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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 the quality of life, safety and security. Applications of vehicular networks vary from safety applications such as blind spot warning and traffic light violations to entertainment such as streaming media or convenience such as parking space identification. 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 to improve the transportation in cooperation with the Information and Communication Technologies (ICTs). VANETs are specialized form of mobile ad hoc networks (MANETs) but protocols that perform well in MANETs may not be ideal for VANETs due to high mobility, intermittent connectivity and heterogeneity. Cloud computing offers the option to offload local resources to a shared pool and can be 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 a 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 to help stimulate future studies in this emerging research field.

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

1. INTRODUCTION

Smart city and digital cities retrieve 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 an 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 such as 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 concept motivate 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, the concept of Vehicular Ad Hoc Networks or VANETs 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. Recent work in this area has resulted in established standards such as IEEE 802.11p and IEEE 1609.

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 has been proven to be in the case of MANETs.

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 its 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.

A vehicular cloud is formed by a cluster of vehicles to enhance unified communication and to enable self-organization based on 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 inter-networked for resource sharing directly in a decentralized manner. However, for the sake of computing efficiency, one vehicle might be elected as the broker that is responsible for resource allocation 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 conditions to assist paramedics to hospitalize the patients who need urgent medical care. 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 assur-

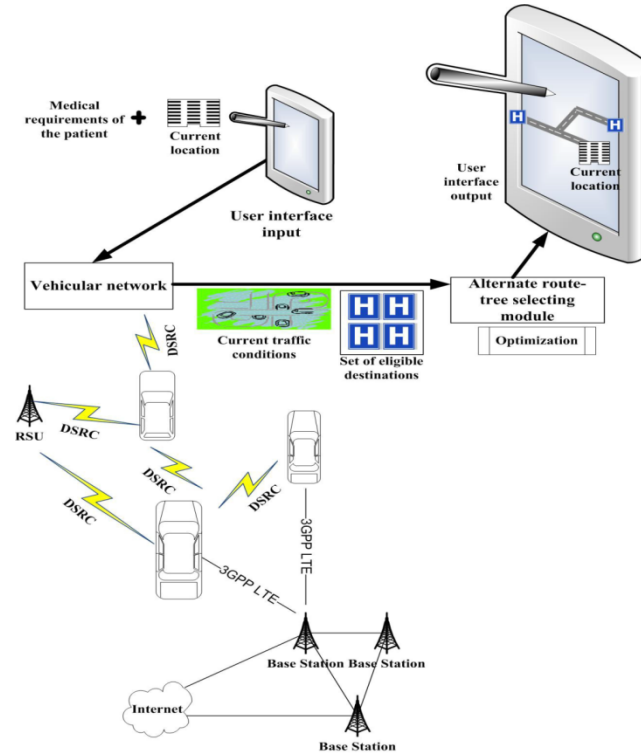


Figure 1: Sample smart city application in an urban area aiming at emergency assistance for paramedics [8]

ance, vehicle-to-infrastructure/infrastructure-to-vehicle communication challenges in VANETs 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 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 and context-aware solutions for all services in vehicular cloud environments. 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 [9]. Vehicular Networks are the key component of an ITS, enabling and integrating the use of various technologies, communication standards and the infrastructures [10, 11, 12]. The city is turned into a smart, connected city by the intelligent transportation system with the use of vehicular networks and its infrastructure. Every region, facility, driver, passenger and even pedestrian is envisioned to be connected to the ITS and could be made aware of local, or region of interest (ROI), or city-wide events and updates/changes to 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 [13].

Since the 1980s, modern vehicles have been able to gather a massive amount of data from the electronic control units placed within them. These data has been stored on board by the vehicles but has been processed by only the manufacturers. However, there is a great demand in the industry to utilize these data for various purposes, e.g. safety, efficiency and driving comfort. 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.

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 [14, 15, 16]:

- **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) [17], IEEE 802.11p [18], WAVE IEEE 1609, WIMAX IEEE 802.16, and even ZigBee IEEE 802.15.4 are amongst these technologies.

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 Table 1 [19, 20, 21, 22, 23, 24, 25]. IEEE 802.11p (IEEE Std 802.11p-2010) [18] 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 2). 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 [26].

