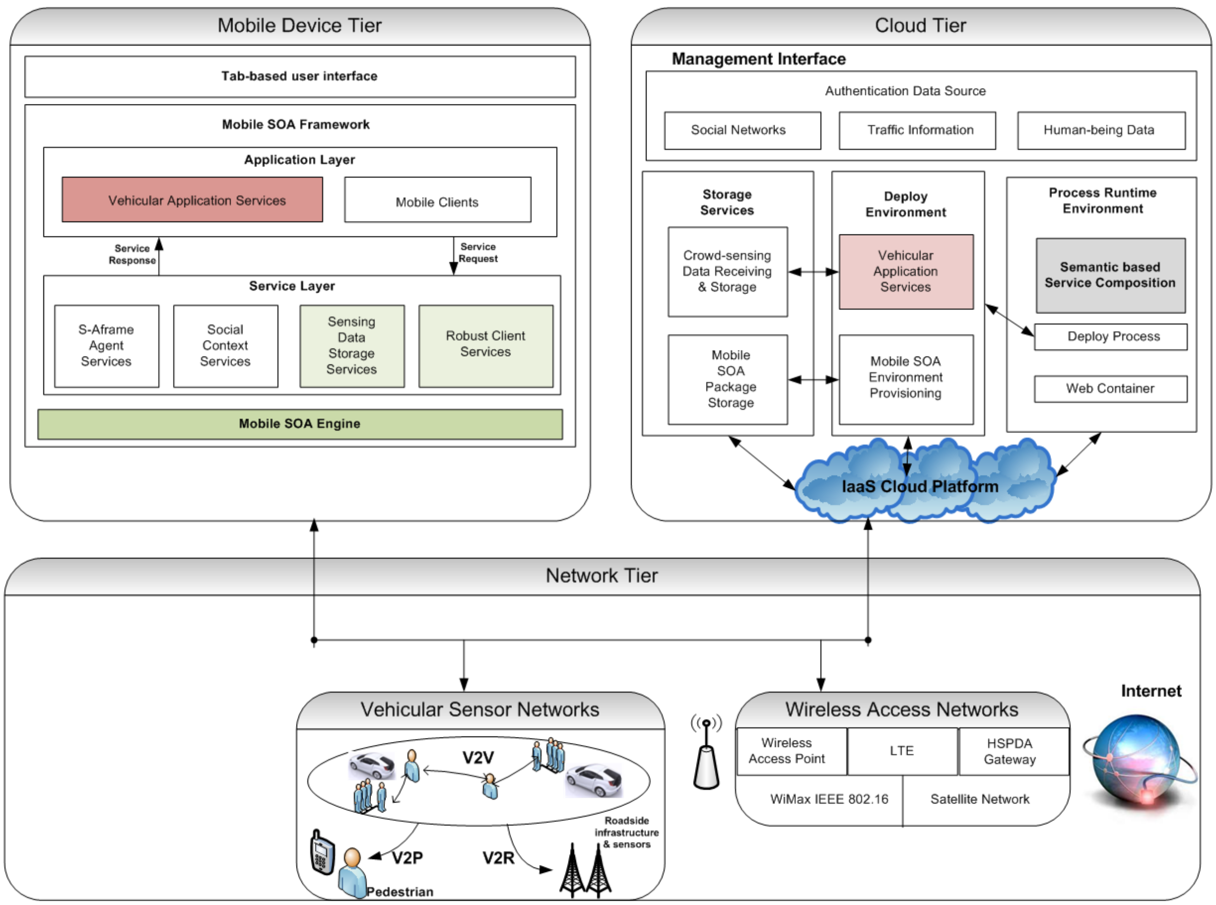

Figure 8: System architecture of Service Centric Contextualized Vehicular (SSCV) cloud [7]

As a vehicular cloud system is said to be a variant of a conventional cloud data center with mobile hosts (i.e., intermittent on/off switching), virtualization is the key component to maximize resource utilization and isolate services provided to different users or groups. Virtual machine (VM) placement [43] is the mapping of virtual resources allocated to given service requests to physical resources. VM placement in a vehicular cloud is mostly application-driven. Real time navigations run data mining functions, and they mostly run on roadside clouds due to enhanced computing capability. Roadside clouds can also provide VM hosting for distributed storage for video surveillance. Furthermore, downloading large files in a cooperative manner requires VM hosting in the roadside clouds. Virtual machine mapping schemes that are proposed for conventional data centers can be adopted whereas migration of VMs is a crucial issue.

In the conventional cloud data centers, virtual machines can be migrated between physical hosts due to several reasons such as energy saving, maintenance, efficiency, hot-spot prevention and so on [43]. In a vehicular cloud, the factors that trigger VM migration are various and mostly mobility-driven as the physical hosts rapidly change their location. Therefore, connected vehicles as physical hosts of the VMs in a vehicular cloud system experiences VM management as an ongoing challenge. In Section 5, ongoing works and preliminary research findings in the literature will be summarized along with potential applications.

4. VANET CHALLENGES AND SOLUTIONS IN SMART CITIES

VANETs have become unique solution for implementation safety and security standard for transportation system. This intelligent transportation system (ITS) not only standardizes/improvises the overall road safety but also it makes vehicle driving more comfortable and stress-less. With the combination of Road Side Units (RSU) and smart vehicles the traffic incidents and laws can be monitored by local and centralized system. Under the circumstances, challenges and solutions of VANETs are important aspects for smart cities.

