Intelligent and Energy Efficient Mobile Smartphone Gateway for Healthcare Smart Devices based on 5G

By Sigwele Tshiamo

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***Abstract*—The healthcare sector is now blending with Information and Communications Technology (ICT) using Internet of Things (IoT) to potentially minimise medical errors and reduce healthcare cost. Patients are now embedded with smart devices like body sensors and wearable devices which can monitor their health without the need for a doctor in physical contact. Such smart devices have the downside of low battery power and are unable to transmit their data to the medical personnel when the patient is on the move away from the smart home/smart clinic fixed gateway. A mobile gateway is required which moves with the patient to process the smart device data without depleting the smartphone battery. This paper proposes an Intelligent and Energy Efficient 5G based smartphone Gateway for healthcare smart devices (IEE5GG). In IEE5GG, the 5G architecture is adopted and the patient's smartphone is used as a gateway where multiple smart devices are connected e.g. via Bluetooth. To save energy, requests to the smartphone can either be executed on the smartphone gateway or offloaded and executed in the Mobile Edge Computing (MEC) cloud at close proximity to the smartphone in the 5G Base Station (BS) central Unit (gNB-CU) while considering the transmission power, Quality of Service (QoS), smartphone battery level and Central Processing Unit (CPU) load. Results show that the proposed IEE5GG framework saves up to 38% of energy in the healthcare mobile gateway smartphone and reduces healthcare application service time by up to 41%.**

***Index Terms*—5G, C-RAN, Energy-efficiency, Healthcare, IoT, Mobile Edge Computing, Smart Gateway.**

I. Introduction

The use of Information and Communications Technology (ICTs) in healthcare has the potential of minimising medical errors, reducing healthcare cost and improving collaboration between healthcare systems which can dramatically improve the healthcare service quality. It has been estimated that in the next 10 years, the way healthcare is currently provided will be transformed from hospital centred, first to hospital home balanced in 2020, and then ultimately to home-centred in 2030 [1]. This essential transformation necessitates the fact that the convergence and overlap of the Internet of Things (IoT) architectures and technologies for smart spaces and healthcare domains should be more actively considered. The smart medical devices include medical body sensors and wearable devices for monitoring things like blood pressure, sugar level, heart-beat, etc. In smart home and smart hospitals,

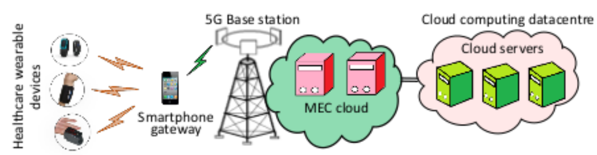

Fig. 1. An illustration of MEC architecture.

the smart devices are connected to fixed healthcare gateways which can compress data, perform analytics and also send data to remote data centers in the cloud. These fixed gateways have fixed power supplied and never runs out of power unless the grid is down. However, when a patient moves out of the range of the fixed healthcare gateway, e.g. away from the smart home into a stadium or city centre, the smart devices then requires a healthcare mobile gateway that moves with the patient since therey are of low battery power and can not transmit to the fixed healthcare gateway.

With the introduction of 5G [2] smartphones are becoming energy efficient, with low transmission delays (1ms) and high data-rates up to 20GBs. These patient's 5G smartphones are the perfect choice for the healthcare mobile gateway for relaying sensed data to the remote medical personnel or to the remote cloud for storage.

However, using a smartphone as a healthcare gateway is computer intensive and will drain a lot of energy in the smartphone. The smartphone healthcare gateways can hardly cope due to limitations in terms of battery life, storage, processing power and display size [3]. Extended battery life is one of the key requirements for 5G as such there is a need for improvement of energy efficiency in mobile devices to be used as smartphone healthcare gateway. One possible approach is to offload the smart device computation to the remote public clouds such as Amazon EC2 and Windows Azure using Mobile Cloud Computing (MCC) which will save some amount of energy in the smartphone healthcare gateway device. These cloud centers provide virtually unlimited computation capacity to augment the processors in smartphone. However, the communication between smartphone and remote cloud centers is often over a

