Battery and Stream-Aware Adaptive Multimedia Delivery for Wireless Devices

Martin Kennedy, Hrishikesh Venkataraman and Gabriel-Miro Muntean
Performance Engineering Laboratory
Dublin City University (DCU)
Dublin, Ireland
martin.kennedy@ieee.org, hrishikesh@eeng.dcu.ie, munteang@eeng.dcu.ie

Abstract— **Over the last number of years, smart mobile devices have been rapidly replacing computers as the most commonly-used web-access devices. Mobile device capabilities have improved exponentially with time, when compared with the relatively small increase in their battery life. This has had a serious impact on these devices' practical use, especially for multimedia streaming and video-on-demand applications. This paper proposes a cross-layer Battery and Stream-Aware Adaptive Multimedia Delivery mechanism (BaSe-AMy) that monitors mobile device remaining battery level, remaining video stream duration and packet loss rate. BaSe-AMy makes use of these values to decide whether or not video quality adaptation is required in order to achieve power saving, while also maintaining good user perceived Quality of Service (QoS) levels. The proposed mechanism is evaluated and compared with a non-adaptive scheme in terms of battery duration and video quality (expressed in terms of Peak Signal-to-Noise Ratio - PSNR). It is shown that such a mechanism not only results in an increase in battery life by up to 18%, but also raises the video quality by up to 4%.**

Keywords-adaptive mechanism; battery-aware; multimedia delivery; wireless

I. INTRODUCTION

In recent years, the functionality of mobile phones and other wireless devices has improved substantially and they are now capable of performing a wide range of communication and computationally intensive operations. These include high bandwidth applications such as multimedia streaming and videoconferencing. In fact, some of the latest devices are even capable of handling High Definition (HD) videos. While the computational power of devices has increased exponentially at a rate similar to Moore's Law, the average annual increase in battery life has been far lower. For example, Panasonic, one of the global market leaders in battery production, has an average annual increase in battery capacity in the region of 11% [1]. Therefore it can be said with a very high degree of confidence that one of the largest limiting factors for any wireless mobile device is now its battery life. According to Apple, the battery of an iPhone 3GS lasts for just 5 hours of regular Internet use over a 3G connection. In reality, a video streaming application is liable to deplete the battery far quicker than this. The battery life of a modern laptop computer can last up to 8 or more hours, but again this depends entirely on the applications that are running on the device.

It is estimated that video streaming on mobile devices has increased by 99% during the second half of 2009 [2]. Streaming is a particularly energy intensive application mainly because of the high energy consumption rate for receiving, decoding and displaying video streams. Given the number of different tasks performed, making the mobile device run on small batteries for longer periods of time is a major challenge. As a result, significant emphasis is being directed to extending the battery life of these devices. An efficient mechanism to optimize the energy consumption includes run-time behavior analysis of the wireless device. Such an analysis performs continuous monitoring of all the applications including the power consumed by the receiving, decoding and the displaying module. However, implementing a comprehensive energy-management strategy imposes new system-level requirements with both hardware and software implications.

In this paper a novel cross-layer solution is presented for Battery and Stream-aware Adaptive Multimedia Delivery (BaSe-AMy). BaSe-AMy monitors the energy consumption at the Wireless Network Interface Card (WNIC) in the physical layer, packet loss rate at transport layer and stream playback duration in the application layer. These three parameters are sampled at regular intervals and are assessed in BaSe-AMy's adaptation algorithm on the mobile device. The device can then request an adaptation in the video quality which consequently results in modifications to the bit-rate of data streamed from the server. The performance of BaSe-AMy is evaluated by simulating the battery performance of a mobile wireless device while receiving video content and that is compared with the scenario when there is no adaptation. The PSNR of the received videos for both situations is also computed.

II. RELATED WORK

There has been significant recent research on energy efficient communication mechanisms in wireless networks and devices. At the radio network level, techniques like co-operative communication [3], multihop design [4], cluster architecture [5], etc. have been investigated. Significantly, at the end-device level, there have been major contributions in recent years. The various approaches can be classified into four categories: utilization of the WNIC's *sleep mode*, *higher compression* rates for transmissions to the client, dynamic control of a device's underlying hardware through *middleware* frameworks and the use of specific *hardware*.

A. *Sleep Mode*

The IEEE 802.11 standard outlines a built-in Power Save Mechanism (PSM) when it is operating in infrastructure mode. A simple energy saving technique is to put the WNIC of a device into sleep mode when not in use [6]. However, this is not always feasible, depending on the application in use on a device. Multimedia streaming and video-on-demand applications have different QoS requirements as compared to traditional data transmission applications. Saidi *et. al*. [7] have proposed a battery-aware localization mechanism for the wireless networks wherein they investigate the trade-off between conserving energy in a wireless node by lengthening the sleep-cycle period while still allowing it to be able to perform accurate localization calculations. However this approach is not tailored for streaming applications either as it also does not consider whether the increase in sleep cycle is required at all.

