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Review of Energy Consumption in Mobile Networking Technology

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***Abstract*: The Smartphone market has been growing at phenomenal rate. A major source of smartphone energy consumption is accessing the Internet via 3G or WiFi when running various interactive apps and background services. The energy consumed by the wireless interfaces is perceived as a necessity – after all, a smartphone provides the user with a ubiquitous portal to the Internet. Ideally, accessing the Internet should consume an amount of energy commensurate with the amount of traffic being transported and the (peak) throughput supported by the wireless technology used.**

In this paper, we present a measurement study of the energy consumption characteristics of three widespread mobile networking technologies: 3G,GSM, and WiFi. We find that 3G and GSM in cure a high tail energy overhead because of lingering in high power states after completing a transfer. Based on these measurement, we study TailEnder a protocol that reduces energy consumption of mobile application.

***Keywords*: Cellular networks, WiFi, Energy savings, Mobile applications, Power measurement.**

I. INTRODUCTION

Mobile phones are ubiquitous today with an estimated cellular subscription of over 4 billion worldwide . Most phones today support one or more of 3G, GSM, and WiFi for data transfer. For example, the penetration of 3G is estimated at over 15% of cellular subscriptions worldwide and is over 70% in some countries . How do the energy consumption characteristics of network activity over 3G, GSM, and WiFi on mobile phones compare with each other? How can we reduce the energy consumed by common applications using each of these three technologies? To investigate these questions, we first conduct a detailed measurement study to quantify the energy consumed by data transfers across 3G, GSM, and WiFi. We find that the energy consumption is intimately related to the characteristics of the workload and not just the total transfer size, e.g., a few hundred bytes transferred intermittently on 3G can consume more energy than transferring a megabyte in one shot.

II. MEASUREMENTAL STUDY

A. Devices and Tools:

The majority of our experiments are performed using four Nokia N95 phones (http://en.wikipedia.org/wiki/Nokia_N95). Two of the phones are 3G-enabled AT&T phones that use HSDPA/UMTS technology and two are GSM-enabled AT&T phones that use EDGE. All four phones were equipped with an 802.11b WiFi interface. It use Python, PyS60 v1.4.2, developed for the Symbian OS 3rdEd FP 1 to conduct data transfer experiments. To measure energy consumption, use Nokia's energy profiling application, the Nokia Energy Profiler (NEP) v1.1 1. NEP provides instantaneous power measurements sampled once every 250 milli-seconds. Using the power measurements, we estimate the energy consumed by approximating the area under the power measurement curve over a time interval. Unless stated, all measurement results are averaged over 20 trials and error bars show the 95% confidence interval. We also report results from a smaller scale measurement study performed on the HTC Fuze phone that runs Windows Mobile 6.5. The HTC phone is also a 3G-enabled AT&T phone and is equipped with an 802.11b WiFi interface.The energy measurements on the HTC phone were performed using a hardware power meter that measured power once every 0.2 milliseconds.

B. 3G Measurements:

In 3G measurements quantify the: 1) Ramp energy: energy required to switch to the high-power state, 2) Transmission energy, and 3) Tail energy: energy spent in high-power state after the completion of the transfer. In this measurements for data transfers of different sizes (1 to 1000 KB) with varying intervals (1 to 20 seconds) between successive transfers. It measure energy consumption by running NEP in the background while making data transfers. For each configuration of (x; t), where x 2 [1K, 1000K] and t 2 [1, 20] seconds, the data transfers proceed as follows: The phone initiates an x KB upload/download by issuing a http-request to a remote server. After the upload/download is completed, the phone waits for t seconds and then issues the next http request. This process is repeated 20 times for each data size. Between data transfer experiments for different intervals, the phone remains idle for 60 seconds. The energy spent during this period is subtracted from the measurements as idle energy. Extract the energy measurements from the profiler for analysis, and use the time-stamps recorded by NEP to mark the beginning and end of data transfer as well as the beginning and end of the Ramp time and the Tail time. The energy consumed by each data transfer is computed as the area under the power-curve between the end of Ramp time and the start of Tail time.

