Energy Management in Mobile Devices

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Abstract---Mobile consumer-electronics devices, especially phones, are powered from batteries which are limited in size and therefore capacity. This implies that managing energy well is paramount in such devices. Wireless communication technologies enable communication among different devices that are within a certain radius. Although, this radius is definite, communication when using wireless communication technologies is more flexible than when using wireline approach. This paper presents results from a measurement study where we measured energy consumption of three wireless communication technologies, namely, Bluetooth, WiFi and 3G . We proposed an energy and time consumption model that is based on these measurements. Using proposed model one can not only calculate energy consumption for each communication technology, but can also save energy while simultaneously using WIFI, Bluetooth and 3G at the same time. This paper shows how our energy consumption model can be used on an example of the service called Collaborative Consumption of Energy (CCE). The primary goal of CCE service is to lower the overall energy consumption of mobile users while downloading data combining together 3G and Bluetooth or 3G and WiFi communication technologies; as well as, when all of the above components are in play, which one hibernates or kept inactive and which one remains active.

I. INTRODUCTION

Mobile devices derive the energy required for their operation from batteries. In the case of many consumer-electronics devices, especially mobile phones, battery capacity is severely restricted due to constraints on size and weight of the device. This implies that energy efficiency of these devices is very important to their usability. Hence, optimal management of power consumption of these devices is critical. A core requirement of effective and efficient management of energy is a good understanding of where and how the energy is used: how much of the system's energy is consumed by which parts of the system and under what circumstances.

Earlier research in power analysis for smartphone devices has produced power models with differing features and focuses. This paper differs from these research efforts in the following key aspects. We perform measurements and data collection of each device subsystem's power consumption. This enables us to acquire both accurate measurements and at the same time reduce the power and computational requirements of model generation on the phone. Operational states of individual subsystems are taken in order to construct the model. Measurements of behaviour is performed for all the primary device subsystems under different conditions which provide an in-depth understanding of how the power is consumed on a phone. This model helps to regulate the power consumption by each of the modules: namely, Wifi, Bluetooth, 3G by making them hibernate when not in use and thereby diverting the energy to the one which is active.

Modern high-end mobile phones combine the functionality of a pocket-sized communication device with PC-like capabilities, resulting in what are generally referred to as smartphones. These integrate such diverse functionality as voice communication, audio and video playback, web browsing, short-message and email communication, media downloads, gaming and more. The rich functionality increases the pressure on battery lifetime, and deepens the need for effective energy management.

II. LITERATURE REVIEW

A. Wifi Power Consumption: The power consumption by the Wi-Fi subsystem during transmission depends on the rate of packets sent or received. Experiments were conducted to determine the exact relationship between these factors and to create equations to fit the findings into our model. The readings were generalized to arrive at one single equation to govern all states of transmission. Our study does not include or identify the power consumed to seek a connection with a Wi-Fi access- point. A separate study can be conducted to extend our model to include the power consumed to find and connect to different access points.

Experimental Setup: The network link used was a Local Area Network (LAN) with a Wi-Fi 802.11G router. For testing outgoing traffic (Tx) a program was used which sent User Datagram Protocol (UDP) packets from the mobile device over Wi-Fi at different data transmission rates. The program was run natively on the mobile device. UDP packets were sent from the device at a rate of 0 KB/s for the first 20 minutes and the transmission rate increased by approximately 100 KB/s each 20 minutes until a transmission rate of 950 KB/s was reached. The number of bytes transmitted from the device and the battery charge count were recorded. A second experiment was conducted to determine if the amount of incoming traffic (Rx) had a similar impact on the rate of current discharge.

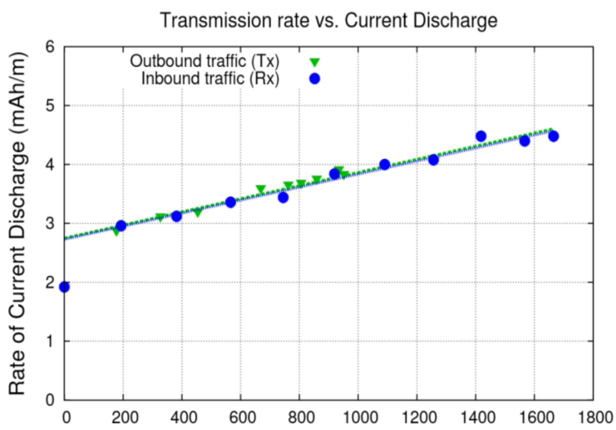

Fig. 1: Transmission Rate Vs Current Discharge

A program was run on the device to receive UDP packets sent to the device at different transfer rates by another client on the network. The client on the network sent UDP packets to the device at a rate of 0 KB/s for the first 20 minutes and then increased the rate at which it sent packets by 100 KB/s each 20 minutes, until a rate of 1700 KB/s was reached. The device was kept stationary for the entire experiment.

