A Review of Computation Offloading For Mobile Cloud Computing Based On Fuzzy Set Theory

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ABSTRACT
Smart Mobile Devices (SMD) refers to one of the components present on the Internet of things (IoT), which can support many applications. The rapid consumption of data traffic of SMDs' users from an intensive application has lead in emerging Mobile Cloud Computing (MCC). However, this has caused several issues such as reliability, security, trust, and privacy. Recently, there are many existing methods proposed to solve the issues mentioned above by various authors. Thus, it is difficult to distinguish the various methods in terms of how it manages to perform the offloading task from SMD to MCC. This paper aims to provide a comprising review of the existing methods that relate to offloading decisions. Based on the comprehensive review of the related papers, this study focuses on a technique that utilised fuzzy set theory in the offloading computation. Besides, this paper highlights several challenges and issues which occur while implementing a fuzzy-based decision method in offloading computation. Next, this paper proposes an improved offloading computation framework based on offloading decisions using a fuzzy multi-criteria decision analysis (MCDA). The comprehensive review of the existing techniques, the systematic synthesis of challenges and issue as well as the new proposed framework are the significant contribution of this paper.

Keywords : *Fuzzy multi-criteria decision analysis, Mobile Cloud Computing, Offloading technique.*

I. INTRODUCTION

Smart Mobile Devices (SMD) are referring to as devices that present on the Internet of things (IoT) component [1], which supports many applications. Researchers in [1] proposed a smart device as a context-awareness electronic tool, which capable of performing autonomous computing and connecting to other devices wire or wirelessly for data exchange. The rapid consumption of data traffic of SMDs' users from an intensive application such as online games, entertainment processing, business and online social activities [2]–[4] lead to emerging Mobile Cloud Computing (MCC). In [5], the formal definition of MCC is reported as an abundant resource of computational power, memory, storage, energy, and context-awareness to integrate from mobile devices to cloud computing. Nowadays, the usage of MCC is essential since the majority of SMDs are unable to execute computation-intensive tasks due to several problems such as resource constraints in a device, battery lifetime and security. Thus, MCC can utilize where all the processing and computation of SMD could happen outside the SMD. This infrastructure exploits the MCC in the sense of storage capabilities and the computation computing task of intensive can be executed on limited resources [6], [7].

The usage of MCC gives several advantages to remote and cloud server such as power of computational, storage, and context-awareness to become more resourceful and energy-efficient. The usage can happen when applications are allowed to offload intensive-application tasks to the cloud, and cloud-based is used to perform the computational cycles. Based on [8], the basic taxonomy of MCC is divided according to the different level issues such as operational level, end-user and services level, applications level, privacy and security, context-awareness level and data management. However, this paper only puts forward a discussion under an operational level issue that focusses on the method of offloading computations.

Recently, researchers discover the importance of energy-efficient in MCC. Authors in [9] found that intensive applications require extensive computing capability, storage, and battery lifespan than an existing resource on mobile devices. Due to the narrow resources, mobile devices still unable to replace the established desktops [10].

Therefore, one of the conventional methods to enhance and minimize computation capabilities in MCC area work is offloading techniques[11]. Recent research indicates that the offloading technique is a crucial element of a migrating intensive mobile application to a cloud platform [12]. However, several issues and challenges exist while implying various offloading techniques such as platform diversity, security, and privacy in mobile cloud applications, fault-tolerance, and continuous connectivity, automatic mechanism, offloading economy, or cost and partition offloading and external data input [12].

Based on the review papers in the previous part, several propose methods on offloading techniques exist such asdistributed energy-efficient dynamic offloading and resource scheduling (eDors) algorithm [2], a genetic algorithm (GA) [7], multi-criteria decision analysis (MCDA) [11] and also fuzzy MCDA [13]. Zadeh introduced fuzzy set theory (FST) in 1965 [14], where it is an extension from a set theory whose elements have degrees of membership. Based on the study in [15], FST commonly used in applications such as artificial intelligence, computer science, medicine, control engineering, decision theory, expert systems, logic, management science, operations research, pattern recognition, and robotics.

