Vehicular Clouds: State of the Art, Challenges and Future Directions

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***Abstract* —Cloud computing and Vehicular Communications are profoundly emerging fields towards realization of smart cities. While cloud computing is stage of development, vehicular cloud computing combines the benefits of Mobile Cloud Computing (MCC) and vehicular communications. Recent studies expect that vehicular cloud computing will be the gateway to the future of transportation systems. However, the development process still reveal on several issues and challenges that need to be carefully addressed in such environment. Privacy, service cost and provisioning delay are identified as the most crucial challenges to be addressed. State of the art includes several proposals to address these issues. In this position paper, we will gather and present a comprehensive study of vehicular cloud computing architecture, applications, and approaches. More importantly, we will discuss the current possible services provisioning solutions with their drawbacks, then, we will provide a thorough discussion on the benefits of using the concept of Quality of Experience (QoE) in such environment.**

***Keywords* — Cloud computing, mobile cloud computing, quality of experience, privacy, vehicular cloud computing.**

I. INTRODUCTION

The Internet of Things (IoT) paradigm has introduced significant changes into the conventional computing and communication concepts. The vision of the IoT concept is to have billions of uniquely identifiable objects that are ubiquitously inter-connected accessible through the Internet backbone. Realization of the IoT paradigm requires computational and storage offloading. As a result of the need for offloading, cloud computing-based architectures and communication models have become emergent [1].

Cloud-based solutions have been attractive for individuals and enterprises due to several reasons as stated in [2]. With the advent of mobile computing and communications, market share of smartphones has increased significantly, and mobile applications for computing, processing and storage purposes have become an inseparable part of the mobile Internet [3].

Researchers and developers agree on the fact that cloud transforms the way that runs the *Information and Communication Technology* (ICT) business rather than transforming the technology. However, it is worthwhile mentioning that transformation of the business empowers reformation of the existing ICT solutions [4]. The main benefits of CC idea that it's provides rapid, flexible and scalable access to computing resources at all times based on the pay as you go fashion [38].

The conceptual cloud model is inspired by the electricity distribution via power grid. Thus, customers do not carry electric generators with them but it is available through electrical power outlets, and usage is metered and charged accordingly. If this idea is projected onto the ICT business, ICT users do not have to carry (install) software on their local devices. Similarly, enterprise companies do not need to invest for their IT infrastructure as they can lease the infrastructure from infrastructure providers. This business model introduces consolidation of various computing services and storage resources on remote platforms, and the platforms to be consolidated on designated infrastructures. [39][40]. This broad definition also points out the need for specification of requirements, such as on-demand, metered delivery of the services in a secure and scalable manner over the Internet [5].

Mobile cloud computing is an emerging field which attracts interest from both academia and industry. Advances of cloud computing have made it possible to provide software, platform and infrastructure as a service to mobile users. These advances services overcome lots of the mobile existing challenges, such as, storage and power consumption.

With the advent of mobile networking and cloud computing; vehicular cloud computing arisen as a viable solution in such environment [6][7]. Vehicular cloud computing is an emerging descent of mobile cloud computing and vehicular networking concepts, vehicular clouds inherits the benefits of both concepts. Vehicle drivers can join mobile cloud via mobile devices or in-vehicle computers from anywhere to process any type of data on demand anytime [8].

Vehicular cloud computing has a wide set of available on-demand applications and services, which make it a desirable area to be adopted in the future. Multimedia content delivery, content sharing, and storage are examples of such services that can come through vehicular cloud.

The purpose of this survey is to understand the basic concepts and technologies necessary related to this area. Three groups of information are introduced: *i)*, mobile cloud computing systems, which will basically cover the definitions, architectures, and the system applications; *ii)* background information of vehicular cloud computing, covering the definitions, classifications, standards, and the state of the art solutions; *iii)* open challenges and possible methodologies to address them.

