A Survey on Mobile Cloud Computing Architecture, Applications and Challenges

Ms. Gayathri M R¹, Prof. K. Srinivas²

¹ Department of Information Science and Engineering, Acharya Institute of Technology, Bangalore
² Department of Information Science and Engineering, Acharya Institute of Technology, Bangalore

ABSTRACT

With an explosive growth of Mobile applications and emergence of Cloud Computing concept, Mobile Cloud Computing (MCC) has been introduced to be a potential technology. Hence it drives a strong demand for mobile cloud applications and services for mobile users. This brings out a great business and research opportunity in MCC.

This paper first discusses the definitions of Cloud Computing, Mobile Computing and Mobile Cloud Computing (MCC). Then it presents an overview of MCC in terms of its concepts, Essential Characteristics, Service and Deployment models. Later it presents the architecture of MCC and its challenges. Finally it discusses some of the applications, advantages and current Research issues.

Keywords - Cloud, Deployment Models, Essential Characteristics, MCC Architecture, Service Models

I. INTRODUCTION

Cloud computing is a coalesce of many computing fields like Information Technology, Business, Agriculture, Medical Science and it has gained much popularity in the recent years. It provides computing, storage, services, and applications over the Internet. Moreover, cloud computing facilitates to reduce capital cost, decouple services from the underlying technology, and provides flexibility in terms of resource provisioning. Mobile devices like smartphone, tablet pc’s are increasingly becoming an essential part of human life as the most effective and convenient communication tools which are not bounded by time and place. Mobile users accumulate rich experience of various services from mobile applications like iPhone apps, Google Apps, which run on the devices or on remote servers via wireless networks.

Similarly, smartphones are also gaining enormous popularity due to the support for a wide range of applications such as games, image processing, video processing, e-commerce, and Online social network services. Meanwhile, with the rapid development of mobile network and portable terminals, smartphones are more and more favoured by users. It is becoming a trend to use mobile devices to access the services provided by the cloud. The growth of mobility has changed people’s lives gradually in an unpredictable way [4].

According to Cisco IBSG (Internet Business Solution Group), close to 80% of the world’s population has access to the mobile phone and new devices like Android smartphones, iPhones, palmtops and tablets have brought a host of applications at the palms of people’s hands [2]. Therefore Mobile Cloud Computing (MCC) is grown out of the above hot technologies like Cloud Computing and Mobile Computing. The term “Mobile Cloud Computing” is introduced not long after the concept of “Cloud Computing” has launched.

Cloud Computing has emerged as a phenomenon that represents the way by which IT services and functionality are charged for and delivered. NIST (National Institute of Standards and Technology, USA) definition from September [3], 2011 released in its “Special Publication 800-145” of Cloud Computing is: “Cloud Computing is a model for enabling convenient, on-demand network access to a shared pool of configurable resources like networks, servers, storage, applications and services that can be rapidly provisioned and released with minimal management effort or service provider interaction”.

And “Mobile Computing is a human computer interaction by which a computer is expected to be transported during normal usage”.

It includes Mobile Communication, Mobile Hardware and Mobile Software. MCC is introduced as an integration of Cloud Computing into the Mobile environment.

The Mobile Cloud Computing Forum defines MCC as follows [1]:

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

Unlike conventional mobile computing technologies, the resources in mobile cloud computing are virtualized and assigned in a group of numerous
distributed computers rather than local computers or servers. Many applications based on Mobile Cloud Computing, such as Google’s Gmail, Maps and Navigation systems for mobile, Voice Search, and some applications on Android platform, MobileMe from Apple, LiveMesh from Microsoft and Motoblur from Motorola have been developed and served to users [7]. The general architecture of Mobile Cloud Computing is as depicted in Fig 1 below.

