



Mobile Cloud Computing: The Future of Cloud

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Abstract: Mobile Cloud Computing (MCC) has revolutionized the way in which mobile subscribers across the globe leverage services on the go. The mobile devices have evolved from mere devices that enabled voice calls only a few years back to smart devices that enable the user to access value added services anytime, anywhere. MCC integrates cloud computing into the mobile environment and overcomes obstacles related to performance (e.g. battery life, storage, and bandwidth), environment (e.g. heterogeneity, scalability, availability) and security (e.g. reliability and privacy).

Keywords: Cloud Computing, Mobile Cloud Computing, Challenges in MCC, Research Areas in MCC

I. INTRODUCTION

The market of mobile phones has expanded rapidly. According to IDC [1], the premier global market intelligence firm, the worldwide Smartphone market grew 42.5% year over year in the first quarter of 2012. The growth of mobility has changed our lives fundamentally in an unprecedented way. According to Cisco IBSG [2], close to 80 percent of the world's population has access to the mobile phone and new devices like the iPhone, Android smartphones, palmtops and tablets have brought a host of applications at the palms of people's hands.

At the same time, 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 [3] from September, 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 (e.g. networks, servers, storage, applications and services) that can rapidly be provisioned and released with minimal management effort or service provider interaction."

A more formal definition that encapsulates the key benefits of cloud computing from a business perspective as well as its unique features from a technological perspective given by Sean Martson *et al.* [4] in their research paper is as follows:

"It is an information technology service model where computing services (both hardware and software) are delivered on-demand to customers over a network in a self-service fashion, independent of device and location. The resources required to provide the requisite quality-of service levels are shared, dynamically scalable, rapidly provisioned, virtualized and released with minimal service provider interaction. Users pay for the service as an operating expense without incurring any significant initial capital expenditure, with the cloud services employing a metering system that divides the computing resource in appropriate blocks."

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 an Android platform, MobileMe from Apple, LiveMesh from Microsoft and Motoblur from Motorola, have been developed and served to users. The general architecture is as depicted in Fig 1 below.

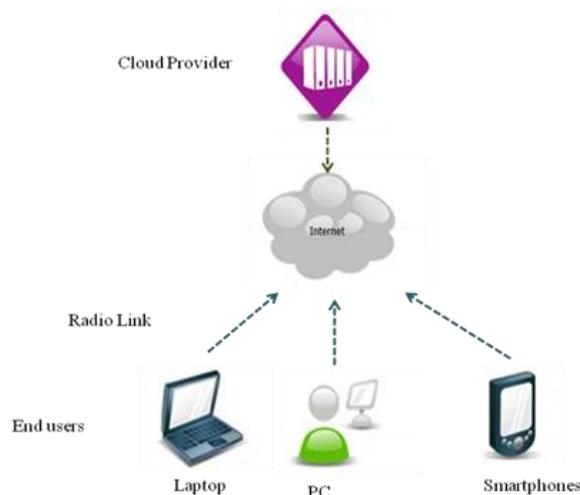


Fig 1: Mobile Cloud Computing

Delivering cloud services in a mobile environment brings numerous challenges and problems. Mobile devices cannot handle complicated applications due to their innate characters. Also, it is impossible that a mobile device is always online, the offline solution of the device need be considered as well. The absence of standards, security and privacy, elastic mobile applications requirement may obstruct the development of Mobile Cloud Computing. In order to understand the challenges and provide further scope for research, an understanding of this novel approach is essential. This paper introduces the basic model of MCC, its background, key technology, challenges, current research status and future research perspectives. The paper is organized as follows: Section I gives an introduction to the technology, Section II gives a background where the cloud definition is presented, Section III details the general architecture of MCC, Section IV presents Challenges and Solutions, Section V gives an overview of present work, Section VI presents Open Research Issues. The conclusions are drawn in Section VII.

II. BACKGROUND

As an inheritance and emergence of cloud computing and mobile computing, mobile cloud computing has been devised as a new phrase since 2009.

