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Cloud Computing for Mobile Health: Opportunities and Challenges

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Abstract: *Mobile Cloud Computing (MCC) is a new paradigm for mHealth applications. It has the potential to leverage mobile platforms limitations, improve capacity, reliability, and accessibility of mHealth services, benefit mHealth research, and change the face of healthcare information technology. However, as with any innovation, the integration of cloud computing with mobile computing should be evaluated before its widespread adoption. The aim of this paper is to explore the main limitations of mobile platforms, and identify the opportunities and challenges of MCC. This paper discusses the concept of MCC and its current state in mHealth, and evaluates the opportunities and challenges of this computing paradigm from various aspects including contextual, technical, technological, management, security, and quality aspects.*

Keywords: *Cloud Computing; Mobile Computing; Mobile Cloud Computing; Mobile Health.*

I. Introduction

The use of mobile phones has increased dramatically in recent years. The International Communication Union [1] indicated that there were approximately 7 billion mobile subscriptions of the end of 2014. At the same time, the consumers and enterprises market for cloud-based mobile applications rose to $9.5 billion by the end of 2014 according to a study from Juniper Research [2]. Another report conducted by ABI Research [3] showed that "By the 2015, more than 240 million business customers will be leveraging cloud computing services out of mobile devices, for revenues of $5.2 billion." These indicators highlight the importance of cloud computing for mobile applications where smart phones are now considered the main platform to overtake the role of PCs.

The pervasive and ubiquitous access to healthcare data becomes essential for proper diagnosis and treatment. Establishing mHealth records (MHRs) systems will offer a wide range of advantages such as providing accurate, up-to-date, complete information about patients at the point of care.

Moreover, it will enable healthcare professionals to access the patients' medical records easily and quickly, and provide an interaction and communication platform between patients and health professionals[4].

Mobile health offers hospitals and healthcare organizations a variety of on-demand services on clouds rather than standalone applications on local servers. Thus, it is clear that mobile health systems have a diverse spectrum of stakeholders with different needs. Hence, establishing MHRs systems on a national level requires a user's acceptance. Despite its importance, the adoption of the use of mHealth applications still faces challenges and barriers at the cultural, technological, social, organizational, and political levels, especially in developing countries [5]. Moreover, developing mHealth infrastructure for information and communication is very hard from the technical perspective [6], because infrastructure needs are huge and it is very difficult to offer quick and easy access in general data centers.

Mobile devices are facing several challenges in terms of their resource requirements [7], which poses problems in promoting mHealth applications. Most mHealth applications require extensive processing and storage capacity (e.g. image and video storage and processing, and storage of patients records), all these computational and storage capacities restrict the developers in building health applications for mobile phones.

These problems and barriers need to be overcome in order to realize the full potential of mobile computing.

Several research papers and reports predicted that cloud computing can leverage mobile platforms limitations, enhance security, improve capacity, reliability and accessibility of mHealth services, benefit mHealth research, and change the face of healthcare information technology (IT) [8] [9] and [10].

MCC is a new paradigm for mHealth applications [11] whereby most of the processing and data storage associated with these applications is moved off the mobile devices to powerful centralized computing platforms located in the cloud. The strength of cloud computing can be abstracted in terms of the services: software as a service (SaaS), platform as a service (PaaS), and infrastructure as a service (IaaS). Cloud computing provides facilities to access shared resources and manage information in a ubiquitous and pervasive manner supporting several platforms, systems, and applications [12]. Compared with traditional computing, cloud computing provides four new advantages: extensive computing resources and services available on demand, broadband network access, moves IT infrastructure from an upfront capital expense to an operational one, and finally payment for use on a short-term basis as needed [13].

Although cloud computing for mHealth applications has the potential to improve mobile platforms limitations and save cost [12, 14, 15], there also are several technical, management, technology, security, and quality issues that need to be addressed. The aim of this paper is to explore the main limitations of mobile platforms, discuss the concept of cloud computing and mHealth records, and identify and evaluate the opportunities and challenges of mHealth cloud computing.

