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Towards Computational Synergy: Present State-of-the-art of Mobile Cloud Computing

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Abstract: *Cloud computing has emerged as a new computing paradigm that has potential to commoditize computing resources in pay per use model. It is the technology that is on top of virtualization for affordable service models. With ever growing mobile technologies cloud computing is expanded to mobile devices as well. This has led to the concept of mobile cloud computing which makes the resource constrained mobile devices more powerful as they can connect to cloud resources and outsource the storage and computing to cloud. Thus mobile devices became ubiquitous and used by people of all walks of life, mobile cloud computing is growing in rapid pace. Since mobile devices are inherently vulnerable to various kinds of attacks, there are security and privacy issues in mobile cloud computing. The knowledge of ins and outs of mobile cloud computing, or in other words, the present state-of-the-art of mobile cloud computing in terms of architectures, application models, security and other challenges can help individuals and organization to have expert decisions. Towards this end, this paper throws light into the same to bring about useful insights pertaining to mobile cloud computing as the future generation computing model.*

Index Terms – Cloud computing, mobile cloud computing, security, applications, and architectures

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1. Introduction

Mobile cloud computing is the extension of cloud computing paradigm to mobile devices. The dream of commoditizing computing resources has been realized with cloud computing. Expanding cloud computing phenomenon to mobile devices can provide synergic benefits of both cloud computing and mobility advantages. Cloud computing offers rich set of services and the cloud can support various deployment models. The deployment models include private cloud, public cloud, community cloud and infrastructure cloud. In the same fashion it has service models such as Software as a Service (SaaS), Platform as a Service (PaaS) and Infrastructure as a Service (IaaS). With the invent of technologies in mobile computing and ubiquitous usage of mobile by people of all walks of life across the globe it is very interesting to know the fact that the resource constrained mobile devices can connect and be integrated with resource-rich cloud thus delivery energy efficient services to users through mobile devices. Mobile Cloud Computing (MCC) is the paradigm where mobile devices are involved in computing. The mobile devices outsource the storage and processing to cloud so as to reduce overhead and improve efficiency in providing resource-intensive services as well [1].

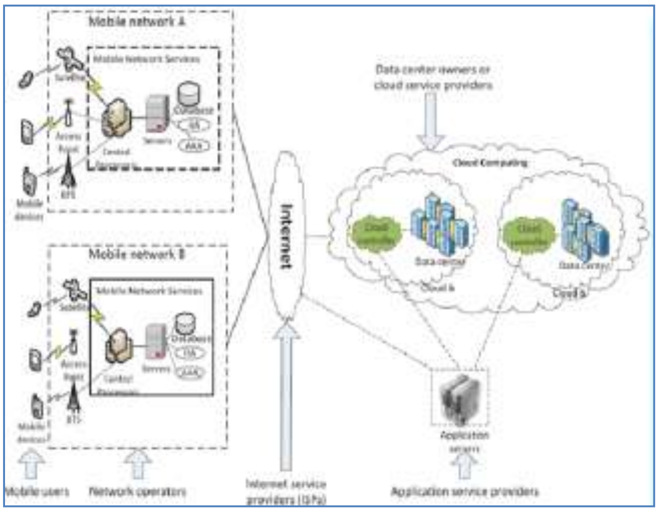


Figure 1 – Architecture of MCC [1]

As shown in Figure 1, it is known that mobile devices are able to harness the benefits of cloud computing. Network operators are able to access cloud through Internet and bestow the synergic benefits of cloud to mobile users. The technologies used to realize this are Web4.0, Cloudlets, Hypervisor, HTML5, 4G and CSS3. All the advantages of cloud computing are bestowed to cloud-aware mobile devices. Therefore the benefits of mobile cloud computing include offloading computing, outsourcing storage, remote execution of applications, migration of tasks, scalability, reliability, availability, health cloud, gaming, dynamic programming, mobile commerce and mobile learning [1].

