RESEARCH ARTICLE

MOBILE CLOUD COMPUTING AN EFFICIENT TECHNIQUE FOR MOBILE USERS

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Abstract— Mobile cloud computing is an emerging technology to improve the quality of mobile services. Together with an explosive growth of the mobile applications and emerging of cloud computing concept, mobile cloud computing (MCC) has been introduced to be a potential technology for mobile services. 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. In this paper, we describe what is mobile cloud computing, including its scope, current developments, and research challenges This section lists some of the major issues in Mobile Cloud Computing. One of the key issues in mobile cloud computing is the end to end delay in servicing a request.. We had also seen the comparison between mobile cloud computing and the cloud computing, the architecture of mobile cloud computing and the developing areas and the application of mobile cloud computing.

Keywords— cloud computing; mobile cloud computing; architecture of mobile cloud computing; advantage; application

I. INTRODUCTION

Mobile devices (e.g., Smartphone and tablet PC) are increasingly becoming an essential part of human life as the most effective and convenient communication tools not bounded by time and place. Mobile users accumulate rich experience of various services from mobile applications (e.g., iPhone apps and Google apps), which run on the devices and/or on remote servers via wireless networks. The rapid progress of mobile computing (MC) becomes a powerful trend in the development of IT technology as well as commerce industry fields. However, the mobile devices are facing many challenges in their resources (e.g. battery life, storage, and bandwidth) and communications (e.g., mobility and security) The limited resources significantly impede the improvement of service qualities. Cloud computing (CC) has been widely recognized as the next generation computing infrastructure. CC offers some advantages by allowing users to use infrastructure (e.g., servers, networks, and storages), platforms (e.g., middleware services and operating systems), and softwares (e.g., application programs) provided by cloud providers (e.g., Google, Amazon, and Salesforce) at low cost. In addition, CC enables users to elastically utilize resources in an on-demand fashion. As a result, mobile applications can be rapidly provisioned and released with the minimal management efforts or service provider's interactions. With the explosion of mobile applications and the support of CC for a variety of services for mobile users, mobile cloud computing (MCC) is introduced as an integration of CC into the mobile environment. MCC brings new types of services and facilities mobile users to take full advantages of CC.

This paper presents a comprehensive survey on MCC .section 2 provides need of MCC and comparison between mobile cloud computing and cloud computing Section 3 provides a brief overview of MCC including architecture and its advantages. Section 4 discussed the use of MCC in various applications. Then, Section 5 presents several issues that

arise in MCC and approaches to address the issues .And the concept of sky computing over MCC Next, the future research directions are outlined in Section 6. Finally, we summarize and conclude.

II. A MOTIVATION: THE NEED FOR A MOBILE CLOUD

The case for mobile cloud computing can be argued by considering the unique advantages of empowered mobile computing, and a wide range of potential mobile cloud applications have been recognized in the literature. These applications fall into different areas such as image processing, natural language processing, sharing GPS, sharing Internet access, sensor data applications, querying, crowd computing and multimedia search. However, as explained in applications that involve distributed computation do have certain common characteristics, such as having data with easily detectable segment boundaries, and the time to recombine partial results into a complete result must also be small. An example is string matching/manipulation such as grep and word frequency counters.