Fig 1: Basic model of Mobile Cloud Computing

II. BACKGROUND

As an inheritance and emergence of Cloud Computing and Mobile computing, Mobile Cloud Computing has been devised as a new phenomenon since 2009. From simple perspective, Mobile Cloud Computing (MCC) can be thought as, an infrastructure where data storage and processing will be moved from the mobile device to powerful and centralized computing platforms located in cloud. Many mobile cloud applications are not restricted to powerful smartphones only, but to a broader range of less advanced mobile phones. The mobile devices can be connecting with a base station or a hotspot by a radio link such as Wi-Fi, GPRS or 3G. The centralized applications located in cloud are then accessed over the wireless connection based on a thin client or web browser on the mobile devices. Although the client is changed from PCs or fixed machines to mobile devices, the main concept is still cloud computing. By integrating cloud computing into the mobile environment, MCC overcomes the obstacles related to the performance (e.g., battery life, storage and bandwidth), environment (e.g., heterogeneity, scalability and availability) and security [12].

2.1 Essential Characteristics of MCC
On-demand self-service: A client with an instantaneous need at a particular time and place can obtain the computing resources such as network storage, software use, CPU time in an automatic fashion without resorting to human interaction with service providers.

Broad network access: The computing resources are delivered to users over the network and they are used by various client applications with heterogeneous platform (such as smart phones, laptops and PDA’s) situated at a client’s site.

Resource pooling: A cloud service provider’s computing resources are “pooled” together to serve multiple clients’ using either the multi-tenant or virtualization model, with different physical and virtual resources dynamically assigned and reassigned according to client demand. The client does not have knowledge and control about the exact location of the provided resources.

Rapid elasticity: For the clients, computing resources will become immediate rather than persistent; there are no up-front commitment and contact here. The client can use them to scale up whenever they want, and release them once they finish scaling down.

Measured Service: Although computing resources are pooled and shared by multiple clients, the cloud infrastructure is capable of using appropriate mechanisms to measure the usage of these resources for each individual client through its metering capabilities.

2.2 Service Models of MCC
Infrastructure as a Service (IaaS): Clients directly use IT infrastructure (processing, storage, network and other computing resources) provided in the IaaS cloud. Virtualization is extensively used in IaaS cloud in order to integrate or decompose physical resources. Clients are able to deploy and run arbitrary software, which can include operating systems and applications. The client does not manage or control the underlying cloud infrastructure but has control over the operating systems; storage, deployed applications and possibility limited control of selected networking components (e.g. host firewalls). An example of IaaS is Amazon’s EC2.

Platform as a Service (PaaS): PaaS is a development platform supporting the full “Software Lifecycle” which allows client to develop cloud services and applications directly on the PaaS cloud. PaaS offers a development platform that hosts both completed and in-progress cloud applications. An example of PaaS is Google AppEngine.

Software as a Service (SaaS): Client releases their application on a hosting environment which can be accessed through network from various clients by application users. The client does not manage or
control the underlying cloud infrastructure with the possible exception of limited user-specific application configuration settings. Google Apps and Microsoft Office 365 are the examples for SaaS.

2.3 Deployment Models of MCC

Private Cloud: The cloud infrastructure is operated solely within a single organization, and managed by that organization or a third party regardless whether it is located on premise or off premise.

Public Cloud: This is the dominant form of current cloud computing deployment model. The public cloud is used by the general public client and the cloud service provider has the full ownership of the public cloud with its own policy, value, profit, costing and charging model.

Hybrid Cloud: The cloud infrastructure is a combination of two or more clouds (private, community, or public) that remain unique entities but are bound together by standardized or proprietary technology that enables data and application portability (e.g., cloud bursting for load-balancing between clouds).

Community Cloud: Several organizations jointly construct and share the same cloud infrastructure as well as policies, requirements, values and concerns. The cloud community forms into a degree of economic scalability and democratic equilibrium. The cloud infrastructure could be hosted by a third-party vendor or within one of the organization in the community.

