Smartphone Energy Consumption Models for Multimedia Services using Multipath TCP

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***Abstract*—Multipath TCP (MPTCP) is an evolution of the regular TCP that allows multiple radio interfaces to be used simultaneously by a single connection while presenting regular TCP interface to applications. Although its benefits include better resource utilization, higher throughput and smoother reaction to connection failures, MPTCP does not take energy consumption into account, especially important when using wireless mobile devices with limited power resources. In this paper, we demonstrate that smartphones with MPTCP support consume more energy than those with regular TCP when using the same service and the same network interface. Additionally, novel energy consumption models are developed based on real life measurements on a real life smartphone. The proposed energy consumption models consider four different multimedia-based services (i.e. video streaming, voice over IP, web-browsing and file download) in 3G and WiFi networks when MPTCP or regular TCP are used, respectively.**

***Index Terms*—energy consumption model, multipath TCP, smartphone, 3G, WiFi**

I. Introduction

BROADBAND wireless network technologies including WiFi are being used extensively in many countries all over the world. WiFi is one of the most successful of these wireless network technologies, allowing cheaper deployment of LANs, including in places where cables cannot be deployed, such as historical buildings and outdoor areas. Cellular or mobile networks powered by technologies such as GSM, CDMA and UMTS (3G), on the other hand, are the most important communication technologies that cover large geographic areas and have relative low battery power usage, increased capacity and reduced interference from other signals.

With the widespread of WiFi and 3G, more and more mobile devices like smartphones and tablets are supporting wireless data transmissions. There is also significant growth in rich media applications delivered wirelessly to mobile devices. Among these applications, video streaming and voice over IP (VoIP) services are less tolerant to both delay and jitter and in general require high bandwidth [1] [2] [3]. At the same time, TCP is the most widely-used transport layer protocol which handles data transmission between mobile devices.

One of the problems of regular TCP is that the bandwidth consumed by mobile devices is growing every year and regular TCP cannot support this bandwidth growth. Multipath TCP (MPTCP) [4] was introduced to address this problem. MPTCP

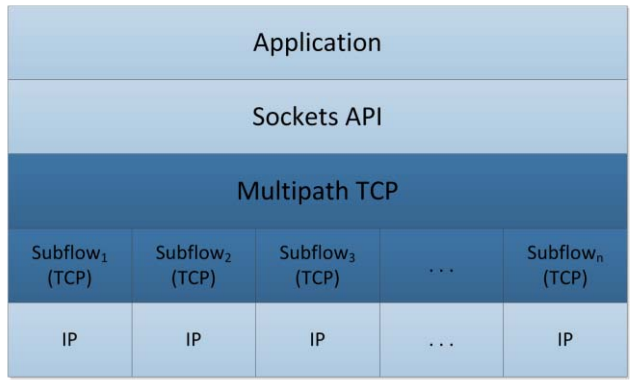


Fig.1. Multipath TCP Protocol Stack

presents regular TCP interfaces to applications, while also allowing multiple radio interfaces to be used simultaneously by a single connection by spreading the data flow across several TCP sub-flows. Theoretically the throughput of MPTCP is much higher than that of regular TCP, as transmission via multiple paths is employed. Fig.1. shows the protocol stack for MPTCP.

One of the key concerns when using mobile devices with MPTCP support via wireless networks is energy consumption because of the limited battery capacity of most wireless mobile devices. This aspect is not considered in MPTCP.

This paper studies the energy consumption of different 3G/WiFi multimedia services on a wireless mobile device using MPTCP and regular TCP, respectively. A specific kernel with MPTCP support is implemented and deployed on a Samsung Galaxy S3 smartphone. The measurement results show that when using the same type of multimedia service, the energy consumption when using 3G is higher than that when WiFi is employed. Next, novel energy consumption models are developed for different multimedia services using both MPTCP and TCP.

The paper is organized as follows: section II presents related works on MPTCP and energy consumption. Section III describes the experimental setup including how to make and flash a MPTCP kernel into a Galaxy S3 smartphone and the energy consumption measurement setup. Section IV presents test results and the corresponding analysis. Section V describes the energy consumption models for four multimedia services derived from the test results. The last section summarizes our work.

