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A Survey of Mobile Cloud Computing: Architecture, Existing Work and Challenges

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Abstract— Mobile Cloud Computing (MCC) is evolving as one of the most important branches of cloud computing. MCC is defined as combination of cloud computing and mobile computing. Mobile users are provided with data storage and high processing services via cloud computing. Because mobile cloud computing is still in its initial stages, existing works and an overview of recent advances in mobile cloud computing is provided. We explore representative architecture of mobile cloud computing and analyse key components. Furthermore, emerging MCC models and services are discussed, and challenging issues are identified that will need to be addressed in future work.

Keywords— Mobile Cloud Computing, Cloud computing, Cloudlets, Hyrax, Issues in MCC

I. INTRODUCTION

The markets of mobile phones have expanded rapidly as mobile devices (smartphones, tablets etc.) are becoming the most essential part of life. This rapid progress of mobile computing has become a powerful part in the development of IT industries as well as commerce and other industry field. In recent research on Mobile cloud computing, one of the central challenges is to swing up the data and programs from desktop and install them on cloud. Cloud computing is defined as an application services provided to the end user over the internet and also the hardware and systems software in the data centres that provide those services. Cloud computing provides advantages by allowing users to use infrastructure, e.g. Servers, storages, networks, platforms i.e. Operating Systems, development tools and Software i.e. application programs. These services are provided by the cloud providers such as Google, Amazon , windows azure and salesforce at low cost. It also provides elasticity in terms of utilization of resources as a on demand service. As a result, mobile applications can be quickly provisioned and released with the minimal management efforts or service provider's interactions. Thus, with the evolution of cloud computing and mobile application, Mobile Cloud Computing (MCC) is introduced as an integration of mobile computing and cloud computing.

It brings various services to the end user that takes full benefits of cloud computing. Although mobile device hardware and mobile network continue to evolve and to improve, mobile devices will always lack resources, security, unstable connectivity and energy as they are powered by battery. But the mixture of cloud computing, portable computing devices, wireless communication infrastructure, location-based services, mobile, web, etc. has laid to the solution called MCC. It provides unlimited power and storage space. Thus, MCC can be defined as "A model for transparent elastic expansion of mobile device capabilities via wireless ubiquitous access to cloud storage and computing resources, with context-aware dynamic adjusting of offloading, while preserving available capabilities of mobile devices."

This paper is a comprehensive survey on mobile cloud computing, section II gives a brief overview of mobile computing and cloud computing and architecture of MCC. Section III discusses about the existing work on MCC. Section IV provides the use of MCC in various applications. Then at last section V presents challenges and various approaches to address the issues. Finally, we summarize and conclude the survey in section VI.

II. OVERVIEW AND ARCHITECTURE OF MCC

The term "Mobile Cloud Computing" was introduced no longer after the introduction of "Cloud Computing". It has been a major attraction as it offers reduced development and running cost. This section provides an introduction and definition of Cloud Computing and Mobile Computing and its architecture.

A. Cloud Computing

Cloud computing can be defined as a way of using computational resources such as storages, operating systems etc. which are located remotely and are provided as a service over internet. A huge change in the IT sector and IT marketing has been expected by the researchers and academicians. The basic advantages of cloud computing includes low costs, high availabity, scalability and elasticity.

