WiFi Throughput and Power Consumption Tradeoffs in Smartphones

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***Abstract*—This paper examines the throughput and power consumption tradeoffs of WiFi in three smartphones with different display characteristics. The obtained throughput measurements are under different communication protocols while the power requirements of WiFi with respect to each communication mode are also examined. Smartphones with different screen resolution and sizes were selected while the power consumption is evaluated on each smartphone for a variety of configurations including screen mode and operating system. The study reveals several interesting phenomena and tradeoffs. Experiments show that screen resolution affects the total energy consumption while the screen size does not always translate to higher power consumption. The results of this study can be used to improve the design of power optimization algorithms for the next generation of smartphones.**

I. Introduction

Smartphones are quickly becoming the main platform not only for communication but also for computing. Nowadays, most smartphones have WiFi capability, while the average screen resolution is getting higher year after year. WiFi improves user's web surfing experience whenever a WiFi Access Point (AP) is available [1]. It can also be used to improve localization [2] and crowdsourcing [3]. At the same time, screens with high resolution have a strong impact on the perceived quality. Experiments have shown that high screen resolution can increase user engagement, especially for multimedia and gaming sessions [4], [5]. Sometimes, as the resolution increases, the screen size increases as well. However, this is not always the case.

In general, as the screen resolution increases, the power consumption increases as well. Besides the screen resolution, smartphones power consumption is a function of many factors [6], such as screen size, CPU performance, and so on. At the same time, a higher resolution screen is paired with a more capable graphics processor, which also contributes to high power consumption.

In a smartphone, the screen is on when there is a process that requires it, while there are many processes running at the background which do not require an active screen. Hence, the time the screen remains on is an important factor towards energy optimization. Applications should minimize the required screen on time. If there is no interaction with the user, screen should switch back to sleep mode. As it can be inferred, based on the usage and the applications, users with same smartphone configuration may experience different energy requirements and battery lifetimes.

The power requirements of the 802.11n standard in smartphones also contributes to the total energy consumption. WiFi performance of the 802.11n-enabled smartphones is an important energy concern. Their performance is different in comparison with similar chipsets used in laptop computers [7]. Studies shown that popular 802.11n wireless cards could deplete a typical smartphone battery in 2 to 3 hours and would produce nearly enough heat to burn a user's hand [8]. An energy characterization of the 802.11n chipset in comparison with the screen status will help the designers to optimize energy efficiency.

In this paper, a power and throughput study of WiFi on three smartphone devices is presented. The devices were selected in order to have different screen resolution and sizes as well as Operating System (OS). The power consumption of TCP and UDP protocols under different screen mode is also examined.

According to experimental results:

- In idle mode with the screen on, the screen resolution contributes more towards the total power consumption than the screen size.
- The communication protocol, TCP or UDP, does not change much with the screen mode.
- The screen resolution has greater effect on the power consumption than the screen size, when high wireless traffic is considered.

The differences in the performance results, as measured across the different smartphones, result from the design choices taken mostly by the OS and the driver developers.

The rest of the paper is organized as follows: Section II provides a brief review of the related work. Section III describes the experimental setup followed by the performance results and analysis in Section IV. Section V concludes the paper.

II. Related Work

In recent years, a number of experiments examined the performance of 802.11n in WLANs [9], [10], as well as in smartphones [11], [12], [13].

A first look at 802.11n power consumption was presented in [7]. The authors evaluated the power consumption of smartphones under different configurations, such as MAC bitrates, channel conditions and frame sizes. According to experimental results, reception power consumption increases significantly with the bitrate. The power-throughput tradeoffs of WiFi and Bluetooth in details were considered in [17].

The authors used six devices with different OS and conducted extensive experiments with both WiFi and Bluetooth, while the results can be used as preferred usage pattern as well as operative suggestions. The power consumption of WiFi on mobile devices was studied in [16]. The authors introduce a utility value to assess the performance of different protocols. In [18], the authors further examine the power-throughout tradeoffs in 802.11n/ac.

Android power consumption was examined in [14], where a prototype was proposed to improve energy performance while in [15], the relationship between battery life and energy consumption is examined. Based on the experimental results, energy saving do not always extend battery lifetime.

In this work, the energy consumption of WiFi is further examined in order to find any correlation between power consumption during WiFi communication and screen resolution and size, and operating system. Three smartphone with different display characteristics were used. According to the experimental results, display characteristics are correlated with power consumption during wireless communication.