From a simple perspective, mobile cloud computing can be thought of as infrastructure where data and processing could happen outside of the mobile device, enabling new types of applications such as context-aware mobile social networks. As a result, many mobile cloud applications are not restricted to powerful smartphones, but to a broad range of less advanced mobile phones and, therefore, to a broader subscriber audience. MCC can be simply divided into mobile computing and cloud computing. The mobile devices can be laptops, PDA, smartphones and so on, which connect with a base station or a hotspot by a radio link such as 3G, Wi-Fi or GPRS. Although the client is changed from PCs or fixed machines to mobile devices, the main concept is still cloud computing. Mobile users send service requests to the cloud through a web browser or desktop application. The management component of cloud then allocates resources to the request to establish connection, while the monitoring and calculating functions of mobile cloud computing are implemented to ensure the QoS until the connection is completed.

The cloud model as defined by NIST promotes availability and is composed of five essential characteristics, three service models and four deployment models.

A. Essential characteristics:

On-demand self service: A consumer can unilaterally provision computing capabilities, such as server time and network storage, as needed automatically without requiring human interaction with each service provider.

Broad network access: Capabilities are available over the network and accessed through standard mechanisms that promote use by heterogeneous thin or thick client platforms like mobile phones, laptops, PDAs etc.

Resource pooling: The provider's computing resources are pooled to serve multiple consumers using a multi-tenant model, with different physical and virtual resources dynamically assigned and reassigned according to consumer demand. The customer does



not have control or knowledge over the exact location of the provided resources. Examples of resources include storage, processing, memory, network bandwidth and virtual machines.

Rapid elasticity: Capabilities can be rapidly and elastically provisioned, in some cases automatically, to quickly scale out and rapidly released to quickly scale in.

Measured Service: Cloud systems automatically control and optimize resource use by leveraging a metering capability at some level of abstraction appropriate to the type of service (e.g. storage, processing, bandwidth and active user accounts).

B. Service Models:

Software as a Service (SaaS): The capability provided to the consumer is to use the provider's applications running on a cloud infrastructure. The applications are accessible from various client devices through a thin client interface such as a web browser (e.g., web-based email). The consumer does not manage or control the underlying cloud infrastructure with the possible exception of limited user-specific application configuration settings.

Platform as a Service (PaaS): The capability provided to the consumer is to deploy onto the cloud infrastructure consumer-created or acquired applications created using programming languages and tools supported by the provider. The consumer does not manage or control the underlying cloud infrastructure including network, servers, operating systems, or storage, but has control over the deployed applications and possibly application hosting environment configurations.

Infrastructure as a Service (IaaS): The capability provided to the consumer is to provision processing, storage, networks, and other fundamental computing resources where the consumer is able to deploy and run arbitrary software, which can include operating systems and applications. The consumer does not manage or control the underlying cloud infrastructure but has control over operating systems, storage, deployed applications, and possibly limited control of select networking components (e.g. host firewalls).

Fig 2 below shows a typical Cloud Service Model.

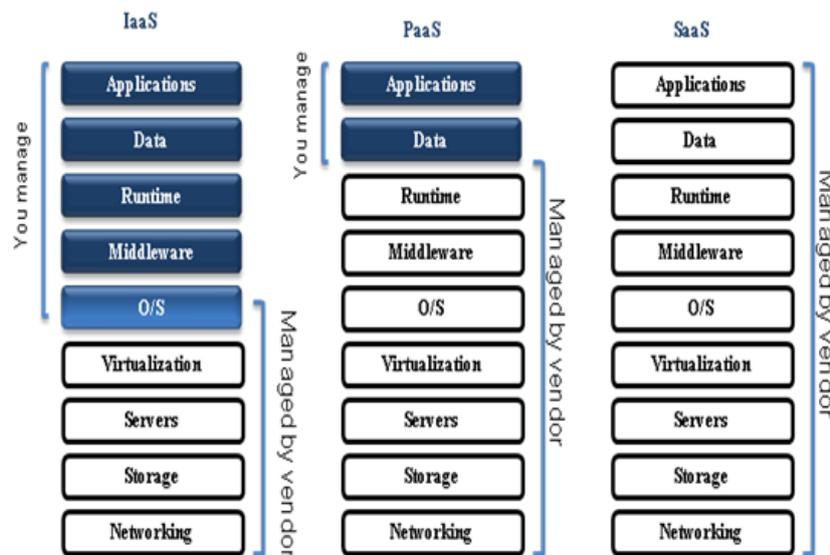


Fig 2: Cloud Service Model

C. Deployment Models:

Private Cloud: The cloud infrastructure is operated solely for an organization. It may be managed by the organization or a third party and may exist on premise or off premise.