B. Different Service Layers of Cloud Computing

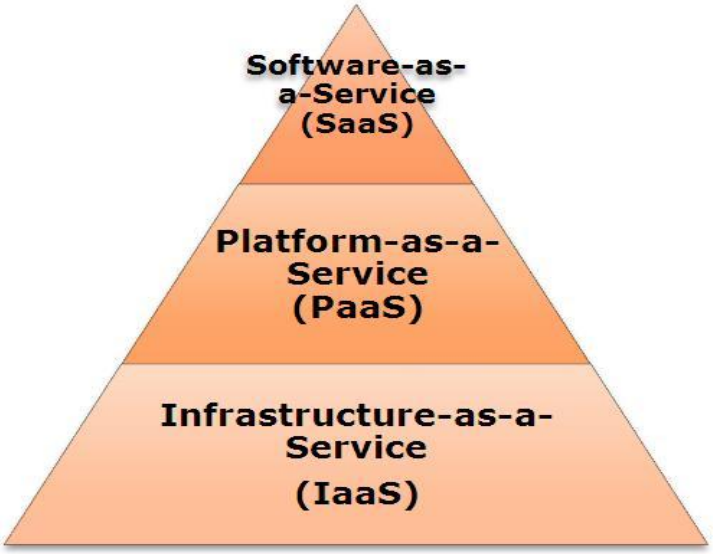


Fig. 1 Layered Architecture of Cloud Computing

1) *Software as a Service:* This layer offers different applications as a service to the end user over the web on a pay-per use model. A SaaS provider deploys software to the user on demand, usually through a licensing model. Salesforce is a pioneer example this service model.
2) *Platform as a Service:* This layer offers development environments which can be used to develop different business applications. This layer differs from SaaS solution in that they provide a cloud-hosted virtual development platform, accessible via a web browser. Both computing platform and solution pile are provided by this layer. It provides toolkits configures for the virtual development environment. In short it provides an integrated atmosphere for building, testing and deploying application. Examples of PaaS are Microsoft Azure, Google App Engine, Amazon Map Reduce service etc.
3) *Infrastructure as a Service:* This layer is at the top of the architecture, it offers storage and computational resources such as hardware, servers, networking components, which can be used by IT organization to deliver business solutions. Smaller shops now have access to much higher level of IT talent and technology solutions and dynamic infrastructure scalability. It also works on per-per-use basis only. The examples of IaaS are Amazon EC2 (Elastic Cloud Computing) and S3 (Simple Storage Service).
4) *Monitoring as a Service***:** It is concerned with the outsourced security, mainly used in business platforms. Security monitoring refers to the protections against the cyber threats. Security plays a vital role in terms maintain confidentiality, integrity, availability of assets. The main functionality of this layer is to monitor the all SaaS, PaaS and IaaS layers

The details of cloud architecture could be different in different contexts. For example, four layer architecture is explained in [2] to compare cloud computing with grid computing. Alternatively, service oriented architecture, called Aneka, and is introduced to enable developers to build .NET applications with the supports of application programming interfaces (APIs) and multiple programming models [3]. [4] Presents architecture for creating market oriented clouds, and [5] proposes an architecture for web delivered business services. Here in this paper we have discussed the basic 3 layered architecture of Cloud Computing (Fig. 1).

C. Mobile Cloud Computing

Definitions of Mobile Cloud Computing can be classified into two classes; first one refers to carrying out data storages and processing outside the mobile device i.e on cloud [6]. Here mobile devices simply acts as a terminal, only intended to provide an easy convenient way of accessing service in cloud. The benefit of this is that the main obstacle of mobile low storage and processing power are avoided and level of security is provided via acute security applications.

The second definition refers to computing where data storage and computing are carried out on mobile device. Using mobile hardware for cloud computing has advantages over using traditional hardware. These advantages include computational access to multimedia and sensor data without the need for large network transfers, more efficient access to data stored on other mobile devices, and distributed ownership and maintenance of hardware. Using these definition one can clarify the differences between mobile computing and cloud computing. Cloud computing aims at providing service without the knowledge of end user of where these services are hosted or how they are delivered. Whereas Mobile computing aims to provide mobility so, that users can access resources through wireless technology from anywhere.

D. Architecture Of Mobile Cloud Computing

In the previous section we discussed about the overview of Cloud Computing and Mobile Cloud Computing. A detailed architecture will be presented in this section, below Fig. 2 shows the typical architecture of Mobile Cloud Computing.