II. Related Works

Recently both MPTCP and energy consumption on smartphones are becoming interesting research topics. This section discusses some relevant research works in these areas.

A. Multipath TCP (MPTCP)

In [4], the authors have proposed new algorithms to solve practical problems such as sharing a limited receiver buffer between multipath flows on a smartphone, or optimizing the MPTCP receiver code. Experiments show that the proposed solutions are effective, making MPTCP ready for adoption. The big challenge, however, is to build a solution that is deployable in today's network environment. A MPTCP implementation is introduced in [5] [6]. However, there are still some issues which need to be addressed in the future including the retransmission mechanism and interaction with the network interface.

The authors of [7] [8] propose eMTCP which extends MPTCP by taking into account both throughput and energy consumption performance (energy efficiency) of mobile device when receiving multimedia services. Additionally, the impact of variable service types (i.e. large file transferring, web-browsing, video streaming, and VoIP) on the energy efficiency is studied. Simulation-based experiments via LTE and WiFi interfaces show increase in energy efficiency when using eMTCP in comparison with MPTCP and single-path TCP.

B. Energy Consumption in Smartphones

In [9], some common wireless communication technologies are discussed such as Bluetooth, WiFi and 3G. The authors investigate the energy consumption variation in time and function of the amount of transferred data when using Bluetooth, 3G or WiFi respectively. Based on the test results, the authors proposed an energy consumption model for Android smartphones. The results show that using the 3G interface consumes the most energy, followed by WiFi which consumes less and Bluetooth which consumes the least.

A measurement study of the energy consumption in three mobile networks: GSM, 3G and WiFi is presented in [10]. The authors develop a simple model of energy consumption of network activities for each of the three technologies. By using this model, they have developed a protocol called *TailEnder* for scheduling data transmission which reduces energy consumption of common mobile applications. A comprehensive energy consumption study of video streaming to Android mobile devices is performed in [11].

Q-PASTE [12] is a cross-layer solution which enables MAC layer to achieve energy savings by adjusting data delivery according to the traffic pattern. [13] proposes a cross-layer smartphone battery and stream-aware adaptive multimedia delivery mechanism (BaSe-AMy). The solution monitors mobile device remaining battery, remaining video length and packet loss rate, which are used for a video quality adaptation module. Experimental results show how BaSe-AMy increases the battery life with up to 18%.

C. Limitations

Although the previous works discussed above involve MPTCP and energy consumption in smartphones, few of them have combined the two features and have analyzed the energy consumption of smartphones with MPTCP support.

III. Test-bed Setup

The smartphone used for the test is a Samsung Galaxy S3 device with Android OS 4.2.2 (Jelly Bean). We choose an open-source ROM from the CyanogenMod team [14] which is convenient to flash the kernel into the chosen smartphone. The wireless networks interfaces include WiFi and 3G. Regarding the WiFi, the Cisco epc3925 wireless router is used to provide support for IEEE 802.11n WLAN, whereas for 3G support, Lycamobile's[1] 3G network is selected. Additionally, we setup a specific test-bed to measure the energy consumption of the smartphone using both WiFi and 3G interfaces.

Details of the test bed setup are described as follows.

A. Building MPTCP Kernel for Samsung Galaxy S3

1) *Retrieving the kernel source*

The kernel source was developed by the CyanogenMod team (CM).

2) *Based on the kernel source, finding the kernel version used and merging the existing phone kernel source with the MPTCP kernel source.*

The version of the CM kernel and the corresponding MPTCP kernel source is 3.0.x [15]. Table I lists the commands for merging of the two kernel sources under the *Ubuntu* operating system on a PC with the smartphone plugged in.

3) *Building a custom kernel for Samsung Galaxy S3 with MPTCP support*

Some preparations needed to do before building the kernel are listed as follows:

- Android SDK (with adb tools and fastboot features);
- *abootimg* installed (command on debian-based systems: apt-get install abootimg);
- An original *boot.img* that can be retrieved from the factory image by unzipping the CM Rom file;
- Cross compiler that can be set up according to the process in [16]. For deployment convenience the version of the cross compiler used in our tests is *arm-eabi-4.6*.