B. Cloud computing vs. mobile cloud computing

1) *Cloud computing:*

''Cloud computing refers to both the applications delivered as services over the Internet and the hardware and systems software in the data enters that provide those services'' [6]. A cluster of computer hardware and software that offer the services to the general public (probably for a price) makes up a 'public cloud'. Computing is therefore offered as a utility much like electricity, water, gas etc. where you only pay per use. For example, Amazon's Elastic cloud, Microsoft's Azure platform, Google's App Engine and Salesforce are some public clouds that are available today. However, cloud computing does not include 'private clouds' which refer to data centres internal to an organization. Therefore, cloud computing can be defined as the aggregation of computing as a utility and software as a service. Virtualization of resources is a key requirement for a cloud provider—for it is needed by statistical multiplexing that is required for scalability of the cloud, and also to create the illusion of infinite resources to the cloud user. Ambrust et al. Holds the view that ''different utility computing offerings will be distinguished based on the level of abstraction presented to the programmer and the level of management of the resources''. To take an example from the existing cloud providers, an instance of Amazon's EC2 is very much like a physical machine and gives the cloud user almost full control of the software stack with a thin API. This gives the user a lot of flexibility in coding; however it also means that Amazon has little automatic scalability and failover features. In contrast, Google's App Engine enforces an API on the user but offers impressive automatic scalability and failover options. Microsoft's Azure platform is something in between the aforementioned providers by giving the user some choice in the language and offers somewhat automatic scaling and failover functions. Each of the aforementioned providers has different options for virtualizing computation, storage and communication.

2) *Mobile cloud computing:*

There are several existing definitions of mobile cloud computing, and different research alludes to different concepts of the 'mobile cloud':
- Commonly, the term mobile cloud computing means to run an application such as Google's Gmail for Mobile6 on a remote resource rich server (in this case, Google servers) as displayed in Fig. 1,7 while the mobile device acts like a thin client connecting over to the remote server through 3G. Some other examples of this type are Facebook's location aware services, Twitter for mobile, mobile weather widgets etc.
- Another approach is to consider other mobile devices themselves too as resource providers of the cloud making up a mobile peer-to-peer network. Thus, the collective resources of the various mobile devices in the local vicinity, and other stationary devices too if available, will be utilized as shown in Fig. 2. This approach supports user mobility, and recognizes the potential of mobile clouds to do collective sensing as well. Peerto- peer systems such as SATIN for mobile self-organizing exist, but these are based on component model systems representing systems made up of interoperable local components rather than offloading jobs to local mobile resources. This paper focuses primarily on this latter type of work.
- The cloudlet concept proposed by Satyanarayanan is another approach to mobile cloud computing this approach where the mobile device offloads its workload to a local 'cloudlet' comprised of several multi-core computers with connectivity to the remote cloud servers. PlugComputers8 can be considered good candidates for cloudlet servers because of their form factor, diversity and low power consumption. They have the same general architecture as a normal computer, but are less powerful, smaller, and less expensive, making them ideal for role small scale servers installed in the public infrastructure. These cloudlets would be situated in common areas

such as coffee shops so that mobile devices can connect and function as a thin client to the cloudlet as opposed to a remote cloud server which would present latency and bandwidth issues. Mobile cloud computing would also be based under the basic cloud computing concepts. As discussed by Mei et al. There are certain requirements that need to be met in a cloud such as adaptability, scalability, availability and self-awareness. These are also valid requirements for mobile cloud computing. For example, a mobile computing cloud also needs to be aware of its availability and quality of service and enable diverse mobile computing entities to dynamically plug themselves in, depending on the requirements and workload. And in order for mobile users to efficiently take advantage of the cloud, a suitable method of self-assuming one's own quality is needed—since the internal status and the external environment is subject to change. However, in addition to the similar requirements, a mobile cloud needs to consider other aspects such as mobility, low connectivity and finite source of power as well