Community Cloud: The cloud infrastructure is shared by several organizations and supports a specific community that has shared concerns (e.g., mission, security requirements, policy, and compliance considerations). It may be managed by the organizations or a third party and may exist on premise or off premise.



Public Cloud: The cloud infrastructure is made available to the general public or a large industry group and is owned by an organization selling cloud services.

Hybrid Cloud: The cloud infrastructure is a composition 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).

Fig 3 below illustrates Public, Private and Hybrid cloud deployment example.

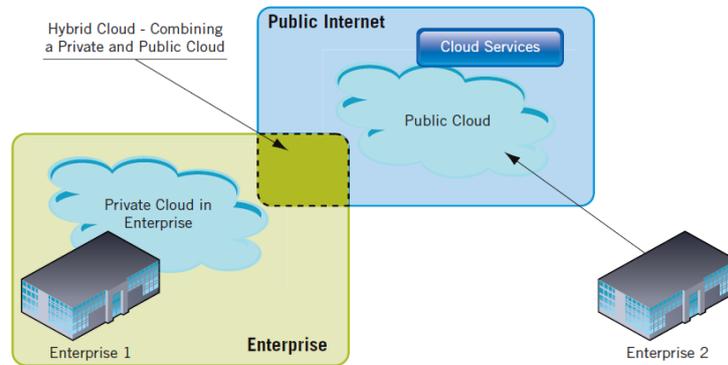


Fig 3: Public, Private and Hybrid Cloud deployment

III. ARCHITECTURE

An overview of basic Mobile Cloud Computing was presented in the previous section. A general architecture in a broader sense was as depicted in Fig 1. A more detailed representation will be presented in this section.

Fig 4 presents a typical Mobile Cloud Computing architecture [8].

