Strategies for Energy-Efficient Mobile Web Access: An East African Case Study

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Abstract. The limited battery life of mobile handheld devices coupled with the lack of readily or reliable access to electricity is proving to be a major barrier to both adoption and usage of mobile Internet services in most African countries. Therefore, new methods of energy-efficient delivery of mobile web content are essential for prolonging battery life. This paper discusses and evaluates four energy-saving strategies, namely mobile optimization, HTTP compression, caching and proxy. The proposed energy-efficient proxy achieves at most 60% and 74% energy saving in 2G and 3G networks respectively without affecting user experience. As a case study, we consider usage trends and sample web content from three East African countries (Kenya, Tanzania and Uganda).

Keywords: Energy efficiency, Web, Proxy and 2G/3G.

1 Introduction

Mobile computing and communication is quickly becoming a commodity with manufacturers introducing new smart phones almost weekly and operators extending their third generation (3G) and Long-Term Evolution (LTE) network coverage. The development is very welcome for people in developed countries where the society has a state of the art civil infrastructure. In particular, a well-developed power grid is essential for users of modern smart phones because the technological gap between the power consumption of the devices and the current battery technology is increasing [1]. In practice this means that modern smart phones need to be recharged every day because of their increasing demand for energy. Big and bright displays, high-speed mobile connectivity, fancy applications and games all need power from the device battery. For inhabitants of developed countries, charging a phone every day at the office or in the evening at home is not an issue. Yet, in many other countries and geographical locations a stable power grid is not available everywhere [11]. Thus, a mobile device simply has to be very energy-efficient because it can not be charged constantly.

Majority of power consumed by smart phones are attributed to its radio transceiver and modem circuitry [1]. For instance, compared to 848mW power consumption of screen with maximum brightness on a Nokia N900[1], the power consumption of its 3G

[1] Nokia N900 specification: http://europe.nokia.com/find-products/devices/nokia-n900.

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radio is around 878mW according to our measurements. As we can see, one of the main factors dominating the energy consumption of web access in the mobile devices is the transmission energy that is proportional to the length of a transmission and the transmit power level. In our earlier work, we have analyzed the power dissipation of 2G, 3G and Wireless Local Access Network (WLAN) radio interfaces [6]. The fixed overhead of transmission is significant when the radio interfaces are in communication state, thus data should be sent in quick bursts (compared to constant small transfers) to enable a longer battery lifetime as interfaces can benefit more efficiently from low power mode. As discussed in [2][3], 2G and 3G links exhibit a residual energy cost after the last packet transmission, before the links switch back to low power state. This is standardized in 3GPP [4], an activity timer triggered when there is no activity still keeps radio modem in high power consumption state for certain period, which can be configured by network operators. Even in WLAN, the radio needs to wait for a predetermined interval to switch from active mode back to power save mode after no frames are received or transmitted.

In the case of web access, energy efficiency is intensively affected by Transmission Control Protocol (TCP) throughput, through the round-trip time (RTT). Based on our measurements, energy consumption per bit significantly increases from 0.536 uJ/bit to 2.103 uJ/bit when RTT rises from 60ms to 1060ms [6]. We can identify different strategies for delivering information and web content more efficiently to the user: the content can be optimized for mobile devices; Hypertext Transfer Protocol (HTTP) compression can be enabled on the server; caching data close to the users help since access times become lower, and we can deploy performance enhancing proxies [5]. The motivation to make use of any of these techniques is that the end users' Quality of Experience (QoE) is improved, which is reflected also back to the network operator and the content provider.

In this paper, we discuss different strategies to help people benefit from mobile web services in areas where stable sources for electric power simply do not exist. As a case study, we consider mobile Internet access and electrification trends from three selected East African countries, namely: Kenya, Tanzania and Uganda. By various measurements we show how much a given enhancement can help the end users and their struggle to extend the lifetime of a modern mobile device.

2 Access to Internet and Electricity

Mobile networks are currently enabling Internet access for millions of previously unconnected users in most emerging markets of Africa. Typically these countries are characterized by miniscule penetration of fixed lines, which implies that Internet access via wireline access infrastructure (e.g. DSL cables) is only possible for a minor segment of the population. On the other hand, mobile networks provide wide-area connectivity with relatively lower upfront costs, thus enabling instant and flexible Internet connectivity for a larger number of users in areas covered with evolved second generation (2.5G) mobile networks, or evolutions thereof.

