On the Impact of Wireless Traffic Location and Access Technology on the Mobile Device Energy Consumption

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***Abstract*—In the context of wireless user's increasing demands for better device power and battery management, this paper investigates some factors that can impact the power consumption on the energy consumption of mobile devices. The focus is on two factors when performing multimedia streaming: the impact of the traffic location within a WLAN; and the impact of the radio access network technology (WLAN, HSDPA, UMTS). The energy measurement results show that by changing the quality level of the multimedia stream the energy can be greatly conserved while the user perceived quality level is still acceptable. Moreover, by using the cellular interface much more energy is consumed (up to 61%) than by using the WLAN interface.**

Keywords- multimedia, energy consumption, wireless networks, smartphone battery.

I. INTRODUCTION

Smart mobile computing devices become increasingly affordable and powerful, generating more than 90% of the entire mobile broadband traffic with mobile video expected to reach 66% of the world's mobile data traffic by 2014 [1]. Ensuring seamless multimedia experience to the user becomes a challenge. This led to the appearance of new standards and protocols (e.g., 3GPP-Adaptive HTTP Streaming Protocol [2], Open IPTV Forum with HTTP Adaptive Streaming [3], MPEG DASH [4]). Moreover, some of the key market players adopted their own adaptive streaming proprietary solutions (e.g., Microsoft IIS Smooth Streaming, Adobe HTTP Dynamic Flash Streaming, Apple HTTP Live Streaming).

In order to cope with the increase in traffic network service providers started offloading the mobile data traffic onto WLAN networks at peak times. The Wi-Fi offload solution is adopted by many service providers: Swisscom "Mobile Unlimited"[1], T-Mobile "Hotspot@Home"[2], the British Telecom "BT Fusion"[3], Deutsche Telekom and iPass WiFi Mobilize[4], etc.

In terms of energy conservation EU Commission has called for Information and Communications Technologies (ICT) to reduce its own carbon footprint by 20% by 2015. One of the key challenges in the next generation mobile multimedia networks is better understanding the power consumption in order to provide efficient power management.

A survey of power-aware mobile multimedia mechanisms with the main focus on video coding and video delivery is presented in [5]. A state-of-the-art power management method for next-generation wireless networks with a focus on operation modes (e.g., sleep, idle, etc.) is presented by Kim et al. [6]. The authors conclude that alternating available and unavailable intervals can provide an efficient and basic power saving method. However, by doing this, extra power consumption will be spent on activating and deactivating components, so the number of mode changes needs to be kept low. The authors in [7] propose a cross layer solution for adaptive multimedia delivery mechanism. The mechanism decides whether or not to adapt the multimedia stream in order to achieve power saving while maintaining good user perceived quality levels.

Despite the amount of research done in the area of energy conservation, not much focus has been placed on the impact of the multimedia communication environment (e.g., traffic load location, wireless access network technology, etc.) on the energy consumption. In our previous work [8] we presented an in-depth study on how the wireless link quality and the network load impact the energy consumption of an Android device while performing WLAN VoD streaming.

In this work we investigate the impact of the traffic load location (within the IEEE 802.11g network) and the impact of the wireless access network technology type on the energy consumption of an Android mobile device while performing VoD streaming. The aim of this paper is two-fold:

- Understanding the impact of the IEEE 802.11g traffic load location (impact of the location of traffic sources and their load) on the energy consumption while performing VoD;
- Understanding the impact of the radio access network technology (e.g., WLAN, UMTS, HSDPA) on the energy consumption while performing VoD.

II. EXPERIMENTAL TEST-BED SETUP

A. WLAN Test-Bed Setup

The WLAN test-bed is illustrated in Figure 1 and consists of: an IEEE 802.11g Wireless Router, a Multimedia Server, a Traffic Generator, a Network Monitor, an Android Mobile Device, and a Power Consumption Monitor which integrates

[1] Swisscom 'Mobile Unlimited' Service - http://www.swisscom.ch/solutions/Solutions-products/Mobile-Unlimited

[2] T-Mobile 'Hotspot@Home' - https://content.hotspot.t-mobile.com/AssetProcess.asp?asset=com.default.main.001

[3] Britich Telecom 'BT Fusion' - http://www2.bt.com/static/i/btretail/consumer/btbenefits/fns/fusion.html

[4] Deutsche Telekom and iPass 'WiFi Mobilize' - http://www.telekomicss.com/dtag/cms/content/ICSS/en/1508330

an Arduino Duemilanove[5] board connected to the Android mobile device and a laptop that stores the energy measurements.

