

CHAPTER 14

EcoLearn: Battery Power Friendly E-Learning Environment for Mobile Device Users

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Abstract: Among the challenges involved in the delivery of online content to anybody, anytime, and anywhere, one can note the limited battery power that mobile devices have. This paper presents a mechanism for saving battery power by adapting educational multimedia type content not only based on the learner profile, but also based on device characteristics. In order to support this type of adaptation, metadata is added to the content and adaptation rules are defined using an authoring tool. Experimental tests have shown that significant mobile device battery power can be saved using the proposed content adaptation solution, whereas subjective tests conducted on a number of participants have shown that this can be done without significantly affecting the learning process.

Introduction

Mobile devices have become increasingly over the past years, and smartphones sales alone are expected to reach 619 million units by 2015 (Coda Research Consultancy 2010). This is in part due to the fact that the price of mobile devices has continuously decreased and they have gained new features and capabilities, such as being able to render full web pages, and to receive and display high quality multimedia content. Mobile devices allow Internet content, and in particular educational content to be accessed almost from anywhere and anytime, even from areas where such content was inaccessible before.

More recently, multimedia content has become a common format for educational content, and its usage in education is expected to increase fast over the coming years (Kaufman & Mohan 2009). There are many forms of creating multimedia educational content such as: lecture and lab sessions recordings, screencasts and video explanations, educational animations, etc. Multimedia content has the advantage of providing a rich display of information and can be used for further enforcing the understanding of the concepts being taught.

However, delivering rich multimedia content to mobile devices connected to wireless networks is a very resource intensive task. Significant network bandwidth and computational power are required to decode, receive, and display a multimedia clip. This in turn drains the device battery power quicker, and leads to situations when the battery runs low and the learner cannot finish the online learning session. The learner has either to charge the battery or to use another device in order to be able to continue the learning session. This interruption can be annoying, a source of frustration and has negative effects on the learning process in general.

This chapter presents a solution that aims at saving battery power when multimedia type educational content is accessed over the Internet, supporting the learners in completing their current learning activities. EcoLearn m-learning system that adapts the multimedia type educational content and reduces the battery power consumption is also presented.

A number of experimental tests and subjective evaluations were conducted, and the results have shown that significant battery power can be saved without affecting the learning experience and the learning outcome.

The rest of this chapter is organised as follows. Section two presents the latest research and the current trends in the area of adaptation and personalisation in e/m-learning and, battery saving. Section three presents the architecture and the adaptation principle of the EcoLearn system and provides an example on how a course can be authored and adaptation strategies defined to support the adaptation. The chapter continues by presenting the setup and the results of the tests that have been conducted. In the end conclusions are drawn and possible further directions of this work are presented.

State of the Art

The research work presented in this chapter, falls in the following three areas: adaptation and personalisation of educational content for e/m-learning systems, battery power saving for mobile devices and educational content authoring for e/m-learning systems. The latest research work in these areas is presented next.

Learner-oriented Personalisation and Adaptation

Technology development allows learners to access content anytime and from anywhere, whereas adaptation and personalisation allow the delivered content to be tailored to the learner's needs. Different aspects were considered in the adaptation and personalisation process when the learner is on the move such as learner profile (e.g. goals, knowledge, skills, etc.), learning styles, learner Quality of Experience (QoE), the context in which the learning occurs, as well as the learner's mobile device characteristics.

Learner profiles are built by adaptive educational systems and they store various characteristics about the learner such as: demographic information, knowledge level, system usage, learner progress, and goals (Chen et al. 2008; Graf et al. 2009; Yin et al. 2007). The

system captures these characteristics directly from the learner or automatically while the learner interacts with the e/m-learning environment.

In order to adapt the content for a learner's profile the system applies various layout and content adaptation techniques, such as link hiding, annotation or disabling, inclusion of explanatory information, guide the learner towards the relevant information and hiding inappropriate or non-relevant information (Brusilovsky & Milan 2007).