There are 75 MHz of bandwidth in the 5.9 GHz (5850-5925 MHz) that have been allocated for Intelligent Transportation Systems (ITS) in the U.S. [27] and 70 MHz of bandwidth in the same spectrum has been allocated in E.U. (between 5855-5925 MHz)[28]. Channel allocations vary in US and EU [28, 29, 30]. As shown in Figure 3, allocated bandwidth is divided into seven channels of 10 MHz forming one control and six service channels in U.S. and E.U. regulations [30]. The control channels are located in the middle and are used for control and safety messaging. The

Table 1: IEEE 802.11p and IEEE 1609 protocol

WAVE Standard	Usage	Description
IEEE 1609.0-2013	Architecture	Describes the Wireless Access in Vehicular Environments (WAVE/DSRC) architecture and services necessary for multi-channel DSRC/WAVE devices to communicate in a mobile vehicular environment.
IEEE 1609.2-2013	Security Services for Applications and Management Messages	Defines secure message formats, and the processing of those secure messages, within the DSRC/WAVE.
IEEE 1609.3 2010	Networking Services	Describes standard that supports 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 Draft	Communication Manager	Defines communication management services in support of wireless connectivity among vehicle-based devices, and between fixed roadside devices and vehicle-based devices for Wireless Access in Vehicular Environments.
IEEE 1609.11 2010	Over-the-Air Electronic Payment Data Exchange Protocol for Intelligent Transportation Systems (ITS)	Specifies the application service layer and profile for Payment and Identity authentication, and Payment Data transfer and defines a basic level of technical interoperability for electronic payment equipment, i.e. onboard unit (OBU) and roadside equipment (RSE) using DSRC.
IEEE 1609.12-2012	Identifier Allocations	Specifies allocations of WAVE identifiers defined in the IEEE 1609 series of standards.

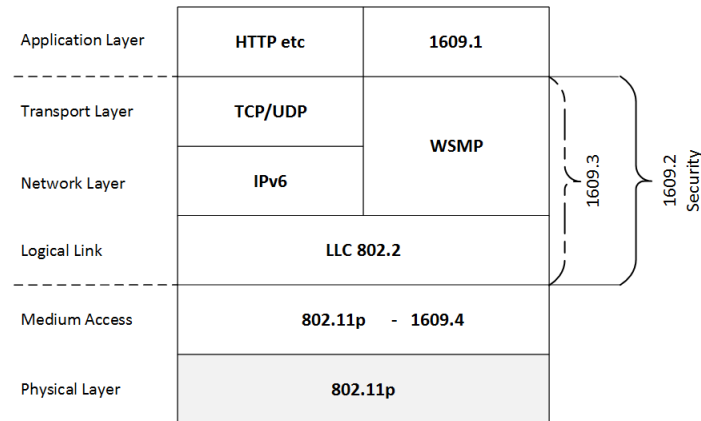


Figure 2: IEEE 802.11p and IEEE 1609 protocol family in the communication protocol stack

service channels are used for messaging by non-safety applications after coordination in the control channel.

2.2. VANET Applications

VANET applications are classified in a variety of ways in the literature. Willke et al. [31] define four types of applications according to the aim of the application: 1) General Information Services, 2) Vehicle Safety Information Services, 3) Individual Motion Control and 4) Group Motion Control. Karagiannis et al. [32] categorize applications in three categories: 1) Active road

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

safety applications, 2) Traffic efficiency and management applications and 3) Infotainment applications. One classification has been defined in [33] as shown in Figure 4. In [33], applications in VANETs are generally classified as safety or non-safety applications. Safety applications are 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.

