Cloud Computing in Smartphone: Is offloading a better-bet?

Milindkumar H. Tandel, Vijay S. Venkitachalam,
Department of Electrical Engineering and Computer Science
Wichita State University
Wichita, Kansas 67260-0083
mhtandel@wichita.edu, vxvenkitachalam@wichita.edu

***Abstract*—Smartphones have evolved a lot over the years. However they are still limited by the amount of computation power and storage space they have. On the other hand, cloud-computing aims to augment smartphone capabilities by providing vast pool of computation power and unlimited storage space. It is evident that smartphone computation power has risen enormously due to cloud computing. However, it is not clear whether cloud computing paradigm in smartphones can lead to sustainable energy consumption or not. Though cloud enabled smartphones consumes less battery than their counterparts in some cases, the total energy consumption including the backend data servers may prove otherwise. Therefore it is necessary to do evaluation of end to end energy consumption from mobile device to datacenter taking into consideration all the network components energy consumption. This paper presents a model for comparative analysis of energy consumption and performance when the task is performed locally and when the task is offloaded to remote server. Wi-Fi and 3G are two most common technologies used to connect to internet. This paper also compares energy consumption while offloading using both Wi-Fi and 3G architecture.**

***Index Terms*—energy consumption, cloud computing, smartphones, offloading, Wi-Fi, 3g, edge routers, core routers, base station, support nodes**

I. MOTIVATION

SMARTPHONES opened a new horizon of portability and information assessment. The tablet-phone combo changed how the world perceives cell phones. Even though the new generations of smartphone provide higher computation power and more storage space compared to their previous generation, they still fall short to the growing demand of computation power and storage space. Additionally, the battery industry is not as progressive as the telecommunication and semiconductor industries. Though, we saw a significant development in processing capacity and memory in a smartphone, it is still limited by its battery life. There is always a trade-off between the computation capacity and battery life. Portability, storage space and battery life are the main characteristics of a smartphone. The functionality and form-factor are dependent upon each other as more powerful a smartphone be, bigger battery it needs. Processing speed and storage capacity is inversely proportional to battery life which limits smartphones as a replacement for laptops and tablets.

The advent of cloud computing in smartphones eradicated the computation power, storage and battery constraints that limited smartphones from running PC like capabilities. It made smartphones scalable in terms of storage and processing capability. Shared resources, storage, hardware and software are the peculiar characteristics of cloud computing which made the smartphone motto work anywhere anytime. Thousands of new applications are being developed every day which are one of the main energy consuming components in smartphones [7]. These applications not only maximized the software capability but also minimized the hardware limitation in a smartphone. The cloud computing minimizes the energy needed for running computation intensive applications in smartphones as it offload the same.

Cloud computing also increases device reusability factor as functionalities in the smartphones are based on the cloud expendability and not the hardware [14]. Hardware free computation is another factor that makes cloud computing unique. This reduces frequent hardware updates and thus reduces electronic waste leading to sustainable mobile computing.

Though cloud computing can reduce the energy consumption at client device in some cases, it is necessary to have analysis of end to end energy consumption from smartphones to the backend servers encompassing all the intermediate components involved in communication, can we still stick to the above statement? This is what we try to do in this paper. This paper presents a model for evaluation of total energy consumption in an offloading scenario to arrive a conclusion whether offloading a better-bet or not. Offloading web request can either be done via Wi-Fi or cellular data (3G in our case). We measure the energy consumption in both the cases to get a complete picture in context to energy savings.

Figure 1: Overview of 3G communication

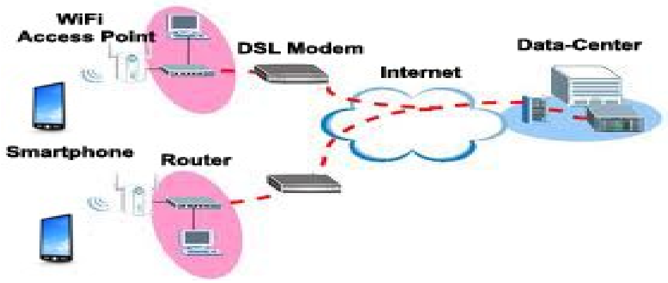


Figure 2: Overview of Wi-Fi communication

Wi-Fi and 3G are the most popular ways of getting connected to internet today. The 3G hotspots and mobile tethering are in advance and process of changing outlook of internet connectivity. This paper also does an extensive comparison of the Wi-Fi communication and 3G cellular data communication infrastructure to get a picture of performance and energy consumption.