The subscription data gathered by regulators in the three East African countries of study confirm this trend of exploding mobile Internet service adoption. Statistics from

Kenya's regulator note that the Internet penetration increased from 10% in September 2009 to 22% in September 2010, with mobile Internet access accounting for 99% of the total Internet subscriptions for that period [7]. Similarly, Tanzania's regulator reports that mobile Internet access subscriptions are having the fastest growth rates (42% per year between 2008 and 2010), compared to other fixed wireless and wireline Internet access types [8]. In Uganda, the regulator notes that the mobile Internet subscriptions constituted 94% of all Internet subscriptions by June 2010 [9]. The mobile Internet growth is evident not just in terms of increased subscriptions but also in terms of usage (mobile web traffic). For instance, the mobile web statistics provided by Opera Software (a mobile browser maker) concluded that the number of web page-views and data transferred on mobile handsets in Tanzania grew by 335% and 288%, respectively, in the one year period from December 2009 to December 2010 [10].

However, the continued success in growth of mobile Internet subscriptions is facing a number of barriers, most notably, the lack of a readily available power supply for re-charging of mobile Internet devices. Throughout East Africa, the fraction of the population with mobile Internet access but no access to electricity is growing, particularly in rural areas where less than 3% of the rural population has access to electricity (see Figure 1). Furthermore, with less than 5% of households having computers, mobile handsets are the likeliest Internet access devices. Whilst about half of the urban population has access to electricity (see Figure 1) the supply of electricity can be highly unreliable due to frequent blackouts (see Table 1), because electricity demand exceeds generation capacity in all those countries [11].

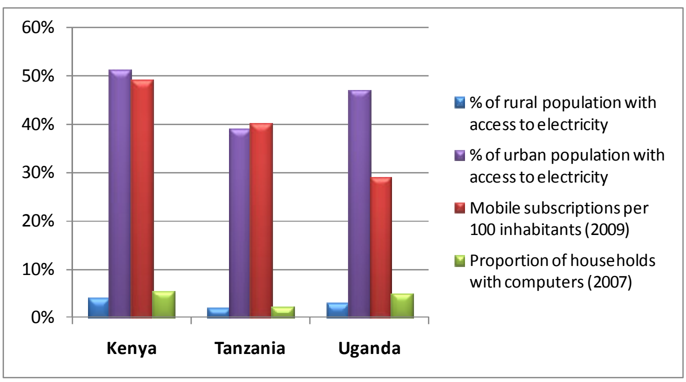

Fig. 1. Comparison of electrification and ICT indicators for three East African countries (Data source: World Bank [11], ITU [12])

Table 1. Electricity blackout data (Data source: World Bank [11])

	Outages (days/year)	Average duration (hours)	Outages (hours/year)	Downtime (% of year)
Kenya	86	8.20	702.6	8.0
Tanzania	67	6.46	435.9	5.0
Uganda	71	6.55	463.8	5.3

It is clear that the very limited access to electricity and unreliable electricity supply presents a significant barrier to continued adoption of mobile Internet services in and sustainability of an acceptable QoE for mobile Internet users in the region. Innovative mobile battery charging methods using solar chargers, used-car batteries or local charging service providers have proved to be very useful for maintaining mobile devices for voice or text messaging services. However, with mobile Internet devices consuming relatively more energy, then energy-efficient methods that prolong the mobile battery life are now very essential.

3 Energy-Saving Solutions

As discussed already, energy-saving solutions become more and more important due to the power constraints. In this section, we discuss four different strategies: mobile web optimization, HTTP compression, caching and performance enhancing proxy.