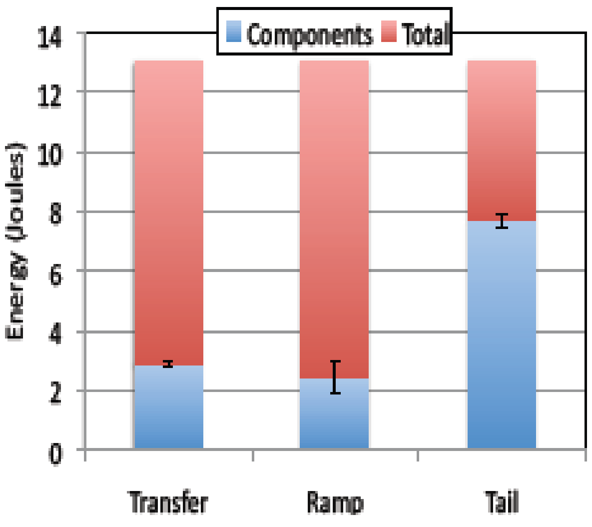

Fig. 1. 3G: Energy Component

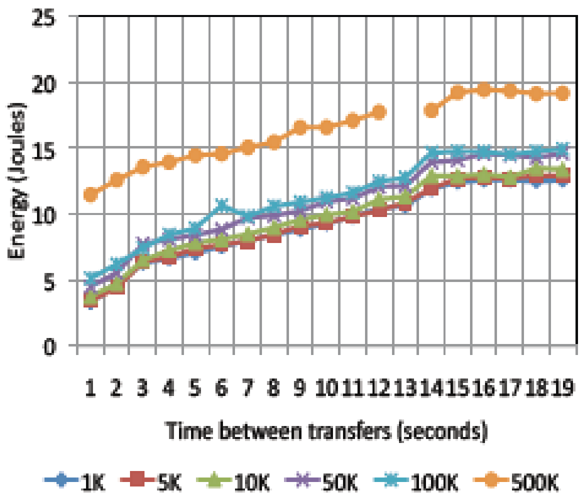

Fig. 2. 3G: Varying inter-transfer time

In Fig.1 shows average ramp, transfer and tail energy consumed to download 50K data. The lower portion of the stacked columns show the proportion of energy spent for each activity compared to the total energy spent. The average energy consumption for a typical 50KB download over 3G. We find that the Tail energy is more than60% of the total energy. The Ramp energy is significantly small compared to the tail energy, and is only 14% of the total energy.

In fig.2 shows average energy consumed for downloading data of different sizes against the inter-transfer time. This observation suggests that the Tail energy can be amortized using multiple transfers, but only if the transfers occur within Tail time of each other. This observation is crucial to the design of TailEnder, a protocol that reduces the energy consumed by network applications running on mobile phones.

C. GSM Measurements:

In GSM measurements using the two Nokia phones equipped with GSM. Fig.3 shows the average energy consumption in GSM networks as a proportion of the Tail energy, Ramp energy and transfer energy for a 50K download. Unlike in 3G, the Tail energy only accounts for 30% of the transfer energy. However, similar to 3G, the Ramp energy in GSM is small compared to the Tail energy and the transfer energy. Also observed that the Tail time is 6 seconds and GSM incurs a small maintenance energy between 2-3 J/minute (not shown in figure). Due to the small Tail time in GSM (unlike 3G), data sizes dominate energy consumption rather than the inter-transfer times. Fig.4 shows the average energy consumed when varying the timebetween successive transfers. The average energy does not vary with increasing inter-transfer interval. For example, for data transfers of size 100 KB, the average energy consumption is between 19 Joules to 21 Joules even as the time between successive transfers is varied. In comparison, Fig.2 shows that the average energy consumption varies significantly in 3G with varying inter-transfer interval, until the inter-transfer interval grows to more than the Tail time.