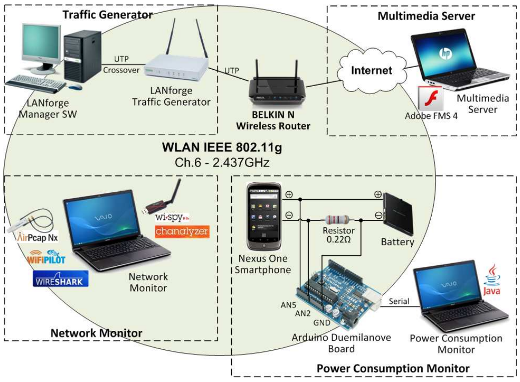

Figure 1. Experimental Test-bed Setup: Traffic Generator, Multimedia Server, Network Monitor and Power Consumption Monitor

B. *Background Traffic Specifications*

The reports provided by Cisco in [1] and by Plum Consulting[6] state that over the next years the ratio of downlink (DL) to uplink (UL) traffic will rise to 10:1, and video traffic is expected to reach 66% of the total mobile traffic by 2015. Based on this, the background traffic was selected as in Table I, where video is traditional video traffic over UDP (data rates of 0.25Mbps - 2Mbps, 1514 bytes packet size) and other (web-browsing/e-mail, file sharing, VoIP, etc.) is TCP traffic (data rates of 0.250Mbps - 1Mbps, 300-1514 bytes packet size).

TABLE I. BACKGROUND TRAFFIC SPECIFICATIONS

Type	% Traffic Cisco 2015	% downlink	% uplink
Video	66%	98%	2%
Other	34%	76%	24%

C. *Multimedia Encoding Specifications*

Adobe Flash Media Server 4[7] was used for streaming using the proprietary streaming protocols RTMP (TCP) and RTMFP (UDP). The Blender Foundation's 10 minute long Big Buck Bunny[8] animated clip was used and encoded at five different quality levels, as illustrated in Table II. The video play-out is scaled to the device screen resolution.

TABLE II. ENCODING SETTINGS FOR THE MULTIMEDIA TEST SEQUENCES

	Encoding Parameters				
Quality Level	**Video Codec**	**Overall Bitrate [Kbps]**	**Resolution [pixels]**	**Frame Rate [fps]**	**Audio Codec**
QL1	H.264/ MPEG-4 AVC Baseline Profile	1920	800x448	30	AAC 25 Kbps 8 KHz
QL2		960	512x288	25	
QL3		480	320x176	20	
QL4		240	320x176	15	
QL5		120	320x176	10	

D. *Quality-Energy Tradeoff*

In order to assess the quality of the five encoding settings used, objective and subjective measurements were performed. The Peak Signal-to-Noise Ratio (PSNR) was computed with MSU Video Quality Measurement Tool[9]. This is done by comparing the quality of the degraded versions (QL2 to QL5) to that of the highest quality level (QL1). The video clips were scaled to the same video resolution and video frame rate.

Subjective tests were performed in order to assess how human subjects perceive the quality of the five clips. 16 (10 Males, 6 Females) non-expert subjects participated in the study. The test sequences were played locally in full screen on the Android device following standard recommendations [9]. The quality of each sequence was rated on a 5-point scale (e.g., 1-Bad, 2-Poor, 3-Fair, 4-Good, 5-Excellent) and the Mean Opinion Score (MOS) was computed.

Local video playback was performed in order to assess the quality-energy tradeoff and study how much energy can be conserved by changing the quality level of the video. Table III illustrates the results together with the computed PSNR and the Subjective MOS. The Discharge and Battery Life values were estimated using eq. (1) and eq. (2) presented below [8]:

$$\text{Discharge [mAh]} = \text{Avg. Energy[J]} * 1000/(3.7V*3600sec.) \quad (1)$$

$$\text{Battery Life [hrs]} = 1330mAh*3.7V/\text{Avg. Power[mW]} \quad (2)$$

where 3.7V and 1330mAh represent the nominal voltage and capacity of the mobile device's battery.

