

# A Systematic Literature Review of Mobile Cloud Computing

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## **Abstract**

*Mobile cloud computing (MCC) is a relatively new concept that leverages the combination of cloud technology, mobile computing, and wireless networking to enrich the usability experiences of mobile users. Many field of application such as mobile health, mobile learning, mobile commerce and mobile entertainment are now taking advantage of MCC technologies. Since MCC is new, there is need to advance research in MCC in order to deepen practice. Currently, what exist are mostly descriptive literature reviews in the area of MCC. In this paper, a systematic literature review (SLR), which offers a structured, methodical, and rigorous approach to the understanding of the trend of research in MCC, and the least and most researched issue is presented. The objective of the study is to provide a credible intellectual guide for upcoming researchers in MCC to help them identify areas in MCC research where they can make the most impact. The SLR was limited to peer-reviewed conference papers and journal articles published from 2002 to 2014. The study reveals that privacy, security and trust in MCC are the least researched, whereas issues of architecture, context awareness and data management have been averagely researched, while issues on operations, end users, service and applications have received a lot of attention in the literature.*

**Keywords:** *Mobile Cloud Computing, systematic literature review, security, privacy, interoperability, virtualization*

## **1. Introduction**

Mobile cloud computing (MCC) is a paradigm of computing that enables on-demand access to remotely-based resources on the internet through mobile devices using a utility-based payment model. Mobile computing facilitates effective, efficient and economical access to resources by mobile clients thereby making services constantly available over the internet [1-4]. It eliminates the shortcomings of mobile computing by allowing information processing on the cloud to make up for the low computational capability of mobile devices, thereby increasing the battery life, providing more extensive storage services and pervasive computing. According to [5], application partitioning is an independent aspect of dynamic computational offloading, also, a thematic taxonomy for application partitioning algorithms (APAs) in MCC was proposed. The APAs are reviewed comprehensively to qualitatively analyze the implications and critical aspects.

The advent of mobile devices and more sophistication of mobile technology suggest that users could derive more advantage from mobility if cloud and mobile computing technologies are combined. The cloud experience on mobile computing yields a friendly service in mobile commerce, mobile entertainment, navigation, reliable information storage and access on the mobile platform as found in the Google's Gmail for mobile. Furthermore, mobile cloud computing has given access to rural dwellers to enjoy mobile services (mobile learning, commerce, health, entertainment *etc.*) on their phones leveraging on the internet access provided by their telecommunication companies [6].

Although, previous authors have reviewed extant literature on mobile cloud computing, these reviews were largely descriptive reviews and not systematic literature reviews. Unlike this paper, previous reviews did not: 1) seek to provide answers to specific research questions; 2) disclose the criteria or search strategy used for identifying reviewed papers, which makes their findings prone to bias; and 3) make it clear whether a structured, methodical and rigorous evaluation of relevant literature on MCC was done in order to arrive at their conclusions. In contrast to previous literature reviews, this paper employs a methodical, structured, and rigorous analysis of existing literature in order to attain its objectives, which is to understand the trend of research interests so far in MCC.

This work aims to explore existing literature to attain these two objectives in order to provide direction for upcoming researchers in the domain of MCC. Being an emerging domain, the research community has shown interest in MCC progressively from 2007 till date, therefore, it is essential to articulate the trend in MCC research.

The rest of the paper is structured as follows. Section 2 provides a brief background and a summary of related work. Section 3 describes the methodology used for conducting the systematic literature review. The limitations and further study are discussed in Section 4, while the conclusions and future work are presented in Section 5.

## 2. Background and Related Work

This section discusses cloud computing and mobile cloud computing. The related research works in MCC are also summarized.

### 2.1. Cloud Computing

A cloud is a virtual pool of computing resources that comprises computers, servers, and the systems that provide resources to clients [7]. Also, [8] defined cloud computing as a parallel and distributed computing system employing virtualization with internal links and a Service Level Agreement (SLA), followed by scheduled allocation of resources. Also, [9] opines that data storage on cloud servers remains the paramount benefit of cloud computing using the user's client memory to fetch data from the server.

Cloud computing builds on previous researches in the areas of distributed computing, grid computing, virtualization, utility computing, and networking [10-13]. The basic models of cloud computing are: Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS).

*Infrastructure as a Service (IaaS)*: It provides the required infrastructure for efficient technology, datacenters, servers, memory, network, and other hardware for expected IT pedestal to cloud service customers. Examples are Amazon's Elastic Computing Cloud (EC2), Cisco Unified Service delivery, and Flexiscale.

*Platform as a Service (PaaS)* : This provides development environment for applications, using the Internet, operating system and associated services are provided and users need not worry to download or install applications on their computers; for instance Google Apps Engine, Amazon web services, and Microsoft Azure.

*Software as a Service (SaaS)*: Is a software distribution model, the service provider makes applications ready to customers over the internet, It supports web services and service-oriented architecture (SOA) Examples include Salesforce.com and IBM Lotus Live

*Anything as a Service (XaaS)*: This refers to the diverse models of information technology-based on demand services that can be delivered via the cloud computing platform.