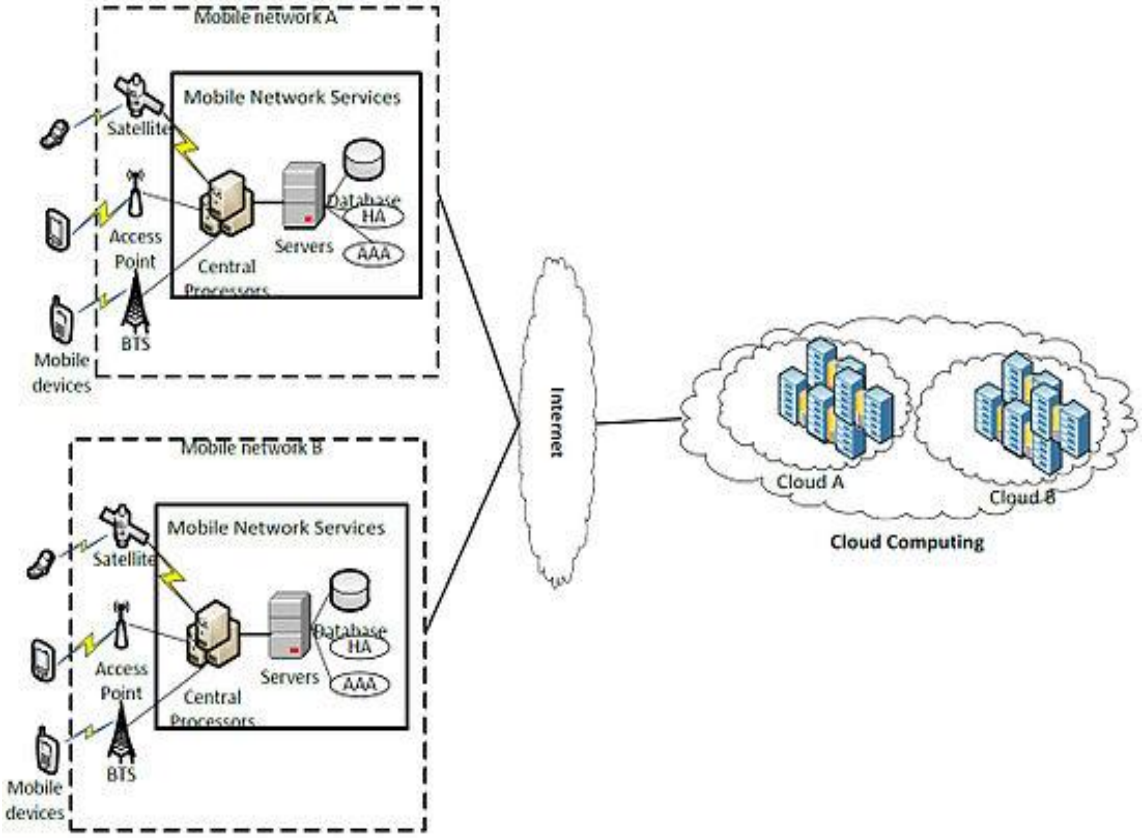


Fig. 2 Architecture of Mobile Cloud Computing

As shown in figure 2. Mobile devices are connected to the mobile networks through Base Transceiver Station, Access Point or Satellite and hence control the connection links and interfaces between the networks and mobile device. Whenever mobile users' requests, information i.e. ID and locations are transmitted to the central processors which are further connected to the servers that are responsible for providing network service. Here service provided to the mobile users by mobile network operators are as AAA (Authentication, Authorization and Accounting) based on the HA (Home Agent) and the data stored in database. After that, user's request is then delivered to the cloud via Internet. In cloud, cloud controllers process the request in order to provide the demanded cloud service by the user. These services include provisioning of virtualization; pay-per-use i.e. utility computing and service oriented architecture (e.g. web services, web application and database servers).

III. EXISTING WORK ON MOBILE CLOUD COMPUTING

Existing work on Mobile Cloud Computing can be categorized based on the cloud platform or based on access schemes. This section discusses about the existing works on mobile cloud platform consisting of mobile devices. The Hyrax [7] platform is derived from Hadoop [8] and it ropes cloud computing on Android smartphones. Moreover, we discuss about the existing work on MCC.

A. Hyrax

The main purpose of Hyrax is to develop a infrastructure of mobile cloud that empowers smartphones with computation and distributed data. It allows application to use data and perform computations easily on smartphones network or heterogeneous networks of phones or servers. Its infrastructure is based on Map Reduce [9]. The MapReduce runtime system divides input data; reduce tasks, and schedules map and transfers i/o data to machines that runs the task. There is a master whose task is to manage jobs and also assigns tasks to slave machines and provide location of intermediary values.

Hadoop is an open source employment of MapReduce which is mainly used for processing large data. Hadoop Distributed File System (HDFS) is mainly used for data stored in distributed file system. There are four types of methods in Hadoop i.e. NameNode, JobTracker, DataNode, and TaskTracker. In hadoop cluster, there is one NameNode and one TaskTracker.

