Measuring the Power Consumption of Smartphones

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Abstract

Smartphones are becoming a part of everyday life and as such, a better understanding of hardware and software power consumption is crucial to develop more efficient smartphones. In order to extend battery life, application developers and phone designers must become aware of the limitations of a phone's CPU power, as well as the LCD display consumption and connectivity via WiFi, 3G, and GPS systems. We present power consumption measurements of an *HTC Incredible S* and compare these results to known analytical models. The evaluation shows that power consumption is considerably varying with different types of smartphones and that well known models underestimate the actual consumption. The results illustrate that touching the screen nearly doubles the power consumption, which is not captured by any analytical model. Moreover, we present in which way the transmitted packet size of WiFi and cellular communications affect the power consumption.

1 Introduction

As todays smartphones offer a variety of broadband services and applications, the power consumption of such devices has monotonously increased over the last years. Due to this, knowledge about power consumption and power saving potential is required in order to extend battery service life. Since many components interact within smartphones, power consumption measurements as well as analytical modeling are quite challenging and very few works on the subject have been published yet. Subsequently, most of the publications address power consumption of special applications, algorithms or technologies instead of considering the overall consumption of such devices. For example, the authors of [1] propose a new energy-efficient tracking algorithm, while [2] presents power consumption measurements of location-aware applications. In contrast to that, [3] deals with analyzing the power consumption of 802.11n, i.e. of the WiFi interface within a smartphone, whereas [4] reduces the power consumption of 3G data transmissions by shifting the local computation from the smartphone to a Virtual-Machine based Proxy. In order to reduce the overall power consumption by considering the interaction of different components within the smartphone, [5] identifies a methodology for collecting measurements, while [6] derives an analytical model for the power consumption.

We focus our following analysis on the analytical model presented in [6], which is derived in an empirical manner by power measurements. Here, the authors used a Nokia N95 with an internal power meter and compared measurements with different utilization of the GPS, 3G, and WiFi interface as well as the brightness and the CPU. Based upon these measurements, they identified the most power-consuming components and determined an analytical model, which is given by

$$P = (\beta_{uh}f_h + \beta_{ul}f_l)\,\mathrm{u} + \beta_{CPU}\mathrm{CPU}_{on} + \beta_{br}\mathrm{br} + \beta_{Gon}\mathrm{GPS}_{on} + \beta_{Gsl}\mathrm{GPS}_{sl} + \beta_{WiFi_l}\mathrm{WiFi}_l +$$
$$\beta_{WiFi_h}\mathrm{WiFi}_h + \beta_{Audio}\mathrm{Audio} + \beta_{3G_{idle}}\mathrm{3G}_{idle} + \beta_{3G_{FACH}}\mathrm{3G}_{FACH} + \beta_{3G_{DCH}}\mathrm{3G}_{DCH}\,. \tag{1}$$

The power consumption of the CPU is modeled by the first two terms, the consumption of the LCD display by the third term, the consumption of the GPS by the fourth and
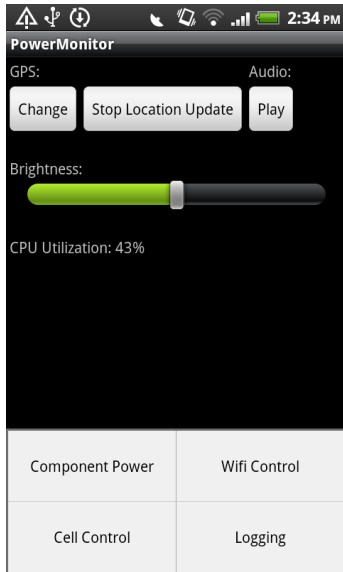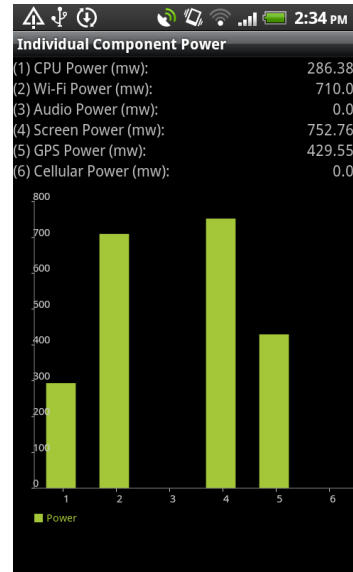
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Figure 1: Graphical User Interface

Figure 2: Component Power Consumptions

fifth term, the consumption of the WiFi module by the sixth and seventh term, the consumption of the audio module by the eighth term and the cellular power consumption by the rest of the terms. Numerical values and clarifications for all parameters of this model can be found in [6] and are matched to an *HTC Dream*.

