Energy Consumption in Android Phones when using Wireless Communication Technologies

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***Abstract*— 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: Bluetooth, WiFi and 3G. We proposed an energy consumption model that is based on these measurements. Using proposed model one can calculate energy consumption for each communication technology. We show how our energy consumption model can be used on an example of the service called *Collaborative Downloading*. The primary goal of *Collaborative Downloading* 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.**

Keywords: Bluetooth, WiFi, 3G, energy consumption model, energy savings

I. Introduction

When talking about Machine-to-Machine (M2M) systems, it is well known Ericsson's 50 B prediction saying that by 2020 there will be up to 50 billion interconnected devices [1]. However, it is less known that by 2016 282 million of them will be cellular M2M subscribers [2]. Not only does this predict the sizable and long-term growth opportunities for mobile operators, but also shows that the potential size of the cellular M2M market is enormous. Cellular M2M subscribers can use different kinds of M2M devices (e.g. smartphones) and different kinds of communication technologies (e.g. WiFi, 3G). Common characteristic of those M2M devices is that they have limited energy resources (i.e. batteries). Namely, when using devices with limited energy resources, it is very important to know how much energy is consumed during communication.

Therefore, in this paper we present a measurement study of energy consumption and throughput when using Bluetooth, WiFi and 3G communication technologies in Android phones. We investigate relationships between energy consumption and the elapsed time, as well as between energy consumption and the amount of transferred data when using aforementioned communication technologies. Based on those measurements, we developed an energy consumption model for Android phones. All measurements were performed on HTC Desire HD phone running Android operating system version 2.3.

The rest of this paper is organized as follows. Section II presents related work, while Section III describes our methodology used for the measurement study. This section also proposes an energy consumption model for Android phones. Section IV shows a simple case study example explaining the usage of our model. Finally, Section V gives conclusions and the guidance for future work.

II. Related work

Many papers have recently investigated how characteristics of wireless communication technologies affected energy consumption. For instance, in [3] and [4] authors proposed different algorithms for predicting the availability of the smart WiFi networks together with the energy consumption reduction. Furthermore, in [5] Xiao et al. compared 3G with WiFi, while Balasubramanian et al. compared GSM, 3G and WiFi [6]. However, none of these papers compared energy consumption of Bluetooth, WiFi and 3G communication technologies in smartphones (i.e. Android).

In [3] Gupta and Mohapatra made a measurement study of energy consumption when using VoIP applications with WiFi connection in smartphones. They showed that the usage of *power save mode* in WiFi together with intelligent scanning techniques for networks can reduce energy consumption. Rahmati and Zhong modeled wireless interfaces selection as a statistical decision problem [4]. Xiao et al. measured energy consumption when using mobile applications for a video streaming [5]. They compared 3G and WiFi communication technologies and concluded that WiFi is more energy efficient than 3G communication technology.

Furthermore, Balasubramanian et al. present a measurement study of energy consumption when using GSM, 3G and WiFi [6]. They showed that 3G and WiFi have high tail energy overhead at the end of data transfer and therefore proposed the *TailEnder* protocol to reduce energy consumption after data transfer is completed. Feeney and Nilsson made the series of experiments in which they obtained detailed measurements of energy consumption of an IEEE 802.11 wireless network interface operating in ad hoc networking environments [7]. Their work provided linear equations collection for calculating energy consumption for sending, receiving and discarding broadcast and point-to-point data packets of various sizes.

In 2011 Friedman et al. made a measurement study where they measured power and throughput performance of Bluetooth and WiFi usage in smartphones [8]. They concluded that power consumption for WiFi is generally linear with the obtained throughput, while power consumption while sending and receiving using Bluetooth is lower than WiFi, but only by about a half. Their work was performed using different platforms (i.e. Samsung Omnia i900 running Windows Mobile 6.1, HTC Diamond 2 running Windows Mobile 6.5, Samsung Galaxy running Android 1.5 and Samsung Spica running Android 2.1). Their conclusion was that none of the phones can be claimed to be better than the others taking into an account all the measured parameters.

In [9] authors presented the *CoolSpots* system in which a switch between WiFi and Bluetooth interfaces is performed in order to increase battery lifetime. Similar to the *CoolSpots* system, Agarwal et al. presented the *Cell2Notify* system in which they use GSM interface to wake up WiFi interface when VoIP call comes to achieve a better service and reduce energy consumption [10]. Finally, Rahmati and Zhong presented a study in which they proved that intelligent switching between WiFi and GSM reduces energy consumption [11]. They have also presented an algorithm that predicts WiFi availability in specific area to reduce high energy consumption while searching for WiFi networks.