Tasks of each method are as follows:

1) *NameNode*: Its work is to schedules job and manages sub-tasks among TaskTrackers.
2) *Jobtracker:* to track and assign tasks.
3) *DataNode and TaskTracker:* They both run on each worker machines. The task of DataNode is to store data and that of TaskTracker is to execute tasks assigned to it by JobTracker.

Hyrax docks Hadoop to Android platform. To access a file client first requests block locations from NameNode and then requesting blocks directly from these locations. One instance of NameNode and JobTacker runs on each machine. DataNode and TaskTracker are run on each phone but within the same application in separate Android service. DataNode and TaskTracker can runin background of other application, since they are run as android service.

To record information about the system load, network, power level, disk I/O measures, CPU memory into local file, a thread is produced. Also for control data uploading, check the program status and killing programs, a server runs within an application for the execution of external scripts. Fig. 3 illustrates the interaction of data between each of the software components of each phone.

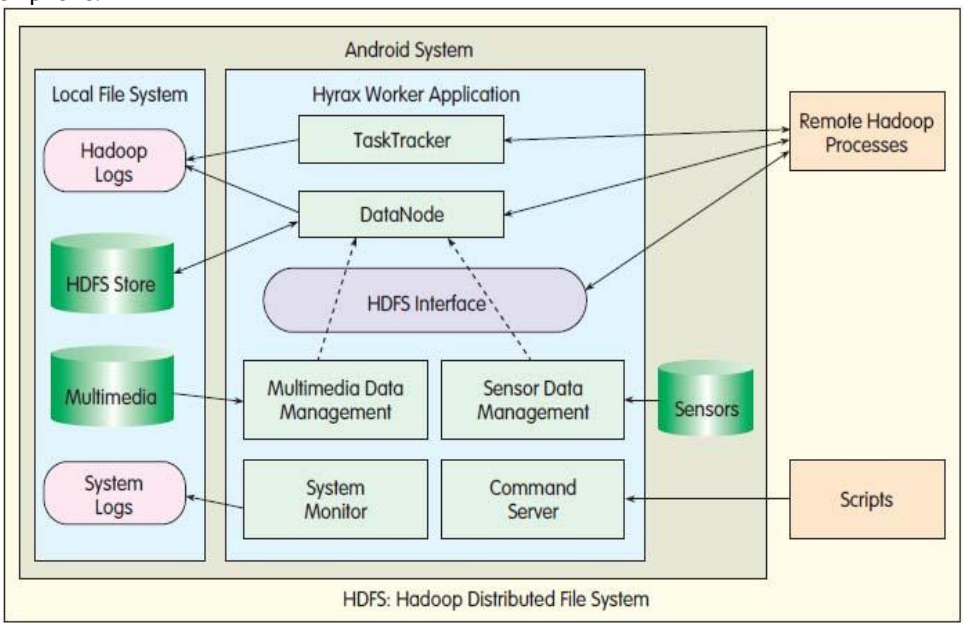


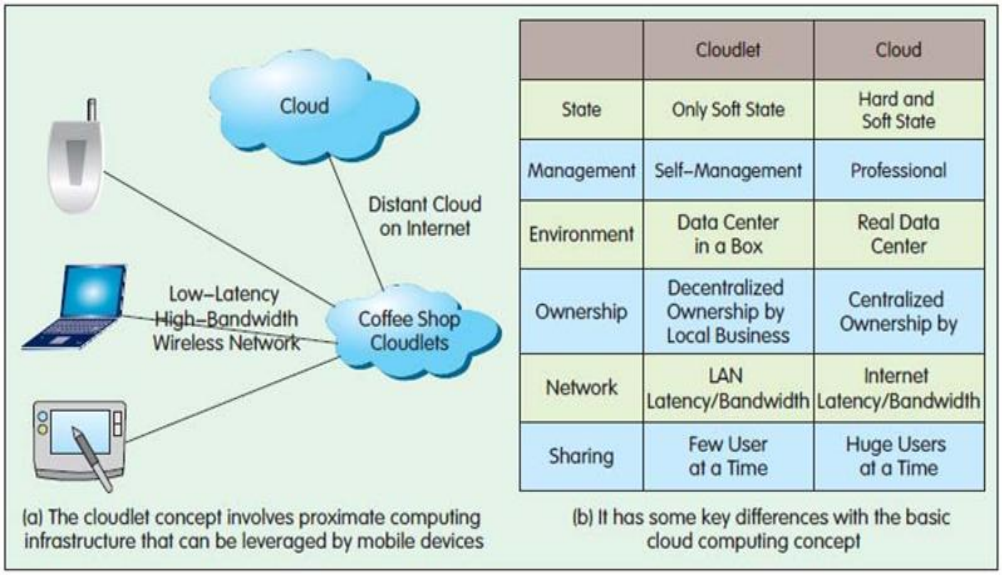
Fig. 3 Hyrax worker application component interaction diagram.

