Mobile Cloud/Edge Computing in Internet of Things

Research · April 2019

DOI: 10.13140/RG.2.2.19482.49603

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***Abstract*—The increase of Internet of Things (IoT) means more active user devices on the Internet. IoT devices can be everyday objects from vehicles, smart phones to wearable sensors. Massive amounts of data are generated by IoT devices through the collection and transmission of data needed for the output of useful outcomes and therefore, an efficient way to operate is important.**

By using Cloud Computing with IoT, data computations are located outside the devices hence reducing the strain on the devices themselves. IoT devices are also often mobile and with mobility comes the need to have wireless connections to the cloud. Therefore, Mobile Cloud Computing (MCC) becomes applicable. However, factors such as communication time between the cloud and the IoT devices come into play introducing latency that is intolerable especially for more critical applications using IoT devices. Therefore, to reduce the dependency on the cloud and lower the latency experienced, the cloud services are brought closer to the devices in form of "edge computing". Therefore, a shift from the centralized Mobile Cloud systems towards the distributed Mobile Edge Systems is explored.

This paper analyses features, advantages, applications and challenges of Mobile Cloud Computing as well as the transition to Mobile Edge Computing. Research efforts towards the implementation of Mobile Edge Computing are also discussed giving an insight into the future of the technology.

***Index Terms* - Internet of Things, Cloud computing, Mobile Cloud Computing, Mobile Edge Computing, Context-awareness, Fog Computing, Cyber-Foraging.**

I. Introduction

Internet of Things according to [1] simply implies things, machines that gather data without the help of humans. Figure 1 shows an illustration of possible Internet of Things, however it is not exhaustive of all the possibilities.

Mobile Computing is essentially a combination of portable user devices such as phones and computers and how they connect to other devices through wireless networks [2].

Since mobile devices are usually small for portability, their resources can be limited in terms of battery life and storage [3] and technologies such as Cloud Computing make it possible to provision such computing resources to consumers according to demand [4] through resource-intensive computing from the cloud [3].

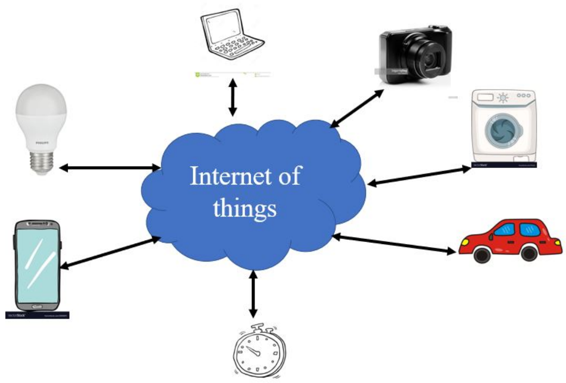

Fig. 1. Internet of Things

Consumers use standardized platforms such as laptops and mobile phones to access over the network the resources that are then "monitored and controlled providing transparency to both the provider and consumer of the utilized service" [4].This eliminates the need to have powerful device configurations such as CPU speed and memory capacity on the device. Some of the Cloud Computing features include:

- Virtualization: According to [4], virtualization is the "foundation of cloud computing". Hardware virtualization utilizes hypervisors to abstract and pool resources as well as "dynamically assigning or reassigning" the resources to virtual machines on demand [4].
- Autonomic computing: This involves self-managing computing systems operating under "defined general policies and rules without human intervention" [4]. Cloud computing is more focused on resource cost reduction achieved through interconnecting and integrating the distributed data centers across continents.
- Grid computing: This involves employing dis-

tributed resources to achieve on-demand resource sharing.Applications that depend on location of the mobile user such as; getting information about the nearest restaurants need distributed data computation [2]
- Utility computing: Resources are provided on demand hence maximizing resource utilization and reducing operating costs in the context of the service providers and customers charged based on usage.

Cloud Computing has a stack structure that includes cloud service models which are built on top of the data center layer. A Data center layer provides the hardware and infrastructure facilities for the clouds and is typically built in less populated areas with high power supply [5]. Table I shows the layers of cloud computing, with definitions and typical examples of applications for each. In the stack structure, Infrastructure as a Service (IaaS) is at the bottom, Platform as a Service (PaaS) is in the middle and Software as a Service (SaaS) is at the top. However, this can sometimes differ in arrangement.

Cloud Computing is also explained through its deployment Models such as:

- the *Private cloud* used exclusively by one organization with the highest level of reliability and security [4],
- the *Community cloud* shared by several organizations with shared needs such as security requirements, policies and compliance considerations [4],
- the *Public cloud* that is available to the public owned by cloud provider for example, Amazon, Google and Microsoft that sell cloud services. This deployment model lacks "fine-grained control over data, network and security setting" [4] and
- the *Hybrid cloud* which is a composition of two or more clouds bound together to enable data and application portability for example, cloud bursting for load [4].

The following section explains the concepts of the centralized Mobile Cloud Computing.