III. ARCHITECTURE

In mobile cloud computing mobile network and cloud computing are combined, thereby providing an optimal services for mobile clients. Cloud computing exists when tasks and data are kept on individual devices. Applications run on a remote server and then sent to the client. Here the mobile devices are connected to the mobile networks through the base stations; they will establish and control the connections (air interface) and functional interfaces between the mobile networks and mobile devices. Mobile users send service requests to the cloud through a web browser or desktop application. The information’s are transmitted to the central processors that are connected to the servers providing mobile network services. Here, services like AAA (Authentication, Authorization and Accounting) can be provided to the users based on Home Agent (HA) and subscriber’s data stored in databases. A general architecture in a broader sense is presented in Fig 1. A more detailed representation will be presented in Fig 2 [13].

Fig 2: Mobile Cloud Computing Architecture

The subscribers’ requests are then delivered to a cloud through the Internet. Cloud controllers present in the cloud, process the requests to provide the mobile users with the corresponding cloud services. These services are developed based on the concepts of utility computing, virtualization and service-oriented architecture. The major function of a cloud computing system is storing data on the cloud and using technology on the client to access that data. Several business models rapidly evolved to harness this technology by providing software applications, programming platforms, data-storage, computing infrastructure and hardware as services.

IV. CHALLENGES

In MCC landscape, an amalgam of mobile computing and cloud computing communication networks creates several complex challenges. This part describes some of the challenges. Although some of these challenges such as seamless connectivity, vendor lock-in, and security and privacy are common with mobile computing and cloud computing [6][8].

4.1 Mobile Computation Offloading

Leveraging heterogeneous cloud resources, to augment computing limitations of multitude of mobile devices towards realizing the vision of unrestricted functionality, storage, and mobility is a nontrivial task. Realizing cloud-based augmentation vision is impeded by multi-dimensional overhead of
identifying and efficiently partitioning resource intensive components, VM (Virtual Machine) creation and migration, and monitoring the overall outsourcing process. Moreover, a plethora of hurdles in utilizing cloud resources such as latency, heterogeneity, security, code portability, and cloud mobile interoperability intensifies the situation. Although several efforts such as CloneCloud, MAUI, Cloudlet, SAMI, and MOMCC are facilitating and promoting cloud-based computation offloading, still research and development in this domain remains a top priority [5].

4.2 Seamless Connectivity

Wireless networks are characterized by low bandwidth, intermittent, and less reliable transmission grounds compared with the wired networks. Establishing and maintaining seamless sessions between nomadic MCC users and other entities (e.g. smartphones and clouds) in a wireless medium composed of heterogeneous network technologies are critical issues to fully unleash the power of MCC. The intermittent connectivity causes several challenges such as dismissal of always on connectivity, excessive consumption of limited mobile resources, and disproportionate delaying of application execution that sharply degrade quality of computing services. Seamless connectivity in heterogeneous MCC environment demands reliable inter-system signal handoff schemes along next generation wireless networks. Unstable wireless bandwidth, low wireless network security and the high probability of signal interception are challenges likely intensified by crossing the Internet channel in order to utilize the cloud services for mobile augmentation.

4.3 Long WAN Latency

Latency adversely impacts on the energy efficiency and interactive response of cloud-mobile applications by consuming excessive mobile resources and raising transmission delays. In cellular communication, distance from the base station and variation in bandwidth and speed of various wireless technologies affect the energy efficiency and usability of MCC devices. For example, data transfer bitrate consumes comparatively more energy in cellular networks than WLAN. Higher the transmission bit-rate, the more energy efficient the transmission. Moreover, leveraging wireless Internet networks to offload mobile intensive applications to distant cloud resources creates a bottleneck. Consequently, the long WAN latency is increased while the quality of user experience is decreased. To reduce interaction latency, proposals such as Cloudlet, MOMCC, and SAMI are proposed to create a proximate cloud to access nearby remote resources, but further advancement to achieve crisper response is required.