The drawbacks and advantages of Hyrax were determined by developing an application on it. This application allows users to browse videos and images stored on a network and searched by time, location, and quality. By periodically executing a MapReduce job quality ratings based on sensor data were done. Requests are serviced by reading results generated by the MapReduce job from HDFS. The client interface is employed as a web application so as to use on mobile devices and desktop machines.

B. VM-Based Cloudlets

Satyanarayan et al. [10] presents a new vision for MCC. They forecast a new world in which mobile computing flawlessly enhances users' intellectual abilities such as recognition of speech, computer vision, natural language processing and enhanced planning, decision making and reality.

These all can be achieved via VM technology that rapidly instantiate customized service software on nearby cloudlet, which is then used over wireless LAN. A cloudlet is an important cluster of computers that are connected to the internet and available for use by nearby mobile devices.



	Cloudlet	Cloud
State	Only Soft State	Hard and Soft State
Management	Self-Management	Professional
Environment	Data Center in a Box	Real Data Center
Ownership	Decentralized Ownership by Local Business	Centralized Ownership by
Network	LAN Latency/Bandwidth	Internet Latency/Bandwidth
Sharing	Few User at a Time	Huge Users at a Time

(b) It has some key differences with the basic cloud computing concept

Fig. 4 Cloudlet Concept

The issue of poor mobile device resources and WAN latency have been addressed by this solution. Fig. 4 illustrates cloudlets and its work. It bears a resemblance to a data centre in a box. It requires comparatively more power, control setup and connectivity and it is self-managing. Internally, a cloudlet looks like a cluster of multicore computers, with gigabit connectivity and high-bandwidth WLAN. Cloudlet infrastructure is almost similar to Wireless Fidelity (Wi-Fi) access points. A VM neatly encapsulates and separates the guest software environment from the cloudlet's permanent software environment. Therefore, a VM-based approach is less inelastic than alternatives such as software virtualization or process migration. It is also less restricting as compared to the virtualization approaches that require applications written in C# or Java.

C. Intelligent Access Schemes

Mobile Computing rests on a permanent connectivity. This, Intelligent Access Scheme [6] try to meet this requirement by detailed information such as the user's location, request services and context provided by mobile cloud controller. Solution discussed here is about a wide range of different radio access technologies and context information which is designed for heterogeneous access scenario. This Intelligent Radio Network Access (IRNA) concept considers the characteristics and status of Radio Access Technology (RAT). IRNA is depicted in below fig. 5.