4.1. Smart Driving

The major concerns of enabling ITS based smart cities are to introduce a city with safe road and green environment with optimized energy. Bifulco et al [44] have addressed the 2020 ambition of Europe with efficient and sustainable energy utilization. According to the study of Kley et al [45] one of the solution to achieve the goal will be introducing electric vehicles with modern intelligent transportation systems. In addition, Bifulco et al mentioned the concept of smart driving which have been experimented through the projects of Microsoft in San Francisco, Accenture in Amsterdam and IBM in Singapore to build smart cities. For smart transportation Microsoft launched smart parking in 2004 in Bay Area of San Francisco. With combination of geo-referencing and Windows Azure; Microsoft research utilizes real time data on transportation system and traffic flow.

One of the interesting characteristics of VANET is to provide real time update to drivers. However, VANET equipped vehicles and smart cars are extremely limited in present transportation system of smart cities. Google is collaborating with open automotive alliances (OOA) [46] to bring Android platform in vehicles. Smart parking solutions like Parker [47] and Apparcar [48] assist drivers to identify easily about nearby parking places. Moreover, mobile application like Waze [49] can assist to trace traffic status of particular region. VANETs can contribute to avoid possible accident by motion and change detection of vehicles. Apparently, instant roadside curves and damages are passed through car to car to assist the drivers. Special scenarios e.g. Ambulance, Fire brigade vehicles can pass the emergency message to surrounding vehicles and roadside units to create space for vehicles.

A grand challenge of VANETs is to pass this sort of application information from vehicle to vehicle and enhance the real-time collaboration of vehicular network with efficiency.

4.2. Safety Challenges

Traffic law violations have a major impact on road safety of smart cities. Specially, speed, tailgate and fitness issues are primarily being monitored to ensure road safety standard. Moreover, unregistered and law violating vehicles have impact to create major security threats with privacy intruding and profile hacking.

Existing solutions for VANET safety are primarily based on trusted third parties (TTP) or proxies [50, 51]. Barba et al have introduced a protocol for VANET which is able to report traffic violation anonymously.

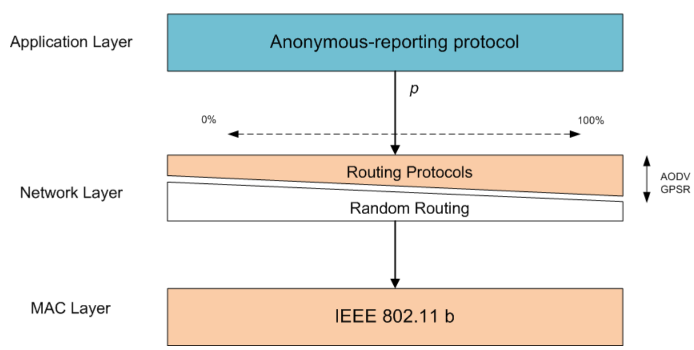

Figure 9: Barba et al consider standard protocols in conjunction with their proposed approach that is an anonymously reporting protocol [50].

The protocol chooses next forwarding route randomly by maintaining privacy anonymousness and uses a forward probability measurement (Figure 9). For privacy, the protocol operates in application layer while reporting to next hop being anonymous for privacy. The approach considers 802.11b MAC protocol and other routing protocol e.g. AODV, GPSR during communication.

4.3. Management Challenges and Clustering Solutions

There are several clustering algorithms proposed to address the challenges of VANET clouds. One good clustering algorithm for VANETs should form fewer clusters to ease maintenance and stability. A fuzzy clustering-based vehicular cloud architecture (Fcvca) has been proposed in [52] with a new clustering technique to group vehicles. In the paper, authors propose a new

3-step approach for estimation of traffic volume in a particular road segment. Initially traffic information has been collected from different clusters with the help of the proposed clustering algorithm. With a virtual chain among clusters this information is transmitted towards the roadside cloud. The virtual chain is used to meet the connectivity demand between clusters with RSU as RSUs have limited transmission range. Later, the total traffic volume has been calculated with a generalization method from the collected data. In the simulation, the proposal has been tested with performance metrics of inter-vehicle distance, density and ow rate. Flow rate is the amount of nodes crossing particular road segment within specific time. The metrics used for simulation environment are duration of cluster head and amount of clusters. Within the similar environmental scope, the proposed algorithm is compared with Lowest-ID [53] and MCMF [54] techniques. According to comparison result, it has been reported that the proposed approach can construct higher number of stable clusters. Authors also measured the quality of volume estimation for the evaluation of the traffic volume estimation accuracy in their approach. While the scheme is compared with online learning, weighted support-vector regression (OLWSVR), the proposed method performs better in terms of low, mid or high flow rates. Thus this proposed scheme has been illustrated with reduced amount of cluster formation in comparison with Lowest-ID and MCMF approaches.

Arkian et al [55] have proposed another clustering technique to solve the resource limitation problem by cooperatively providing the resources in vehicular cloud. The scheme focuses to create clusters with flexibility and to select a cluster head using the fuzzy logic. Fuzzy logic is a decision making process based on input membership functions which operates similarly to the human brain. To improve the efficiency of cluster head decisions, a Q-Learning based service provider selection has been introduced in this scheme. With Q-learning, each cluster head maintains a two-dimensional Q-table and periodically updates the Q-table to improve actions. In addition, three queuing strategies have been considered for resource allocation in Virtual cloud for efficiency, quality of service and fairness. While comparing with Lowest-ID and user-oriented fuzzy logic-based clustering Scheme [56], the simulation study refers a better performance of proposed COHORT clustering approach. The simulation results also demonstrate that proposed COHORT clustering have significant impact to reduce service discovery delays and service consuming delays in comparison with CROWN. CROWN (discovering and consuming services within vehicular clouds) [57] is a system that enables vehicles in a VANET to search for mobile cloud servers that are moving nearby and discover their services and resources. The system uses RSUs for cloud directories to registers the mobile cloud servers. Within a specific zone, RSUs distributes their registration data to vehicles to discover and act as mobile cloud server.