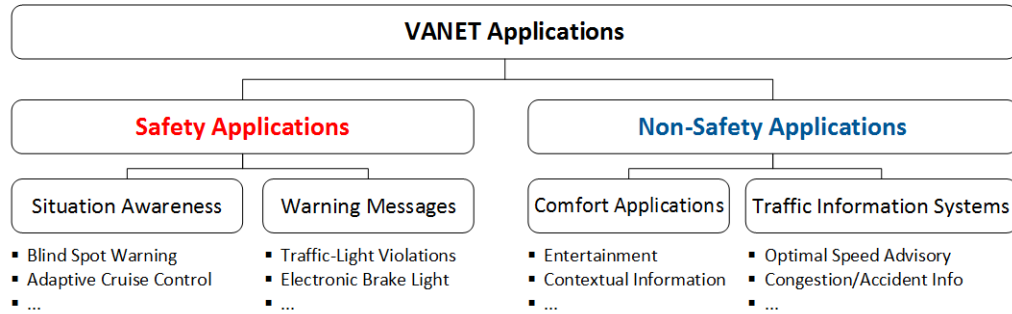


Figure 4: Classification of the VANET Applications [33]

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 a service to others. With the advent of the cloud computing paradigm, offloading local resources and rapidly accessing to a shared pool of resources has appeared as a more feasible solution to accelerate computing and storage services. A vehicular cloud is formed by incorporating cloud-based services into vehicular networks. Many service models such as Computing-as-a-Service (CompaaS), Storage-as-a-Service (STaaS), Network-as-a-Service (NaaS) [34], Cooperation-as-a-Service, (CaaS) [35], Entertainment-as-a-Service (ENaaS), Information-as-a-Service (INaaS) [36], and Traffic Information-as-a-Service (TIaaS) can be delivered via vehicular clouds. In [37], 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 drivers to access mobile cloud resources rapidly in a pay-as-you-go fashion.

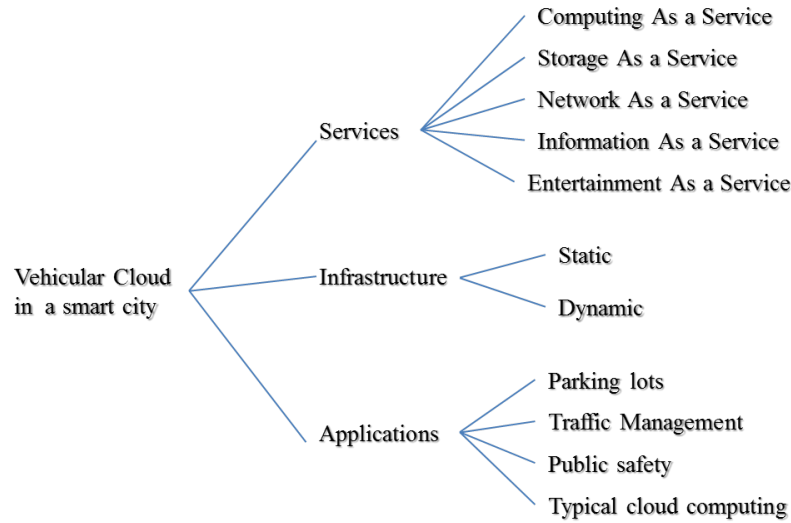


Figure 5: Vehicular Cloud System Design in a smart city

As shown in Figure 5, vehicular cloud infrastructure can be either static or dynamic. In the static implementation of a vehicular cloud, the computing resources of a group 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 more limited computing and 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 such a dynamic implementation, incorporating the roadside units in the vehicular cloud infrastructure improves the manageability of mobile hosts (i.e., computing resources in vehicles) [38]. As mentioned in [37], a vehicular cloud system should ideally utilize the underlying VANET infrastructure and minimize the involvement of RSUs.

Vehicular cloud computing architectures consist of three segments: vehicle-unit, communication and cloud (see Figure 6). The vehicle-unit segment retrieves the vehicle information through various sensors to monitor characteristics such as vehicle pressure, temperature and driver attributes [39]. This information can be transmitted to the cloud for storage. The communication segment of a vehicular cloud operates with Vehicle-to-vehicle (V2V) and vehicle-to-

infrastructure (V2I) systems. V2V uses DSRC protocol [40, 41] and uses Emergency Warning Messages (EWMs) to warn of abnormal road characteristics, sudden changes in direction, speed limits or major problems with individual vehicles. Vehicles propagate information to neighboring vehicles and to the cloud for storage. V2I exchanges occur through 3G, Internet or satellite communication and improve the safety standards and performance of the vehicular network [42].