III. Experimental Methodology

In this section, the experimental methodology is described. The experimental setup is presented followed by the experimental procedure.

A. Experimental setup

The experimental setup includes one desktop PC acting as a receiver, one router acting as an Access Point (AP) and a smartphone acting as the sender.

The desktop PC has an Intel Xeon CPU E3-1270 v5 3.60GHz with 16 GB memory, running Windows 7 64-bit. The wireless card is a Dell Wireless 1540 802.11a/b/g/n PCIe card attached to a Dell Ru297 Wx492 wireless network antenna. The router is a IEEE 802.11g/n up to 300 Mbps router.

The three smartphones that were characterized are: Samsung Galaxy S4 mini, Samsung Galaxy MEGA and Samsung Galaxy Note 4. The smartphones were selected in order to test the same WiFi chipset and different screen sizes and resolutions. The WiFi chipset is popular among other smartphone manufacturers as well. The batteries are lithium-ion with nominal voltage around 3.8 V. The main specifications of the three smartphones are summarized in Table I.

Manufacturer	Samsung	Samsung	Samsung
Model	Galaxy S4 mini	Galaxy MEGA	Galaxy Note 4
OS	Android 4.4.2	Android 4.4.2	Android 5.1.1
WiFi	802.11 a/b/g/n	802.11 a/b/g/n/ac	802.11 a/b/g/n/ac
Screen size	4.3 in	6.3 in	5.7 in
Screen res.	540 × 960	720 × 1280	1440 × 2560
Batt. voltage	3.8 V	3.8 V	3.85 V
Batt. capacity	7.22 Wh	12.16 Wh	12.40 Wh

TABLE I: Smartphones specifications.

The power consumption was measured in three modes:

i) **Idle mode:** In this mode all the processes/ application on the smartphone are off. Bluetooth, GSM and 3G radios are disabled, with minimal background application activity.
ii) **TCP transmission mode:** In this mode, the smartphone acts as a TCP client and the desktop computer as a TCP server. The smartphone forwards all the packets to the AP at the maximum bandwidth and the AP to the server.
iii) **UDP transmission mode:** In this mode, the smartphone acts as a UDP client and the desktop computer as a UDP server. The smartphone forwards all the packets to the AP and the AP to the server. The smartphone was set to forward the data at a rate of 54 Mb/s, which is the theoretical 802.11g link bandwidth. This is to achieve the maximal available link throughput.

The Android driver does not allow the user to configure any 802.11n parameters. The AP uses a 802.11n adapter. All the experiments were conducted in a laboratory environment during night in order to minimize interference from other wireless devices. During the experiments, the router was used only as an access point between the PC and the smartphones, without Internet connectivity.

The power was measured with Power Monitor from Monsoon Solutions. The power monitor measures the total power consumption and cannot provide a per-component, per-state, or per-packet breakdown. As a results, the measurements include the idle power consumption between packet receptions (sender backoff, carrier sensing, DIFS/ SIFS), the transmit power consumption, TCP ACKs, and any CPU processing power. To minimize the power used by processes running in the background, all the background processes before each experiment were stopped. Bluetooth, GPS, and LTE were also deactivated during the experiments.

The throughput was measured through `iperf`, a standard network performance measurement tool [19]. The CPU usage of `iperf` application on the smartphone was measured and it was negligible in comparison with the total energy usage.

B. Experimental procedure

The initial set up has the smartphone and the PC connected to the AP. All the three are close to each other to minimize the interference and ensure strong connection. The power monitor is attached to the smartphone acting as the battery. The voltage output of the power monitor is set at 4.2 V. The sampling rate with Monsoon is 2 ms and the `iperf` records the data every 1 s.

In total, there are six experimental sessions for every smartphone: three with the screen off for every mode and three with the screen on. When the screen is off, only the `iperf` process is running for TCP/ UDP mode. When the screen is on, all the three smartphones they have the same white background image.

At the beginning of every session a waiting period of 120 s takes place. This time is necessary in order for the smartphone and the network connection, in the case of TCP/ UDP, to stabilize. After the waiting period, the measurements last for 300 s for every session.

All the six sessions were repeated three times. In the next section, the average values of the experiments are presented.