The adaptation of the learning process may be driven by the learner's abilities, motivation and their previous interaction with the e-learning environment, as well as by the learner's concentration level and frequency of disruptions (Bomsdorf 2005).

Apart of the learner profile, learner's **Quality of Experience (QoE)** has been shown to be an important factor in the adaptation process (Muntean & McMannis 2006). As opposed to the Quality of Service, which objectively measures the service provided, QoE is a subjective measure of the learners' experience, their expectations and their satisfaction with the provided service. Learners' QoE may be affected by the mobile device network capacity and variable network conditions (e.g. bandwidth, loss, delay) (Muntean 2008). Considering these factors in the adaptation process learners' QoE can be improved (Muntean & Muntean 2007).

Since learners have different learning particularities, much research has considered the **theories of learning and cognition**, as well as the **learning styles** in the personalisation process.

Adaptive e/m-learning systems based on the cognitive theory of learning, support active participation of the learners in order to help them organise and structure their knowledge, and to link the new knowledge to prior structures (Sampson & Karagianidis 2002). In contrast, the adaptive systems based on the constructivist theory encourage the learners to actively explore the concepts and to improve their thinking by creating "new ideas or concepts based both on their past and current knowledge" (Naismith et al. 2004).

Adaptation based on the learning styles (e.g. visual, auditory and kinesthetic) uses multiple media channels, such as text, images, audio and video to present the information (Franzoni & Assar 2009). Examples of adaptive systems that have integrated learning styles based adaptation include AHA! (Stash et al. 2006), and iWeaver (Wolf 2007).

The **context** in which the learning takes place can be different from person to person. The context is described by a multitude of factors such as learners' location in time and space, their identity, their intrinsic and psychological properties (e.g. emotional state, confusion, focus of attention), but also by the technologies (Wang 2004). Therefore, m-learning systems have to adapt to the context the learning take place that often may change.

Many context-aware m-learning systems use GPS to locate the learner (Ryu & Parson 2008; Rogers et al. 2005; Ogata et al. 2008). For example, the Learning Reminder project (Ryu & Parson 2008) uses GPS to locate learners' passing by the library and notifies these about available the books. Chen et al. (2007) combines the time for the learning to take place, the learner location, and the learner abilities to determine what content is suitable. While GPS can be used solely for detecting learners' outdoor location, the indoor location can be done by

tagging the surrounding objects using technologies such as RFID (Radio Frequency Identification), barcodes and infrared (Naismith & Smith 2009).

Although learner's location and time detection can be easily done learner's psychological properties can be detected only using special devices. For example, tiredness and confusion are detected using an eye-tracking system (Gütl et al. 2005). However, due to high cost is not feasible to integrate these special devices with mobile devices.

Since m-learning involves a **diversity of mobile devices** various solutions considered the learner device for content personalisation. Devices have different characteristics such as screen size and resolution, CPU speed, memory capacity, battery life, network connectivity.

The majority of the solutions focused on the mobile device screen size and resolution, and various device independent user interfaces were proposed (Ally et al. 2005; Zhao & Okamoto 2008). These solutions separate the learner interface from the educational content and use a device independent language (e.g. XML) to describe the interface. The user interface is then automatically generated, based on the mobile device characteristics.

Mobile devices also have different battery capacity and the available battery power changes in time influencing the learner's ability to study. In such context, a content adaptation technique can be applied by changing the video compression that reduces power consumption, in order to support learning for longer periods of time (Moldovan & Muntean 2009a).

Mobile learners also depend on the wireless networks support for accessing the educational content. Since wireless networks differ widely in terms of available bandwidth, coverage area, delays, etc., the device network performance was also considered in the adaptation process (Trifonova et al. 2004, Muntean 2008).

Battery Power Saving in Mobile Devices

As battery life represents a major constraint of the mobile devices, much research effort has concentrated on reducing the device power consumption in various scenarios. Receiving, decoding and displaying a multimedia clip streamed over the wireless network, is a very power demanding task due to continuous packets flow and high processing power needed to decode and display them (Korhonen & Wang 2005). The proposed solutions proposed can be classified into two categories:

- hardware / software optimisation;
- multimedia content adaptation.