II. Mobile Cloud Computing

Mobile Cloud Computing (MCC) is essentially a combination of Mobile Computing and Cloud Computing. Where as Cloud Computing enables the computation of resources to occur outside of a device, MCC enables the resources to be explored on the mobile device as well [8]. [9] explains MCC as "an integration of Cloud Computing technology with mobile devices to make the mobile devices resource-full in terms of computational power, memory, storage, energy, and context awareness" while the authors in [5] describe MCC as "an infrastructure where both the data storage and the data processing happen outside of the mobile device". In both these descriptions it is evident that MCC sets out to overcome the obstacles related to performance due to the limitations of battery life, storage and bandwidth of mobile devices, as well as scalability and security.

MCC service models encompass relationships between the *infrastructure providers* (who provide supplements for hardware and software services), *application and service providers* (who execute user requested services), *developers* (who develop applications being hosted on the cloud data centers) and the *end-users* (consumers of cloud services) [10].

A. Advantages of Mobile Cloud Computing

Mobile Cloud Computing overcomes the obstacles that stem from Mobile Computing such as limited battery life, scalability, and performance. These advantages are explained below as:

- **Extending battery life:** Energy/power consumption is a limiting factor for the functionalities that can be placed on mobile IoT devices hence, reducing this power consumption is essential [11]. Computation offloading removes large computations from "resource-limited devices" to "resourceful machines" such as servers in clouds. In this way, application execution time that consumes power is reduced [5] as result extending the device battery life.
- **Data storage capacity and processing power:** The adoption of virtualization differentiates Cloud Computing from the Client-Server model. Cloud providers offer mobile users computing cycles to reduce the computation time on the mobile device which saves power consumption [12]. Furthermore, large data can be accessed through wireless networks [5]. An example of a cloud service is *Amazon Simple Storage Service* (Amazon s3) which enables customers to store and protect any amount of data for a number of uses. [13]
- **Reliability:** Data and applications are stored and backed up by the cloud servers [5]. Offloading "detection functionality" to a network service provides mobile IoT devices with "protection capabilities of multiple detection engines" such as virus scanning, malicious code detection and authentication [14].
- **Dynamic on-demand reservation and provisioning of resources** on a self-service basis [5].
- **Scalability:** Changing user demands can be catered for by the flexible resource provisioning enabled by cloud computing [5].

Cloud Service Model	Definition and Examples
Infrastructure as a Service	Built on top of the Data center layer, enables provision of storage, hardware, servers and networking components with users paying for only resources they use(per-use basis) [5].Typical providers include Amazon Elastic Cloud (EC2) and GoGrid.
Platform as a Service:	Offers integrated environment for building, testing and deploying custom applications [5]. Examples include; Google App Engine [6] which offers Python, Java and Go programming platforms, Microsoft Windows Azure Platform which supports languages in .NET Framework, Java, PHP, Python, and Node.js.
Software as a Service	Support software distribution with specific requirements. Applications accessed and paid for via the internet [5]. Examples include; Salesforce.com, which is a pioneer provider [7], Google Apps and Zoho

TABLE I
CLOUD COMPUTING SERVICE MODELS

- **Multi-tenancy:** Computing resources and costs that come with cloud computing can be shared among the network operators and cloud providers (data center owners) [5].

B. Issues in Mobile Cloud Computing

Mobile Cloud Computing has some challenges both on the mobile communication side affecting the users of the technology and the computing side which affects how the technology can be implemented. Below are some of the issues cited in the mobile communication side.

- *Low bandwidth:* With an increase of mobile devices in turn the Internet of Things, most cellular backbone infrastructures face demanding pressure for better capacity and coverage. To overcome the overall demand on the cellular infrastructure, the authors in [15] suggest that devices in close proximity can pool their resources to using a data distribution policy which determines "when and how much portions of available bandwidth are shared among users and from which networks (e.g., WiFi and WiMAX)"(see also [5]).
- *Availability:* Due to "traffic congestion, network failures and the out-of-signal" [5], mobile users may not be able to connect to the cloud. Authors in [16] suggest that mobile devices can act as virtual cloud computing providers, however, mobility, capability of the mobile devices and privacy of users are not considered [5].
- *Heterogeneity:* Handling wireless connectivity in heterogeneous networks that consist of different radio access technologies such as WCDMA, GPRS, WiMAX, CDMA2000, and WLAN while satisfying Mobile Cloud Computing requirements is a challenge [5].

The issues in the Computing side include:

- *Computing offloading in a static environment*: Experiments have been conducted in [17] to determine if remote execution of processes could save battery power. Authors in [5] argue that the results in the experiments showed that computing offloading in the static environment is not always effective.
Instead of running applications on servers owned by service providers, cloud providers can implement virtualization in Cloud Computing by running the applications from different customers on virtual machines [12]. With cloud computing, data can be stored on the cloud and computations made from it for example, google photos [18]. This eliminates the need to send data over the wireless network while requiring only "a pointer to the data".
- *Computing offloading in a Dynamic environment*: In this environment for example, "changing connection status and bandwidth" can introduce a number of challenges [5]; in case a mobile device is disconnected due to network failures, only the failed subtasks of the application are re-offloaded.
- *Security*: Security for mobile applications can be achieved by having the virus detection software and detection capabilities moved to the clouds [5]. Other challenges such as privacy issues and security of data on the cloud are still concerns.
However, authors in [19] address the privacy issues caused by the GPS positioning devices and location-based services most often used in mobile computing by proposing location privacy based on "*k*-anonymity" which clocks a person's location such that there are at least k-1 other people within the clocked area and reveals only the clocked area to a location-based service.
In [20], an "energy-efficient protocol" that ensures integrity of storage services in Mobile Cloud Computing is presented. In the system design, three main entities are included: the mobile client (IoT device user), the cloud service and a trusted third party allocated to multiple registered clients with whom unique secret keys are shared. Verification of data can take place with comparison of hash codes between the mobile client and the trusted third party.