II. Concepts of Cloud Computing and Mobile Health Records

2.1 Cloud Computing: An Overview

A. *Cloud Computing* refers to "an on-demand, self-service Internet infrastructure that enables the user to access a shard pool of computing resources (e.g., networks, servers, storage, applications, and services) anytime from anywhere, these resources can be rapidly provisioned and released with minimal management effort or service provider interaction" [16].

B. *Services Models* of cloud computing can be categorized into the following three services models [16], [13] and [17]: (1) Software as a service (SaaS): healthcare organizations release their applications (e.g, EHRs) on a hosting environment and they are made available to customers over a network. Healthcare organizations do not have control over the cloud infrastructure. Example of non-health SaaS include: Google Mail, and Google Docs. (2) Platform as a Service (PaaS): PaaS provides a development infrastructure that supports the full software lifecycle such as programming languages, tools, and management. Health applications developers can develop their applications and services directly on the cloud. Examples of PaaS are Google App Engine and Windows Azure. (3) Infrastructure as a Service (IaaS): A cloud user uses IT infrastructure to support operations, including processing, storage, hardware, servers, and networking components. An example of IaaS is Amazon's EC2, Microsoft Azure, Dropbox and so on.

C. *Deployment Model* defines where the physical servers are deployed and who manages them. To deploy cloud-computing services, the US National Institute of Standards and Technology (NIST) identify four models [16]: (1) Public cloud: owned by specific cloud services provider, it is designed to make resources (applications and storage) available to public users on the Internet. Amazon EC2, S3, Google AppEngine, and Force.com are examples of public cloud [13]. (2) Private cloud: A cloud infrastructure is operated solely for a single organization. Private cloud is usually used by enterprises or organizations where the services can only be accessed locally, and are managed by their IT managers. (3) Community cloud: The infrastructure for the community cloud is shared by several organizations and supports a specific community that has common concerns (e.g. security requirements). (4) Hybrid cloud: The cloud infrastructure is an integration of two or more clouds (private, community, or public).

2.2 Mobile Health Records

Nowadays, most hospitals and medical centers have been integrated with IT technologies to improve their daily operations. A primary aspect of health information systems is the development of patients' electronic medical records as a means to record health activity and create a communication platform between patients and healthcare professionals for better care.

The term electronic health record (EHR) is widely used. It is an efficient way to improve the healthcare services and to enable healthcare providers to access and share patients' information [14]. EHR describes the concept of a comprehensive system; it is a collection of patient's health records (PHRs) and healthcare data. Therefore, it includes information from all the clinicians, immunizations, family medical histories, previous health providers and so on [18]. An EHRs system is the system that supports the medical information collection, management, storage, sharing, and performance [19]. The Mobile Health Record (MHR) is a similar concept to HER.

Using MHRs will make medical information accessible not only for health providers, but also for patients. MHRs have the potential to help patients and health providers to access and share the medical data from numerous locations at any time.

As the shift from paper-based records to EHRs provides several benefits to health providers and patients, MHRs can also optimize the benefits of EHRs. A substantial portion of a doctors' time can be spent on obtaining the patient's medical history, and then the physician dictates, arranges the information before he or she can make a diagnosis or other treatment procedures [14]. Accessing a patient's previous health information form mobile devices will save a lot of time, and it will help healthcare professionals to provide better services to patients, as well as, it will be a suitable way to exchange and manage health information on the go.

III. Mobile Cloud Healthcare Applications Initiatives

The applications of pervasive and ubiquitous technologies in healthcare involve patients' monitoring systems**,** telemedicine, location-based medical services, data collections, healthcare information systems, and emergency response, which have already been applicable. There are few schemes of mobile cloud applications in the healthcare domain. A telemedicine mobile cloud homecare management system [20] is implemented in Taiwan to monitor participants, especially for patients with hypertension and diabetes. The system monitors 300 participants and stores more than 4736 records of blood pressure and sugar measurement data on the cloud. The authors in [15] built an application for management of medical image data in a cloud. [21] proposes @Health Cloud, a prototype implementation of a mHealth information management system based on cloud computing and a mobile client running the android operating system. Some researchers use cloud computing to enhance mHealth applications in the field of security [12].