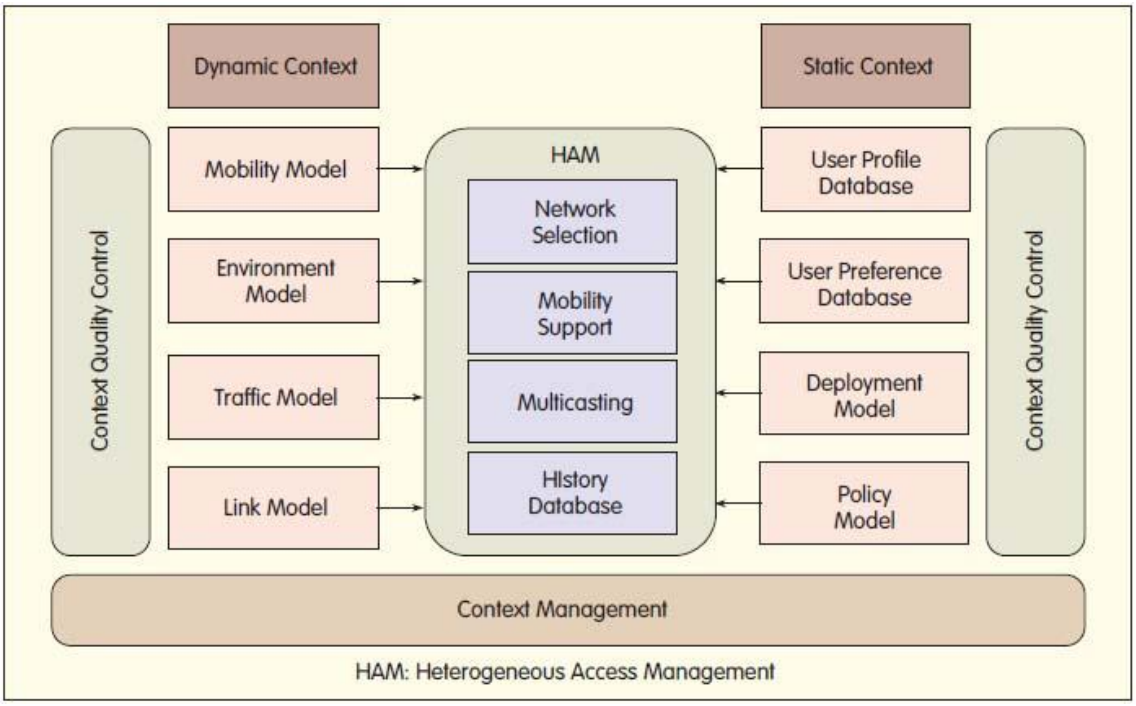


Fig. 5 Concept of Intelligent Access

This Context Management Architecture (CMA) procures processes, manages, and delivers context information. A Context Quality Enabler (CQE) is incorporated into the architecture. The CQE controls the provision of context information According to the requirements of the Mobile Cloud Controller. A Context-Aware Radio Network Simulator (CORAS) is proposed to model context availability, accuracy, and delay, and enable an evaluation to be made on the impact of context relevance, confidence and quality on simulation results.

IV. APPLICATIONS OF MCC

A. M-Commerce

Mobile Commerce is a business model for commerce using mobile devices. Examples of M-commerce are mobile transactions and payments, mobile messaging, and mobile ticketing; these all application fulfils the task that requires mobility. These m-commerce applications can be categorized as finance, advertising and shopping. Low network bandwidth, high complexity of mobile device configuration and security are the various challenges that are faced by m-commerce application. In order to address these issues m-commerce applications are integrated into cloud computing environment [11]. Proposes 3G e-Commerce platform based on cloud computing.

B. M-Learning

Mobile Learning is based on electronic learning and mobility. Nevertheless, old-fashioned m-learning applications have limitations in terms of high cost of devices and network, low network transmission rate, and limited educational resources [12], [13], [14]. In order to solve these issues cloud-based m-leaning applications are introduced. Examples of these m-learning applications are utilizing a cloud with large storage capacity and powerful processing ability; the learners are provisioned with much better services as data size or information size, higher processing speed and longer battery life.

C. M-Healthcare

The purpose of applying MCC in medical applications is to minimize the limitations of traditional treatment (e.g. small physical storage, security and privacy, and medical errors [15]). M-Healthcare provides users a convenient way of accessing resources easy and quickly (e.g. patient health records). Further, M-healthcare offers on-demand services on clouds rather than owning standalone application on local servers to the hospitals and healthcare organization. There are several schemes of MCC application in healthcare such as comprehensive health monitoring services, intelligent emergency management system, Health aware mobile devices, universal access to healthcare information, pervasive lifestyle incentive management.

D. M-Gaming

Mobile game (m-game) is a probable market generating profits from service providers. M-games that requires large computing resources (e.g. Graphics rendering) are offloaded to the server in the cloud and gamers or users only interacts with user interface on their devices [16]. This offloading helps to save battery life of mobile devices and thereby increases the game playing time on mobile device.

E. M-Banking

M-banking (mobile banking) is used for balance checking, transactions, payments, etc., through smart phones, personal digital assistant (PDA) or mobile phones. Today, mobile banking is performed via SMS or mobile internet but can also use special applications or programs that are downloaded on mobile devices.