The proposed system is later evaluated in NS2 to measure performance service discovery and service consuming delays and packet success ratio. The result of CROWN is compared with a broadcasting-based protocol. CROWN is the one of the pioneer cloud service discovery protocol proposed for vehicular clouds.

4.4. Emergency and Disaster Recovery

VANETs have important role for message propagation during emergency situation and disasters as cyclone, earthquake, fire, volcano etc to reduce loss of life and resources. It has been noted that message dissemination during the crisis or disaster is one of the key challenges for future research in this area. Alazawi et al [58] have proposed a system by utilization of VANETS, cloud computing and mobile technologies which is based on the transportation of Ramadi city. The system is able to retrieve real-time data and utilize the connectivity in between mobile and social networks with VANETs. Moreover the system can monitor traffic information with proper signaling and route map and analysis the impact of the information through data analysis. Through VANETs and cloud based intelligent approach data can be retrieved automatically, with proper analysis of the propagated message.

In a smart city vehicular network, emergency service solution is a new research direction. Amici et al [59] have introduced a routing protocol where real traffic scenario is collected through 370 taxi cab every 7 seconds in the city of Rome. Thus cabs are connected throughout the city without the utilization of 3G/4G network infrastructure. From the real traffic data the protocol can trace particular vehicle which is able to identify the emergency situation,which is termed as infected vehicle. The vehicle propagates the message to other participants of the network. Considering the average speed and wait time in real traffic scenario, the message can propagate throughout the network.

5. VEHICULAR CLOUDS CHALLENGES AND SOLUTIONS IN SMART CITIES

As vehicular clouds are envisioned to be widely adopted in smart cities several challenges have to be adopted [60]. Most of the studies identify security and trust issues as the grand challenge in vehicular clouds. Due to mobility of vehicles and intermittency of short range communication links makes the definition of trust relations authorization of mobile vehicular nodes rather complex than conventional VANETs [61]. Indeed, provisioning delay in such an environment is also a big concern due to the same factors as mentioned in [62]. As there are multiple service providers, privacy preserving in the intermittent contracts between the vehicular nodes and the service providers have to make sure that reveal of private information should be minimal. Besides, virtualization-based challenges remain in vehicular clouds as VM migration on the move is inevitable in an IaaS scenario where vehicular nodes are mobile [36].

5.1. Security in vehicular clouds

Security challenges in VANETs and cloud computing are inherited by vehicular clouds as mentioned in [42]. These challenges have been studied in detail in [63, 64, 65]. These studies can be improved by taking the specific conditions and requirements of vehicular clouds into consideration. In [61], the authors summarize these challenges as spoofed identities, non-repudiation, Denial of Service (DoS) attacks, and mobile authentication. Yan et al. have proposed a security framework that addresses most of these challenges [63]. The main targets for an adversary are reported as confidentiality of VMs in the vehicular cloud, integrity of the content that is stored in a distributed manner, and the availability of physical machines, resources, services and applications in the vehicular cloud. Based on these three targets, a typical attack scenario has been defined as follows: The geographic location of the victim vehicle is identified and possible physical hosts (i.e., vehicular nodes) in the vicinity are discovered where the victim vehicle is possibly being served. The vehicular node that serves the victim vehicle is discovered upon submitting several service requests to the cloud. Once the VM that is allocated to the victim is identified, services are requested on the same host. Finally higher privilege is aimed to be obtained to collect assets via system leakage. This type of attack is inspired from the attacks that explore information leakage in the clouds [66]. While authenticating the nodes with high mobility, it is not viable to use well-known metrics such as ownership, knowledge and biometrics. Furthermore, Sybil-like attacks are always possible in such an information network [67].

In [63], the authors propose building trust relationship between vehicle clusters. It is essential that the behavior of a vehicle in a cluster can be monitored by all members in the same cluster. Besides, for mission critical applications in a vehicular cloud, the authors propose geographic location-based security. Thus, when a ciphertext is sent by a vehicle, only vehicles in a certain area are authorized to access the ciphertext and the corresponding decryption key. Figure 10 illustrates a scenario that is presented in [63]. A group of cars communicate with the cloud that provides service to the clients at a naval base. Once a message is encrypted and sent out to the cloud, only vehicle-a can access the ciphertext and the decryption key.

As the cloud topology changes dynamically, based on the number of vehicles, security strategy of the vehicular cloud may need to be reconfigured. The idea behind this is that the higher the number of vehicles involved, the stricter the security protocols should get. Hence, the authors propose a queuing theory-based mode to predict the volume vehicles in the vehicular

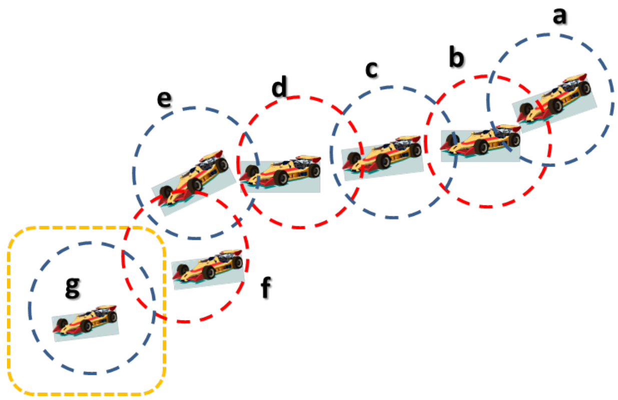

Figure 10: Geographic security approach presented in [63]. The square is a securely protected area (e.g., military headquarter). Only vehicle-g can access the ciphetext sen by vehicle-a

cloud. Increasing volume of the vehicles in the cloud introduces the scalability problem for the security schemes. To cope with the scalability issue, each VM is divided into sub-VMs when the number of accesses to the VM exceeds a pre-defined threshold. The VM allocates the resources of an incoming request to the sub-VMs in order to fulfill the load balancing requirements. A VM middleware serves like a resource broker; it caches the recent accesses and usage information. Whenever a new request arrives, the sub-VMs are allocated based on the recent usage and load balancing among the sub-VMs.