3.1 Mobile Web Optimization

Mobile web optimization reformats and tailors the web pages to be more accessible and fitted for particular mobile devices. One solution is to tailor any website into a mobile friendly one by concatenating all columns of the pages into a single vertical column, removing the site header, advertisements, resizing or removing all images or even customizing the site with logo adding, and style changing [13][14]. However, the content delivered to mobile devices may not necessarily be the format the site owner intends for mobile users. The other solution is to create the mobile version of websites such that more reliable and optimized content can be directly delivered to mobile users. For example, Facebook offers its mobile web, a lighter version of the actual Facebook.com [15]. Besides, .mobi as a top-level domain name is for mobile devices accessing Internet via mobile web and engaged with the World Wide Web Consortium (W3C) mobile web initiative to formulate practices and publish guidelines for achieving mobile and ubiquitous web [16]. Moreover, a framework for web content and resources adaptation in mobile devices (WRAMD) was proposed in [17]. It adapts web content for specific devices namely standard web content production for desktop machines, which is faster and simpler web content for mobile devices.

Generally, mobile web optimization facilitates web work on mobile devices with speed and less power consumption. However, this strategy, which relies on rather simplified web elements and content, may lead to reduction of QoE for mobile users.

3.2 HTTP Compression

According to RFC 2616 [18], HTTP compression is defined as a way in HTTP 1.1 to transfer HTTP response messages in compressed format from web servers to requesting web browsers. HTTP compression requires both web server and web browser sharing same understanding of compression algorithms (gzip, deflate) so that the web server is capable of encoding the outbound content and the web browser is able to decode the content, which normally are HTML, XML, JavaScript, CSS and other textual files. Nowadays, a majority of network traffic is HTTP traffic and HTTP compression has been widely supported by servers and browsers.

The adoption of HTTP compression in mobile networks are more beneficial because the energy consumed on a single bit transmission over wireless is over 1000 times greater than a single 32-bit CPU computation [19]. The phenomenon indicates that it is energy wise to squeeze bits transmitted over the radio link by spending some CPU cycles in calculations. So, HTTP compression decreases the number of transmitted bits resulting in reduction of the transmission time and leads to reduction in energy consumption as well.

3.3 Web Caching

A further energy-saving technique is web caching which is a mechanism to temporarily store copies of web content on proxy. When subsequent URL requests for the same content are made, the cache responds with either a hit or a miss, indicating the presence of the URL object on the cache. If it is a hit, the web content is transmitted from the cache directly instead of from web server. Caching helps to reduce the traffic on the Internet and server load. On the other hand, it decreases response time and, thus, reduces power consumption of mobile devices when visiting web sites since the devices are able to retrieve web pages faster and be back to idle state quicker.

Normally, there are two types of web caches, namely a browser cache and a proxy cache. A browser cache keeps the copies and returns them to browser locally. By contrast, a proxy cache typically is located in Internet Service Provider (ISP) network and shared by many users. Therefore, a repeat of the download from the original content source can be dramatically decreased. Caching was originally designed for storing static documents. However, dynamic pages, generated dynamically based on request parameters, have been increasing. Thus, dynamic content is also cached on proxy to further reduce download latency and power consumption by increasing hit ratio, as indicated in [20].

3.4 Performance Enhancing Proxy

We have designed an energy-efficient proxy, which applies a simplified data exchange process instead of following standard HTTP to download bundled and compressed web content from web proxy after all the embedded objects are fetched by the web proxy.

By deploying the strategy, the following benefits are offered:

(1) Simplified HTTP message exchange procedure is applied by replacing standard HTTP with bundling between the mobile client and the proxy. Once the proxy receives HTTP request, it is on behalf of the mobile client to fetch all the web content and sends all of the web objects in one bundle to the mobile client. The entire interactive web fetching is offloaded from the mobile device to the web proxy. The

bundling enables the mobile device to enter idle mode and wait in low power consumption state till the proxy sends the bundled objects back instead of keeping its radio on until downloading is finished.

(2) Some studies [20], [21] evaluated the trade-off between transmission and compression, and the results show that compression can be adaptively used to gain energy saving when fulfilling certain conditions, which include considerations of link quality, computation load, file type and compression algorithms. In order to further reduce power consumption, the proxy also compresses the objects selectively based on the compression ratio of compressing the objects and power consumption of mobile devices required for decompressing during the web fetching.

(3) The proxy separates transmission connections between the client and the proxy, and between the proxy and the server. Without the mobile client explicitly requesting all the objects by itself, it improves TCP throughput by reducing delay and enables higher utilization of the wireless network bandwidth between the mobile client and proxy. Ideally, web proxies should be deployed by ISPs or network operators enabling the proxies to be located as close as possible to mobile clients so that the delay between the mobile devices and the web proxy can be minimized.