4.4 Mobility Management

Integration of dissimilar wireless networks is a challenging task due to heterogeneity in access technologies, architectures, protocols, user mobility pattern, and user service requirements. To achieve the converged wired, mobile, and broadband communication not only accurate and efficient mobility management schemes are prerequisite, but also seamless integration and interoperation of mobility management approaches to address intra system and especially intersystem mobility is mandatory in MCC environment. Hence, an adaptive protocol suit similar to AdaptNet is essential to alleviate a plethora of heterogeneity made issues, particularly rate adaptation and congestion control, and provide interoperation among various networks. Integration and interoperation of converged heterogeneous networks in MCC demand lightweight, resource- and cost-effective, sustainable, and user-friendly approaches with optimized performance to address seamless mobility. Realizing such vital need with least signal traffic and latency can significantly enrich quality of cloud-mobile user experience.

4.5 Context-Processing

Contemporary mobile devices are capable of gathering extensive context and social information, specifically available cloud resources, network bandwidth, weather conditions, and users’ voice and gestures from their surrounding environment. Exponential growth in context and social information creates several challenges such as storing, managing, and processing information on resource constraint smartphones. Although cloud infrastructures are connected to be a suitable platform for context storage, management, and processing, the need for an energy efficient, reliable, and robust cloud-mobile data migration and communication is unavoidable.

4.6 Energy Constraint

Energy is the only un-replicable resource in mobile devices that cannot be restored spontaneously and
requires external resources to be renewed. Current technologies can increase battery capacity by only 5% per annum. Several energy harvesting efforts have been in progress since the 1990s to replenish energy from external resources like human movement and wireless radiation, but these intermittent resources are not available on-demand. Alternatively, application offloading and fidelity adaptation approaches are proposed to conserve local mobile resources, especially energy. However, application offloading is a risky, resource-intensive approach that needs further research and development to be deployed in real scenarios. Fidelity adaptation solutions compromise quality to conserve local resources which impoverish quality of user experience in MCC. Researchers endeavoured to mitigate application offloading challenges by exploiting secure, reliable, elastic cloud resources instead of insecure, limited surrogate’s resources. However, cloud based application offloading cannot always save energy with current developments and demands further efforts. Therefore, the energy constraint of mobile nodes remains a challenge in MCC.

4.7 Vendor/data Lock in

Variety of cloud servers and mobile devices beside a varied OSs and applications on one hand and non-uniformity of APIs in the absence of underpinning standards on the other hand, intensify data lock-in problem in MCC that bounds customers to a specific mobile device and cloud provider. For example, if cloud-mobile users utilize Apple iCloud as an automatic cloud-based storage service developed and dedicated to Apple products, no data fetch from non-Apple devices is addressable. Alleviating vendor locking problem in MCC is more challenging compared with cloud computing. Vendor lock-in solutions need to be applied in both mobile and cloud sides in an interoperable manner which is excessively challenging.

4.8 Security and Privacy

A drastic hike in cybercrimes and Internet threats mandates restricted security provisions for publicly accessible cloud resources, especially storage. At a cursory glance, security is only an issue for requesters, but in a deep view, service providers need to set up tighter security provisions to protect their properties and clients’ privacy. Ensuring user privacy and security of varied mobile applications running on different mobile devices that utilize heterogeneous cloud resources are the most challenging tasks in MCC. Security and privacy in MCC become more volatile compare to cloud computing due to the insecure nature of wireless communication medium. Hence, the absence of adaptive, rationalized, and rigorous security arrangements is a potential challenge with catastrophic consequences for service providers and requesters in MCC.

4.9 Elasticity

Cloud providers confront situations in which there are more demands than available resources. Adverse impact of cloud-resource unavailability and service interruption for MCC clients is more severe than stationary clients connected to the wall power and fixed network. Frequent suspension of energy-constraint mobile clients due to resource scarcity, not only shrinks usefulness of cloud outsourcing for MCC end-users, but also divests privilege of intensive computation anytime, anywhere from mobile users. Therefore, several challenging tasks need to be realized since service unavailability and interruption prolong execution time, increase monitoring overhead, and deplete smartphones local resources, especially battery.

4.10 Cloud Policies for Mobile Users

Cloud service providers apply certain policies to restrain service quality to a desired level by imposing specific limitations via their intermediate applications like Google App Engine bulk loader. Also, service provisioning, controlling, balancing, and billing are often matched with the requirements of desktop clients rather than mobile users. Considering the great differences in wired and wireless communications, disregarding mobility and resource limitations of mobile devices in design and maintenance of cloud structures can significantly impact on feasibility of MCC solutions. Metrics such as bandwidth quota and number of API calls per day limit clients and impact on user experience.