In order to evaluate power consumption changes regarding different smartphone types, we implemented the model in (1) on an *HTC Incredible S* in terms of an Android application. The graphical user interface and the resulting component power consumptions are shown in Fig. 1 and Fig. 2. In the following, we use the results of this application as a comparison for the actual measurements. To facilitate the comparison, we used system parameters that are the same as in [6].

2 Measurement Setup

According to the analytical model in (1), there are six main components that characterize the power consumption of smartphones. They are the CPU of the smartphone, the LCD display, the WiFi network, the 3G network, the audio output, and the GPS localization. As already mentioned, the application shown in Figures 1 and 2 monitors all the components and measures their theoretical power consumption accordingly. This provides the base for our experimentation and, by using these numbers also a validation of our measurement results. The power averages of the theoretical model are obtained using the implementation of the application. We implemented it by recording the instantaneous component powers in a feature of the application and saving them to a .txt file on the phone's MicroSD memory card. Then, the measured data could be mounted on a computer interface and analyzed in MATLAB for comparison later on.

Due to hardware restrictions, it is only possible to measure the instantaneous total power for a given period of time. The difficulty in our measurement setup was to overcome
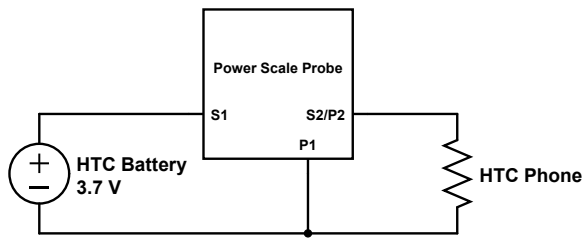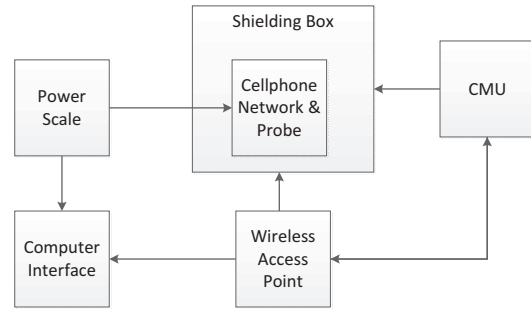
Figure 3: Probe Circuit

Figure 4: Block Diagram of Setup

the small gap between the smartphone battery and the connector of the smartphone, i.e. the resistive network. This was accomplished by extending the length between the two connections with a small piece of breadboard, which added the needed surface area. From here, the probes of our power meter (Power Scale) were connected in series and in parallel as can be seen in Fig. 3. With this circuit established, we could alter various settings on the smartphone and record all the instantaneous results via a computer interface. But again, this setup is only capable of displaying and recording total power fluctuations of the circuit. Therefore, measuring the individual component power is a future endeavor and is necessary in order to make more complex and precise power models.

Once the Power Scale was operational with the smartphone, we began to add each additional piece of equipment in order to isolate the testing of each component. The CPU, the GPS, the LCD screen and the audio output did not need any additional equipment besides the interface to measure their power output. For the WiFi power testing, the smartphone had to send data packets using WiFi. This was achieved by connecting a wireless router to the computer which would allow the *HTC Incredible S* to connect to the network of our choice. In order to measure the 3G power consumption, the smartphone had to send data packets over a 3G network. This was accomplished by connecting a Universal Radio Communication Tester (CMU) to the computer and wireless port. The probe circuit was then placed in a shielding box during the test in order to increase reception. The final equipment setup is depicted in Fig. 4 and Fig. 5 , where an overall connection layout can be seen with the block diagram, accompanied by the actual setup.
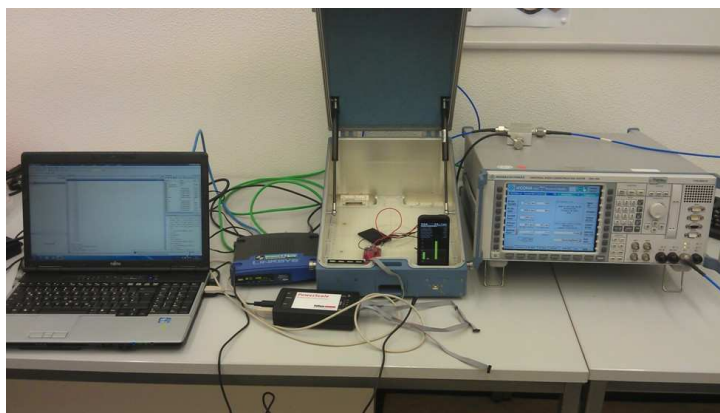

Figure 5: Physical Measurement Setup

3 Results of Power Measurements

The Power Scale is provided with a MATLAB application programming interface (API) which allows us to plot the instantaneous power for each test and obtain power averages for selected time sequences. These averages were plotted per activity of the interface that was currently commanded during that testing sequence. These results were then compared to power averages obtained from the theoretical model in [6].