The authors in [68, 69] propose a pseudonym system by introducing anonymous public keys and the public key infrastructure (PKI). Despite the efficiency of the PKI-based framework, certification of the public key may lead to latency while there exists a trade-off between the frequency of updating the public key certification and communication overhead.

5.2. Privacy and user experience in vehicular clouds

Privacy is a major concern for cloud users due to virtualization-based vulnerabilities where sensitive information can be revealed to adversaries [70, 71]. The authors in [72, 73] present the benefits of mobile cloud computing in a vehicular cloud environment while presenting the privacy and security challenges of a vehicular cloud environment in detail. Existing privacy considerations for cloud systems and VANETs [68, 64, 65] can be adopted by vehicular clouds however special requirements of vehicular clouds have to be taken into consideration.

Anastasopoulou et al. [74] use game theory-based solutions to improve privacy of cloud-based mobile apps. The proposed methodology analyzes the user interactions, and makes a compromise between the quality of service in the cloud and user privacy.

Recently, Aloqaily et al. have defined privacy as a component of a function denoting user experience [75]. Moreover, the authors propose a hierarchical framework where multiple cluod providers and multiple trusted third parties exist. To this end, the authors formulate a weighted sum of provisioning delay, the amount of information reveal and the service cost of each trusted third party-cloud provider tuple. Three key factors have been considered for vehicular clouds. This solution employs a Trusted Third Party (TTP) between the vehicular nodes and the Service Providers (SPs). To ensure scalability and to cope with computation overhead, a hierarchical clustered architecture is used. Service requirements of the vehicular users determine the best TTPs.

The benefit of the QoE-based architecture is reported as the vehicle node's ability to prioritize its preferences on latency, price and information revealed to the SP. With the adjustment of the coefficients, the vehicular nodes can be served with affordable price, by revealing less information to SP and/or low latency. The output of the negotiation can be improved if the experience of previously provisioned drivers is used as an input. Furthermore the service provider cannot detect any identifier about the vehicular nodes that request service through the vehicular cloud as minimal reveal of identifying information to the SP is without disclosure of the user identities. As the user always has the flexibility of switching between SPs, dealing with the TTPs rather than trusting the SP as the user can switch to another SP in the future.

A vehicular node initially requests service from the first available TTP within its range. Upon the vehicular node-TTP matching, the TTP negotiates with the SP on behalf of the vehicular node, and the SP delivers the service to the vehicular node through the TTP. Direct feedback of the vehicular node is used to evaluate the delay, price, and privacy offered by the SP. As the vehicular node can prioritize any of these objectives, the vehicular nodes that are associated with users who are more sensitive to revealing personal information can minimize the information revealed to the SP. It is worthwhile mentioning that in such an architecture, the user credentials such as credit card/visa information are not kept with multiple SPs but within one TTP.

5.3. Virtualization-based challenges

As mentioned before, a vehicular cloud can be considered as a data center with unstable physical hosts. Therefore, virtual machine management appears to be a challenging issue in vehicular clouds. VM migration may occur when a vehicle is about to go off the grid and cannot be in range of any RSUs, or when a handover occurs between two RSUs that are in range of a vehicle. To cope with this challenge, Refaat et al. have proposed a VM migration scheme in [36]. The VM migration algorithm works as follows: Out of the nearest vehicles, the source vehicular node selects a destination vehicular node based on the search criteria. If the destination vehicular node does not have sufficient available capacity to host the VM or if the VM cannot be migrated to the destination node in a pre-defined time window, migration is re-attempted by excluding the corresponding destination. Otherwise, the VM is migrated to the destination vehicular node. A migration attempt is marked as unsuccessful is a certain number of migration attempts fail. An unsuccessful migration requires intervention of the RSU. Thus, the VM is directed to the RSU if the migration cannot be completed.

The authors have proposed two approaches against random selection of the destination vehicular node. The first approach is called the Vehicular Virtual Machine Migration with Least Workload (VVMM-LW) while the second approach is called Vehicular Virtual Machine Migration with Mobility-Awareness (VVMM-MA). The former ranks the v nearest vehicles with respect to their current workload and selects the one(s) with the lightest workload. The latter uses the vehicles' trajectories and estimates the future location of all vehicles in the vehicular cloud and excludes the ones that are forecasted to go off the grid. For those who are forecasted to remain in the grid, the algorithm runs the VVMM-LW to select the destination vehicular node to migrate the virtual machine. The authors have shown that VVMM-MA can improve the performance of random selection policy by up to 60% under highly congested traffic conditions whereas the improvement is still above 35% under lightly congested traffic scenarios.

5.4. Context-awareness

Context-awareness in a vehicular cloud is emergent for smart city applications for various reasons. In [76], the authors propose a behavior pattern recognition methodology to detect anomalies in driver behaviors, and inform the other drivers in the vicinity for their safety. On the other hand, Santa and Gmez-Skarmeta propose a context-aware information provisioning scheme for vehicle-to-vehicle and vehicle-to-infrastructure communications for road safety [77]. The vehicles are identified by the RFID technology, and by keeping track of vehicles, current traffic and road condition information is obtained as provided to all drivers in the vehicular network. Wan et al. have extended these ideas to propose a cloud-assisted context-aware architecture [60]. A multi-layer architecture is proposed for context-aware vehicular cloud implementation. The three layers are summarized below:

- *Vehicular computational layer* is the upmost layer where context-aware driver behavior detection system is implemented. The behavior detection module communicates with other vehicular nodes to share context-aware road and safety information. Furthermore, the behavior detection module also shares this information with mobile user who wish to access these services via smart phones.