Switching from QL4 to QL5 a low saving of 4.5%, for a MOS decrease from Good to Fair, is provided. However, switching from QL1 to QL3 provides a 44.8% energy saving for a MOS decrease from Excellent to Good, while a switch from QL1 to QL2 offers 34% energy savings at no significant change in MOS.

TABLE III. LOCAL PLAYBACK

Quality Level	Avg. Energy [J]	STDEV Energy	Avg. Power [mW]	Discharge [mAh]	Battery Life [hrs]	PSNR [dB]	Subjective MOS
QL1	712	3.28	1196	53	4.11	-	4.84
QL2	470	1.18	788	35	6.24	47	4.63
QL3	393	1.06	658	29	7.48	41	4.33
QL4	374	1.03	627	28	7.85	36	3.70
QL5	357	4.15	598	27	8.23	31	3.38

E. *Cellular Test-Bed Setup*

The cellular network test-bed is illustrated in Figure 2. The tests were run inside the Electronic Engineering building over the cellular networks provided by two mobile internet service providers in Ireland: O2[10] which offers HSDPA services and eMobile[11] which offers UMTS services. Due to network operator data security reasons, obtaining network related information (e.g., received throughput, network load, etc.) was not possible. The gathered information is the power consumption of the mobile device and generic network information (e.g., network type, maximum downlink rate, cell id (CID), location area code (LAC), mobile country code (MCC), mobile network code (MNC), signal strength (SS)) provided by the Network Signal Info Android application and listed in Table IV. Because cellular networks have lower

[5] Arduino Duemilanove - http://www.arduino.cc/en/Main/ArduinoBoard Duemilanove
[6] www.plumconsulting.co.uk
[7] Adobe Flash Media Server - http://www.adobe.com /products/flashmedia server/
[8] Big Buck Bunny - http://www.bigbuckbunny.org/
[9] MSU Video Quality Measurement Tool - http://compression.ru/video/quality_measure/ video_measurement_tool_en.html
[10] O2 Ireland - http://www.o2online.ie/o2/
[11] eMobile Ireland - http://www.emobile.ie/

transmission rates than WLAN (e.g., 384kbps for UMTS whereas 54Mbps for IEEE 802.11g), a subset of three quality levels from the five encoded for WLAN were considered. The three quality levels were streamed through the cellular networks to the Android device. The O2 network blocked UDP streaming, and the tests were conducted for TCP streaming only. In case of eMobile, both protocols were enabled and full tests were conducted.

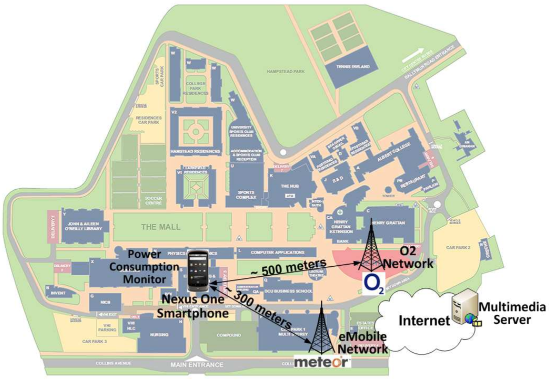

Figure 2. Cellular Test-bed Setup

TABLE IV. CELLULAR NETWORK CHARACTERISTICS

Operator	Network Type	Downlink Rate	CID	LAC	MCC+MNC	SS
O2	HSDPA	7.2Mbps	2044410	36006	27202	-95dBm
eMobile	UMTS	384kbps	60902	3006	27203	-73dBm

III. TEST CASE SCENARIOS

In order to study how the network traffic load location and the wireless access network technology impact the energy consumption of an Android mobile device, three scenarios were considered, as illustrated in Figure 3. In all the scenarios the Multimedia Server stores the five ten-minute clips being streamed sequentially to the Android device over UDP/TCP.