One of the applications of FST in decision theory is multi-criteria decision making (MCDM). Currently, fuzzy MCDM increase attention by many researchers to solve a problem for ranking of criteria with an infinite set of alternative [16]. It is reported in [16] that computer science is one of the most widely used application areas in the fuzzy MCDM other than engineering, mathematics, decision sciences, business and management, and environmental sciences. In the context of MCC, MCDM can be one of the alternatives that help to solve complex problems by selecting, comparing, and ranking MCC attributes to process MCC offloading such as network technologies.

This paper aims to provide detail discussion about the basic offloading techniques architecture, the decision-making process that involves in the offloading techniques as well as to provide a review of existing decision-making methods for offloading technique. Furthermore, this study proposes an improvement framework for decision-making on the offloading technique using the fuzzy MCDA method.
The remainder of this paper is divided as follows: In Section II provides an explanation of mobile cloud computing with its architecture and application, definition offloading and its techniques. Section III reviews the recent offloading techniques in MCC and classifies them into a few categories. Section IV provides the proposed improved framework in performing the decision-making process in choosing the optimal platform to offload the MCC computations task. Lastly, Section V provides the conclusion and future work.

II. BACKGROUND

Offloading in MCC is a crucial process to improve the intensive used of application computation capabilities. Thus, in this section, we provide an overview of MCC and offloading techniques with their definition, architecture, and application.

A. Mobile Cloud Computing

According to [2] Mobile Cloud Computing emerge from in execution of an intensive mobile application to a cloud server. Data processing and storage from mobile devices migrate to centralised computing in clouds and happen in the cloud environment. MCC consists of three computing categories, as shown in Fig.1, 1) Smart Devices, 2) Cloud Server, and 3) Cellular Network.

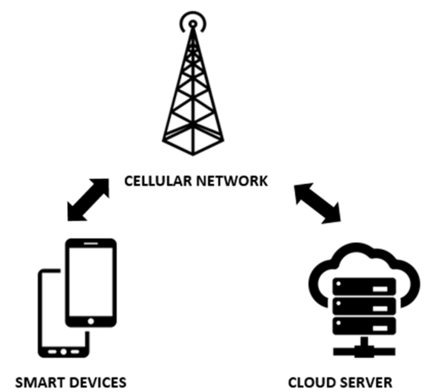

Figure 1: Basic architecture of MCC

Cloud computing within cloud server means a wide-range distributed network system in data centre and provides three services, Infrastructure as a Service (IaaS), Platform as a Service (PaaS) and Software as a Service (SaaS) while network in MCC determines as compound base stations (e.g., base transceiver station, access point, or satellite) [3]. Among the importance of cloud computing is to become a platform in education in the country [4]. The teachers and student need cloud access to share data and information.

MCC provides many advantages and solutions to the issues and challenges, including prolong battery lifetime, enhance processing power, and upgrade data storage capacity. Moreover, MCC can improve reliability while storing data and running applications on clouds [3]. Several examples of applications from MCC are mathematical tools, file search, imaging tools, games, download applications, antivirus applications, and security [5].

B. Offloading techniques

Offloading is the task that migrates resource-intensive computations from remote to the cloud server[5]. As shown in Figure 2, the offloading task needs several steps. The first step in offloading is getting permission for an application partitioning for mobile applications, whether it can be offloaded or vice versa. Secondly, to execute the application in SMD, we need devising selected remote servers and allocation of the code and. Lastly, a selection of applications is made using a suitable decision-making approach to offload selected components.

Several comparisons offloading frameworks are found from the recent survey paper [6][7]. Authors in [6] compared offloading frameworks with the following categories: preparation before offloading, supported partitioning, decision, offloading mechanism, granularity level, annotation, and contribution. Besides that, authors in [7] compared offloading frameworks based on four principle characteristics: multisite-spot, granularity level, privacy and security, offloading strategy. The offloading decision will be divided into two types: dynamic and static.

