This full text paper was peer reviewed at the direction of IEEE Communications Society subject matter experts for publication in the IEEE CCNC 2010 proceedings

Parallel Connections and Their Effect on the Battery Consumption of a Mobile Phone

Jukka K. Nurminen
Nokia Research Center
Helsinki, Finland
jukka.k.nurminen@nokia.com

Abstract- **In this paper, we analyze the end-to-end communication activities of a modern mobile phone, Nokia N95, to understand how much energy different communication alternatives consume. In particular, we investigate the interactions when multiple connections are used in parallel. Parallel connections save energy but the gains vary depending on the technology. TCP downloads during 3G voice calls result into 75%-90% energy savings, TCP downloads during VoIP calls result into 30%-40% savings, and TCP downloads when other TCP streams are active at the same interface result into 0%-20% savings. The results indicate that there is a significant potential to save energy if applications are engineered to take advantage of this phenomenon.**

Keywords-energy analysis; low-power; wireless interfaces; mobile phone; TCP; voice calls; measurement study

I. INTRODUCTION

In this paper, we analyze the end-to-end communication activities of a modern mobile phone, Nokia N95, to understand how much energy different communication alternatives consume. In particular, we investigate the interactions when multiple connections are used in parallel. As mobile phones are increasingly used for web browsing, emailing, multimedia, and other data communication activities, the management of the connections in an energy-efficient way is important. With the increasing number of mobile services, opportunities to transfer data in parallel will increase. Parallel transfer can happen by accident but it can also be an engineering goal if it results into energy savings.

In this paper, we focus primarily on the observed behavior as seen at the application level and measure the performance of the device. This research can be useful for multiple purposes. First, understanding the energy consumption of different communication alternatives allows solution developers to make informed design decisions. Second, observations from the real behavior and interaction of end-to-end traffic streams can be a basis for new mechanisms for energy-efficient operation.

While there are number of studies of live cellular network performance, e.g. [1,2], the effect of end-to-end communication to energy consumption of the mobile device has not been widely investigated. For WLAN there has been more work on this, especially on the area of multimedia content transfer e.g. [3-5]. The interaction of multiple connections has been investigated, in particular, in the context of parallel TCP connections [6]. Bu et al. [7] have investigated parallel TCP and VoIP/UDP connections but their perspective has been how the traffic mix affects Internet performance. To the best of our knowledge, our work is the first one that investigates the effect of parallel connections to the power consumption of a mobile device.

The rest of the paper is structured as follows. In section II we describe our measurement setup. In section III we analyze the energy consumption of 3G and WLAN data transfers and observe why grouping communication activities has potential for energy savings. In section IV we analyze the parallel voice/VoIP and TCP connections, and in section V we perform similar analysis for parallel TCP connections. Finally, section VI concludes the paper.

II. MEASUREMENT SETUP

We performed the energy measurements with the Nokia Energy Profiler application that is available free of charge at Forum Nokia (www.forum.nokia.com). We used Python for S60 to execute the TCP data transfers while we manually set up the voice calls. No additional applications were active in the test device except the factory default background processes.

TABLE I
TCP MEASUREMENTS WITH DIFFERENT CONNECTIONS AND SERVERS

		Power (W)	Speed (kB/s)	Time (s)	Energy (J)
Test	WLAN download	1.1	143.1	18.0	20.0
	WLAN upload	1.1	115.3	22.3	23.7
	3G download	1.3	48.3	53.3	69.0
	3G upload	1.3	43.2	59.7	75.6
Funet	WLAN download	1.4	435.1	50.0	71.3
	3G download	1.5	272.0	80.0	119.2
Hit	WLAN download	1.2	143.3	18.7	21.3
	3G download	1.5	128.7	20.3	29.4