The commands used to actually build the kernel and to optionally change the branch are listed in Table II.

If compiling is successful, a *zImage* kernel file is observed in folder "arch/arm/boot/" in the file structure of the smartphone. Otherwise recompilation is needed. The commands used for generating a new boot.img are listed in Table III.

The commands generate a file newboot.img that can be used to boot and/or to flash the smartphone. As the Samsung Galaxy S3 smartphone used in our tests does not support fastboot feature, we choose to use a different tool *Heimdall* to flash the new kernel.

[1] Lycamobile. http://www.lycamobile.ie/en/

TABLE I
COMMANDS FOR MERGING KERNEL SOURCES

```
$ git init android_kernel_samsung_smdk4412
$ cd android_kernel_samsung_smdk4412
$git remote add cm
git://github.com/CyanogenMod/android_kernel_samsung_smdk4412.git
$ git fetch cm
$ git merge cm/cm-10.1
$ git remote add mptcp_3.0.x
git@github.com:multipath-tcp/mptcp_3.0.x.git
$ git fetch mptcp_3.0.x
$ git merge mptcp_3.0.x/mptcp_3.0.0
```

TABLE II
COMMANDS FOR BUILDING KERNEL

```
$ export ARCH=arm SUBARCH=arm CROSS_COMPILE=arm-eabi-
$ make cyanogenmod_i9300_defconfig
$ make –j5
```

TABLE III
COMMANDS FOR GENERATING NEW BOOT.IMG

```
$ abootimg -x boot.img
$ sed -i 1d bootimg.cfg
$ abootimg --create newboot.img -f bootimg.cfg -k
PATH_TO_ZIMAGE -r initrd.img
```

B. *Energy Consumption Measurement Test-bed*

There are many pieces of software that can measure the energy consumption of a smartphone. However, they cannot provide precise battery consumption measurements. Hence, we use Arduino Duemilanove board [17] to measure the energy consumption of multimedia services on the Samsung Galaxy S3.

Fig.2 (a) and Fig.2 (b) show the setup of our measurement test bed. Voltage drop (V_D) across resistor R_1 (here the value of R_1 is 0.22Ω) is measured. The current intensity is calculated using equation (1):

$$I = \frac{V_D}{R_1} \quad (1)$$

Voltage (V_P) at the positive terminal of battery is measured, so power is calculated using equation (2):

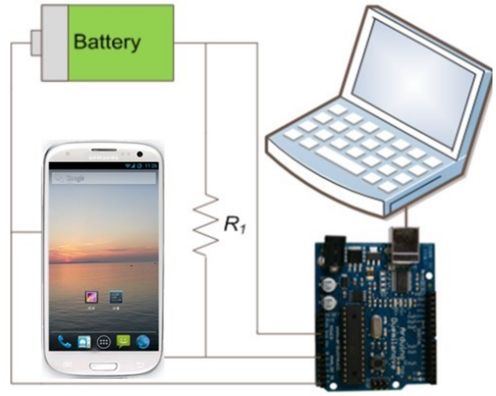
$$P = I \times V_P \quad (2)$$

The calculation is performed by a Java application running in a Dell Inspiron N4030 laptop.

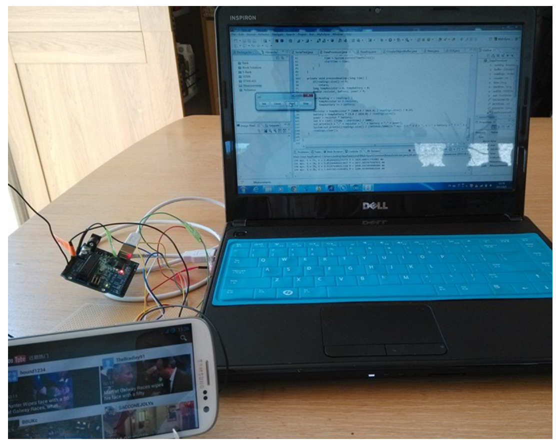
IV. TESTING SCENARIOS AND RESULTS ANALYSIS

In this section, we present the energy consumption test scenarios and the results analysis. We measure the energy consumption of the Galaxy S3 device for four types of multimedia services:

1) Video Streaming service: e.g. YouTube
2) VoIP service: e.g. Skype
3) Web browsing service: e.g. Chrome
4) File download service: e.g. Download a file from a remote FTP server.