Cloud computing has five basic characteristics as established by the National Institute of Standards and Technology (NIST), which are:

- *Resource pooling*: Cloud resources are allocated automatically as requested by the customer. Resources could be physical or virtual and reallocation is constantly allowed; this is cost efficient and convenient to the customers.

- *Measured service or billing*: Cloud Computing implements a utility service model that is based on a pay as you use basis, with an automated billing system. The usage by customers is monitored, controlled, audited, confirmed in alignment to existing SLA and transparently billed.
- *Broad network access*: Cloud Computing services and its features must be constantly available over the internet or other networks based on standard protocols.
- *Rapid elasticity*: There is capability to scale up or down requested services as demanded by customers. This should be achieved without any noticeable reduction in the quality of service delivery.
- *On-demand self- service*: It should be possible to avoid complications due to human interference in services delivered, as customers can get whatever they need, once the request for service is made.

In the last decade, network based computing and on-demand applications have enhanced cloud computing which has commanded huge research attention since 2007 [14]. According to [12], cloud computing refers to a catalogue of services rendered by an Internet-oriented cluster of computers. The cluster has low cost servers, well-organized resources management providing new supplement, consumption and delivery model for IT services, which are on demand, scalable, device-independent, reliable, fast, and convenient. The next generation network boasts of ubiquity and mobility through wireless networks technology providing Internet on mobile devices. Bringing the capabilities of cloud computing and mobile computing together gave birth to a new paradigm called mobile cloud computing (MCC). The aim of MCC is to use cloud computing techniques for storage and processing of data on mobile devices thereby reducing the perennial limitations of mobile devices in terms of low computational power, low storage capacity.

## 2.2. Mobile Cloud Computing

Mobile cloud computing (MCC) is based on eliminating the shortcomings of mobile computing by combining it with the strength of cloud computing and mobile Internet [11] [15]. It has turned weaknesses or shortcomings in cloud computing and mobile computing into opportunities, putting the power of cloud computing on handheld devices by Internet access via wireless networks. Enhanced technologies and thirst for mobility have encouraged sophisticated networking, security and mobile technologies; leading to the advent of smart phones, laptops, PDA, and GPS navigations. Nowadays, it may not be necessary to download and install software for use as mobile cloud computing makes them readily available [3].

WiMax, ad hoc network, and Wi-Fi allow for flexibility in wireless networks for mobile operations. Mobile computing enjoys wide accessibility due to its mobility but has frequent disconnections due to network conditions, security shortcomings, discrepancy in downlink and uplink. Topography, weather and buildings can also have impact on the quality of service [16]. According to [17], in 2008, the world has 42.8 million mobile cloud computing subscribers representing 1.1% of total mobile users and it is expected to skyrocket into 998 million (19% of total mobile users) in 2014.

MCC employs key technologies such as virtualization, mass distributed data storage, distributed data management, parallel programming model, wireless networks and security, and others, in order to deliver its implementation objectives [18]. It is noteworthy that numerous developed and deployed applications do exist, including Google Gmail, Maps and Navigation systems for Mobile, Voice Search (Android platform), MobileMe (Apple), Live Mesh (Microsoft), and MotoBlur (Motorola). For now, MCC has a number of challenges, which includes poor wireless network, unreliable mobile internet access, low bandwidth, poor network handover among different network access technologies, unreliable transport channels, screen size and memory limitation, and information security [6, 19-21].

### **2.3. Key Issues in Mobile Cloud Computing (MCC)**

MCC is a new area of academic research with brilliant prospects but currently confronted with some challenges. Some of these challenges as documented in the literature are outlined as follows.

#### **Cloud API Security Management**

One of the challenges of MCC is the need for a fine-grained security management API, this is a big issue such that MCC cannot be a success without paying attention to it, a poor security management API will harbour viruses, worms, Trojan horses, malware, and hijackers that will bring MCC service to a halt for the subscribers with privacy dangers. Installing and running security software on mobile devices helps to detect threats and protect subscribers. However, a more effective uniform protection remains the cloudAV [19].

In an attempt to provide a solution, [20] built the lightweight application server (LAS) as a community engine for a mobile community cloud platform. The challenges encountered in building the LAS are: Extension API developments for inclusiveness, interoperability, runtime service deployment requirements, real time communication support, context-aware services supports, user and community management. Success factors for mobile community information systems include: System quality, information quality, use, user satisfaction, individual impact and community impact while recommending scalable infrastructure architecture as a solution.

#### **Battery Life and Energy Awareness**

Battery conservation is one of the main challenges for mobile devices and a flat battery disconnects the user from MCC usage. In the literature, several proposed solutions have been presented. The solutions were meant to manage the screen and the disk intelligently [22-23] and to improve CPU performance [24-25] all in attempt to reduce power consumption. However, the suggested solutions might be infeasible in some cases, and the required hardware investment is commonly too high [19]. MCC is meant to allow the users a constant service irrespective of location and time. However, resources, battery and connectivity constraints are eminent. With these constraints, computationally intensive operations such as sensor usage for GPS reading, extensive processing in video games, speech synthesis, wearable computing and natural language processing has been unsuccessful.