Examples of **hardware/software optimisation** solutions include optimising the power consumption of various components such as the wireless network interface card (WNIC) (Wei et al. 2006; Adams & Muntean 2007), the processor (Lee et al. 2005), or the display (Pasricha et al. 2003; Shim et al. 2004).

In order to save battery power at the wireless card, a number of studies have proposed to reshape the traffic flow and send the packets in bursts instead of sending them individually. This allows the WNIC to sleep for a longer period due to longer intervals of time when packets are not retrieved. The major drawback is that traffic bursts may cause congestion in routers

or overflows in transmitter buffers leading to packet losses and a decrease in overall network quality. To avoid the congestion problem, Korhonen and Wang (2005) have proposed to adjust the length of the bursts based on the congestion conditions.

Adams & Muntean (2007) have used an additional buffer to hide the data corresponding to several beacon intervals, from the station it is intended for, and forcing it to return to sleep. The buffered data is finally released at once at the mobile station after several attempts to receive it.

Most of the battery power consumed by the CPU is due to the video decoding computation. A solution that offers good power saving for multimedia streaming is Dynamic Voltage Scaling that varies the supplied voltage and thus the CPU clock speed, based on the computational requirements of the application (Lee et al., 2005). Computation offloading also reduces the CPU power consumption. Instead of letting the mobile device CPU to execute all the computations, some of them are offloaded to a powerful server over the wireless network (Zhao et al. 2006).

Solutions for reducing the battery power consumption of the device screen include: decreasing the screen backlight luminosity level, and compensating it by changing the luminosity and the contrast of the video at an intermediate proxy node (Pasricha et al. 2003); making use of the advantage of transfective LCD panels that can operate with or without backlight and allow an image to remain visible even without backlight (Shim et al. 2004); reducing the display refresh frequency from the native rate, to a value equal with the frame rate of the video that is being played (Gatti et al. 2002).

Multimedia content adaptation based solutions usually save battery power at the WNIC or CPU level, by reducing the quantity of information being received by the mobile device and/or by decreasing the audio/video computation, respectively.

The solutions are based on multimedia transcoding that re-encode a clip in a new version that is less expensive to be retrieved and processed by the mobile device. This can be achieved by changing the compression technique to a less computational intensive one, or by decreasing parameters such as video bitrate, frame-rate or resolution (Moldovan & Muntean 2009a, b). The re-encoding can be done off-line, in which case the adaptation process consists in a dynamic selection from several different versions previously created, or it can be done on the fly while the video is transmitted from the server to the mobile device (Tamai et al. 2004). The re-encoding solutions adjust the bitrate, the frame rate, or the resolution of the multimedia clip, enabling its display for the specified duration within the remaining battery life.

Although it is the most popular, multimedia transcoding has the drawback that it affects equally the quality of whole viewing area and of the multimedia clip generally. An example of a different solution that selectively reduces the quality of the multimedia clip, involves detecting the regions the viewers are most interested in, and when necessary, affecting the quality of the regions they are less interested (Muntean et al. 2008).

Authoring tools for e/m-learning systems

Different authoring tools have been proposed, in order to ease the development of online courses and of the adaptation strategies. They cover different aspects such as: authoring for multimodal devices (Kuo & Huang 2009; Simon et al. 2005) or creating adaptive courses (Foss & Cristea 2009; De Bra et al. 2008).

Three approaches can be distinguished when authoring for multimodal devices: *single authoring*, a single version of the content is created for every device type (Simon et al. 2005), *multiple authoring*, multiple versions of the content are created to suit different devices (Simon et al. 2005), and *flexible authoring* which combines single and multiple authoring (Kuo & Huang 2009).

Authoring adaptive courses, and in particular the adaptation process, is considered to be a difficult task. Different solutions have been proposed to ease this process and to reuse already developed adaptive courses such as:

- defining convertors between different authoring tools. A course created by one authoring tool can be re-used by another tool (Power et al. 2005);
- defining adaptation rules or strategies that can be used as they are, or with small modifications by other authors (Hendrix & Cristea 2008, Molnar et al. 2009);
- creating graphical interfaces for defining the adaptation rules (De Bra et al. 2008).