II. OVERVIEW AND FUNDAMENTALS OF THE CLOUD SYSTEM

Mobile cloud computing and vehicular cloud computing forms the basis for both mobile cloud and vehicular cloud paradigms. Cloud computing serves as an umbrella to define a category of on-demand computing services offered by commercial providers, such as *Microsoft, Amazon, and Google*. The main objective of the cloud is to offer computing, infrastructure, and storage, as a service. There are several definitions of cloud computing. Vaquero et al. [10] defined the clouds as a large pool of virtualized resources easily accessible; such resources can be easily reconfigured to ensure scalability, while the resources are rented by a pay-per-use scheme.

Buyya et al. [11] have also defined the cloud as a parallel distributed computing system based on service-level agreements (SLA). Virtualized resources that can dynamically provision and presented as a unified computing resources recognized through conciliation between the service provider and cloud users.

Armbrust et al. [40] defined cloud more generically as a hardware and software data centers that deliver services. The National Institute of Standards and Technology (NIST) has provided a definition which is widely accepted by almost everyone nowadays. Thus, directly quoting from NIST; *"Cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction. This cloud model is composed of five essential characteristics, three service models, and four deployment models*" [17].

A. Properties of the cloud

As we have seen earlier, the researchers foresee the cloud as the gateway to the future communications systems. Abovementioned definitions of the cloud have shown us some common properties, some of these properties are: pay-per-use and no contract commitment, adaptable and dynamic system, self-configure, scalable system, unlimited capacity with no restriction on the usage quota, unlimited number of available resources, and life-time power consumption.

These proprieties were a huge burden on the current communication system. Over the past decades, several solutions have been proposed to enhance and override these obstacles. One of the main problems has been the consumption power or the battery life time. Some of the research focuses on the CPU performance [12], others handles the screen and related peripherals [13][14] to reduce the consumption.

Storage capacity is also a huge constraint for mobile devices. However, cloud solutions offer to the end user unlimited storage capacity for their data [15]. One of the biggest storage services available these days is Amazon Simple Storage Service (Amazon S3) [16].

B. Layers of the cloud

A cloud system offers three main layers of service [16][17], namely, *Infrastructure as a Service (IaaS)*, *Platform as a Service (PaaS)*, and *Software as a Service (SaaS)*, as shown in Figure 1. IaaS offers computation and communication resources such as, hardware, servers, and storage [18]. The client is charged based on the volume of the usage only. This technique can save the users a considerable cost as they are charged only per use. In addition, IaaS can be very dynamic with the possibility to expand or shrink based on the number of the users. The most popular examples of IaaS these days are Amazon EC2 (Elastic Cloud Computing) and S3 (Simple Storage Service).

Figure 1: Layers of the cloud

PaaS is a higher level of abstraction than IaaS. PaaS makes cloud easily programmable by offering advanced integrated environment for building, testing and deploying users applications. Google Apps Engine, Microsoft Azure, and Amazon Maps are the widest examples of PaaS [18][19].

SaaS is the highest level of abstraction in the cloud. It allows the users to share and access applications remotely via the Internet. SaaS shifts the burden of local computer programs to remote on-line software services with the same software functionalities. Salesforce is one of today's examples which allow customers to access applications on demand [15][18][19].

In some special environments, a fourth layer is added to the bottom of the cloud layers, namely, Data Centers (DC). Data centers are usually built in less populated areas using cheaper energy rate and less chance of natural disasters. Mainly, this layer provides the hardware facility and infrastructure for clouds [15][20].

III. MOBILE CLOUD COMPUTING

Mobile cloud computing consolidates cloud computing and mobile communications, thereby defining a new business model between mobile users, mobile network operators and cloud providers. Mobile clouds offload the data storage and processing at the user's mobile device. This offload saves computing power and keeps the data storage away from mobile devices and into the cloud [5][15][22]. All users' applications are then accessed over the wireless connection through web browser on the mobile devices.