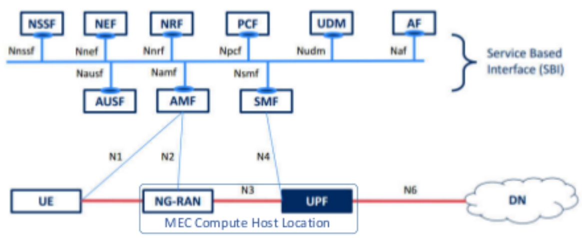

Fig. 2. MEC architecture on Standadised 5G framework.

long distance, adding to the latency in cloud computation. To overcome this limitation, Mobile Edge Computing (MEC) [4], also termed FOG computing [5] was proposed as shown in Fig. 1. MEC is envisioned as a promising approach to improve the offloading efficiency. In the MEC framework, cloud computing capabilities are provided within the Radio Access Network (RAN) in close proximity to these smartphone. In other words, with the aid of MEC, smartphones are enabled to offload their application tasks to the MEC servers on the edge of the network, rather than utilising the servers in the core network in the cloud datacenters. This MEC paradigm can provide low latency, high bandwidth, high computing agility and improve the energy performance of the smartphone gateway [4].

Fig. 2 shows the 5G architecture [2] and possible locations (either in the 5G New Radio RAN (NG-RAN) or in the 5G Core (5GC)) for placing the MEC servers. The reader is directed to [2] for the acronym definitions in Fig. 2. In this paper, an energy efficient MEC scheme in Heterogeneous Cloud RAN (H-CRAN) called IEE5GG is proposed. H-CRAN architecture has been adopted in 5G as a promising solution for reducing energy consumption within the cellular networks by performing Base Station (BS) processing in a centralised infrastructure [6] called the 5G BS Centralised Unit (gNB-CU) while radio heads called 5G BS Distributed Unit (gNB-DU) are distributed in the coverage area. The aim is to reduce energy consumption in the smartphone healthcare gateway by offloading the offloadable application modules to the MEC cloud located in the gNB-DU. In this paper, the MEC servers are centralised to form a MEC cloud located within the gNB-CU within the NG-RAN. In IEE5GG, macro gNB-DU (gNB-DUm) are overlaid by small cell 5G gNB-DU (gNB-DUs). The gNB-DUm provides coverage while the gNB-DUs are to increase capacity in hotspot areas. The gNB-DU are connected to the gNB-CU by high bandwidth low latency fiber using F1 interface [2]. In this paper, the MEC paradigm is extended to H-CRAN to benefit from cloud computing processing, increased storage, quick execution response and increased capacity. In summary, the contributions of this paper are as follows:

i) An energy efficient MEC offloading scheme called IEE5GG is proposed to save energy in the smartphone healthcare gateways. In IEE5GG, an application from the smart device is sent to the smartphone gateway and partitioned into modules/tasks where decisions are made as whether to execute the tasks on the local device while others are offloaded and executed in Virtual Machines (VMs) in the MEC cloud taking into consideration the 5G network transmission cost and delay.
ii) A 5G based architecture for IEE5GG is proposed leveraging cloud computing technology for resource pooling. The 5G small cells gNB-DU in IEE5GG are used to improve capacity while the macro gNB-DU are used for maintaining coverage.

Saving energy in the H-CRAN network have already been taken care of as proposed in our previous works in [7] [8] [9], so this paper only concentrate on saving energy in the smartphone as a healthcare smart gateway.

The rest of the paper is organised as follows: Section II discusses the related works on energy efficiency in mobile devices using MEC paradigm. Section III present the proposed architecture for IEE5GG and the proposed offloading scheme. The system model and problem formulation are also presented in this section. The simulation results and discussion are provided in Section IV. Finally, the concluding remarks are presented in Section V.