III. Energy consumption model

In order to design an energy consumption model of Bluetooth, WiFi and 3G communication technologies, we conducted measurements in which we used each of aforementioned communication technologies at full load. Our measurement methodology can be divided into three phases, while in the fourth phase we analyzed our results. In the first phase we collected relevant data for each communication technology (i.e. percentage of available battery, amount of transferred data and elapsed time). In the second phase we compared the collected data and showed them in relation to one another. Based on measurements performed in the previous phase, in the third phase we presented a simple energy consumption model of all three communication technologies. Finally, in the fourth phase we compared our results with the results of previous studies. Moreover, we compared our results with the data specified in technical specifications for the given communication technology.

A. The first phase

In order to collect the required data, we developed a simple Android application that sends or receives data continuously and monitors a battery status (i.e. percentage of available battery). The application also records the elapsed time and the amount of transferred data. Measurements of data transfer when using these three communication technologies are performed for continuous data download from the server as well as for continuous data upload to the server.

B. The second phase

Figure 1 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.

Figure 2 shows energy 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 Bluetooth, WiFi and 3G communication technologies. Bluetooth measurements were performed using Bluetooth v2.0 that allows 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 measurements 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.

TABLE I
Throughput ratios for 3G vs. Bluetooth, WiFi vs. Bluetooth and WiFi vs. 3G