V. ADVANTAGES OF MOBILE CLOUD COMPUTING APPLICATIONS

MCC provides the software engine that fuels the convergence of open mobile networks, mobile cloud computing, on demand solutions, web and mobile applications, opening up new opportunities in IT sector and IT markets. The benefits are given in the following section:

A. Network Operator:

It empowers operators to monetize their mobile network and billings by providing full commercial solution for Network as a Service.

B. Mobile Cloud Providers:

By providing on- demand services and adding mobile network enablers and intelligent commerce to their range, it empowers themselves to develop new industry and rich B2B solutions.

C. Enterprise Solution Providers:

These solutions help organisations and enterprise to increase employee collaboration, enhance business processes, improve customer service, and get productivity gains.

D. Web and Mobile Application Developers :

It enables web and mobile application developers to differentiate their applications with mobile network features and allow them to reach better potential customer base. The solution makes it easy for developers to improve their applications with valuable mobile network capabilities and intelligence and provides a new direct-to-billing canal for their applications.

VI. CHALLENGES IN MOBILE CLOUD COMPUTING

As mentioned in previous section, Mobile Cloud Computing has many benefits and good application examples for mobile users and service providers. On the other hand, as mentioned in some parts, there are also some challenges relates to cloud computing and mobile networks communication. This section gives an overview about these obstacles and solutions.

A. Mobile Side Challenges

1) *Low Bandwidth:* As mobile network resources are much smaller, Bandwidth becomes one of important issues in mobile cloud environment. These can be overcome by P2P Media Streaming which shares limited bandwidth among the users that are located in nearby same area and content such as the same video [17]. With this method, each user transmits or exchanges parts of the same content with the other users, which is resulted in improvement of quality.
2) *Availability:* The main threat of users to connect themselves to cloud is network failures due to high traffic related poor performance or signal errors. But there are some solutions proposed that helps user to connect to cloud without any threat. One amongst of them is Wi-Fi Based Multihop MANET [18], [19]. It is an infrastructure less and distributed content sharing protocol. In this method, in case of failure of connection to the cloud firstly nearby nodes are detected. Further, instead of establishing a direct link to the cloud, mobile user connects to the cloud via neighboring nodes. Although, certain security issues arises but this can further be solved.
3) *Heterogeneity:* In mobile environment, there are different types of networks which are used simultaneously such as CDMA, ECDMA, GPRS, WiMAX, and WLAN. As a result, to handle these heterogeneity among networks become hard while satisfying mobile cloud computing requirements such as connectivity which is always on, on-demand scalable connectivity, and the energy efficiency of mobile devices. These problems can be solved by using standard interfaces and messaging protocols to reach, manage and distribute content.

4) *Pricing:* For MCC, mobile users require both mobile network provider and cloud service provider. Nevertheless, these providers have different methods of payment and prices for services, features and facilities. Therefore, this has possibility of raising many problems like how to determine price, how the subscribers can pay and how the price could be shared among the providers or parties. For e.g., when a mobile user wants to run a not free mobile application on the cloud, this participates three owners as one of them is application provider for application license, second one is mobile network provider for data packages from user to cloud, and third is cloud provider for providing and running application on the cloud.

B. Computing Side Challenges

Main obstacles and solutions in the cloud side are given below:

1) *Computing Offloading:* Computing offloading is one of the main features of MCC to improve the battery life time and to increase the application's performance by using cloud. 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). Although this solution is very useful in terms of process power and storage, it can be ineffective in some situations. For instance, mobile devices can consume more energy for an application by using the cloud rather than local processing [20] and [21].

Therefore, problem arises that the optimum way to trade-off between the communication and calculation costs have to be calculated for mobile application. The communication cost mainly depends on the size of transmitted data and the network bandwidth, while computation cost is in terms of computation time. The decision of program partitioning can be made at runtime dynamically, with the help of operating cost algorithms.

For example consider an approach for deciding which part of java programs should be offloaded in the cloud. In this approach, a java program is divided into methods and depending on the several parameters like size of method or lines of code execution costs are calculated and further the local execution cost and remote execution costs are compared to make the optimal decision.

