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Mobile Cloud Computing Research – Issues, Challenges and Needs

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ABSTRACT

With the rapid advance of mobile computing technology and wireless networking, there is a significant increase of mobile subscriptions. This drives a strong demand for mobile cloud applications and services for mobile device users. This brings out a great business and research opportunity in mobile cloud computing (MCC). This paper first discusses the market trend and related business driving forces and opportunities. Then it presents an overview of MCC in terms of its concepts, distinct features, research scope and motivations, as well as advantages and benefits. Moreover, it discusses its opportunities, issues and challenges.
Furthermore, the paper highlights a research roadmap for MCC.

Keywords : Mobile Cloud Computing, Cloud Computing, Mobile Cloud Services, Mobile Cloud Applications, And Mobile Computing.

I. INTRODUCTION

Recently, there is a significant increase of mobile subscriptions due to the rapid advance in mobile computing and wireless technology and networking. According to TechNavio analysts' forecast, the Enterprise Mobile Cloud Computing market in North America will grow at a CAGR of 18.12 percent in 2011–2015. One of the key factors contributing to this growth is the growing demand for enterprise mobility. The primary vendors, dominating this market space, include Amazon, Terremark Worldwide, IBM, and Salesforce.com

Today's advance in cloud computing provides significant benefits to mobile users as cloud infrastructures and platforms supply virtually large-scale computing power with elastic scalability and higher resource sharing and usage. This may overcome many traditional limitations in mobile computing. By carrying out the advantages from mobile computing in ubiquitous, convenient mobile access, and location-ware application services, mobile cloud computing has the following unique advantages [3].

- Compute and storage efficiency: By offloading demanding workloads and large data to the cloud, the mobile device can limit the amount of processing power and data storage that it requires.

- More powerful mobile applications: Since the mobile device now has access to a powerful cloud on the back end, we have the potential to create more powerful mobile applications than previously possible. - Energy efficiency: Much of the resource-intensive work in mobile applications can be offloaded to the cloud, which means that mobile clients can focus more on reducing energy consumption without trading off on performance. - Thin Mobile Clients: Less resource demands on the mobile client means that we can build less powerful mobile devices that achieve better overall performance when coupled with a cloud platform. This gives us the ability to "dumb down" the mobile clients, to the extent that they only handle user interaction and offload all application work and data to the cloud.

The primary objectives of the MCC paradigm are to take the advantages of cloud computing and apply it to the mobile space, to utilize the cloud only when it is advantageous (i.e. when it improves performance, reduces resource utilization, or provides robustness), leverage location-awareness when possible, and leverage the scalability potential of cloud platforms.

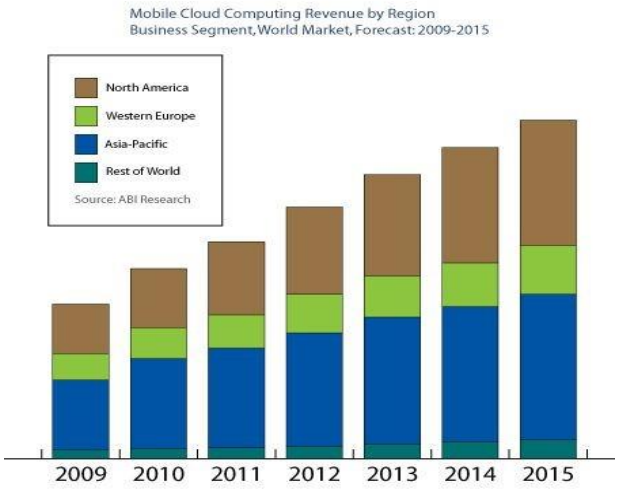

Figure 1 Mobile Cloud Computing Revenue by Region 209-2015
(ABI Research)

According to the latest Visiongain report, "the mobile cloud computing market will generate 45 billion dollars in revenues by 2016. This strong business market trend brings many business opportunities and research needs on mobile cloud computing. According to the authors in [21], mobile clouds are in demand to meet application needs in image processing, natural language processing, crowd computing, sensor data applications, multimedia search, and social networking.

Recently, there are a number of published papers addressing mobile cloud computing concepts and research issues from different perspectives. For example, L. Zhong, B. Wang, and H. Wei in [20] address mobile cloud computing from mobile internet point of views. They point out six major characteristics of mobile cloud computing. They are: a) break through the terminal hardware limitations, b) convenient data access, c) intelligent load balancing, d) effectiveness of task processing, e) on-demand service to reduce costs, and f) elimination of regional restrictions. In addition, they discuss a service model and the system architecture of mobile cloud computing. In addition, the authors in [34] examine the existing mobile cloud computing models and present their comparisons.

Han Qi and Abdullah Gani in [19] discuss mobile cloud computing using an integrated view of cloud computing and mobile computing. They reviewed some earlier research in mobile cloud infrastructures and architectures, including Hyrax Infrastructure,

Cloudlet, AlfredO Architecture, and CloneCloud. In addition, they also point out some challenges in MCC in three perspectives: a) mobile device limitations, b) quality of communications, and c) division of application services. Moreover, the paper also

presents some open research issues in data delivery, task division, and services.

S. Dey in [18] looks at early trends in cloud mobile media services, and opportunities and benefits in the near future, and analyzes the possible impacts and issues in system and user response time, cloud user experience, energy, privacy, cost and scalability. Moreover, the paper addresses several research directions for possible solutions in cloud mobile media.

Hoang T. Dinh et al. [23] point out that MCC integrates the cloud computing into the mobile environment and overcomes obstacles related to the performance (e.g., battery life, storage, and bandwidth), environment (e.g., heterogeneity, scalability, and availability), and security (e.g., reliability and privacy) discussed in mobile computing. The paper discusses a number of popular mobile applications in MCC, including mobile commerce, mobile healthcare, mobile learning, mobile gaming, and mobile search. In addition, the paper also presents two groups of issues. The first group includes mobile communication issues, such as low bandwidth, availability, and heterogeneity. And the next group contains computing issues, such as offloading in both static and dynamic environments, security and privacy, and data access efficiency. Moreover, the paper also presents some open issues for future research directions in low bandwidth, network access management, pricing, quality of service, standards, and service convergence.