III. ARCHITECTURES OF MOBILE CLOUD COMPUTING

From the concept of MCC, the general architecture of MCC can be shown in Figure 1. In Figure 1, mobile devices are connected to the mobile networks via base stations (e.g., base transceiver station, access point, or satellite) that establish and control the connections (air links) and functional interfaces between the networks and mobile devices. Mobile users' requests and information (e.g., ID and location) are transmitted to the central processors that are connected to servers providing mobile network services. Here, mobile network operators can provide services to mobile users as authentication, authorization, and accounting based on the home agent and subscribers' data stored in databases. After that, the subscribers' requests are delivered to a cloud through the Internet. In the cloud, cloud controllers process the requests to provide mobile users with the corresponding cloud services. These services are developed with the concepts of utility computing, virtualization, and service-oriented architecture (e.g., web, application, and database servers). The details of cloud architecture could be different in different contexts. For example, a four-layer architecture is explained in to compare cloud computing with grid computing. Alternatively, a service-oriented architecture, called Aneka, is introduced to enable developers to build. Microsoft .NET applications with the supports of application programming interface (APIs) and multiple programming models. Presents an architecture for creating market-oriented clouds and proposes an architecture for web-delivered business services. In this paper, we focus on a layered architecture of CC (Figure 2). This architecture is commonly used to demonstrate the effectiveness of the CC model in terms of meeting the user's requirements. Generally, a CC is a large-scale distributed network system implemented based on a number of servers in data centres. The cloud services are generally classified based on a layer concept (Figure 2). In the upper layers of this paradigm, Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS) are stacked.

A. *Data centre layer:* This layer provides the hardware facility and infrastructure for clouds. In data centre layer, a number of servers are linked with high-speed networks to provide services for customers. Typically, data centers are built in less populated places, with a high power supply stability and a low risk of disaster

B. *IaaS:* Infrastructure as a Service is built on top of the data centre layer. IaaS enables the provision of storage, hardware, servers, and networking components. The client typically pays on a per-use basis. Thus, clients can save cost as the payment is only based on how much resource they really use. Infrastructure can be expanded or shrunk dynamically as needed. The examples of IaaS are Amazon Elastic Cloud Computing and Simple Storage Service (S3).

C. *PaaS.* Platform as a Service offers an advanced integrated environment for building, testing, and deploying custom applications. The examples of PaaS are. Google App Engine, Microsoft Azure, and Amazon Map Reduce/Simple Storage Service.
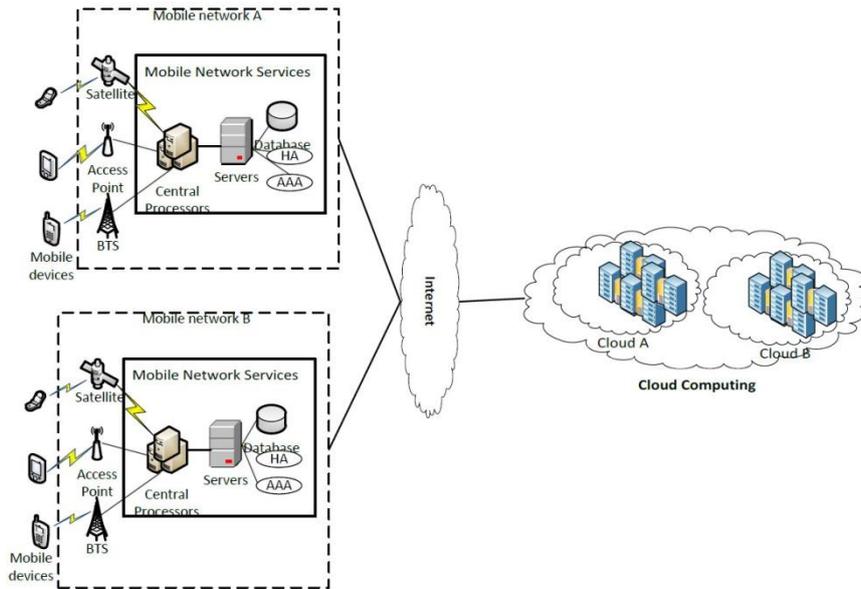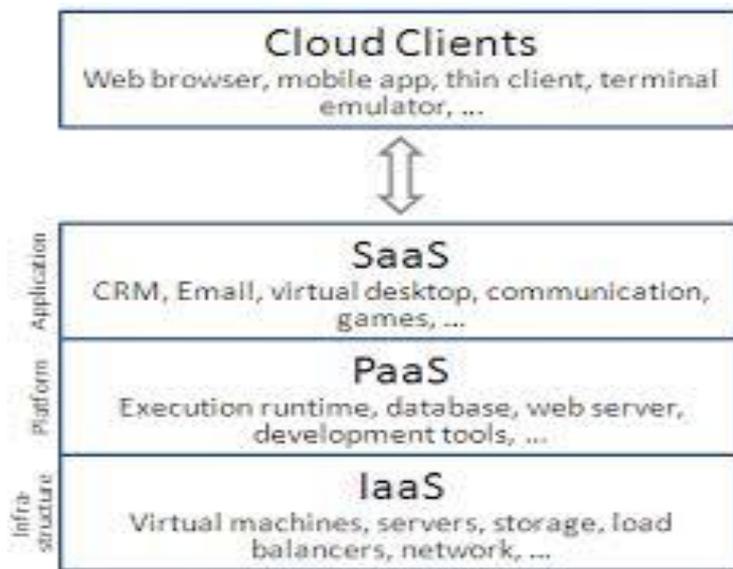
Fig1. Architecture of MCC