II. Related Work

The MEC paradigm is a new area and an attractive option for computer intensive healthcare applications using technologies like argumented reality or electroencephalogram (EEG) [10]. These applications when processed in the smartphones consume a lot of battery power, as such energy efficient schemes for saving energy in smartphone gateways by offloading application tasks to the MEC cloud are presented in this section. The reader is directed to a comprehensive survey on MEC in [11] [12]. Only energy efficiency mobile devices/smartphone in MEC will be addressed in this paper.

Chen L. *et al.* in [13] addresses the challenge of incorporating MEC into dense cellular networks, and propose an efficient online algorithm, called ENGINE (ENergy constrained offloadINg and slEeping) which makes joint computation offloading in order to maximise the quality of service while keeping the energy consumption low. However, the author assumes that traffic among BSs is equally distributed while traffic is randomly distributed in reality. The author in [14] investigates a green MEC system and develop an effective computation offloading strategy. The execution cost, which addresses both the execution latency and task failure, is adopted as the performance metric. Nevertheless, the author assumes that the battery capacity is sufficiently large which is impractical, also the author ignores the execution delay caused by the MEC server. The author in [15] study the multi-user computation offloading problem for MEC computing in a multi-channel wireless interference environment by formulating the distributed computation offloading decision making the problem among smartphone users as a multi-user computation offloading game. Numerical results corroborate that the proposed algorithm can achieve superior computation offloading performance and scale well as the user increases. However, the application to be offloaded is assumed to be atomic (the application cannot be divided into modules) as such, the whole application is either executed locally or the whole application code is send to the MEC server which can incur more transmission costs. Zhang K. *et al.* in [4] proposed an Energy Efficient Computation Offloading (EECO) mechanisms for MEC in 5G heterogeneous networks. In EECO, an optimisation problem was formulated to minimise the energy consumption of the offloading system, where the energy cost of both task computing and file transmission are taken into consideration. However, the author considers MEC servers with limited capacity that are not consolidated in a centtralised fasion as in C-RAN.

All the above MEC schemes were based on random architectures that were just labelled as 5G but this paper addresses the gateway framework from a standardised 5G architecture [2] with accurate 5G requirements considered.

III. Proposed IEE5GG Framework

A. System Model

The proposed IEE5GG framework in Fig. 3 considers a 5G transmission scheme based on Orthogonal Frequency Division Multiple Access (OFDMA) of a two-tier H-CRAN. For simplicity, the gNB-DUm is termed as Macro Remote Radio Head (MRRH) and overlaid by small cell gNB-DUs herein termed small cell/pico RRH (PRRH). Define the set of RRH as $\mathcal{R} = \{n : n = 1, 2, ..., N_{rrh}\}$, where N_{rrh} denote the total number of PRRHs. Each RRH is connected to the gNB-CU via high speed fiber cables. The term smartphone is used interchangeably with user equipment (UE). Consider a set of UEs denoted as $\mathcal{K} = \{k : k = 1, 2, ..., N_{UE}\}$. Each UE k will associate with a serving RRH. The UEs are associated to RRHs by the criterion of Cell Range Expasion (CRE) [16] to maximise transmission rate. In the MEC cloud/gNB-DU, there are multi core high processing MEC General Purpose Processors (GPPs) with VM instantiated according to traffic demand of offloaded task requests from smartphone gateways. The Global MEC Controller (GMC) in the gNB-CU is responsible for receiving task requests from the smartphone gateway and distributing them to VMs with available capacity. The VMsfor processing application tasks are abstracted from the GPP using the GMC. It should be noted that the gNB-CU is originally ment for baseband processing as such some of the VMs are for baseband processing. We only concentrate on VMs for processing tasks for healthcare applications offloading.