4.11 Service Execution and Delivery

Cloud-mobile users require an efficient monitoring means to measure and evaluate the quality of service they receive. SLA as a formal contract is employed and negotiated in advance to enforce certain level of quality against a fee. During
negotiation phase, the terms of services are defined, while the real-time performance is screening during monitoring phase. However, considering MCC dynamism, several network challenges such as inconsistent bandwidth and packet delivery ratio, delay, jitter, and network blips hamper service delivery, raise ambiguity, and increase dispute between cloud vendors and MCC end-users. Therefore, current static SLA can be fleshed out with more powerful, dynamic representation and monitoring techniques established in heterogeneous wireless environment for cloud mobile users.

4.12 MCC Billing

Client mobility in the rapidly changing environment diverges the cloud billing system in MCC from cloud computing. Designing an appropriate billing system for MCC with dynamic heterogeneous environment requires considering additional parameters compared with cloud computing. Interception latency, jitter, session reestablishment delay, bandwidth capacity, and quality of security are examples of major parameters in designing a MCC billing system. Designing an appropriate billing system for cloud-mobile users that continuously adapts to the heterogeneity and dynamism of MCC environment requires considering additional parameters compared with cloud computing. Interception latency, jitter, session re-establishment delay, bandwidth capacity, and quality of security are examples of major parameters in designing a MCC billing system.

V. APPLICATIONS

Mobile applications gain increasing in a global mobile market. Various mobile applications have taken the advantages of MCC. In this section, some typical MCC applications are introduced [7] [11].

5.1 Mobile Commerce

Mobile commerce (m-commerce) is a business model for commerce using mobile devices. The m-commerce applications generally fulfil some tasks that require mobility (e.g., mobile transactions and payments, mobile messaging, and mobile ticketing). The m-commerce applications are classified into a few classes which includes finance, advertising and shopping. The m-commerce applications have to face various challenges like low network bandwidth, high complexity of mobile device configurations, and security. Therefore, m-commerce applications are integrated into cloud computing environment to recover from these issues. 3G E-commerce platform is based on cloud computing which combines the advantages of both 3G network and cloud computing to increase data processing speed and security level based on PKI (Public key infrastructure). This mechanism uses an access control based on encryption and an over-encryption method to ensure privacy of user’s access to the outsourced data.

5.2 Mobile Learning

Mobile learning (m-learning) is based on both electronic learning (e-learning) and mobility. However, m-learning applications have limitations with high cost of devices and network, low network transmission rate, and limited educational resources hence Cloud-based m-learning applications are introduced to solve these limitations. For example, utilizing a cloud with the large storage capacity and powerful processing ability, the applications provide learners with much better services in terms of data (information) size, faster processing speed, and longer battery life. JavaME UI framework and Jaber is a web site built using Google Apps Engine; here students can communicate with their teachers at any time. Also, the teachers can obtain the information about student’s knowledge level of the course and can answer student’s questions in a timely manner. In addition, a contextual m-learning system based on IMERA platform shows that a cloud-based m-learning system helps learners to access learning resources remotely. Through mobile phones, learners can understand and compare different algorithms used in mobile applications (e.g., de-blurring, de-noising, face detection, and image enhancement).

5.3 Mobile Healthcare

The purpose of applying MCC in medical applications is to minimize the limitations of traditional medical treatment (e.g., small physical storage, security and privacy, and medical errors). Mobile healthcare (m-healthcare) provides mobile users with convenient access to access resources (e.g., patient health records) easily and quickly. Besides, m-healthcare offers hospitals and healthcare organizations a variety of on-demand services on clouds rather than owning standalone applications on local servers. There are many schemes of MCC applications in healthcare. For example, the following presents five main mobile healthcare applications in the pervasive environment.

