V-Cloud: Vehicular Cyber-Physical Systems and Cloud Computing

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ABSTRACT
The widespread use of smart phone devices and their ubiquity has brought up new application domains. One such interesting domain is vehicular networks. Furthermore, cloud computing is a next-generation information and communication technology that is gaining popularity due to its pay-as-you-go service model. In this paper, we propose our novel V-Cloud architecture which includes vehicular cyber-physical system (VCPS), vehicle-to-vehicle network (V2V) and vehicle-to-infrastructure network (V2I) layers. Each of these layers is explained in further details. We discuss research challenges in V-Cloud domain and introduce new services to show wide potential of such intelligent transportation system to meet safety and comfort requirements for driver.

Keywords
Cloud Computing, Cyber-Physical Systems (CPS), Vehicular Cloud (V-Cloud)

General Terms
Design, Theory, Performance

1. INTRODUCTION
Over the past couple of years, advancement of network technologies has led to deployment and usage of 4G network. At the same time, to meet the growing on-demand storage and computing resources, cloud computing has rapidly emerged in recent years [1][2]. The smart phones are driving the data explosions, such as iPhone data usage and storage doubled (200%) when its 3G version released across Europe. With the widespread adoption of smartphones, there is also a consensus on the enabling technologies such as cloud computing and 4G network services that can be used to meet data-storage and quality-of-service requirements. Looking ahead, we envision a network of smart-cars that are connected to cloud through 3G/4G network. Additionally, smart-car itself may be regarded as a 'vehicular cyber-physical system' [3][4][8].

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In US alone, there were 33,000 causalities and 2.2 million other injuries due to motor vehicle crashes in 2009. In addition to this loss, these crashes impact the society economically as well and incur annual estimate cost of $230 billion dollars. This means that every single person in USA is affected by $750 dollar. Moreover, the highway congestion costs $78 billion annually. We claim that one such cause of fatalities on highway is due to driver's mood and behavior.

In response to the above mentioned statistics, national highway safety traffic administration (NHTSA) has drafted vehicle safety and fuel economy rulemaking plan. They have given vehicle crash avoidance and mitigation along with vehicle communication (both V2V and V2I) as top vehicle safety priorities [5].

In last decade, there has been tremendous amount of research work conducted in area of vehicular ad-hoc networks (VANET) [10][11]. The VANETs are distinguished from other kind of ad hoc networks due to their hybrid architecture and node movements. They integrate ad hoc networks, wireless LAN and cellular technology for intelligent transportation system (ITS). However, the major focus of VANET is to address routing and MAC layer communication issues.

In this paper, we propose a novel V-Cloud architecture that combines the concept of VANET, CPS and Cloud Computing to provide safety and comfort for driver, and improve environmental conditions. To the best of our knowledge, it is novel concept that combines vehicular cyber-physical systems with cloud computing paradigm. Our main contributions in this paper are summarized as below:

1) We propose three-layer V-Cloud architecture that includes cloud computing paradigm for application services;
2) We recommend new application domain for ITS which includes research scope as well as commercial aspect;
3) We propose in-car services that are essential for driver's safety and comfortable drive on highways.

The rest of this paper is organized as follow: In section 2, we discuss related work. The V-Cloud architecture is given in section 3. The major focus of the paper, vehicular cyber-physical system is discussed in section 4, followed by research challenges, discussion and conclusion in section 5, 6 and 7 respectively.

2. RELATED WORK

The most notable related work is cartel project by MIT [7][8]. It use smartphone embedded sensors to collect raw data and transmits this information to cloud where it is used for modeling, prediction and analysis. It is essentially a mobile sensing and computing system and one may view it as 'vehicular cyber-physical system'. The application domains of cartel project does not address drivers behavior and healthcare monitoring, however the research contribution includes traffic congestion mitigation, road surface monitoring, vehicular networking and location privacy of users.

The survey of VANET is given in [10][11], which suggests that focus of past research has been on communication issues in VANET and not on infrastructure. Several works in past propose routing protocols for VANET and address other MAC layer communication issues. The security and privacy for vehicular networks is yet another domain that is under-explored.

The authors in [12] proposed a drowsiness alert system for car-driver. They used in-car camera to detect various features of human face such as yawn frequency and head movement. Consequently, this prevents drivers falling asleep while driving at highway. The services provided by intelligent vehicles are well maneuvered by human but one at a time. Therefore, in the design of service scheduling such human-factors should be considered. This problem is addressed by authors in [13], and verified that one service at a time is sufficient for human's active perception and reaction.

The research in area of vehicular cyber-physical system has formally commenced since NSF CPS workshop held in 2006. The US project called USCAR is joint collaboration between Chrylser LCC, the Ford Motor company and General Motor Corporation [14][15]. USCAR is considering cyber-physical concepts for building a smart adaptive vehicle. One such autonomous vehicle concept is presented in [21]. In parallel with USCAR, the Toyota Company also planned to use cyber-physical systems concepts for validation, verification and collision avoidance system [16].