According to [21], the challenges of MCC can be categorized into operational, end user, service level, privacy and security, context awareness, and data management issues. When a battery goes off, the user cannot access the MCC services, leading to poor quality of service, denial of service or a total downtime. Offloading is employed to achieve an elongated battery life, whereby applications requiring long execution time are processed on the cloud and delivered on the mobile devices for power conservation. The effectiveness of offloading methods to save battery power of portable devices has been evaluated in [26] and [27] by experiments. The result reveals that remote execution of complex tasks can reduce power consumption by 50%. The 915MHz AT&T Wavelon card was the wireless device used, advanced power management (APM) tools were employed, three applications were used as test cases and it was conducted on a Dell latitude XP portable computer on Linux operating system.

In [28], the remote execution systems use sophisticated prediction techniques that guide computational offloading for efficient resource optimization. An efficient power management is achieved by policy optimization using a linear programming approach. Also, the theory of Markovian decision processes were employed for excellent task migration and remote processing to achieve extended battery life.

The work in [29] developed PowerScope as a profiling tool for mobile applications, in order to analyze power draining procedures; the tool can help developers to modify their software to be more effective in energy conservation. Using PowerScope, 46% energy conservation was achieved profiling an adaptive video application running on Odyssey platform [30]. After data collection, profiling is done offline to avoid addition of overheads to the analysis.

Battery levels can be queried by software as done by Powerspy in [31], in windows OS it does two operations; event tracking (application run and tracked for CPU time) input or output activity and energy consumption analysis stage (data acquired from event tracking is processed).

### **Presentation and Usability Issues**

Presentation of services on mobile devices is one of the key challenges of MCC because of constraints such as the screen size and technology of implementation of some mobile devices that cannot perfectly handle the graphical user interface quality of some services. For example, the appearance of certain images for mobile learning might not give required comprehension to a fraction of students due to screen capability of the mobile equipment they can afford.

The work in [7] showed that this scenario can be avoided by ensuring that the cloud server has a system resource management (SRM) module that manages user interface, resource provisioning and coordinating network of servers in parallel operations to achieve the best of security, availability, support, compliance and interoperability.

### **Context Awareness**

Different MCC subscribers need diverse services and operations, thereby the service, API, security and configuration requirements are different; consequently this becomes a serious issue of concern in MCC. The preferences of mobile users must therefore be effectively monitored and satisfactorily provided by the service provider.

Context-aware service can be spatial (location-based, collaborative and mobile energy conservative) or social (cooperating by proximity, using mobile devices for data relay); application partition disintegrate complex operations to allow for parallel processing of elastic applications and offloading takes off task from client to cloud for mobile device energy conservation [32].

In support of an agent-client scheme, [33] featured a resourceful cloudlet-based mobile computing approach. The mobile device is a client getting the services from the client and displaying to the users. The cloudlet is simply a decentralized and wholly available Internet platform where storage and overall processing take place and accessed by mobile devices. Furthermore, the work of [34] presented an application where the user interface is on the mobile equipment but computations, resources, storage and scheduling take place on the cloud. Another example is Hyrax from Hadoop for mobile cloud computing that was explored by [35] using Mapreduce. The Hyrax is a good instance of a collaborative mobile cloud computing on android mobile equipment where applications randomly utilize distributed resources [36].

### **Resource Constraint and Platform Heterogeneity**

Due to the mobility factor, mobile devices are limited in screen size, storage, battery life, and network availability. These are serious issues that push operations or high energy processing to the cloud, but any little network failure due to changing of position means a suspension of service, and it gets the user frustrated.

In [12], the challenges and solutions of MCC include mobile devices constraints, which can be solved by virtualization and task migration; quality of communication which

bandwidth upgrading can nullify and the last challenge is the division of applications services which elastic application division mechanism puts to a halt.

Presentation of MCC details to mobile devices has specific requirements for full delivery of GUI suitable for the screen size [37-38]. The heterogeneous platforms involved need different requirements in design and development of interfaces posing complications to developers [39]. Certain priorities must be considered in MCC delivery based on where a device is located, connection protocol bandwidth and battery life, the availability and quality of service (QoS) delivered to the users [40].

According to [11], available system architecture is required for an effective, reliable and secure mobile cloud computing (MCC). The system architecture has four layers.

1. Access layer: Ensures cooperation between client and cloud end, obeying MCC rules for effective access.

2. Basic managing layer: Takes standard operations to services like noticing, acknowledgement, directory, and security, provides standard procedure interface and protocol to application service.

3. Virtual layer: Virtual environment, system, platform for computing, storage and network pools.

4. Physical layer: Hardware equipment and the technology that supports mobile cloud service

### **Heterogeneity and Connection Protocols**

MCC wireless network interfaces are heterogeneous in nature and it leads to complications that must be well managed. Diverse wireless access technologies such as WCDMA, WLAN, WiMAX, GPRS and CDMA 2000 are used by mobile nodes to connect to the cloud for services delivery [19]. Handling network connectivity without trading off MCC requirements (constant connectivity, on-demand scalability of wireless connectivity, and mobile device energy efficiency) is a big issue.