Many researchers contributed towards MCC. As Pragya and Sudha [2] said, MCC enabled users to have rich experience in terms of services. Mobile technologies are being improved rapidly and at the same time the technologies such as virtualization and cloud computing make the MCC paradigm affordable and feasible. MCC gains the benefits in case of energy consumption, storage and bandwidth. There are many application models for MCC as explored by Kovachev *et al.* [3]. The true dynamics of MCC and its effectiveness can be understood with the help of those application models. However, there are some challenges or limitations of MCC. They include communication quality, division of labor, and the natural limitations of mobile devices. There are technologies like virtualization for mitigating the drawbacks of MCC such as elastic application division [4], task migration, improved bandwidth and virtualization. MobiCloud is one of the frameworks proposed by Huang *et al.* [5] for MCC. A good survey of MCC and related issues are made by Frenando *et al.* [6]. Architecture of MCC, computing approaches and applications are provided in [7]. Important applications of MCC such as M-Healthcare, M-Commerce and M-Gaming are explored in [8]. This researcher also focused on challenges and solutions to overcome those challenges pertaining to MCC.

Energy efficient MCC was the focus of the work in [9]. The energy is saved by offloading storage and processing to cloud. Similar research was carried out in [10] besides finding the reasons for MCC usefulness to mobile users and the energy efficiency capabilities exhibited by MCC. By default mobile devices are vulnerable inherently. This can have severe impact on MCC. Secure issues related to MCC were explored in [11]. As security issues cause problems in MCC, investigations are made to overcome the issues. Similar kind of research was carried out in [12].

More on MCC, applications, challenges, proposed architectures for security and successful MCC besides other aspects. Our contributions in this paper include the investigation into synergic effects of cloud computing and mobile computing besides reviewing the present state-of-the-art of MCC. The remainder of the paper makes a review of academic thinking on application models for MCC, security issues in MCC, MCC with Map Reduce programming paradigm, the requirements for the success of MCC, securing MCC communications, energy efficient MCC, and future projections of MCC.

2. Application models for mobile cloud computing

Application models for MCC can provide required guidelines for good applications. Such models are explored in [3] by Dejan *et al*. These applications can help leverage the MCC as the models bring about systematic approach into MCC. These researchers focused on decoupling the service delivery from the models so as to gain advantages in terms of delivery of services, cost over Internet, processing cost, and the overall cost of the MCC. It is a challenging job to ensure that all the benefits of MCC are reaped. The applications of MCC are of two types namely online and offline [3]. The following subsection throws light into application models of MCC.

2.1 Novel Application Models for Mobile Cloud Computing

As explored in [3] there are many application models for MCC as shown in Figure 2. The models are known as ad-hoc mobile cloud, elastic portioned model, and augmented execution model.

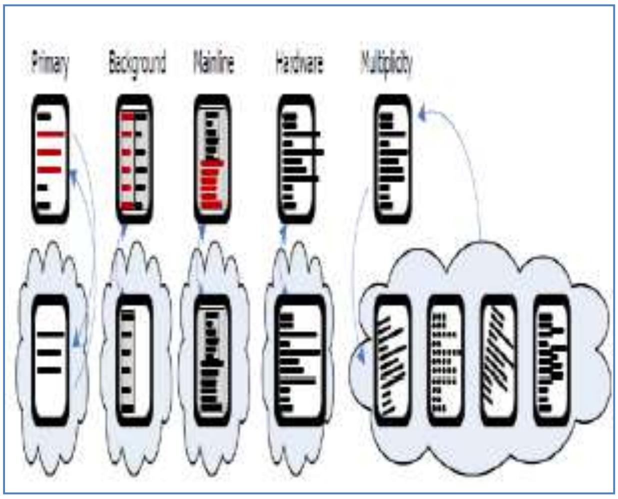


Figure 2 – Models for augmented execution [3]

As shown in Figure 2, there are models of application pertaining to MCC. The models include main line, outsourcing primary functionality, and background augmentation. The multiplicity model is meant for executing tasks in parallel while the hardware model uses virtual machines [3].

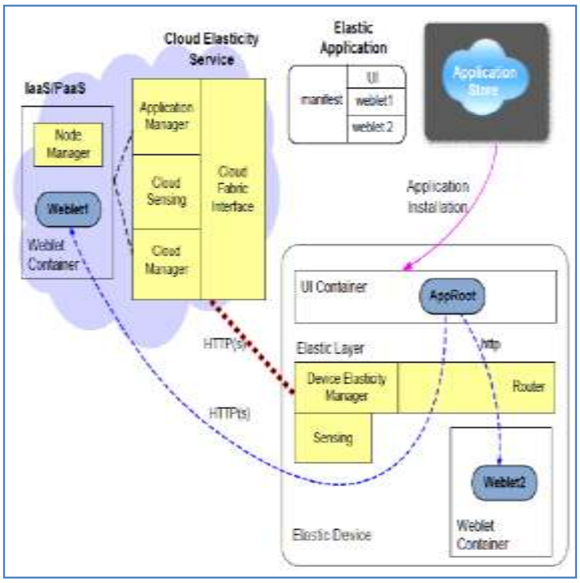


Figure 3 – Reference architecture for elastic applications [3]