IV. Adopting Cloud Computing for Mobile Health: Opportunities and Challenges

As with any innovation, the integration of cloud computing with mobile computing should be evaluated before its widespread adoption. According to our knowledge so far there is no research effort that has systematically studied the impact of cloud computing on mHealth care in terms of its opportunities and challenges. This study reviews the literature and evaluates the opportunities and challenges from contextual, technical, technological, management, security, and quality aspects.

4.1 Contextual Aspects

Before evaluating the flexibility of adopting cloud computing for mHealth, it is important to pay attention to assessing mHealth technology first. Studying users' acceptance is a very critical important factor to determine the success or failure of such technology. It is difficult to adopt mHealth services unless there is social acceptance and official support. In this context, we proposed a technology acceptance model for mobile health systems [5].The research provided an in-depth exploration and examination of the factors that influence the user's intention to use mHealth services focusing on technological, cultural, organizational, political, and social aspects. Twelve factors are used to assess mHealth technology acceptance including intention to use, perceived usefulness, perceived ease of use, social influence, facilitating conditions, perceived value, mHealth anxiety, trust, data privacy, resistance to change, self-efficacy, and portability. The main challenges for adopting mHealth technology according to 302 health professionals and patients questionnaire replies, are the lack of health awareness, absence of official support, absence of needed legislation, and lack of confidence in mobile health services and services providers.

4.2 Technical Aspects

The key technical opportunities for mHealth cloud computing are to improve data storage capacity and processing power, extend battery lifetime, and increase efficiency, as discussed in the following:

A. Improve Data Storage Capacity and Processing Power: Storage capacity is considered one of the main limitations in mobile devices. MCC is established to enable mHealth cloud users to store/access the large data on the cloud (e.g. medical images exchange) through wireless networks [15]. With the cloud, mHealth users can save considerable amounts of energy and storage space on their mobile devices since all images and files will be sent via and processed on the cloud [7]. A typical example of such services today is the Apple's iCloud which provides a large amount of storage space for mobile cloud users.

B. *Extend Battery Lifetime:* The battery is one of the main limitations of mobile devices. The extension of battery life in smart phones seems to be a key factor. A number of solutions have been suggested to improve the performance in terms of the reduction of power consumption by applying computation-offloading techniques. Computation offloading aims to migrate the large computations and complex processing from resource-limited devices (i.e., mobile devices) to resourceful machines (i.e., servers in clouds) [12]. Several studies have shown that computation offloading avoids taking a long application execution time on mobile devices, which results in a large reduction of energy consumption [22] and found that the remote application

execution can save energy significantly. However, reliability and security aspects need to be considered in addition to energy saving aspects.

The technical challenges for adopting mHealth cloud computing can be listed in the follows:

C. ***Multiple Mobile Platforms and Development Languages****:* Different mobile platforms are presented such as iOS operating system for Apple, android for Google and windows phone 7 for Microsoft and their associated development platforms vary (from Objective C, C++, Java, Silverlight). It is hard to deliver mHealth applications that operate across-device platforms. Recently, more developers are looking towards HTML5 applications as a solution for targeting multiple devices and platforms [23]. This is because that web browser is becoming the default platform and its de facto standards are HTML5 and JavaScript.

D. ***Computation Offloading Overhead:*** Performance correlates positively with offloading health data to be stored and processed in the cloud servers in order to save energy consumption. However, there are concerns regarding the offloading overhead for privacy, security, reliability, and data communication during the offloading process especially in a dynamic environment (e.g., changing connection status and bandwidth).

4.3 Technological Aspects

Scalability and flexibility are considered the main technological opportunities of MCC in healthcare systems. MHRs systems have a large amount of health information, which would be accumulated overtime in traditional servers, so data maintenance becomes a problem. When the patient population increases, the scalability of the applications becomes another problem. Mobile healthcare systems offer healthcare providers dynamic on demand services on the cloud computing rather than owning standalone applications on local servers [24]. Dynamic on demand services, rapid elasticity, pervasive and ubiquitous access to health resources, multi-tenancy, ease of integration, self-service are features offered by service providers that allow mobile users to run their applications without advanced reservation of resources [13]. Whenever demand increases, the healthcare providers do not need to adjust their infrastructures to keep up with the changes. Service providers can easily add and expand an application and service without or with few constraints on the resource usage.