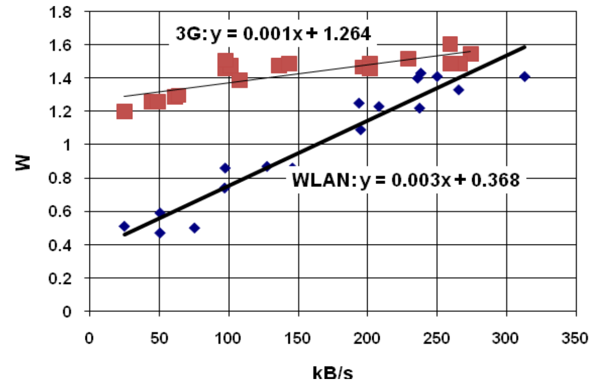

Figure 1. Power consumption of 3G (red squares) and WLAN (blue dots) communication with different bitrates

As a test device, we used Nokia N95 8G mobile phone (Symbian OS v9.2, S60 3rd Edition, N95-2 V 15.0.015). We performed the measurements in May 2009 in downtown office area in Helsinki, Finland, using the network of Sonera cellular operator.

For our analysis, we used three different data sources. Since the behavior of the data stream affects the results, we tried to find representative test cases of end-to-end connections that, in particular, differ in the speed. The test case denoted as “Test” was using our own Apache server. It was connected both to WLAN and to public 3G network. The connection, especially to 3G network, was slow, around 50 kB/s in maximum. The test case called “Hit” represented a public web service, http://www.hitestrecords.com/mp3, which had medium end-to-end access speed, around 150 kB/s in maximum. In both of these cases we used the same file “brains.mp3” with a size of 2576 kB. Finally, for fast end-to-end connection, denoted “Funet”, we used http://ftp.funet.fi/pub/Linux/INSTALL/SuSE to access file “ls-Ral.txt” with a size of 21756 kB. With a fast connection “Funet” test case allowed studying the cases where the radio connection is the bottleneck.

For the voice call analysis, prior to data transfer we formed a voice call to another mobile phone in a different operator network and had a two directional flow of words during the analysis period.

The phone was stationary during the measurement to reduce field strength variability and to eliminate eventual handovers arising from the movement of the device.

We performed each measurement at least three times and calculated their averages, which we use in the following analysis.

Measurements with live networks are naturally subject to variability in external circumstances that are beyond our control. Our WLAN measurements showed a clear dependency on the external context while the variance of repeated 3G measurements was very small. The results are also influenced by the phone model, its chipsets and operating system. To evaluate the sensitivity of the results we replicated a subset of the measurements at geographically different locations (urban and suburban home), with another cellular operator (Elisa) and with another device (Nokia N96). The outcome was that the relative results did not change much even though the absolute values of the measurements were different in different cases. Therefore, it is better to focus more on the observed phenomena rather than on the specific numbers.

III. ENERGY CONSUMPTION OF A TCP CONNECTION

Table I shows the average power, bitrate, time, and energy that downloading or uploading each test case via a single TCP connection required.

We can observe that WLAN is clearly more energy efficient than 3G. This can be mainly explained by the more aggressive power saving mode of WLAN at lower bitrates as well as by the higher bitrates that WLAN enables. It is also visible that uploading consumes more energy than downloading (18% more with WLAN and 10% more in 3G).

Figure 1 shows the dependency between end-to-end download speed and power consumption. The linear trendlines fitted with the measurement results show for 3G only slight increase in power consumption when bitrate increases. For WLAN the dependency is three times stronger and lower bitrates have a major power difference to 3G.

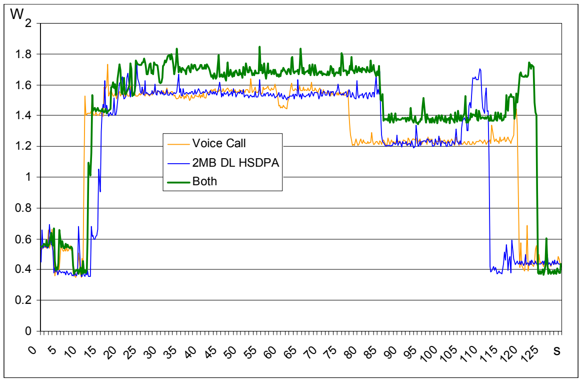

Figure 2. Power consumption when a) a voice call is active, b) a data download is active, and c) both voice call and data download are active at the same time