Elastic applications are explored with a reference model in [3]. It is evident in Figure 3 that there are three architectural components namely manifest, weblet and UI. The UI provides necessary user interface. Weblets are software entities that have certain functionality. The Elasticity service has cloud fabric interface, cloud sensing, application manager and cloud manager. The configuration details are found in manifest. The summary of existing applications models presented in [3] is shown in Table 1.

Application Model	Underlying Technologies	Cost Model	Programming Abstraction	Solution Generality	Implementation Complexity	Static Adaptation	Dynamic Adaptation	Network Load	Scalability
Ofline	Vendor SDK	/	/	medium	low	high	low	high	low
Online	eb rvices,HTM .0	/	high	low	low	high	high	medium	high
Chun and Mantiatis [14] (clone Cloud)	Dalvik VM (Android)	in [31]	/	low	high	high	low	low	high
Satyanaranan et.al [3] (cloudlets)	VirtualBox Dynamic VM synthesis	/	high	low	low	/	/	low	low(vertical)
Giurgiu et.al [16] (alfredo and ROSGI)	OSGI ,Java	consumption Graph	high	medium	low	high	low	low	Medium (vertical)
Cuero et.al [21] (MAUI)	.Net	Linear Optimization	high	high	low	high	high	low	high
Zhang et.al [20] (Weblets)	REST ,C#	Naïve Bayes Classifier	high	high	low	high	high	/	high
Ahlund et.al [23]	p2p	/	/	low	low	medium	/	/	/
Satyanaranan et.al	VM,Distributed File System	/	medium	low	low	low	low	high	Medium (vertical)

[26] (ISR)									
Huerta - Canepa and Lee [28]	Handoop, XMPP	/	high	low	low	medium	low	high	high(horizontal
Cao et.al [30] (Mobile WS)	Web Services	/	high	medium	low	medium	low	medium	Medium (vertical)
Marinelli [29] (Hyrax)	Handoop	/	high	low	low	medium	medium	high	high(horizontal)

Table 1 – Summary of comparison of existing and proposed mobile cloud models [3]

As shown in Table 1, there are many mobile architectures proposed and implemented. The technologies for the implementation include Restful Web Services, Web Services, Hadoop, OSGi, Java and HTML and web resources [3]. The possible future work in this case includes the integrating inter-disciplinary research between networks and Human Computer Interaction (HCI).

3 Security issues in mobile cloud computing

Caytiles and Lee [13] explored security issues in mobile cloud computing. Though MCC provides flexible and on-demand access to cloud computing resources, it throws challenges pertaining to security. User's security, security of mobile applications in terms of privacy, data ownership, and data access with security, and securing information on the cloud are the concerns. Towards it cloud computing offers compliance and risk management, service integrity, endpoint integrity and information protection. However accountability with respect to privacy and security are to be given paramount importance with respect to mobile cloud computing. Bhadauria and Sanyal [14] specified the security issues in cloud computing. They are many challenges with respect to MCC. They include network accessibility, data latency, scalability and network monitoring, confidentiality in data sharing, access control and identity management. In [14] there was much focus on various aspects of security issues in cloud computing when compared with [13]. Bhadauria *et al*. [16] also contributed to find security issues in cloud computing. The basic level security issues include SQL injection attacks, cross site scripting, and data leakage. The network level security issues include DNS attacks, sniffer attacks, reused IP addresses, and BGP prefix hijacking. The application level security issues include issues with hypervisor, denial of service attacks, hidden field manipulation, backdoor and debug options, distributed denial of service attacks, captcha braking and Google hacking. The suggestions towards improving security in MCC given by these researchers include usage of multi-layered security model and URL filtering.