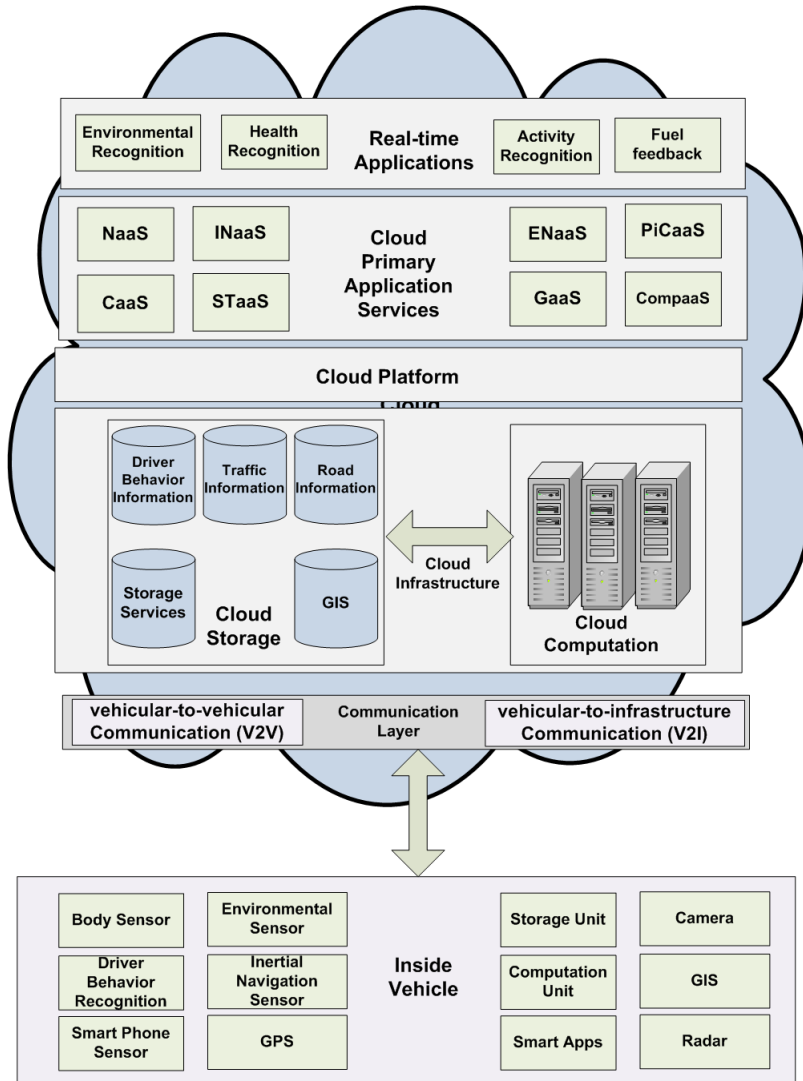


Figure 6: Vehicular cloud computing architecture [41]

The cloud layer employs data aggregation and data mining techniques on the data stored in a distributed manner. Stored data can be of the same type with the VANET data which is related to safety, entertainment or driving comfort. Hence, data stored in the cloud is analyzed in a distributed manner to retrieve information with the ultimate goal of safety and quality-of-life in the smart city. By adopting the cloud computing concept in vehicular communications, having computing and storage resources in the vehicles will be avoided to be underutilized most of the time. Thus, a vehicle can rent its computing, storage or communication capacity to

other vehicles in the network. Primarily cloud services are applications in real-time such as Network-as-a-service (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 is used to compute data based on storage and real-time data.

In [43], 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 7 along with the corresponding system architecture.

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 [44] 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