In domain of cloud computing and vehicular networks, there has been few works proposed in near past. The authors in [17] present the autonomous vehicular cloud (AVC) concept. Taking one step further, authors in [18] discuss platform as a service (PaaS) model for vehicular domain with possible applications. Lastly the authors in [20], presents an approach for taking VANETs into the cloud. Instead of using public cloud infrastructure they consider each vehicle in parking lot as computing and storage device and part of cloud.

In contrast to the related work stated above, our approach is to integrate cloud computing with vehicular networks utilizing advancement in network technologies. Some of the previous works focused on in-car systems, and others present their view of taking VANETs to clouds; however none of them specify a system taking vehicle as cyber-physical system enabled cloud computing entity.

3. V-CLOUD ARCHITECTURE

The V-Cloud architecture can be divided into three layers namely in-car vehicular cyber-physical system, vehicle-to-vehicle network (V2V), and vehicle-to-infrastructure (V2I) network layers. It is shown in Figure 1. Each layer is further divided into sub-components, and on top of that a component is responsible for cooperation between these layers. The detailed architecture is shown in Figure 2.

The vehicles on highway form a cluster, where they can communicate with each other as well as with the infrastructure. There are three types of communication technologies available for V2V and V2I, namely Dedicated Short Range Communication (DSRC), Wi-Fi and cellular networks (WiMax/3G/4G). The smartphones such as iPhone and Android Galaxy are used inside car, and they serve two purposes. Firstly, they are used to monitor health and mood conditions of driver through embedded sensors. Secondly, they send the collected information in first part to cloud. The long-term history of driver is stored in cloud that can help to predict mood of drivers beforehand. The description of major layers in Figure 1 is given as follows:

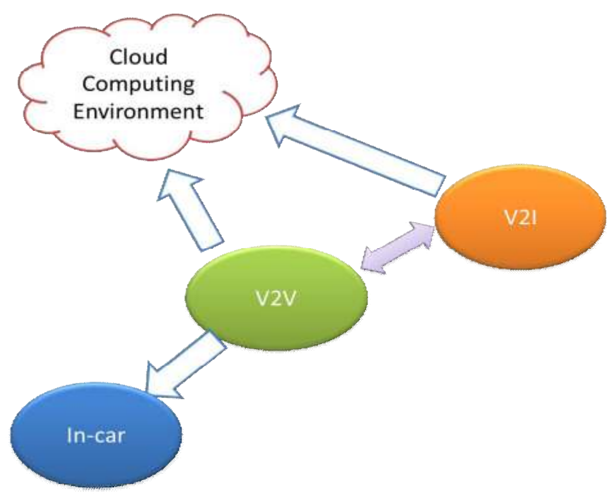

Figure 1. V-Cloud Architecture: Top Level

3.1 In-Car

The in-car layer consists of two types of sensors, namely vehicle's internal physical sensors and smart-phone embedded sensors. Keeping security issues in mind, the module of *smart authorizer (SA)* is added inside smart phones. The SA may be a perspective smart phone application. The authorizer is responsible for V2V cluster *invitation* and *monitoring*. During time spend on highway, there are many cases where vehicles join and leave the cluster. Moreover, few vehicle drivers are not interested in sharing their information, therefore they can decline cluster invitation request.

The two other functions provided by smart authorizer are cloud *formation* and *management*. It is responsible for sharing resources, storing and retrieving information from cloud. The services provided by in-car layer are smart car/vehicle and driver behavior that encompasses context awareness, healthcare monitoring and mood detection. Throughout the scope of this