-*Location computational layer* is below the vehicular computational layer, and it consists of the RSUs deployed at specific locations to exchange information with onboard equipment units.

Thus, whenever a vehicle is outside the range of a vehicular network, it can still access the roadside information via RSUs. The location computational layer is connected to the Internet and receives service from the cloud computational layer.

-*Cloud computational layer* provides context-aware cloud services through interconnected clouds of automative multimedia content cloud, traffic authority cloud, location-based service cloud automative manufacturer cloud and other application clouds. This layer provides context-aware cloud services to vehicular drives, traffic authorities or vehicular social networks.

As mentioned above, vehicular social networks and context-aware vehicular security are two key components of this architecture. Vehicular social networks are envsioned to be an inseparable part of vehicular clouds they will primarily serve for traffic data mining and mobile crowd sensing [60]. Context-awareness in vehicular security is necessary to reconfigure the security policies based on the changes in the user's context. The authors have proposed a context-aware vehicular security framework that consists of data collection, policy management, anomaly detection and trust management modules. Data collection module collects data such as time, road conditions, velocity, that would reveal context information. The context information is passed to the policy management, anomaly detection and trust management modules. When an anomaly is detected, the trust management unit assesses the trustworthiness of the vehicular node that has been detected to have misbehaved. The authors showed that if context-aware vehicular cloud framework is adopted as an alternative to the traditional traffic routing, travel times can be reduced by around 50% as the distance travelled increases.

6. OPEN ISSUES AND FUTURE DIRECTIONS IN VEHICULAR SMART CITY SYSTEMS

Vehicular networks still experience several challenges that have to be addressed before they are widely adopted by smart cities. As mentioned above, VANETs operate on a mature communication infrastructure however VANETs can be enhanced by incorporating cloud-inspired operational model as the data collected is huge and needs to be analyzed, interpreted and communicated. Therefore vehicular clouds in smart cities need novel and effective solutions for virtual machine management, vehicular node security, vehicular driver's privacy and context-aware services via mobile crowdsensing over vehicular social networks.

Vehicular VM management calls for novel solutions that fulfill service quality requirements. Moreover, migration efficiency is still an open issue, thus new algorithms to ensure minimum VM migration latency and minimum service disruption. Furthermore virtualization-based vulnerabilities have to be addressed in vehicular VM management and migration.

As security and privacy are the grand challenges in any cloud system, vehicular clouds have to incorporate robust solutions to avoid unauthorized access to the vehicular resources. Anomaly Introducing anomaly detection-based continuous authorization techniques into existing authorization schemes will improve robustness of vehicular clouds. Indeed, anomaly detection will require analysis of massive amount of unstructured data. Therefore, cloud-based big data analytics solutions will have to be integrated into the cloud computational layer in a multi-layered vehicular cloud architecture. While behavior analysis and anomaly detection will improve security, due to computing overhead, degradation in service quality should be expected. Hence, the researchers working in this field should also address the trade-off between security-privacy and service quality.

Vehicular social networks (VSNs) is another emerging field to accelerate the performance of vehicular clouds. VSNs can help vehicular clouds make use of crowdsensed data. Having said that, mobile cloud-basd crowdsensing systems experience several challenges. As reported in [78], injection of specious information into crowdsensed data may introduce public safety vulnerabilities in case of an emergency [79]. Trustworthy crowdsensing schemes [78] can be enhanced by new trust derivation models [80]. As mentioned above, Sybil attacks threaten the lifetime and the reliability of the vehicular cloud; hence VSNs call for behavior recognition-based Sybil detection techniques to improve the robustness of the vehicular cloud.

7. SUMMARY

Connected vehicles have various application areas in future smart cities. Having an established communication infrastructure and standards, VANETs can be adopted in these applications. However, due to continuously increasing demand for computation, storage and communications, a cloud inspired model is required for vehicular networks. This chapter has provided a survey of vehicular networks for smart city applications, and presented an overview of the studies that pave the way towards implementation of vehicular clouds in smart cities. To this end, the chapter has prsented the VANET architecture and the vehicular cloud architectures utilizing the VANET infrastructure. Then the challenges and solutions in VANETs and vehicular clouds for smart cities have been presented in detail. The chapter has also dedicated one section to discuss future directions and still open issues in this topic.

REFERENCES

[1] GregoryS. Yovanof and GeorgeN. Hazapis, "An architectural framework and enabling wireless technologies for digital cities & intelligent urban environments," *Wireless Personal Communications*, vol. 49, no. 3, pp. 445–463, 2009.

[2] Taewoo Nam and Theresa A. Pardo, "Conceptualizing smart city with dimensions of technology, people, and institutions," in *Proceedings of the 12th Annual International Digital Government Research Conference: Digital Government Innovation in Challenging Times*, New York, NY, USA, 2011, dg.o '11, pp. 282–291, ACM.

[3] Rudolf Giffinger and Haindlmaier Gudrun, "Smart cities ranking: an effective instrument for the positioning of the cities?," *ACE: Architecture, City and Environment*, vol. 4, no. 12, pp. 7–26, 2010.

[4] Doug Washburn and Usman Sindhu, "Helping CIOs Understand "Smart City" Initiatives. Defining The Smart City, Its Drivers, And The Role of The CIO," *Forrester*, 2010.

[5] M. Gerla, Eun-Kyu Lee, G. Pau, and Uichin Lee, "Internet of vehicles: From intelligent grid to autonomous cars and vehicular clouds," in *Internet of Things (WF-IoT), 2014 IEEE World Forum on*, March 2014, pp. 241–246.