B. Communication Model

The 5G system bandwidth, B, is divided into N_{ch} channels each of bandwidth w. Denote a set of channels in the system as $\mathcal{C} = \{c : c = 1, 2, ..., N_{ch}\}$. We assume that smartphones in the same cell transmit over orthogonal channels, whereas UEs of different cells may interfere against each other. We

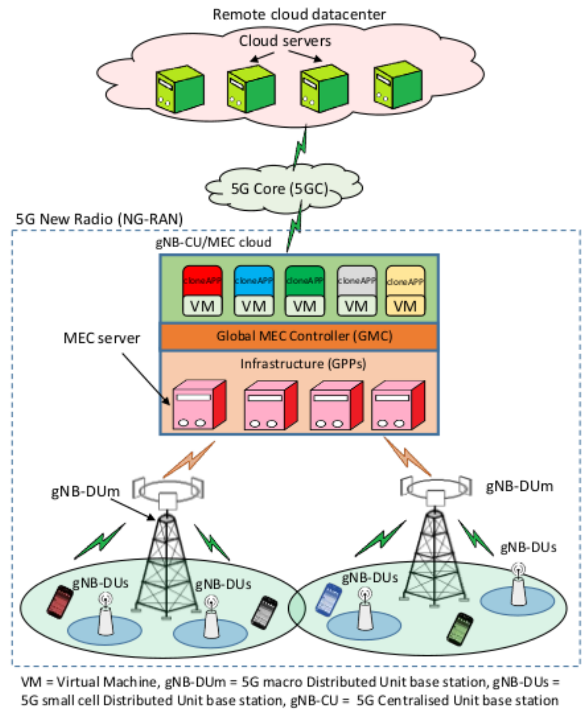

Fig. 3. Proposed IEE5GG architecture.

consider that each smartphone runs 5G healthcare application, which can be split into several tasks. Each task T_k of UE k can be executed either locally on the smartphone or remotely on the MEC cloud by computation offloading. Consider that k can offload T_k either via the MRRH or via the PRRH. Denote $a_{k,m,c} = \{0, 1\}$ as the offloading decision profile of k where $m = \{1, 2, 3\}$ is the user device chosen modes which are computing locally, transmitting via the MRRH and transmitting via the PRRH, respectively. $a_{k,m,c} = 1$ means device k uses mode m to offload task T_k through channel c otherwise if $a_{k,m,c} = 0$, otherwise. The item c is meaningless when $m = 1$ as there are no channels in local computing, thus $a_{k,1,1} = 1$ is taken as the indicator that device k select local computation. In case smartphone k offload the task T_k via the MRRH on channel c, the accurate uplink data rate of the UE can be computed as

$$r^M_{k,c} = w log_2(1 + \frac{P^M_k H^M_k}{\sum_{j=1,j\neq k}^{N_{UE}} a_{k,3,c} P^S_j H^M_j + \sigma^2}) \quad (1)$$

where w is the channel bandwidth, P^M_k is the transmission power from EU k to the MRRH, H^M_k is the channel gain between UE k and the MRRH. The denominator is the interference caused by other UEs using the same channel for transmission. The variable σ^2 denotes the background noise power. The total uplink data rate of UE k to the MRRH is calculated as

$$r_k^M = \sum_{c=1}^{N_{ch}} a_{k,2,c} r_{k,c}^M \tag{2}$$

Similarly, if the UE offload a task via the PRRH through channel c, the uplink data rate is given as

$$r_{k,c}^S = wlog_2(1 + \frac{P_k^S H_k^S}{\sum_{j=1, j\neq k}^{N_{UE}} a_{k,3,c} P_j^M H_j^S + \sigma^2}) \tag{3}$$

$$\text{and, } r_k^S = \sum_{c=1}^{N_{ch}} a_{k,3,c} r_{k,c}^S \tag{4}$$

C. Computation Model

Each task of UE k is denoted as $T_k = (B_k, D_k, t_k^{max})$. Here B_k denotes the size of computation input data in bytes (e.g., the program codes and input parameters) involved in the computation task T_k and D_k denotes the processing requirement in million instructions per second (MIPS) required to accomplish the computation task T_k. The variable t_k^{max} denotes the maximum latency required by the computation task T_k or the execution deadline in milliseconds (ms).

1) Local Computation: Local computation is when the smartphone k executes its computation task T_k locally. Denote F_k^l as the computation capability of the smartphone in MIPS. It is assumed that k can have various computation capabilities. The execution time for executing task T_k for k can be expressed as

$$t_k^l = \frac{D_k}{F_k^l} \tag{5}$$

The energy expended by k for local computation can be expressed as

$$e_k^l = t_k^l P_a \tag{6}$$

where P_a is the power consumed by k when active.