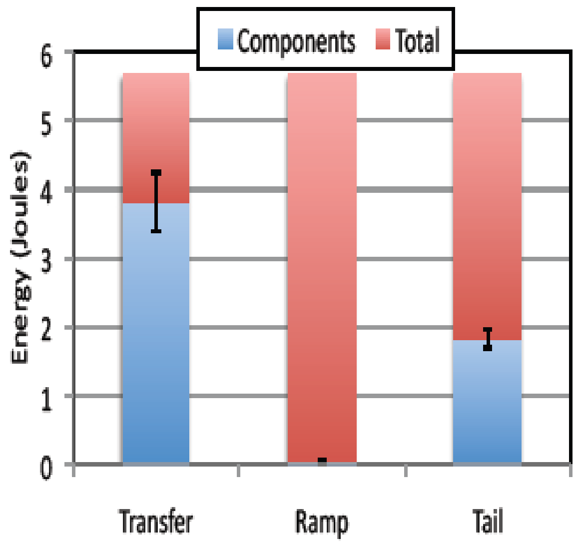

Fig. 3 GSM: Energy Component

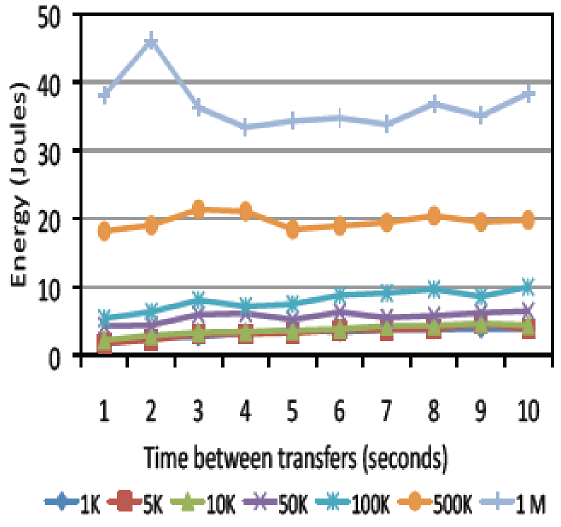

Fig. 4 GSM: Varying inter-transfer times

D. WiFi Measurements:

In WiFi measurements quantify the energy : 1) to scan and associate to an access point and 2) to transfer data. In which two sets of measurements. In the first set of measurements, for each data transfer, In first scan for WiFi access points, associate with an available AP and then make the transfer. In the second set of measurements, only make one scan and association for the entire set of data transfers to isolate the transfer energies. Fig.5 shows the average energy consumption in WiFi composed of scanning, association and transfer, for a 50 K download. It observe that the scanning and association energy is nearly five times the transfer energy. Our results confirm previous measurements by Rahmati et al. . Fig.6 shows that for WiFi, the energy consumption increases when time between successive transfer increases. Interestingly,energy consumption does not plateau after a threshold inter-transfer interval like in 3G (Fig. 2). The reason for increasing energy consumption with increasing inter-transfer interval is the high maintenance energy in WiFi. We measured the maintenance overhead (not shown) for keeping the WiFi interface on to be 3-3.5 Joules per minute.

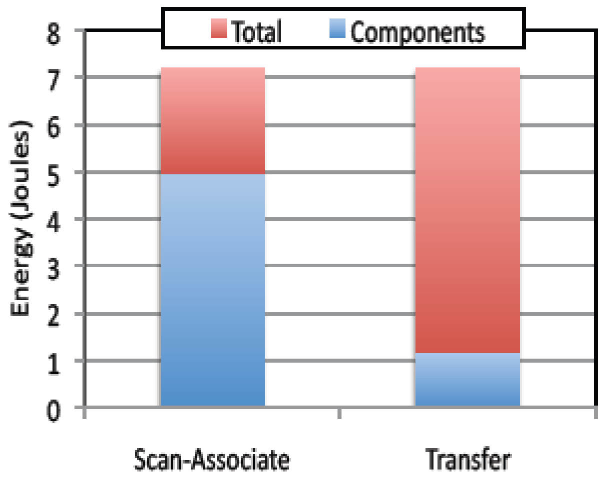

Fig. 5 WiFi: Energy Components

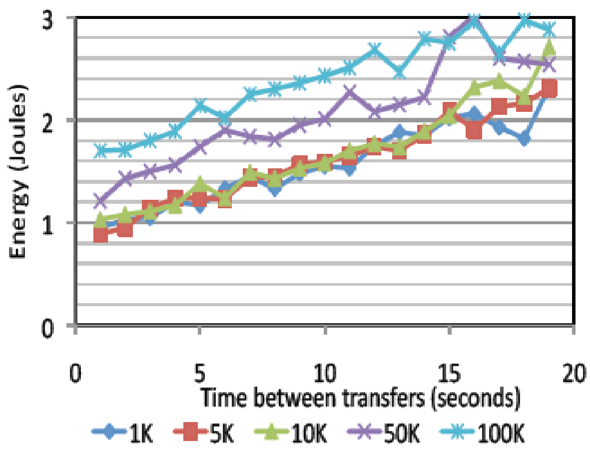

Fig. 6 WiFi: Varying inter-transfer times

III. PROTOCOL

TailEnder a protocol whose end-goal is to reduce energy consumption of network applications on mobile phones. Common network applications on mobile phones include e-mail, news-feed, software updates and web search and browsing. Many of these applications can be classified under two categories: 1) applications that can tolerate delays, and 2) applications that can benefit from prefetching.