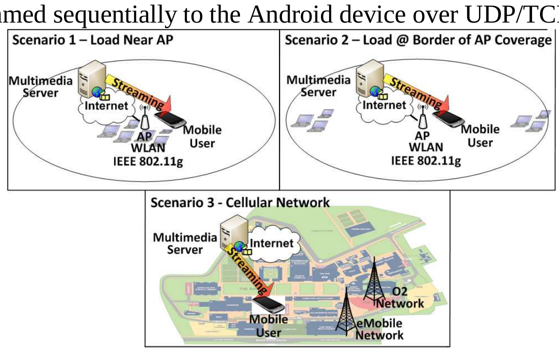

Figure 3. Considered Scenarios

A. *Scenario 1 – Load Near AP*

The mobile user is located near the AP (approximately 1m away) with varying SS [-48dBm, -52dBm]. 25 to 28 virtual wireless stations located near the AP with varying SS [-28dBm,-32dBm] generate background traffic. The load level was selected so that a fairly high network traffic load was maintained but avoiding to use the network at its maximum capacity (e.g., 20-21Mbps).

B. *Scenario 2 – Load at the Border of AP Coverage*

The mobile user kept the same location and the background traffic was moved to an area with poorer varying SS [-78dBm, -82dBm]. The traffic load is between 4Mbps-4.3Mbps with 11-12 virtual wireless stations. This is done in order to keep the same ratio of traffic load when located in areas with poor SS. This helps to study the impact of network load location on the energy consumption of the Android mobile device.

C. *Scenario 3- Cellular Network*

The mobile user performs VoD over the two cellular networks: O2 (HSDPA) and eMobile (UMTS). The impact of the network technology on the energy consumption of the Android device is studied.

IV. EXPERIMENTAL RESULTS AND ANALYSIS

For each considered scenario, for each transport protocol (UDP or TCP) and for each of the quality levels the tests were repeated three times (a total of 87 tests were carried out). The results were collected and the average values computed.

A. *Impact of the Traffic Load Location on Energy Consumption while Performing WLAN VoD Streaming*

In order to study the impact of the background traffic location, Scenario 1 (background traffic near AP) and Scenario 2 (background traffic in poor SS area) were compared. The results of both scenarios are listed in Table V and Table VI.

TABLE V. SCENARIO 1 – UDP AND TCP VOD STREAMING

	QL	Avg. Energy [J]	Avg. Power [mW]	Dis-charge [mAh]	Battery Life [hrs]	Avg. Th. [Mbps]	Avg. Ch. Traffic [Mbps]	Total Net. Retr. [%]	Play-out Time [s]
UDP	**QL1**	897	1489	67	3.30	2.27	24.32	3.82	600
	QL2	657	1102	49	4.47	1.18	25.12	7.98	600
	QL3	536	895	40	5.50	0.65	24.97	8.37	600
	QL4	466	779	35	6.32	0.36	24.90	5.61	600
	QL5	438	733	33	6.71	0.18	24.89	5.98	600
TCP	**QL1**	885	1483	66	3.32	2.09	24.46	4.07	600
	QL2	615	1030	46	4.78	1.06	24.66	4.79	600
	QL3	495	829	37	5.93	0.67	24.84	5.28	600
	QL4	462	774	35	6.36	0.35	24.18	9.1	600
	QL5	415	695	31	7.08	0.30	24.69	5.57	600

While for Scenario 1 the playout is smooth without interruptions (600 seconds), for Scenario 2 it presents frequent periods of video motion loss, with re-buffering periods representing: 19% - QL1 and 11% - QL2 (UDP); 10% - QL1 and 5% - QL2 (TCP). These re-buffering periods lead to increases, in playout duration and therefore, to increases in energy consumption. For the lower three quality levels the playout is smooth without interruptions (playout time 600s). The Mean Opinion Score decreases with the increase in buffering percentage level [10]. Consequently, 10% re-buffering determines a quality decrease of 1 MOS unit and 20% re-buffering severely affects the quality with a corresponding drop of more than 1.2 MOS units. Another important factor is the total number of retransmissions (Retr.) which shows the relative number of the overall packets that were retransmitted vs. normal traffic. Table VI shows that the overall number of retransmissions is very high. This is because most of the traffic in the network is located in an area with poor SS, thus the competition for the network resources is high.

The results show that because of the bad location of other mobile users (e.g., near the cell border) the users located near the AP will also be penalized in terms of user perceived quality, which is unfair.