Unlike other research work, in this paper, we discuss mobile cloud computing in an integrated view from mobile computing; cloud computing, and network computing. The paper first discusses MCC in a tutorial approach to cover its concepts, motivation, distinct features, advantages and benefits. Then, it presents the research scope and a road map of mobile cloud computing and services in three generations. Some detailed discussion and comparisons are given to show their distinct features and improvements. Finally, we address the important issues and challenges in MCC for future research in different areas, including mobile cloud security and privacy, mobile SaaS engineering, mobility, green computing, and mobile cloud infrastructures.

II. Mobile Cloud Computing

2.1 What is mobile cloud computing?

Several definitions of MCC are available, For example, MCC is defined as "a rich mobile computing technology that leverages unified elastic resources of varied clouds and network technologies toward unrestricted functionality, storage, and mobility. It serves a multitude of mobile devices anywhere anytime through the channel of Ethernet or Internet regardless of heterogeneous environments and platforms based on the pay-as-you-use principle [1].

The MCC forum (http://www.mobilecloudcomputingforum.com/) defines MCC as follows:

'Mobile cloud computing at its simplest, refers to an infrastructure where both the data storage and data processing happen outside of the mobile device. Mobile cloud applications move the computing power and data storage away from mobile phones and into the cloud, bringing applications and MC to not just smartphone users but a much broader range of mobile subscribers'.

According to Aepona's white paper, titled as Mobile Cloud Computing Solution Brief, MCC is defined as "a new paradigm for mobile applications whereby the data processing and storage are moved from the mobile device to powerful and centralized computing platforms located in clouds. These centralized applications are then accessed over the wireless

connection based on a thin native client or web browser on the mobile devices.''

Furthermore, MCC often involves three foundations, namely cloud computing, mobile computing, and networking, and can be considered as an emerging cloud service model following the trend to extend the cloud to the edge of networks". [2]

We define MCC as follows:

MCC is an emergent mobile cloud paradigm which leverage mobile computing, networking, and cloud computing to study mobile service models, develop mobile cloud infrastructures, platforms, and service applications for mobile clients. Its primary objective is to delivery location-aware mobile services with mobility to users based on scalable mobile cloud resources in networks, computers, storages, and mobile devices. Its goal is to deliver them with secure mobile cloud resources, service applications, and data using energy-efficient mobile cloud resources in a pay-as-you-use model.

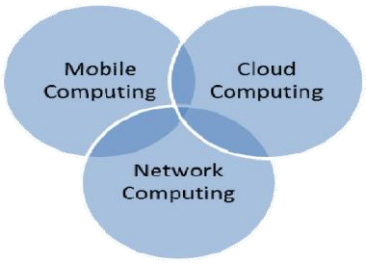

Figure 1. The Scope of Mobile Cloud Computing

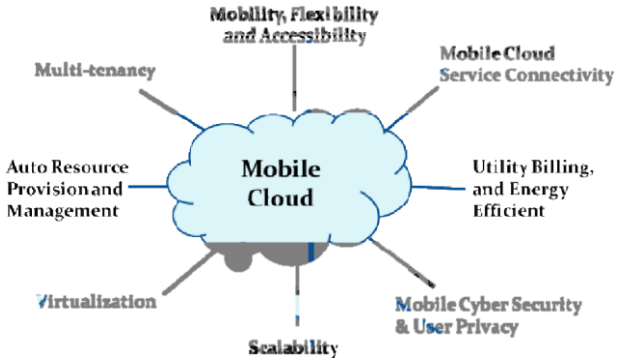

Figure 2 Primary Features of Mobile Clouds

As shown in Figure 2, mobile clouds have the following features:

• Auto resource provision and de-provision – Mobile clouds enable auto resource provisions and de-provisions of cloud computing resources, network resources, and mobile device resources.

• Scalability – In mobile clouds, scalability includes three dimensions: a) cloud scalability, b) network scalability, and c) mobile scalability in terms of mobile users and devices.

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• Mobility, flexibility, and accessibility – Mobile clouds enable mobile users to access mobile cloud applications and services anytime and anywhere with personal accessibility.

• Mobile cloud service connectivity – Mobile clouds offer welldefined connectivity APIs and protocols to enable easy and secured connectivity between different networks, and standards, and third-party software and systems.

• Virtualization – Three types of virtualizations can be supported in mobile clouds: a) network virtualization, b) cloud virtualization for various computing resources, and c) mobile devices and resources.

• Multi-tenancy – This feature allows single mobile cloud software instance to serve multiple mobile tenants on a wireless Internet or heterogeneous networks.

• Mobile cyber security and privacy –This refers to the body of security capabilities, technologies, processes and practices designed to protect mobile devices, heterogeneous networks (both wireless network and Internet), cloud servers, mobile application service programs, and data from attack, damage or unauthorized access.

• Mobile utility billing and energy efficient – This refers to the provided mobile-based utility models, i.e., meter-based, volume based, and subscription-based for service billing.

2.2 Why Mobile Cloud Computing?

Mobile computing is the major driving force of MCC. Worldwide mobile application store downloads were forecasted to reach 17.7 billion downloads in 2011. That is a 117 percent increase from an estimated 8.2 billion downloads in 2010. According to Gartner Group, by the end of 2014, over 185 billion applications will have been downloaded from mobile app stores.

The motivations of MCC are listed below.

- ✓ Address the needs in increasing the processing power and battery life time of mobile devices.
- ✓ Cope with the increasing services and application needs of most mobile users with low-end mobile devices.
- ✓ Maximize the resource sharing and reuse of existing computing resources in cloud infrastructures and Internetbased applications and services.
- ✓ Eliminate existing limitations of the current mobile devices.
- ✓ Leverage the mobile handsets to the existing and future cloudbased network and mobile enabled service infrastructures

MCC brings the following benefits to businesses:

- ✓ Broader reaching to all mobile users over the wireless Internet as mobile cloud applications can be accessed through a browser, the cloud computing applications can be reached by all mobile users not only smartphone users, as long as the mobile has access to the Internet.
- ✓ Expanding the scope of enterprise mobile connectivity from mobile users to the cloud community, including social network and social media cloud users.
- ✓ Increasing resource sharing and utilization in networks, cloud resources, and mobile devices diverse mobile connectivity.
- ✓ Sharing mobile information and applications, cloud applications and SaaS systems by connecting to diverse sensor networks and mobile devices so that mobile enabled smart information applications can be easily developed and deployed in various mobile applications.
- ✓ Reducing costs in mobile-based application development, deployment, and maintenance by leveraging with the existing cloud technology.
- ✓ Cut down energy consumption of mobile clouds by using energy-efficient solutions in mobile cloud infrastructures, networks and communications, platforms, and mobile SaaS.

