Smartphone Energy Consumption of Multimedia Services in Heterogeneous Wireless Networks

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***Abstract*—Energy consumption is a key issue that impacts on user quality of experience when delivering rich media services to smartphones via heterogeneous wireless networks. Previous research works have studied the smartphone energy consumption in a broad manner only. This paper focuses on comparative energy consumption investigation of rich media transmissions over 3G and WiFi networks involving a real life smartphone device. In particular, the energy consumption of the CPU and radio interfaces (i.e. HSDPA and WiFi) for different rich media services (i.e. video streaming, interactive video call, file download, web-browsing) is recorded. The results obtained show how deliveries over the WiFi interface are more energy efficient than those over the 3G interface (i.e. up to 36.5% for downloading service). Additionally, the difference between the energy consumption when employing WiFi and 3G is the lowest and highest for web-browsing and file downloading services, respectively. Outcome of the investigation can provide beneficial input for smartphone energy optimization solutions.**

Keywords*—*Smartphone, Energy Saving, 3G, WiFi, Multimedia

I. Introduction

THE popularity of smartphone devices in our society has risen dramatically in the last decade and is showing no signs of slow down. It was estimated that of the 5 billion mobile phone users worldwide over 1 billion of them have smartphone devices[1] and it is very easy to understand why these devices have become so popular. Smartphones offer users the ability to perform everyday computing tasks including having email access, browsing the web, enabling social networking, etc. as well as have access to all the other features one would associate with typical mobile phones. These tasks can all be done even when users are highly mobile due to the new wireless technologies (WiFi, 2G, 3G, LTE, etc) that smartphones make use of. Although they and their associated technologies provide clear benefits, smartphones present some problems in relation to the quality of service they offer to their users.

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Moore's law states that processing power doubles for devices at least every second year and this indeed holds true for smartphone devices. This allows the applications and services that smartphones provide to become more elaborate and much more powerful. However with this increase in processing power the energy consumption of the devices rises considerably and as was mentioned before that processing power is increasing dramatically, the same does not hold true for the battery capacity of these smartphone devices. Currently the majority of smartphones use lithium-ion batteries and the storage capacity of these batteries has not even doubled in the last decade[2]. Unfortunately, at the moment the only way of increasing the battery life of a smartphone device is to increase the size of the battery unit powering it, which does not correspond to the demands of consumers, who desire their devices to be small and light in order to enable mobility.

Alternative solutions for battery life increase are sought by researchers worldwide, and these also include optimizing the applications and services that run on smartphones along increasing the efficiency of the hardware components. Smartphones run a wide range of applications and services and the power consumption associated with each of them varies greatly. By profiling these different applications and services in terms of their energy consumption, an energy model can be created which can aid in the development of more efficient smartphones and smartphone applications.

This paper performs an energy consumption investigation of rich media transmissions over 3G and WiFi networks involving a real life smartphone device which runs an energy measuring application PowerTutor [3]. The energy consumption of the CPU and cellular and broadband wireess radio interfaces for different highly popular rich media services including multimdia streaming, interactive video call, file download, and web-browsing is measured and analysed. The test setup, description and scenarios are presented in section III. The results obtained show significant differences in energy consumption between the cases when WiFi and 3G networks are used as well as between the different network services that are being tested. The results of these tests are presented in section IV and are analysed in section V.

II. Related Works

Previous studies have looked at the performance and energy consumption of smartphones across a wide range of applications. Perrucci et al. [1] takes a low level look at the different services that smartphones provide and outlines the energy cost associated with them. Another approach considered by Metri, Grace et al. [4] looks at a few specific applications popular among smartphone users and observes their energy consumption. After analysing these studies it is clear that data transfer is one of the main sources of energy consumption. These two studies focus on a broad range of applications, but the studies could go more in depth in order to better understand how energy is consumed by network activities. In [5], the smartphone energy consumption of using multipath TCP is studied and the reports shows that smartphones with multipath transmission support consume more energy than those with regular TCP when using the same service and the same network interface.

