Power Consumption and Throughput of Wireless Communication Technologies for Smartphones

Evan Fallis and Petros Spachos
School of Engineering, University of Guelph, Guelph, ON, N1G 2W1, Canada
E-mail: efallis@uoguelph.ca, petros@uoguelph.ca

***Abstract*—As the popularity of smartphones increases, so does the need for their power efficiency. Many hardware components such as sensors are added to smartphones which contribute to higher power consumption. Although battery efficiency tries to balance this issue, sometimes it is not enough. In this paper, we evaluate the power consumption, throughput, and data transmission efficiency of three wireless technologies on smartphones. Specifically, through extensive experimentation, we examine the performance of Wi-Fi, Bluetooth and LTE of four smartphones. The results can help designers estimate the power usage of wireless technologies commonly found in smartphones of today.**

I. Introduction

Following the culture shift tending towards the popularity of smartphones and other mobile electronics, data streaming has become integral in the way modern media is consumed. Smartphones today have battery lives that are very low relative to cellphones manufactured before the last decade [1]. This lack of battery efficiency is due to many factors, including display resolution, processing demands, and the streaming of data [2] [3]. This trend of increasing smartphone resolution will likely continue in the upcoming years, meaning that batteries will not be able to compensate for the increased energy demand without methods of increasing the efficiency of the battery itself or decrease the energy expended from transferring large amounts of data [4].

In this work, we examine the power consumption, throughput, and data transmission efficiency of three popular communications technologies used in a smartphone: Wi-Fi, Bluetooth, and LTE. Extensive experimentation has been conducted with four devices utilizing different display size, resolution and characteristics. The results from such experiments can help predict the energy usage of varying phones.

According to the experimental results:

- LTE has the highest throughput in our experiments
- Bluetooth has the lowest power consumption among the examined wireless technologies.
- Wi-Fi is the most efficient wireless communication technology, followed by Bluetooth, and LTE.

The rest of this paper is organized as follows: related work is in Section II, Section III describes the experimental design and the methodology, followed by Section IV with a discussion on the experimental results. The conclusion is in Section V.

II. Related Work

In [5], a model to predict the battery life of multiple wireless technologies based on download time and amount of data transferred is proposed. Unfortunately, this study was forced to rely on measuring the reported battery life of the smartphone rather than directly measuring the actual energy consumed. The work in [6] demonstrates the importance of control packets in Transmission Control Protocol (TCP) when considering power usage in smartphones, specifically suggesting the possibility of delaying data packets to save energy. In [7], a new method named the Energy-Aware Refactoring Approach for Mobile (EARMO), which reduces the power consumption of mobile applications, is suggested. This method was tested using benchmarks of 20 Android applications and found that it could extend the battery life. The Context based Wi-Fi Status Prediction Model was introduced in [8] where it was proposed that the activities of the phone user could be predicted and an optimal network configuration could be chosen to minimize battery usage.

Model	Mini	Note 3	Note 4	MEGA
Wi-Fi (802.11) protocols	a/b/g/n	a/b/g/n/ac	a/b/g/n/ac	a/b/g/n/ac
Bluetooth	4.0	4.0	4.1	4.0
Display diagonal (mm)	108	145	145	160
Display area (cm^2)	42.0	75.7	75.7	92.2
Resolution (pixels)	540×960	1920×1080	1440×2560	720×1280

TABLE I: Smartphone specifications.

In this work, the experiments presented are varied in terms of smartphone specifications, network protocols used to transfer data, and the information hosting methods.

III. Experiment Design and Methodology

A. Experimental Setup

Smartphone selection. Four different Samsung smartphones were chosen to conduct the tests: S4 Mini, Note 3, Note 4, and MEGA 6.3. This variety of smartphones help show differences in power usage based on display size, resolution and communication chip version. Smartphone specifications are shown in Table I.

Power measurement. The Monsoon Low Voltage Power Monitor was the main source of measurement used. It was used to supply power to the phone and is able to get very accurate readings since the battery of the smartphone is bypassed. This configuration also keeps a consistent power usage as the phone battery reading will remain relatively constant. The positive terminal of the battery was covered and replaced by the terminal of the Monsoon. The negative terminal of the Monsoon was connected to the node between the negative battery terminal and phone. The data streaming would start a minute before the actual recording due to the power spike from interfacing with the touchscreen. The Monsoon was set to measure for two minutes, with the total length of each run being three minutes.