C. State-of-the-art

Many applications for Mobile Cloud Computing have been researched and developed, including the ones mentioned already in the sections above. This section highlights some of the applications in which the cutting edge technology of Mobile Cloud Computing has been utilised.

- Mobile Commerce (m-commerce): Applications in m-commerce such as mobile transactions and payments, mobile messaging and ticketing require mobility [5]. The authors in [21] present a three-layer platform that enables on-demand and scalable access to resources with servers that process mass data. The platform enhances speed of data processing and ensures low configuration of the client. A PKI (Public Key Infrastructure) mechanism is used to ensure privacy for user's accessing data outsourced to the cloud. [22](see also [23])
- Mobile Learning: Based on electronic learning (e-learning) and mobility [5]. In [24], an analysis was carried out that showed that student's motivation to learn and engage was improved by the use of mobile computing. Centralized shared resources can be distributed to authenticated users who log into a system at any time and anywhere, ensuring security [25]. A contextual mobile learning system that incorporates mobility, cooperation and contextualization is presented in [26] allowing learners to access resources in mobile contexts. The authors in [27] introduce an application called "cornucopia" which is accessed using mobile computers by students in a genetics course to enter data for computations.
- Mobile Healthcare (m-healthcare): Mobile Cloud Computing makes the access to patient health records efficient and easy. Some of the applications in Mobile Healthcare include:
  - *Health monitoring services:* patients can be monitored at anytime and anywhere through broadband wireless communications.The authors in [28] introduce the "sensor based Mobile Health Service" , a cloud computing management model that provides for "sensor signal processing as well as security as a service to mobile devices".
  - *Pervasive access to healthcare information:* allows patients or healthcare providers to access the patients' current and past medical information. Authors in [29] present the use of cloud computing for storage of electronic healthcare data while enabling updating and retrieval of the data using Google's android operating system on the client mobile device and the Amazon's S3 as the cloud service [13]. In [30], an infrastructure for assistive healthcare called "MoCAsH" is proposed that inherits the advantages of cloud computing, for example enabling context-awareness by adapting services based on changed context, and the use of sensors for collecting data using wireless connections to send to the cloud.
- Mobile Gaming (m-game): A game engine that requires large computing resource is offloaded to the server in the cloud, leaving gamers to only interact with the screen interface on their devices [5]. Authors in [31] introduce the "Cloud Mobile Gaming (CMG) approach" offloading compute-intensive tasks such as graphic rendering to the cloud as well addressing the constraints imposed by availability of wireless connectivity. MAUI in [32] is a system that offloads mobile code to the cloud hence offering performance benefits as well less energy consumption by mobile applications. The application codes are partitioned at run time based on the cost of network communication and computation on the mobile device to maximize energy savings given network connectivity [22].
- Other applications: Mobile users that require searching services for information, location, images, voices or video clips can benefit from the context-awareness feature of cloud computing [5]. Examples of these applications include;
  - The "*Restaurant Search mobile system*" prototype presented in [33] that carries out intelligent mobile searches using cloud computing.
  - "*Dessy*" in [34], was introduced as a desktop search tool that allowed users to find files by their content and providing an interface from which files could be located. In [35], authors demonstrated how "Dessy" can be used to synchronize user data that may be saved on multiple devices using cloud computing.
  - An Image processing architectural model that connects mobile devices using 3G network with cloud computing is presented in [36].
  - The context-aware "*traffic lights detector for the Blind navigation* " system that employs the mobile devices with GPS receivers as the "Mobile Navigation and Awareness Server (mNAS)" to provide location data to the Web Services Platform employed as the "Cloud Navigation and Awareness Server(cNAS)" in order to perform location specific functionality.

[37]
- "*Real-Time Online Interactive Applications (ROIA)*" includes virtual environments such as e-learning, online computer games and training applications which are enhanced for use with mobile devices; mobile ROIA, proposed in [38] uses cloud computing by moving computation-intensive tasks like graphic processing to the cloud resources instead of storing them on the mobile devices.
- "*Cloud Torrent*" , an alternative way of sharing files using a remote cloud server onto which large amounts of data can be downloaded via "Bit Torrent" and transferred to the mobile device in an energy efficient manner [39].

III. Mobile Edge Computing(MEC)

Challenges faced in the Mobile Cloud Computing (MCC) such as the "long propagation distance from the end user to the remote cloud center, result in excessively long latency for mobile applications". For the Internet of Things, reliability, mobility and security are some of the top requirements. Authors in [40] argue that MCC is inadequate for a wide-range of emerging mobile applications that are latency-critical. Therefore, with an increase in IoT devices and 5G communications, there has been a shift from centralized Mobile Cloud Computing (MCC) to Mobile Edge computing (MEC). According to [41], MEC is "cloud-computing capabilities at the edge of the mobile network, within the Radio Access Network (RAN) and in close proximity to mobile subscribers". As illustrated in Figure 2, the devices connect to Mobile Edge servers that are in closer proximity. This, according to researchers for example in SectionIII-B will prove to reduce latency, which is among some of the challenges cited in MCC.