In [19] Hu *et al*. also focused on security challenges with respect to cloud architecture. They threw light into the concept encryption on demand provision provided by servers and its possible misuse is presented. Trusted virtual data center was considered to be a solution towards secure cloud computing. The security issues mentioned by Crlin and Curran [20] include the usage of API in cloud has vulnerability as the script can be used for attacks, and data security and privacy problems. Khan *et al*. [21] made a good survey of security issues and possible counter measures in mobile cloud computing. These researchers provided a security solution that has three kinds of services namely secure cloud physical services, secure cloud processes hosting services, and secure cloud application services. The proposed architecture for secure mobile cloud computing is as presented in Figure 4.

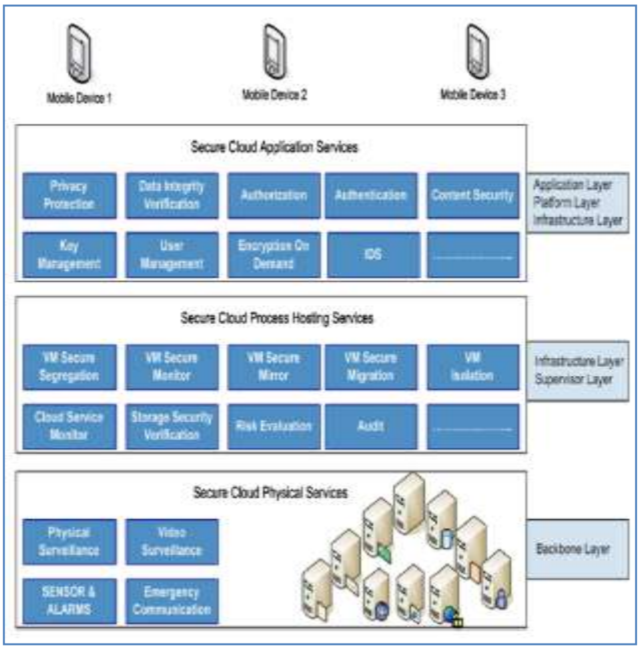


Figure 4 – Layered security services [21]

In the bottom most layer video surveillance and physical surveillance are the mechanisms to secure physical services.

VM secure segregation, VM secure monitor, VM secure Mirror, VM secure migration and VM isolation are the security measures in the middle layer while the top layer has complete security services such as IDS, encryption on demand, user management, key management, content security, authentication, authorization, data integrity and verification and privacy protection [21]. Bacher *et al*. [23] presented four kinds of security issues with respect to mobile devices. They are software-centric attacks, hardware-centric attacks, user layer attacks and device independent attacks.

4 Mobile cloud computing using map reduce

Essential functionality of MCC includes global data access, distributed data processing, fault-tolerance, scalability, privacy, hardware interoperability, battery life, bandwidth of network, CPU cycles and memory, time and storage. These essential functionalities are possible when MCC makes use of the new programming paradigm MapReduce. Hadoop is one of the distributed computing frameworks that support MapReduce programming. It has a distributed file system HDFS which caters to the needs of cloud computing. The advantages of MapReduce programming is that it caters to the essential functionalities of MCC. However, Hadoop has disadvantages with respect to MCC. They include commodity constrained hardware, heavy usage of interfaces and inheritance, does not work in slow network conditions, the architecture might not be suitable for MCC [17]. Hadoop has many assumptions that can cause problems to MCC. For instance it assumes that hardware failures are common, and large data sets are used by applications, low-latency access is not needed, files are read-only, and it is easy to have moving computation. These assumptions made the Hadoop less than ideal choice for MCC [17].

5 what is required for success of mcc?

Sanaei *et al*. [15] studied the trend of emerging MCC in the real world and proposed a success model for MCC which is divided into three major classes. They are ubiquity, energy efficiency and trust.

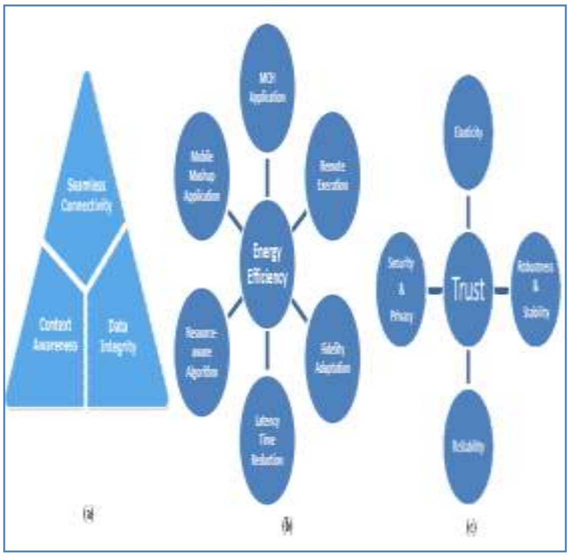


Figure 5 – The Tripod of successful MCC [15]