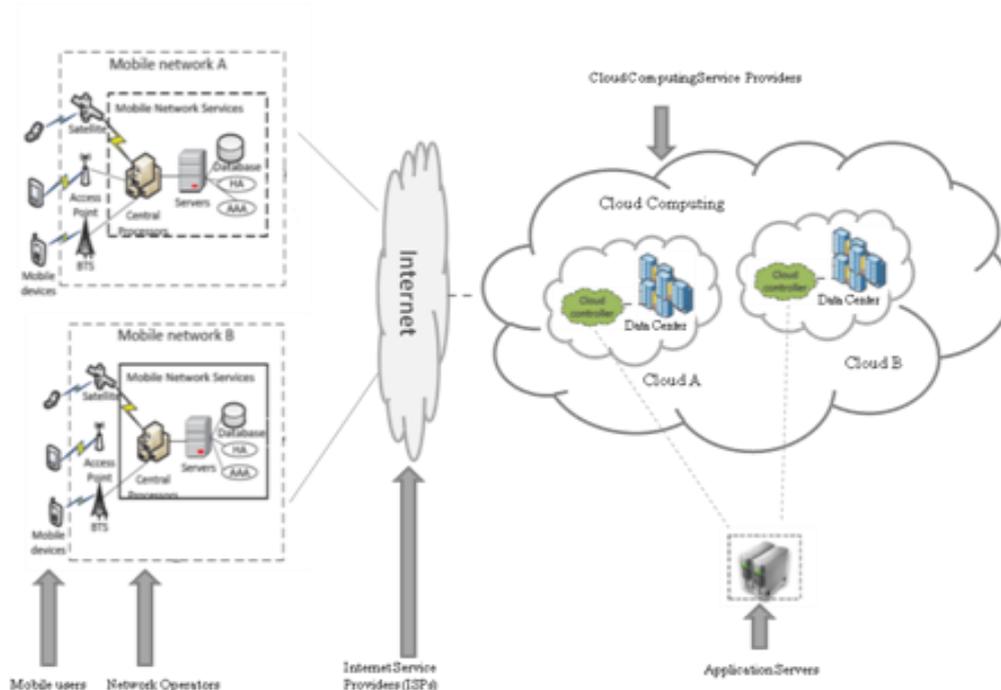


Fig 4: Mobile Cloud Computing Architecture



The mobile devices are connected to the mobile networks through base stations that establish and control the connections (air interface) and functional interfaces between the networks and mobile devices. Mobile users' request and information 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 subscribers' data stored in databases. 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 details of cloud computing will be different in different contexts. The major function of a cloud computing system is storing data on the cloud and using technology on the client to access that data. Some authors mentioned that Cloud Computing is not entirely a new concept. Lamia Youseff et al. have stated in their paper [10] that Cloud Computing has manifested itself as a descendent of several other computing areas such as Service-oriented Architecture, grid and distributed computing, and virtualization and inherits their advancements and limitations. They introduced Cloud Computing as a new paradigm in the sense that it presented a superior advantage over the existing under-utilized resources at the data centers. Several business models rapidly evolved to harness this technology by providing software applications, programming platforms, data-storage, computing infrastructure and hardware as services. R.Buyya et al. have introduced a market oriented architecture in [11] and [12]. They have introduced Cloud as a type of parallel and distributed system consisting of a collection of interconnected and virtualized computers that offer computing resources from service providers to customers meeting their agreed SLA (Service Level Agreement).

We focus on a layered architecture which commonly demonstrates the effectiveness of Cloud Computing model in terms of user's requirements. The service model has been explained earlier in this section. Fig 5 below gives an overview of the layered architecture or cloud stack and who uses these.

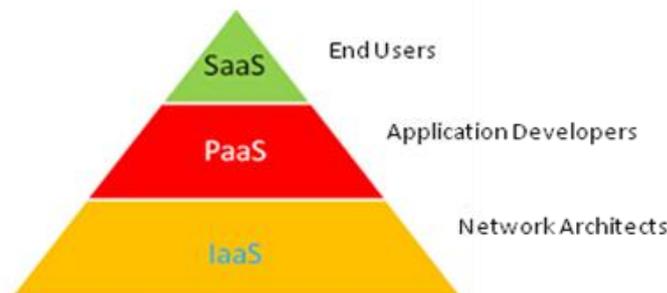


Fig 5: Cloud stack

IV. CHALLENGES AND SOLUTIONS

The last decade brought with it several advancements in the way we perceive computing and mobility. Computing will be the 5th utility (after water, electricity, gas and telephony) and will provide the basic level of computing service that is considered essential to meet everyday needs of the general community. Cloud Computing is the latest paradigm proposed to deliver this vision. It has proved to be a promising solution for mobile computing for many reasons (e.g. mobility, communication and portability).

Resource poverty: As processors are getting faster, screens are getting sharper and devices are equipped with more sensors, a smartphone's ability to consume energy far outstrips the battery's ability to provide it. Thus, battery life of mobile devices remains a key limiting factor in the design of mobile applications. The two main contributors are a) limited battery capacity and b) an increasing demand from users for energy-hungry applications. User demand is increasing by the day for resource intensive applications, like video games, streaming video and sensors equipped on mobile devices that produce continuous streams of data about the user's environment. Several solutions have been proposed to enhance the CPU performance [14] and to manage the resources available optimally in order to reduce power consumption. These solutions, however, require changes in the structure of mobile devices or require new hardware resulting in additional engineering necessary and thus have cost premium over



standard devices. Computation offloading techniques migrate the large computations and complex processing from resource-limited devices to resourceful devices, thus avoiding mobile devices to take a large execution time. Several experiments have been done that evaluate the effectiveness of offloading techniques. Alenxey Rudenko *et al.* have demonstrated in [15] that remote execution of large tasks can reduce their power consumption by upto 50%. Eduardo Cuervo *et al.* have shown in [16] that using MAUI (Memory Arithmetic Unit and interface) to migrate mobile components to servers in the cloud can save 27% of energy consumption for computer games and 45% for the chess game.

Data storage capacity and processing power: Storage is also a major concern for mobile devices. MCC is developed to enable mobile users to store and access large amounts of data on the cloud. Amazon Simple Storage Service (S3) is one such example [17]. It provides a simple web services interface that can be used to store and retrieve any amount of data, at anytime from anywhere on the web. Flickr [18] is almost certainly the best photo sharing application based on MCC. It allows users to upload and share photos through mobile devices and web. Facebook [19] is the most successful social network application today and is also a typical example of using cloud in sharing images. MCC also helps reduce the running cost for compute-intensive applications. Cloud computing efficiently supports various tasks for data-warehousing, managing and synchronizing multiple documents online. Thus, mobile devices are no more constrained by storage capacity because their data is now stored on the cloud. Microsoft will develop new office software [20] to embrace cloud computing to fully integrate with all types of mobile devices. It will enable users to save, publish and share their work with other users as well as their desktop computers and mobile devices.