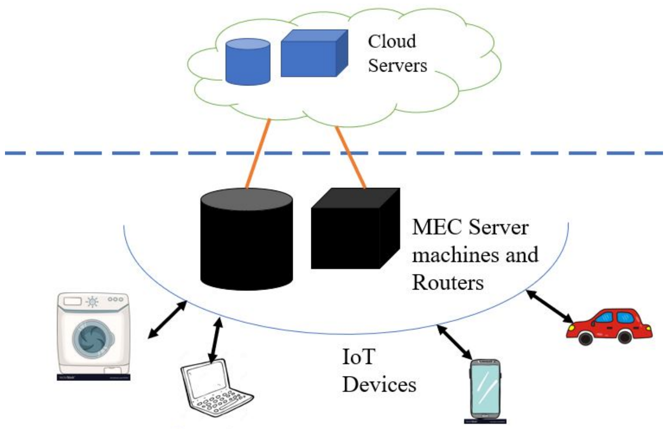

Fig. 2. Mobile Edge Computing

Typically, an MEC system is composed of;
- the mobile devices that can be end users
- the cloud service providers
- the MEC servers

In order to avoid data saturation in backhaul networks caused by end users exchanging data with remote clouds, MEC pushes traffic, computing and network functions towards the network edges. Network edges can range from smartphones, to small cell base stations. [40].

There are certainly significant differences between MEC and MCC as pointed out in [40]. MEC compared to MCC, has advantages such as, lower latency, energy saving, context-awareness and security for mobile applications. According to [41], the aim of MEC includes ensuring efficient network operation and service delivery in addition to improved user experience.

A. Mobile Edge Computing in Internet of Things

From the IoT perspective, the wireless networking technologies used to communicate with edge servers in a Mobile Edge Computing architecture should be readily available to ensure flexibility and mobility to the users. [42]

The key requirements of edge computing for IoT are;
- *Security:* IoT data in transit and at rest needs to be protected through monitoring and automated response before, during and after an attack [43].
- *Latency:* Since most IoT applications are delay-sensitive, low latency is enabled by Mobile Edge Computing by extending services and applications from the cloud closer to the devices in form of edge servers. [42]. According to [43], "Analyzing data close to the device that collected the data can make the difference between averting disaster and a cascading system failure."
- *Reliability:* IoT data according to [43] affects safety and critical infrastructure and hence its integrity and availability should be preserved.
- *Mobility support:* This can be achieved through context-awareness of edge architectures.

B. State-of-the-art

This section looks at the key components considered for application models using Mobile Edge Computing (MEC). Different research material is included showing how computation and communication latency can be manipulated to achieve overall low latency in MEC.

The authors in [9], explain parameters that play critical roles in modeling the computation tasks and these are presented as the criteria for comparing application models for MCC. Among those explained include:

- Context Awareness which affects whether or not to perform computation offloading. As explained in II-B, static offloading is not always beneficial and may cause performance degradation.
- Latency, explained in [9] as the time between offloading a computation and having the results of the computation from the cloud displayed on the device has an effect on real-time applications and depends on the data size, location of required data, etc.
- Bandwidth Utilization is a trade off considered with latency which increases with the amount of data migrated to offload the computation. Bandwidth in cellular networks is limited and therefore, should be efficiently used.

The following four sub-sections explain the areas of research that have been applied to Mobile Edge Computing, including:

1) Computation Offloading: "Computing as a utility" can be enabled on edge computing devices through remote execution of real-time applications in a specific time frame [44]. By migrating computation to more resourceful servers, the capabilities of mobile devices are augmented [45]. This is called "**computation offloading** which is different from the migration model in [46], whereby a process during execution can be moved between processors with continuous access to all resources required. Two main advantages of computation offloading include:

- Improving performance on mobile systems by reducing execution time [44], [45].
- Saving energy by reducing its consumption [44], [45].

Decisions have to be made before offloading such as; *why it should be done, when it should be done, what mobile systems use it, the applications that use it and the infrastructure used for it* [45].

The authors in [40] suggest computation task models used to model the computation tasks mentioned earlier in Section II-C which include latency, bandwidth utilization and context-awareness (see also [9]). These task models include;

- Task model for **Binary offloading** for Mobile cloud computing and
- Task model for **Partial offloading** for Mobile Edge computing.

In binary offloading, a task cannot be partitioned and is therefore, executed as a whole either locally at the mobile device or offloaded to the data server. In partial offloading, however, a program can be partitioned with one part executed at the mobile device and the other offloaded to the edge server for execution. With components in applications being dependent on each other, the execution order of functions can not be random and a decision is to be made about what should be offloaded. In order to capture the "inter-dependency" among the computation functions in an application, the "**task-call graph**" is used [40].