2) MEC Computation: When k chooses computing its task by the MEC server, the input data can be transmitted to the VM through the MRRH or the PRRH. This means k would incur the extra overhead in terms of time and energy for transmitting the computation input data via 5G wireless access. In case k offloads T_k via MRRH, the total time duration (t_k^M) can be calculated as transmission time plus time during MEC cloud execution of task T_k

$$t_k^M = \frac{B_k}{r_k^M} + \frac{D_k}{F_k^{mec}} \tag{7}$$

where F_k^{mec} is the computation ability of the MEC server VM. There are many VMs in the MEC cloud that can process tasks of an application in parallel. The total energy consumed by k via offloading through the MRRH can then be calculated as

$$e_k^M = \frac{B_k}{r_k^M} P_k^M + \frac{D_k}{F_k^{mec}} P_{idle} \tag{8}$$

Similarly for offloading via the PRRH,

$$t_k^S = \frac{B_k}{r_k^S} + \frac{D_k}{F_k^{mec}} \tag{9}$$

$$\text{and, } e_k^S = \frac{B_k}{r_k^S} P_k^S + \frac{D_k}{F_k^{mec}} P_{idle} \tag{10}$$

D. Problem formulation

The aim is to minimise energy consumption in the smartphone by offloading some application tasks to the 5G MEC cloud such that, transmission delay, propagation delay, task processing time, energy consumption in both MEC server and smartphone are minimised while transmission datarate is maximised. The optimization problem is formulated as follows in (11).

$$\min_{\{a_{k,m,c}\}} \sum_{k=1}^{N_{UE}} (a_{k,1,1} e_k^l + \alpha_{k,2} (P_k^M \frac{B_k}{r_k^M} \sum_{c=1}^{N_{ch}} a_{k,2,c} + P_{idle} \frac{D_k}{F^m ec_k}) + \alpha_{k,3} (P_k^S \frac{B_k}{r_k^S} \sum_{c=1}^{N_{ch}} a_{k,3,c} + P_{idle} \frac{D_k}{F_k^{mec}})) \tag{11}$$

$$\text{such that, C1: } a_{k,1,1}.t_k^l \leq t_k^{max}, \; k \in \boldsymbol{\mathcal{K}} \tag{12}$$

$$\text{C2: } \sum_{k=1}^{N_{NU}} \sum_{c=1}^{N_{ch}} a_{k,m,c} \leq N_{ch}, \; m = \{2,3\} \tag{13}$$

$$\text{C3: } \sum_{k=1}^{N_{UE}} a_{k,m,c} = 1, \; k \in \boldsymbol{\mathcal{K}}, m \in \boldsymbol{\mathcal{M}}, c \in \boldsymbol{\mathcal{C}} \tag{14}$$

where $s_{k,m} = 1(\sum_c^{N_{UE}} a_{k,m,c} > 0, j = \{2,3\})$. The function $1(x)$ is an indicator function which is equal to 1 when x is true and zero otherwise. The first constraint $C1$ insures that the delay constraints are met. The second constraint insures that the total number of channels allocated to smartphones does not exceed the total number of channels in the system. Constraint C3 states that only one channel can be allocated to only one smartphone.

E. IEE5GG Offloading Framework

This section will describe the IEE5GG offloading framework in detail. The framework is shown in Fig. 4. The smartphone comprises of an elastic application and other components that enables partitioning and offloading application tasks to the cloud. There exist a VM that runs the clone application and execute offloaded tasks in the MEC VM. The system components are as follows:

i) **Device profiler:** Collects smartphone hardware context at runtime and pass the information to the offloading agent. The hardware context includes the battery State of Charge (SoC), average CPU utilisation and memory usage.