Division of application services: The mobile devices have inherently limited resources. Thus the applications have to be divided in order to achieve a particular performance target (low latency, minimization of data transfer, fast response time etc.) Considering the demands of MCC, the essential factors for delivering 'good' cloud services have been enumerated below:

- Optimal partition of application services across cloud and mobile devices
- Low network latency in order to meet application and code offload interactivity
- High network bandwidth for faster data transfer between cloud and mobile devices
- Adaptive monitoring of network conditions to optimize network and device costs against user-perceived performance of the Cloud application

The following strategies can be adopted by service providers to address the above issues:

- Network bandwidth strategy: Using regional data centers or other means to bring content closer to mobile broadband
- Network latency strategy: Application processor nodes to be moved to the edge of mobile broadband
- Battery saving strategy: Cloning the device in the network for compute and energy intensive management tasks such as automatic virus scanning of mobile devices
- Mobile cloud application elasticity: Dynamic optimization of application delivery and execution between the device and the network

Applications	Cloud infrastructure attributes		
	Compute intensity	Network bandwidth	Network latency
Web-mail (Yahoo!,Gmail)	Low	Low	High
Social networking (Facebook)	Low	Medium	Medium
Web browsing	Low	Low	High
Online gaming	High	Medium	Low
Augmented reality	High	Medium	Low
Face recognition	High	Medium	Low
HD video streaming	High	High	Low
Language translation	High	Medium	Low

Compute intensity – High, required for compute-intensive apps

Network bandwidth – High, required for content, heavy, large data transfer apps

Network latency – Low, required for high interactivity

Table 1: APPLICATION AND CLOUD INFRASTRUCTURE MAPPING

Source: Alcatel-Lucent



There are several other issues related to implementation of MCC. A few of them have been listed below:

A. Absence of standards

In spite of the various advantages of Cloud computing over the conventional computing techniques, there is no accepted open standard available. Portability and interoperability is also impossible between different Cloud computing Service Providers (CCSP). This prevents the service providers to widely deploy and quickly develop Cloud computing. Customers are reluctant to transform their current datacenters and IT resources to cloud platforms owing to a number of unsolved technical problems that exist in these platforms. Some of the problems existing due to a lack of open standards are the following:

- Limited scalability: Owing to the rapid growth, none of the CCSPs can meet all the requirements of all the users.
- Unreliable availability of a service: Dependence on a single CCSP's service can result in a bottleneck in the event of a breakdown of a service.
- Service provider lock-in: Absence of portability makes it impossible for data and application transfer among CCSPs, consequently customer is locked to a CCSP.
- Unable to deploy service over multiple CCSPs: Absence of interoperability makes it impossible for application to be scaled over multiple CCSPs.

In view of the afore mentioned disadvantages, B.Rochwerger *et al.* have introduced a solution called Open Cloud Computing Federation (OCCF) in [21], that solves the problems of interoperability and portability among various CCSPs. However, the move to a common cloud standard is impossible because most of the cloud computing firms have their own APIs and for setting those up lots of funds were spent. The OCCF thus lacks a practical realization mechanism. A possible approach is to have a Mobile Agent Based Open Cloud Computing Federation (MABOCCF) mechanism as introduced by Chetan S. *et al.* in [22].

B. Access Schemes

MCC will be deployed in a heterogeneous access scenario in terms of Wireless Network Interfaces. Mobile nodes access the Cloud through different radio access technologies viz. GPRS, WLAN, LTE, WiMAX, CDMA2000, WCDMA etc. Mobile Cloud Computing requires the following features:

- MCC requires an "always-on" connectivity for a low data rate cloud control signaling channel
- MCC requires an "on-demand" available wireless connectivity with a scalable link bandwidth
- MCC requires a network selection and use that takes energy-efficiency and costs into account

Access management is a critical aspect of MCC. A possible solution is to use context and location information to optimize mobile access, as proposed by A.Klein *et al.* in [23]. Deploying MCC utilizing the context information, such as device locations and capabilities and user profiles, can be used by the mobile cloud server to locally optimize the access management.

C. Security

Mobile devices today have all the functionalities of a standard computer. This, like for the standards computers, poses a security threat to the mobile devices as well. The threat detection services run on the mobile devices to combat these security threats, warrant intensive usage of resources, both in terms of computation and power.