A study by Perrucci et al. [1] takes a detailed look at the energy consumption for different parts of a smartphone device. Perrucci uses a Nokia smartphone and an application called the Nokia Energy Profiler, which is quite similar to the PowerTutor application. The study provides a useful broad analysis of the power consumption of many different services that run on a smartphone device. This study concludes that data transfer via WiFi and 3G on smartphones are some of the most important energy consuming smartphone components and takes an in depth look at these areas in particular. In [10] and [11], novel energy-aware MPTCP-based solutions are developed to find a tradeoff between the improvement of the data transmission throughput and the total energy consumption of mobile devices. They achieve energy saving by performing data traffic offloading, moving part of the data traffic from the most energy-consuming wireless interface to the others.

Balasubramanian et al. [7] investigate the impact of network on energy consumption. It is reported that the majority of energy is consumed during the start and end of data transfer when using GSM, 3G and WiFi. Nevertheless the study does not consider the impact of different applications on power consumption, which is covered in our study. Metri et al. [4] observes how popular applications perform in terms of their power consumption. The tests are performed using an Apple iPhone 4S which uses Apple Instruments performance analyser which can be used to track hardware statistics such as CPU activity. The study looks at Facebook, Skype and other popular applications and contrasts and compares their energy usage. Unfortunately the Apple Instruments software does not give a real life representation of power consumption (mW, joules etc.) but instead rates the energy consumption on a scale of 1-20 to allow the different applications to be compared. While the findings of the report are indeed useful, the study presented in this paper extends this and provides highly accurate real life measurements of the power consumption.

III. Energy Consumption Study

This section presents the steps taken to generate the results in terms of energy consumption for diverse services distributed over different network types. It also details the methodology and the tools used along the way.

TABLE I: Relevant Hardware Details

Battery	Li-Ion 1500 mAh battery
WLAN	Wi-Fi 802.11 b/g/n
3G	HSDPA, 7.2 Mbps; HSUPA, 5.76 Mbps

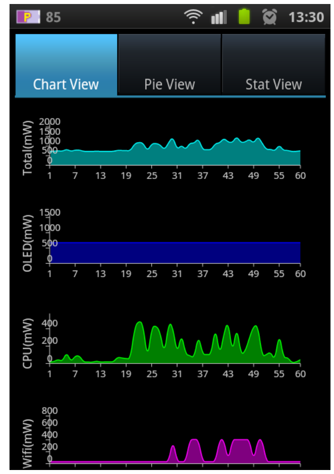

Fig. 1: Screenshot of PowerTutor on Android 2.3.3

A. Hardware Description

The smartphone used in this study was a Samsung Galaxy S GT-I9000 [8] running Android 2.3.3 Operating System. The smartphone is capable of network communication via both WiFi and 3G and is powered by a lithium-ion battery typical of most smartphones. These make the Samsung Galaxy S a highly suitable choice in this study. Table I describes the device and network-related characteristics.

B. PowerTutor

The PowerTutor [3] application was used to measure the power consumption. PowerTutor is available on the majority of Android devices and allows real time graphing of a phone's current power consumption. The overal power consumption can be viewed as well as the consumption of various individual device components such as the CPU, display, WiFi interface, 3G interface, and much more. PowerTutor also outputs a log file, which can be parsed in order to gain useful information. This is particularly useful to this study as it focuses specifically on data transfer and the associated energy costs.

C. Testing Scenarios

Four tests were carried out making used of both the 3G and the WiFi networks. The tests involve four rich media services: web-browsing, file downloading, interactive video/audio service and multimedia streaming and are described in details in Table II. These four scenarios reflect typical usage of a smartphone.

D. Assessment

The outputs of the tests were stored in log files by PowerTutor, which has created and saved them on the mobile device. These logs were then transfered from the mobile to a PC so that they could be parsed.