(a) Schematic of Energy Consumption Measurement



(b) Test-bed of Energy Consumption Measurement

Fig. 2 Test-bed topology and screenshot

A. *Video Streaming Service*

The YouTube Android version (which can be downloaded from Google Play) was selected as the application to be measured for energy consumption of video streaming service. We chose a video clip named "Taylor -Swift-Red" [18] to stream over WiFi and 3G networks by using regular TCP and MPTCP, respectively.

In the four scenarios (regular TCP over WiFi; MPTCP over WiFi; regular TCP over 3G; MPTCP over 3G), we play the chosen video for the same time period of time and measure the energy consumption in each scenario. Fig. 3 and Fig. 4 show the results of the energy consumption in the four scenarios.

From the two figures, we can see how the amount of energy consumed in the four scenarios can be ordered in inverse order as follows: MPTCP over 3G > MPTCP over WiFi > Regular TCP over 3G > Regular TCP over WiFi.

When using the WiFi interface, about 77.74 % more energy is consumed when employing MPTCP in comparison with the case when using the regular TCP. When the 3G interface is employed, the energy consumption when using MPTCP is about 64.45% higher than that when using the regular TCP.

When using MPTCP over 3G about 2.95% more energy is consumed than when using the WiFi interface. When using regular TCP, the 3G interface consumes about 11.27% more energy than when using the WiFi interface.

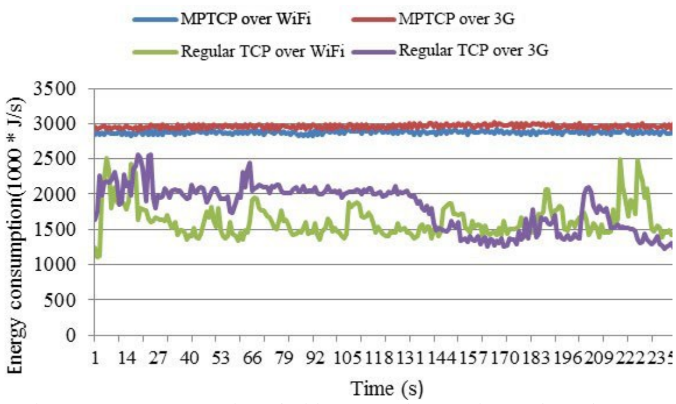


Fig.3. Energy Consumption of Video Streaming Service on the Galaxy S3 Smartphone in the Four Scenarios

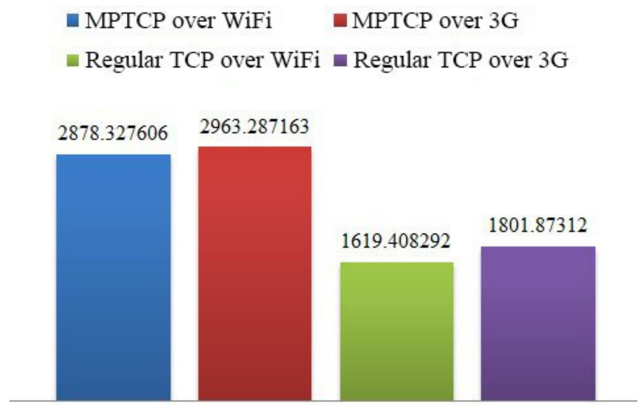


Fig.4. Average Energy Consumption of Video Streaming Service on the Galaxy S3 Smartphone in the Four Scenarios in one second (1000*Joule)