2) *Security:* Trust is the major issue of users in this platform of mobile. This issue gains more importance as the stakeholder increases in the cloud for protecting user privacy and data/application secrecy. One of the security issues is mobile device users and the other is data privacy and security.

We often use various security programmes on mobiles device to overcome the issue related to the security threats like malicious codes like virus, worm, Trojan horses and certain privacy concerns with respect to global positioning system (GPS) which lead subscribers to be tracked. But as these security programs consumes more resources of mobile device. Therefore, there is some approaches to move the threat detection part from mobile to cloud. For example, Cloud AV platform provides a multiple service based on both cloud and mobile device for malware detection. A simple and lightweight part of the application runs on the mobile device and it communications with the major component of the application in the cloud [22], [23].

3) *Authentication:* While storing and processing large amount of data/application on a cloud, both application developer and mobile users should be careful about dealing with the data or application in terms of rights and authentication. Some secure authentication mechanisms are required due to the increase in the hacking technology. For example, authentication method, TrustCube is considered, It policy based cloud authentication mechanism that uses open standards and integrates various methods of authentication [24], [25].

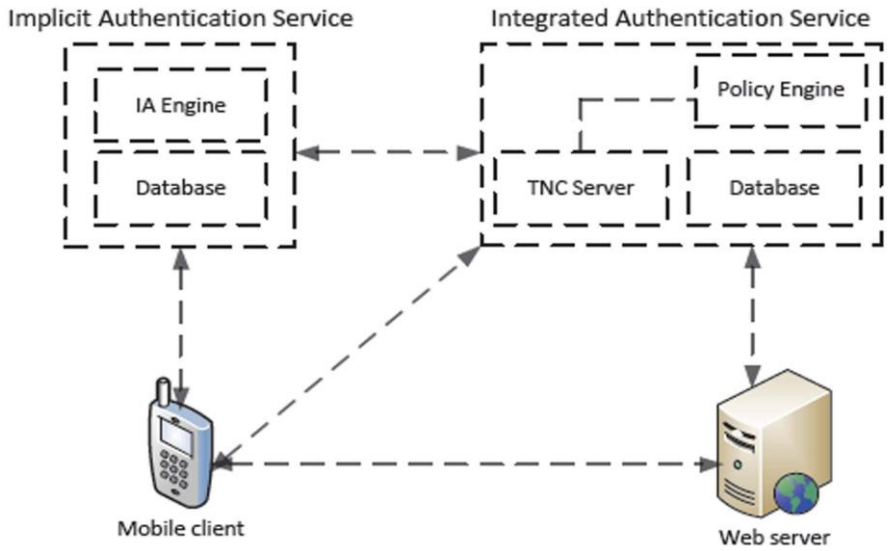


Fig. 6 TrustCube Architecture

Above figure depicts the TrustCube architecture, one method of authentication failure. When a web server sends request to Integrates Authenticated Service (IAS) along with the details about request, IAS receives the request and extracts information and control the policies of the message. It further sends an inquiry to IA server over a secure trusted network connection protocol TNC). IA server considers the inquiry and responds to IAS with a generated report about the authentication rules. IAS checks the authentication result, and sends this result to the web server. Hence in this way a user can be authenticates at the end.

4) *Data Access:* Dealing with data resources in terms of storing, managing or accessing has become challenging with the increase in the number of data resources and cloud services. Cloud storage providers like Amazon S3, executes the functions, at file level which increases the cost of data communication and processing for mobile clients. One of the solutions that provide an efficient and less costly way is of using block level based on I/O algorithms instead of file level. In this way, not all the files are transmitted, instead data blocks are transmitted, in case of necessity, which is useful by the means of time and network communication cost.

VII. CONCLUSION

Mobile Cloud Computing is one of the mobile computing technology trends in future as it combines the advantages of both cloud computing and mobile computing, and hence providing optimal services. With the emergence in cloud computing and mobile field, Network as a service has been bought up as a new dimension. Mobile Cloud Computing will provide a new way to the market and will provide full commercial application and easy way of for users to utilize the service. According to a recent study more than 250 million businesses will use cloud services through mobile devices by 2015. That traction will push the revenue of mobile cloud computing to $5.2 billion. With this importance, this article has provided an overview of mobile cloud computing in which its definitions, architecture, existing work application, advantages and challenges have been presented.

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