TABLE II
TCP DOWNLOADING DURING A VOICE CALL

		Power (W)	Speed (kB/s)	Time (s)	TCP energy (J)	Energy ratio
	3G call	1.3				
	VoIP call	1.0	10.2			
Test	3G download + 3G call	1.4	48.0	53.7	9.5	14%
	WLAN download + VoIP call	1.6	166.3	15.7	10.1	59%
Funet	3G download + 3G call	1.6	268.1	81.7	31.7	27%
	WLAN download + VoIP call	1.9	375.1	58	52.2	73%

The difference can be explained by the different ways the power save modes of these two systems work. The PSM mechanisms of WLAN enters the idle state much more rapidly than the 3G data transfer where the timers that control changes between radio states are typically an order of magnitude longer than in WLAN. Therefore 3G radio circuitry is constantly powered on while WLAN is able to enter low-power sleep state between data packets.

In both 3G and WLAN cases the energy per bit decreases significantly when the bitrate increases. This suggests a strategy for energy saving. The higher the bitrate we are able to use in the communication, the better for the battery duration. However, the possibilities to influence the end-to-end bitrate of individual services and their access over Internet are limited because they depend on the capacity of the servers and on the Internet bottlenecks. Moreover, in many cases, e.g. real time voice communication, the application needs determine the bitrate.

A possibility to increase the bitrate and thus transfer data in more energy efficient fashion is to execute multiple communication actions at the same time. In this way we do not need to influence the speeds of the individual connections but we are still be able to take advantage of the more energy efficient data transfer enabled by higher bitrates. As the number of services on mobile devices increases, possibilities for managing the connections and delaying some of the non-urgent data transfers to allow their execution in parallel with other connections increase.

IV. TCP CONNECTIONS DURING VOICE CALLS

In spite of the increasing use of mobile services, the primary use of a mobile phone for most users is still making and receiving phone calls. Phone calls require almost constant flow of data but the bandwidth required by the speech is small in comparison to the capacities available in modern cellular networks. Therefore, data transfer during a voice call is likely to be a good opportunity to exploit the parallelism to save energy.

Figure 2 shows the chart of an example measurement. The x-axis of the chart shows the time and the y-axis the power consumption. The chart shows the energy consumption in three different cases. The light gray/orange curve shows the energy consumption when only a voice call is active. In the early part 15-80 s the voice call is active and the display light is on. When the display light is switched off at 80 s the power consumption drops from 1.5 W to 1.2 W. The dark grey/blue curve shows the energy consumption when the phone is downloading content (a 2MB file). As the figure shows the energy consumption is rather similar than in the case of voice call. The thick gray/green curve shows a case when both voice call and data download are active simultaneously. The power consumption is around 1.7 W and 1.4 W when the display light is on and off respectively.

We can see from the combined curve that when data download is performed during a voice call the power consumption is only slightly higher than what the voice call would anyhow require. In this measurement, the extra power is only 10%. Likewise, the data transfer time increases slightly up to 12% during a parallel voice call. As a result, if we do the data transfer during a voice call we are able to perform the same activity with only 23% of the energy that it would take without the voice call.

Table II summarizes our measurement results to analyze this effect. Power, speed, and time indicate the average values we measured for these attributes. TCP energy column means the energy needed for the TCP data transfer. For example, in case of download operation during 3G call, the TCP energy value is calculated by subtracting from the total energy of a parallel voice call and data transfer the energy that a voice call of equal length would consume alone. Finally, energy ratio is the value of the TCP energy column divided by the energy the same operation would require as a stand-alone activity (from Table I).

As already illustrated by the example above, data transfer during a cellular call is very energy efficient. As the values in Table II indicate, the communication energy saving can be close to 90% if we can perform the communication during voice calls.

Table II also shows the values of similar measurements when we used VoIP over WLAN instead of cellular calls. The energy savings in VoIP case are clear (around 30% to 40%) although they are far less than what we are able to achieve in the 3G call case.

VoIP measurements are also interesting because we have two connections carrying IP traffic: UDP based VoIP and TCP based data transfer. Therefore, it is possible that the similar gains can be achieved in other applications based on UDP such as in media streaming.