The following challenges represent the main technological concerns of MCC:

A. Lack of Standards*:* In spite of the benefits that cloud computing is believed to have, there will be ongoing challenges with interoperability, portability, and migration [17] [25]. Cloud computing services still does not have an open acknowledged standard. Cloud services providers speak different languages; all the major providers offer unique data storage (for example, Google's BigTable, Amazon's Dynamo, and Facebook's Cassandra). Cloud users face severe constraints if they need to move their data or services to another provider or back to an in-house IT environment. For example, Google decided to discontinue its Google Health service on January 2012; users have a year to download their health data [26]. Thus, establishing standards that rely on multiple cloud services providers should solve the highlighted issues and would facilitate interoperability between services providers [27].

B. ***Bandwidth Stability and Network Delay:*** Compared with traditional cloud computing, MCC poses challenges in the way that mobile devices access data stored on the cloud. This is due to the inherited challenges of mobile computing such as low bandwidth, and mobility characteristic, and transient connectivity [28]. Maintaining a constant bandwidth by mobile network operators will enable MCUs to improve data access and achieve low delay/ wait time. As mHealth applications make ever-more intense use of large volumes of data, mHealth users may find that there is a data transfer bottleneck because of network limitations.

4.4 Management Aspects

Cloud Computing can provide several opportunities and concerns on MHRs management systems:

A. On Demand Self-Service*:* Cloud computing offers hospitals and healthcare organizations dynamic on demand services on the cloud and allows accessing cloud services easily without going through a long process. mHealth providers can get the provisioned computing capabilities, such as server and network storage, as needed automatically without requiring human interaction with each service provider [13].

B. Economic Savings*:* It is important to mention that the use of cloud computing avoids a large initial investment in the infrastructure, which is impossible to face for some health care organizations. Without cloud computing, MHRs systems' providers need to estimate the number of potential users that the system would have to handle in the future [8]. If the estimation fails, the health providers will have to increase the number of servers, which means a large economic cost. Cloud computing is a cost-effective way to optimize their resources and save costs. However, mHealth providers must consider the tradeoffs amongst computation, communication, and integration [13]. Hosting mHealth data on the cloud can significantly reduce the infrastructure cost, but it does raise the cost of data communication, i.e. the cost of transferring 10 Tbytes of data to or from the public cloud required US$1,000 in network transfer fees. Another example, Amazon's Scalable Storage Service (S3) charges $0.12 to $0.15 per gigabyte-month, with additional bandwidth charges of $0.10 to $0.15 per gigabyte to move data in to and out of AWS over the Internet.

C. Access Schemes*:* mHealth cloud services will be deployed in a heterogeneous way with a wide range of different access technologies such as WLAN, CDMA2000, GPRS, WiMAX and WCDMA [25]. The access management process is considered one of the most significant issues in mobile cloud services. MCC requires 'always-on', 'on-demand' available wireless connectivity, and network selection services in order to meet some of the mHealth cloud services requirements such as scalability, availability, as well as cost and energy efficiency [28].

***D. Revenue Model*:** Using cloud for mHealth involves two services providers, which are: cloud services provider and mHealth services provider. Both of these providers have different services management, customer's management, methods of payment and prices. Therefore, this will lead to many issues, i.e., how to price the service offerings, how the revenue will be shared among different providers, and how the mHealth users pay.

4.5 Security and Privacy Aspects

Security is one of the biggest challenges of cloud computing [17] and mobility. The security threats are categorized as threats associated with mobile devices, cloud platforms and application containers, and communication channels. Moreover, mobile devices face challenges with regard to delivering secure health services due to limitations in computation and power. Thereby, they are unable to run heavy-duty security algorithms [12]. One potential solution is to move threat detection services to the cloud. It will save the mobile CPU and memory requirements but at the same time, it will increase bandwidth cost.