B. Experimental Procedure

All smartphones were tested with matching conditions including full brightness, white background, and no applications running aside from those relating to the experiment. Power measurement started one minute after setup to ensure the only power consumption in the smartphone is from the experiments. All experimentation was done past 8:00 pm in the same lab each time. There are three experiments for each smartphone:

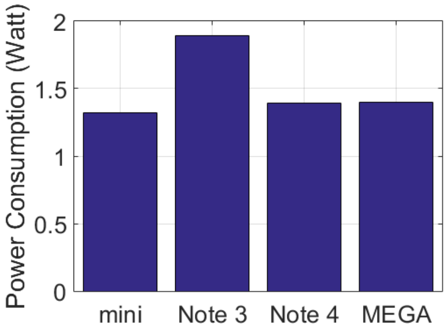


Fig. 1: Baseline power consumption.

i) **Baseline.** The smartphone is powered but all communications are turned off. This baseline is used later on to estimate the actual power being used by the different types of connections.

ii) **Wi-Fi.** The smartphone connects to a PC through a dedicated wireless router using 2.4 GHz. iPerf3 was used to measure the throughput. iPerf3 contains options to either stream data to or from the smartphone based on a client/server model as well as stream through Transmission Control Protocol (TCP), or User Datagram Protocol (UDP). All smartphones were approximately 50 cm from the router. The router in this experiment has the possibility of limiting the throughput as would be the case in every situation. This setup contains four configurations:

   a) The phone is a server and moves data to the PC using TCP.
   b) The phone is a server and moves data to the PC using UDP.
   c) The phone is a client and moves data from the PC using TCP.
   d) The phone is a client and moves data from the PC using UDP.

iii) **Bluetooth.** The smartphone is connected to a Bluetooth peer to peer connection. The measured smartphone being the server and then client. Both configurations will be communicating with an LG G4 smartphone for the duration of the experiment. The distance between devices is approximately 30 cm.

iv) **LTE.** The smartphone uses the LTE network to connect to the Internet. Data is either uploaded to or downloaded from the connected LTE network. All experiments connect to the same network located in Ontario, Canada.

A total of 9 tests exist for each smartphone. Considering that all experiments are run with four different phones, 36 sets of data exist to be compared.

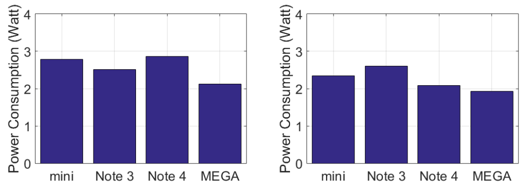
IV. Results and Analysis

A. Baseline

The power consumption of each smartphone in the baseline experiment is shown in Fig. 1. The Note 3 has a much higher baseline than the other smartphones tested, while the Mini has the lowest power consumption overall, due to the smaller display size and lower display resolution. In the following experiments after the baseline test, the baseline power consumption of each smartphone was subtracted from the measured power consumption. This is to have a fair comparison between the smartphones and focus only on the wireless technology characteristics.

B. Wi-Fi

The power consumption of each smartphone in the Wi-Fi TCP experiments are shown in Fig. 2a and Fig. 2b, for the smartphone acting as a client and as a server, respectively, and the throughput performance is shown in Table II. According to the experimental results, the Note 3 consumes the most power out of all the smartphones in server mode while the Note 4 is slightly higher than the rest when the smartphone is acting as the client. The Note 4 has the highest throughput in client mode, while the other smartphones have similar performance. In server mode, all the smartphones perform similarly.

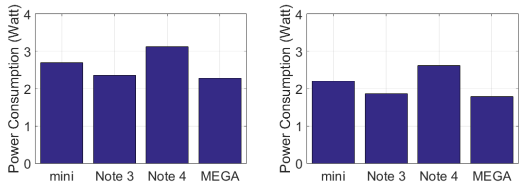


(a) Smartphone Client. (b) Smartphone Server.

Fig. 2: Wi-Fi TCP Power Consumption.

	Mini	Note 3	Note 4	MEGA
Client	26.5	25.8	37.8	25.7
Server	30.3	26.3	26.7	26.8

TABLE II: Wi-Fi TCP throughput (Mbits/s).



(a) Smartphone Client. (b) Smartphone Server.

Fig. 3: Wi-Fi UDP Power Consumption.

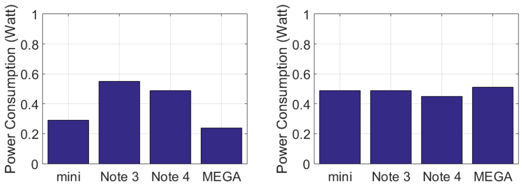
	Mini	Note 3	Note 4	MEGA
Client	19.9	29.1	42.4	21.8
Server	35.7	30.5	35.6	30.3

TABLE III: Wi-Fi UDP throughput (Mbits/s).

The power consumption of each smartphone in the Wi-Fi UDP experiments are shown in Fig. 3a and Fig. 3b for the smartphone acting as client and server respectively, and the throughput is shown in Table III. The Note 4 has the highest energy consumption and throughput. The Mini follows in terms of energy consumption while the MEGA and Note 3 are comparable. It is clear that the Note 4, which has a newer version of the Wi-Fi chip is more efficient and achieves a higher throughput [9]. When the smartphone is the server it can be seen that the data rate is approximately 5 Mbits/s more when comparing UDP to TCP. This may be related to minimized setup and teardown when conducting experiments with UDP.