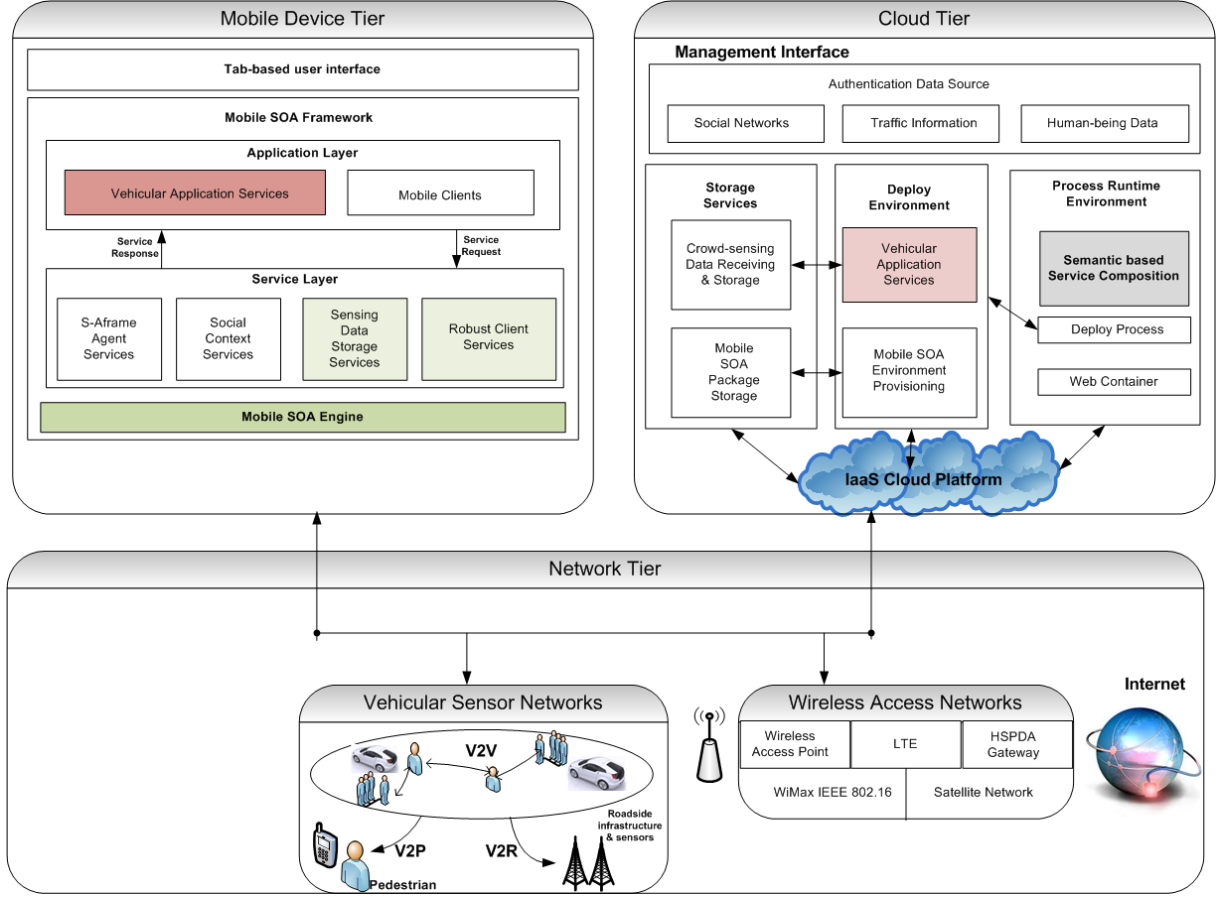


Figure 7: System architecture of Service Centric Contextualized Vehicular (SSCV) cloud [7]

and so on [44]. 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 a unique solution for implementing safety and security standards in transportation systems. The intelligent transportation system (ITS) not only standardizes an approach to overall road safety, but also it makes vehicle driving more comfortable and stress-free. With the combination of Road Side Units (RSU) and smart vehicles the traffic incidents and laws can be monitored by local and centralized systems.

4.1. Smart Driving

The major goals of enabling ITS based smart cities are to increase traffic safety and to increase energy efficiency. Bifulco et al [45] have addressed the 2020 ambition of Europe with

efficient and sustainable energy utilization. According to the study of Kley et al [46] one 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 has been explored in various research projects including projects from 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.[Rodier,44]

The major goals of enabling ITS based smart cities are to increase traffic safety and to increase energy efficiency. Bifulco et al [45] have addressed the 2020 ambition of Europe with efficient and sustainable energy utilization. According to the study of Kley et al [46] one 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 has been explored in various research projects including projects from 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 [45, 47].