MCC brings important benefits to mobile users and customers.

- ✓ Converting mobile devices into virtual, portable and personal desktops that are provided with unlimited virtual mobile data storage and processing power by leveraging of cloud-based data storage and access services over the wireless Internet.
- ✓ Increasing the battery life and computing power of mobile devices by offloading computation tasks cloud servers through wireless networking and mobile internet.
- ✓ Offering unlimited mobile connectivity to emergent mobile cloud infrastructures, platforms, app. stores, software–as-aservice (SaaS), and cloud-based applications.
- ✓ Eliminating the regional limitations, network connectivity and standard problems, and service barriers of wireless network service plans offered by different carriers.
- ✓ Enabling diverse virtualizations of wireless networks, mobile devices, and connectivity to existing cloud infrastructures and technologies.

2.3 Mobile Cloud Service Business Models

Similar to cloud computing, MCC adopt the utility billing model to achieve low-cost services using the pay-as-you-use approach for required resources and provided services. Several primary service models in MCC are listed below.

- ✓ Mobile Network-as-a-Service (MNaaS) – In this model, a heterogeneous network infrastructure and related resources are provided by a vendor to clients to respond on-demand requests to dynamically configure, deploy, and structure a desirable wireless network infrastructure for the mobile connectivity to existing cloud infrastructures. MNaaS provides mobile networking infrastructures as a service [6][7]. The main advantages or MNaaS is its higher elastic scalability that requires a relatively low start-up cost for a network service vendor. A MNaaS example is OpenStack Networking (http://www.openstack.org/software/openstack-networking), which is an open-source cloud operating system. It allows users to create their own networks, control traffic, connect servers, and devices to one or more networks.
- ✓ Mobile Cloud Infrastructure-as-a-Service (MIaaS) – In this model, a mobile enabled cloud infrastructure and its resources are provided to clients in the pay-as-you-use approach. In MIaaS, computing and storage resources, as well as network components and devices are provisioned, managed, and returned according to on-demand mobile client requests in a pay-as-you-use model.
- ✓ Mobile Data-as-a-Service (MDaaS) – In this model, a largescale mobile enabled databases (or data stores) and necessary storage resources are provided to clients to support data transactions, management, accesses over wireless Internet by leveraging with emergent cloud DB technology.
• Mobile Platform-as-a-Service (MPaaS) – In this model, a MCC platform is provided as a service [5]. It usually supports mobile application development, deployment, hosting, and validation with tools. A great MPaaS example is AppMobile
- ✓ (http://www.appmobi.com/) is a great MPaaS example. It provides a rich set of tools to make mobile application development and deployment as easy as possible, taking care of the development tools, hosting, and analytics.
- ✓ Mobile Software-as-a-Service (MSaaS) – In this model, a mobile enabled software-as-a-service (SaaS) and related function services are provided to clients with the mobility and location-aware capability at anywhere and anytime [4][5]. In this model, a mobile application is deployed and executed on a cloud, and mobile users will access the mobile application services through a thin mobile client based on wireless internet communications.

Figures 3 shows an ecosystem for a mobile cl ud includes the above five major contributors.

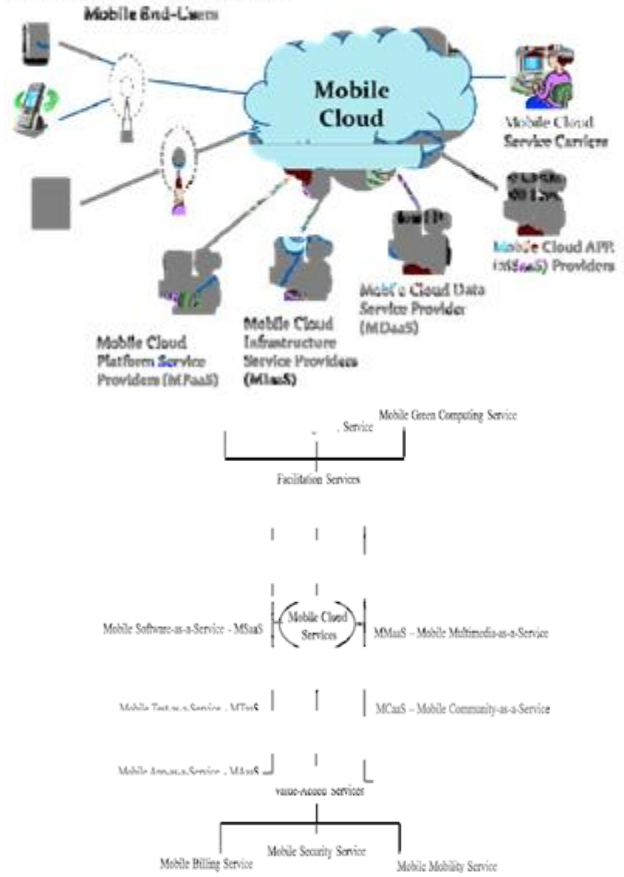

Figure 3 An Ecosystem of a Mobile Cloud

2.4. Mobile Cloud Service and Deployment models

Mobile clouds usually are set up to meet different business objectives, and service different bodies of mobile users. These resources mobile applications as well as underlying cloud computing resources, virtual/real cloud-based mobile data storage, and wireless Internet. Here are some common deployment models for mobile cloud services.

- ✓ Ad-hoc mobile cloud – This refers to a MCC model where a service vendor offers mobile users with diverse mobile cloud resources to form an ad-hoc mobile network cloud.
- ✓ Private mobile cloud – This refers to a MCC model where a service vendor provides mobile cloud resources available to a selected group of mobile users over a selected wireless Internet. These public mobile cloud services usually are offered on a pay-per-usage model.
- ✓ Public mobile cloud - This refers to one MCC model where a service vendor provides resources, such as mobile applications, virtual/real mobile data storage, available to the general public mobile device users over a provisioned wireless Internet. These public mobile cloud services may be free or offered on a pay-per-usage model.
- ✓ Mobile community cloud - This refers to a MCC model that provides resources for its clients to form various mobile-based social networking communities over the wireless Internet. Diverse social community service applications can be launched and deployed, managed, and executed there. These mobile cloud resources and services usually are free or offered on a pay-per-usage model.
- ✓ Enterprise mobile cloud – This refers to a MCC model, set up for business clients by providing them mobile cloud resources to launch, manage, maintain enterprise-oriented mobile application service systems to their mobile users over the wireless Internet. The enterprise mobile cloud resources and services usually are offered on a pay-per-usage model.