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

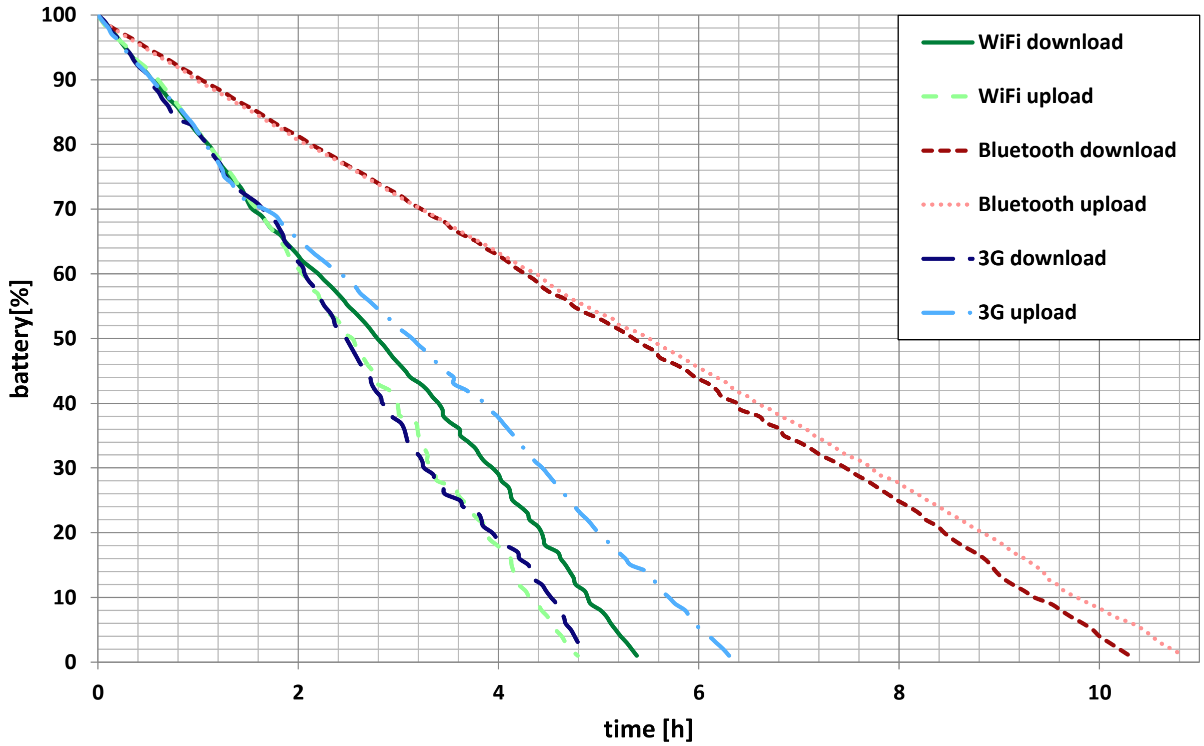

Figure 1. Energy consumption compared to the elapsed time

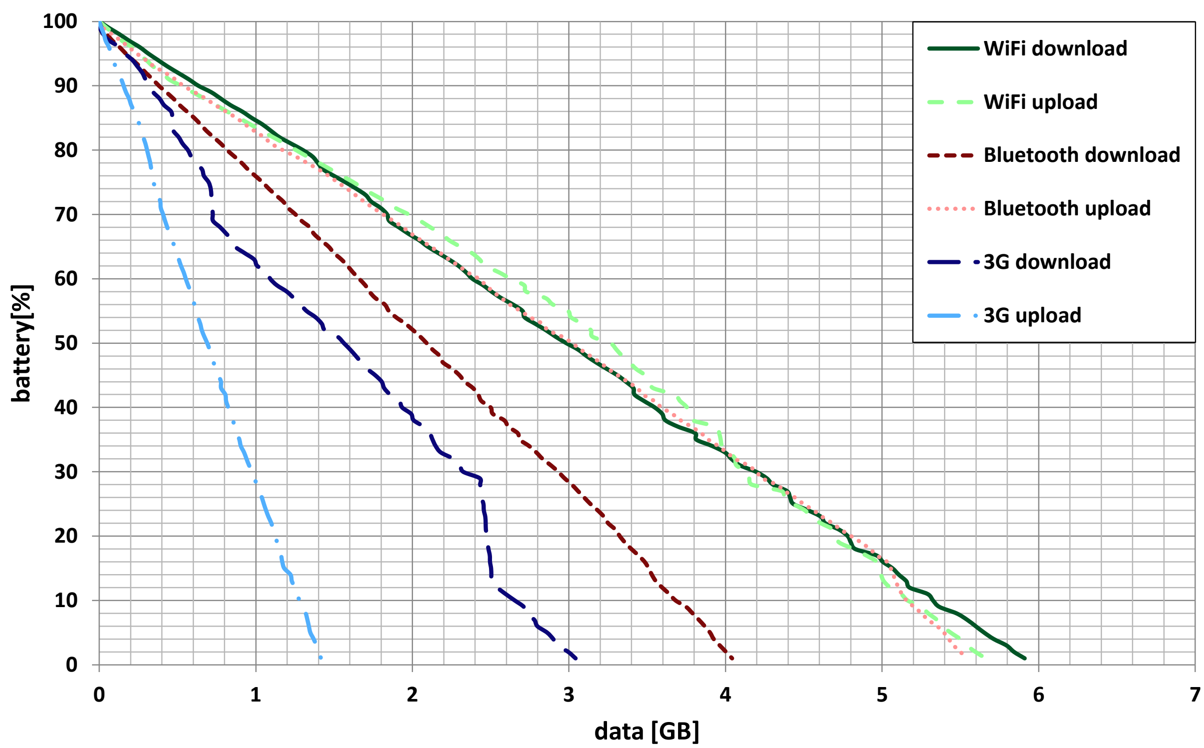

Figure 2. Energy consumption compared to the amount of transferred data

C. The third phase

Based on the collected and processed data, we propose a simple linear energy consumption model. Table II shows energy consumption functions in respect to the elapsed time when using Bluetooth, WiFi and 3G communication technologies for data download and data download. These functions can be used to calculate the percentage of battery (i.e. y) that is consumed when using a particular communication technology for a period of x hours. Additionally, Table III shows energy consumption functions in respect to the amount of transferred data when using Bluetooth, WiFi and 3G communication technologies for data download and data upload. These functions can be used to calculate the percentage of battery (i.e. y) that is consumed when using a particular communication technology for the x amount of transferred data expressed in GB.

In order to verify our energy consumption model, we made additional measurements and compared obtained results with the results calculated with energy consumption functions from Table II and Table III. For instance, if we download files for 0.18 hours using WiFI, according to Table II and the following function $y = 18.09x + 0.17$, for $x = 0.18$, we need 3.43% of the battery. Moreover, since the measured download throughput of WiFi is around 2.5 Mbit/s, it means that during that time 0.21 GB of data is downloaded. Measurements in a real world environment showed that this downloading process consumed around 4% of the battery and that during that time 0.25 GB of data was downloaded on the Android phone. Real world energy consumption is slightly higher than energy consumption calculated using energy consumption functions from Table II due to slightly higher network throughput at the time of measurement.

