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# Mobile cloud computing: Challenges and future research directions

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ABSTRACT

Mobile cloud computing promises several benefits such as extra battery life and storage, scalability, and reliability. However, there are still challenges that must be addressed in order to enable the ubiquitous deployment and adoption of mobile cloud computing. Some of these challenges include security, privacy and trust, bandwidth and data transfer, data management and synchronization, energy efficiency, and heterogeneity. We present a thorough overview of mobile cloud computing and differentiate it from traditional cloud computing. Also presented here is a generic architecture that evaluates 30 recently proposed mobile cloud computing research architectures (i.e., published since 2010). This is achieved by utilizing a set of assessment criteria. Finally, we discuss future research challenges that require further attention.

## 1. Introduction

Over the past few years, mobile cloud computing has been changing the landscape of traditional mobile computing by providing on-demand, self-service, measured, elastic, and broad access mobile services. Mobile cloud computing devices such as smartphones and tablets are becoming a significant part of our modern and virtual lifestyle. For example, the number of smartphone and tablet shipments has grown exponentially and by 2016 reached 1.9 billion units globally according to the International Data Corporation (IDC) Worldwide Quarterly Smart Connected Device Tracker (Meulen, 2016). The mobile cloud computing paradigm emerged as a way to combine the benefits of mobile computing (Dinh et al., 2011) with those of cloud computing (Fernando et al., 2013) in order to better employ datacenters' computing capabilities and deliver them as mobile services. For mobile computing, mobile devices are designed with limited hardware, software, and communication capabilities with mobility being the major criteria. Regarding cloud computing, massive computing capabilities are delivered as services using virtualization and service oriented techniques to reduce cost, improve performance, or allow remote access. Mobile cloud computing enables large and powerful computing capabilities to be delivered as services. This allows mobile devices with limited resources to perform complex computations that require more powerful computing resources.

Although mobile cloud computing can offer several important benefits such as extended battery life and higher storage, scalability, and reliability, several key challenges continue to be a major impediment to mobile cloud computing adoption. These challenges include security and privacy, bandwidth and data transfer, data management and synchronization, energy efficiency, and heterogeneity that need to be resolved. We also need to address such challenges in order to enable mobile cloud service consumers to enjoy the advantages of mobile cloud computing. Traditional cloud computing approaches might not be adequate for the current mobile cloud computing environment due to their limited connectivity, energy constraints, and distributed nature (Fernando et al., 2013; Dinh et al., 2011; Kovachev et al., 2011).

In this study, we compare and contrast traditional cloud computing with mobile cloud computing. We compare 26 recent surveys (i.e., published from 2010 to the present day) on mobile cloud computing by highlighting their focus; the components of the proposed architecture for mobile cloud computing if there is any, expressing their contributions, identifying the analysis technique used to determine research challenges for mobile cloud computing and describe these challenges. Moreover, we propose a generic architecture that covers all layers of mobile cloud computing to identify the relevant issues. In particular, we compare 30 recent representative mobile cloud computing research architectures (i.e., since 2010) using our proposed architecture. To study these research architectures, we identify several assessment criteria. As well, we provide a holistic view of the current status of mobile cloud computing by presenting a quantitative analysis (i.e., where statistical information about mobile cloud computing architectures is used), and benchmark comparison to determine research challenges for

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mobile cloud computing which represent the main contribution of our work. Furthermore, we also discuss future research challenges for mobile cloud computing based on the comparison of the recent representative mobile cloud computing research architectures.

The rest of the article is organized as follows. In Section 2 we present the related work and compares 26 recent surveys on mobile cloud computing. In Section 3, we present some background information and document a comparison between traditional cloud computing and mobile cloud computing. In Section 4, we propose a generic architecture for mobile cloud computing and identify a set of dimensions which are used for comparing recent representative mobile cloud computing research architectures. Section 5 presents our survey and evaluation of 30 recent representative mobile cloud computing research architectures. In Section 6, we discuss critical research challenges and propose future research directions. In Section 7, we make some concluding remarks and point out the implication of this research.

## 2. Related work

Mobile cloud computing has been an active research area in recent years and several surveys have been published on this topic. (Chetan et al., 2010), conducted one of the first surveys that focus on mobile cloud computing issues. This survey presents an overview about how mobile cloud computing works, discusses some problems and possible solutions related to mobile cloud computing, and outlines the advantages of mobile cloud computing. Furthermore, the survey presents some research issues that needs to be addressed such as absence of standards, access schemes, security, and the need for elastic mobile applications (Dinh et al., 2011). present an overview of mobile cloud computing definitions, architecture, and benefits. The survey proposes an architecture of mobile cloud computing which consists of five components including mobile users, network operators, Internet service providers, application service providers, and datacenter owners. Apart from a discussion of the issues, existing solutions and approaches of mobile cloud computing, the survey provides future research directions in mobile cloud computing with a focus on low bandwidth, network access management, quality of service, pricing, standard interface, and service convergence (Kovachev et al., 2011). compare several mobile application models that are compatible with cloud computing according to a set of criteria including the enabling middle-ware, cost model, programming abstraction, solution generality, implementation complexity, static and dynamic adaptation, network load, and scalability. Based on the comparison, the authors discuss many research challenges including programming abstraction, cost model, adaptation, cloud integration, and trust, security and privacy (Cox, 2011). presents a brief overview of mobile cloud computing devices, trends, issues, and enabling technologies. The author argues that in a few years, there will be one trillion cloud-ready devices such as smart phones, tablets, and WiFi sensors. The most challenging issues present in this work include device resource poverty, latency, bandwidth, and security.