The authors in [47], suggest a trade off point when considering computation offloading, between energy consumed by computation (during local processing) and the energy consumed by communication (dependent on the energy efficiency of wireless communication during computation offloading). The authors also state that the "traffic pattern" is important since sending a "sequence of small packets consumes more energy" compared to sending the whole data at once. An "energy trade-off analysis" is performed considering the energy costs of local computation on the mobile device, E_{local} versus the energy cost of transferring the input and output during offloading, E_{cloud}. For offloading to be beneficial,

$$E_{cloud} < E_{local} \tag{1}$$

The authors, suggest that the best energy efficiency for communication can be achieved with bulk data transfers and delays if immediate responses are not required to wait for a "bearer" with better energy efficiency.

Since an increase of Internet of Things will increase mobile traffic, the authors in [48] suggest that the percentage of data offloaded should be optimized via each radio interface on the mobile device such as WiFi, 3G, HSPA and LTE. Maximizing radio resources available to the device according to the authors can minimize energy consumed by the device. However, the question remains if indeed a mobile device can use both radio interfaces, say WiFi and LTE simultaneously at the same time.

The authors in [44] suggest that "*computation time*" (which is the completion time for a job(transaction)) depends on whether it was executed locally on the mobile device or offloaded to the cloud. In case of local execution, the completion time of a job would depend on the execution rate of the device whereas in the case of offloading, the time will depend on the execution rate of the selected cloud resource, plus the time taken to transmit the input and output data through the network; "*communication time*". The communication time as the time required to transmit a packet across one hop in the network depends on the processing, queuing, transmission and propagation delays and the size of the packet. Two ratios where used for the computation offloading analysis including; *the computing-to-communication ratio (CCR)*, which is the ratio of the computation time to the communication time and the *remote-to-local ratio (RLR)* which is the ratio of the cloud resource execution speed to the local execution speed. An inequality that shows that there is an inverse relationship between RLR and CCR is used to determine the computations that can benefit from computational offloading.

The authors in [40] point out factors that can limit the efficiency of offloading and also suggest communication models of mobile devices that can evaluate the computation performance. The challenges faced in wireless communications include: multi-path fading caused by obstructing objects like trees and buildings, interference by other signals occupying the same spectrum and the shortage of spectrum. In their work, they suggest that, wireless access points co-located with MEC servers can enable access to the remote data centers through back haul links there by facilitating the MEC servers to offload computation tasks to other MEC servers or to large-scale cloud data centers. Furthermore, Device-to-Device (D2D) communications help mobile devices with insufficient wireless interfaces to communicate with MEC serves through D2D communications with neighboring devices.

Design considerations for the IoT computation mobility framework in [49], suggest that IoT devices have different capacities from sensing, computing, storing to sending and receiving data. This only increases the complexity of employing computation offloading to IoT.

2) Cyber Foraging: The authors in [50] suggest augmenting the limited computing resources of mobile devices by using "*cyber foraging*", that exploits "data staging servers" in close proximity to the mobile devices at different locations during the user's movements. By utilizing a distributed file system, an un-trusted and un-manged computer can facilitate secure data access for mobile users. The un-trusted computer is called a "*surrogate*" computing tier that is a wired infrastructure server between the mobile users and the cloud data centers.

In [51], communication protocols utilized to maintain communication between the mobile device and the surrogate machine are seen to play a major role in determining the efficiency of Cyber Foraging. Technologies such as 4G LTE have high throughput but consume more power compared to WiFi and Bluetooth, therefore, a tradeoff between energy consumption and high speed is considered. Having dedicated surrogate machines can be costly and Cyber Foraging Frameworks such as LOCUSTS [52] which enable mobile devices to act as surrogates can drain battery power and limit performance

3) Fog Computing: Fog computing according to [53] is considered in scenarios where "data needs to be collected close to the edge devices". IoT devices send their data to the *fog nodes* which receives the data in real-time, running applications on the collected data. The cloud then collects data from the fog nodes at intervals and processes the data used in later decision making processes. From the IoT perspective, the wireless networking technologies used to communicate with edge servers should be readily available to insure flexibility and mobility to the users. [42].

The EdgeIoT proposed in [54] is an approach purposed to "handle data streams at the mobile edge" using fog computing and Software Defined Networking (SDN). Fog nodes are deployed on base stations equipped with multiple wireless interfaces to facilitate the IoT-based wireless communications. Examples of the wireless communications include: *Zigbee*, for "devices with short transmission range, low data rate and long battery life requirements" [54], *Device-to-Device (D2D) communications with relay, Bluetooth low energy, Millimeter-wave and massive Multiple-Input Multiple-Output (MIMO) communications, Low-power wide area technologies*, for devices with low mobility, power and cost in a wide area network, and *Narrowband IoT communications*.