IV. Performance Results and Analysis

In this section, the average power consumption and the throughput of the different modes are presented and discussed. The *utility* value, i.e. the throughput per unit power in Mb/Ws, was also calculated. The utility value, similar to [17], indicates which protocol in more efficient (TCP or UDP) in terms of transmitted bytes per amount of consumed energy.

Table II summarizes the experimental results for TCP and UDP.

	TCP		UDP	
	Screen on	Screen off	Screen on	Screen off
Throughput (Mb/s)	31.1	28.1	41.7	38.2
Power (W)	3.88	0.862	4.06	0.389
Utility (Mb/Ws)	8.01	32.59	10.27	34.04

(a) MEGA

	TCP		UDP	
	Screen on	Screen off	Screen on	Screen off
Throughput (Mb/s)	27.4	25.6	34.4	32.4
Power (W)	3.57	0.97	2.64	0.266
Utility (Mb/Ws)	7.67	26.39	13.03	121.8

(b) Mini

	TCP		UDP	
	Screen on	Screen off	Screen on	Screen off
Throughput (Mb/s)	36.2	42.3	50.3	44.6
Power (W)	4.16	1.52	4.78	0.518
Utility (Mb/Ws)	8.7	27.82	10.52	86.1

(c) Note 4

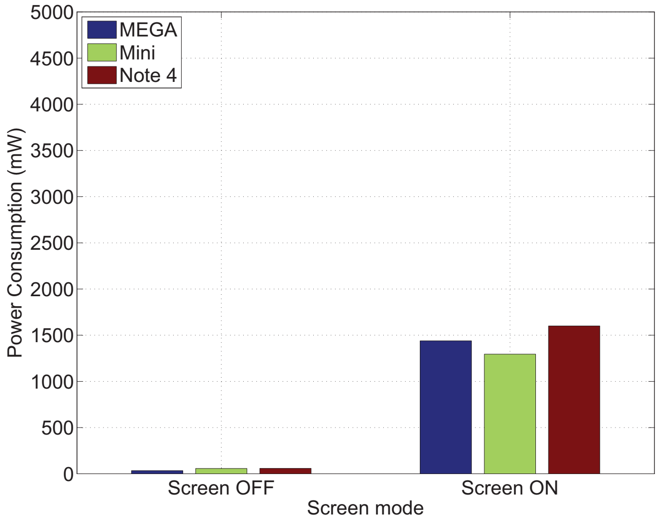
TABLE II: Experimental results -NEEDS UPDATE!.

A. Power Consumption

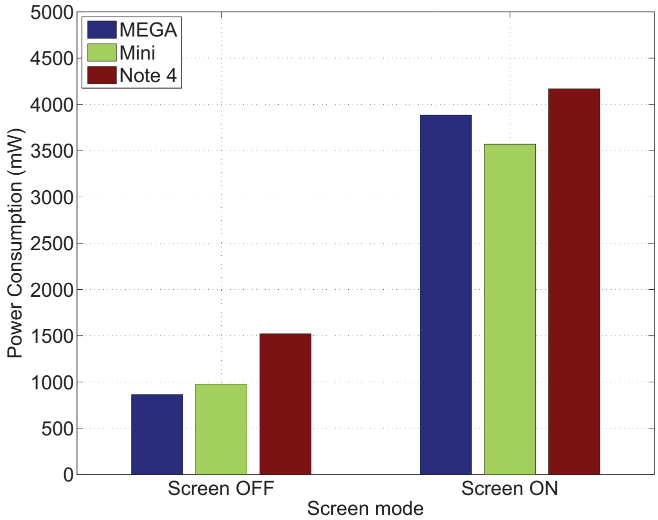
The average power consumption of the different modes was measured. The results are shown in Fig. 1

In idle mode with the screen off, all the three smartphones have similar power consumption. As expected, since there are no other processes running the smartphones have almost the same power requirements. Small differences can be due to different OS and different hardware components. When the screen is on, Note 4 has the highest power consumption followed by MEGA. This can be explained due to the high resolution of Note 4 as well as some extra hardware components in Note 4 in comparison with the other two smartphones. Mini which has the lowest resolution and the smallest screen size has the lowest power consumption over all.