Fig2:service oriented cloud computing architecture

D. *SaaS:* Software as a Service supports a software distribution with specific requirements. In this layer, the users can access an application and information remotely via the Internet and pay only for that they use. Salesforce is one of the pioneers in providing this service model. Microsoft's Live Mesh also allows sharing files and folders across multiple devices simultaneously. Although the CC architecture can be divided into four layers as shown in Figure 2, it does not mean that the top layer must be built on the layer directly below it. For example, the SaaS application can be deployed directly on IaaS, instead of PaaS. Also, some services can be considered as a part of more than one layer. For example, data storage service can be viewed as either in IaaS or PaaS. Given this architectural model, the users can use the services flexibly and efficiently.

IV. ADVANTAGES OF MOBILE CLOUD COMPUTING

Cloud computing is known to be a promising solution for MC because of many reasons (e.g., mobility, communication, and portability). In the following, we describe how the cloud can be used to overcome obstacles in MC, thereby pointing out advantages of MCC.

A. *Extending battery lifetime.*

Battery is one of the main concerns for 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 power consumption. However, these solutions require changes in the structure of mobile devices, or they require a new hardware that results in an increase of cost and 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 resource-limited devices (i.e., mobile devices) to resourceful machines (i.e., servers in clouds). This avoids taking a long application execution time on mobile devices which results in large amount of power consumption. Rudenko *et al.* and Smailagic and Ettus evaluate the effectiveness of offloading techniques through several experiments. The results demonstrate that the remote application execution can save energy significantly. Especially, Rudenko *et al* evaluates large-scale numerical computations and shows that up to 45% of energy consumption can be reduced for large matrix calculation. In addition, many mobile applications take advantages from task migration and remote processing. For example, offloading a compiler optimization for image processing can reduce 41% for energy consumption of a mobile device. Also, using memory arithmetic unit and interface (MAUI) to migrate mobile game components to servers in the cloud can save 27% of energy consumption for computer games and 45% for the chess game.

B. *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 on the cloud through wireless networks. First example is the Amazon Simple Storage Service 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 the cloud, the users can save considerable amount of energy and storage space on their mobile devices because all images are sent and processed on the clouds. Flicker and ShoZu are also the successful mobile photo sharing applications based on MCC. Facebook is the most successful social network application today, and it is also a typical example of using cloud in sharing images. Mobile cloud computing also helps in reducing the running cost for compute-intensive applications that take long time and large amount of energy when performed on the limited-resource devices. CC can efficiently support various tasks for data warehousing, managing and synchronizing multiple documents online. For example, clouds can be used for transcoding , playing chess , or broadcasting multimedia services to mobile devices. In these cases, all the complex calculations for transcoding or offering an optimal chess move that take a long time when perform on mobile devices will be processed efficiently on the cloud. Mobile applications also are not constrained by storage capacity on the devices because their data now is stored on the cloud.