The ubiquity essentials are as presented in Figure 5 (a), the energy efficiency approaches are presented in Figure 5 (b) while the trust metrics are as shown in Figure 5 (c). Seamless connectivity, context awareness and data integrity are requirements of ubiquity. The energy efficiency approaches include latency time reduction, resource-aware algorithm, mobile mashup application, MCH application, remote execution and fidelity adaptation. The trust metrics explored in [15] include reliability, security and privacy, elasticity, and robustness and stability. Thus the work done in [15] tried to have a comprehensive success criteria for MCC as it is meant for overcoming challenges such as privacy and security, seamless connectivity, interoperability and so on.

6.Securingmobilecloudcomputingcommunications

Towards securing MCC communications Huang *et al*. [5] proposed an architecture which is named “MobiCloud”. It combines modern and traditional services including concepts such as trust management, risk management and secure routing. The framework facilitates to have a range of applications that can be used to leverage the synergic benefits of integrating mobiles with cloud [5].

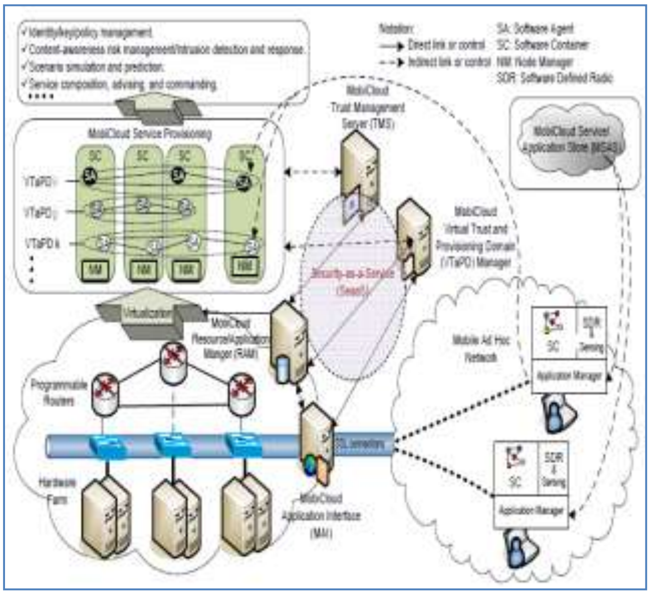


Figure 6 – Architectural overview of MobiCloud [5]

Mobile networks and cloud infrastructure are integrated as shown in Figure 6. The architecture has provisions for many components such as service provisioning, trust management server, application store and resource manager. In the architecture, dotted lines indicate indirect while the solid lines indicate direct links. SSL is used for secure communications. SSL ensures that MobiCloud communications are encrypted and thus provide security to information flows in the network. The infrastructure also demonstrates MANET [5].

6.1 Attribute Based Encryption

Information stored in cloud can be divided into attributes. This will help encryption mechanism to be applied easily on the data selectively. Thus attributes based encryption process came into existence. The encryption scheme has attributes like A_1 to A_n, a key for data encryption, secret sharing threshold gates and private key components [5].

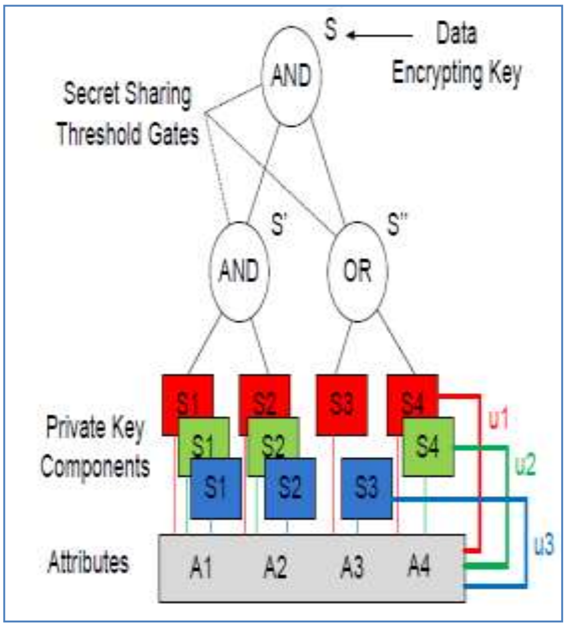


Figure 7 – Illustrates attribute based encryption [5]