EcoLearn m-learning System

System Architecture

EcoLearn extends the classic architecture of, an adaptive e-learning system that personalises educational content based on user profiles, by considering the battery power level of learner's mobile device. The architecture of the EcoLearn m-learning environment is presented at block level in Figure 1, where the green (dark) colour indicates new components that were added or existing components that were extended with additional functionality.

User Model (UM) maintains user profiles that contain information about the learners such as: demographic data (e.g. name, age, gender, etc.), knowledge level on the studied material, evaluation results, interests, content related preferences, etc.

Domain Model (DM) stores educational content. It is organised in a hierarchical structure of concepts among which logical relationships exist. At the lowest level, each concept corresponds to a specific piece of educational information (e.g. a text, an image, a media clip, etc.). The DM was extended to allow multiple versions of the same multimedia clip to be associated with a concept. Each version has a different video resolution and/or video bitrate. Metadata regarding the encoding characteristics (multimedia format, audio and video compression, audio and video bitrates, video resolution and frame rate) is added to each version using an authoring tool.

Adaptation Model (AM) consists of a set of condition-action rules used to express adaptive strategies based on the learner profile. A new set of adaptive rules that considers the learner’s device battery level were defined. These rules are applied only for adaptive multimedia type content. Section 3.3 provides more details in defining rules.

Device Power Model (DPM) maintains various Device Battery Profiles (DBPs) characteristic to different mobile devices. The battery profile contains information regarding the power consumption of the learner’s mobile devices, such as: device name, battery type and model, battery capacity, power consumption of different components (e.g. wireless card, CPU, display, etc.). This information is retrieved in a transparent way to the learner, from external sources (e.g. manufacturers datasheets, Internet, etc.) based on the device name provided by the learner. DPM also updates regularly in real time the DBPs with information such as: battery load, application load, power consumption, etc.

Personalisation Engine (PE) performs the personalisation of the educational content, by selecting from the DM the educational concepts that are suitable to a specific learner. Concepts selection is done following the adaptive rules. PE is also responsible with the adaptation of the multimedia type content, based on the learner’s device battery level.