1. Comprehensive health monitoring service- This enables patients to be monitored at any time irrespective of place through broadband wireless communications.
2. Intelligent emergency management system—This can manage and coordinate the fleet of emergency vehicles effectively.

3. Health aware mobile devices—These devices will detect pulse-rate, blood pressure, and level of alcohol to alert healthcare emergency system.

4. Pervasive lifestyle incentive management—This can be used to pay healthcare expenses and also to manage other related charges automatically.

5. Seamless connection to cloud storage—This allows users to retrieve, modify, and upload medical contents (e.g., medical images, patient health records and bio signals) utilizing web services and a set of available APIs called REST.

5.4 Mobile Gaming

Mobile game (m-game) is a potential market generating revenues for service providers. M-game can completely offload game engine requiring large computing resource (e.g., graphic rendering) to the server present in the cloud, and gamers only interact with the screen interface on their devices. Number of experiments is conducted to evaluate the energy used for game applications with 3G and WiFi network. Instead of offloading all data to the cloud for processing, an advanced user interface partitions the application data at a runtime based on the costs of network communication and CPU on the mobile device.

VI. ADVANTAGES

Cloud computing is known to be a promising solution for mobile cloud computing due to many reasons (e.g., mobility, communication, and portability). In the following, we describe how the cloud can be used to overcome obstacles in MCC, there by pointing out the advantages of MCC [7] [10].

6.1 Extending battery lifetime

Battery is one of the main concerns for the mobile devices. Several solutions have been proposed to enhance the CPU performance and to manage the disk and screen in an intelligent manner to reduce the power consumption. However, the proposed solutions require changes in the architecture of mobile devices, or they require a new hardware that results in an increase of cost and these may not be feasible for all mobile devices. Computation offloading technique is proposed with the objective to migrate the large computations and complex processing from mobile devices to the servers in clouds. This avoids longer application execution time on mobile devices which results in extending the battery lifetime.

6.2 Improving data storage capacity and processing power

Storage capacity is also a constraint for mobile devices. MCC is developed to enable mobile users to store/access the large data present in the cloud through wireless networks. First example is the Amazon Simple Storage Service (Amazon S3) which supports file storage service. Another example is Image Exchange which utilizes the large storage space in clouds for mobile users. This mobile photo sharing service enables mobile users to upload images to the clouds immediately after capturing. Users may access all images from any devices. With cloud, the Users can save large amount of energy and storage space on their mobile devices since all images are sent and processed on the clouds.

6.3 Improving reliability

Storing data or running applications on clouds is an effective way to improve the reliability since the data and application are stored and backed up on a number of computers. This reduces the chance of data and application lost on the mobile devices. In addition, MCC can be designed as a comprehensive data security model for both service providers and users.

VII. RESEARCH

Mobile cloud computing encompasses numerous research fields and subjects. Here there are some interesting research subjects in MCC [9].

7.1 Engineering for MCC

The research work on engineering for MCC must focus on how to use well-defined and cost-effective modelling, 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-tenant mobile SaaS, energy-efficiency mobile computing, cloud mobility and mobile security.

7.2 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.
7.3 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.

7.4 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 IBSG Cisco, “Mobile Consumers reach for the Cloud”.

the potential for huge disruption through a subtle merger of traditional desktop computing and mobile platform.

7.5 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.

7.6 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 and frameworks, services and engineering.

7.7 Green computing in MCC

Green computing has been a very hot research field in mobile computing and cloud computing. 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-saving computing on mobile devices and mobile client technology.

VIII. CONCLUSION

Mobile Cloud computing (MCC) is one of the mobile technology trends in future since it combines the advantage of both mobile computing and cloud computing. With the importance, this paper has provided an overview of mobile cloud computing in which its definitions, architecture and advantages have been presented. The applications supported by MCC which includes mobile commerce, mobile learning and mobile healthcare have been discussed which clearly show the applicability of the mobile cloud computing to a wide range of mobile services. Then the challenges and related approaches for MCC have been discussed. Finally, the future research directions have been outlined.

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