[6] Euisin Lee, Eun-Kyu Lee, M. Gerla, and S.Y. Oh, "Vehicular cloud networking: architecture and design principles," *Communications Magazine, IEEE*, vol. 52, no. 2, pp. 148–155, February 2014.

[7] Xiping Hu, Lei Wang, Zhengguo Sheng, Peyman TalebiFard, Li Zhou, Jia Liu, and Victor C.M. Leung, "Towards a service centric contextualized vehicular cloud," in *Proceedings of the Fourth ACM International Symposium on Development and Analysis of Intelligent Vehicular Networks and Applications*, New York, NY, USA, 2014, DIVANet '14, pp. 73–80, ACM.

[8] Research and Innovative Technology Administration (RITA) U.S. Department of Transportation (US DOT), "About ITS," [Online] http://www.its.dot.gov/faqs.htm, 2015.

[9] T. Taleb, E. Sakhaee, A. Jamalipour, K. Hashimoto, N. Kato, and Y. Nemoto, "A stable routing protocol to support its services in vanet networks," *IEEE Transactions on Vehicular Technology*, vol. 56, no. 6, pp. 3337–3347, Nov 2007.

[10] F. Losilla, A.J. Garcia-Sanchez, F. Garcia-Sanchez, and J. Garcia-Haro, "On the role of wireless sensor networks in intelligent transportation systems," in *Transparent Optical Networks (ICTON), 2012 14th International Conference on*, July 2012, pp. 1–4.

[11] Yi Yang and Rajive Bagrodia, "Evaluation of vanet-based advanced intelligent transportation systems," in *Proceedings of the Sixth ACM International Workshop on VehiculAr InterNETworking*, 2009, pp. 3–12.

[12] Hannes Hartenstein and Kenneth P. Laberteaux, *VANET: Vehicular Applications and Inter-Networking Technologies*, John Wiley Sons, Jan. 2010.

[13] Uichin Lee and Mario Gerla, "A survey of urban vehicular sensing platforms," *Computer Networks*, vol. 54, no. 4, pp. 527 – 544, 2010, Advances in Wireless and Mobile Networks.

[14] Mario Gerla and Leonard Kleinrock, "Vehicular networks and the future of the mobile internet," *Computer Networks*, vol. 55, no. 2, pp. 457 – 469, 2011, Wireless for the Future Internet.

[15] N. Wisitpongphan, Fan Bai, P. Mudalige, V. Sadekar, and O. Tonguz, "Routing in sparse vehicular ad hoc wireless networks," *Selected Areas in Communications, IEEE Journal on*, vol. 25, no. 8, pp. 1538–1556, Oct 2007.

[16] "IEEE Standard for Message Sets for Vehicle/Roadside Communications," *IEEE Std 1455-1999*, pp. 1–134, Sept 1999.

[17] "IEEE 802.11p, ieee 802.11p, Amendment to Standard for Information Technology-Telecommunications and Information Exchange Between Systems-Local and Metropolitan Area etworks-Specific requirements Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications-Amendment 7: Wireless Access in Vehicular Environment," *IEEE Std. IEEE 802.11p, version 2010*, 2010.

[18] Draft Guide for Wireless Access in Vehicular Environments (WAVE) Architecture IEEE P1609.0, ," .

[19] IEEE Std 1609.2 2013 Standard for Wireless Access in Vehicular Environments (WAVE) Security Services for Applications and Management Messages, ," 2013.

[20] IEEE Std 1609.3 2010 Standard for Wireless Access in Vehicular Environments (WAVE) Networking Services, ," 2010.

[21] IEEE Std 1609.4 2010 Standard for Wireless Access in Vehicular Environments (WAVE) Multi-Channel Operations, ," 2010.

[22] Draft IEEE P1609.6 Remote Management Services, ," .

[23] IEEE Std 1609.11-2010 Over the-Air Data Exchange Protocol for Intelligent Transportation Systems (ITS), ," 2010.

[24] IEEE Std 1609.12 2012 Identifier Allocations, ," 2012.

[25] Research and Innovative Technology Administration (RITA) U.S. Department of Transportation (US DOT), "Fact Sheet on IEEE 1609 - Family of Standards for Wireless Access in Vehicular Environments (WAVE)," [Online] http://www.standards.its.dot.gov/Factsheets/PrintFactsheet/80.

[26] 371 377: Regulations governing the licensing FCC 47 CFR 90 Telecommunications, Private land mobile radio services and use of frequencies in the 58505925 MHz band for dedicated short-range communications service (DSRCS), ," .

[27] ETSI EN 302 571 V1.2.1 (2013-09), "Intelligent Transport Systems (ITS); Radiocommunications equipment operating in the 5 855 MHz to 5 925 MHz frequency band," September 2013.

[28] ETSI Standard (Draft), "Intelligent transport systems (its); access layer specification for intelligent transport systems operating in the 5 ghz frequency band," *ETSI EN 302 663 V1.2.0 (2012-11)*, 2012.

[29] Status of ITS Communication Standards Document HTG3-1 Version: 2012-11-12, ," *EU-US ITS Task Force Standards Harmonization Working Group Harmonization Task Group 3*, November 12 2012.

[30] T.L. Willke, P. Tientrakool, and N.F. Maxemchuk, "A survey of inter-vehicle communication protocols and their applications," *Communications Surveys Tutorials, IEEE*, vol. 11, no. 2, pp. 3–20, Second 2009.

[31] G. Karagiannis, O. Altintas, E. Ekici, G. Heijenk, B. Jarupan, K. Lin, and T. Weil, "Vehicular networking: A survey and tutorial on requirements, architectures, challenges, standards and solutions," *Communications Surveys Tutorials, IEEE*, vol. 13, no. 4, pp. 584–616, Fourth 2011.