C .*Improving reliability:*

Storing data or running applications on clouds is an effective way to improve the reliability because 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. For example, the cloud can be used to protect copyrighted digital contents (e.g., video, clip, and music) from being abused and unauthorized distribution. Also, the cloud can remotely provide to mobile users with security services such as virus scanning, malicious code detection, and authentication. Also, such cloud-based security services can make efficient use of the collected record from different users to improve the effectiveness of the services. In addition, MCC also inherits some advantages of clouds for mobile services as follows:

1) *Dynamic provisioning*. Dynamic on-demand provisioning of resources on a fine-grained, self-service basis is a flexible way for service providers and mobile users to run their applications without advanced reservation of resources.
2) *Scalability*. The deployment of mobile applications can be performed and scaled to meet the unpredictable user demands due to flexible resource provisioning. Service providers can easily add and expand an application and service without or with little constraint on the resource usage.

3) *Multitenancy*. Service providers (e.g., network operator and data center owner) can share the resources and costs to support a variety of applications and large number of users.

4) *Ease of integration*. Multiple services from different service providers can be integrated easily through the cloud and Internet to meet the user demand.

V. APPLICATIONS OF MOBILE CLOUD COMPUTING

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

A. 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 can be classified into few classes including finance, advertising, and shopping (Table II). The m-commerce applications have to face various challenges (e.g., low network bandwidth, high complexity of mobile device configurations, and security). Therefore, m-commerce applications are integrated into CC environment to address these issues. Yang proposes a 3G E-commerce platform based on CC. This paradigm combines the advantages of both third generation (3G) network and CC to increase data processing speed and security level based on public key infrastructure (PKI). The PKI mechanism uses an encryption-based access control and an over-encryption to ensure privacy of user's access to the outsourced data. A 4PL-AVE trading platform utilizes CC technology to enhance the security for users and improve the customer satisfaction, customer intimacy, and cost competitiveness.

B. Mobile learning

Mobile learning (m-learning) is designed based on electronic learning (e-learning) and mobility. However, traditional m-learning applications have limitations in terms of high cost of devices and network, low network transmission rate, and limited educational resources. 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 richer services in terms of data (information) size, faster processing speed, and longer battery life. Zhao *et al.* presents the benefits of combining learning and CC to enhance the communication quality between students and teachers. In this case, smartphone software based on the open source Java ME UI framework and Jaber for clients is used. Through a web site built on Google Apps Engine, students 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 students' questions in a timely manner. In addition, a contextual m-learning system based on Mobile Interaction in Augmented Reality Environment platform shows that a cloud-based m-learning system helps learners access learning resources remotely. Another example of MCC applications in learning is 'Cornucopia' implemented for researches of under graduate genetics students and 'plantations pathfinder' designed to supply information and provide a collaboration space for visitors when they visit the gardens. The purpose of the deployment of these applications is to help the students enhance their understanding about the appropriate design of MCC in supporting field experiences. An education tool is developed based on CC to create a course about image/video processing. Through mobile phones, learners can understand and compare different algorithms used in mobile applications (e.g., deblurring, demonizing, face detection, and image enhancement).

C. 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 helps to access resources (e.g., patient health records) easily and efficiently. 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 a few schemes of MCC applications in healthcare. For example, presents five main mobile healthcare applications in the pervasive environment.

1) *Comprehensive health monitoring services* enable patients to be monitored at anytime and anywhere through broadband wireless communications.

2) *Intelligent emergency management system* can manage and coordinate the fleet of emergency vehicles effectively and in time when receiving calls from accidents or incidents.

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

4) *Pervasive access to healthcare information* allows patients or healthcare providers to access the current and past medical information.

5) *Pervasive lifestyle incentive management* can be used to pay healthcare expenses and manage other related charges automatically.

5) *Seamless connection to cloud storage* allows users to retrieve, modify, and upload medical contents (e.g., medical images, patient health records, and biosignals) utilizing web services and a set of available APIs called Repretational State Transfer.

6) *Patient health record management system* displays the information regarding patients' status, related biosignals, and image contents through application's interface.