B. *Higher Compression*

In a notable contribution, Adams *et al.* [8] have proposed an algorithm that investigates the three main areas where energy can be saved on a mobile wireless device (reception, decoding & playing) and performs adaptations at each of these stages. On the other hand, the paper proposed by Reinhardt *et al.* [9] analyzed how energy conservation can be achieved by compressing/decompressing network transmission data in a sensor network thus sending less bits from the WNIC. The significant aspect of this work was that it investigates what kind of trade-off can be made between saving energy on the micro-controller/processor and on the WNIC.

C. *Middleware*

An important area in energy savings research has been the idea of middleware frameworks. These allow a device to coordinate the adaptation of multimedia applications running on them and to dynamically manage their underlying hardware resources. This allows the multimedia applications to meet user-based QoS requirements [10]. Another significant paper is [11] wherein the authors have proposed a power management middleware for mobile devices, which not only considers energy savings for the processor but also optimized energy savings for other device parts such as display unit, RF unit, keyboard, memory, etc.

D. *Hardware Specific Savings*

Specific hardware configurations can also lend themselves to energy savings. Bahl *et al*. [12] investigated using a low-power radio in conjunction with a normal WNIC. One benefit of this idea is that it allows a mobile device and its radio to be powered off, while the low-power radio maintains a network presence and can be used to wake the device up.

This paper exploits the WNIC's sleep mode and adaptive stream compression to obtain energy savings.

III. ARCHITECTURE

BaSe-AMy makes use of a client-server model architecture, which is illustrated in Fig. 1, within the context of a video streaming application in an IEEE 802.11b wireless network. On the client side, BaSe-AMy works in three separate phases.

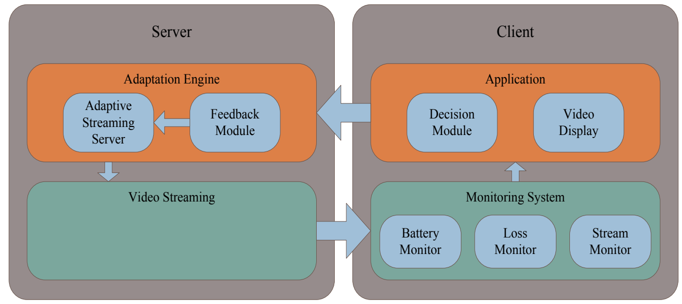

Figure 1. BaSe-AMy Architecture

A. *Monitoring*

This first phase periodically collects data about the battery, the packet loss and the remaining video stream duration. The interval for these readings can be set by the user. The instantaneous battery power level of the device is read and an estimate of the remaining battery duration is calculated from this and previous readings. This loss rate is computed over each monitoring interval. Finally the third module focuses on stream monitoring and determines the remaining stream duration.

B. *Decision*

The value of each parameter from the monitoring phase is fed into the decision module which decides whether or not to adapt to a lower/higher video quality level. A novel adaptation algorithm is used in the decision module on the BaSe-AMy client. The algorithm allows an adaptation request to be sent on each of these four conditions:

1. (batteryTimeLeft > streamTimeLeft) &&
(loss < *LossThresh*) &&
(batteryPercentageLeft > *BattThresh1*)
   - Adapt up one quality level

2. ((batteryTimeLeft < streamTimeLeft) ||
(loss > *LossThresh*)) &&
(qualityLevel > *QualityThresh1*) &&
(batteryPercentageLeft > *BattThresh1*)
   - Adapt down one quality level

3. ((batteryTimeLeft < streamTimeLeft) ||
(loss > *LossThresh*)) &&
(qualityLevel > *QualityThresh2*) &&
(*BattThresh2*<=batteryPercentageLeft<=*BattThresh1*)
   - Adapt down one quality level

4. ((batteryTimeLeft < streamTimeLeft) ||
(loss > *LossThresh*)) &&
(qualityLevel > *QualityThresh3*) &&
(batteryPercentageLeft < *BattThresh2*)
   - Adapt down one quality level

The thresholds described here were configured to provide a balance between energy savings and user QoS. In a finished streaming application, these values would be exposed as user preference settings. It is important to note that the two lowest video quality levels provide quite a poor QoS but they do enable the viewing of video for longer before total battery depletion. For that reason the algorithm provide the option to only allows these lower quality levels to be streamed when the