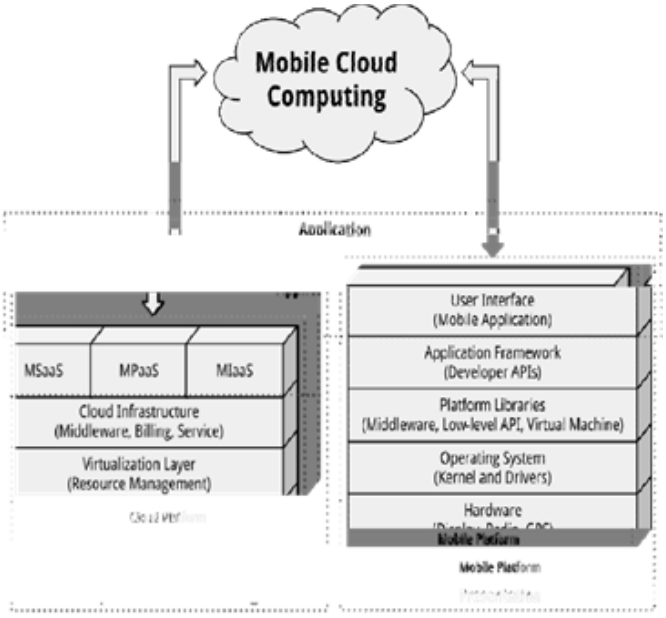

Figure 4 Different Types of Mobile Cloud Services

Figure 4 displays the common groups of mobile cloud services. In addition to MIaaS, MSaaS, MDaaS and MPaaS, there are other important types of mobile cloud services, which are listed below.

- ✓ Mobile App-as-a-Service (MAaaS): This refers to a service business model where diverse mobile applications can be deployed, managed, hosted, and monitored for mobile app. vendors using a pay-as-you-use model.
- ✓ Mobile Testing-as-a-Service (MTaaS): This refers to a service business model where various mobile-based testing devices, tools, and services are provided by a vendor as resources to its mobile clients to support testing of mobilebased software and applications using a pay-as-you-use model.
- ✓ Mobile Community-as-a-Service (MCaaS): This refers to a service business model where various mobile social networks and communities can be dynamically established and managed to provide social community services and networking to mobile clients using a pay-as-you-use model.

The authors in [13] proposed a Community Cloud Platform (MCCP) to support virtual mobile community on clouds.

- ✓ Mobile Multimedia-as-a-Service (MMaaS): This refers to a service business model where rich media based application services (such as movies and digital games) can be deployed, managed, and hosted to deliver multimedia services to clients using a pay-as-you-use model.[18]

In addition, there are several popular added-value services for mobile clouds. They include billing, mobility services, and security services. Furthermore, there are several facilitating services in mobile clouds, including energy saving service, migration service, and synchronization service.

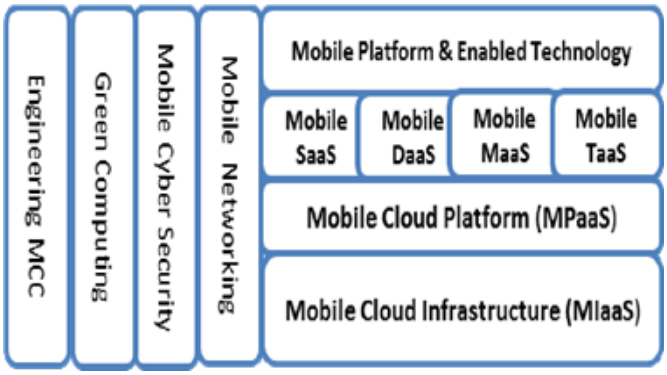

Figure 5 A Basic Research Scope in Mobile Cloud Computing

III. Mobile Cloud Computing Research

(a) Research Scope of Mobile Cloud Computing Mobile cloud computing encompasses numerous research fields and subjects. Here are some interesting research subjects in MCC.

- ✓ Engineering for MCC – The research work on engineering for MCC must focus on how to use well-defined and cost-effective modeling, design, validating, and measurement methodologies and techniques and tools to support the development of mobile clouds and service applications. Here, special attentions should be given to design and testing for mobile cloud scalability, multi-tenanted mobile SaaS, energy-efficiency mobile computing, cloud mobility and mobile security.
- ✓ Mobile networking for MCC – Mobile networking in mobile clouds encompasses diverse wireless networks and Internet. Innovative network protocols and communication technologies should be the major research focuses in the networking community to address desirable needs in energy-efficient communications, elastic scalability in network infrastructures, and intelligent connectivity among networks, devices, and computers.
- ✓ Mobile cloud infrastructure – The research work on this subject focuses on how to build cost-effective and energy efficient mobile cloud infrastructures to support three groups of underlying resources: a) computing resources, b) network resources, and c) storage resources. The typical topics include resource provision, virtualization, management, and monitoring, as well as load balancing and usage billing.
- ✓ Mobile platform and enabled technologies - Providing efficient and easy to use mobile platforms on mobile devices has been a focused subject in both academic and industry. As mobile apps become more sophisticated, they can be preferable over their desktop counterparts: fully functional, but faster and easier to use. Two major computer makers (Apple and HP) recognize what this means: the potential for huge disruption through a subtle merger of traditional desktop computing and mobile platforms. In addition, Table 1 Personal Clouds for Mobile Users earlier some research work projects have been done to develop virtual mobile platforms on clouds to cope with the diverse needs from mobile users with low-end mobile devices.
- ✓ Mobile cyber security in MCC – The research on this address security issues and needs at different

levels in MCC, including mobile cloud infrastructures, networks, platforms, and service applications. Typical attentions could be given to mobile data and information security, end-to-end mobile transactions, secured mobile cloud connectivity, and security management and assurance on mobile clouds. Some recent study on this subject can be found in [35].

- ✓ Mobile SaaS – According to a recent report from Forrester forecasts, mobile SaaS market will reach over $92 billion by 2016. Some existing mobile SaaS examples include Apple's MobileMe, Funambol, and Microsoft's LiveMesh. For large-scale mobile SaaS applications, we expect to see interesting research topics on mobile SaaS reference infrastructures and architectures, mobile SaaS platforms [13] and frameworks [10], services and engineering [12].
- ✓ Green computing in MCC – Green computing has been a very hot research field in mobile computing and cloud computing. As pointed out in [9][11], energy-efficient computing will be a hot research subject on mobile clouds to address different issues and challenges in three different areas: a) green cloud infrastructures and servers, b) energy-efficient communications, and b) energysaving computing on mobile devices and mobile client technology.