The techniques that are used to save energy must not compromise the performance of smartphones as user experience is an important factor. This paper does a performance metric calculation based on time taken for executing the task. We assumed that there is uninterrupted internet connectivity. However, internet connectivity problems can influence user experience if considered. Also, we are considering the power considered by routers and ignored the power consumed by switches and other network devices.

The mobile computing has been predicted to be the dominant energy consuming area within ICT sector [15]. We hope we can deduce whether the shift in computing from laptops and desktops to tablets and smartphones due to the portability and convenience are worth energy savings or not.

The paper is organized into five sections excluding the Motivation and Related Work. Section III describes about our proposed communication models for 3G and Wi-Fi. Section IV describes about the experimental setup and device specs. Section V describes about the energy model we derived to calculate the total energy consumption. Section VI describes the measurements and evaluations. Finally, Section VII is our conclusion.

II. Related Work

Although, lot of researches have been done in cloud computing and energy conservancies using the same, no work stated end-to-end energy consumption involving networking infrastructure, data-center and its overhead (HVAC, UPS and lighting). There have been similar works related to finding whether offloading can save energy consumption for mobile devices or not [6][7][8]. Offloading computation intensive task to powerful servers has been a look up for many years but it's mainly concentrated on getting performance gain [9][10]. Our work is very much related to the work in [6]. However [6] is concentrated in finding the energy consumption in laptops (large form factor) and not that of smartphones (small form factor). Also, they have neglected energy consumed by data-center overhead (HVAC, UPS, and lighting) and networking infrastructure. Since the overhead energy required for maintaining data center infrastructure is equivalent or higher than that required for computation, we have included it in calculating the overall energy consumption for offloading scenario. To find the overhead energy consumption, we had to do an enumerative study of energy required for the total facility inclusive of overhead (HVAC, UPS, and lighting) vs. energy required for IT equipment only at a data-center [11], [12]. Apart from the energy consumption for client device as well as at data centers, we had to measure energy consumption by network as in [6] [13]. Once we have all the energy consumed for all individual parameters, we will integrate them to get the overall energy consumption for offloading scenario and compare it with that of no offloading scenario as in [6]. Also [6] did only take Wi-Fi as communication method. No research has been done on end-to-end power consumption in cloud-computing on smartphones.

Cloud computing is possible on smartphones either via Wi-Fi or cellular data. No research has been done on cloud computing involving cellular data even though it is the most widely popular medium of communication as it is widely available compare to Wi-Fi. We take the efficiency equation of base station from the [17] as it made easy for us to derive the per size power consumption in base-station.

III. Communication Strategy

In offloading scenario, as mentioned the task can be sent to the server either via Wi-Fi or 3G cellular data. We propose a communication model for both the cases in context of the energy consumption involved. We might have avoided some or many intermediate components which consumes negligible or less energy compared to the other components. Although, procuring power statistics of all the intermediate components is not possible with time constrains and confidentiality reasons, we did our best to approximate the energy consumption of major nodes involved in the communication.

A. *Wi-Fi Communication Model*

In the Wi-Fi model, the smartphone through the Sorting Client application sends the input file to the nearest access-point. From the access point, the packet gets routed to the service provider edge routers. After edge routers, the packet gets routed to the core routers behind the internet backbone and then to the data centers. The number of edge routers and core routers are mentioned in the Results and Evaluation section. The power consumption of switches has been excluded as in most cases there will be only a few number of them and their power consumption in insignificant when considered.