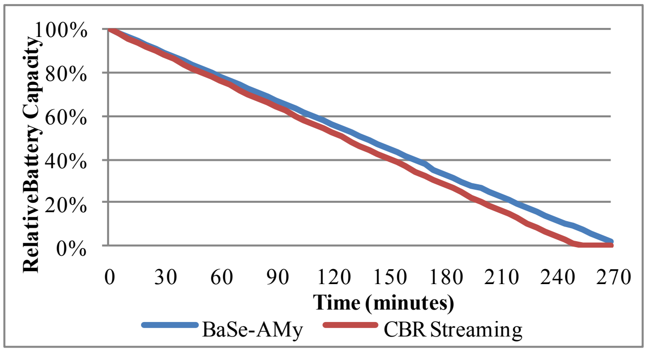

Figure 2 (a). Simulation 1 – Battery Capacity over Time

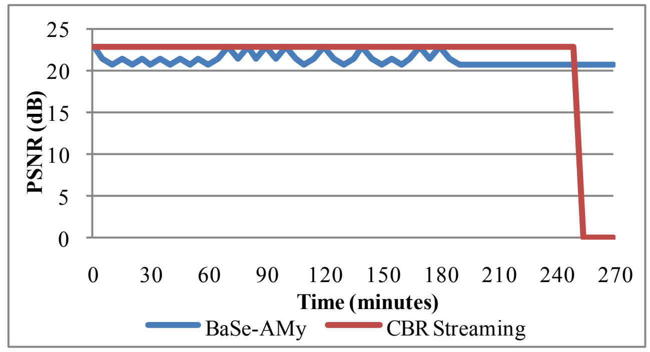

Figure 2 (b). Simulation 1 – PSNR over Time

battery has depleted under a certain capacity. This would be a last resort effort to display the most video possible.

C. *Implementation of Adaptation*

If an adaptation is required, the request is then sent from the client to the server (base station). On the server-side, upon receiving an adaptation request from the client, the server switches over to the new video quality level as directed by the client.

IV. Testing & Setup

A. *Network Topology and Settings*

BaSe-AMy was evaluated by modeling and simulations in the OMNeT++ 4.1 simulator [13]. OMNeT++ was chosen for the simulations because of its modular, object-oriented structure, because it has a comprehensive simulation framework available for modeling battery consumption and because it is open-source. The energy model is available through the MiXiM framework [14], which also contains mobility and wireless networking models. The network topology is that of a client-server. In order to implement an infrastructure-based network, it was decided that the server would also act as the access point for the client. The reason for this specification is that a WNIC will not use sleep mode in an 802.11 *ad hoc* network. Sleep mode is not fully catered for in the MiXiM framework so this was implemented manually. A single user network was targeted in the simulations as the video streaming transmission was realized by unicasting. The effect of multiple users causing background traffic in the network is beyond the scope of this paper. Among other parameters, the network configuration involved setting the energy consumption of the WNIC while it is in its different states (sleep, reception and transmission). For this a low-powered Qualcomm WNIC was modeled. The background energy consumption of the Nexus One device during video streaming in strict conditions was measured and subsequently incorporated into the simulations. The nominal battery capacity was also set to 1400 mAh and the voltage to 3.7 V for the simulations. These settings were all chosen so that a real world device, the Nexus One, could be accurately modeled in the simulations. Hence, the results presented in this paper have quite a high degree of practical use. The threshold values used in these simulations can be found in Table I.

B. *Video Quality Measurements*

The video that was used to illustrate the user perceived quality was a 145 second long high-action video clip. This was transcoded into MPEG4 format to five target bit-rates which correspond to each of the five levels of video quality (400 kbps, 800 kbps, 1.2 Mbps, 1.6 Mbps and 2 Mbps). PSNR is an objective metric for comparing two images (or video frames). PSNR is often used to approximate the user perceived quality of images and videos in the absence of subjective testing. The average PSNR for each quality level was computed with respect to the original video (with a bit-rate of 3 Mbps). This calculation was done on a pixel-by-pixel basis in the corresponding frames of the two videos using (1). In (1) MAX_i stands for the maximum intensity level of a pixel (usually 255) and MSE stands for the Mean Square Error.

$$PSNR = 10 \times \log_{10}\left(\frac{MAX_i^2}{MSE}\right) \quad (1)$$

Having calculated the adaptation occurrences in the simulation it was then possible to compare an approximation of the QoS for BaSe-AMy with that of the non-adapting Constant Bit Rate (CBR) stream.