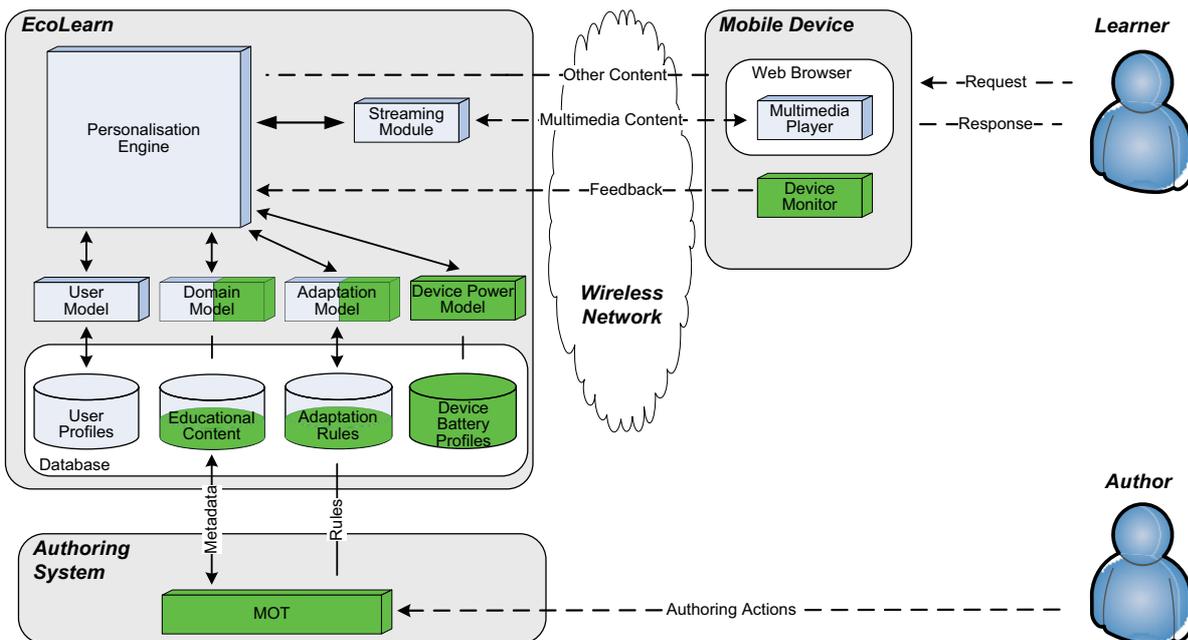


Figure 1: Block-level architecture of EcoLearn m-learning system.

Additional details on the adaptation process are provided in the following section.

Adaptation Principle

EcoLearn stores multiple versions of the same multimedia clip, and automatically switches between them depending on the learner's mobile device screen resolution and device battery level. Since it is unfeasible to store a version for all the existing mobile device screen resolutions, only some of the most common used ones are considered (e.g. 320x240, 480x320 and 640x480). Furthermore, for each resolution two versions having different video bitrates are stored. The bitrate of the first version, considered as the reference value, is selected so to offer an excellent quality level at that particular resolution. In order for the learners QoE not to be significantly impacted by the adaptation process, the bitrate of the second version is estimated as the minimum value still offering a good quality level. The estimation is done individually for each educational multimedia clip and for each resolution being considered.

The automatic bitrate estimation mechanism uses objective metrics for assessing the multimedia quality. As opposed to the subjective methods, which require a large number of subjects to view and grade the quality of each multimedia clip on a specific scale, the objective metrics are measured using computer software. Therefore they are much faster, repeatable, and can be integrated easily into an automatic mechanism. In case of the subjective metrics, scores assigned by all the observers for a specific clip, are averaged in order to obtain the Mean Opinion Score (MOS).

Since different studies have showed different levels of correlation between the values of the objective metrics and the MOS scores, EcoLearn considers the two most used objective metrics: Peak Signal-to-Noise Ratio¹ (PSNR) and Structural Similarity Index (SSIM) (Wang et al. 2004).

Using as reference the mapping of the two metrics to the MOS scores presented in Table 1, the minimum bitrate threshold is detected as the lowest value for which the equivalent MOS (MOS_{PSNR} , MOS_{SSIM}) of at least one of the two metrics is 5, whereas for the other can be 4 but the corresponding PSNR or SSIM value needs to be very close to the MOS 5 threshold ($PSNR \geq 42dB$, $SSIM \geq 0.98$). The bitrate detection starts from the reference and gradually reduces it depending on how big the reference bitrate is (e.g. 128 Kbps for 1200 Kbps).

¹ Peak signal-to-noise ratio - Wikipedia, the free encyclopedia, http://en.wikipedia.org/wiki/Peak_signal-to-noise_ratio

<i>MOS</i>	<i>PSNR [dB]</i>	<i>SSIM</i>
5 (Excellent)	≥ 45	≥ 0.99
4 (Good)	$\geq 33 \ \& \ < 45$	$\geq 0.95 \ \& \ < 0.99$
3 (Fair)	$\geq 27.4 \ \& \ < 33$	$\geq 0.88 \ \& \ < 0.95$
2 (Poor)	$\geq 18.7 \ \& \ < 27.4$	$\geq 0.5 \ \& \ < 0.88$
1 (Bad)	< 18.7	< 0.5

Table 1: Mapping of PSNR and SSIM objective metrics to subjective MOS scores (Zinner et al. 2010)

For efficient power consumption, when a learner device requests an educational clip, EcoLearn automatically selects the reference bitrate version having the closest resolution to that of the device screen. During multimedia streaming, the PE retrieves information in real-time about the mobile device power consumption and its battery state from the Device Monitor. Based on this information PE continuously estimates the available battery power and compares it with the power required to complete the current study session. When the learner mobile device does not have sufficient battery power to complete the session, additional power is saved by shifting to the version having the same video resolution but the lower bitrate.