Analysis: The above figure 1 displays the results from the inbound and outbound transmissions performed. As the Wi-Fi transmission rate increases by 100 KB/s, the rate of power discharge increases by an average of 0.11 mAh/m. The slope of the two curves can be averaged to form . Current Discharge Rate (CDR) = 0.0011x ∗ 2.739.
To calculate the Wi-Fi subsystem usage UWiFi for each time window, we calculate the cdr for average transmission rate from (7), and get the time that the Wi-Fi subsystem was active in the given interval.
UWiFi(t) = CDR ∗ WiFi uptime. [1][2]

B. Bluetooth Power Consumption: To get an idea of Bluetooth power consumption, the audio benchmark on the G1(where it represents an android phone, say a HTC Dream Phone) is run with the audio output to a Bluetooth stereo headset. The power difference between this and the baseline audio benchmark yielded the consumption of the Bluetooth module, because the power consumed by the audio subsystem is almost entirely static.

	Power (mW)	
Benchmark	Total	Bluetooth
Audio baseline	459.7	-
Bluetooth (near)	495.7	36.0
Bluetooth (far)	504.7	44.9

Table. 1: G1 Bluetooth power under the audio benchmark

Table 1 shows the total and estimated Bluetooth power consumption for the audio benchmarks. In the ”near” benchmark, the headset was placed approximately 30cm from the phone, and about 10m in the ”far” benchmark.[3]

1) Comparison of Power Consumption between Wifi, Bluetooth and 3G:

	Download	Upload
3G/Bluetooth	1.56	0.45
WiFi/Bluetooth	2.78	2.45
WiFi/3G	1.79	5.40

Table. 2: Throughput comparison

The above table shows the comparison of throughput ratios of downloading and uploading data .[4]

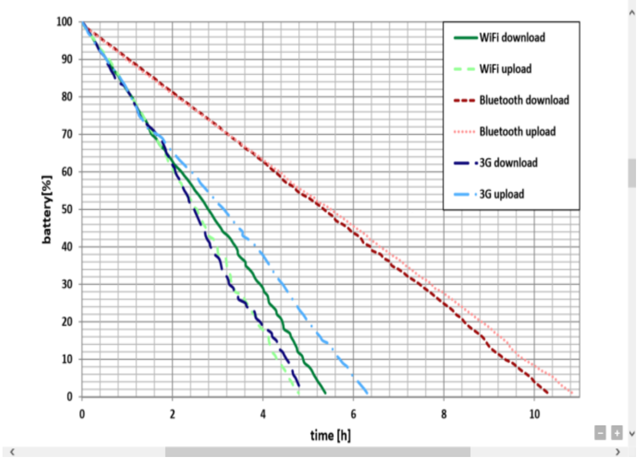

Fig. 2: Energy Consumption vs TIme

Figure 2 shows energy consumption compared to the elapsed time when using Bluetooth, WiFi and 3G communication technologies for data download and data upload. As shown in Figure 1, data transfer when using Bluetooth consumes significantly less energy than data transfer when using WiFi or 3G. The battery lasted approximately 4 hours longer when using Bluetooth communication technology continuously than when using WiFi or 3G. If we compare WiFi and 3G communication technologies, we can conclude that the battery lasted approximately equal, but WiFi communication technology transferred twice more data than 3G communication technology.