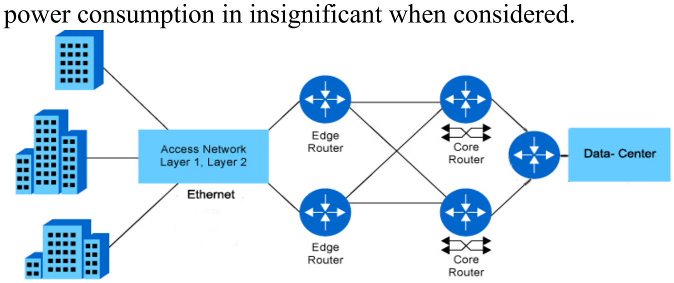


Figure 3: Offloading via Wi-Fi

B. 3G Communication Model

In the 3G model, the input file is sent to the nearest base station. The 3G communication has three main components: 1. User Equipment, which is the cell-phone with Subscriber Identity Module (SIM), 2. UMTS Terrestrial Radio Access Network, which is the base station and the Radio Network Controller (RNC), and 3. Core Network, which is the circuit switched network and packet switched network. Here, we consider only the packet switched network as circuit switched network is mainly for call routing. The packet switched network has two components Serving GPRS support node and Gateway GPRS support nodes. These two can be supposed as service provider edge routers as they are similar in function and power consumption [16]. From the core network, the packet gets to the core routers and then ultimately to the data center. We have excluded the RNC energy consumption as in the UTAN section, base station is the highest consumer of energy [20], [17]. From the communication model itself, we can predict that the 3G energy consumption will be more than Wi-Fi. However, we evaluate it in the later section to get a clear idea about the end-to-end power consumption.

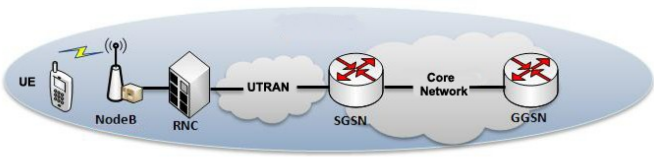


Figure 4: Offloading via 3G

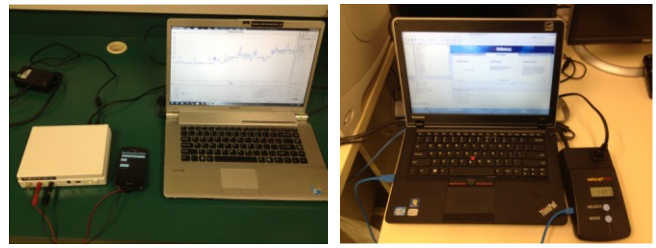
IV. Experimental Setup

A. Apparatus

1. 3G enabled Smartphone (Samsung Galaxy SII) under T-mobile cellular provider.
2. Server (Lenovo Thinkpad E420)
3. *Watts up? PRO* energy meter (Server power measurement)
4. Monsoon Power Monitor (Smartphone power measurement)

B. Client-Server Setup

The smartphone used as a host had 1.5 GHz of processing speed, 1GB of RAM (It can support up to 42Mbps via cellular data and 54Mbps via Wi-Fi) and was running Android OS 4.04 Ice-cream Sandwich. The device used as server was a powerful laptop. It has 2.3GHz of speed, 4GB of RAM and was running Netbeans IDE and Eclipse IDE on Windows 8 platform. The task assigned was to perform sorting of certain number of digits for 2,00,000 times. The sorting algorithm used was insertion sort. For no offloading scenario, the task was performed locally on the smartphone. For offloading scenario, the task was offloaded to a remote client using both Wi-Fi and 3G communication technologies. The input to the application was given using a text file. For offloading scenario, the input text file was sent to remote server. The client and server were put in different networks so that we can maintain consistency between Wi-Fi and 3G scenario. The client and server set up are as shown in Figure 5.

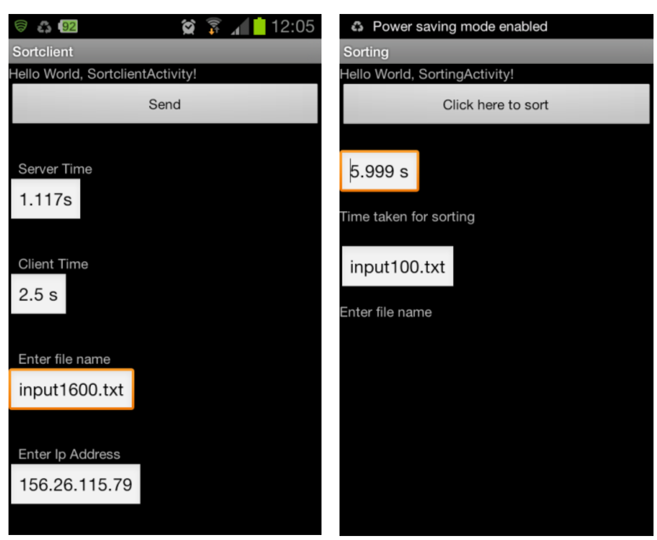


(i)Client Setup (ii) Server Setup

Figure 5: Experimental setup for Client(i) and Server(i) with Power Monitor tool and Watts up? Pro meter connected for power measurement.