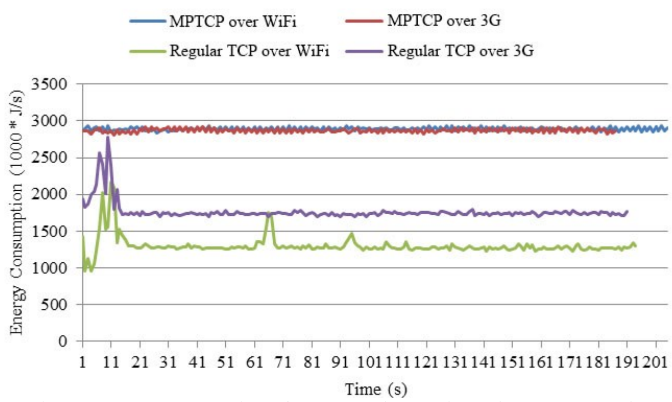


Fig.5. Energy Consumption of VoIP Service on the Galaxy S3 Smartphone in the Four Scenarios

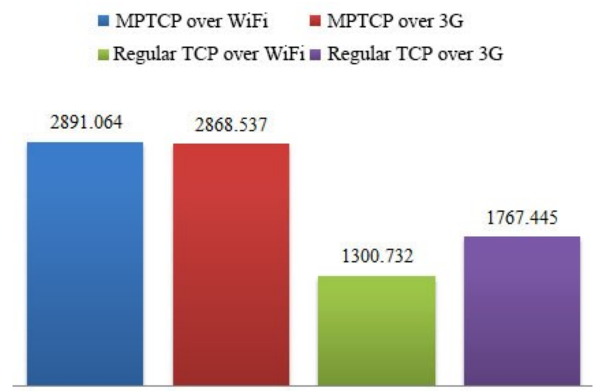


Fig.6. Average Energy Consumption of VoIP Service on the Galaxy S3 Smartphone in the Four Scenarios in one second (1000*Joule)

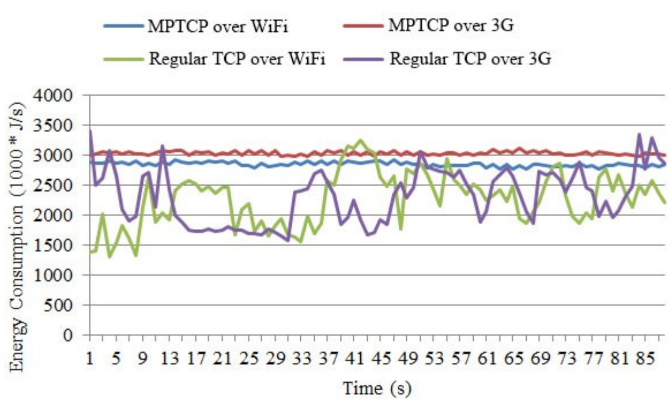


Fig.7. Energy Consumption of Web Browsing Service on the Galaxy S3 Smartphone in the Four Scenarios

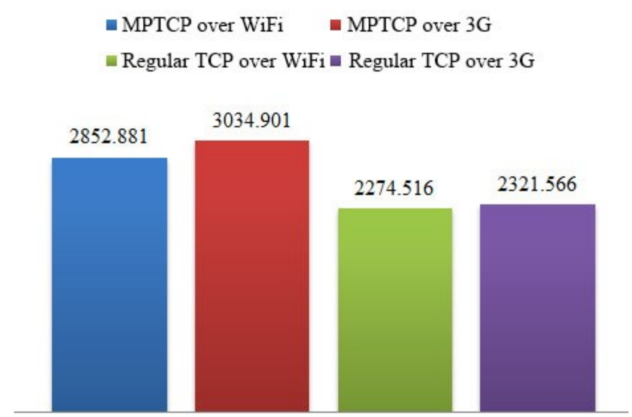


Fig.8. Average Energy Consumption of Web Browsing Service on the Galaxy S3 Smartphone in the Four Scenarios in One Second (1000*Joule)

B. VoIP Service

In this section, we choose Skype as the VoIP service application for energy consumption measurement, as Skype is one of the most popular VoIP applications in the world. We use Skype to generate a voice chat session for 3 minutes in the four scenarios.

As shown in Fig. 5 and Fig. 6, the WiFi interface consumes about 122.26% more energy using MPTCP in comparison with the case when using regular TCP. However, the mobile consumes about 62.30% more energy when using MPTCP in comparison with using regular TCP over 3G.