Firstly, the testing of the 3G communication was established by placing the *HTC Incredible S* in the shielding box and by activating all the devices as described in the setup above. The CMU can often be capricious when registering the *HTC Incredible S* at the base station emulator, therefore certain options on the CMU were adjusted in order to maximize the measurement process. Once the smartphone has successfully registered to the CMU, the Apache server is switched on and a network protocol analyzer software (WireShark) is used to monitor and verify successful data transmission. The option to send data is selected via the Android application, while the data packets and their protocols can be detected with the help of WireShark.

In Fig. 6, the transmission of a 1KB data packet within 3G can be readily seen. The average power begins quite low, as the HTC phone starts in an idle state with nothing running but the CPU background activity. At around 15s, the phone is told to connect to the 3G network provided by the nearby base station emulator. The power nearly doubles here as the phone is searching to register to the CMU. Once it does, the power returns to its usual idle power. After roughly 30s, the user chooses to send a 1KB data packet. The several touches of the screen cause small, immediate spikes in the power consumption of the smartphone as depicted in Fig. 6. Although these spikes are only occurring in short time intervals, typically below half a second, the power consumption is nearly doubled or tripled. Therefore, touching the screen will considerably raise the average power consumption and cannot be neglected. As known analytical power consumption models do not account for this, they are not able to predict the power consumption in an accurate way. After the user stops interfering with the touchscreen, the power consumption remains steady as the phone sends the data packet to the server. Comparing the average experimental power to the average theoretical power allows us to draw some
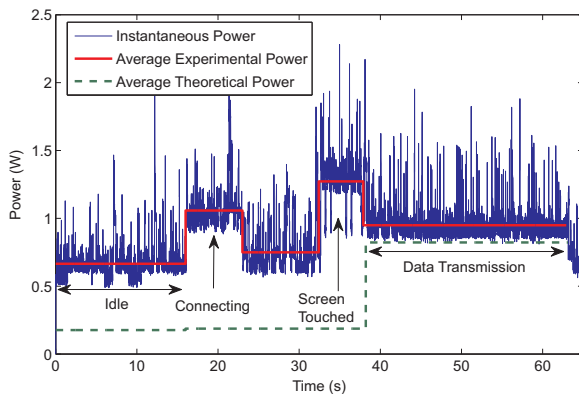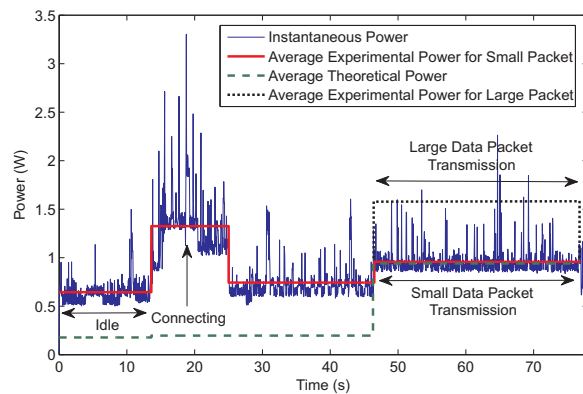
Figure 6: 3G Power vs. Time

Figure 7: WiFi Power vs. Time

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important conclusions about the accuracy of the theoretical model. There is a much larger power during 3G network connection (about 400 mW) than predicted by the model (only 10 mW). An important flaw of the theoretical model is its failure to accurately portray increases in power consumption when the touch screen is heavily utilized. In this case, if the screen is pressed thoroughly a few times, it greatly affects the total power and skews the final average. However, the model does quite well to represent the power consumed during data transmission and represents a difference of only 100 mW.

For testing the wireless network communication, again the network protocol analyzer as well as the wireless server port which allowed the *HTC Incredible S* access to the wireless network were used. Data packets of various sizes were tested during communication with the server, but no difference in power consumption was noticed while using only 3G communication.

Examining Fig. 7, it is clear that there are similar comparisons involving WiFi communication to the server. As with 3G communication, the power consumption idles, then is raised to connect to the local WiFi network, and finally a constant high strain on power consumption during the transmission of a 1KB data packet is reached. We also tested the transmission of a 1MB data packet via WiFi which yields further interesting results. The instantaneous powers that preceded data transmission are identical for both packet sizes but once the data transmission starts, the average power is much higher for larger packets, which can be seen at the tail end of Fig. 7. Clearly, data size significantly influences the power consumption when using WiFi, while the theoretical model as described by [6] does not account for this phenomenon. In the same way, the power consumption is raised when severe fading arises between the phone and the base station (emulator). For instance, if the line of sight is blocked or if shadowing or diffraction occurs, the transmission power of 3G as well as that of WiFi increases considerably. This effect is typically neglected in analytical power consumption models for smartphones as well.