C. Sorting Application

The applications were created using Eclipse IDE enabled with Android SDK and plugins. The Android version used for development was Android 2.1. The application created was upward compatible and was even supported on the latest Android version 4.1 JellyBeans. Two applications were created for measurement. Both the applications would take text file containing unsorted digits as input. The digits were read from the file and sorted using *insertion sort algorithm*. One application peformed sorting locally, using the computation power of the mobile device and the other sent the text file to remote server using TCP protocol and used the computation power of remote powerful server for performing the computation. As discussed before, the task was to perform sorting of the digits from the file for 2,00,000 times. Once the task was completed, the application would return and display the time taken for performing the task on the smartphone. In case of offloading scenario, the application would return the client time as well as the server time as shown in figure. Sorting was performed for file containing 100, 200, 400, 800 and 1600 digits. An option for selecting the file (whether 100 digits, 200 digits, etc.) to be sorted was provided in the sorting application on the smartphone. Also, there is an option for providing IP address of the remote server.



(i) Remote execution (ii) Local execution

Figure 6: Snapshot of two sorting application.

D. Power Measurement set up for Smartphone and Laptop(server)

The power consumption of smartphone and Laptop was measured using Monsoon power monitor tool and Watts up? Pro meter respectively as shown in Figure 5(i) and 5(ii). The power consumption by an application P_{app} is given by the difference of the peak power and the base power. Base power is the power consumed by the smartphone when no application is running on the smartphone and the system is in idle state. Peak power is the power consumed by smartphone when the the application is executed. Power consumption of the remote server is measured in a smilar way using Watts up? Pro meter. The power consumed by the application is thus given by :

$$P_{app} = P_{peak} - P_{base}$$

To obtain the base power, the phone and the laptop were run in idle mode with no application running and the power consumption was measured. Peak power was then measure when the application was executed.

V. Analytical Model

The power consumption of the smartphone was measured using Monsoon Power Monitor and that of the server was measured using *Watts up?* Pro meter. Time taken for executing the task was returned by the server and is displayed on the android application. In case of no offloading scenario, the client returned just the client time. In case of offloading scenario, the client returned both the client and the server time. Energy consumption was then calculated using the formula:

$$\text{Energy} = \text{Power} * \text{Time}.$$

A. No Offloading

In case of no offloading scenario, the task is executed locally on the smartphone itself. If T_{task} is the time taken for executing the sorting algorithm, then time taken by the client for no-offloading scenario is:

$$T_{client} = T_{task}$$

For offloading scenario, the task is executed on remote server. Hence, in this case $T_{server} = T_{task}$ and total time returned at the client is given by.

$$T_{client} = T_{task} + T_{comm}$$

Where, T_{comm} is communication time for sending the input file to server and getting the result back from server. For no-offloading scenario, the total energy consumption $E_{no\_offload}$ is given by:

$$E_{no\_offload} = E_{client} = P_{client} * T_{client}$$

B. Offloading

In case of offloading scenario, the offloading was done using Wi-Fi as well as 3G interface. For offloading, total energy consumption $E_{offload\_wifi}$ and $E_{offload\_3G}$ respectively are given by:

$$E_{offload\_wifi} = E_{client} + E_{internet\_wifi} + E_{datacenter}$$

$$E_{offload\_3G} = E_{client} + E_{base\_station} + E_{internet\_3G} + E_{datacenter}$$

Here, E_{client} = Energy consumed by the client device,
$E_{datacenter}$ = Energy consumed at the datacenter.
$E_{internet}$ = Energy consumed by the internet infrastructure

Energy consumption at the datacenter is given by:

$$E_{datacenter} = E_{server} + E_{overhead}$$

Where, $E_{overhead}$ = Energy consumed by HVAC, power supply and other overheads at datacenter.