As shown in Figure 7, it is evident that the encryption mechanism in the architecture makes use of the concept of attributes for efficient key management. Many application scenarios are supported by this framework. For instance it supports scenarios pertain to security, isolation, delay tolerance, secure isolation, damage recovery and fine-grained resource isolation. Based on the framework in mind the applications are designed. The main services of the framework include monitoring services, on-demand services, and so on. There is advising service also that take care of MANET activities required by MCC. MobiCloud is used by the researchers to have experiments in terms of routing overhead, and data transmission interval. The intervals used include 10, 100 and 1000. The results are shown in Figure 8.

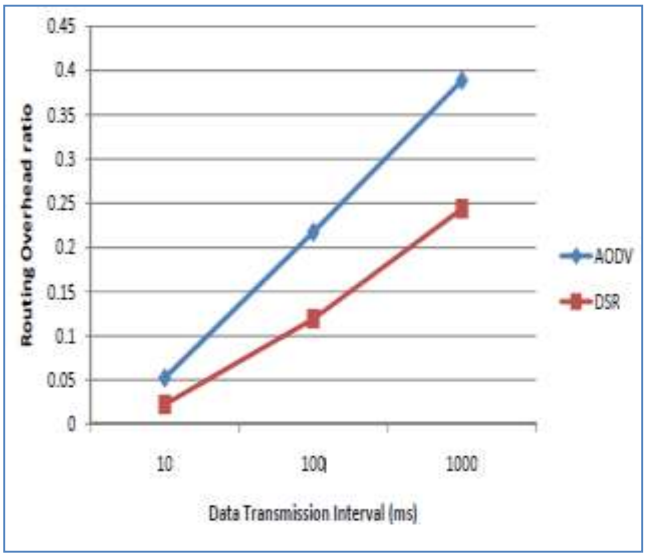


Figure 8 – Routing overhead ratios vs. data transmission interval for DSR and AODV [5]

As shown in Figure 8, the AODV exhibited more routing overhead when compared with DSR protocol. Damage recovery can be incorporated into this framework in future for finding lost mobile devices besides to have the ability to have fine grained resources, increased efficiency and security isolation [5].

7 Energy efficiency of mobile clients in cloud computing

Miettinen and Nurminen [10] explored MCC in terms of energy efficiency. As the mobile devices do have limited energy, this research assumes importance. Optimum utilization of energy resources is possible in MCC as the processing and storage are offloaded. In the process energy is saved. However, it should be greater than the overhead cost required to connect to cloud resources. More details are provided in [10] for critical factors that can be observed to know energy efficiency when mobiles are connected to cloud computing. Measurements are used to know the energy consumption accurately besides providing a concrete example for energy saving. Miettinen and Nurminen explored the trade-off between energy efficiency and overhead. The energy consumption of local device is denoted as E_{local} while the same of cloud is denoted as E_{cloud}. Then the following equation should mean a beneficial situation [10].

$$E_{cloud} < E_{local}$$

The meaning is the local energy consumption is more than the energy consumed when connected to cloud. This ensures that the MCC is useful and ideal situation for synergic effects. The computations of E_{cloud} and E_{local} are made as follows. D refers to data transferred while C refers to computational power for data transfer.

$$E_{cloud} = D/D_{eff}$$
$$E_{local} = C/C_{eff}$$

Experiments are made with two devices namely Nokia N810 and Nokia N900. The computational characteristics of these devices are as shown in Table 2.

Device/Frequency	Power/W	Cycles/energy(Ceff)
N810/400 MHz	0.8	480 MC/J
N810/330 MHz	0.7	480 MC/J
N810/266 MHz	0.5	540 MC/J
N810/165 MHz	0.3	510 MC/J
N900/600 MHz	0.9	650 MC/J
N900/550 MHz	0.8	690 MC/J
N900/500 MHz	0.7	730 MC/J
N900/250 MHz	0.4	700 MC/J

Table 2 – Energy characteristics of local computing [10]

The energy consumption dynamics are shown for the devices used in the experiments. Table 3 shows computing results of the same devices.