Measuring power fluctuations of the LCD and GPS activity did not require the use of the CMU base station and therefore made experimentation more consistent and reliable. However, the same setup was still used in order to maintain a constant and unbiased environment for the smartphone.

In Fig. 8, the power distribution of the LCD display is represented by the measured instantaneous and average powers as well as the theoretical averages from the analytical model (Android application). The power of the *HTC Incredible S* begins at minimal screen brightness, i.e. no backlighting, while at 10s the screen is incrementally increased to its maximum brightness. Averages are computed as usual for minimum and maximum brightness, but for increasing brightness, a sliding average computation was applied. Thereby, the sliding average uses linear regression in order to get time-variant averages. This was then compared to the linear power consumption regarding equation (1). The power from the analytical model is quite accurate here and provides a near perfect prediction of the LCD power consumption with a difference in power of only 100 mW throughout the measurement.

Lastly, in Fig. 9, the GPS power of the *HTC Incredible S* is plotted according to its different activity stages. After approximately 10s, the GPS satellite interface is turned on, which yields a small difference in actual power compared to what the theoretical
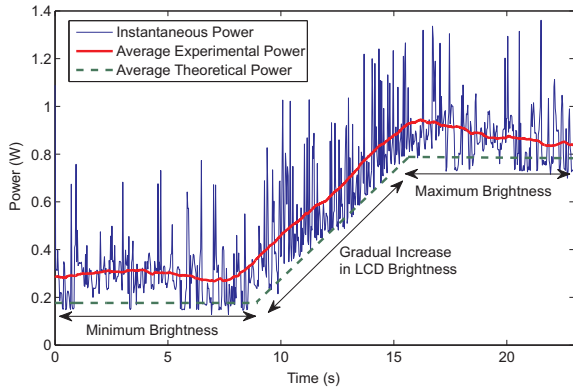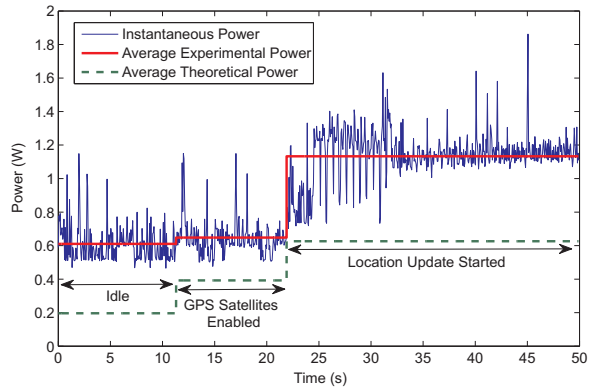
Figure 8: LCD Power vs. Time

Figure 9: GPS Power vs. Time

model predicts. After 20s, the smartphone is requested to start a location update using GPS. The model predicts an increase in power but the actual (measured) increase is much greater in fact. This has been a common problem throughout the testing. The theoretical model as proposed by [6] is quite accurate in knowing when the power will increase, but in every case, it underestimates the total power consumption. This is more evident than ever here, as during the satellite location update, the measured power differentiates more than 500 mW from the power derived by the analytical model. Therefore, certain scaling should be applied to the theoretical model to get it on par with the experimental Power Scale measurements.

4   Conclusion

Since the power consumption of smartphones has monotonously increased during the last years due to numerous launched broadband applications and services, we have presented power consumption measurements. By using a power meter, we were able to determine the actual power consumption of the CPU, the screen, 3G, and WiFi. In order to maximize the accuracy of the results, we used the original battery during the measurements by interconnecting the power meter between the phone and the battery. The corresponding measurement results were compared to known analytical models predicting the actual consumption. The comparison shows that analytical models underestimate the real consumption as a consequence of neglecting some effects. We have shown that power consumptions of smartphones are very sensitive to touching the screen, as the overall power consumption is doubled or tripled when pressing buttons on the screen. None of the known analytical models consider this effect. Moreover, the results show that power consumption of wireless transmissions, like WiFi or 3G is a function of the used packet sizes and channel environments. As analytical models typically neglect the channel environment, i.e. whether the smartphone is used in an urban, suburban or rural environment, they are not able to accurately predict the power consumption. These unaccounted discrepancies have to be implemented in future models and the acute interdependence that the different components may or may not have on each other has to be modeled. In order to target these discrepancies, a measurement setup able to determine the instantaneous

power of each component individually is necessary, in order to see what effect they have on each other.

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