The fog node locations are flexible that is, directly at a base station or at the edge of a cellular core network enabling different base stations to share the same fog node. In the authors' "hierarchical fog computing architecture", each user can have a proxy virtual machine (VM) located in a nearby fog node. The proxy VM is decomposed into one that serves static IoT devices (in the home) or one that migrates to other fog nodes for roaming mobile IoT devices. This facilitates proxy VM migration. As regards migration of the "Fog service", the authors in [55] point out that frequent migration can be very CPU and bandwidth-consuming and could implicate a "minimum of downtime". Therefore, knowing where, when and how to migrate the service is important. In [54], therefore, estimating the profit for migrating the proxy VM among the fog nodes whenever the user's mobile IoT devices roam to a new base station is necessary. The profit for migration is defined as "total SDN-based core network traffic reduction with and without migrating the proxy VM whenever the user's mobile IoT devices roam into a new base station". The equations are explained below as:

$$p = L^{static} - L^{migration} \tag{2}$$

where $L^{migration}$ and L^{static} "are the total traffic amounts generated in the SDN-based core network for migrating and not migrating, respectively".

$$L^{migration} = T^{migration}(r^{migration} + r^{data}) \tag{3}$$

$L^{migration}$ comprises of the migration traffic and the total data streams transmitted between the proxy VM and its registered IoT devices during the migration process. $T^{migration}$ is the total migration time, $r^{migration}$ is the average bandwidth provisioning for migration and r^{data} is the average data rate for transmitting the data streams between the user's mobile IoT devices and their proxy VM.

$$L^{static} = T^{Basestation} * r^{data} \tag{4}$$

L^{static} contributes to the total data streams transmitted between the proxy VM and its registered mobile IoT devices when the mobile IoT devices remain in the new base station. $T^{Basestation}$ is the retention time of the mobile IoT devices remaining in the new BS.

Therefore, the estimated migration profit would have to be larger than a predefined value, e whereby, $e \geq 0$.

4) Context-awareness: Context-awareness is required for services and applications in order to adapt to environment changes. Authors in [56] propose a context management system (CMS) based on the producer-consumer role model designed to manage and distribute context information required for Heterogeneous Access Management(HAM) purposes. Architectural components required in the CMS include:

- *Context Providers* that gather data from sensors and other sources,
- *Context brokers* that maintain the registry of available context providers and their capabilities and
- *Context Consumers* that use the context data.

IV. Research Challenges

Challenges faced by researchers in the field of Mobile Cloud Computing and Mobile Edge Computing include:

- Lack of a single agreed platform providing an open environment for researchers to work
- Limited simulation platforms for researchers to experiment various research scenarios of Mobile Edge Computing
- Implementing a mobility management technique with which users can access edge applications without any disconnection.
- Appropriate pricing model for user access to edge services from roaming base stations.

V. Conclusion

This paper analyses the state-of-the-art of two related technologies; Mobile Cloud Computing (MCC) and Mobile Edge Computing (MEC). Insights about the features and applications of the earlier MCC technology and the application models of the newer MEC technology, in relation to the Internet of Things are also included in the report.

A transition is evident from MCC to MEC due to a number of reasons among which includes the increased usage of mobile data and the advent of the Internet of Things. With some researchers suggesting that MCC comes with long transition time between cloud servers and mobile devices that increase latency, researchers seek probable ways of implementing MEC (that brings cloud services in closer proximity to mobile devices) to maximize computing resources such as battery life, power and storage. In addition, trade offs are made between the time it takes to upload data to the cloud servers and edge servers for the MCC and MEC respectively and the energy it takes to complete transactions either locally on a mobile device or at the cloud servers. These determine when to use either technology to better take advantage of resources.

However, research is still pending. Some of the research challenges have been included in this paper, however, they are neither exhaustive nor conclusive.

References

[1] K. Ashton *et al.*, "That 'internet of things' thing," *RFID journal*, vol. 22, no. 7, pp. 97–114, 2009.

[2] A. Goñi and A. Illarramendi, "Mobile computing: Data management issues," *Advanced Database Technology and Design, Artech House Inc*, 2000.

[3] V2Soft, "Mobile solutions: Mobile cloud computing." https://www.v2soft.com/services/technology/mobility-solutions/cloud-mobility-solutions. Accessed: 2019-01-30.

[4] L. Zhao, S. Sakr, A. Liu, and A. Bouguettaya, "Cloud computing," in *Cloud data management*, pp. 9–20, Springer, 2014.

[5] H. T. Dinh, C. Lee, D. Niyato, and P. Wang, "A survey of mobile cloud computing: architecture, applications, and approaches," *Wireless communications and mobile computing*, vol. 13, no. 18, pp. 1587–1611, 2013.

[6] "Google cloud platform." https://console.cloud.google.com/projectselector/appengine?src=ac&pli=1&supportedpurview=project. Accessed: 2019-01-30.

[7] "salesforce.com." https://www.salesforce.com/products/platform/products/force/?d=70130000000f27V&internal=true. Accessed: 2019-01-30.

[8] S. Umair, U. Muneer, M. N. Zahoor, and A. W. Malik, "Mobile computing: issues and challenges," in *High-Capacity Optical Networks and Enabling/Emerging Technologies (HONET), 2015 12th International Conference on*, pp. 1–5, IEEE, 2015.

[9] M. Othman, S. A. Madani, S. U. Khan, *et al.*, "A survey of mobile cloud computing application models," *IEEE Communications Surveys & Tutorials*, vol. 16, no. 1, pp. 393–413, 2014.

[10] J. Panneerselvam, J. Hardy, L. Liu, B. Yuan, and N. Antonopoulos, "Mobilouds: An energy efficient mcc collaborative framework with extended mobile participation for next generation networks," *IEEE Access*, vol. 4, pp. 9129–9144, 2016.