Mobile Cloud Computing Forum [23] organization defines mobile cloud as an infrastructure where both the data storage and processing are moved towards the cloud and away from the user side. This model of offloading the computing power and data storage outside the mobile devices is indeed promising to have a much broader range of mobile subscribers.

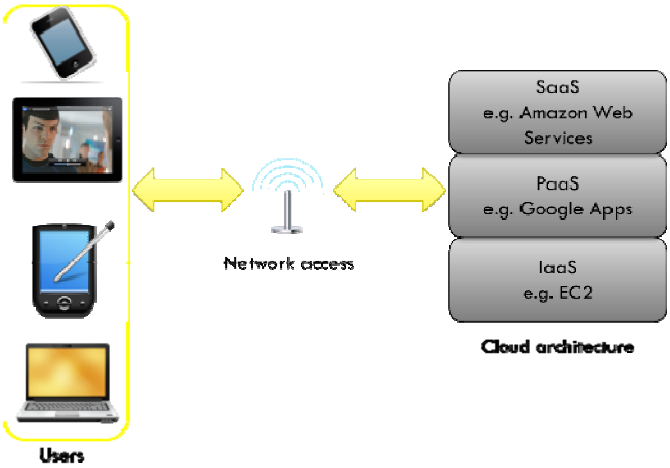

Figure 2: Mobile cloud computing model

Presently, mobile cloud computing can be defined as the offloading solution for mobile devices by providing access to shared pool of resources for mobile users via mobile backbone. Thus, the users' mobile devices do not need large capacity or powerful processing resources, since compute-intensive services as well as services requiring high capacity storage are handled at the cloud [24].

Mobile cloud computing general architecture can be seen in Figure 2. Left side of the figure illustrates the mobile front-end devices that access the Internet via mobile backhaul. Service requests and other relevant information are transmitted to the service provider via mobile backhaul.

A. Advantages of mobile cloud computing

Mobile cloud computing is recognized to be a promising solution for most of mobile computing issues. This assumption is due the following arguments:

- *Mobile cloud computing* is set to be flexible and dynamic. The use of the dynamic recourses will allow the users to run their applications without any lack of resources on the go.
- *Power efficiency:* Battery lifetime of mobile devices will run longer since all computations are happening at the cloud. Several studies in the literature have conducted to evaluate the effectiveness of offloading computation power in cloud [25][26][27]. Results show that using cloud to save the lifetime of users mobile device batteries can introduce significant energy savings.
- *Scalability:* User's demands can be easily deployed due to the flexible resource expansion on the cloud.
- *Integration*: Different service providers can easily integrate several services and introduce them to the end mobile users.
- *Elimination of upfront commitment:* No early planning of resource provisioning is required.
- *Ubiquity:* With mobile cloud computing, services can be accessed from any and everywhere.

B. Applications of mobile cloud computing

Numerous mobile system applications have taken the advantages of mobile cloud computing [15][22][28]. Some of these applications are as follows:

- *Mobile Healthcare* [15][29], mobile cloud-based healthcare will resolve the drawbacks of the legacy medical treatments. Mobile cloud-based healthcare will make of several medical services (e.g. medical records of the patients) available on-demand within the same medical facility or across the globe. In addition, Mobile healthcare applications could offer hospitals, medical centres, medical laboratories, and healthcare organizations a wide selection of on-demand services.
- *Mobile Commerce*, mobile commerce requires high mobility usage to perform on-demand tasks. With mobile commerce, cloud computing will increases any ongoing data processing and will have more security to perform any mobile transactions, payments, or online trading [41].
- Numerous mobile cloud applications also take the benefits of the cloud, such as, *mobile e-learning* [42] and *mobile gaming*. For example, in [42], the authors present a holistic study of combining mobile learning systems and cloud computing so they could enhance the quality of the communication between students and teachers.