It is interesting to note the energy consumption difference when using the 3G and WiFi networks, respectively. When using MPTCP over 3G approximately the same energy is consumed as in the case when the WiFi interface is used. However, when using regular TCP, about 35.88% more energy is consumed when suing 3G than when making use of the WiFi interface.

C. Web Browsing Service

In this section, we use the default web browser within the Galaxy S3 smartphone to browse the web pages for 90s.

Fig. 7 and Fig. 8 show the results of the energy consumption measurements.

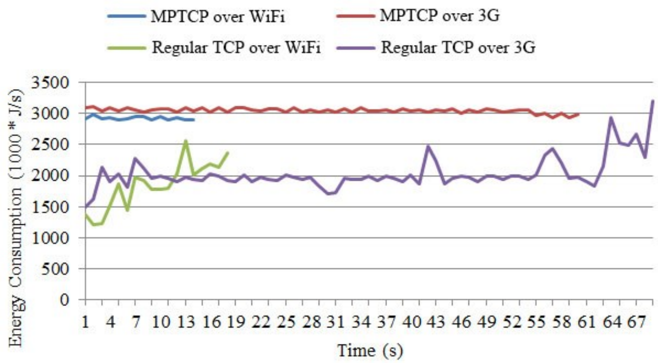


Fig.9. Energy Consumption of File Download on the Galaxy S3 Smartphone in the Four Scenarios

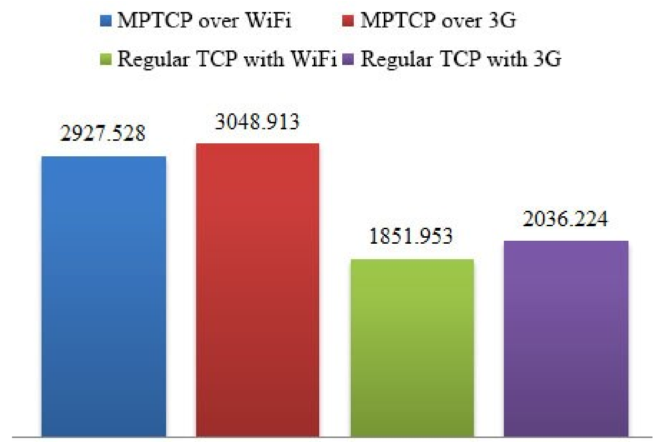


Fig.10. Average Energy Consumption of File Download on the Galaxy S3 Smartphone in the Four Scenarios in One Second (1000*Joule)

TABLE IV
ENERGY CONSUMPTION MODELS FOR VIDEO-STREAMING SERVICE

MPTCP over WiFi	$E=960+4.59986*10^{-3}*B$
MPTCP over 3G	$E=960+2.09910*10^{-2}*B$
Regular TCP over WiFi	$E=960+1.62834*10^{-3}*B$
Regular TCP over 3G	$E=960+9.29721*10^{-3}*B$

TABLE V
ENERGY CONSUMPTION MODELS FOR VOIP SERVICE

MPTCP over WiFi	$E=960+1.45426*10^{-1}*B$
MPTCP over 3G	$E=960+1.32354*10^{-1}*B$
Regular TCP over WiFi	$E=960+2.90672*10^{-2}*B$
Regular TCP over 3G	$E=960+7.89892*10^{-2}*B$

TABLE VI
ENERGY CONSUMPTION MODELS FOR WEB BROWSING SERVICE

MPTCP over WiFi	$E=960+2.76782*10^{-2}*B$
MPTCP over 3G	$E=960+4.86305*10^{-2}*B$
Regular TCP over WiFi	$E=960+3.10924*10^{-2}*B$
Regular TCP over 3G	$E=960+4.61548*10^{-2}*B$

TABLE VII
ENERGY CONSUMPTION MODELS FOR FILE DOWNLOADING SERVICE

MPTCP over WiFi	$E=960+2.40571*10^{-3}*(S/T)$
MPTCP over 3G	$E=960+1.09463*10^{-2}*(S/T)$
Regular TCP over WiFi	$E=960+1.40220*10^{-3}*(S/T)$
Regular TCP over 3G	$E=960+6.48555*10^{-3}*(S/T)$

From the figures it is clear that the mobile device consumes about 25.43% more energy when using MPTCP in comparison with the case when using the regular TCP, both over WiFi. The energy consmuption difference increases to about 30.73% when using the 3G interface.