[32] Christoph Sommer and Falko Dressler, *Vehicular Networking*, Cambridge University Press, Dec. 2014.

[33] S. Arif, S. Olariu, J. Wang, G. Yan, W. Yang, and I. Khalil, "Datacenter at the airport: Reasoning about time-dependent parking lot occupancy," *IEEE Transactions on Parallel and Distributed Systems*, vol. 23, pp. 2067–2080, Nov. 2012.

[34] H. Dinh, C. Lee, D. Niyato, and P. Wang, "A survey of mobile cloud computing: Architecture, applications and approaches," *Wireless Communications and Mobile Computing*, vol. 13, pp. 1587–1611, Aug. 2013.

[35] H. Mousannif, I. Khalil, and H. al Moatassime, "Cooperation as a service in vanets," *Journal of Universal Computer Science*, vol. 17, pp. 1202–1218, Aug. 2011.

[36] T.K. Refaat, B. Kantarci, and H.T. Mouftah, "Dynamic virtual machine migration in a vehicular cloud," in *IEEE Symposium on Computers and Communication (ISCC)*, June 2014, vol. Workshops, pp. 1–6.

[37] S. Olariu, T. Hristov, and G. Yan, "The next paradigm shift: From vehicular networks to vehicular clouds," *in Mobile Ad Hoc Networking, John Wiley and Sons Inc.*, . 2013.

[38] Tein-Yaw Chung, Yung-Mu Chen, and Chih-Hung Hsu, "Adaptive momentum-based motion detection approach and its application on handoff in wireless networks," *Sensors*, vol. 9, no. 7, pp. 5715, 2009.

[39] Xue Yang, Jie Liu, N.F. Vaidya, and Feng Zhao, "A vehicle-to-vehicle communication protocol for cooperative collision warning," in *Mobile and Ubiquitous Systems: Networking and Services, 2004. MOBIQUITOUS 2004. The First Annual International Conference on*, Aug 2004, pp. 114–123.

[40] Md Whaiduzzaman, Mehdi Sookhak, Abdullah Gani, and Rajkumar Buyya, "A survey on vehicular cloud computing," *J. Netw. Comput. Appl.*, vol. 40, pp. 325–344, Apr. 2014.

[41] Lawson Bordley, Christopher R Cherry, Denny Stephens, Robert Zimmer, and Joseph Petrolino, ""commercial motor vehicle wireless roadside inspection pilot test, part b: Stakeholder perceptions"," *Transportation Research Board 91st Annual Meeting*, 2012.

[42] R. Hussain, J. Son, H. Eun, S. Kim, and H. Oh, "Rethinking vehicular communications: Merging VANET with cloud computing," in *IEEE 4th International Conference on Cloud Computing Technology and Science)*, Dec. 2012, pp. 606–609.

[43] Boutaba R., Q. Zhang, and M. F. Zhani, "Virtual machine migration in cloud computing environments: Benefits, challenges, and approaches," in *Communication Infrastructures for Cloud Computing*, H. T. Mouftah and B. Kantarci, Eds., pp. 383 – 408. IGI Globa, Hershey, PA, 2013.

[44] F. Bifulco, C. Amitrano Cristina, and M. Tregua, "Driving Smartization Through Intelligent Transport," *Chinese Business Review*, vol. 13, pp. 243–259, 2014.

[45] Fabian Kley, Christian Lerch, and David Dallinger, "New business models for electric carsa holistic approach," *Energy Policy*, vol. 39, no. 6, pp. 3392 – 3403, 2011.

[46] Open Automotive Alliance, ," [Online] http://openautoalliance.net.

[47] Parker Application, ," [Online] http://theparkerapp.com/.

[48] Aparcar Application, ," [Online] http://aparcar.com/.

[49] Waze Application, ," [Online] https://www.waze.com/.

[50] Carolina Tripp Barba, Luis Urquiza Aguiar, Mnica Aguilar Igartua, Javier Parra-Arnau, David Rebollo-Monedero, Jordi Forn, and Esteve Pallars, "A collaborative protocol for anonymous reporting in vehicular ad hoc networks," *Computer Standards and Interfaces*, vol. 36, no. 1, pp. 188 – 197, 2013.

[51] Vicente Benjumea, Javier Lopez, and Jose M. Troya, "Specification of a framework for the anonymous use of privileges," *Telematics and Informatics*, vol. 23, no. 3, pp. 179 – 195, 2006.

[52] Hamid Reza Arkian, Reza Ebrahimi Atani, Atefe Pourkhalili, and Saman Kamali, "Cluster-based traffic information generalization in vehicular ad-hoc networks," *Vehicular Communications*, vol. 1, no. 4, pp. 197 – 207, 2014.

[53] Mario Gerla and Jack Tzu-Chieh Tsai, "Multicluster, mobile, multimedia radio network," *Wireless Networks*, vol. 1, no. 3, pp. 255–265, 1995.

[54] Hrishikesh Venkataraman, Romain Delcelier, and Gabriel-Miro Muntean, "A moving cluster architecture and an intelligent resource reuse protocol for vehicular networks," *Wireless Networks*, vol. 19, no. 8, pp. 1881–1900, 2013.

[55] Hamid Reza Arkian, Reza Ebrahimi Atani, Atefe Pourkhalili, and Saman Kamali, "A stable clustering scheme based on adaptive multiple metric in vehicular ad-hoc networks," *Journal of Information Science and Engineering*, vol. 31, no. 2, 2015.

[56] I. Tal and G.-M. Muntean, "User-oriented fuzzy logic-based clustering scheme for vehicular ad-hoc networks," in *Vehicular Technology Conference (VTC Spring), 2013 IEEE 77th*, June 2013, pp. 1–5.