7) *Image viewing support* allows the mobile users to decode the large image files at different resolution levels given different network availability and quality. For practical system, a telemedicine homecare management system is implemented in Taiwan to monitor participants, especially for patients with hypertension and diabetes. The system monitors 300 participants and stores more than 4736 records of blood pressure and sugar measurement data on the cloud. When a participant performs blood glucose/pressure measurement via specialized equipment, the equipment can send the measured parameters to the system automatically. Also, the participant can send parameters by SMS via their mobile devices. After that, the cloud will gather and analyze the information about the participant and return the results. The development of mobile healthcare clearly provides tremendous helps for the participants. However, the information to be collected and managed related to personal health is sensitive.

D. *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 in the cloud, and gamers only interact with the screen interface on their devices. Li demonstrates that offloading (multimedia code) can save energy for mobile devices, thereby increasing game playing time on mobile devices. Cuero proposes MAUI, a system that enables fine-grained energy aware offloading of mobile codes to a cloud. Also, a number of experiments are conducted to evaluate the energy used for game applications with 3G network and WiFi network. It is found that instead of offloading all codes to the cloud for processing, MAUI partitions the application codes at a runtime based on the costs of network communication and CPU on the mobile device to maximize energy savings given network connectivity. The results demonstrate that MAUI not only helps energy reduction significantly for mobile devices (i.e., MAUI saves 27% of energy usage for the video game and 45% for chess), but also improves the performance of mobile applications (i.e., the game's refresh rate increases from 6 to 13 frames per second). Wang and Dey [50] presents a new cloud-based m-game using a rendering adaptation technique to dynamically adjust the game rendering parameters according to communication constraints and gamers' demands. The rendering adaptation technique mainly bases on the idea to reduce the number of objects in the display list because not all objects in the display list created by game engine are necessary for playing the game and scale the complexity of rendering operations. The objective is to maximize the user experience given the communications and computing costs.

E. *Other practical applications*

A cloud becomes a useful tool to help mobile users share photos and video clips efficiently and tag their friends in popular social networks as Twitter and Facebook. MeLog is an MCC application that enables mobile users to share real-time experience (e.g., travel, shopping, and event) over clouds through an automatic blogging. The mobile users (e.g., travellers) are supported by several cloud services such as guiding their trip, showing maps, recording itinerary, and storing images and video. Ye *et al* introduces a mobile locationing service allowing

users to capture a short video clip about the surrounding buildings. The matching algorithm run on a cloud can use a large amount of information to search for a location of these buildings. Also, One Hour Translation provides an online translation service running on the cloud of Amazon Web Services. One Hour Translation helps mobile users, especially foreign visitors, receive the information translated in their language through their mobile devices. A cloud becomes the most effective tool when mobile users require searching services (e.g., searching information, location, images, voices, or video clips).

1) *Keyword-based searching.* Pendyala and Holliday proposes an intelligent mobile search model using semantic in which searching tasks will be performed on servers in a cloud. This model can analyze the meaning of a word, a phrase, or a complex multiphase to produce the results efficiently and accurately. Lagerspetz and Tarkoma presents an application using the cloud to perform data searching tasks for mobile users. Lagerspetz and Tarkoma   uses Dessy system to find the users' data, metadata, and context information through desktop search (e.g., indexing, query, and index term stemming, and search relevance ranking), and synchronization techniques.

2) *Voice-based searching.* Fabbrizio proposes a search service via a speech recognition in which mobile users just talk to microphone on their devices rather than typing on keypads or touchscreens. Fabbrizio *et al.* introduces the AT&T speech mashup model that utilizes web services and CC environment to meet the speech service demands of customers. This model optimizes the data transmission in a mobile network, reduces latency, and is flexible in integrating with other services. Several examples are demonstrated (e.g., speak4it, iPizza, and JME local business search).