Bahl et al. (2012) provide a brief study on the combination of mobile and cloud computing, and argue for the need to offload tasks of mobile applications. In their study, the authors propose a mobile cloud computing architecture which consists of four components, including mobile devices, wireless core, WiFi AP, and Regional Data Centers (RDC). Moreover, the authors compare different programming models (e.g., CloneCloud (Chun and Maniatis, 2009), MAUI (Cuervo et al., 2010), Odessa (Ra et al., 2011), and Orleans (Bykov et al., 2011)) for mobile cloud computing (Qi and Gani, 2012). review mobile cloud computing characteristics and architectures. Also, the authors propose a mobile cloud computing architecture comprising four components; mobile devices, wireless access point and mobile tower, servers and VMs. Furthermore, the authors provide a comparison of four mobile cloud computing architectures including CloneCloud system architecture (Chun and Maniatis, 2009), AlfredO system architecture (Giurgiu et al., 2009), and CloudLet (Satyanarayanan et al., 2009). It is contended that more research is required on data delivery, task division, and better service provisioning. (Fernando et al., 2013), present a survey on mobile cloud computing and provide a taxonomy based on some key issues such as operational issues, end user and service levels, security, context awareness, and data management. In addition, the survey proposes a mobile cloud computing architecture which consists of five components including privacy and security manager, context manager, resource handler, cost manger, and job handler. Furthermore, the study provides an overview of cost models in mobile clouds and a comparison of connection protocols used in mobile clouds. Based on the results of the comparisons, the authors think that the challenging research issues in mobile cloud computing include operational, presentation and usability, service level, privacy and security, context awareness, and data management. (Rahimi et al., 2014), present a survey on mobile cloud computing and provide a comparison of 16 mobile could computing systems based on a set of criteria including objectives, used technology, wireless connectivity type, and security and privacy. The survey discuss some research open issues such as power and execution time efficiency, communication bandwidth efficiency, and security and privacy.

More recently (Stergiou and Psannis, 2017), in their more generic survey cover the latest advances in mobile cloud computing and Internet of Things (IoT) concerning big data applications. There is an emphasis on the main features and trade-offs concerning IoT and mobile cloud computing. Furthermore, the survey discusses research challenges such as security, connectivity, performance, latency, and privacy (Wang et al., 2015). look at existing infrastructure-based mobile cloud computing applications in their analysis. They categorizes mobile cloud computing into four categories namely i) crowdsourcing applications, ii) collective sensing applications (e.g., traffic monitoring, social networking, and healthcare), iii) location-based applications, and iv) augmented reality and mobile gaming applications. Furthermore, the research challenges that emerge in their paper include code computation (offloading), task-oriented mobile services, elasticity and scalability, security, and cloud service pricing. (Abdo and Demerjian, 2017), investigate mobile cloud computing architectures and applications. In particular, the survey proposes a mobile cloud computing architecture characterized by four components specifically E-UTRAN, mobile operator's core network, internet, and cloud service provider's network. Moreover, their study presents a comparison of four mobile cloud computing architectures' performance against non-quantifiable requirements which include privacy, mobility, scalability, and multicast capability. In addition, the survey compares 14 mobile cloud computing applications performance when deployed across different mobile cloud architectures. The application performance is measured using quantifiable metrics such as cost, delay, and power consumption.

Some surveys on mobile cloud computing focus on specific aspects such as security and energy efficiency. For example (Alizadeh et al., 2016), comprehensively focus on authentication methods in mobile cloud computing. Their study proposes four mobile cloud computing architecture models including i) Distant immobile cloud, ii) Proximate immobile computing, iii) Proximate mobile computing, and iv) Hybrid computing. Specifically, these authors compare authentication methods used in mobile cloud computing with the ones used in traditional cloud computing. The survey also evaluates existing authentication methods using five metrics namely; usability, efficiency, security and robustness, privacy, and adaptability to mobile cloud computing environments. Furthermore, the challenges they found requiring further analysis concerning authentication in mobile cloud computing include heterogeneous infrastructure, seamless handover, identity privacy, and resource scheduling. (Gai et al., 2016a), explore intrusion detection techniques for mobile cloud computing in heterogeneous 5G. In their comparison of 5 intrusion detection techniques for mobile cloud computing, they employ a set of metrics comprising methodologies, principle, performance, and limitations. Offered here is a high level framework for leveraging mobile cloud computing-based intrusion