TABLE VI. SCENARIO 2 – UDP AND TCP VOD STREAMING

	QL	Avg. Energy [J]	Avg. Power [mW]	Dis-charge [mAh]	Battery Life [hrs]	Avg. Th. [Mbps]	Avg. Ch. Traffic [Mbps]	Total Net. Retr. [%]	Play-out time [s]
UDP	**QL1**	991	1389	74	3.5	1.88	5.54	18	**714**
	QL2	709	1058	53	4.65	1.03	5.44	35	**670**
	QL3	525	879	39	5.59	0.52	11.82	53	600
	QL4	477	800	36	6.15	0.28	3.97	9	600
	QL5	435	730	33	6.74	0.15	7.46	35	600
TCP	**QL1**	974	1467	73	3.35	2.07	5.96	14	**664**
	QL2	637	1016	48	4.84	1.14	6.01	17	**627**
	QL3	504	845	38	5.82	0.54	7.53	31	600
	QL4	451	756	34	6.5	0.27	6.53	25	600
	QL5	420	705	32	6.9	0.15	8.67	43	600

B. Impact of the Wireless Access Network Technology on the Energy Consumption while Performing VoD Streaming

In order to study the impact of the network technology on the energy consumption, a set of measurements were conducted over two cellular networks: HSDPA from O2 and UMTS from eMobile. All the tests were performed with minimal background activities as for WLAN, and with the wireless interface disabled. The results are listed in Table VII.

TABLE VII. SCENARIO 3 – UDP AND TCP VOD STREAMING

		Quality Level	Avg. Energy [J]	Avg. Power [mW]	Dis-charge [mAh]	Battery Life [hrs]	Playout [s]
O2 (HSDPA)	TCP	**QL3**	850	1330	64	3.70	**640**
		QL4	728	1173	55	4.19	**621**
		QL5	680	1119	51	4.39	**607**
eMobile (UMTS)	UDP	**QL3**	747	1254	56	3.92	600
		QL4	693	1160	52	4.24	600
		QL5	663	1110	50	4.43	600
	TCP	**QL3**	737	1230	55	4.00	600
		QL4	647	1078	49	4.56	600
		QL5	602	1004	45	4.90	600

Although O2 offers HSDPA (7.2Mbps data rate) video motion loss is experienced, with re-buffering periods representing 6% - QL3, 4% - QL4, and 1% - QL5. However, when streaming over UMTS (384kbps data rate) the playout is smooth without interruptions and is more energy efficient. O2 owns 32.6% of the total market[12] while eMobile is new in the market. A realistic assumption is that O2 has more customers sharing the bandwidth. This is reflected on the playout duration of the multimedia streams.

Figure 4 illustrates a comparison overview in terms of energy consumption between local playback (Table II), WLAN interface (WLAN VoD (UDP) and no load [8]) and the UMTS interface (VoD over UDP). The UMTS interface accounts for 47% of the total energy consumption, presenting an increase of 85% to 90% in energy consumption. Using the UMTS interface over the WLAN one, the energy consumption presents an increase of 50% (QL3) up to 61% (QL5).

V. CONCLUSIONS

This paper presents an in-depth study on how the wireless traffic load location and wireless access network technology type impact the energy consumption of an Android device while performing VoD Streaming. Five different quality levels of the multimedia stream were considered and their impact on the energy consumption was analyzed.

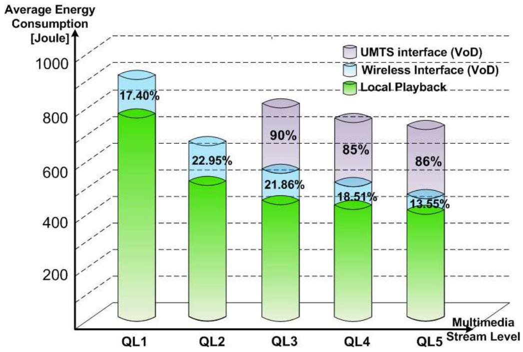

Figure 4. Avg. Energy Consumption for VoD Streaming: Local Playback vs. WLAN vs. UMTS

Subjective tests were carried out in order to validate the choice of the five quality levels. Studying the impact of the traffic load location on the energy consumption, the results show that because of the bad location of other mobile users (e.g., near the cell border) the user located near the AP will be heavily penalized in terms of user perceived quality level of the multimedia stream, which is unfair. In order to study the impact of the radio access technology used on the energy consumption of the Android device a set of measurements were conducted over two cellular networks: HSDPA and UMTS. The results show that by using the cellular interface over the WLAN interface, much more energy is consumed.

VI. ACKNOWLEDGEMENTS

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