TABLE II
ENERGY CONSUMPTION FUNCTIONS IN RESPECT TO THE ELAPSED TIME

	Download	Upload
Bluetooth	$y = 9.53x - 0.39$	$y = 9.01x + 0.84$
WiFi	$y = 18.09x + 0.17$	$y = 21.24x - 2.68$
3G	$y = 20.59x - 1.09$	$y = 15.31x + 2.67$

Additionally, if we want to calculate how much energy is consumed when receiving 0.25 GB of data using Bluetooth, we use the following function $y = 24.58x + 0.18$ from Table III. When we include $x = 0.25$ in the aforementioned function, we calculate that for data transfer of 0.25 GB, we need 6.33% of the battery. Measurements in a real world environment showed that this receiving process at throughput of 1.14 Mbit/s consumed slightly more than 5% of the battery and took 0.48 hours, which corresponds to the calculated value obtained from our energy consumption model.

TABLE III
ENERGY CONSUMPTION FUNCTIONS IN RESPECT TO THE AMOUNT OF TRANSFERRED DATA

	Download	Upload
Bluetooth	$y = 24.58x + 0.18$	$y = 17.09x - 0.53$
WiFi	$y = 17.01x - 0.93$	$y = 17.31x - 2.28$
3G	$y = 31.74x + 2.15$	$y = 71.27x - 0.03$

D. The fourth phase

In this section we compare our results with the results from related work. Based on the measured data, we can calculate energy consumption ratios for all three communication technologies (see Table IV). 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. Our results confirmed the results obtained by previous studies. 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.

In [6] Balasubramanian et al. showed that data transfer of 50 KB when using 3G needs 12.5 J, while when using WiFi the same data transfer consumes 7.6 J of energy indicating that WiFi communication technology is 39.2% more energy efficient than 3G communication technology. Our measurements showed that for data transfer of 0.5 GB when using WiFi 8% of the battery was used, while 3G for the same amount of data needs 18% of the battery. This implies that WiFi communication technology is up to 55.56% more energy efficient than 3G communication technology. In [8] Friedman et al. calculated energy consumption ratios for WiFi and Bluetooth and showed that it is equal to 3.03. In our model we measured the same ratio and calculated that it is 1.32 when downloading files and 2.22 when uploading files.

TABLE IV
ENERGY CONSUMPTION RATIOS FOR 3G VS. BLUETOOTH, WIFI VS. BLUETOOTH AND WIFI VS. 3G

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

IV. Case study

Different communication technologies (e.g. WiFi, 3G) have different data transfer throughputs and consume different amounts of energy. By combining these communication technologies together, energy consumption can be reduced. In our previous work, we proposed a collaborative service called *Collaborative Downloading* [13], [14], [15], [16]. Its purpose is to increase energy efficiency of the mobile telecom service provisioning process. This is important for mobile users since limited energy resources are the main obstacles for frequent usage of advanced mobile telecom services and for mobile telecom operators since it enables service provisioning compliant with the green communication concept.

The *Collaborative Downloading* presents a distributed model of service provisioning process for mobile users who share a common interest in a service content offered by mobile telecom operators. The model is based on an idea that such users could individually acquire disjunctive parts of service content from a remote server using 3G communication technology, and then subsequently exchange those parts among themselves in a Bluetooth or WiFi ad hoc network in a peer-to-peer fashion. The system model for the *Collaborative Downloading* service is illustrated in Figure 3. $I = i_1, ..., i_N$ denotes the set of N mobile users who are subscribers of a mobile telecom operator, while $J = j_1, ..., j_M$ denotes the subset of mobile users who form the ad hoc network. Finally, $K = k_1, ..., k_P$ denotes the set of content parts on the server.

In our previous work [16] we made an analytical model for energy consumption of mobile users for the *Collaborative Downloading* service. In this paper we modified our analytical model according to our energy consumption model proposed in the previous section. 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:

$$E_{ind} = NE_{\%(3G)}S_{file} \tag{1}$$

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 S_{file} denotes size of the downloaded file in GB. Energy consumption E_{col} of a single file download when mobile telecom operators use the *collaborative approach* can be calculated as follows:

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

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

where

$$\alpha = \frac{E_{\%(Bluetooth)}}{E_{\%(3G)}}, \quad \beta = \frac{E_{\%(WiFi)}}{E_{\%(3G)}}. \tag{4}$$