Energy consumed by the client and the server can be measured as:

$$E_i = P_i * T_i, \text{ where i = client or server.}$$

$$E_{overhead} = P_{overhead} + T_{server}$$

$P_{overhead}$ is difficult to measure but can be estimated using the PUE (Power Usage Effectiveness) equation with the value of Power consumed by IT equipments. PUE can be defined as the ratio of total power consumed by the data center (i.e. power consumed by IT equipment in addition to power consumed by overhead) to power consumed by IT equipments.

$$PUE = (P_{overhead} + P_{IT}) / P_{IT}$$

$$P_{overhead} = (PUE * P_{IT}) - P_{IT}$$

According to the survey conducted by Uptime institute [2], the average PUE value of datacenters for the year 2012 is in between 1.8 to 1.89. For our calculation, we are considering the PUE value to be 1.8. If we ignore the power consumed by the switches and other devices at datacenter, then $P_{IT} = P_{server.}$ $P_{overhead}$ can then be calculated using PUE and P_{IT}.

Energy consumed by the internet infrastructure, $E_{internet\_wifi}$ in case of Wi-Fi is given by:

$$E_{internet\_wifi} = E_{access\text{-}point} + E_{edge} + E_{core}$$

In case of 3G, there is no access point involved. Hence Energy consumed by internet $E_{internet\_3G}$ is given by:

$$E_{internet\_3G} = E_{edge} + E_{core}$$

$E_{access\text{-}point}$, E_{edge} and E_{core} is the power consumed by access point, providers edge routers and internet core routers. The paper [3] defines a model for calculating the power consumed by the router. We tried to remodel that equation. The energy consumed by routers could then be given by:

$$Er = \frac{V * P * u}{C}$$

Where, V is the volume of the data passing through router in bits. If we ignore the protocol overhead, volume is equal to the size of file. P is the power consumption in Watts, u is utilization and C is capacity of router in bits/second. The specifications of the equipments we considered like its power consumption, capacity and typical utilization values are given below.

Type	Equipment	Capacity	Power Consumption	Utilization
Provider Edge router	Cisco 12816	160 Gb/s[4]	4.21 KW[4]	25%[3]
Core Router	Cisco CRS-1	640 Gb/s[4]	10.9 KW[4]	25%[3]

Energy consumed by edge and core routers can then be given by:

$$E_i = Er_i * h_i$$

Where, i = edge or core
h_i is the number of hops(routers).

For core routers, we will be considering the number of hops equal to 18 and for edge routers the equal to 2[5].

The paper [18] derives energy efficiency for wireless access point for different categories of access points. The energy consumed by access point can thus be given by:

$$E_{access\text{-}point} = V * 0.45 / 10^6$$

Where, V is volume of the data bits passed.

In case of 3G communication, $E_{base\_station}$ is derived from the efficiency formula [17].

$$\eta = \frac{P(tx)}{P(el)}$$

From the above equation if we modify a little bit,

$$P(tx) = P(el) * \eta$$

Where, P(tx) = Power consumption of the amplifier per each sector
P(el) = Power consumption at the electricity grid which includes total power consumption in the base station (which includes power consumption of power amplifier, transceiver, Digital Signal Processing unit, rectifier, microwave link and air conditioning)
η = Efficiency of the base station which is 12.8% for HSPA network (3G) [17].

The P(el) is approximated as 1500 W for all the three sectors in the base station [19].

The P(tx) value which we found out is for 11Mb of data as the smartphone in normal condition had 11mbps download speed. We assume the power consumed by the transmitter will be corresponding to the maximum bandwidth that it can tolerate. The 11 mbps is a real time download speed achieved with T-mobile service provider which we used for the whole experiment.

Also, we considered the packet routed to four base stations before it goes to the RNC as it is the maximum possible routing scenario.