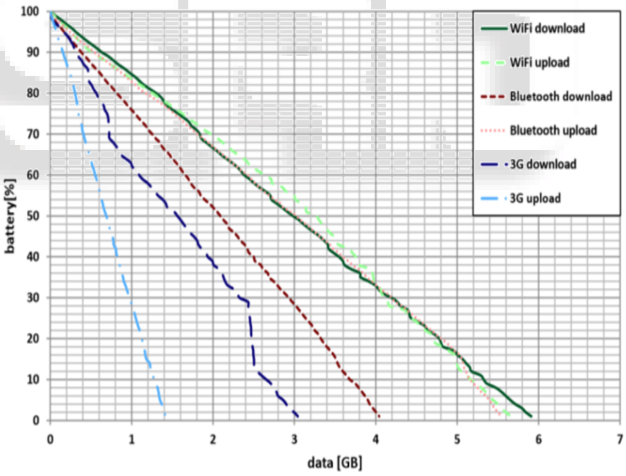

Fig. 3: Battery Consumption Vs Data

Figure 3 shows Battery consumption compared to the amount of transferred data when using Bluetooth, WiFi and 3G communication technologies for data download and data upload. As shown in Figure 2, the smallest amount of data is transferred when using 3G (3.04 GB data in download and 1.42 GB in upload). WiFi and Bluetooth transferred several times more data than 3G. WiFi transferred 5.91 GB in download and 5.66 GB in upload, while Bluetooth transferred 4.04 GB in download and 5.54 GB in upload. The amount of transferred data when using WiFi and Bluetooth is similar, but it is important to note that data transfer when using Bluetooth lasted twice longer than when using WiFi.

Combining results from Figure 1 and Figure 2, we can calculate measured download and upload throughputs of Blue- tooth, WiFi and 3G communication technologies.

Bluetooth measurements were performed using Bluetooth v2.0 that al- lows a maximum application throughput of 2 Mbit/s [12], while our results showed that throughput in real world environments is around 1 Mbit/s (0.9 Mbit/s in download and 1.1 Mbit/s in upload). WiFi measurements were performed using 802.11g network with a maximum throughput of 20 Mbit/s in download and upload, while the measured throughput was 2.5 Mbit/s in download and 2.7 Mbit/s in upload. Finally, 3G mea- surements were performed using HSDPA mobile network that provides a broadband Internet access with throughput of 7.2 Mbit/s in download and 1.4 Mbit/s in upload. Results of our measurements showed throughput of 1.4 Mbit/s in download and 0.5 Mbit/s in upload. Table I shows measured throughput ratios for 3G/Bluetooth, WiFi/Bluetooth and WiFi/3G.

The Below table shows the energy consumption ratios of the modules for uploading and downloading data based on the measured data, we can calculate energy consumption ratios for all three communication technologies . Energy consumption ratios shown in Table IV were calculated using the data obtained by measuring energy consumption and the amount of transferred data in download and upload. Thus these above results show that 3G communication technology is the largest consumer of energy, followed by WiFi and Bluetooth communication technologies. This implies that energetically the most economical way to transfer data is when using Bluetooth communication technology.

	Download	Upload
3G/Bluetooth	2.81	8.89
WiFi/Bluetooth	1.32	2.22
WiFi/3G	0.47	0.24

Table. 3: Energy Consumption Ratio

Thus the results show that the majority of power consumption can be attributed to the 3G module and the display, including the LCD panel and touchscreen, the graphics accelerator/driver, and the backlight. In all except the 3G-intensive benchmarks, the brightness of the backlight is the most critical factor in determining power consumption. However, a mobile phone is a relatively simple device from a power-management perspective, and largely depends on the user's brightness preference. The 3G module consumes a great deal of both static and dynamic power. Merely maintaining a connection with the network consumes a significant fraction of total power. During a phone call, 3G consumes in excess of 800mW average, which represents the single largest power drain in any of our benchmarks. Unfortunately, a phone-call-heavy workload presents little scope for software-level power management. Dimming the back- light during a call, as Android does, is clearly good policy, saving up to 40% power even with the large 3G consumption. Overall, the static contribution to system power consumption is substantial.

The individual approach refers to the standard approach of the mobile telecom service provisioning, while the collaborative approach refers to the approach proposed in the Collaborative Downloading service. Energy consumption E*ind* of a single file download when mobile telecom operators use the individual approach for mobile telecom service provisioning can be calculated as follows:

$$E_{ind} = NE\%(3G)S_{file} \quad (1)$$

where N is the number of mobile users in the system, E%(3G) denotes energy consumption in percentage per GB needed for downloading data via 3G and Sfile denotes size of the downloaded file in GB. Energy consumption Ecol of a single file download when mobile telecom operators use the collaborative approach can be calculated as follows:

$$E_{col}(3G+Bluetooth) \approx E_{ind}((1-2\alpha)/N+2\alpha), \quad (2)$$

$$E_{col}(3G+WiFi) \approx E_{ind}((1-2\beta)/N+2\beta), \quad (3)$$

Where $\alpha = (E\%(Bluetooth)/E\%(3G))$, $\beta = (E\%(WiFi)/E\%(3G))$ [5][6][7][8]