Table I showed a summary of the different algorithms used in offloading area work. MCDA is one of the techniques proposed to execute and enhance competitiveness of the offloading process. The comparisons are made based on a parameter in three categories MCC, local computing, remote computing, and network. To extend battery lifetime, authors in [8] introduced context-aware offloading decision algorithms aiming to implement code offloading decisions at execution time on selected network medium and possible cloud resources as the offloading location based on the device circumstances. MAO (Mobile Application's Offloading) [9] also introduced to extend the battery autonomy of mobile terminals.

Energy-efficient dynamic offloading and resource scheduling (eDors) policy and distributed algorithm are proposed to reduce energy consumption, optimisation problem, and shorten application completion time by implement eDors algorithm, consumption and application completion time can be reduced[10]. The unstable network location can interfere with the offloading process. Therefore, the*Mob-aware decision-maker* algorithm is introduced [11] to stabilise the offloading processwhen users are movingaround. Genetic algorithm (GA) [2] also introduced to stabilise connectivity due to limited hardware. Thus, the min-cost offloading partitioning (MCOP) algorithm developed for the purpose of finding the optimal partitioning plan under different cost models and mobile environments [12].Another MCDA methods used in cloud computing environment is Multi-criteria algorithm (RMK) [13] where it used in job scheduling and resource load balancing.

III. REVIEW OF OFFLOADING COMPUTATIONS METHODS

A. Offloading computation using MCDA

MCDA is an alternative that intends to choose the best solution by calculation multiple alternatives in decision making [14]. The author claimed that AHP and TOPSIS are predominantly used techniques to solve complicated decision-making problems. TOPSIS is a widely used technique that ranks the alternatives by simultaneously having the shortest distance to the ideal solution and farthest distance to the negative ideal solution[15].

In recent years, various offloading techniques emerge to optimizeintensive computation tasks. The comparison of the MCDA method has been made in the paper[14]in utilizing the offloading using two keywords, certainty and uncertainty. For instance, authors in [16] found that

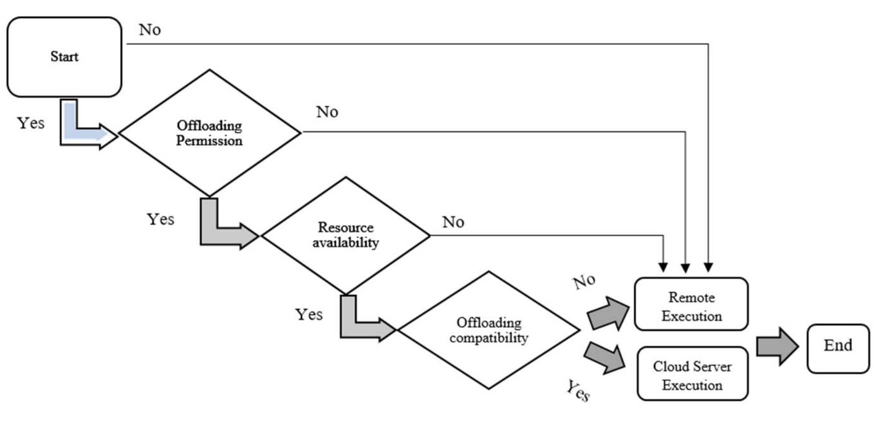

Figure 1: Stepwise procedure in offloading technique

the Analytic Hierarchy Process (AHP) is the most proposed technique in making a decision. Meanwhile, to determine with uncertain and ambiguous information, the fuzzy method is commonly used in MCC offloading.

Table II shows a recent survey of MCDA methods implemented by various authors in solving offloading problems. Based on the table, it found that many researchers choose MCDA to select a solution in enhancement offloading capabilities. There exists a question about offloading selection that needs to be answered, such as what, when, how and where to offload.The combination of certainty and uncertainty MCDA methods is a method that is rarely used by recent research to select criteria in the MCC environment, although using both methods can eliminate the option to proceed withthe offloading process [14].