Fig. 2 shows a sample of the PowerTutor log file content. The 5th line of the log indicates that the WiFi connection

TABLE II: Details of Testing

Name	Description	Purpose	Application
Test 1	Users browses to www.imgur.com and browses sporadically for 60 seconds.	Simulates TCP traffic at random intervals over a small timeframe.	Firefox web browser[12]
Test 2	User downloads a large file from a web server for 80 seconds..	Simulates constant TCP traffic over a short time-frame.	Firefox web browser
Test 3	User engages in a 45 second video and audio call.	Simulates constant UDP and TCP traffic for a fixed duration.	Skype[13]
Test 4	User streams live video and audio for a fixed time period of 45 seconds.	Simulates UDP traffic over a fixed duration.	RTE News Now[14]

```
CPU-10081 0
CPU-10082 18
CPU-10093 9
CPU-10104 371
Wifi 405
Wifi-on true
Wifi-packets 102
Wifi-uplinkBytes 6861
Wifi-downlinkBytes 56730
Wifi-uplink 0
Wifi-speed 36
Wifi-state HIGH
Wifi-10104 404
3G 0
3G-on false
GPS 0
```

Fig. 2: Sample of PowerTutor log file content

```
6     49    10    59
7     140   10    150
8     76    10    86
9     209   401   610
10    177   570   747
11    255   570   825
12    111   570   681
```

Fig. 3: Output log file content sample

is using 405mW of power. Also presented is some useful information about the number of bytes transmitted uplink and downlink, respectively. However this study is concerned with certain information from this very large log file (several thousand lines). Therefore the file must be parsed in order to obtain the desired information.

The two components that this study focuses on for power consumption are the CPU and the network interface in use (i.e. 3G or WiFi). A Java application was developed so that the detailed PowerTutor output log was parsed and a new output log file containing the information required only, was produced. A sample of the output log's content is presented in Fig. 3. The first column refers to the current time cycle, the second is the CPU power consumption, the third is the network interface power consumption and the fourth is the total power consumption. All these values are expressed in mW.

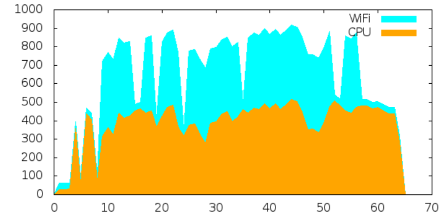

Fig. 4: Browsing using WiFi

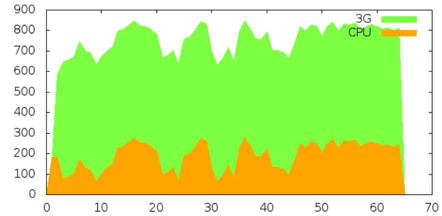

Fig. 5: Browsing using 3G

IV. RESULTS ANALYSIS

In this section, testing results from the four test scenarios (described in section III) are presented and analyzed, respectively. The energy consumption of CPU and WiFi or 3G radio interfaces for different multimedia services is measured and shown for each test scenario. The consumed energy (E) is computed according to equation (1), where P denotes the instant power consumption (in mW) of the studied device component and t is the time duration measured on the component.

$$E = P \times t \quad (1)$$

A. Test 1: Web Browsing

This test involves opening a web browser and browsing sporadically for approximately 60 seconds. The results are illustrated in Fig. 4 and Fig. 5 and the measured energy consumption values are shown in Table III.

According to Fig. 4 and Fig. 5, it is clear that the energy consumed by CPU is higher when the WiFi connection is used than when the 3G interfaces is employed. Statistics from Table III further shows that although the energy consumption of CPU is 51.2% higher in the WiFi case than in that of 3G, the total energy consumption (including data processing) of using WiFi connection is still 11% lower than that of using 3G. It is likely that the reason for the high CPU energy consumption for WiFi is due to the high arrival rate of packets. Since the bitrare of the traffic over the WiFi interface is much higher than that in the 3G case, the CPU is forced to work more frequent in order to process the data compared to a more staggered arrival rate with 3G.

B. Test 2: File Downloading

This test involves downloading a file for around 80 seconds. The results are presented in Fig. 6, Fig. 7 and Table IV.