[11] P. J. M. Havinga and G. J. M. Smit, *Low power system design techniques for mobile computers*. Centre for Telematics and Information Technology, 1997.

[12] K. Kumar and Y.-H. Lu, "Cloud computing for mobile users: Can offloading computation save energy?," *Computer*, vol. 43, no. 4, pp. 51–56, 2010.

[13] "Amazon s3." https://aws.amazon.com/s3/. Accessed: 2019-02-02.

[14] J. Oberheide, K. Veeraraghavan, E. Cooke, J. Flinn, and F. Jahanian, "Virtualized in-cloud security services for mobile devices," in *Proceedings of the first workshop on virtualization in mobile computing*, pp. 31–35, ACM, 2008.

[15] E. Jung, Y. Wang, I. Prilepov, F. Maker, X. Liu, and V. Akella, "User-profile-driven collaborative bandwidth sharing on mobile phones," in *Proceedings of the 1st ACM Workshop on Mobile Cloud Computing & Services: Social Networks and Beyond*, p. 2, ACM, 2010.

[16] G. Huerta-Canepa and D. Lee, "A virtual cloud computing provider for mobile devices," in *Proceedings of the 1st ACM Workshop on Mobile Cloud Computing & Services: Social Networks and Beyond*, p. 6, ACM, 2010.

[17] A. Rudenko, P. Reiher, G. J. Popek, and G. H. Kuenning, "Saving portable computer battery power through remote process execution," *ACM SIGMOBILE Mobile Computing and Communications Review*, vol. 2, no. 1, pp. 19–26, 1998.

[18] "Google photos." https://photos.google.com/. Accessed: 2019-02-05.

[19] G. Zhong and U. Hengartner, "A distributed k-anonymity protocol for location privacy," in *Pervasive Computing and Communications, 2009. PerCom 2009. IEEE International Conference on*, pp. 1–10, IEEE, 2009.

[20] W. Itani, A. Kayssi, and A. Chehab, "Energy-efficient incremental integrity for securing storage in mobile cloud computing," in *Energy Aware Computing (ICEAC), 2010 International Conference on*, pp. 1–2, IEEE, 2010.

[21] X. Yang, T. Pan, and J. Shen, "On 3g mobile e-commerce platform based on cloud computing," in *Ubi-media Computing (U-Media), 2010 3rd IEEE International Conference on*, pp. 198–201, IEEE, 2010.

[22] S. Mathews, A. Sundhari, and N. Vijaya Shanthi, "Cloud-based impact for mobile and pervasive environments: A survey,"

[23] J. Dai and Q. Zhou, "A pki-based mechanism for secure and efficient access to outsourced data," in *Networking and Digital Society (ICNDS), 2010 2nd International Conference on*, vol. 1, pp. 640–643, IEEE, 2010.

[24] K. Swan, M. v. t. Hooft, A. Kratcoski, and D. Unger, "Uses and effects of mobile computing devices in k–8 classrooms," *Journal of Research on Technology in Education*, vol. 38, no. 1, pp. 99–112, 2005.

[25] N. M. Rao, C. Sasidhar, and V. S. Kumar, "Cloud computing through mobile-learning," *arXiv*

preprint arXiv:1204.1594, 2012.

[26] C. Yin, B. David, and R. Chalon, "Use your mobile computing devices to learn-contextual mobile learning system design and case studies," in *Computer Science and Information Technology, 2009. ICCSIT 2009. 2nd IEEE International Conference on*, pp. 440–444, IEEE, 2009.

[27] R. Rieger and G. Gay, "Using mobile computing to enhance field study," in *Proceedings of the 2nd international conference on Computer support for collaborative learning*, pp. 218–226, International Society of the Learning Sciences, 1997.

[28] M. Nkosi and F. Mekuria, "Cloud computing for enhanced mobile health applications," in *Cloud Computing Technology and Science (CloudCom), 2010 IEEE Second International Conference on*, pp. 629–633, IEEE, 2010.

[29] C. Doukas, T. Pliakas, and I. Maglogiannis, "Mobile healthcare information management utilizing cloud computing and android os," in *Engineering in Medicine and Biology Society (EMBC), 2010 Annual International Conference of the IEEE*, pp. 1037–1040, IEEE, 2010.

[30] D. B. Hoang and L. Chen, "Mobile cloud for assistive healthcare (mocash)," in *Services Computing Conference (APSCC), 2010 IEEE Asia-Pacific*, pp. 325–332, IEEE, 2010.

[31] S. Wang and S. Dey, "Rendering adaptation to address communication and computation constraints in cloud mobile gaming," in *Global Telecommunications Conference (GLOBECOM 2010), 2010 IEEE*, pp. 1–6, IEEE, 2010.

[32] E. Cuervo, A. Balasubramanian, D.-k. Cho, A. Wolman, S. Saroiu, R. Chandra, and P. Bahl, "Maui: making smartphones last longer with code offload," in *Proceedings of the 8th international conference on Mobile systems, applications, and services*, pp. 49–62, ACM, 2010.

[33] V. S. Pendyala and J. Holliday, "Performing intelligent mobile searches in the cloud using semantic technologies," in *Granular Computing (GrC), 2010 IEEE International Conference on*, pp. 381–386, IEEE, 2010.