Personal Cloud	Supporting Features	URL address
Lenovo Cloud By Lenovo	Personal mobile data storage and applications	http://www.lenovo.com/products/us/lenovocloud/#lenovocloudstorage
Acer By AcerCloud	Music, photos, videos and documents on PC machines from mobile devices.	http://www.computerworld.com/s/article/9223247/
iCloud By Apple Inc.	Personal storage mobile users, including key values, documents, and personal core data.	https://www.icloud.com/
Polkast Cloud By Polkast	Docs and photos, as well as videos and music with stream support. Plus connectivity between computers and mobile devices	http://support.polkast.com/entries/20050987-what-is-polkast

(b) A Roadmap of Mobile Cloud Services Infrastructures

As reported in [15], there are numerous published papers addressing mobile cloud infrastructures. Figure 6 shows a login view of mobile cloud infrastructures. It presents a typical view of current understanding of mobile cloud infrastructures, and conceptualizes the different components in a mobile cloud infrastructure, which encompasses mobile service applications, and computing cloud infrastructures, platforms, and storages, as well as mobile platforms and technologies. Here, we discuss three generations of mobile cloud infrastructures and services based on our recent literature study and technology survey as well as our observations.

Figure 7 Personal Cloud Infrastructures for Mobile Users

First generation – Personal mobile cloud

In the recent years, there are a number of vendors providing personal mobile clouds to their mobile users. Table 1 lists several examples. All of them are known as personal clouds, which provide mobile users with mobile data, contents, storage, and certain personal application services, such as music and video players, calendars and schedules, photos and documents. These personal clouds for mobile users provide the first generation of mobile cloud services. Figure 7 shows its common infrastructure which is supported by the current wireless networks and mobile Internet. As shown in Table 2, their key features are listed below.

- Mobile application service – Mobile application servers are deployed, hosted, and maintained on a computing cloud infrastructure (or platform) in a data center.
- Network communication - Mobile communications are supported by existing heterogeneous wireless networks and wireless internet, which are operated by current wireless communication careers.
- Scalability - Computing and service scalability are supported by leveraging with the existing computing and storage clouds.
- Resources - Computing and storage resources are provisioned, managed, and delivered upon on-demand requests in a pay-as-you-use billing model.
- Synchronization – Mobile content and application data (or states) are synchronized to provide content consistency and integrity for mobile clients.
- Mobility – Mobility of personal mobile clouds is supported for user-oriented mobile contents based on their current locations.

Table 2. A Comparison of Mobile Clouds in Three Different Generations

- Multi-tenancy – Single tenant-based application server is provided to support and deliver pre-defined mobile application services.

Figure 8 Second-Generation: Mobile Cloud Infrastructures

Second Generation:
Cloud-Based Mobile Cloud Infrastructures

As shown in Figure 8, a common infrastructure for the secondgeneration mobile cloud services has the following key features.

- Mobile application service – Mobile enabled application servers are developed as mobile SaaS systems. They are deployed, hosted, and

maintained on a computing cloud infrastructure (or platform) in a data center.

- Network communication – Similar to personal clouds, mobile communications are still supported by existing heterogeneous wireless networks and wireless internet.
- Scalability – Mobile SaaS systems offer computing and service scalability by leveraging with the existing computing and storage clouds.
- Resources – Mobile SaaS systems provide the required computing and storage resources, which are provisioned, managed, and delivered upon on-demand requests in a pay-asyou-use billing model.
- Synchronization – Mobile application data and service contents are synchronized for enterprise users and multitenants according to the consistent requirements for predefined application services.
- Mobility – Mobility is supported by Mobile SaaS to offer multi-tenanted mobility services to mobile users and enterprises customers based on their current locations.
- Multi-tenancy – Multi-tenanted application services (such as SaaS systems) are provided to enterprise users and their customers to support diverse tenanted business logics, application work flows, QoS requirements, user interface forms and business databases.
- On-demand service – In addition to on-demand mobile data and content services for mobile clients, on-demand computing and storage services are provided to mobile SaaS vendors.

Mobile Cloud Features	**First Generation – Personal mobile cloud services**	**Second Generation- Mobile enabled cloud application services**	**Third Generation- Mobile cloud application services**
Mobile accessibility	Mobile-based accessibility	Service-oriented mobile accessibility	Cloud-based mobile accessibility
Mobile client	Thin/Fat/Smart clients on the existing mobile devices	Thin clients and smart clients	Mobile cloud-based thin clients with strong portability and energy-efficient solutions
Networking	Heterogeneous wireless networks and wireless Internet hosted and operated by service vendors	Wireless networks and wireless Internet are hosted and operated by service vendors	Cloud-based virtual networks with highly elastic scalability and large-scale network resources
Mobile DB and repository	Mobile DB technology on mobile devices and existing conventional databases on clouds	Cloud-based distributed mobile databases and mobile repositories using the existing NoSQL cloud DBs and cloud-based distributed relation DBs as well as distributed file systems (such as Hadoop/MapReduce)	Mobile cloud DB technology by leveraging with the current cloud-based databases technologies and cloud-based distributed file systems (such as Hadoop/MapReduce)

Energy-efficient	Energy-efficient computing on mobile devices and servers	Energy-efficient computing on mobile data storages, mobile devices, and computing servers	Energy-efficient computing on mobile data storages, mobile devices, networks, and computing servers
Scalability	Offer limited vertical scalability in both computing resources and network resources	Provide limited scalability in networks, and support both vertical and horizontal scalability in computing resources	Provide both vertical and horizontal scalability in networks, storage and computing servers.
Resources	Pre-configured computing resources Pre-contracted wireless networks and internet	Auto-provisioned computing and storage resources Pre-provisioned networking resources	Auto-provisioned computing, storage, and network resources
Multi-tenancy	Most time only support single multi-tenancy with mobile user personalization and customization	Multi-tenanted computing services for mobile tenants and users supported by service vendors	Multi-tenancy support in networking, computing storage and servers, as well as application services
Mobility	User-oriented content mobility	Multi-tenant based service mobility is offered by MSaaS for enterprise users and customers	Mobility support for mobile content, application services, and mobile cloud resources
Connectivity	Connectivity between mobile clients and mobile application servers	Standard connectivity between mobile clients and mobile application servers on clouds.	Connectivity between mobile clients, mobile cloud networks, and mobile SaaS, and mobile clouds
Business model	Contract-based or usage-based service models for mobile contents and application services.	Pay-as-you-use billing models for computing resources, storages, application services, and mobile content and data.	Pay-as-you-use billing models for networking, computing, storage resources, application services, and mobile content and data.
Comp ability and portability	Limited client portability and compatibility among different mobile devices	Strong client portability and compatibility among different mobile devices.	Portability and compatibility among at different levels of mobile clouds, infrastructures, networks, services, and mobile devices.
Service delivery model	Delivery of mobile data and content services	Delivery of computing resources, mobile application services, and mobile contents	Delivery of mobile contents, application services, and mobile cloud resources