V. Results & Analysis

Simulations were performed for two different test scenarios.

1. For the first simulation, 15600 seconds of video were streamed to the client. The battery in the client device had enough capacity to receive the whole video clip when the BaSe-AMy mechanism was used. However, while streaming a 2 Mbps CBR version of the video, the client's battery depleted after just 15101 seconds. This first simulation scenario is illustrated in Fig. 2 (a) and (b). Fig. 2 (b) shows the PSNR comparison

TABLE I. BaSe-AMy Algorithm Settings

Monitoring Interval (s)	60
LossThresh (packets/s)	0.1
BattThresh1 (battery level percentage)	30%
BattThresh2 (battery level percentage)	10%
QualityThresh1 (video level)	3
QualityThresh2 (video level)	2
QualityThresh3 (video level)	1

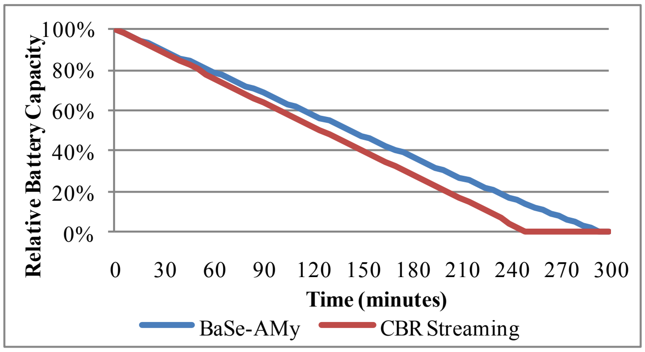

Figure 3 (a). Simulation 2 – Battery Capacity over Time

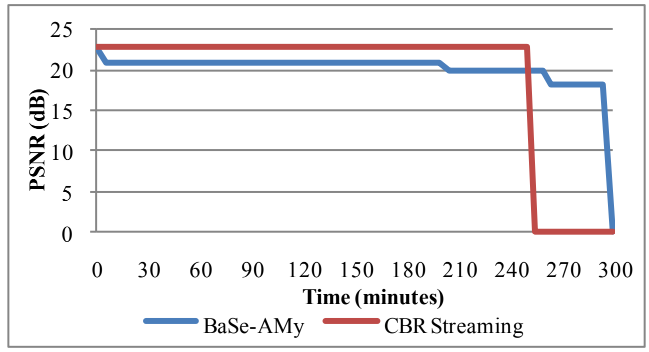

Figure 3 (b). Simulation 2 – PSNR over Time

between the received video file from the CBR stream and the BaSe-AMy stream.

2. The second simulation involved streaming an 18000 second video, which was too long to be fully received by the client using either the CBR streaming or BaSe-AMy. In this scenario, the CBR stream failed at the same point but the BaSe-AMy stream lasted for 17750 seconds. Fig. 3 (a) and Fig. 3 (b) illustrate these results.

The results in Table II show a comparison of the BaSe-AMy and CBR streaming mechanisms in terms of client battery duration, throughput and the PSNR of the received video. In almost every metric, for both simulations, BaSe-AMy significantly outperformed CBR streaming.

VI. Conclusion & Future Work

This paper introduced a novel cross-layer Battery and Stream-aware Adaptive Multimedia Delivery (BaSe-AMy) mechanism. BaSe-AMy monitors energy consumption, packet loss rate and stream playback duration and performs video streaming adaptation in order to increase battery life, while maintaining a high QoS. Simulations show how BaSe-AMy improves the battery performance of a mobile wireless device when delivering video content by up to 18% in comparison with the case when no adaptation is employed. This is achieved with a scaled degradation of video quality down to a minimum PSNR value of 18.16 dB, which is still an acceptable viewing-quality level. It was also found that the average video quality of the stream increased by up to 4% when BaSe-Amy was used.

Future work would focus on enhancing the intelligence of the BaSe-AMy algorithm. One avenue for this would be to add a fourth phase to the architecture which would adapt the algorithm and threshold values based on past experience. The algorithm would also be tested in various conditions which include diverse device types, and increased load in terms of both background traffic and number of users.

TABLE II. Comparison of Simulated Streaming Mechanisms

Video Length (s)		CBR	BaSe-AMy	Benefit
16200	Battery Life (s)	15101	>16200	7.28 %
	Avg Throughput (Mbps)	1.86	1.44	22.58%
	Avg PSNR (dB)	21.37	21.27	-0.48%
18000	Battery Life (s)	15101	17750	17.54%
	Avg Throughput (Mbps)	1.68	1.02	39.38%
	Avg PSNR (s)	19.23	20.01	4.09%

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