[57] K. Mershad and H. Artail, "Finding a star in a vehicular cloud," *Intelligent Transportation Systems Magazine, IEEE*, vol. 5, no. 2, pp. 55–68, Summer 2013.

[58] Z. Alazawi, S. Altowaijri, R. Mehmood, and M.B. Abdljabar, "Intelligent disaster management system based on cloud-enabled vehicular networks," in *ITS Telecommunications (ITST), 2011 11th International Conference on*, Aug 2011, pp. 361–368.

[59] Raul Amici, Marco Bonola, Lorenzo Bracciale, Antonello Rabuffi, Pierpaolo Loreti, and Giuseppe Bianchi, "Performance assessment of an epidemic protocol in {VANET} using real traces," *Procedia Computer Science*, vol. 40, no. 0, pp. 92 – 99, 2014, Fourth International Conference on Selected Topics in Mobile & Wireless Networking (MoWNet2014).

[60] J. Wan, Lao S. Zhang, D., L. T. Yang, and J. Lloret, "Context-aware vehicular cyber-physical systems with cloud support: Architecture, challenges, and solutions," *IEEE Communications Magazine*, vol. 52, pp. 106–113, Aug 2014.

[61] G. Yan, D. B. Rawat, and B. B. Bista, "Towards secure vehicular clouds," in *In Proc. Complex, Intelligent and Software Intensive Systems (CISIS)*, 2012, pp. 370–375.

[62] M. Aloqaily, B. Kantarci, and H. T. Mouftah, "Provisioning delay effect of partaking a trusted third party in a vehicular cloud," in *Global Information Infrastructure Symposium (GIIS)*, September 2014, pp. 1–3.

[63] G. Yan, D. Wen, S. Olariu, and M. C. Weigle, "Security challenges in vehicular cloud computing," *IEEE Transactions on Intelligent Transportation Systems*, vol. 14/1, pp. 284–294, March 2013.

[64] S. Pearson and A. Benameur, "Privacy, Security and Trust Issues Arising from Cloud Computing," in *IEEE Second International Conference on Cloud Computing Technology and Science (CloudCom)*, 2010, pp. 693–702.

[65] "Y. m. younis, k. kifaya. secure cloud computing for critical infrastructure: A survey," Liverpool John Moores University, United Kingdom, Tech. Rep, 2013.

[66] Ristenpart T., E. Tromer, H. Shacham, and S. Savage, "Hey, you, get off of my cloud: Exploring information leakage in third-party compute clouds," in *Proc. ACM Conference on Computer and Communications Security (CSS)*, Nov 2009, pp. 199–212.

[67] S. Chang, Y. Qi, H. Zhu, J. Zhao, and X. Shen, "Footprint: Detecting Sybil Attacks in Urban Vehicular Networks," *IEEE Transactions on Parallel and Distributed Systems*, vol. 23/5, pp. 1103–1114, June 2012.

[68] M. Raya and J. P. Hubaux, "The security of vehicular ad hoc networks," in *3rd ACM workshop on security of ad hoc and sensor networks*, 2005, pp. 1–11.

[69] M. Raya and J. P. Huabux, "Securing Vehicular Ad Hoc Networks," *Computer Security*, vol. 15/1, pp. 39–68, Jan 2007.

[70] A. A. Almutairi and A. Ghafoor, "Risk-aware virtual resource management for multitenant cloud datacenters," *IEEE Cloud Computing*, vol. 1/3, pp. 34–44, March 2014.

[71] Hsin-Yi T., M. Siebenhaar, A. Miede, H. Yu-Lun, and R. Steinmetz, "Threat as a service?: Virtualization's impact on cloud security," *IT Professional*, vol. 14/1, pp. 32–37, March 2012.

[72] M. Gerla, "Vehicular cloud computing," in *11th Annual Mediterranean Ad Hoc Networking Workshop (Med-Hoc-Net)*, June 2012, pp. 152–155.

[73] M. Whaidduzzaman, M. Sookhak, Ghani A., and R. Buyya, "A survey on vehicular cloud computing," *Journal of Network and Computer Applications*, vol. 40, pp. 325–344, March 2014.

[74] K. Anastasopolou, T. Tryfonas, and S. Kokolakis, "Strategic interaction analysis of privacy-sensitive end-users of cloud-based mobile apps," in *HCI2014 International-Human aspects of information security, privacy, and trust*, June 2014.

[75] M. Aloqaily, B. Kantarci, and H. T. Mouftah, "On the impact of Quality of Experience (QoE) in a vehicular cloud with various providers," in *In Proc. HONET-PFe*, Dec. 2014, pp. 1–5.

[76] S. Al-Sultan, A. Al-Bayatti, and H. Zedan, "Context aware driver behaviour detection system in intelligent transportation systems," *IEEE Transactions on Vehicular Technology*, vol. 62/9, pp. 4264–4275, Sep. 2013.

[77] J. Santa and A. Gmez-Skarmeta, "Sharing contextaware road and safety information," *IEEE Pervasive Computing*, vol. 8/3, pp. 58–65, July-Sep. 2009.

[78] B. Kantarci and H. T. Mouftah, "Trustworthy sensing for public safety in cloud-centric Internet of Things," *IEEE Internet of Things Journal*, vol. 1/4, pp. 360–368, Aug 2014.

[79] L.I. Besaleva and A.C. Weaver, "Applications of Social Networks and Crowdsourcing for Disaster Management Improvement," in *Intl. Conf. on Social Computing (SocialCom)*, Sept 2013, pp. 213–219.

[80] J. Duan, D. Gao, D. Yang, C.H. Foh, and H. Chen, "An energy-aware trust derivation scheme with game theoretic approach in wireless sensor networks for IoT applications," *IEEE Internet of Things Journal*, vol. 1, no. 1, pp. 58–69, Feb 2014.