C. Bluetooth

The power consumption of each smartphone in the Bluetooth experiments are shown in Fig. 4a and Fig. 4b for the smartphone acting as client and server, respectively. The throughput is shown in Table IV. The throughput performance of all the four smartphones in this experiment is essentially the same since they have similar chips which is common for Bluetooth. The Note 3 consumed the most power in downloading mode, the Note 4 had the second highest power consumption while the MEGA and Mini had significantly lower power consumption. The consumption was very similar for each smartphone in the Bluetooth upload experiments. Bluetooth has a much lower energy when compared to other technologies.



(a) Smartphone Client. (b) Smartphone Server.

Fig. 4: Bluetooth Power Consumption.

	Mini	Note 3	Note 4	MEGA
Client	1.23	1.22	1.22	1.18
Server	1.16	0.96	1.00	0.88

TABLE IV: Bluetooth throughput (Mbits/s).

D. LTE

The power consumption of each smartphone in the LTE experiments are shown in Fig. 5a and Fig. 5b for the smartphone acting as client and server respectively. The throughput is shown in Table V. LTE was seen to use a very large amount of energy when compared to other tests. Fortunately, this was also associated with a fairly high data rate across all phones. The benefit of LTE is that it is not dependent on the throughput of a router, hence, it is not constrained when the network is under a heavy load with multiple users.

E. Efficiency

In order to decide the efficiency of different smartphones, a simple equation was used, which is calculated as follows:

$$Efficiency = \frac{Total\ Throughput}{Total\ Power\ Consumption} \quad (1)$$

In the calculation of the efficiency value, we assume the display of the smartphone is ON, so the acquired power consumption has both the power consumed from the display as well as the power consumed from the wireless technology. For the Wi-Fi experiments, Fig. 6a shows the results. It is clear from the results that for Wi-Fi transmission, the Note 4 is the most energy efficient smartphone while the Note 3 has the worst performance out of all the other smartphones in Wi-Fi data transmission. For the Bluetooth experiments, Fig. 6b shows the results. The Mini has the best performance out of all the other smartphones while the Note 3 is again the worst. Finally, for the LTE experiments, Fig. 6c shows the results. The Note 3 has the best performance overall. This is mainly due to the high throughput that this smartphone can achieve in LTE data transmission. It is clear that the display size affects the final results of the efficient data transmission. Wi-Fi is the most efficient data transmission technology, followed by Bluetooth and LTE. UDP is more efficient, however, there are errors in the transmission that should be considered as well.

F. Estimations

By utilizing the baseline data, it is possible to create an estimate of the wireless power consumption without considerations for the actual smartphone. For this model, the MEGA was used to extract an offset that represented wireless energy usage of varying types. The MEGA was chosen because it was found to best model the predictions in terms of accuracy. For instance, an estimate for the Mini Bluetooth usage would use the following equation:

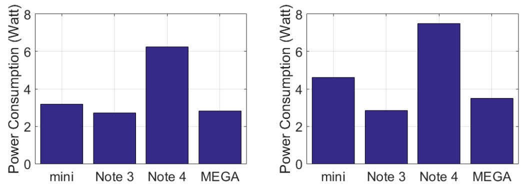
$$Mini_{Blue} = (MEGA_{Blue} - MEGA_{Base}) + Mini_{Base} \quad (2)$$

To get the estimate, TCP and UDP, as well as upload and download have been averaged. The estimates were plotted against the results found through experimentation. In each graph, the estimated value is compared to the actual/experimental from the previously collected data. The percent error for the value of the overall lifetime of the battery can be found in Table VI. This table only considers the values when each line of best fit intercepts with the x-axis. As with the lifetime estimations, each line is based on a small set of data to allow an extrapolation.

Fig. 7a shows the comparison of estimated and experimental. It can be seen that this prediction is fairly close to the actual values although nowhere near perfect. Fig. 7b shows the predictive model for the Note 3. Although not exact, it does show a fairly close estimate of the energy usage. Fig. 7c shows the Note 4 prediction, which is the least accurate for Wi-Fi. It is interesting to note that all estimations for Wi-Fi overestimate the battery life.

Fig. 8a contains the data recorded for the Mini in the Bluetooth experiments. This seems to be extremely accurate without much fluctuation in the estimated battery life. Fig. 8b shows the Note 3 comparisons. Again, the estimated is very similar to the experimental value with a very low error although this one in particular is the least accurate. The Note 4 can be seen in Fig. 8c where it is again very accurate. The difference in Wi-Fi and Bluetooth estimations seems to indicate that Bluetooth chips are much more standardized and therefore consistent when compared to Wi-Fi chips.