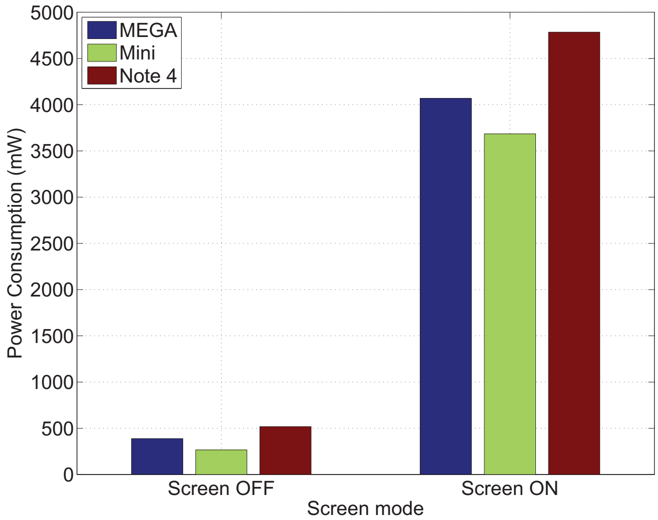
In TCP mode with the screen off, Note 4 has the highest consumption. This due to the higher transmission rate as it will be shown later. MEGA and mini have similar power consumption with the screen off. When the screen is on, again Note 4 had the highest power consumption. The difference of the power consumption between mini and Note 4 as the screen changes mode is almost the same, hence, it can be inferred the



(a) Idle

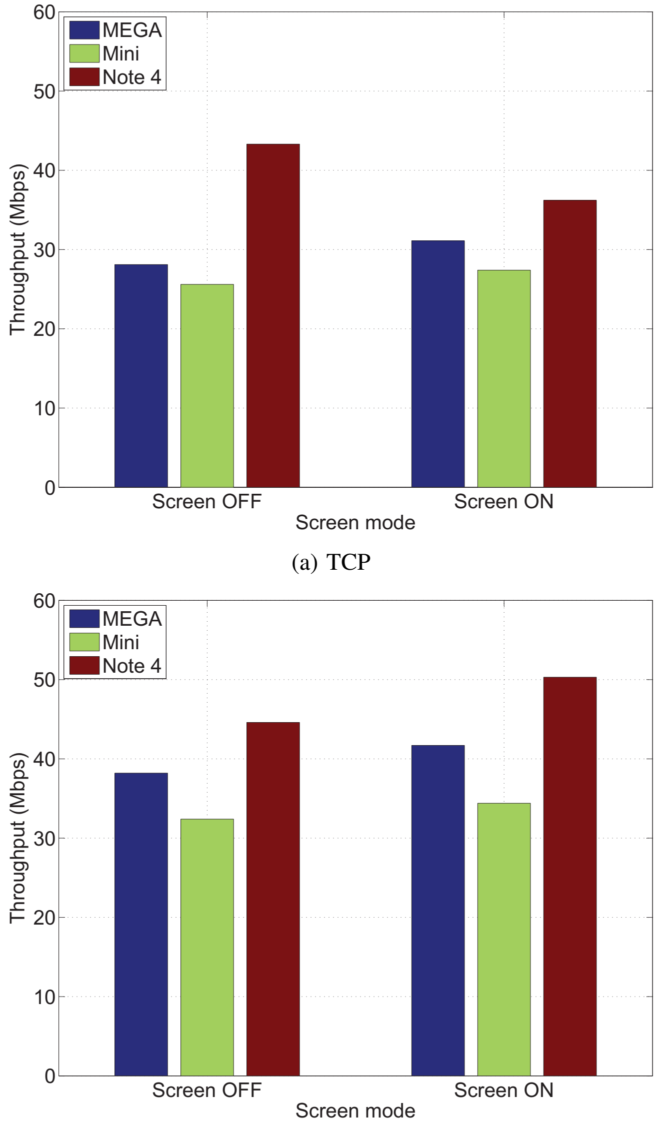


(b) TCP



(c) UDP

Fig. 1: Power consumption with screen on and off and under different modes



(a) TCP

(b) UDP

Fig. 2: Throughput of the devices under different protocol and screen mode.

screen resolution and size of these two smartphones contribute similar amount to the total power consumption. On the other hand, MEGA has the second higher power consumption, higher than the mini. It seems that the large screen size of MEGA affects the power consumption significantly, in comparison with mini.

In UDP mode, the results are similar with the results in TCP as expected. The protocol that is used, TCP or UDP, although it affects the power consumption, it does not change the relationship of the power consumption between the three smartphones.

B. Throughput

The average power consumption of the different modes was measured. The results are shown in Fig. 2.