IV. VEHICULAR CLOUD COMPUTING

Nowadays, vehicular computing and communications has become a hot research area, vehicles are likely to conduct more communication, share more on board services, and provide storage. Thus, vehicular cloud can be defined as a group of vehicles that share computing and storage resources via wireless network backbone [8][9][30]. This section will focus on the taxonomy of vehicular and today's issues and challenging.

A. Taxonomy of Vehicular Cloud Computing

Vehicular cloud computing taxonomy has several cooperating entities within its architectures such as: Vehicular Clouds (VC), Vehicles using Clouds (VuC), and Hybrid Clouds (HC) [30].

Several applications and services can be useful in the vehicular cloud computing taxonomy (Figure 3) such as, managing parking lot, accident alerts, monitoring road safety, controlling evacuation plans of shopping mall, and managing traffic lights [9]. Network as a service of vehicular clouds is one of most useful services to share information and storage between vehicles. Therefore, cars with Internet access can offer such service to cars on the road without Internet connection.

B. Open issues and challenges in vehicular cloud computing

Nowadays, vehicular cloud computing concept arises as a promising model to be deployed on vehicular networks. Several research issues and challenges need to be carefully addressed. Using virtual resources in cloud, storing personal information and data in cloud led to freeing control over such data [31][32]. Security and privacy aspects are of paramount importance as they still remain grand challenges. Furthermore, establishing trust relationships between drivers is a vital part of trustworthy communication. In addition, users should have more control to decide what information could be exposed to others (e.g. service providers) and what information should be kept private [8][33].

In addition, limited storage on mobile devices, inadequate battery life, scalability and service availability are another set of research challenges in vehicular cloud computing. Furthermore, service delay and service metering are still unaddressed issues. Pricing is an important factor in determining cloud service providers. Besides, service delay is crucial for certain applications and users. Providing security and privacy in a vehicular cloud computing is more difficult than it is in other networks due to the high mobility and frequent topology changes in the network, the dynamicity of the environment, and the heterogeneity of vehicles [34].

In this section, we focus on the three main issues of privacy, service cost, and service delay (i.e., latency).

The researchers in [32][33] and [34] present the existing challenges and solutions in cloud computing. These studies present promising solutions and their agendas are applicable to extensions and future directions. On the other hand, the scopes of those studies are limited to privacy and security only. These studies do not handle the price or the delay aspects. In addition, the abovementioned studies of privacy/security are broadly for cloud, without taking into consideration the special requirements of vehicular cloud computing.

Provisioning delay and pricing are relatively less explored in vehicular cloud computing. Vehicle drivers can be concerned about service pricing and service delay. Currently, there is no standard method of service provisioning for the drivers in a liberalized cloud service market. Moreover, there is no available service-price matching for the users. In addition to the impact on time efficiency, provisioning delay also increases service usage time, leading to higher charges to the user [35].