Intelligent Radio Network Access (IRNA) is an effective model to deal with the dynamics and heterogeneity of available access networks [41]. Authors in [42] proposed a content management architecture for acquiring, managing and distributing a context information; providing an intelligent network access strategy for mobile users to meet the application requirements.

The connection protocols in use for MCC are 3G, Bluetooth, and WiFi. The WiFi is the commonest in use because it has a wider range of operation (100m radius) and it supports a data rate of up to 11Mbps [21]. Compared to 3G, WiFi has a lower energy consumption but with interoperability issues between brands, and security threats. However, all existing MCC systems in this paper except Cuckoo, MAUI, CloneCloud and MMPI use WiFi as it performs better due to the high allowable range. [43-44,21].

According to [19], countermeasures to low bandwidth, availability and heterogeneity include the use of 4G technology, controlled access management, improved quality of service and pricing, standard interface, and service convergence.

### **Network Congestion**

Network congestion has become a big issue in MCC because of its wide acceptance and usage. Similar or different MCC services are constantly subscribed by users as they engage and disengage from the environment and the network infrastructure is strained with increased users' population. The basic requirements of mobile cloud computing are interoperability, availability, reliability, privacy and security. To ensure constant availability in MCC, offloading methods are used in the client-server communication in an attempt to reduce instances of traffic congestion, enhance battery life, and improve reliability. Examples of offloading implementations used in MCC include: Spectra, chroma (using remote procedure calls), cuckoo (using remote method invocation) and

hyrax [45-46, 43, 35, 21]. However, these offloading implementations are prone to network congestion.

Virtualization is an alternative offloading method that overcomes network congestion, it requires no code rewriting and virtual machine boundaries to insulate server. However, virtual machine synthesis is time consuming, and has an overlay of compatibility challenges. Examples of virtualization schemes already implemented for MCC include Cloudlets, MAUI, Clonecloud and Mobicloud [33,47-49]. However, MCC virtualization has not solved all the problems, hence the use of mobile agents for example Scavenger [50], which is excellent for overcoming the vulnerabilities of all other offloading methods but not devoid of security constraints.

### **Mobility Management**

Constant access to Internet service for MCC becomes a more prominent challenge than in cloud computing service through wired services. The movement of users makes connection to the strongest available network per location necessary, this requires more intelligent allocation, monitoring, and sharing [19].

Intelligent mobility management techniques are required in MCC for availability. The methods to attain excellent QoS irrespective of location change in MCC could be infrastructure-based or peer-based techniques. The infrastructure-based mobility management use GSM, WiFi, RF, GPS, RFID and IR. However, these techniques are not perfect for mobile cloud computing (MCC), for instance, they are energy consuming in MCC context but mobile equipment have energy constraint.

Peer-based methods are better for mobility management of MCC running devices, giving correct relative location data for operations, sharing, and offloading. They can be achieved by protocols requiring low power and short area of operation for example the Bluetooth technology as used in Virtual compass [51]. A system called Escort was presented in [52] as a simple peer-based technique, using mobile phones (using nearby device as resource provider). For an enhanced security and privacy in peer-based techniques, a decentralized design was presented in [53] called 'Friends Radar' where only recognized contacts are feasible and it uses GPS. Other peer-based localization techniques already reported are NearMe, Beep Beep and DOLPHIN [54-56] they have special requirements that give them limitations.

### **Fault Tolerance**

Fault tolerance is a big issue in MCC, the impact of any hitch in Internet connectivity is highly felt despite the countermeasures put in place. However, it is required that MCC systems will fail securely. To achieve an efficient fault tolerance in MCC, servers are interlinked with high-speed networks to provide uninterrupted services for customers; power supply stability, effective backup, restore operation, and a low risk of disaster are in place.

To avoid any downtime to users due to disconnections, [57-58] have proposed catching and pre-fetching that allows users full delivery of service in offline mode in case of disconnections but within a limited time. The web service caching is important to MCC since the web is the most popular tool for mobile users to access applications and services on the internet.

Battery life exhaustion and loss of connection simply bring MCC service to a halt. Mobile devices in a similar location are expected to have some similar needs; therefore the context manager tracks incoming and outgoing devices for appropriate service allocations for mutual benefits. When a surrogate server leaves without a standard substitution, MCC delivery will have hitches; therefore an effective mobility tracking to avoid hitches is a fault tolerance effort.

In Hyrax [35], Hadoop is used for fault tolerance as it avoids disconnectivity. The architecture of Hadoop and HDFS is meant to bridge the gap caused by any hardware failure [36]. The probability of mobility of resourceful mobile devices can be calculated over time using a Markov chain model [21] and subsequently classified users into low mobility, middle mobility and high mobility users. This is commonly done in workplace, university, and car park settings to get an excellent MCC service availability. A well implemented fault tolerance ensures an excellent quality of service, optimizes resources and makes services constantly available on devices. Hadoop recovers from task failure by re-execution and redundancy.

### **Security and Trust**

The concern about security in MCC cannot be overemphasized, it is the most critical issue and it has not got the commensurate attention of researchers. Today, users keep information in the cloud based on trust, but when technological or technical problems arise from the service provider, server failure or total business failure of the provider, the MCC users are at a risk. Also, mobile devices face battery exhaustion attack [59], and targeted attacks.