Synchronization	Content and data synchronization for mobile clients	Content and application service synchronization for both mobile clients and service vendors	Synchronization on mobile cloud infrastructures, resources, application services, and contents for both mobile clients and service vendors
Location-aware	Location-aware applications and contents for mobile clients	Location-aware contents and application services	Location-aware mobile cloud resources, infrastructures, application services and data for service vendors as well as mobile clients
On-demand service	Offer on-demand mobile data and application services at the user level	Offer on-demand mobile data and application services at the user level. Provide on-demand computing resource services for service vendors	Offer on-demand application services at the user level and provide on-demand computing resource services for service vendors

Third Generation - Mobile cloud services

As pointed out by Virgin Media Business CEO Mark Heraghty, the explosive growth in mobile data usage has lead to dramatic shifts in how mobility is being used in enterprise, to mobile replacing plastic for payments, to emerging technologies like SDNs and network virtualization. As pointed by Lee Chooking in [12], this is an incredibly innovative and disruptive time, and he believes that today's ICT operators will look drastically different a decade from now. Fixmo, Guardtime and Joyent are dedicated to smoothing that transition. In addition, the significant increase of mobile access traffic has demands a new shift in wireless network communication services to cope with the following major limitations of current wireless networks and services:

- Limited scalability in network bandwidths and traffic support
- Carrier-oriented network infrastructures
- Limited portability and connectivity between different wireless networks hosted and operated by wireless service vendors
- Limited network resource sharing, in-efficient usage of network resources
- Highly dependency on pre-configured physical network components and devices.
- Less green computing in networking

Figure 9 Third-Generation: Mobile Cloud Service Infrastructures

These issues become solid huddles in the road to mobile cloud computing. To achieve elastic scalability for mobile networking and communication services, we need to change the existing wireless network and wireless internet infrastructure by moving to the third generation of mobile clouds, in which wireless network computing is moved into network clouds with network cloud centers and network virtualization solutions. Figure 9 shows an example of a third generation mobile cloud service infrastructure.

It consists of the following four layers:

- Computing cloud layer – Scalable cloud infrastructures and platforms, where diverse back-end mobile application servers are deployed, executed, and maintained on a selected cloud as residential software to take advantages of the existing cloud infrastructures (IaaS) and cloud platforms (PaaS) in computing resource sharing, scalability and elasticity, higher resource utilization, and cost reduction with utility billing.
- Network layer – Network resources are grouped, provisioned, and managed, and delivered by network-as-a-service (NaaS) using network virtualization solutions and energy-saving techniques to achieve elastic network scalability, good network virtualization, and higher network resource usage.
- Mobile cloud layer – This layer consists of essential service capabilities in mobile cloud computing, such as energyefficient solutions, mobile cloud resource provision and management, mobile application brokerage service, locationaware management service, and mobile cloud security management and service.
- Mobile Layer – Mobile connectivity interfaces are provided to mobile users for consistent and comprehensive accesses to mobile cloud application services with secured end-to-end mobile transactions and connectivity as well as strong user privacy.

As discussed in Table 2, the third-generation mobile cloud infrastructures offer the following distinct advantages comparing with the others.

- It increases elastic scalability of wireless networks and their resource usage and sharing.
- It reduces the capital expenditure for the development of diverse mobile network resources that support a variety of access technologies as well as business models that cater to different market segments.
- It reduces operation costs through energy saving solutions and higher utilization of deployed resources due to the copresence of multiple service offerings.
- It reduces mobile application development costs through elasticity of back-end services and unified access.

As regards the cloud layer of this reference model, the main research challenge specific to mobile application relate to the provision of surrogate computational services. Indeed, cloud infrastructure management and content and software distribution networks are issues that are shared with standard cloud service provision and they are also relevant and critical for the success of mobile cloud applications. A feature specific to mobile clouds is the need for reducing the computational load placed on resource contained mobile devices for tasks such as voice recognition or image processing. In such situations, depending on the trade-off between communication and computational delay tolerance for the specific application; developing efficient and effective adaptive techniques to negotiate this trade-off at runtime is one of the core ingredients of successful mobile cloud service provision.

Explorations on the visualization of mobile network layer have already been underway for some time due to strong cost incentive for mobile network operators. Network sharing typically implemented at the Radio Access Network level has become prevalent across medium size operators in particular across the globe. A notable development over the past five years has been the emergence on mobile virtual network operators (MVNO) which have specialized in catering for specific, often niche, and market segments. However, from a technical perspective such solutions are static and incur a significant management and operational overhead. We anticipate that such visualization will become a core feature of systems in the future for example through the development of Base Station visualization techniques and the increasing use of software radios.

The current state of the art in device technology however does not allow for the main functions carried out at the mobile device layer to be moved to the cloud. Instead, we anticipate that the major developments in this layer will affect access, in the sense that services enabled by cloud technology in the mobile network and cloud layers of the model presented in Figure 9 will be accessed in a consistent and relatively transparent manner. From this perspective, the main aim is to develop expressive and efficient mechanisms for adaptive access to mobile cloud systems and services.

IV. Issues, Challenges, and Needs

The authors in [21] present the taxonomy of mobile cloud computing, and highlight some important issues in six different perspectives, including operations, end users, application services, context-awareness, data management, as well as security and privacy. In this section, we discuss the research issues, challenges, and needs in five different areas: a) privacy in mobile cloud computing, b) mobile SaaS engineering, c) mobile cloud infrastructures, d) mobility, d) mobile data as service (MSaaS), and e) green computing.