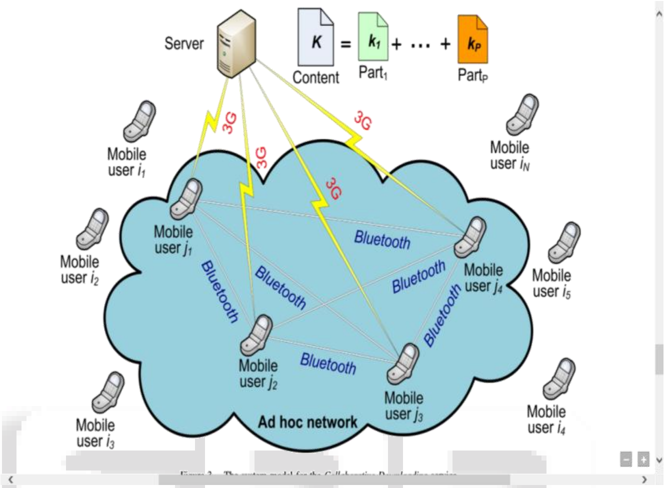

Fig. 4: Connectivity of Network

III. PROPOSED METHODOLOGY

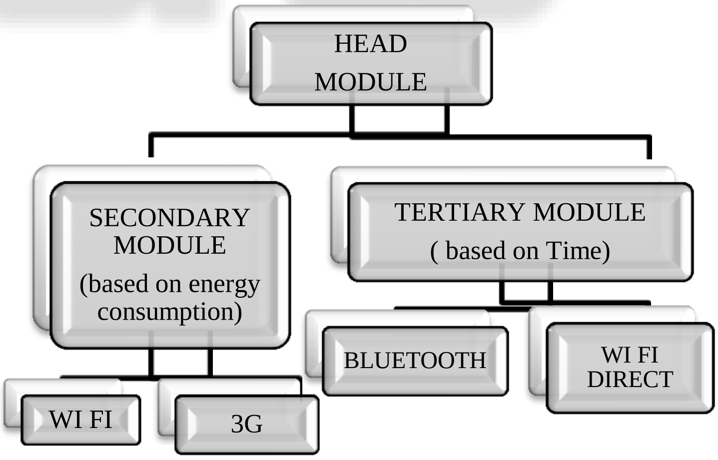

Fig. 5: Modules of Proposed Method

The above model is based basically on two principles, namely :

- *Energy Consumption* –which is employed by the secondary and tertiary module
- *Time Delay*- which is employed by the tertiary module

Which applications Hibernate?

To check which applications hibernate, we follow the below scenarios:

A. Secondary Module: Here……we check the availability of the application through energy consumption.
For each application to be active, there will be a change in the number of packets being received or sent by the applications.

If the number of packets being sent and received remains the same, or does not change, then that application will hibernate or be inactive.

If both the applications are active, ie, if in both there is a change in the number of packets being sent and received, the one which consumes more power will hibernate- In this case 3G will hibernate because as shown from the above study in this paper, it consumes the maximum energy when compared to WIFI and Bluetooth.

B. Tertiary Module: Here…..we check the availability of the applications through energy consumption and time delay
If an application(s) is switched on and not being used , ie, the number of packets being sent and received remains constant or doesn't change ; then after a particular time span or delay (say t=2min), the application(s) will hibernate or go into inactive state.

However for the running of WIFIDIRECT, the Wifi and/or 3G of the Secondary module should remain in active state. If both are in active state, the WIFIDIRECT will get its signals from 3G for reasons stated above.

IV. CONCLUSION

In this paper we presented a measurement study of energy consumption for data transfer when using Bluetooth, WiFi and 3G communication technologies. This is important since devices are becoming more powerful and tasks that they can perform are becoming more complex. That results with the increased demands for energy.

Therefore, if device can use several of different communication technologies for data transfer, it is important to know energy consumption characteristics of each of them. The measured data were collected and analysed . On that basis a simple energy consumption model for all phones was designed. Using our model, we showed which applications hibernate and which don't and under which conditions do they perform hibernation. The main idea behind this paper is to combine different communication technologies when downloading files in parts, and reduce the amount of energy required to transfer the entire file to a group of mobile users.

The ultimate aim of this work is to enable a systematic approach to improving power management of mobile devices. We hope that by presenting this data, we will enable such future research, both in our lab as well as by others.

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