Multimedia Educational Content Authoring

EcoLearn system adopts and personalises the multimedia type educational content using the adaptive rules specified in the AM, and the metadata attached to each concept from the DM structure. The metadata and the adaptive rules can be developed using an authoring tool for adaptive e-learning systems.

EcoLearn architecture integrates an extension of the MOT 3.0 authoring tool (Foss & Cristea 2009) for creating the metadata, and the rules that implement the QoE-LAOS authoring model (Muntean et al. 2007). QoE-LOAS is based on the LAOS model (Cristea & Calvi 2003) and includes three new sub-layers: QoE Content Features sublayer, QoE Characteristics sublayer, and QoE Rules sublayer, that provide support for defining content adaptation that involves selection of a multimedia version among a list of available versions.

The QoE Content Features sublayer specifies the metadata that describes the multimedia type content, as well as different versions of the same multimedia clip having different characteristics. The metadata that is attached to each multimedia file is: frame rate, bitrate, format, video compression and audio compression techniques (see Figure 2). Other metadata already defined in MOT, is also attached such as the title, which represents the title of the concept, and explanation, that contains the actual multimedia file.

The QoE Characteristics sublayer contains information on the recommended characteristics of the multimedia clip content such that the battery lifetime is extended. For example PM.bitrate represents the required bitrate for a multimedia file. Other characteristics used are: PM.resolution, PM.frame_rate, PM.format, PM.video_compression and PM.audio_compression.



Figure 2: Multiple versions of multimedia clips and metadata attached to each clip, using MOT 3.0 authoring tool

The QoE Rules sublayer consists of a set of rules or adaptation strategies. These rules take into account the metadata associated with a multimedia file, as well as the recommendations provided by the *QoE Characteristics sublayer*. Among the versions associated with a multimedia type concept, the one that satisfies the *QoE Characteristics sublayer* recommendations is selected. The rules are written in the LAG adaptation language (Cristea & Verschoor 2004).

An example of a rule that selects a multimedia file from a list of versions is presented next (Equation 1). The rule checks whether the bitrate of multimedia type concept is the same with the required bitrate.

```

if enough (DM.Concept.access,
           UM.GM.display == true
           DM.Concept.bitrate == PM.bitrate ,3)
then UM.GM.Concept.display = true
else UM.GM.Concept.display = false
    
```

(Equation 1)

An auxiliary value, *UM.GM.display* is initialised with true at the beginning of the adaptation process. This rule checks first for the accessed concept, whether the auxiliary variable is still true (*UM.GM.display == true*) and whether the bitrate is the same with the required bitrate (*DM.Concept.bitrate == PM.bitrate*). If the condition is met, the auxiliary variable is set to true, otherwise the value is set to false.

If all metadata attributes of the accessed concept satisfy the required parameters, the title and the explanation of the concept are displayed to the user (Equation 2). More details on writing the adaptive rules are presented in Molnar et al. (2009).

```

if enough (UM.GM.Concept.access
           UM.GM.display == true
           UM.GM.Concept.type == title
           UM.GM.Concept.type == explanation, 3)
then UM.GM.Concept.show = true
else UM.GM.Concept.show = false

```

(Equation 2)

Testing and Results

Two studies were conducted with the goal to evaluate the benefits brought by the proposed solution for adapting the educational multimedia content in low battery power situations. The first experimental study addressed the battery power saving capabilities of the solution. The second study, conducted on a number of participants, has assessed the impact of this solution on the learning process. Two factors were specifically targeted in the second study. The first one was the learner perceived quality of the adapted multimedia content, as this is an important factor contributing to learner's QoE. The second one assesses the learners' knowledge achievement when the multimedia quality was decreased.