In [14], a comparison showed that if other researchers used both certainty and uncertainty methods such as AHP, TOPSIS and, fuzzy [12], Quality of Service (QoS) based on criteria in-network, cloud and mobile environment can be determined. In a fuzzy environment, the decision is made to choose which cloud is the most relevant for offloading. The AHP widely used to decide the weights of the criteria for cloud-path alternatives. The fuzzy TOPSIS is to obtain the final ranking of alternative clouds.Recent research found that Fuzzy TOPSIS and fuzzy logic also used for multi-criteria decision making problems [17].These methods used to handle high level linguistic variable.Due to the higher consumption of devices, while offloading to the cloud, Ravi et al., [18] proposed MCDM TOPSIS algorithm to priorities among the service providing resources such as Cloud, Cloudlet, and peer mobile devices. The proposed techniques fuzzy vertical handoff algorithm triggers handoff from a resource to another, when the energy consumption of the device increases or the connection time with the resource decreases.

Another research found in [19] which authors proposed Fuzzy Analytic Hierarchy Process (FAHP) based MCDA to select the optimum cloud path. FAHP based MCDA gives numerous options for a user to choose optimum clouds from predetermined sets of clouds. There are five criteria to be considered to make an optimum path selection; availability, capacity, privacy, speed, and cost selected, and weight of those criteria can be obtained from FAHP technique. Based on the Consistency Index (CI) result, the most important criteriato enhance SMD performance is selected.

Fuzzy Analytic Hierarchy Process (FAHP) and Fuzzy Technique for Order Preference by Similarity to Ideal Solution (FTOPSIS) proposed in [20] to select an optimal cloud where uncertainty and subjectivity are parameterized using triangular fuzzy members and handled by using linguistic values. If criteria weights are uncertainty and unreliable, then FAHP and Fuzzy TOPSIS are the preferred techniques.

Another technique that uses AHP and TOPSIS in fuzzy environment found in recent research is in paper [21]. Wu et al., [21] research by select several alternative clouds in terms of many different criteria provides. Thecloud-path selectionis calculated by using AHP to calculate the weights of the criteria, while to calculate the final ranking of selection clouds, fuzzy TOPSIS is used in their experiment.

B. Offloading Computation using Fuzzy Approach

In [22], researchers introduced Mobile Cost Monitor (MCM) and MCM Analyzer based on fuzzy logic rules as solution offloading trade-off whether data should be processed locally on the device or remotely in the cloudVarious variables collected by MCM and are analysed the variables using MCM Analyzer to determine which variables can assist in decision offloading trade-off. Results showed that removing dependent variables and find connections between two or more variables can decrease monitoring costs. Thus, a fuzzy logic-based approach can give an advantage for MCM and MCM analysers to decide for offloading trade-off.

Another offloading technique that utilises the fuzzy set theory is introduced in [36]. Authors in [36] proposed new techniques which can support offloading decision by implemented two versions of the fuzzy logic engine, using Java and C language at the mobile platform. Next, at the cloud level, authors build Android Open Source x86 architecture. Besides that, Google Cloud Message (GCM) notification service from Google, which sending asynchronous messages to Android also implemented in this technique. However, the paper did not include all variables state in their experiment

IV. ISSUES AND CHALLENGES OFFLOADING IN MCC

A. Diversity

Even though computation offloading is an essential component in MCC, however, it still faces challenges during its execution. For instance, computation offloading need to be compatible with various SMD architectures and operating system. For example, MAUI [23] and Mirror Server [24] are frameworks that compatible with a different platform. MAUI is applicable with .Net framework while Mirror Server suitable with the Android platform. Another issues and challenges that related with diversity in MCC is heterogeneity whichrefers to software and hardware in SMD such as various applications, storage, and battery while diversity in cloud resources indicate as cloudlets, mobile ad-hoc cloud, private and public clouds and wireless network such as Wi-Fi, 3G/5G, Bluetooth can affect performance of computation-intensive tasks integration from SMD to cloud platform[25] . Even though there have been a few methods to minimize integration performance in MCC such as the energy-optimal offloading algorithm [26] and energy-efficient computation offloading (EECO) scheme [27] has been proposed, its still lack from other MCC attributes such as mobility performance.