A possible solution is to move these detection services to the cloud. It saves the device CPU and memory requirements with increased bandwidth as the price to be paid. This approach has the following benefits:

- Better detection of malicious software
- Reduced on-device resource consumption
- Reduced on-device software complexity

D. Elastic Application Models

Cloud computing services are scalable, via dynamic provisioning of resources on a fine grained, self-service basis near real-time, without users having to engineer for peak loads. This requirement particularly manifests in Mobile Cloud Computing due to the intrinsic limitations of mobile devices. For example, the iPhone 4s is equipped with 800 MHz CPU, 512 MB RAM allowing about 8 hrs of talktime and 14.4 Mbps speed on HSDPA 4G network, [24]. Compared to today's PC and server platforms, these devices still cannot run compute-intensive applications. Thus, an elastic application model is required to solve the fundamental processing problem.

Fig 6 below shows the performance comparison of mobile and fixed devices.

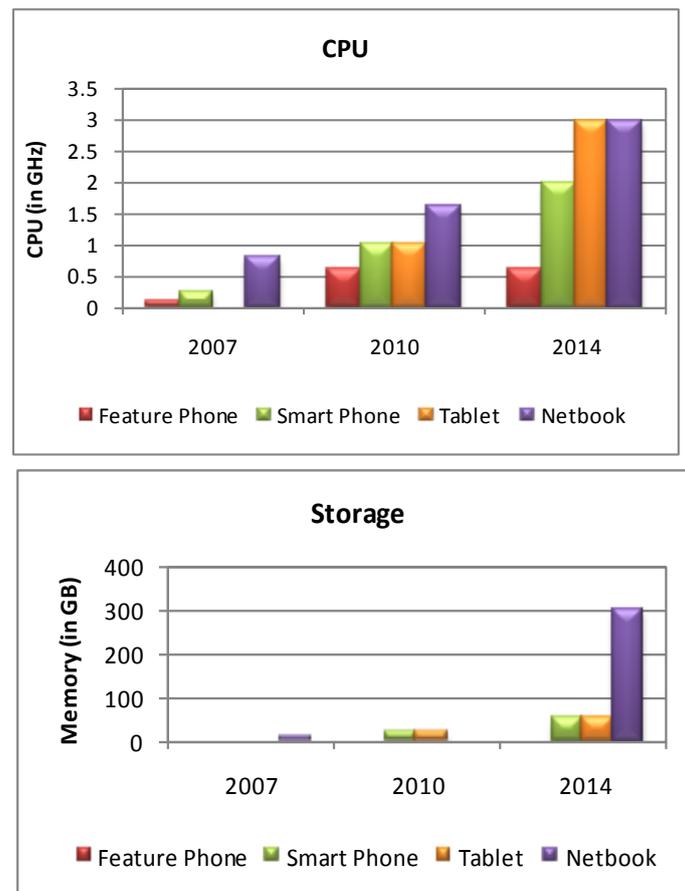


Fig 6: Performance comparison of mobile and fixed devices
Source: Alcatel-Lucent

V. PROPOSED METHOD

S.S Qureshi *et al.* have categorized MCC into two broad categories viz. General Purpose Mobile Cloud Computing (GPMCC) and Application Specific Mobile Cloud Computing (ASMCC) in [26].

A. GPMCC

1) Approach

Cloud Computing has a broad perspective and finds feasible applications in varied applications. This necessitates a mobile device to utilize the internet to use a resource in an on-demand manner. Thus computation hungry tasks that are usually executed on a resource constrained mobile device can now be outsourced to the cloud.

2) Augmented Execution

B. Chun *et al.* have proposed an architecture in [27] that addresses the challenges of executing potential applications on mobile devices via seamlessly but partially off-loading execution from the smartphone to a computational infrastructure hosting a cloud of smartphone clones.

This augmented execution overcomes smartphone hardware limitations and it is provided (semi)-automatically to applications whose developers need few or no modifications to their applications.



The CloneCloud vision was realized in [28]. CloneCloud boosts unmodified mobile applications by off-loading the right portion of their execution onto device clones operating in a computational cloud. The primary motivation was as long as the execution on cloud is significantly faster than execution on the mobile device, the price paid for sending the relevant data and code from the device to the cloud and back would be worth it. The second motivation was to take the programmer out of application partitioning. CloneCloud uses a combination of static analysis and dynamic profiling to partition applications automatically at a fine granularity while optimizing execution time and energy use for a target computation and communication environment. At runtime, the application partitioning is effected by migrating a thread from the mobile device at a chosen point to the clone in the cloud, executing there for the remainder of the partition, and re-integrating the migrated thread back to the mobile device. The evaluation shows that this prototype can adapt application partitioning to different environments, and can help some applications as much as a 20x execution speed-up and a 20-fold decrease of energy spent on the mobile device. This however suffers from limitations because only a fixed computation scheduling in the mobile device is considered.