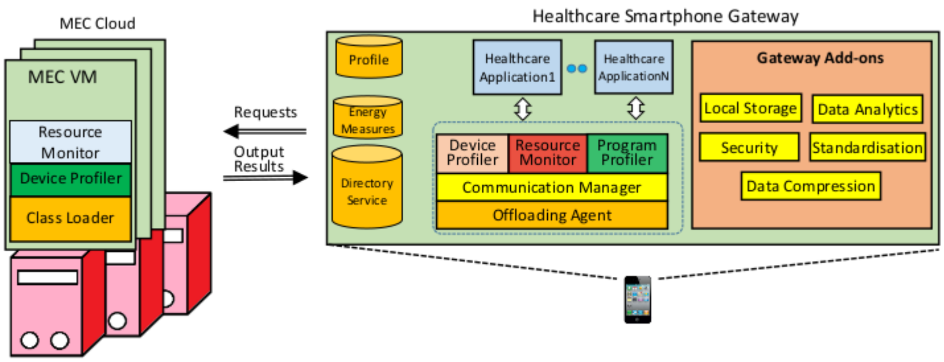

Fig. 4. Proposed IEE5GG framework.

ii) **Resource monitor:** Resides in both the smartphone gateway and the allocated VM. It collects network related context at runtime and pass the information to relevant modules like the offloading agent. The network context include network connection state, bandwidth, and signal strength.

iii) **Program profiler:** The program profiler tracks the execution of the program and collects program context information such as total instructions executed, execution time, memory allocated. The profile is updated at every invocation and it is stored in the smartphone database.

iv) **Offloading Agent:** Consists of a set of cost estimation models like the delay or execution time and the energy models. Based on the received context above, the offloading agent decides on when, where and how to offload the task. If there are MEC VMs with enough processing power, they are registered in the directory services to execute the tasks, the offloadable class codes task is then uploaded to the class loader of the MEC server VM which then execute the class code in the recipient OS, and after execution, the results are loaded back to the offloading agent in the client device. The flow chart in Fig. 5 shows operation of the offloading agent. The offloading agent start with the arrival of a task, T_k. If local execution time is less than the maximum delay tolerable and the battery $SoC \geq 20\%$, the task is executed locally. Else if the offloading delay deadlines are met and energy is saved using offloading, the task is offloaded to the VM in the MEC server. The next task then follows the same order in the flow chart.

v) **Communication manager:** It creates and maintains connection between the client and the server side. It serialises the code on the client side and deserialises the request from the client at the cloud side. It also keep the client and the server VM in sync. The communication manager checks if the required files and programs exist in the server side, else it contacts the client device to fetch the files and related libraries for remote execution.

vi) **Healthcare gateway add-ons:** The healthcare gateway can also be incorporated with some add ons like local temporary storage in case the network is down, data analytics, security, standardisation of the smart device data using healthcare standards like HL7, HL7 2, or HL7 3 and data compression before uploading to a remote cloud storage eg at the hospital to reduce data size and maximise 5G cellular bandwidth utilisation. All these add-ons can have their tasks processed in the MEC server to save energy in the smartphone.

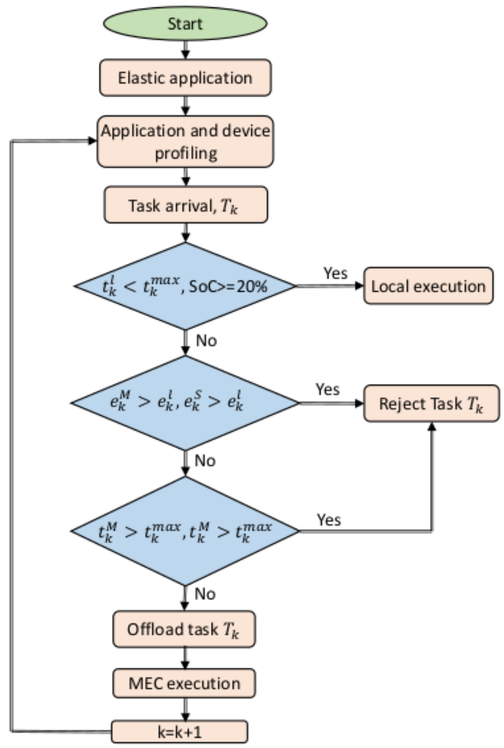

Fig. 5. The IEE5GG offloading agent flow chart.