The phenomenon can be explained by looking at the way the mobile device operates. Communication is a major battery consumer with the radio transmitter and receiver spending together around 50% of the power in a video streaming use case [8]. When a mobile phone is transferring data or voice, most of the components in the device need to be powered on. In case of a cellular voice call, these components are constantly drawing power because the system has no time to enter a low power sleep mode, as the voice stream requires steady transfer of data. However, the voice stream requires only a small part of the available bandwidth. A TCP connection running in parallel with the cellular voice call can use the spare bandwidth but as all the communication circuitry is already powered on to serve the voice call, it needs very little additional power. The slight increase in power consumption can be attributed to the increased use of CPU and memory access.

The reason for smaller savings for VoIP call cases is visible in the trendlines of Figure 1. Parallel transfer of data and voice increases the aggregate bitrate. Because 3G power consumption is not very sensitive to the bitrate changes, the parallel TCP connection has a small impact on power consumption. In the WLAN case the parallel TCP connection increases the power consumption more, resulting into smaller gains. Note that our test device, Nokia N95, supports only the regular power save mode (PSP) of 802.11 standards. The emerging U-APSD power management method (see e.g. [9]), which is more energy-efficient for VoIP type of traffic, can shrink the gains further.

TABLE III
RESULTS OF TWO PARALLEL TCP CONNECTIONS

		Power (W)	Speed (kB/s)	Time (s)	Energy (J)	Energy ratio
Test + Test	WLAN download	1.3	151.9	34.0	42.7	106%
	3G download	1.3	51.2	100.7	133.5	97%
Funet + Test	WLAN download	1.4	367.3	66.7	92.5	101%
	3G download	1.6	262.2	93.3	145.5	77%
	WLAN download + upload	1.5	430.5	56.7	82.7	87%
	3G download + upload	1.5	199.4	122.0	179.7	92%
	3G + WLAN download	1.9	209.8	116.0	219.2	157%
	WLAN + 3G download	1.8	238.7	104.7	194.3	138%
Test + Hit	WLAN download	1.4	216.6	24.3	34.4	83%
	3G download	1.5	98.5	52.3	77.6	79%

V. PARALLEL TCP CONNECTIONS

Another possibility is to use parallel TCP connections. Parallel TCP streams have been shown to improve the throughput [6] but do they also improve the energy-efficiency?

The measurement results of different connection pairs are collected in Table III. The energy column lists the total energy when both of the test files are downloaded or uploaded at the same time. Energy ratio is calculated by dividing the energy column value with the sum of energies of separate download, or upload, of the test files.

The results allow us to conclude that for the parallel TCP case the energy savings depend on the situation in a complicated way. First, if two streams experience the same internet or server bottleneck there is no gain (Test + Test case). Second, if there are two slow to medium speed streams that do not fulfill the radio channel completely then sending them in parallel reduces the energy consumption (Test + Hit case). In our measurements, the reduction was around 20% but it is likely to depend on stream speed and other properties. The case of a fast and a slow stream (Funet + Test) is the hardest to interpret. On 3G parallel connections created over 20% savings but on WLAN there was no gain. A possible reason is that downloading with two parallel streams slowed down the average bitrate; in WLAN case by 16%.

In general, we can say that parallel TCP downloading may reduce energy need by up to 20%. Detecting when this gain can be achieved can be difficult, especially for dynamic run-time decision making. Fortunately, the worst case does not consume extra in energy, which suggests that trying to apply parallel downloading is a good strategy even if it does not guarantee energy savings.

We also investigated the case where we use one TCP connection for downloading and at the same time another TCP connection for uploading to see if the two-directional traffic would change the situation. Interestingly, in this case the results were different for WLAN and for cellular. In case of WLAN, parallel uploading and downloading reduced total energy by 11 % in comparison to two parallel downloading connections. In 3G we saw the opposite effect; parallel download and upload required 24% more energy than the two parallel downloads. This case indicates clearly that there are fundamental differences in wireless technologies; WLAN results cannot be blindly generalized to apply to 3G and vice versa.