Accenture have been collaborating in Amsterdam for smart city intelligent transportation system where the initiative is to connect cars, electric bicycles, vessels and river cruisers in smart grid [48]. This smart city project launched in 2009 with the ambition of energy solutions with smart grid. Eventually the platform trends to integrate all necessary service in single smart system and progresses for intelligent transportation system [49]. IBM have tested the intelligent transportation system in Singapore to monitor traffic in roadways. The system is expected to deliver accurate traffic patterns and already have been implement in Lyon (France). The algorithm considers road type, density, speed-limit and event data to predict traffic patterns [50].

One of the interesting characteristics of VANETs is to provide real time updates to drivers. However, VANET-equipped vehicles and smart cars are currently rare in the market. Google is collaborating with open automotive alliances (OOA) [51] to bring the Android platform to vehicles. Smart parking solutions like Parker [52] and Apparcar [53] assist drivers to identify nearby parking places. Moreover, mobile application like Waze [54] can assist in tracking the traffic status in a particular region. VANETs can help avoid accidents by monitoring motion and direction change in vehicles. Awareness of upcoming roadside curves and damage can be

passed from car to car to assist the drivers. Special notification for ambulance, fire and brigade vehicles can be passed to surrounding vehicles and roadside units to create space for service 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 standards. Moreover, unregistered and law violating vehicles can create security threats.

Existing solutions for VANET safety are primarily based on trusted third parties (TTP) or proxies [55, 56]. Barba et al have introduced a protocol for VANET which is able to report traffic violation anonymously.

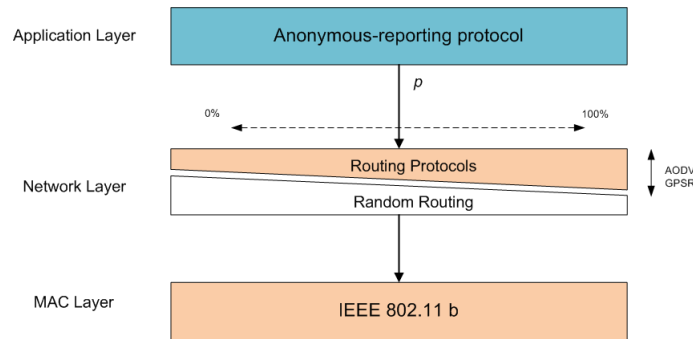


Figure 8: Barba et al consider standard protocols in conjunction with their proposed approach that is an anonymously reporting protocol [55].

The protocol chooses next forwarding route randomly by maintaining privacy anonymousness and uses a forward probability measurement (Figure 8). 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. Main challenge in clustering algorithms is forming more stable clusters in terms of cluster size, member node exchange, cluster head election and long duration of cluster heads. One good clustering algorithm for VANETs should also form fewer clusters to ease maintenance and stability. A fuzzy clustering-based vehicular cloud architecture (FCVCA) has been proposed in [57] with a new clustering technique to group vehicles. In this 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 flow rate. Flow rate is the amount of nodes crossing particular road segment within specific time. The metrics used in the simulation environment are duration of cluster head and amount of clusters. Within the similar environmental scope, the proposed algorithm is compared with Lowest-ID [58] and MCMF [59] techniques. According to comparison result, it has been reported that the proposed approach can construct a 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 [60] have proposed another clustering technique to solve the resource limitation problem by cooperatively providing the resources in a 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 [61], the simulation study demonstrates improvement with the proposed COHORT clustering approach. The simulation results also demonstrate that the proposed COHORT clustering approach has a significant impact on reducing service discovery delays and service consuming delays in comparison with CROWN. CROWN (discovering and consuming services within vehicular clouds) [62] 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 an important role for message propagation during emergency situations and disasters such as cyclones, earthquakes, fires, volcanos, etc to reduce loss of life and resources. It has been noted that message dissemination during a crisis is one of the key challenges for future research in this area. Alazawi et al [63] have proposed a system using 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. In emergency situation, an efficient system is expected to control road traffic accordingly and able to propagate the information with available resources. Through data analysis the system can design a strategy to optimize the impact of disaster e.g. public transportation for evacuation from the point of incident. Authors have evaluated the proposed solution during disaster scenario and found the proposed system better than conventional approach for evacuation. Their future work aims to work on real time cases and enlighten the scopes of intelligent disaster management system.