4 Experimentation and Results

In order to evaluate discussed strategies, we first benchmark our experimental criteria. Then experimental setup is introduced. After that we show our results and discussion.

4.1 Benchmarks

The criteria used for selecting web content samples for use in the experiments are the ranking in terms of being accessed by subscribers in the East Africa region and the origin of the content (local or international content). To that end, the leading website is the international Facebook social media site (which has some localization for local consumptions), while the leading sites from local content providers are the news sites from local publishers [10]. The lack of local content that is optimized for mobile web has been identified as major stumbling block in East Africa [23], this not only reduces accessibility of the content via mobile devices but may also impact on the battery life. Therefore, for the sample websites, we select both regular sites and those that are optimized for the mobile web (see Table 2), so as to further highlight the energy-saving opportunity enabled by optimization of content for the mobile web,

Table 2. Websites selected for the experiment

Note[2]	Facebook	Daily Nation	Daily Monitor
Normal web pages	www.facebook.com	www.nation.co.ke	www.monitor.co.ug
	320978 Bytes	732645 Bytes	820468 Bytes
Mobile optimized web pages	m.facebook.com	mobile.nation.co.ke	mobile.monitor.co.ug
	6458 Bytes	140153 Bytes	87742 Bytes

[2] The web pages were obtained the 30^{th} of June, 2011.

4.2 Experimental Setup

In order to obtain quantitative and qualitative understanding of how different strategies affect energy dissipation, we measured the power consumption on the Nokia N900 smartphone and calculated its energy power consumption when mentioned web pages were downloading. To achieve accurate power consumption measurements, the battery of the N900 was replaced by an adapter, which was connected to a 4.1 V DC power supply[3] for stable power source as shown in Figure 3. Then the power supply was serially connected with a 0.1 Ohm resistor. NI cRIO-921[4] was used to collect voltage fluctuations with a rate of 1000 samples per second across the resistor and readings were recorded on a Windows PC with NI-DAQmx software installed. As seen in right upper part of the figure, the readings can be showed in real-time. Based on our measurements, the basic power consumption of the N900 with screen off is around 20mW.

As the benchmarked web sites are located in different countries, RTT between the N900 and each site is variable. Thus, we kept the copies of each web page on our Apache web server for same evaluation criteria and the artificial RTT was 100ms. Besides, the energy-efficient proxy was designed and implemented based on Qt 4.7.3[5], which is the latest SDK of a cross-platform application framework.

4.3 Experimental Results

Considering the electric power is normally accessible in the areas with WLAN coverage, we focus evaluating power dissipation of the cases in 2G and 3G networks. In order to evaluate different strategies, the baseline case for fetching the normal pages was set up by measuring the energy consumption of only using normal HTTP downloading without the help of HTTP compression, cache and proxy. The time spent on fetching the web pages is shown in Figure 3. The relatively higher throughput of 3G networks leads to much less time on downloading the web pages. However, there are no obvious energy consumption differences when the N900 connected to 2G or 3G networks in the cases of downloading normal pages, mobile optimized pages, compressed pages or cached pages, as illustrated in Figure 4. The reason is that the power consumption was 531.9mW and 878.5mW when the device was operating in 2G and 3G modes respectively. Thus, the product of the time and the power consumption yields basically similar amount of energy consumption, and the average difference is around 10%.

HTTP compression and caching provide almost similar energy-saving according to our measurements. However, as the RTT between proxy and web server increases, caching should provide more energy saving. Mobile optimization as one of the most promising alternatives that offers great energy-saving potential for energy-efficient web access and already has been widely deployed. However, simplified web content affects QoE of mobile users, who have to consider the trade-off between user experience and battery dissipation.