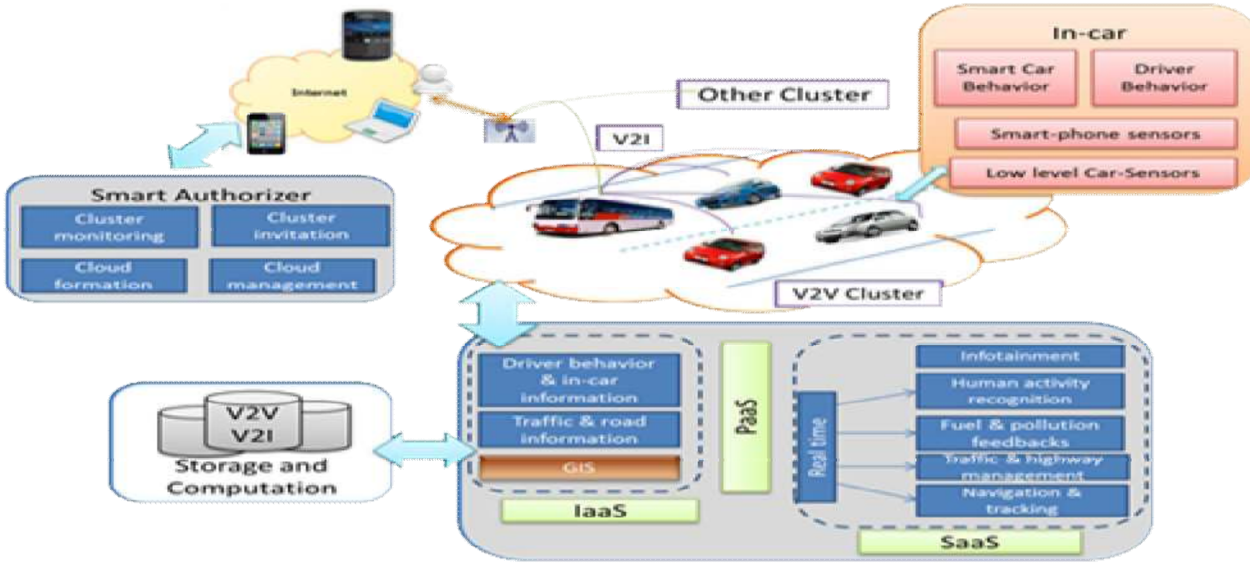

Figure 2. Detailed V-Cloud Architecture

paper we use in-car as top layer and vehicular cyber-physical systems to explain in-depth details.

3.2 Vehicle to Vehicle Cluster (V2V)

The vehicles on highway form a network cluster, and may leave or join it according to distance and location with others. The front vehicle constantly sends a communication message for keeping a distance to the rear vehicle and issues a warning message in case of violation. This also helps traffic administration to control and mitigate accidents and identify the mistakes for legal actions. The communication between vehicles to vehicle is exchanged via DSRC standard [23]. Vehicles in V2V organize themselves into clusters based on defined road segmentation. Each cluster is organized as a node in cloud computing and there is one cluster header to send all information to other vehicles in each cluster as well as to neighboring cluster headers. Each cluster header will identify whether it is near any base station (access point) or not in order to transmit their cluster needed information to cloud computing environment. Figure 2 shows details vehicle cloud architecture that includes infrastructure as a service (IaaS), PaaS and software as service (SaaS) as a node in the cloud computing.

In IaaS, the wireless sensor network and electronic equipments collect the driver behavior information, in-car information, traffic and road information also geographical information system (GIS) information from GIS systems. Then we build the future PaaS for this system and pass that into the SaaS. This kind of system will communicate and process in real-time and give useful services such as infotainment, human activity recognition, fuel and pollution feedbacks, traffic and high way management, navigation and tracking, etc. All these tasks, we can deploy in available resources in vehicles nowadays.

3.3 Vehicle to Infrastructure (V2I)

The major difference between state-of-the-art VANET and V-Cloud is role of V2I layer. It serves as a mean to connect with cloud platform. It is vital to characterize which decision can be taken on-board (in-car) and what information is relayed to cloud for further processing. The communication technologies used for V2I are 3G/4G and Wi-Fi or sometimes DSRC, to connect with road-side infrastructure as well as cloud.

3.4 Cloud Computing

Cloud computing provides the basic infrastructure for all the vehicular and smart-car services. These include but are not limited to real-time services such as *human activity recognition, fuel and pollution feedback, traffic and highway management, navigation and tracking* etc. Other than that, the information and entertainment (*infotainment)* services are non-real time services offered that include music and movies download, weather information, and location-based discount offers. Cloud infrastructure can be either rent out from public cloud providers such as Microsoft Azure, Amazon EC2 and Google App engine, or it can be built privately and hosted at central traffic management authority.

Cloud computing for vehicular networks provides functionalities of PaaS and SaaS. As mentioned earlier the IaaS can be rented out from cloud provider such as Amazon EC2, Google App Engine or Microsoft Azure. Alternatively, the traffic department can deploy and manage private cloud. The Paas layer has database which contains *driver behavior and in-car information, traffic and road information and GIS data.* This aforementioned stored information in database is used for data mining and processing to extract useful knowledge and trends. This may help automotive industry as well as traffic administration department for knowing the behavior of drivers as well traffic statistics.

4. VEHIULAR CYBER-PHYSICAL SYSTEMS

The in-car or inside vehicle system can be rightly termed as 'vehicular cyber-physical system', or in short VCPS. Traditional cyber-physical concepts in vehicular domain imply toward automobile's functional control architecture. The vehicular cyber-physical system architecture is shown in Figure 3. In contrast, the main contribution of our work is to make smart phone embedded sensors in use along with automobile's health monitoring system.