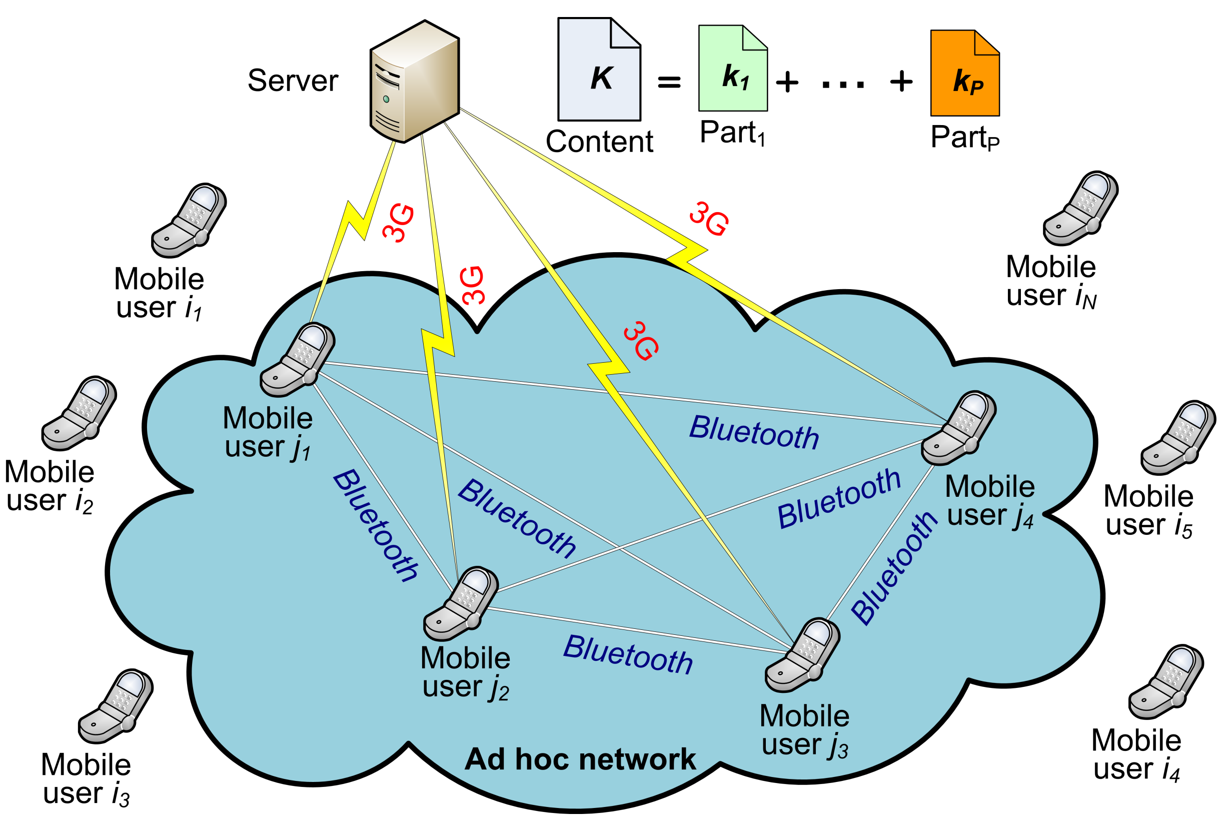

Figure 3. The system model for the *Collaborative Downloading* service

Using data from Table IV (for download), we can calculate that $\alpha = 1/2.81 = 0.36$ and that $\beta = 0.47$. If we have 5 mobile users, then we can calculate $E_{col(3G+Bluetooth)}$ and $E_{col(3G+WiFi)}$. $E_{col(3G+Bluetooth)} \approx 0.78\ E_{ind}$ and $E_{col(3G+WiFi)} \approx 0.95\ E_{ind}$. In our previous work [16] we compared GPRS and Bluetooth communication technologies and calculate that $E_{col(GPRS+Bluetooth)} \approx 0.27\ E_{ind}$. Moreover, we compared UMTS and WiFi communication technologies and got the following result $E_{col(UMTS+WiFi)} \approx 0.82\ E_{ind}$. Results are different due to different versions of communication technologies.

V. Conclusions and future work

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 analyzed. On that basis a simple energy consumption model for Android phones was design. Using our model, we showed how to calculate energy consumption for the *Collaborative Downloading* service. The main idea behind the service 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.

Measurements were made using a simple Android application in which we were downloading or uploading data continuously. In future work we will upgrade our application in order to adjust the size of the file being transferred, as well as the time between transmissions. Moreover, apart from monitoring the battery status in percentage, we will directly measure phone's energy consumption using a measuring device.

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