3) *Tag-based searching.* A photo searching technique based on ontological semantic tags. Mobile users search only recall parameters that are tagged on images before such images are sent to a cloud. The cloud is used for storing and processing images for resource-limited devices. The current service is designed for the images stored on private CC environment. In the future, it is expected to expand for searching images in a public cloud environment. In addition, there are a mobile-cloud collaborative application to detect traffic lights for the blind, a CC framework to monitor different corners in a house through a mobile device, and some efforts which integrate current services (e.g., BitTorrent, and Mobile Social Network) into the clouds as in [61,62]. Thereby, we can recognize that MCC is probably a prevailing technology trend with numerous applications in the near future.

VI. OPEN ISSUES AND FUTURE RESEARCH DIRECTIONS

Several research works contribute to the development of MCC by tackling issues as presented in the previous section. However, there are still some issues which need to be addressed. This section discusses several open issues and possible research directions in the development of MCC.

A .Low bandwidth

Although many researchers propose the optimal and efficient way of bandwidth allocation, the bandwidth limitation is still a big concern because the number of mobile and cloud users is dramatically increasing. We consider that fourth generation (4G) network and Femtocell are emerging as promising technologies that overcome the limitation and bring a revolution in improving bandwidth.

1)4G network.: Fourth generation network is a technology that significantly increases bandwidth capacity for subscribers. 4G network is capable of providing up to 100 Mbit/s (for 'LTE Advanced' standard) and 128 Mbit/s (for 'WirelessMAN-Advanced' standard) for mobile users, whereas the current 3G network supports a maximum of 14.4 Mbit/s. Furthermore, 4G network also promises other advantages such as widering mobile coverage area, smoothering quicker handoff, varied services, and so on . Nevertheless, 4G wireless networks still have several issues related to network architecture, access protocol.

*2)Femtocell.:*Femtocell is a small cellular base station, designed for use in a small area. Hay Systems Ltd (HSL) develops a service to combine femtocells and CC to deliver a highly economical, scalable, and secure network for mobile operators. This allows the resources employed in delivering mobile services over the femtocell network to expand or contract as user demands for services increase or decrease, respectively. The result is a highly economical femtocell network with only sufficient resources being used at any given point, without impacting the ability to immediately scale to meet demands. In this paradigm, femtocells located in homes and offices of users connect via the Internet to the cloud to gain access to their operator's network. Mobile operators connect with the cloud enabling their subscribers to gain access to their network when using a

femtocell connected to the cloud. However, just shows that femtocell is practically useful when used with clouds. We need to investigate a uniform standard and performance impact of using femtocells in MCC.

B. Network access management

An efficient network access management not only improves link performance for mobile users but also optimizes bandwidth usage. Cognitive radio can be expected as a solution to achieve the wireless access management in mobile communication environment . Cognitive radio increases the efficiency of the spectrum utilization significantly, by allowing unlicensed users to access the spectrum allocated to the licensed users. When this technique is integrated into MCC, the spectrum can be utilized more efficiently. The spectrum scarcity can be solved and thus millions of dollars for network providers can be saved . However, cognitive radio is defined as wireless communication technology in which each node communicates via an optimal wireless system based on recognition of radio resource availability in heterogeneous wireless communication environment. Therefore, mobile users in MCC must be able to detect this radio resource availability (through spectrum sensing) while ensuring that the traditional services will not be interfered.

C. Quality of service

In MCC, mobile users need to access to servers located in a cloud when requesting services and resources in the cloud. However, the mobile users may face some problems such as congestion due to the limitation of wireless bandwidths, network disconnection, and the signal attenuation caused by mobile users' mobility. They cause delays when the users want to communicate with the cloud, so QoS is reduced significantly. Two new research directions are CloneCloud and Cloudlets that are expected to reduce the network delay.

1) *CloneCloud.* CloneCloud brings the power of CC to your smartphones. CloneCloud uses nearby computers or data cantres to increase the speed of running smartphone applications. The idea is to clone the entire set of data and applications from the smartphone onto the cloud and to selectively execute some operations on the clones, re-integrating the results back into the smartphone. One can have multiple clones for the same smartphone, and clones pretend to be more powerful smartphones, and so on. CloneCloud is limited in some respects by its inability to migrate native state and to export unique native resources remotely. A related limitation is that CloneCloud does not virtualize access to native resources that are not virtualized already and are not available on the clone.