Device	Power/W	Bytes/energy(DeFF)
N810/400 MHz	1.5	390 KB/J
N810/400 MHz	1.4	370 KB/J
N810/400 MHz	1.3	350 KB/J
N810/400 MHz	1.1	310 KB/J
N900/WLAN	1.1	860 KB/J
N900/3G/receive (near)	1.1	450 KB/J
N900/3G/transmit (near)	1	190 KB/J
N900/3G/receive (far)	1.4	350 KB/J

N900/3G/transmit (far)	3.2	60 KB/J

Table 3 – Energy characteristics of mobile devices [10]

Energy consumption is measured by the device known as Nokia Profiler. As per the measure, the local consumption of energy is observed. Bit rate has got its influence on the data transfer rate. The energy consumption is in tune with the bit rate. The more in bit rate and less in energy consumption. Separate bit rate channels are used to achieve this. Cellular networks depend on both data transfer and bit rate for efficiency.

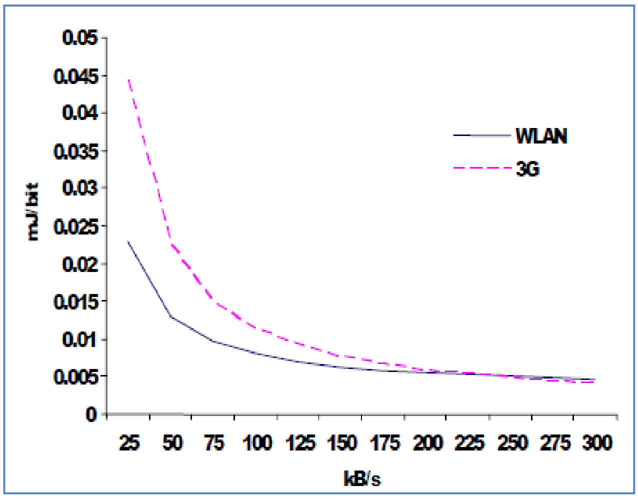
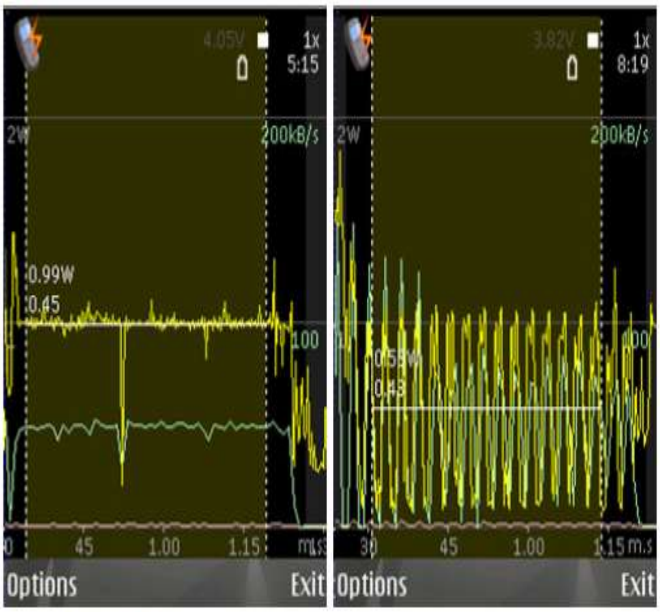


Figure 9 – Energy per bit for N95 WLAN and 3G [10]

As shown in Figure 9, it is clear that there is relationship among the data transfer, bit rate and energy efficiency. With respect to cellular networks like WLAN, bit rate is having its including on both data transfer and energy consumption.



(a) Smooth traffic source. (b) Bursty traffic source.

Figure 10 – Illustrate traffic pattern effect for N95 WLAN [10]

As shown in Figure 10, the bursty traffic resources have their own trends or patterns. Smooth traffic sources and bursty traffic sources are associated with underlying device used in WLAN. The bit rate 1w causes smooth communication while 0.6w causes bursty communications.