4.1 Privacy in Mobile Cloud Computing

According to the Oxford Dictionary, privacy means "a state in which one is not observed or disturbed by other people." Therefore, in the everyday email you received, advertising emails, if unsolicited or unwanted, constitute an invasion or a violation of your privacy. However, it is nearly impossible to stop all these junk emails.

Fast forward to the MCC, the cloud providers collect much personal information. It is equivalent to a gold mine waiting to be explored (or is already exploited). The detriments to personal privacy have just begun and its long term effects are yet to be seen.

However, every cloud has a silver lining. In the past personal data are stored on a computer's hard disk or USB drive, when the computer is sold or recycled, or when the USB drive is lost or stolen, data stored may be compromised. Important personal information was often found in a used hard drive. Fortunately, this will not happen for data stored in a cloud. But cloud leads to other types of privacy problems:

• Users do not physically possess storage of their own data, and thus cloud providers are responsible for data protection.

• With data held externally, data privacy related issues are in the hands of the cloud provider.

• When a user changes the cloud provider, data migration becomes an issue. Will new cloud site data be complete? Will old cloud site data be completely cleared?

• What happens if a cloud provider goes out of business? Where the data will go? Who will own the data? In addition to those privacy issues in clouds, MCC introduced new problems due to mobility. The most serious problem is that numerous applications will be available, but are these safe? Do they collect private information from mobile devices to another party? Do they have any hideous functions?

With the proliferation of mobile smartphones, the mobile cloud privacy problem will become more sophisticated and serious. US congress is trying to enact laws to protect mobile users. But free mobile applications usually depend on advertisements and advertisements require personal information. However, it is not appropriate to provide too much protection and many applications may change from free to fee-based.

The solution is to give users more controls and choices. Mobile applications need to let the users know what information is being collected and sent out, i.e., the transparency issues of mobile applications.

Mobile devices have become the default tool for business as the starting point for getting instantaneous, just-in-time services. Most MCC platforms are designed with security for the provisioning of applications and services to users over mobile networks. Mobile cloud provisioning can take advantage of the benefits of cloud computing in monitoring, security detection and malware prevention that can protect mobile customers. However, this doesn't imply that cloud-based applications and services have become totally free from the danger of malware. It only means that it is now more difficult for perpetrators to manipulate cloud service providers and their services than it is to simply distribute malware applications. With applications and services now residing in the cloud makes it unnecessary for installing and maintaining complex anti-virus and -malware software on the client terminals although some on-device protection may still be considered as an extra protection.

For mobile cloud, the current security concern is primarily the threats to smartphones and tablet platforms. These threats can be classified into three major categories: (1) physical threats, (2) threats to mobile network security and (3) the threats of malware.

Physical threats

Physical threats to mobile devices occur with the lending, loss or theft of a device; for it makes it possible for someone else to access data or applications without proper authorization. Although mobile devices are equipped with a pin- or password-based lockout capability, this feature is often not used by the owners. Even when such a feature is enabled, there are numerous ways of subverting it. Also, applications installed on mobile devices often provide direct and automated access to cloud services and data.

Challenges: Subscriber-identity-module (SIM) cards can be removed from many mobile devices easily and thus accessed by anyone.

Possible solutions: Developer can add an extra layer of security at the application level when sensitive data may be accessed by their software. Developer should make sure not to store such data on the SIM cards. On the cloud side, backup service is needed when a mobile phone is lost so that the user can recover the data from the cloud center. In addition, more advanced identification techniques, such as voice recognition and fingerprints can be used as a second authentication method to protect mobile devices.

Threats to mobile network security

Smartphones can be accessed through 3G or 4G cellular networks, Wi-Fi and Bluetooth. Using smartphones, users can gain access to phone services, Internet services and Short Messaging Services (SMS). From a security perspective, all interfaces have the danger of exposing sensitive information and receiving malicious data. In addition, in wireless networks, eavesdropping and spoofing are easier than in wired networks. Major attacks include eavesdropping, man-in-the-middle attack, and denial of service. There are also some other threats from fraud management in mobile networks, such as access fraud and subscription fraud. Therefore, there is a need for real-time fraud detection to monitor subscriber behavior in real-time and subsequently adapt user profile based on the monitoring.

Challenges: Dealing with threats is a major challenge. Whether it be through the cloud or the user terminals, or in the mobile network infrastructure, mobile service operators are ultimately responsible for protecting the network and the end users from a variety of security attacks. Mobile cloud by nature is highly virtualized and highly federated. Thus, an approach needs to be developed to control and manage identities across different clouds.

Possible solutions: There are some measures that can be taken to prevent unauthorized access to mobile devices and to provide protection for access to the cloud. The first thing is always to educate the users so that every mobile user knows about the right way of using the networks. Also, policies should be established to govern the use of wireless devices. In addition, one-time passwords should be rather than those stored on the handsets. It is

possible to have a personalized configuration profile on each mobile device to support the implementation of a personal security token or credential on the device. Then, only users with trusted devices that comply with the security policy can access applications and data in a cloud. Both mobile and cloud require new security control that stands below mobile devices and above the cloud providers. Finally, one need to control and protect the flow of information between mobile devices and cloud storage.

The threats of malware

Smartphones are becoming sophisticated and, thus attract growing attention of malware creators. As the number of Internet-enabled mobile devices continues to grow, Web-based threats become a serious security issue, not only in the form of viruses and botnets, but also phishing from malicious domains and social networks, identity theft and spam.

Challenges: From a security perspective, mobile devices interact with each other and with the external world intimately using a wide array of technologies. Therefore, one needs to protect mobile Internet users from many types of sophisticated security threats. Cloud-based applications differ from traditional applications in many ways. The identity layer is much harder for the simple reason that there are more applications per user than ever before and services are becoming anywhere-to-anywhere internal and external classifications do not matter nearly as much as before.

Possible solutions: Authorized software can be pre-installed and distributed from the cloud. When malware is detected, smartphone software should be restored from trusted backups in the cloud. First, it is important to change users' behavior by education. A company should educate its employees about threats that are out there in the wild and make sure that employees understand what to expect when using their mobile network or applications. Second, one need to continue improving the network infrastructure and make sure that every mobile user will protect his/her network and mobile devices with anti-malware, anti-spyware, and other security software to restrict mobile access to unauthorized sites and filter spam.

MCC is an emerging market driven by the popularity of smartphones and tablet computers. As more mobile devices are brought to the market, the number of security issues will certainly grow and effective security solutions must be developed continuously.