TABLE I
SIMULATION PARAMETER SETTINGS.

Parameters	**MRRH**	**PRRH**
Cellular Layout	1 macro	12 per MRRH
BS transmission power	46 dBm	30 dBm
Number of smartphones	50 to 250	
MEC Server processing	20000 MIPS	
Smartphone processing	1000MIPS	
Smartphone active power	0.9 Watts	
Smartphone idle power	0.3 Watts	
Mobile transmission power	0.3 Watts	
Health App Task1	3500MIPS, 500bytes	
Health App Task2	1000MIPS, 1000bytes	
Probability of offloading	0.1	
Poisson interarrival time (sec)	3	

IV. SIMULATION AND RESULTS

A. *Simulation Settings*

To analyse the performance of the proposed IEE5GG framework, one MRRHs overlaid by 12 PRRHs per MRRH is considered. The proposed IEE5GG framework is compared with the EECO scheme introduced in Section II in [4]. In EECO, the MEC servers are of limited processing capacity and standalone. Table I shows the simulation parameters. The application to be considered is the heavy computation health application that uses electroencephalogram (EEG) device connected to the patient's smartphone to monitor brain state as the patient is on the move. The EEG application is broken into two tasks to be executed (Task1 and Task2) with their parameters shown in Table I.

The simulation was performed using an open source Edgecloudsim simulation tool [17]. The Edgecloudsim is a toolkit for modelling and simulation of resource management techniques in IoT and MEC taking into consideration the communication aspects.

B. *Results Evaluation*

Fig. 6(a) shows the average energy consumed in the smartphone for all the schemes. On average, compared to the local computation, the EECO and the proposed IEE5GG scheme saves 5% and 38% respectively, this is because both the EECO and the proposed IEE5GG schemes involves computation offloading to the MEC both via the MRRH and the PRRH as such energy is saved in the smartphone. The proposed IEE5GG performs 33% better than the EECO scheme because it adopts the standadised 5G arcitecture with multiple MEC servers located at the gNB-CU as such tasks are processed quickly in multiple MEC servers in VMs compared to a single MEC server in EECO which is a single point of failure.

Fig. 6(b) shows the effects of increases network UEs on the total energy consumption in the smartphone gateway. The figure shows that the energy consumption of local computation is constant since local computation is not affected by the number of UEs in the system. For the EECO and IEE5GG schemes, as the number of network UEs increases, the energy consumption in the smartphone gateway increases since more UEs share the bandwidth which causes the uplink data rate of the smartphone to be lower. For the EECO and IEE5GG, 15% and 65% of energy is saved during low traffic periods and 35% energy increase and 12.5% savings during peak loads, respectively, compared to local computation.

Fig. 6(c) shows the average service time of the health application for all the schemes with the increase in the number of smartphones in the network. The local computation service time is constant and is not affected by the increase in smartphones since there is no mobile transmission. The figure shows that as the number of smartphones increases, the service time increases compared to the local computation scheme due to sharing of bandwidth. As shown in Fig. 6(d) the EECO and the proposed IEE5GG schemes saves on average 33% and 41% respective with IEE5GG 8% better due to high processing speed in the centralised MEC servers.

Fig. 6(e) shows the effects of increasing the smartphones on the percentage of failed tasks. Task failure is due to lack of processing power where VMs are fully utilised of due to mobility of the users from the coverage area. The figure shows that as the more UEs occupies the network, the failure dropping probability of tasks increases but for local computation, fail rate is not affected by the increase in network UEs.

Fig. 6(f) shows the effect of increasing the uplink datarate of a smartphone by allocating the device more channels on the energy expended by the smartphone for various devices. The figure shows that as the transmission data rate increases, the energy consumed slightly decreases since the transmission time is decreased. Also, the higher the device processing power, the lower the energy consumed since less time is taken when executing some tasks locally.