Required security in MCC entails authentication, authorization, and verification of weblots, the cloud and the involved mobile devices [34]. Authors in [34] have proposed a trustworthy weblot container (VM) on mobile equipment and cloud; this is meant to achieve multiple initiations of processes and secure communication between weblots, authentication, and secure session management. Other security measures in MCC are access control, giving less authorization to weblots on the cloud; logging and auditing of weblots are also important to an effective MCC constant service.

Attribute-based identity management was proposed for key management in Mobicloud, signaling a step further in identity-based cryptography. Furthermore, mobile users' information is protected by security isolation, virtual trusted and provisioning domains (VTaPD) as virtual domains with resource isolation [34, 21].

### **Privacy**

Privacy is a critical issue in MCC and it is the principal reason for the non-adoption of MCC by some individuals or groups despite its numerous advantages or benefits.

It has been reported in [60] the installation of CarrierIQ that successfully collected information from mobile phones. User privacy requirements in MCC include: Misuse protection, pirated information detection, ergonomics and information protection laws [61].

The solution in use today is the public key infrastructure (PKI) to avoid malicious devices havoc but for a resource constraint platform, the operational overhead is large. Also, in a situation of constant entry and exit of mobile devices and all must be authenticated, resources may be limited at a stage for effective key management of the PKI [61--21]. However, in [62] a solution was proposed that offloads complex PKI tasks to a remote resource rich server.

For privacy in MCC, anonymous routing has been encouraged, for example, onion routing for mobile nodes. The level of anonymity should be flexible and context dependent (freedom to change privacy settings, freedom to choose feasible information). To achieve the above, [63], proposed the privacy rights management for mobile applications (PRiMMA) with monitoring mechanisms included. However, the cost of a strong effective cryptographic application for strict privacy condition could be high but nothing is too high to achieve safety.

Location based services (LBS) enabled by GPS on mobile devices face privacy challenges as users provide their location which should be a private information. However, [64] presented a location trusted server (LTS) to address this issue. Users'



information are generally known by the LTS but cloaked to avoid linking individuals to the general information cloaked by the server [19].

## 2.4. Related Work

This section presents an outline of previous literature reviews on MCC.

The work of [11] is a review of mobile cloud computing (MCC), it gives a summary of the concept and the core ideas, basic model, architecture, problems and possible solutions. However, there are other problems and solutions not mentioned here but found in other papers. Also, [12] presented a review on the rudiments of MCC, characteristics, recent research work, and future research expectations. It also analyses the features and infrastructure of MCC. Furthermore, in [32], reporting a survey of research in MCC, it presented the challenges of the design of MCC service, and it proposed a conceptual model to analyze related research work. However, it was not a systematic literature review; hence, a clear explanation of the methodical approach that was used to select the set of papers that were reviewed was not provided.

MCC needs to achieve reliable security in an environment of interoperability and heterogeneity with the use of mobile devices, therefore, [65], explored security and privacy in MCC, discussing the issues and providing solutions though not a review paper. The work of [66] is a systematic review of cloud computing security requirements. Its focus is on nine requirements (integrity, access control, non-repudiation, security auditing, attack or harm detection, recovery and prosecution, physical protection, privacy) as coined out of previous papers. This paper dwells on cloud computing security requirements and not MCC.

The paper of [21] is a comprehensive survey of MCC research, outlining issues and presenting solutions from literature. In addition, [19] did a survey of MCC discussing its architecture, applications, approaches, issues and challenges. This paper is different from the previous reviews that were discussed above, because it is a systematic literature review that employs a methodical, structured, rigorous, and unbiased approach for selecting papers used in the review. Also unlike others it was designed to answer specific research questions, which was not the case in the previous reviews. The steps that were taken to accomplish the systematic literature review task are explained in Section 3.

## 3. Research Method

This is a systematic literature review carried out using [67] as a model. Some steps to a successful conduct of a systematic literature review were deduced from [68].

### 3.1. Research Question

This study answers the following research question:

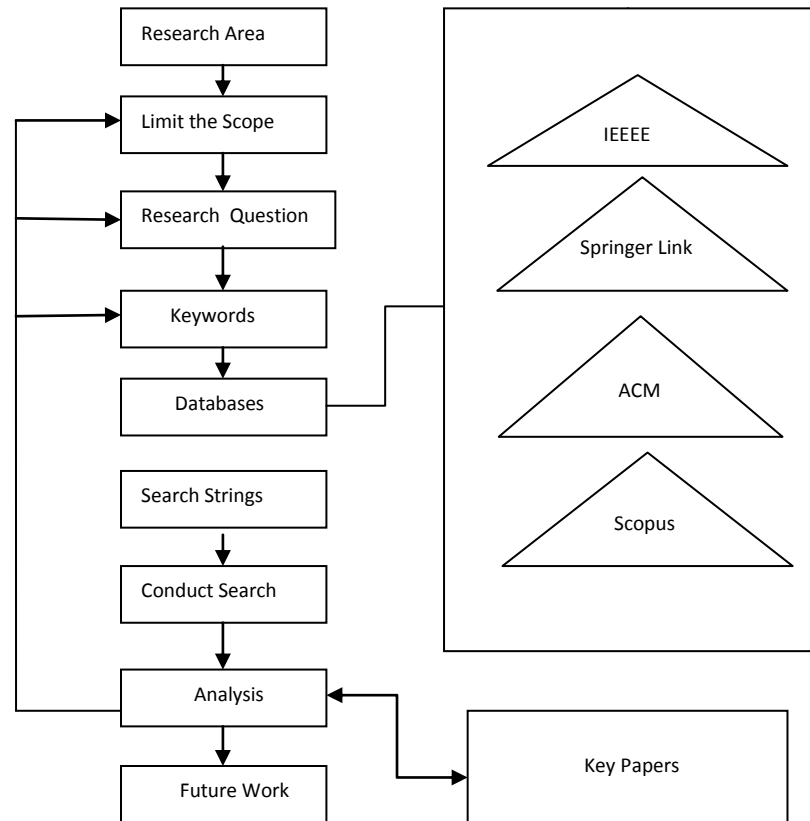
1) RQ: What is the trend of research interests so far in mobile cloud computing, in terms of the least and most researched issues? For an answer to this question, the current works in the literature were reviewed.

### 3.2. Research Question

From the scratch, an adequate scope was defined for the research spanning the concept, its challenges and solutions. This led to the preliminary research questions and the identification of keywords. The keywords were searched in standard and rich databases such as IEEEExplore, ACM Digital Library, Scopus and SpringerLink. From the research results, the scope, questions and keywords were remodeled, search strings restructured, and searches conducted afresh.

Furthermore, to harvest numerous relevant papers, the list of databases was increased. Important, resourceful and relevant papers were generated leading to a validation list to

ascertain the effectiveness of the searches and evaluate search strings. The different search string combinations are “*Mobile cloud computing*”, “*mobile cloud computing reviews*”, “*mobile computing*”, “*MCC*”, “*mobile computing survey*”, “*mobile cloud computing literature review*” “*MCC security*”, “*mobility in cloud*”, “*mobile cloud*”, “*pervasive computing*”, “*ubiquitous computing*”. Figure 1 is a summary of the process that was used to conduct the systematic literature review.



**Figure 1. Search Strategy and Process**

### 3.3. Data Sources

The databases consulted in a progressive usage as discussed earlier are as follow:

1) *IEEEExplore* (<http://ieeexplore.ieee.org>): It houses electrical engineering, computer science, electronics subject areas and provides full-text and bibliographic access to IEEE transactions, journals, magazines and conference proceedings published since 1988. It gives citations to papers found in less structured platforms online but without perfect citations or sources.

2) *ACM portal* (<http://dl.acm.org>): This covers a collection of citations and full-text from ACM journals, newsletter articles and conference proceedings that cover information technology, information systems, electronics, engineering *etc.*

3) *Springer link* (<http://www.link.springer.com>): The existence of this database for decades makes it a very robust research database. Scientific papers are mainly domiciled here from major journals and conference proceedings. Advanced search is done by indicating certain restrictions in different provided fields of the database.

4) *Scopus* ([www.scopus.org](http://www.scopus.org)): This is a very rich database that requires an individual or institutional registration before use. Scopus is the largest index of journal articles and conference papers. It was observed that many papers in ScienceDirect ACM, IEEE, SpringerLink can also be found in Scopus.

5) *Researchgate* (<https://www.researchgate.net/literature>): This is a powerful repository to seasoned academics where they upload their full-text papers and possibly how they want them cited. It is an online database and gets updated with each upload. During the course of this research, some relevant papers that were found in databases that we do not have subscription for were obtained in full text via researchgate.

### 3.4. Data Retrieval

We tried a combination of keywords in order to test for synonyms used in the literature and to cover a variety of mobile cloud computing publications. The following search terms were used:

- (1) mobile cloud computing
- (2) mobile cloud computing reviews
- (3) mobile computing
- (4) MCC
- (5) mobile computing survey
- (6) mobile cloud computing literature review
- (7) MCC security
- (8) mobility in cloud
- (9) mobile cloud.

All these search terms were combined by using the Boolean “OR” operator. This means that any article with anyone of the search terms will be retrieved. Hence, we searched:

1 OR 2 OR 3 OR 4 OR 5 OR 6 OR 7 OR 8 OR 9

The search strings above in Scopus yielded 1,279 results when it was searched from publication titles and the following restrictions were further applied to define the boundaries of our search: i) the source papers were limited to conference papers and journal articles. ii) Publication year limitation of 2002 to 2014. iii) Limit by subject area (Computer Science and IT). At the end a total of 716 publications were retrieved when the search strings above were applied.

Going through the titles, some publications did not strictly address mobile cloud computing but other related concepts or its derivatives, and they were excluded, with 305 papers remaining. Some papers addressed mobile cloud computing but at variance with our research question as revealed from the title at a glance, therefore they were exempted, which resulted in 123 papers. Thereafter, 31 papers were further exempted because they were focused on mobility or cloud and not strictly mobile cloud computing. At this stage, we had 92 papers left and these were manually reviewed for relevance to our research questions. This manual review produced 70 papers that were considered relevant for analysis as regards to the research question.