B. Fault tolerance

As previously mentioned, SMDs are devices that allow users to use them anywhere and support multiple application at a time. However, there still exist several issues during their consumption, such as the connection with the network unstable and will interfere with the data exchange process. Thus, developing offloading code should come out with fault-tolerance strategies and stable connectivity [6]. Fault-tolerance methods have been proposed, such as the trade-off fault tolerance algorithm[2] and fault-tolerant energy efficient framework by the combination of Software as a Service (SaaS) and Infrastructure as a Service (IaaS) model[28] to resolve vague latency, and unstable connectivity. However, those methods need to be enhanced as more complex technologies grow rapidly nowadays.

C. Security and privacy

Other than that, another common issue found by recent research for computation offloading in MCC implementation is security and privacy [6]. Security and privacy are crucial in task integration from SMD to cloud platform because to maintain task integrity and confidentiality. However, there is still the possibility of restricted access and external threats [29]. From the survey in [29,31], many solutions to enhance security and privacy have been proposed, such as multi-clouds for secure storage of data, secure data storage and sharing in mobile media cloud, block base scheme (bbs) and data dynamic encryption strategy which are data confidentiality security features. Another proposed scheme with data integrity security features is cloud data auditing with practical critical update and zero-knowledge privacy, dynamic hash table based public auditing and remote data auditing for secure data storage[29].Even though many methods for security and privacy proposed, there is still in need of the enhancement to meet users' expectations regarding security and privacy in MCC

V. THE PROPOSED FRAMEWORK

Based on the review in the previous section, we found that the proposed existing frameworks still lack detail investigation and exploration about how the decision can be made to migrate the tasks from SMD to other platforms. Therefore, we propose an integrated framework based on Fuzzy TOPSIS methods to be implemented in solving offloading decision prior to the process of offload the computational task. The detail of the Fuzzy TOPSIS method is shown as follows:

A. Define attributes

There are a few alternatives solutions for MCDA problem and we define as n alternatives A_1, A_2,...,A_n,and$m$ criteria as C_1, C_2,...,C_m. For each alternative, consider with respect to criterion m.

B. Rating criteria

The criteria can be rate in format as:
$X = (x_{ij})_{n\times m}$ and $W = (w_1, \dots, w_m)$,
where x_{ij} (i = 1,...,; j = 1,...,n) and w_j (j = 1,...,n)
while for fuzzy rating alternatives can be rate as:
A_i (i = 1,...,m) with respect to criterion C_j (j = 1,...,m)
and the weight of criterion C_j (j = 1,...,m), respectively.

C. Calculation method

Normalise decision matrix $X = (x_{ij})_{n\times m}$ with Eq.(1) while weighted decision matrix is normalised with Eq.(2)

$$V = (v_{ij})_{n\times m} \quad (1)$$

$$v_{ij} = w_j r_{ij},\ i = 1, \dots, n;\ j = 1, \dots, m \quad (2)$$

Determine Positive ideal solution (PIS) and negative ideal solution (NIS). PIS indicates criteria that have the positive impact and expressed in Eq.(3) while NIS indicates to have the negative impact as expressed in Eq.(4)

$$A^* = \{v_1^*, \dots, v_m^*\}\{(\max_j v_{ij} \mid j \in \varphi_b), (\min_j v_{ij} \mid j \in \varphi_c)\} \quad (3)$$

$$A^- = \{v_1^-, \dots, v_m^-\} = \{(\min_j v_{ij} \mid j \in \varphi_b),\ (\max_j v_{ij} \mid j \in \varphi_c)\} \quad (4)$$

Next, by using the Euclidean distance formula, the distance of each alternative from PIS and NIS can be calculated. Eq.(5) is calculation between PIS and target alternatives while Eq.(6) is calculation between PIS and target alternatives.

$$D_i^* = \sqrt{\sum_{j=1}^{m} (v_{ij} - v_j^*)^2,\ i = 1, \dots, n} \quad (5)$$

$$D_i^- = \sqrt{\sum_{j=1}^{m} \left(v_{ij} - v_j^-\right)^2},\ i = 1, \dots, n \quad (6)$$

The proximity of the combination of each alternative is calculated as:

$$CC_i = \frac{d_i}{d_i^* + d_i},\ i = 1, 2,..m \quad (7)$$

By comparing values, the ranking of alternatives is determined according to $i = 1, 2,..m$.