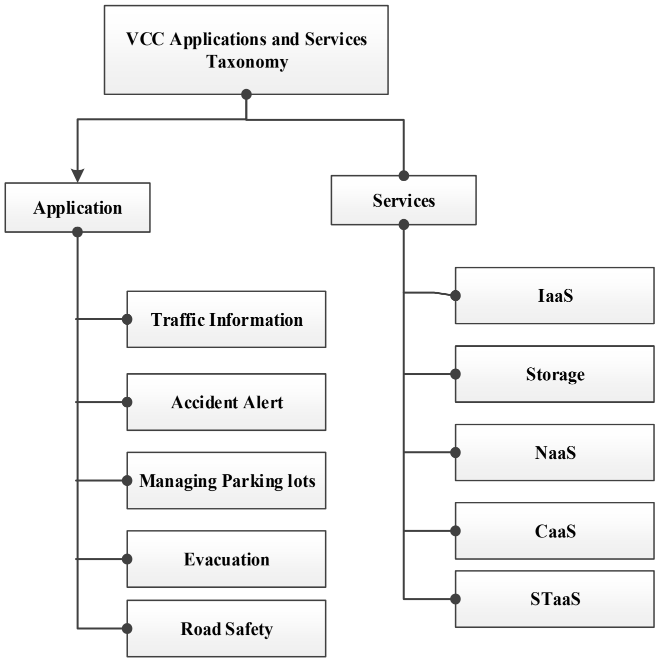

Figure 3: Taxonomy of application and services of vehicular cloud computing

V. QUALITY OF EXPERIENCE (QOE) SERVICE PROVISIONING

The vital need for service provisioning in vehicular cloud computing environments has been motivated and well explained. However, every new technology comes at certain expenses. Vehicle drivers can be concerned about service metrics. Service cost, service delay, and the driver privacy or the amount of the information revealed to the service providers can be among these concerns. To the best of our knowledge, we are the first who tried to tackle these issues all together. Therefore, the motivation of the study in [36][37] is to provide a framework that addresses all of these concerns through a QoE-based methodology.

Thus, the goal was to provide vehicle drivers with services at low cost, with minimum volume of information revealed to service providers, and minimal provisioning delay in one framework.

QoE methodology was the most suitable solution due to the peculiarities and the difficulties of vehicular cloud computing in general. In addition, three different objectives are aiming to be met while each has its own unit (cost=money, delay=time, and privacy=data) [36].

The study in [36][37] formulated the QoE as a weighted function of provisioning delay, service price and the amount of information revealed to the service provider. However, the experience was not enough to handle all of the objectives. Thus a more comprehensive solution was needed to satisfy all the objectives. So, a framework where a Trusted Third Party (TTP) is in setup was proposed [36].

The framework uses a cluster based system to enable scalability. TTPs are in between the drivers and the service providers as shown in Figure 4. The TTP is the central control unit of the proposed framework, which handles all the communication with the service providers. The TTPs are well-known, profitable commercial organizations that provide and sell service to users.

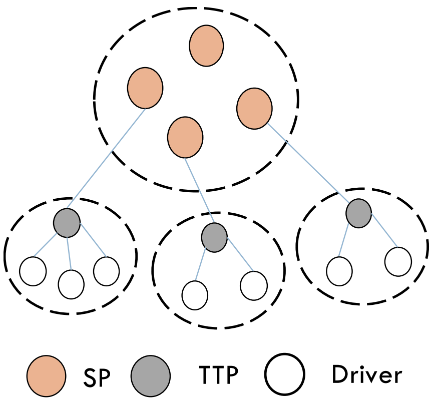

Figure 4: Proposed architecture general framework

The studies in [36][37] present three different modes for testing and comparison. The proposed framework validates our concept and assumptions since the QoE-awareness mode is a compromise between the neutral and economy class modes. At *Economy class*, the drivers are interested in the price only without any worries about the privacy or the delay. On the other hand, *Neutral mode* does not consider any of the QoE aspects, so the user simply connects to the first available TTP around. The QoE in the information revealed experiments shows improvement in the amount of information that must be revealed. The privacy sensitive mode also indicates that users with serious concerns about their personal information/data should select this model, since it reveals the least information to the service provider. The delay performance also has been improved in [37] via delay sensitive mode. The Delay sensitive mode and the Neutral mode introduce the least delay at its early stage of experience. However, when the number of vehicles increases (e.g. ~20), there will be more experience to improve QoE-aware decision. This results in having very close delay compared to delay sensitive and the neutral modes.

VI. CONCLUSION

Cloud Computing and Vehicular Networks are profoundly emerging research fields. Cloud copmuting is still in its early stage of development while vehicular cloud computing consolidates the benefits of mobile cloud computing and vehicular communications. Recent studies expect that vehicular cloud computing will be the gateway to the future of transportation systems. This paper has provided an overview of cloud computing systems (Cloud, mobile clouds, and vehicular clouds) in which its definitions, architectures, advantages, and open issues, as well as directions along with the solutions available. A recently proposed Quality of Experience (QoE)-based service provisioning framework in a vehicular cloud system has also been presented as well.

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