Y.Wan *et al.* have proposed energy-optimal application execution in the cloud assisted mobile platform in [29]. The objective was to minimize the total energy consumed by the mobile device. When the applications are executed in the mobile device, the computation energy can be minimized by optimally scheduling the clock frequency of the mobile device. When the applications are executed in the cloud clone, the transmission energy can be minimized by optimally scheduling the transmission data rate via a stochastic wireless channel. The numerical results indicate that the optimal policy depends on the application profile (i.e. the input data size and the delay deadline) and the wireless transmission model.

B. ASMCC

1) Approach

Application Specific Mobile Cloud Computing involves developing specific applications for mobile devices. While both potentially offload the computation from and improve the efficiency of the mobile device, ASMCC has an advantage over GPMCC that it provides more than simply computation power. For example, e-mail or chatting needs ASMCC as internet is used as the communication resource and not mere storage.

2) Mobile Service Clouds

Samimi *et al.* have introduced service clouds for MCC in [30] and named them Mobile Service Clouds. This model enables dynamic instantiation, composition, configuration and reconfiguration of services on an overlay network to support mobile computing.

3) Elastic Application Weblets

X.Zhang *et al.* have proposed a model that enables the seamless and transparent use of cloud resources to augment the capability of resource constrained mobile devices. The salient features of this model include the partition of a single application into multiple components called weblets, and a dynamic adaptation of weblet execution configuration. While a weblet can be platform independent (e.g., Java or .Net bytecode or Python script) or platform dependent (native code), its execution location is transparent – it can be run on a mobile device or migrated to the cloud, i.e., run on one or more nodes offered by a CCSP. Thus, an elastic application can augment the capabilities of a mobile device including computation power, storage, and network bandwidth, with the light of dynamic execution configuration according to device's status including CPU load, memory, battery level, network connection quality, and user preferences.

4) Thinkair

Sokol Kosta *et al.* have proposed *Thinkair* in [32] which takes the best of MAUI [16] and CloneCloud [27, 28] projects. It addresses MAUI's lack of scalability by creating Virtual Machines (VMs) of a complete smartphone system on the cloud, and removes the restrictions on the applications that CloneCloud induces by adopting an online method-level offloading. It also provides an efficient way to perform on-demand resource allocation and exploits parallelism by dynamically creating, resuming, and destroying VMs in the cloud when needed. It is the first to address these two aspects in mobile clouds.

5) Partitioning and execution of applications

Lei Yang *et al.* have proposed a framework for partitioning and execution of data stream applications in Mobile Cloud Computing in [33]. It aims at optimizing the partitioning of a data stream application between mobile and cloud such the application has maximum throughput in processing the streaming data. Different from other works, the framework not only allows the dynamic partitioning for a single user but also supports the sharing of computation instances among multiple users in the cloud to achieve efficient utilization of the underlying cloud resources.



VI. OPEN RESEARCH ISSUES

A. Energy efficiency

Owing to the limited resources such as battery life, available network bandwidth, storage capacity and processor performance, on the mobile devices, researchers are always on the lookout for solutions that result in optimal utilization of available resources.

B. Security

The absence of standards poses a serious issue specifically with respect to security and privacy of data being delivered to and from the mobile devices to the cloud.

C. Better service

The original motivation behind MCC was to provide PC-like services to mobile devices. However, owing to the varied differences in features between fixed and mobile devices, transformation of services from one to the other may not be as direct.

D. Task division

Researchers are always on the lookout for strategies and algorithms to offload computation tasks from mobile devices to cloud. However, due to differences in computational requirement of numerous applications available to the users and the variety of handsets available in the market, an optimal strategy is an area to be explored.

VII. CONCLUSION

Mobile Cloud Computing, as a development and extension of Cloud Computing and Mobile Computing, is the most emerging and well accepted technology with fast growth. The combination of cloud computing, wireless communication infrastructure, portable computing devices, location-based services, mobile Web etc has laid the foundation for the novel computing model. In this paper we have given an overview of Mobile Cloud Computing that includes architecture, benefits, key challenges, present research and open issues.

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Biography



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