[34] E. Lagerspetz, T. Lindholm, and S. Tarkoma, "Dessy: Towards flexible mobile desktop search.," in *DIALM-POMC*, Citeseer, 2007.

[35] E. Lagerspetz and S. Tarkoma, "Mobile search and the cloud: The benefits of offloading," in *Pervasive Computing and Communications Workshops (PERCOM Workshops), 2011 IEEE International Conference on*, pp. 117–122, IEEE, 2011.

[36] G. Cai-dong, L. Kan, W. Jian-ping, F. Ying-li, L. Jing-xiang, X. Chang-shui, S. Mao-xin, and L. Zhao-bin, "The investigation of cloud-computing-based image mining mechanism in mobile communication web on android," in *Grid and Cooperative Computing (GCC), 2010 9th International Conference on*, pp. 408–411, IEEE, 2010.

[37] P. Angin, B. Bhargava, and S. Helal, "A mobile-cloud collaborative traffic lights detector for blind navigation," in *mobile data management (MDM), 2010 eleventh international conference on*, pp. 396–401, IEEE, 2010.

[38] D. Meilander, F. Glinka, S. Gorlatch, L. Lin, W. Zhang, and X. Liao, "Using mobile cloud computing for real-time online applications," in *Mobile Cloud Computing, Services, and Engineering (MobileCloud), 2014 2nd IEEE International Conference on*, pp. 48–56, IEEE, 2014.

[39] I. Kelényi and J. K. Nurminen, "Cloudtorrent-energy-efficient bittorrent content sharing for mobile devices via cloud services," in *Consumer Communications and Networking Conference (CCNC), 2010 7th IEEE*, pp. 1–2, IEEE, 2010.

[40] Y. Mao, C. You, J. Zhang, K. Huang, and K. B. Letaief, "A survey on mobile edge computing: The communication perspective," *IEEE Communications Surveys & Tutorials*, vol. 19, no. 4, pp. 2322–2358, 2017.

[41] Y. C. Hu, M. Patel, D. Sabella, N. Sprecher, and V. Young, "Mobile edge computing—a key technology towards 5g," *ETSI white paper*, vol. 11, no. 11, pp. 1–16, 2015.

[42] N. Hassan, S. Gillani, E. Ahmed, I. Yaqoob, and M. Imran, "The role of edge computing in internet of things," *IEEE Communications Magazine*, no. 99, pp. 1–6, 2018.

[43] F. Computing, "the internet of things: Extend the cloud to where the things are," *Cisco White Paper*, 2015.

[44] S. Melendez and M. P. McGarry, "Computation offloading decisions for reducing completion time," in *Consumer Communications & Networking Conference (CCNC), 2017 14th IEEE Annual*, pp. 160–164, IEEE, 2017.

[45] K. Kumar, J. Liu, Y.-H. Lu, and B. Bhargava, "A survey of computation offloading for mobile systems," *Mobile Networks and Applications*, vol. 18, no. 1, pp. 129–140, 2013.

[46] M. L. Powell and B. P. Miller, *Process migration in DEMOS/MP*, vol. 17. ACM, 1983.

[47] A. P. Miettinen and J. K. Nurminen, "Energy efficiency of mobile clients in cloud computing.," *HotCloud*, vol. 10, pp. 4–4, 2010.

[48] S. E. Mahmoodi, K. Subbalakshmi, and V. Sagar, "Cloud offloading for multi-radio enabled mobile devices," in *Communications (ICC), 2015 IEEE International Conference on*, pp. 5473–5478, IEEE, 2015.

[49] P. Patil, A. Hakiri, and A. Gokhale, "Cyber foraging and offloading framework for internet of things," in *2016 IEEE 40th Annual Computer Software and Applications Conference (COMPSAC)*, vol. 1, pp. 359–368, IEEE, 2016.

[50] R. Balan, J. Flinn, M. Satyanarayanan, S. Sinnamohideen, and H.-I. Yang, "The case for cyber foraging," in *Proceedings of the 10th workshop on ACM SIGOPS European workshop*, pp. 87–92, ACM, 2002.

[51] P. Vekneswaran and N. R. Dissanayake, "Cyber foraging: What has been missing?,"

[52] M. D. Kristensen, "Enabling cyber foraging for mobile devices," *Proc. MiNEMA'7*, pp. 32–36, 2007.

[53] S. N. Shirazi, A. Gouglidis, A. Farshad, and D. Hutchison, "The extended cloud: Review and analysis of mobile edge computing and fog from a security and resilience perspective," *IEEE Journal on Selected Areas in Communications*, vol. 35, no. 11, pp. 2586–2595, 2017.

[54] X. Sun and N. Ansari, "Edgeiot: Mobile edge computing for the internet of things," *IEEE Communications Magazine*, vol. 54, no. 12, pp. 22–29, 2016.

[55] C. Puliafito, E. Mingozzi, and G. Anastasi, "Fog computing for the internet of mobile things: issues and challenges," in *2017 IEEE International Conference on Smart Computing (SMARTCOMP)*, pp. 1–6, IEEE, 2017.

[56] C. Mannweiler, A. Klein, J. Schneider, and H. Schotten, "Context-awareness for heterogeneous access management," *Advances in Radio Science*, vol. 8, pp. 257–262, 2010.