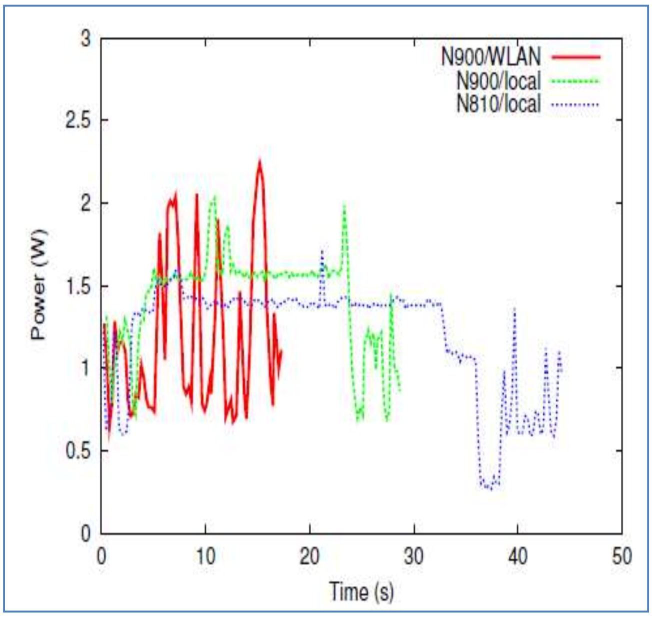


Figure 11 – Illustrates power consumption for viewing PDF [10]

As shown in Figure 11, the results reveal the power needed by the local viewer for the device N900 WLAN. Higher average power has been observed for remote cases. The remote case caused less power consumption because the time of execution becomes significantly shorter. 3G network caused more energy when compared with WLAN. In future this research can be extended by proposing end-to-end security for MCC keeping energy efficiency in mind.

8 Future projections of mobile cloud computing business

MCC has its future as explored in [1]. The possible revenues which have been anticipated or forecasted from 2009 to 2015 are projected as shown in Figure 12. This will provide the possible growth of MCC just by a glance.

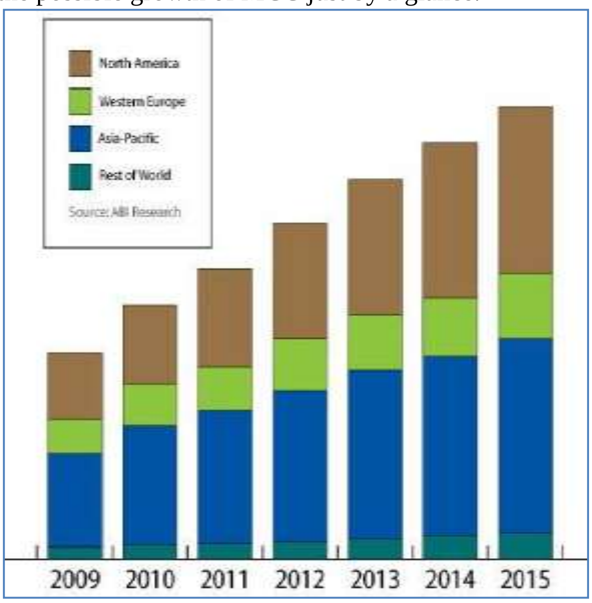


Figure 12 – Forecast on revenues on MCC [1]

As seen in Figure 12, it can be understood that MCC will have its global presence with potential market share. The forecast reveals that fact that every years the market share of MCC is increasing in various regions of the world. Thus it can be known that MCC plays a big role in leveraging the resource constrained devices to have access unlimited resources as part of MCC [1]. Khan and Ahirwar [18] believe that the MCC can be very useful to become future multimedia database while Bahl *et al*. [24] anticipate the VM-Based cloudlets for the success of MCC in future. It appears like new vision of MCC that is making rapid strides in gaining access to have amount of computing resources as mobile networks are resource constrained traditionally.

9 Conclusions

In this paper we studied the present state-of-the-art of mobile cloud computing. The paper throws light into various aspects of mobile cloud computing right from the technical knowhow of MCC to its architectural and security challenges to future forecast of MCC. Energy efficiency is one of the major issues in MCC since mobile devices are resource constrained. Obviously the energy efficiency is expected when mobile devices are given access to the magic of cloud computing which enables them to have commoditized resources which are in abundance. The energy efficiency due to MCC and the communication overhead to gain access to cloud are to be balanced for the success of MCC. Mobile devices outsource storage and processing to cloud thus makes it a powerful paradigm that lets computing resources to be accessed through mobile devices on the go. The paper also highlights the application models of MCC, security issues and counter measures. Layered security services, the future of MCC and the pros and cons of using MapReduce programming framework such as Hadoop for MCC besides the possible usage of VM based cloudlets for successful MCC are reviewed. The research can be extended further to have an empirical study on MCC challenges and the mechanisms to address them.

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