2) *Cloudlets.* A cloudlet is a trusted, resource-rich computer or cluster of computers which is well connected to the Internet and available for use by nearby mobile devices. Thus, when mobile devices do not want to offload to the cloud (maybe due to delay and cost), they can find and use a nearby cloudlet. In this way, mobile users may meet the demand for real-time interactive response by low-latency, one-hop, high-bandwidth wireless access to the cloudlet. If no cloudlet is available nearby, the mobile device may refer to the default mode that will send requirements to a distant cloud, or in the worst case, solely its own resources. Satyanarayanan builds an architecture through exploiting a virtual machine technology to rapidly instantiate customized service software on a nearby cloudlet and then uses that service over a wireless local area network. This technology can help mobile users overcome the limitations of CC due to wide area network latency and low bandwidth. However, there are some considerations that need to be addressed before this idea can be applied widely in practical system. For example, how to distribute processing, storage, and networking capacity for each cloudlet? How to manage policies for cloudlet providers to maximize user experience while minimizing cost? Also, trust and security for cloudlet are other issues in implementing this idea because adversaries can create a fake cloudlet to steal the user's information.

D. Pricing

Using services in MCC involves both mobile service provider (MSP) and cloud service provider (CSP). However, MSPs and CSPs have different services management, customers management, methods of payment, and prices. Therefore, this will lead to many issues; that is, how to set price, how the price will be divided among different entities, and how the customers pay. For example, when a mobile user runs mobile gaming application on the cloud, this involves the game service provider (providing a game license), mobile service provider (accessing the data through base station), and CSP (running game engine on a data centre). The price paid by the game player has to be divided among these three entities such that all of them are satisfied with the division. It is clear that the\ business model including pricing and revenue sharing has to be carefully developed for MCC.

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E. *Standard interface*

Interoperability becomes an important issue when mobile users need to interact and communicate with the cloud. The current interface between mobile users and cloud are mostly based on the web interfaces. However, using web interfaces may not be the best option. First, web interface is not specifically designed for mobile devices. Therefore, web interface may have more overhead. Also, compatibility among devices for web interface could be an issue. In this case, the standard protocol, signaling, and interface for interacting between mobile users and cloud would be required to ensure seamless services. In the future, HTML5 is expected as a promising technique to address this issue. HTML5 WebSockets offer an interface. However, an extensive performance evaluation and feasibility study have to be performed to ensure that it will work in MCC efficiently.

F. *Service convergence*

The development and competition of CSPs can lead to the fact that in the near future, these services will be differentiated according to the types, cost, availability and quality. Moreover, in some cases, a single cloud is not enough to meet the mobile user's demands. Therefore, the new scheme is needed in which the mobile users can utilize multiple clouds in a unified fashion. In this case, the scheme should be able to automatically discover and compose services for user. One of the potential solutions of this issue is the *sky computing*, which will be the next step of *cloud computing*. **Sky computing** is a computing model where resources from multiple cloud providers are leveraged to create a large scale distributed infrastructure. Similarly, the *mobile sky computing* will enable the providers to support a cross-cloud communication and enable users to implement mobile services and applications. However, to offer a service to mobile user in a unified way, the service integration (i.e., convergence) would need to be explored.

VII.   CONCLUSION

Mobile cloud computing is one of the mobile technology trends in the future because it combines the advantages of both MC and CC, thereby providing optimal services for mobile users. That traction will push the revenue of MCC to $5.2 billion. With this importance, this paper had provided an overview of MCC in which its definitions, architecture, and advantages have been presented. The applications supported by MCC including m-commerce, mlearning, and mobile healthcare have been discussed which clearly show the applicability of the MCC to a wide range of mobile services. Then, the issues and related approaches for MCC have been discussed. Finally, the future research directions have been outlined.

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