When using MPTCP, the energy consumption when using the 3G interface is higher with about 6.38% in comparison with the WiFi case. When using regular TCP, the energy consumption when using the 3G interface is about 2.07% higher than that when the WiFi interface is used.

D. File Downloading Service

In this section, we download a file (Viber an application whose size is 11.45MB) from the Google Play and measure the time needed for downloading and the corresponding energy cosumption in the four scenarios. The results are shown in Fig. 9 and Fig. 10.

From the results, it is clear that the time needed for the download in the four scenarios can be ordered as follows: regular TCP over 3G (69s) > MPTCP over 3G (60s) > regular TCP over WiFi (18s) > MPTCP over WiFi (14s). From this perspective, we can see that MPTCP ensures faster download speed than regular TCP.

In terms of energy consumption, when using the WiFi interface about 58.08% more energy is consumed when using MPTCP in comparison with when using the regular TCP. When using the 3G interface the difference in energy consumption is about 49.73% higher when using MPTCP in comparison with when using regular TCP.

When using MPTCP, the energy consumption for file download over the 3G is about 4.15% higher than that over the WiFi. When using regular TCP, the energy consumption for file transfers over 3G interface is with 9.95% higher than when using the WiFi interface.

V. SMARTPHONE ENERGY CONSUMPTION MODELS

Based on the results of the energy consumption measurements in section IV, we have proposed smartphone energy consumption models for the four types of multimedia services for MPTCP and regular TCP when using 3G and WiFi, respectively. The energy models are shown in Table IV, V, VI and VII. Details of the derivation process are as follows.

Assuming linear models, the energy consumption models for video-streaming service, VoIP service and web browsing service are derived as shown in equation (3):

$$E = A + K \times B \tag{3}$$

E represents the average energy consumption (mW) of the smartphone. A refers to the average energy consumption (mW) of the smartphone when there are no applications running and the value of A is set to 960 based on results measured in section IV. K is a constant coefficient factor which is different for variable multimedia services. B represents the data rate (Byte/second) of the application service. In order to calculate the value of K, the total number of bytes transferred during a given time is computed. For example, when browsing web pages using MPTCP via WiFi for 90s, the total number of bytes received by the browser is 6.155MB. The average energy consumed for this web-browsing service is 2852.881 mW. Therefore, the value of K is $2.76782*10^{-2}$ according to equation (3).

The energy consumption models for the file download service, although still linear, are different from those of the three services above and are derived as shown in equation (4).

$$E = A + K \times \left(\frac{S}{T}\right) \qquad (4)$$

The parameter E represents the average energy consumption (mW). A is the constant factor and equals 960, representing the average energy consumption (mW) of the smartphone when there are no applications running. K indicates a constant coefficient factor which is calculated based on the measured test results. T is the time (seconds) needed to download the file. S is the size (Bytes) of the file transferred. For example, the widely used chat software Viber[2] for Android is 11.45MB. When downloading the content using MPTCP via the 3G network, the average energy consumption is 3048.913 mW and the time to download is 60s. Consequently, K can be computed as $1.09463*10^{-2}$ according to equation (4).

In this paper, basic energy consumption models for variable multimedia services are developed separately using linear models. Future works will focus on improving the accuracy and robustness of these models, in particular, the energy consumption model when all the multimedia services are mixed in the sampled data.

VI. Conclusion

This paper has studied the energy consumption of a smartphone for four different types of services (video streaming, VoIP, web-browsing, file download) for both MPTCP and regular TCP over WiFi and 3G networks respectively. Test results demonstrate that a smartphone using MPTCP consumes more energy than when using regular TCP for the same application and the same type of radio interface. Based on the results from real life measurements, we have derived a set MPTCP and regular TCP based energy consumption models for the four types of services for deliveries over both WiFi and 3G networks. The proposed energy consumption models allow estimating the average energy consumption of each service in WiFi and 3G network, respectively.

VII. Acknowledgement

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