V. CONCLUSION

This paper proposed an Intelligent and Energy Efficient 5G smartphone healthcare Gateway for healthcare smart devices (IEE5GG). In IEE5GG, the 5G architecture is adopted and the patient's smartphone is used as a gateway where multiple smart devices are connected e.g. via Bluetooth. To save energy, requests from smart devices can either be executed on the smartphone gateway or offloaded to the Mobile Edge Computing (MEC) server in 5G BS cloud while considering the transmission power, Quality of Service (QoS), battery level and CPU load of the smartphone. In IEE5GG, a healthcare application from the smartphone is partitioned into modules/tasks which are offloaded and executed in Virtual Machines (VMs). Results show that the proposed IEE5GG framework saves up to 38% of energy in the healthcare mobile gateway smartphone and reduces healthcare application service time by up to 41%.

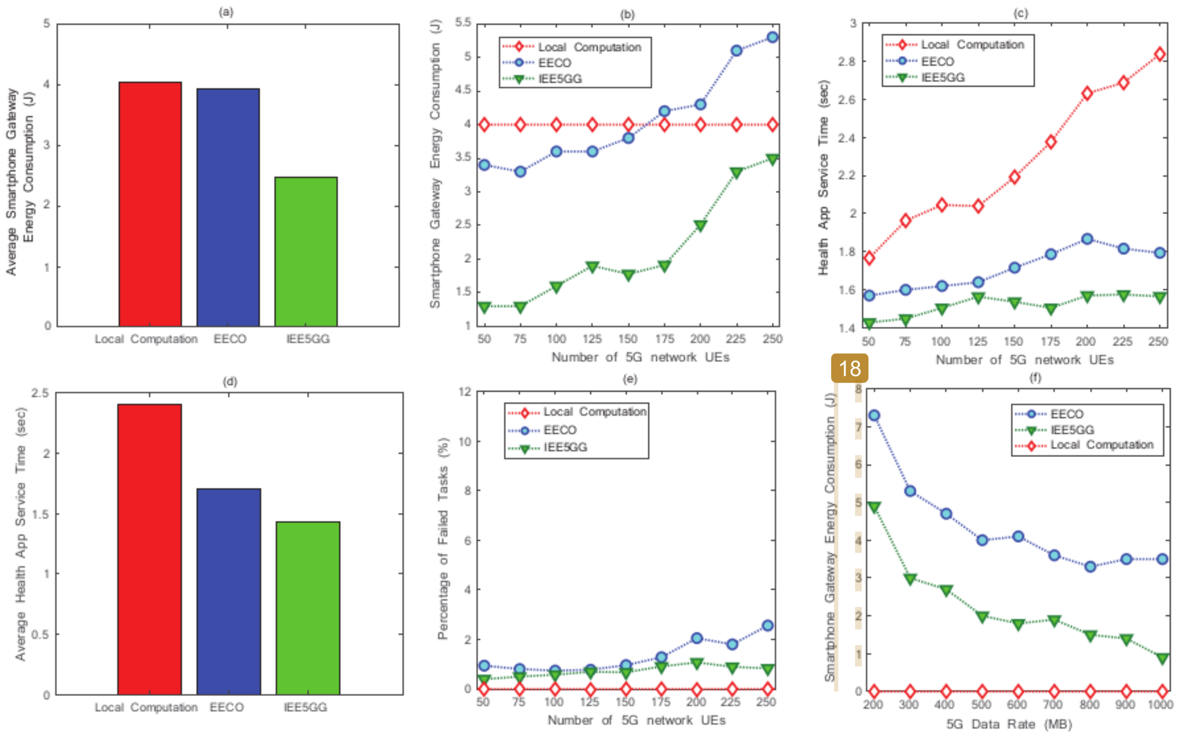

Fig. 6. Simulation results of (a) Average smartphone gateway energy consumption (b) Effects of increased network UEs on smartphone gateway energy consumption(c) Health app task service time (d) Average service time of tasks (e) Failed tasks due to mobility or VM overload (f) Effects of 5G datarate on smartphone gateway energy consumption.

VI. Acknowledgement

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