A. *Enhance Security**:* MCC can act as a comprehensive data security model for both mHealth services providers and mHealth users. MCUs can utilize the benefit of an inclusive data security model, all kinds of security measures and security services such as virus scanning, authentication, encryption, and malicious code and threat detection can be remotely provided to mobile users [12].

B. *Data Privacy*: Although the cloud infrastructure can be used to store patient health information and their personal details, public cloud computing poses privacy concerns with respect to data sharing, this is a very crucial issue for medical data. For organizations whose existence depends upon safeguarding customer data, classified information, or proprietary information such as health data, public cloud providers don't generally offer sufficient protection [17]. As discussed in [29] and [17] using a private cloud is a suitable way to ensure more data security and privacy than public cloud. We should note that mHealth users would need to feel confident when offloading their data to the cloud that their privacy would not be violated.

4.6 Quality Aspect

Quality in MCC was studied in various dimensions such as communication quality [25], services quality, reliability, availability and so on.

A. *Communication Quality*: It is not easy to obtain continued connectivity for mHealth cloud services due to low bandwidth transient connectivity, and mobility characteristics of mobile devices. The MCC concept relies on an "always-on" and "on-demand" wireless connectivity and will need to provide scalable and high bandwidth mobile access [28]. Bandwidth still being one of the biggest issues in MCC, mHealth cloud computing systems require instant processing of large amounts of data that must be sent over the network. New technologies 4G/ Long Term Evolution (LTE)/Femtocell are emerging as promising technologies in order to resolve connectivity problems and increases bandwidth capacity [30].

B. *Services Quality*: Quality of services refers to set of properties that include transmission rate, network status, uptime, performance, trust, data privacy, and satisfaction [31]. Data and privacy protection of mHealth records are essential to health organizations to build customers' trust which is needed for cloud computing to reach its full potential. Cloud providers must adopt clearer policies and provide their clients legal guarantees in security and privacy terms [8]. Compared to traditional cloud services, which may heavily rely on computers and static internet connections, mobile cloud services have more challenges in term of providing an assurance of quality of services. The limited resources of mobile devices (e.g. battery life, storage, and bandwidth), the mobility of mobile users, and the network latency affect the quality of mobile cloud services [31]. A lack of well-defined service level agreements (SLAs) by cloud providers is another problem. Some of the key questions needing answers are: What are the guarantees that make cloud providers fulfill their obligations? What are the repercussions if the provider fails to satisfy a customer's requirements? What will happen to a health organizations' data if the organization moves to a different provider? How does one ensure privacy and data security [17]. To date, the problem of SLAs is still in need of a systematic solution.

C. *Improve Reliability and Availability:* Storing mHealth data in the cloud is an effective way to improve the reliability. Since these data and applications will be saved into various servers, thereby decreasing the chances of loss of data on such smart phones [32]. Storing data and services in the cloud make them always (almost) available even when the users are moving.

V. Conclusion

In fact, mHealth and cloud computing are still under development. The concept of cloud computing provides a brand new opportunity for the development of mHealth applications since it moves the computation and processing overhead to the cloud environment. It is important to emphasize the radical change that the cloud computing paradigm presents in a large variety of fields like mHealth. The bandwidth limitation and transient connectivity are still big concerns in MCC. However, as mobile internet capabilities continue to get better; it is likely that solutions to this particular problem will become apparent. 4G network and femtocell are emerging as promising technologies that overcome network limitations. New programming languages such as HTML5 already provide a solution for the heterogeneity in mobile operating systems and development languages. They

enable data caching through a mobile device, and this allows a cloud application to continue working if a connection is temporarily lost. Trust in cloud providers and data privacy concerns represent a major obstacle in adopting cloud computing for mobile healthcare systems. Over time, these concerns may be resolved or the risks will be reduced to acceptable levels. For now, these concerns have kept cloud adoption at a medium pace. Future work in this area has to include more wide-scale development of prototypes. Enhanced MCC platform are needed to overcome their current limitations.

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