Results show that, in comparison with the web browsing test scenario, the energy consumption of CPU for the WiFi connection case is reduced by 69.1% and it is maintained similar for the 3G connection situation. Additionally, it is shown that the total energy consumption when using the

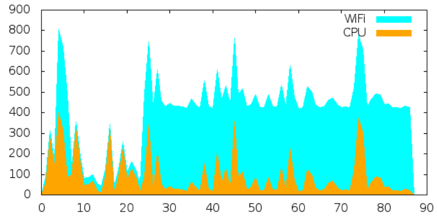

Fig. 6: Downloading using WiFi

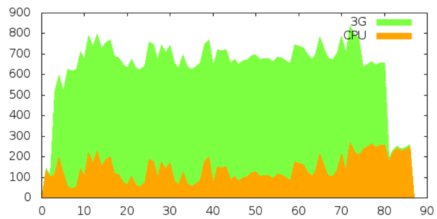

Fig. 7: Downloading using 3G

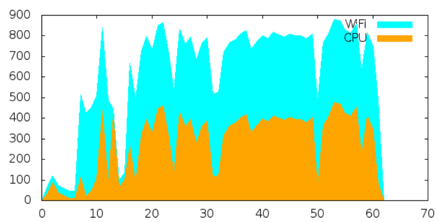

Fig. 8: Skype using WiFi

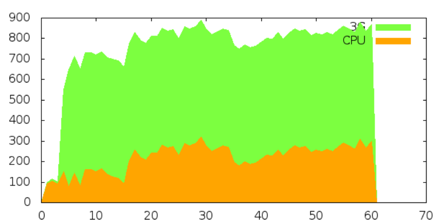

Fig. 9: Skype using 3G

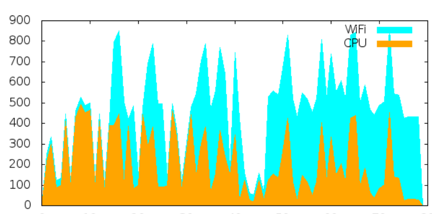

Fig. 10: Streaming video using WiFi

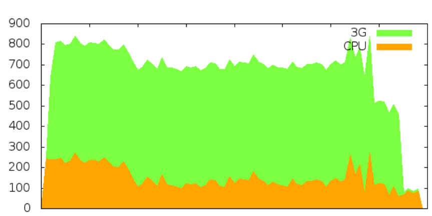

Fig. 11: Streaming video using 3G

TABLE III: Browsing Energy Consumption in Joules

Method	CPU (J)	Data (J)	Total (J)
WiFi	25.282	17.360	42.642
3G	12.187	35.751	47.938

TABLE IV: Downloading Energy Consumption in Joules

Method	CPU (J)	Data (J)	Total (J)
WiFi	7.811	27.344	35.155
3G	12.364	43.019	55.383

TABLE V: Skype Energy Consumption in Joules

Method	CPU (J)	Data (J)	Total (J)
WiFi	17.435	21.359	38.794
3G	13.207	32.351	45.558

TABLE VI: Multimedia Streaming Energy Consumption in Joules

Method	CPU (J)	Data (J)	Total (J)
WiFi	15.955	20.750	36.707
3G	11.754	40.477	52.231

WiFi connection is 36.5% lower than that of using 3G. Consequently, the downloading service records a 69.8% higher difference than web browsing service in terms of total energy consumption between WiFi and 3G. Unlike the bursty web browsing traffic which might cause fluctuations in power status of CPU and radio interfaces, the downloading traffic maintains both CPU and radio interface in high power status since the packets are received continuously. The results indicate that, although both WiFi and 3G antennas are in a high power state during the entire downloading process, WiFi performs more energy efficient than 3G, which gives WiFi a much lower overall energy consumption.

C. Test 3: Interactive Video Calling

This test initializes a skype video calling for 45 seconds after which the call was ended. The measured results are shown in Fig. 8 and Fig. 9 and Table V.

It is shown that the energy consumption of the CPU when using the WiFi connection for skype a video call service increases by 55.2%, in comparison with that of downloading service and maintains a similar level when using 3G, in comparison with that of both web browsing and downloading services. In conclusion, for skype video calling service, the total energy consumption in the WiFi connection case is 14.8% less than when using the 3G connection, which is consistent with that of web browsing and downloading services.