In a smart city vehicular network, emergency service solution is a new research direction. Amici et al [64] have introduced a routing protocol where real traffic scenario is collected using 370 taxi cabs every 7 seconds in the city of Rome. These cabs are connected throughout the city without the utilization of 3G/4G network infrastructure. Real time analysis of this traffic data is used to identify emergency situations. An infected vehicle propagates emergency messages to other participants of the network. An infected vehicle is the uniformly distributed random vehicle at a given time where the primary messages have been delivered. Later, these emergency messages are propagated to other not-infected vehicles when these vehicles are within the coverage range of infected vehicles. Upon receiving the emergency message the vehicles become infected. Considering the average speed and wait time in real traffic scenario, the message can be propagated 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 solved [65]. 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 establishment of trust relations and authorization of mobile vehicular nodes more complex than in conventional VANETs [66]. Indeed, provisioning delay in such an environment is also a big concern due to the same factors as mentioned in [67]. 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 the need to reveal private information is minimized. Other virtualization-based challenges also remain in vehicular clouds such as VM migration in an IaaS scenario where vehicular nodes are mobile [37].

5.1. Security in vehicular clouds

Security challenges in VANETs and cloud computing are inherited by vehicular clouds as mentioned in [43]. These challenges have been studied in detail in [68, 69, 70]. These studies can be improved by taking the specific conditions and requirements of vehicular clouds into consideration. In [66], 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 [68]. 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: 1) 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, 2) the vehicular node that serves the victim vehicle is discovered upon submitting several service requests to the cloud, 3) Once the VM that is allocated to the victim is identified, services are requested on the same host, 4) 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 [71]. 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 [72].

In [68], the authors propose building trust relationships 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 9 illustrates a scenario that is presented in [68]. 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.

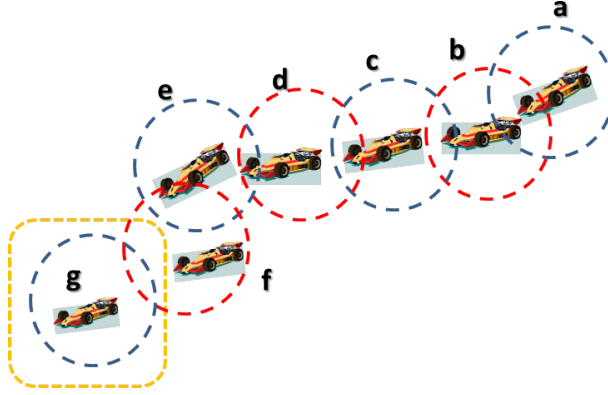


Figure 9: Geographic security approach presented in [68]. The square is a securely protected area (e.g., military headquarter). Only vehicle-g can access the ciphertext sen by vehicle-a

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 cloud. Increasing volume of the vehicles in the cloud introduces the scalability problem for the security schemes. To cope with the scalability issues, 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 [73, 74] 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 [75, 76]. The authors in [77, 78] 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 [73, 69, 70] can be adopted by vehicular clouds

however special requirements of vehicular clouds have to be taken into consideration.

Anastasopoulou et al. [79] 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 [80]. Moreover, the authors propose a hierarchical framework where multiple cloud 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 [37]. 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 if 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.

It is worthwhile noting that VM migration is typically a bandwidth intensive task taking many minutes. Hence, handling frequent migration among moving vehicles is a grand challenge of vehicular clouds. Furthermore, encryption of data in transit is of paramount importance which is resource and time intensive. These issues still remain open for the researchers in this field.

5.4. Context-awareness

Context-awareness in a vehicular cloud is emergent for smart city applications for various reasons. In [81], 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 [82]. 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 [65]. 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 envisioned to be an inseparable part of vehicular clouds they will primarily serve for traffic data mining and mobile crowd sensing [65]. 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. Continuous authorization techniques that incorporate detection of anomalous patterns into the 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-based crowdsensing systems experience several challenges. As reported in [83], injection of specious information into crowdsensed data may introduce public safety vulnerabilities in case of an emergency [84]. Trustworthy crowdsensing schemes [83] can be enhanced by new trust derivation models [85]. As mentioned above, 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 presented 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 discussing future directions and open issues in this topic.

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