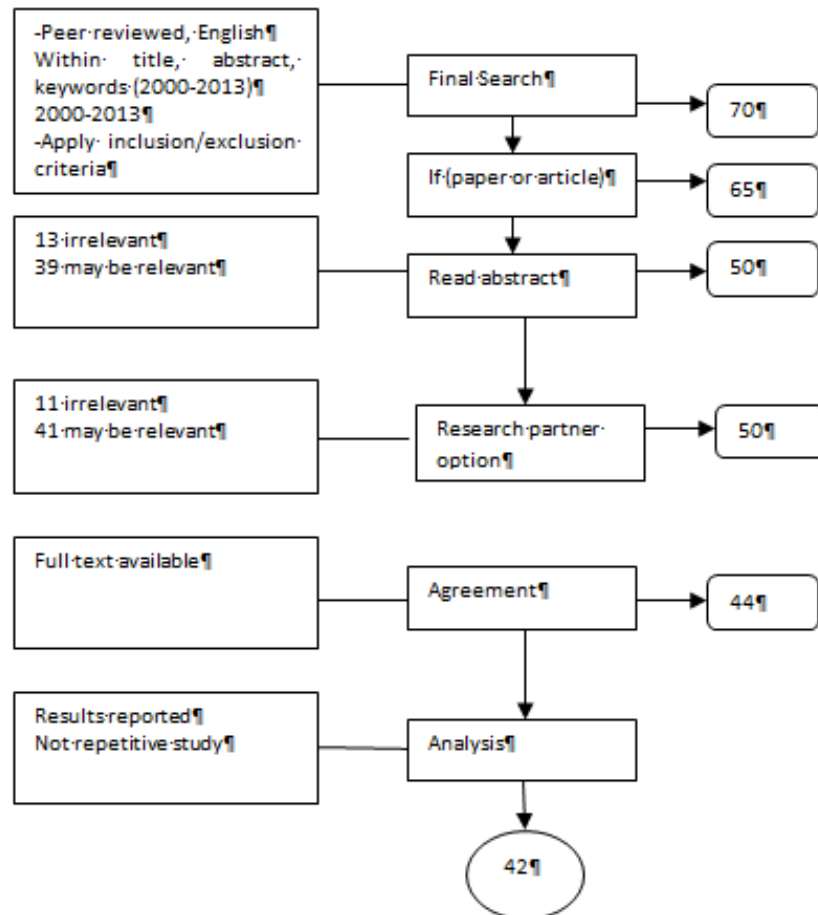
Inclusion criteria: i) Mobile cloud computing or mobile cloud must be in the topic of the publication. ii) With two publications reporting the same research, and the same authors, the most current was selected.

Exclusion criteria: i) Publications that focus on cloud computing were excluded because it is a different concept, although cloud computing is the foundation for mobile cloud computing. ii) Journal articles with professional perception but without academic or scientific references were exempted.

The inclusion and exclusion criteria were applied on the retrieved publications, which resulted in 65 publications, which were moved to the next step. This is also in tandem with the work of [69].

We then read the abstracts of the 65 papers thoroughly in order to ascertain their relevance. Based on the perceived relevance of the title, abstract and keywords, the papers

were grouped into three categories, which are “relevant”, “irrelevant” or “may be relevant”. With this procedure, we identified 50 papers that belong to the “relevant” and “may be relevant” category. These 50 papers were thoroughly analyzed based on their perceived relevance to our research question, in order to arrive at the final set of 42 papers. These 42 papers are a product of consensus among the researchers that are involved in this study, and these are the papers used for data extraction and synthesis (see Figure 2).



**Figure 2. Inclusion Process and Results [69]**

### 3.5. Discussions

As an outcome of the analysis, we observed that the earliest papers from 2002- 2006 focused on pervasive computing and mobility. The papers of 2007 and 2008 are on cloud computing and the required antivirus, discussions about the opportunities that exist by bringing mobility into cloud computing dominated discussions for the next two years (2009 - 2010) and by 2011, the term mobile cloud computing began to be used prominently in the literature. Table 1 is the distribution of papers over the studied years.

**Table 1. Distribution of Papers Over the Studied Years**

2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	<b>Sum</b>
4	4	3	4	1	7	8	6	12	8	8	11	4	<b>80</b>

The highest number of papers was published in 2010 (15%) followed by 13.75% in 2013 and the next being 8% in each of 2008, 2011, and 2012. Also, 2007 ranks next with 8.75%, followed by 7.5% in 2009; 5% each in 2002, 2003, 2005, and 2014, and the least were published in 2006 with 1.25%. The papers analyzed are 45.2% from conferences, 26.2% from journals, 9.5% each from workshops and technical papers, others are research papers from surveys and textbook (s), all in mobile computing, mobile cloud computing, MCC architecture or MCC security.