In state-of-art vehicular systems, the physical sensors are used to measure performance and health of vehicle. However, these days smart phones are becoming ubiquitous technologies in urban areas. These smart phones or devices can serve as mean of communication while driving. VCPS includes two sub-layers for raw sensor data collection and a layer for providing necessary services to user. We discuss VCPS services as follows:

4.1 Smart Car or Vehicle Behavior

The performance monitoring of vehicle's internal system is useful for safe and efficient driving. In addition to that, the location-awareness of vehicle proves beneficial in emergency situations as well as in case of vehicle theft. The state-of-the-art CPS for vehicles requires solid foundations for developing dependable and secure automotive. Context awareness is broad function and it identifies the current situation and location of vehicle. For example, vehicle may be near to a hot-deal shopping area or car-accident spot.

4.2 Driver Behavior

The main difference between previous vehicular cyber-physical systems and our proposed one in this paper is inclusion of this module. Inside car the driver can enjoy luxury of information (news, weather etc.) and entertainment services alongside with his/her mood detection and healthcare monitoring. The driver is connected to cloud via smart phone. The privacy and security issues are addressed by means of smart authorizer module.

5. RESEARCH CHALLENGES

In this work, we presented a novel architecture that combines concepts of vehicular cyber-physical systems and cloud computing. The smooth and error-free functioning of of such system pose several key research challenges that should be addressed in order to make it pragmatic. We list and discuss key research challenges as follows

Fuel and CO_2 emission: The environmental protection is one of the biggest concerns in urban areas. VCPS are smart vehicles that control and reduce the CO_2 emission, when they enter urban environments. Consequently, this will benefit the society in positive ways.

Validation and verification of intelligent automobiles: The human behavior modeling is not limited to healthcare monitoring and mood detection. It is more complex and involves thought process. The correct modeling of human behaviors is of utmost important in validation and verification processor of vehicular cyber-physical systems.

Driver's state and skills: The correction representation of driver's current state while driving determines his safety.

Security and privacy concerns: The driver's privacy and security is always a challenging research issue in V-Cloud services. This can be dealt with by implementing a module with authorization and authentication functionalities.

6. DISCUSSION

The envisioned future that every car on highway will be connected to internet has bought up new application demands. Moreover, the smart phone technology with embedded sensors such as audio, video, GPS, accelerometer and other biomedical sensors has provided an interface between driver or passengers sitting inside vehicle and internet. The integration of VCPS and internet by means of cloud computing is first but vital step in empowering intelligent transportation industry.

Security and privacy has always been a big concern in vehicular networks. It may be used for malicious purposes, therefore, in our architecture we provided security module termed as smart authorizer. Similar to airplane mode in smart devices, the SA module is activated when user enters or starts driving his vehicle.

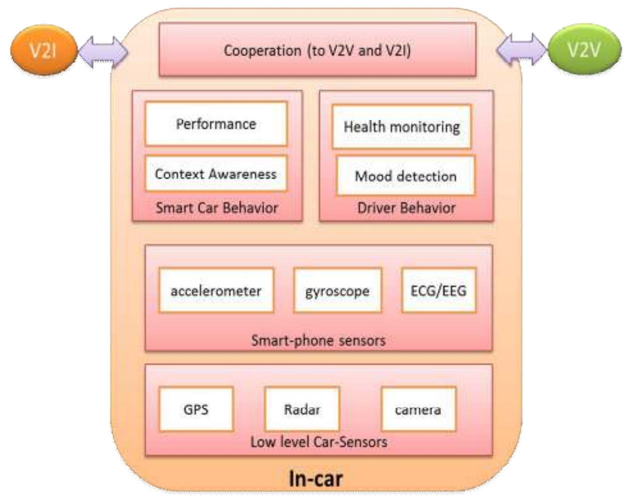

Figure 3. Vehicular Cyber-physical system (VCPS)

The architecture given in this paper is considered as cycled architecture in a way that each layer or module is dependent somehow on other. The three entities of such architecture are sensing and actuation, driver's behavior, and vehicle's behavior. For example, the driver is feeling dizziness as his health conditions is not suitable for driving. The smart phone embedded sensors detect such activity and alter driver to stop driving immediately and take rest. Moreover, the smart phone send information to cloud for saving data to driver's profile and informing the emergency response system in case of any mishap.

7. CONCLUSION

In this paper, we discuss several key research challenges and a potential direction for next generation ITS. We introduce and give a novel idea of V-Cloud, a vehicular CPS and cloud computing enabled system for vehicles. The offered services include but are not limited to healthcare, traffic navigation and tracking, infotainment etc. We propose a novel three-layered V-Cloud architecture with detailed description of each sub-layer. In the circumstance when driver is not healthy and comfortable enough to drive, our system can offer cloud computing based real-time services in order to improve driver's safety and comfort degree.

8. ACKNOWLEDGMENTS

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