This proposed framework of the fuzzy MCDA method can be implemented in the process of selection to decide where the computational task in SMD could be an offload. Since this paper aims to provide a comprehensive review of the existing decision-making method used to offload tasks, thus the implementation of the proposed framework is not shown here as it is out the scope of the study. In the future, the implementation of this proposed framework can be utilized to solve the real-world problems in the future publications

Table II: Selected studies implemented various MCDA methods in MCC

	MCDA METHODS		
Authors / Year	**AHP**	**TOPSIS**	**FUZZY**
Wu, Huaming et al., (2014)[12]	/	/	/
Ravi, Anuradha et al.,.(2014) [18]		/	/
Mascarenhas Kath, et al., (2016) [22]			/
Singla, Chinu, et al., (2015) [19]	/		/
Flores, Huber, et al., (2013) [30]			/
Singla, Chinu, et al., (2017) [20]	/	/	/
Wu, Huaming, et al., (2012) [21]	/	/	/

VI. CONCLUSION AND FUTURE WORK

The growth of MCC due to the intensive application of SMD has caused several issues such as reliability, privacy, and security. Other issues found are low bandwidth, network access management, quality of service, pricing, the standard of interface, and service convergence. However, with suitable offloading techniques, the problem can be solved. Thus, there exist many studies that proposed the method of offloading techniques to MCC. In this paper, we made an extensive review of selected research in the offloading technique with the particular attention is to highlight how the decision is made. In addition, this paper provides the explanation of the MCC's architecture and the offloading techniques to give further depiction.

Based on the review of recent offloading techniques, we found MCDA is the most widely used technique to select the best solution based on criteria given. Thus, we focus on TOPSIS, which is one of the widely used MCDA techniques. We believe that fuzzy TOPSIS will amplify offloading computation techniques. As future work, we plan to utilize fuzzy TOPSIS in enhancement offloading computation, either to process applications in a local or remote server. Further, we will conduct an experiment using fuzzy TOPSIS, which focusses on energy-efficient for offloading techniques in MCC

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Table 1:Different algorithm proposed in MCC

Author/year	Description	Parameter Allocation		
		Local computing	**Cloud Computing**	**Network**
Guo, Songtao et. Al (2016) [10]	Energy-efficient dynamic offloading and resource scheduling (eDors) policy and distributed algorithm proposed to reduce energy consumption, optimization problem and shorten application completion time.	CPU clock frequency	Transmission power	
Deng, Shuiguang et al. (2015) [2]	A genetic algorithm (GA) introduced due to the mobility of portable devices, unstable connectivity of mobile networks can impact the offloading decision.	Fault-tolerance, CPU rate	CPU rate	
Zhou, Bowen, et al. (2015) [8]	Proposed context-aware offloading decision algorithm aiming to provide code offloading decisions at runtime on selecting wireless medium and which potential cloud resources as the offloading location based on the device context.	CPU usage, CPU frequency,memory,battery level	Tracks the instructions executed	Battery level, cell connection state, and its bandwidth, WiFi connection state and its bandwidth, Bluetooth state, the conjunction level of the connection (RTT) to VMs on the cloud, and the signal strength of cell and WiFi connection
Lee, Kilho et al. (2015)[11]	*Mob-aware decision maker* is an algorithm to predict near-future network condition through user mobility models	Response time	The execution time of a method	timestamp, network connectivity, GPS coordinates, WiFi status, and network throughput
Wu, Huaming et al. (2016) [40]	min-cost offloading partitioning (MCOP) algorithm developed for the purpose to find the optimal partitioning plan under different cost models and mobile environments	CPU speed	transmission data size, and the speed	Bandwidth
Ellouze, Amal, et al. (2015) [9]	MAO (Mobile Application's Offloading) proposed to extends the battery autonomy of mobile terminals	CPU usage	Memory, response time	

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