The power consumption per V, volume of the input file is given by:

$$P(v) = \frac{P(el) * \eta * V}{4 * 11M}$$

$$P(v) = \frac{1500 * .128 * V}{4 * 11{,}000{,}000}$$

VI. Results and Evaluation

Once the sorting application was developed for no offloading and offloading scenario, the application was executed and measurements were taken using the experimental setup explained above. The various energy models derived in Section IV were used to calculate end-to-end energy consumption. The total energy consumed for no offloading scenario, offloading using Wi-Fi and offloading using 3G; using different number of input digits for sorting is as shown below in Table 1. From the figures, we can say that the energy consumed in case of no offloading is much higher compared to that of Wi-Fi and 3G scenario. And compared to 3G, offloading using Wi-Fi consumes much less energy for different number of input digits.

Input digits	Energy (Joules)					
	(i) No offloading	Standard deviation(i)	(ii) Wi-Fi	Standard deviation (ii)	(iii) 3G	Standard deviation (iii)
100	2.176252	0.098319	0.094012	0.00797	1.617965	0.00585
200	4.349367	0.232938	0.113482	0.03647	1.65762	0.02826
400	7.849534	0.176652	0.158317	0.06953	1.95828	0.0204
800	15.74538	0.401444	0.225476	0.08212	2.282498	0.1803
1600	32.79877	1.336671	0.447417	0.28092	3.017328	0.45502

Table 1: Mean energy consumption and standard deviation for No offloading, offloading using Wi-Fi and offloading using 3G.

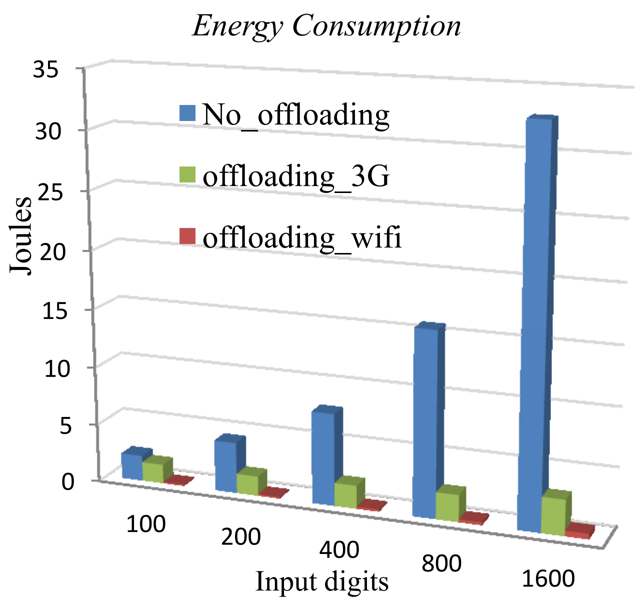


Figure 7: Graph of the energy consumption to the number digits for offloading and no offloading scenario.

In terms of performance, from the Table 2, we can say that offloading scenarios take much less time compared to no-offloading scenarios for different input digit. We can also summarize that the time taken when offloading using Wi-Fi is low compared to that of 3G. This increase in time is because of higher communication time which is directly proportional to data rates. Typical data rates for 3G interface is 42 Mbps whereas that for Wi-Fi is 54 Mbps.

Input digits	Time(Sec)					
	(i) No offloading	Standard deviation (i)	(ii) Wi-Fi	Standard deviation (ii)	(iii) 3G	Standard deviation (iii)
100	5.522	0.1892	0.518	0.068341	2.9786	0.525363
200	10.7368	0.2764	0.5182	0.065082	3.342	0.143403
400	20.6578	0.3588	0.5566	0.096495	3.5574	0.8674
800	40.588	1.2538	0.6456	0.108022	3.7708	0.34779
1600	83.2362	1.2766	0.7386	0.089762	4.6976	0.670604

Table 2: Mean time taken and standard deviation for performing the task using No-offloading, offloading using Wi-Fi and offloading using 3G

The figure 9 and 10 below shows the distribution of energy consumption for Wi-Fi and 3G scenarios. In both Wi-Fi and 3G scenario, energy consumed by the host locally on a smartphone constitutes the major portion of end-to-end energy consumption. The energy consumed by host is higher for 3G scenario because of higher power consumption consumption by the 3G interface. The energy consumption by the data center is 29% of total in case of Wi-Fi scenario, whereas it is 6% in 3G scenario. The energy consumption by internet infrastructure is 10% of the total energy consumption in Wi-Fi scenario. However, it is almost 0 percent for 3G scenario. This is because most of the energy consumption in internet infrastructure is by wireless access points. As wireless access point are not present in case of 3G scenario, energy consumption by internet infrastructure is much less. The base station consume almost 2 percent of the total energy consumption in case of 3G.