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[3] R&S NGMO2 dual-channel analyzer/power supply: http://www2.rohde-schwarz.com/product/ngmo2.html

[4] NI 9215 analog input module: http://sine.ni.com/nips/cds/view/p/lang/en/nid/14166

[5] Qt 4.7.3. http://qt.nokia.com/

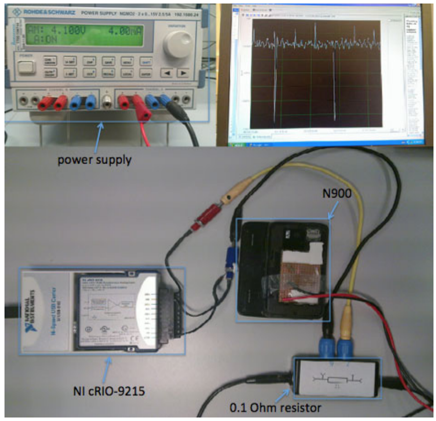

Fig. 2. Experimental setup for measuring power consumption on the Nokia N900

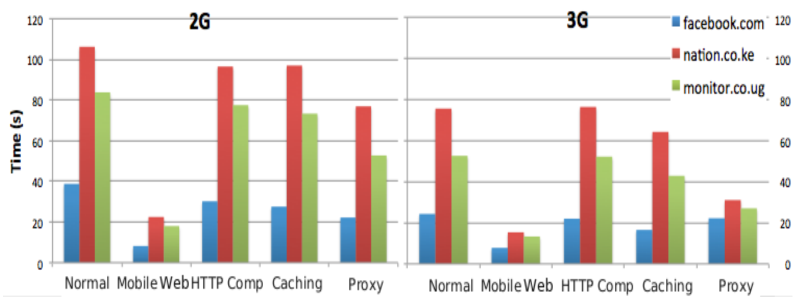

Fig. 3. Time of fetching the three sample web pages using different methods

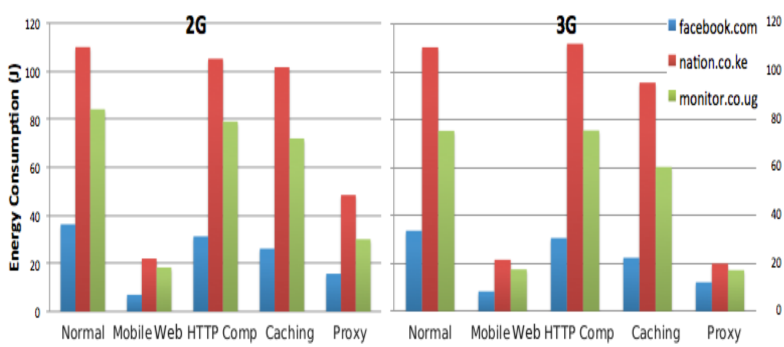

Fig. 4. Energy consumed in fetching the three sample web pages using different methods

Our proposed energy-efficient proxy offers even more energy saving than mobile optimization when the N900 downloaded www.nation.co.ke and www.monitor.co.ug pages in 3G networks. On average, the solution reduces the energy consumption to 41% and 26% of the energy consumption of normal fetching in 2G and 3G networks respectively. Furthermore, it speeds up the downloading speed and decreases the average downloading time to approximately 60% of the time consumed by normal downloading. Since the benefits gained from compression are also depends on the content structure of a web page, the results may be different even through the sizes of two web pages are roughly equal.

As discussed in Section 3.4, the proxy utilizes bundling to simplify message exchange between the mobile device and web server. Based on the measurements, the average power consumption of using the proxy is around 636mW for the 2G connection and 606mW for 3G connection. However, the average power consumption in the other solutions is about 996mW and 1383mW for 2G and 3G networks respectively. The results demonstrate that the simplified web fetching allows radio interfaces to stay in low power consumption state during the web fetching. Besides, the energy consumption is further reduced with the assistance of selective compression and full utilization of link capacity of cellular network.

5 Conclusions

As the growth trend of mobile users and the shift to mobile web access has been accelerating in Africa, the lack of reliable access to electric power for re-charging of mobile devices has become increasingly critical. In this paper, we considered three East African countries as a case study to evaluate different strategies for energy-efficient web access on mobile devices. Our proposed energy-efficient proxy reduced the energy consumption of accessing web content by more than 59% for 2G network and 74% for 3G network. Moreover, it decreased the downloading time to 60% on average compared to normal web content fetching without compromising QoE. The work shows great potential in terms of enhancing energy-efficiency. As future work, thorough analysis of the energy-saving strategies based on the proxy will direct us to even more energy-efficient solution for web access.

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