In all the different modes, Note 4 has the best network performance, in terms of throughput. MEGA has the next higher throughput and mini has the worst. In TCP mode, the screen mode seems to affect Note 4 and MEGA while for mini the performance is almost identical with the screen on and off.

In UDP mode all the three smartphones have higher throughput than it TCP mode. Again, the screen mode seem to not affect the performance of mini while for Note 4 and MEGA the throughput is a bit higher when the screen is on.

It can be inferred that a newer generation chip, along with a newer OS, has better WiFi performance in terms of throughput. Another important outcome of the experiments is that the relationship between the three smartphones, does not get affected either from the protocol or the screen mode.

C. Utility value

The utility value is used as an indicator of which protocol in more efficient (TCP or UDP) in terms of transmitted bytes per amount of consumed energy. Fig. 4 shows the results.

All the smartphones follow a similar pattern. The utility value increases when the screen is off and decreases when the screen is on.

In TCP mode with the screen off, MEGA has the best performance over all. The power requirements of this smartphone along with the WiFi configuration place MEGA as the highest in terms of data transmission per energy unit with the screen off. Note 4, although it has newer OS and WiFi component is the the second highest in terms of the utility value. When the screen is on though, the screen size of MEGA affects its overall performance. With the screen on, note 4 has the highest utility value, hence, it is capable of pushing the most data to the network at the lowest energy unit. MEGA and mini perform similar with the screen on.

In UDP mode with the screen off, mini has the best performance while with the screen on, all the three smartphones perform similar, with note 4 having slightly better performance

V. Conclusion

In this work, we considered the throughput and power consumption tradeoffs of WiFi in smartphones. We used smartphones with different screen resolution and sizes. We examined TCP and UDP protocols with the screen on and off, while the smartphones forwarded packets to an Access Point.

Experimental results shown that both the screen size and the screen resolution effect the power consumption. When high wireless traffic is considered, the screen resolution has greater affect on the power consumption than the screen size.

Further experimentation is necessary to verify the results under different wireless environments.

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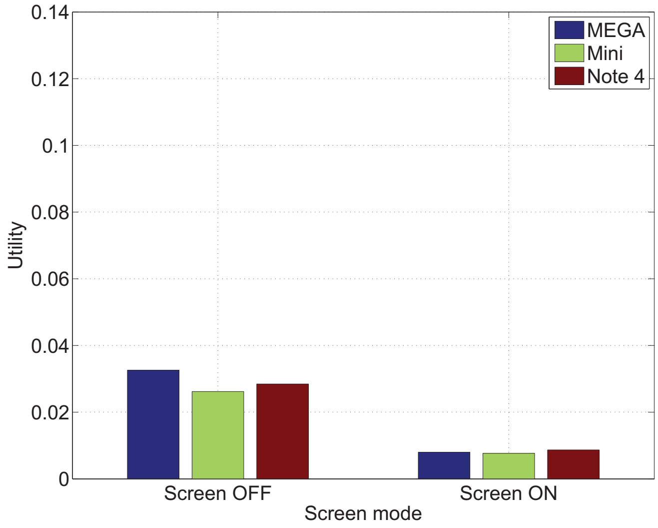
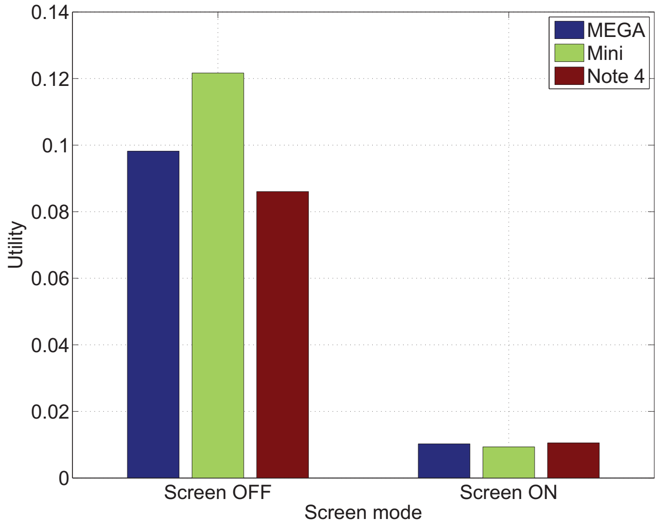


(a) UDP

Fig. 3: TCP



(a) UDP

Fig. 4: Utility value of the devices under different protocol and screen mode.

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