The LTE experiments seem to vary wildly in terms of accuracy. Fig. 9a shows the Mini estimate with the LTE configuration. This seems to be the most accurate estimate out of all estimations with a percent error of only 0.31%. Fig. 9b shows the Note 3 which has a similar accuracy to most other estimations. The Note 4 can be seen in Fig. 9c. This seems to be the worst estimate, having an incredibly high error of 37.04%.



(a) Smartphone Client. (b) Smartphone Server.

Fig. 5: LTE Power Consumption.

	Mini	Note 3	Note 4	MEGA
Client	40.5	69.2	39.0	39.32
Server	37.5	28.7	34.1	10.6

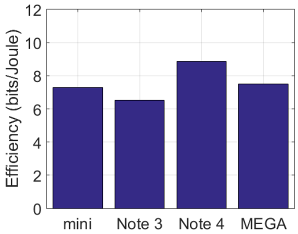
TABLE V: LTE throughput (Mbits/s).

V. Conclusions

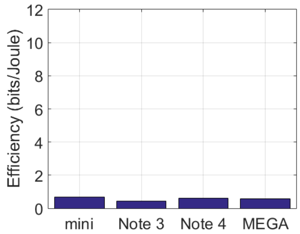
In this paper, three wireless technologies of four smartphones were evaluated in terms of power consumption and throughput. The energy consumed in idle mode was subtracted from the experimental results. Among the wireless technologies, Wi-Fi is the most efficient. Also, estimates were formed to compare with an experimental model for battery life. Bluetooth energy estimations are the most accurate, in comparison with Wi-Fi and LTE.

	Mini	Note 3	Note 4
Wi-Fi	16.89	15.63	18.06
Bluetooth	1.56	5.09	0.88
LTE	0.31	6.36	37.04

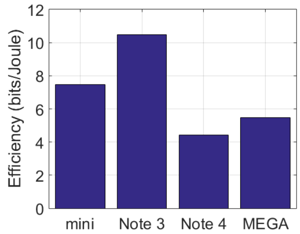
TABLE VI: Estimation Error (%).



(a) Wi-Fi.

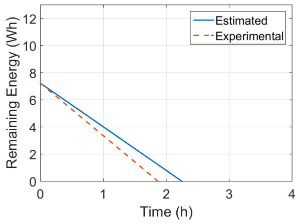


(b) Bluetooth.

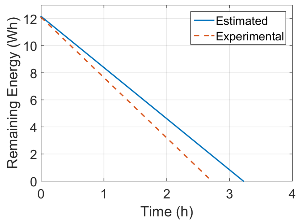


(c) LTE.

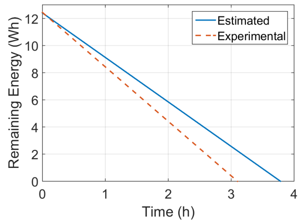
Fig. 6: Smartphone Efficiency.



(a) Mini.

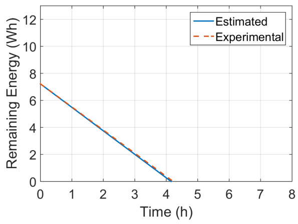


(b) Note 3.

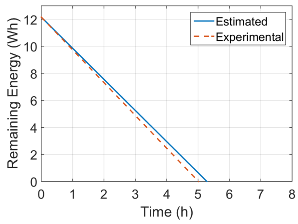


(c) Note 4.

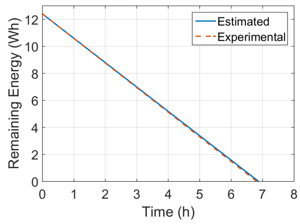
Fig. 7: Wi-Fi Estimation (Based on MEGA measurements).



(a) Mini.

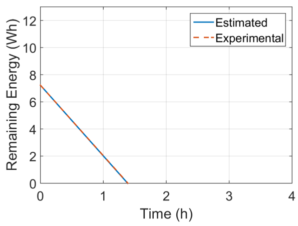


(b) Note 3.

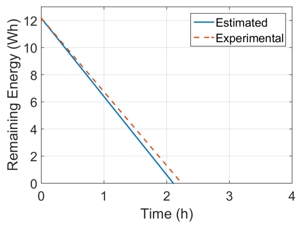


(c) Note 4.

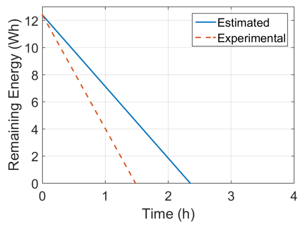
Fig. 8: Bluetooth Estimation (Based on MEGA measurements).



(a) Mini.



(b) Note 3.



(c) Note 4.

Fig. 9: LTE Estimation (Based on MEGA measurements).

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