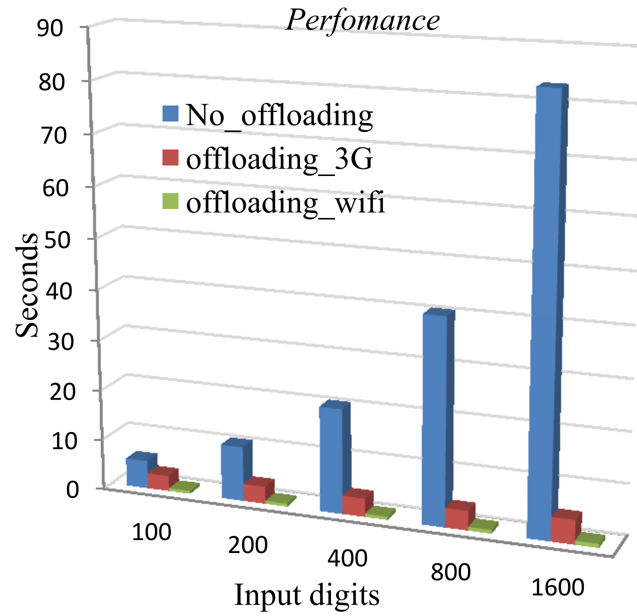


Figure 8: Graph of the execution time versus the number digits for offloading and no offloading scenario.

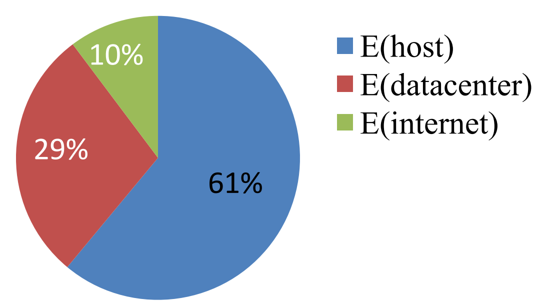


Figure 9: Energy distribution chart for Wi-Fi scenario

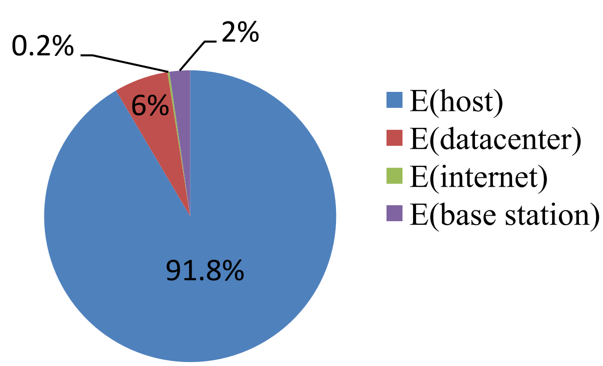


Figure 10: Energy distribution chart for 3G scenario

VII. Conclusion

The paper presents a comparative analysis of (1). Energy consumption in a smartphone when executing a computation intensive task versus (2). End-to-end energy consumption when the same task is offloaded to a remote server. The results show that, energy consumed for a computation intensive task in a no-offloading scenario is much higher compared to the energy consumed for executing the same task in an offloading scenario. Also, the magnitude of energy savings increases as the complexity of task increases. A major portion of energy consumption in offloading scenario was consumed by the client device.

The paper also presents an evaluation between two popular communication technologies i.e. Wi-Fi and 3G. Offloading using Wi-Fi is more energy efficient compared to offloading using 3G. The performance achieved using Wi-Fi is also significantly high compared to the same using 3G. The paper also shows that access point accounts for a major portion of the total network energy consumption in case of Wi-Fi. Similarly base station accounts for major portion of total network energy for 3G network.

VIII. Future Work

Future work will be focused on performing the same task on other mobile OS like iOS, Blackberry OS etc. It would be fascinating to see how the distribution in energy consumption chart changes with different OS. The present implementation offloads the task to a single server. It would be interesting to observe the energy consumption when the task is divided among multiple servers. One other aspect we would like to investigate is the affect of poor network condition on performance and energy consumption.

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