A. Delay- Tolerant Application:

Firsty, how applications can exploit delay tolerance to reduce energy utilization. Assume a user sends two emails within a span of a few minutes. The default policy is to send the emails as they arrive, and as a result the device remains in the high power state for two inactivity timer periods. However, if the user can tolerate a few minutes delay in sending the emails, the two emails can be sent together, and the device remains in the high power state for only one inactivity timer period. Measurement study shows that for low to moderate email size, the second strategy halves the energy consumption.

B. Applications that canbenefit from prefetching:

Our goal is to use user-behavior statistics to make prefetching decisions in the context of Web search and browsing. The information retrieval research community and search engine providers collect large amounts of data to study user behavior on the web. To estimate the expected energy savings as a function of prefetched documents size. Let k be the number of prefetched documents, prefetched in the decreasing rank order and p(k) be the probability that a user requests a document within rank k. Let E be the Tail energy, R(k) be the energy required to receive k documents, and TE be the total energy required to receive a document. TE includes the energy to receive the list of snippets, request for a document from the snippet and then receive the document. For the sake of this analysis, we assume that user think-time to request a document is greater than the value of the inactivity timer. Do not make this assumption in our evaluation or the prefetching algorithm. The expected fraction of energy savings if the top k documents are prefetched is

$$\frac{E \cdot p(k) - R(k)}{TE}$$

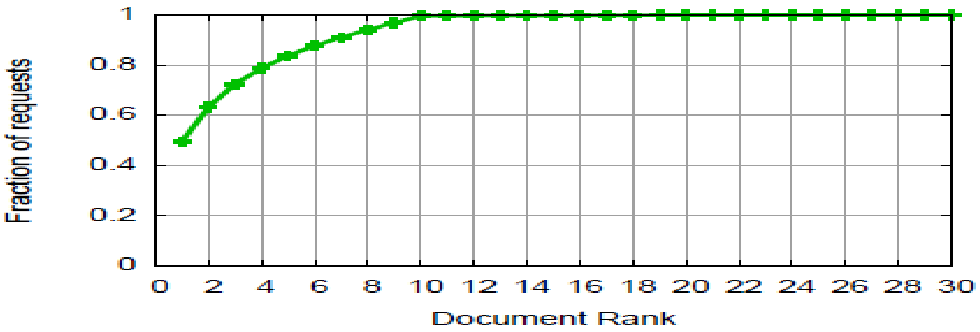

Fig. 7 CDF over more than 8 million queries collected across several days

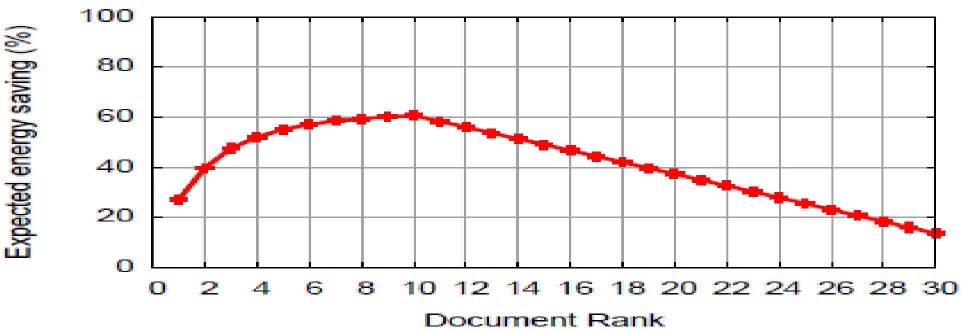

Fig. 8 Expected percentage energy saving as fuction of the number of document prefetch

Fig.8 shows the expected energy savings for varying k as estimated by Equation . The value of p(k) is obtained from statistics presented in Fig.7, and E, R(k) and TE are obtained from the 3G energy measurements . It set the size of a document to be the average web document size seen in the search logs. Fig.8 shows that prefetching 10 web documents maximizes the energy saved. When more documents are prefetched, the cost of prefetching is greater than the energy savings. When too few documents are prefetched, the expected energy savings is low since the user may not request a prefetched document. Therefore, TailEnder prefetches 10 web documents for each user query.

IV. CONCLUSION

Energy on mobile phones is a precious resource. As phones equipped with multiple wireless technologies such as 3G, GSM, and WiFi become commonplace, it is important to understand their relative energy consumption characteristics. To this end, we conducted a measurement study and found a significant tail energy overhead in 3G and GSM. We studied a measurement driven model of energy consumption of network activity for each technology. Experiments conducted on the mobile phone shows that TailEnder can download 60% more news feed updates and download search results for more than 50% of web queries, compared to using the default policy. Our model-driven simulation shows that TailEnder can reduce energy by 35% for email applications, 52% for news feeds and 40% for web search.

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