#### **4. Limitations and Further Research**

To ensure an unbiased categorization after the searches, the inclusion or exclusion criteria were applied to aid decision making, we ensured all selected papers were verified by all researchers involved in this study. However, we discovered that access to relevant papers depends on the promptness of the search strings. It is possible some other relevant paper could have been retrieved with a different set of search strings. Furthermore, our systematic review could still be biased despite efforts to avoid bias, because the databases that we consulted, indexed more of the renowned conferences and journals on the subject of mobile cloud computing; hence, the views of low class publications are ignored. In addition, conducting further searches in non-English sources could minimize the bias in the study.

#### **5. Findings of the Study**

As regards the research question investigated in the study the followings are our findings:

*RQ - What is the trend of research interests so far in mobile cloud computing, in terms of the least and most researched issues?*

We discovered that the literature has covered various application models, comparisons between the models, various cloud architectures, context-aware service, application partition and offloading, also literature have reported the introduction of CloneCloud, which offloads execution on mobile equipment to the distributed and virtualized cloud and the result passed to the mobile device. However, issues of privacy, security and trust in MCC, network access management, and interoperability in MCC have not been well reported in literature. From the 42 papers that we finally analyzed, only four topics were based on security and privacy in MCC [65,61,49,70] and none on either network access management or interoperability in MCC. The concept of trust in MCC has received little or no attention thus far in the literature.

We also found that the challenges of MCC include issues such as device handing off to different wireless transmission district, unreliable transport channels to guarantee cloud service delivery, inability of mobiles to handle complicated applications, constraints in security and privacy standards. However, the concept of application partition and offload has helped to resolve many of the mobile device capability constraints. Nevertheless, we discovered that there is relatively little research on MCC security.

#### **6. Conclusions and Future Works**

In this paper, we have undertaken a systematic literature review of mobile cloud computing (MCC), in order to understand the trend of research interests so far in MCC, in terms of the least and most researched issues. We were able to highlight some of the challenges in MCC such as privacy, security and trust, fault tolerance, mobility management, network congestion, heterogeneity and connection protocols, resource constraint and platform heterogeneity, context awareness, presentation and usability issues, battery life and energy awareness, and cloud API Security Management. In addition, we considered the countermeasures that have been proposed, particularly

existing solutions or systems that have tried to address the challenges in order to achieve an effective MCC service delivery to users. As an answer to the objective of the study, we found that the issues of security and privacy despite their importance have received little attention so far. Also, issues of network access management and interoperability in MCC have not received much attention as yet, while the concept of trust in MCC has received little or no mention so far in the literature. We argue that these outlined issues are of utmost importance therefore, upcoming researchers in MCC should venture into these areas.

Aside these relative virgin areas of research in MCC, we observed that although, a number of solutions have been proposed to address some of the problems so far identified in MCC still there remain gaps that require further research. For example, 4G wireless networks still have problems based on network architecture, access protocol and quality of service [71, 19]. This is despite upgrades in bandwidth availability and allocation that have raised the usage of 4G networks, such that it has widened mobile network coverage area, facilitates quicker handoff and ensures varied services [72].

In addition, the current MCC pricing system has the mobile service provider (MSP) and cloud service provider (CSP) having different service management, customers management, pricing and payment method. How to find an optimal pricing management for MCC that would best serve the MSP and CSP is still an open problem. A solution could be to evolve a collaborative pricing and revenue sharing model for both MSP and CSP [6, 19, 20-21]. Similarly, there is need to address the challenge of network disconnection and signal attenuation that cause delays and reduce quality of service in MCC.

Furthermore, some have advocated the use of CloneCloud and Cloudlets as a way to manage resource constraint, and traffic congestion, thereby leading to enhanced reliability, battery life, and fault tolerance. However, this proposal is not perfect because for now, CloneCloud does not virtualize access to native resources that are not already virtualized and are not available on the clone. In the case of Cloudlet, improvements are still necessary in its processing distribution, storage, user experience maximization, and cost minimization [33]. In same vein, trust and security for cloudlet is an open issue of research because enemies may create a fake cloudlet to steal user's information. Other open issues in MCC are network access management, interoperability and service convergence, which are currently under researched in literature [73].

Lastly, although the aim of MCC is to enhance the opportunities derived from mobile devices by leveraging on the strengths of cloud computing, it is still a relatively new area of research, where many open problems are yet to be resolved. However, it is essential to provide accurate intellectual guide for upcoming research to aid them in identifying the probable areas where they likely to make the most impact in advancing research in MCC. This is what our effort in this paper strived to achieve.

Looking into the future, the influence and impact of MCC will grow. This is particularly due to the growing interest in the integration of the Internet of Things (IoT) and Cloud Computing, which will bring about mobile IoT. This integration explores the potential of the interface between mobile, cloud, and smart objects with sensors to deliver pervasive technology solutions in areas such as smart agriculture, smart homes and smart cities, pervasive healthcare and other smart services and applications. This innovative integration of cloud computing, mobile technology, and Internet of Things (IoT) called Cloud of Things (CoT) is the future of connectivity and reachability. The cloud of things will ensure wider connectivity of real world objects, make it possible to monitor them remotely irrespective of distance or location. This is bound to create new opportunities for research on salient aspects such as security, reliability, safety, interoperability and the likes.

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