D. Test 4: Streaming Video

This test runs the *RTE News Now* application which streams multimedia content (i.e. with video and audio components) for 45 seconds. The results are presented in Fig. 10, Fig. 11 and Table VI.

Results show that although the energy consumption of the CPU is 26.3% higher in the WiFi case than that when using 3G, the total energy consumption whe employing the WiFi connection is still 29.7% lower than that in the 3G situation. Looking at Fig. 11 and Fig. 12, it can be seen that the 3G connection never remains in a high power state for the entire duration of the streaming, but WiFi fluctuates between a high power state and a lower power state as expected. This is due to the higher bandwidth of WiFi which can buffer a sufficient

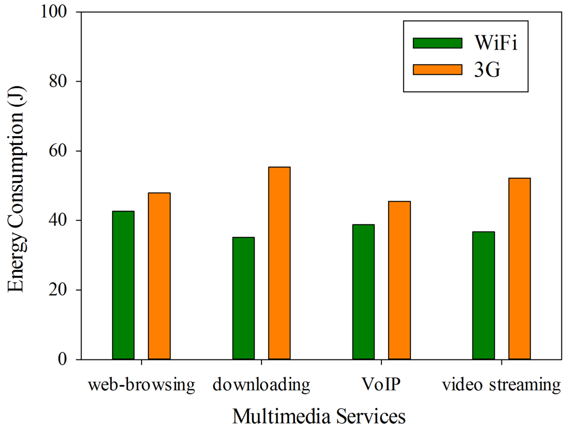

Fig. 12: Energy consumption of WiFi and 3G for different multimedia services

number of video packets and switch to a low power idle state before returning to a high power state.

E. Comparison of Test Results

By looking at Table III-Table VI, it is shown that the energy consumption for processing data packets when using the 3G interface is 51.4%, 36.4%, 34%, and 48.7% higher than when employing WiFi for web browsing, downloading content, performing a skype video call, and using a multimedia streaming service, respectively. Additionally, the energy consumption of the CPU when using 3G is with 51.2%, 24.3%, and 26.3% higher than when using WiFi for web browsing, skype video call, and multimedia streaming service, respectively, and 36.8% lower than when employing WiFi for downloading service.

Additionally, web-browsing service achieves the lowest energy consumption difference between WiFi and 3G cases (i.e. 5.3J). The energy consumption is the highest for the downloading service, 48.2% higher than that of the web-browsing service.

Fig. 12 presents the energy consumption comparison between the cases when WiFi and 3G are employed for the four multimedia services. It is noted that, in general, WiFi is more energy efficient than 3G for all of the four multimedia services. For instance, the WiFi usage results in 11%, 36.5%, 14.8%, and 29.7% lower energy consumption than that of 3G, for web browsing, downloading, video call, and multimedia streaming service, respectively. However the amount by which the solution is more efficient varies greatly depending on a number of factors such as the arrival rate of packets, bandwidth of the connection, type of service, base energy cost of transmitting data (high power state), etc.

F. Study Benefits

The test results can be of great benefit for designing smartphone energy saving solutions. Mobile users can be advised to use either WiFi or 3G for the given application and the current remaining battery life. Devices which employ multipath communications solutions such as MPTCP or eMPTCP [10] can offload traffic between radio interfaces (i.e. WiFi and 3G) based on automatic algorithms in order to achieve optimal energy efficiency. For instance, WiFi is preferred for downloadind servicea over 3G in order to save energy due to the high difference in energy consumption values (Table IV).

V. Conclusion

This paper studies how 3G and WiFi, which are widely used radio interfaces in smartphones, perform in relation to their power consumption. A number of tests were carried out using a real life test bed and the energy consumed was measured for four major ervice types. The energy consumption difference between the cases in which the two interfaces are used reaches the highest value for the downloading service, (i.e. 48.2% higher) in comparison with that for the web-browsing service. The findings reveal that WiFi is more energy efficient than 3G (e.g. up to 36.5 % for downloading service) and this applies to all rich media services used.

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