4.2. Mobile SaaS Design

SaaS is a new software development and deployment approach where tenant developers compose their applications using components in SaaS databases and individual tenant applications will be compiled and executed in the SaaS platform when a client calls the tenant application. Key concepts in SaaS includes

• Multi-tenancy: This means same software instances serve multiple tenant applications, and all the tenant application reside in the same SaaS platform including SaaS database, cache, and execution environment with a virtual partition.

• Individual tenant application customization: This means each tenant application will have different functionality as well as look and feel even though tenant applications share components. This can be done by various configuration mechanisms where individual tenant applications will use shared but customized components.
• Scalability: The SaaS system will allocate more resources when the workload is heavy, or move tenant applications to another cluster for execution.
• Security: As tenant applications share resources in the SaaS platform, each tenant application needs to be distinctly separated in the SaaS system. This kind of virtual partition can be done in the database level, or at any other levels including network and storage level.
• Redundancy and recovery: The SaaS platform provides automated redundancy management and will recover tenant applications including their data and metadata in case of failures.

Most of these issues are still active research areas in enterprise SaaS systems, and they will also be open research issues for mobile SaaS systems. But, in addition to these, a mobile SaaS system has additional issues below:
• Individual client application customization: In addition to tenant application customization, each users may see different results when the same tenant application is called. Furthermore such customization may be done at runtime rather than design time. For example, the mobile SaaS system may embed different advertisements in the apps for different users for the same tenant application based on the user profiles, and the user profiles are continuously being updated. For example, when a user travels to a different location, the user profile is automatically updated, and different messages may be displayed by the mobile device. This requires at least two levels of customization, one for tenant application customization, and the other for individual user customization, and two kinds of customization decisions, design time and runtime. Different customization constraints may need to be imported and enforced depending on the data stored in the mobile SsaS.
• Intelligent partitioning of tasks for platform execution and device execution: Each mobile device has limited computing power while a SaaS platform may have a virtually unlimited computing power, a tenant application may have an intelligent task partitioning strategy to divide computation tasks into those for platform execution, those for device execution with smart caching mechanisms in the platform and in the device

4.3. Green Computing and Energy Saving

Green computing and energy saving has been a hot research topic in the past years. As pointed out in [9], the research issues and solutions in MCC can be classified in three areas: a) green computing in mobile devices, b) green computing in servers and computing infrastructures, and c) networks and communications. In our view, green computing in MCC must address the issues and needs in the two areas.

(a) Energy-efficient communication
With the increasing need of multimedia data communication in the wireless world, MCC must address the following three issues and needs.
• Similar to [23], more energy-efficient communication protocols are needed to support mobile communications in MCC.
• Energy-efficient migration and synchronization techniques and solutions for mobile content/data in MCC are needed.
• Like [24][25], more intelligent solutions are needed to support
the discovery and selection of underlying wireless networks and mobile connectivity to deal with diverse energy consumption of different wireless networks and technologies.

(b) Energy-efficient mobile cloud infrastructure

To reduce the energy consumption, future mobile cloud infrastructures and data centers must address the following special issues and needs.

• Similar to [26][27][28], energy-efficient resource allocation and management methods and solutions are needed in cloud data center, storage clouds and network clouds in MCC.

• Vertical energy-efficient intelligent solutions are needed crossing different layers (such as infrastructures, platforms, and Mobile SaaS) to provide system-level energy monitor and analysis so that cost-driven and green-based resource allocations and management decisions can be made.

4.4. Mobile Cloud Infrastructures and Architectures

Recently, there are a number of papers addressing mobile cloud infrastructures and architectures. One of them is to focus on developing new thin-client architecture for mobile SaaS and applications by leverage existing clouds to offload computations from mobile devices and eliminate device resource shortage. Good examples are ThinkAir[29][30] and Hyrax[31]. The other focused area is on new mobile cloud computing infrastructures and computing models to support computation offloading [32][33].

Based on our observation, here are some open issues and needs in mobile cloud infrastructures.

• Network-oriented computing could infrastructures – To support the third generation of mobile cloud services, we need to address many challenge issues in network cloud infrastructures to meet the new demands on network clouds in auto-resource provision, connectivity standards, load-balance, and green computing to provide on-demand network resource services. Some earlier work are reported in [6][7].

• New connectivity technology and solutions – To overcome limitations of current network bandwidth, and speed in-comp ability problems between networks and computing servers, we need new connectivity technology and infrastructure solutions.

4.5. Mobility

Mobility is a phenomenon determining our daily life and the way business process take place. Always and everywhere available mobile applications are becoming the state of the practice. This brings a challenge for software providers and operation service vendors. Mobile business processes with dynamic marketing needs demand new kinds of organizations, new software and models supporting on-demand business flows, services, and delivery solutions. This is not a local or domain-specific tendency, but a trend that is cross multiple domains such as banks, insurance, healthcare, cross markets (Europe, the US and Asia), cross platforms (Android, iOS, Windows). Specifically, in Europe, more people access the Web via mobile devices than traditional platforms. In emerging markets, the dominance of mobile usage and market trend is even more prevailing because terrestrial infrastructure may not available area-wide. For a CIO (or CTO), this trend is an enormous challenge. "Bring your own device" concepts lead to many securities and privacy issues, mobile device or even mobile application management results in new monitoring requirements unknown in traditional platforms.

But mobility is not the only issue. It comes with demands for agility. Agility means that application development should deliver quickly and frequently. Like mobile devices, mobile users, who are familiar with mobile applications, consider it natural that their apps are available, updated and improved frequently. Agile application development often demands flexible and rapid deployment and operation services.

Mobility also needs a scaling infrastructure because consumer behavior in the mobile arena is difficult to predict. If, however, a mobile app is widely accepted, it will be inevitable to provide robust and sufficient backend support. Horizontal scaling of infrastructure may be necessary. Otherwise it takes too long or does not scale sufficiently. Furthermore, horizontal scaling in mobile clouds, including networks, computing and storage servers needs to be done during runtime, at best automatically or by selfservice. Thus, horizontal scaling and high availability are the key elements that make mobile cloud infrastructures a natural home base for mobile cloud computing and services.

V. CONCLUSION

This paper first reviews mobile cloud computing concepts, motivations, and classifies different mobile cloud services. Then, the paper discusses the related research scope and its road map to mobile cloud computing. Particularly, it presents three generations of mobile cloud service infrastructures by comparing their key features and limitations. Moreover, the paper discusses the issues, challenges, and needs in mobile cloud computing for future research.

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