Finally, we analyzed the case when we used multiple interfaces for TCP download. Some authors like [10] have suggested that a mobile may want to take advantage the additional bandwidth enabled by simultaneously striping data through multiple network interfaces. The energy consumption does not support this approach resulting into 40% to 50% higher energy consumption than the use of a single interface. This is easy to understand because it is useful to transfer the data via the most power-efficient interface, in our case, via WLAN. As long as the interfaces are physically separate and can be powered-off independently from each other, the use of multiple interfaces does not seem to be useful.

VI. CONCLUSIONS

In this paper, we have analyzed the energy consumption of the end-to-end communication tasks of a mobile device and paid special emphasis on the interactions when multiple connections are used in parallel. Parallel connections save energy but the gains vary depending on the technology. TCP downloads during 3G voice calls result into 75%-90% energy savings, TCP downloads during VoIP calls result into 30%-40% savings, and TCP downloads when other TCP streams are active in the same interface result into 0%-20% savings.

These numbers indicate that parallel data transfer has potential for energy-efficient communication. One way to take advantage of the energy gains that parallel transmission enables is to postpone data transfer to a later time [11]. There are many applications, such as synchronization of emails or downloading of RSS feeds, where the data transfer need is not immediate.

Further research would be needed to understand in detail the underlying causes of the phenomena we have discussed in this paper. Additional topics for further research include exploring the sensitivity of the results with different devices and operating systems as well as engineering new mechanisms to utilize the phenomena.

REFERENCES

[1] Y. Lee, “Measured TCP Performance in CDMA 1xEV-DO Network,” in *Proc. 7th Passive Active Measurement Conference (PAM)*, Adelaide, Australia, March 2006.

[2] M. Jurvansuu, J. Prokkola, M. Hanski, and P. Perala, "HSDPA Performance in Live Networks," in *Proc. IEEE Int. Conference on Communications (ICC'07)*, June 2007, pp.467-471.

[3] S. Chandra, “Wireless network interface energy consumption: implications for popular streaming formats,” *Multimedia Syst.* 9, 2, August 2003, pp. 185-201.

[4] L.-M. Feeney and M. Nilsson, “Investigating the energy consumption of a wireless network interface in an ad hoc networking environment,” in *Proc. IEEE INFOCOM 2001*, Anchorage, Alaska, 2001, pp. 1548-1557.

[5] G. Anastasi, M. Conti and W. Lapenna, “A power saving network architecture for accessing the Internet from mobile computers: Design, implementation and measurements,” *The Computer Journal* 46(1), Jan. 2003, pp. 3-15.

[6] T. J. Hacker, B. D. Athey, and B. Noble, "The end-to-end performance effects of parallel TCP sockets on a lossy wide-area network," in *Proc. International Parallel and Distributed Processing Symposium (IPDPS 2002),* 2002, pp. 434-443.

[7] T. Bu, Y. Liu, and D. Towsley, "On the TCP-Friendliness of VoIP Traffic," In *Proc. 25th IEEE Int. Conf. on Computer Communications (INFOCOM 2006)*, April 2006, pp.1-12.

[8] Y. Neuvo, "Cellular phones as embedded systems," in *Proc. IEEE International Solid-State Circuits Conference (ISSCC 2004)*, Feb. 2004, Vol.1, pp. 32-37.

[9] X. Pérez-Costa, D. Camps-Mur, and A. Vidal, “On distributed power saving mechanisms of wireless LANs 802.11e U-APSD vs 802.11 power save mode,” *Comput. Netw.* 51, 9 (Jun. 2007), pp. 2326-2344.

[10] T. Goff and D. S. Phatak, "Unified transport layer support for data striping and host mobility," *IEEE Journal on Selected Areas in Communications,* vol.22, no.4, pp. 737-746, 2004.

[11] J. K. Nurminen and J. Nöyränen, “Parallel Data Transfer with Voice Calls for Energy-Efficient Mobile Services,” in *Proc. 2nd Int. ICST Conference on MOBILe Wireless MiddleWARE, Operating Systems, and Applications (MOBILWARE 2009)*, Berlin, Germany, April 2009