Test Setup

Multimedia Educational Clips

The experimental and subjective tests used eight short video sequences, up to 30 seconds length, extracted from eight different educational multimedia clips. The clips were selected from a list of 904 educational multimedia clips that were downloaded from iTunes² and Miro Guide³. The eight educational clips cover a large spectrum of educational clips in terms of content type and its dynamicity. The short video sequences used for testing cover a learning concept, and a question was created on each of these concepts. Since the perceived video quality and the learning outcome are analysed, the answers for these questions are found only in the visual information and not the audio. The length of the test sequences is up to 30 seconds, in order to maintain an acceptable duration for the subjective testing.

An HP iPAQ 214 PDA mobile device, running MS Windows Mobile 6 was used. The device has a 624MHz Marvell PXA310 CPU, 128MB memory, and a 4" TFT display with a VGA resolution of 640x480 pixels. The capacity of the device's Lithium-ion battery is 2200 MAh.

The encoding characteristics of the eight video sequences are presented in Table 2. Since the resolution and the bitrate of the original eight educational clips were too high for the PDA device, the short video sequences were re-encoded at a lower resolution suitable for the device, using the XMedia Recode⁴ media converter. The resolution was decreased to 640x360 in order to fit best the device screen maintaining the 16:9 aspect ratios of the original clips. The reference bitrate was chosen as 1200 Kbps, following the recommendations for creating multimedia content for m-learning applications (O'Connell and Smith 2007), assuming that

² Apple iTunes U, <http://www.apple.com/itunes/>

³ Miro Guide, <http://www.miroguide.com/>

⁴ XMedia Recode, <http://www.xmedia-recode.de/>

<i>Test Sequence</i>	<i>Content Type</i>	<i>Length [mm:ss]</i>	<i>Frame Rate [fps]</i>	<i>Video Parameters</i>	<i>Audio Parameters</i>
Arts	Slideshow	00:20	23.976		
Dubus	Interview	00:30	29.97		
Hotness	Lab Demo	00:30	23.976	H.264/MPEG-4 AVC	
Hulu	Screencast	00:27	29.917	640x360	AAC
Languagelab	Graphics	00:30	29.97	1200 Kbps (max)	128 Kbps
Obesity	Presentation	00:30	29.97	256 Kbps (min)	44.1 KHz
Sleep**	Documentary	00:26	29.97	512** Kbps (min)	
Sol	Animation	00:30	29.97		

Table 2: Characteristics of the eight video sequences used for testing

this will offer an excellent quality level on the mobile device. Following the procedure described in Section 3.2, the minimum bitrate threshold was detected as 512 Kbps for the "Sleep" sequence and 256 Kbps for the other video sequences. The audio compression technique (AAC - Advanced Audio Codec) and the video frame rate were not changed. The audio encoding settings (compression, bitrate and sampling rate) were the same for all the video sequences used for testing.

Figure 3 illustrates representative frames for the eight test sequences, which contain different types of educational content and different dynamicity:

- **"Arts"** – slideshow consisting of a sequence of images with high level of details, and low dynamicity, represented by the transitions between the images (e.g. fade-in/out, zoom in/out, etc.)
- **"Dubus"** – interview, presenting low level of dynamicity due to almost static characters on a static background;
- **"Hotness"** – live demonstration, with medium-low dynamicity, presenting a demonstrator that shows how to perform different tasks;
- **"Hulu"** – computer screen capture, with high level of details (e.g. text) and medium-low dynamicity (e.g. pop-up windows, text typing, cursor moving, etc.);
- **"Languagelab"** – recording of a computer generated 3D Virtual Learning Environment, with low dynamicity (mostly static characters);
- **"Obesity"** –lecture recordings and presentations; the clip has an medium-low dynamicity, presenting a static presenter and a slideshow projection;
- **"Sleep"** – documentary presenting textual information overlaid on top of various scenes from nature with different levels of dynamicity;
- **"Sol"** – computer generated animation, with medium-low dynamicity.

A more detailed description of the video test sequences and of the eight categories of educational multimedia clips can be found in (Moldovan 2010).

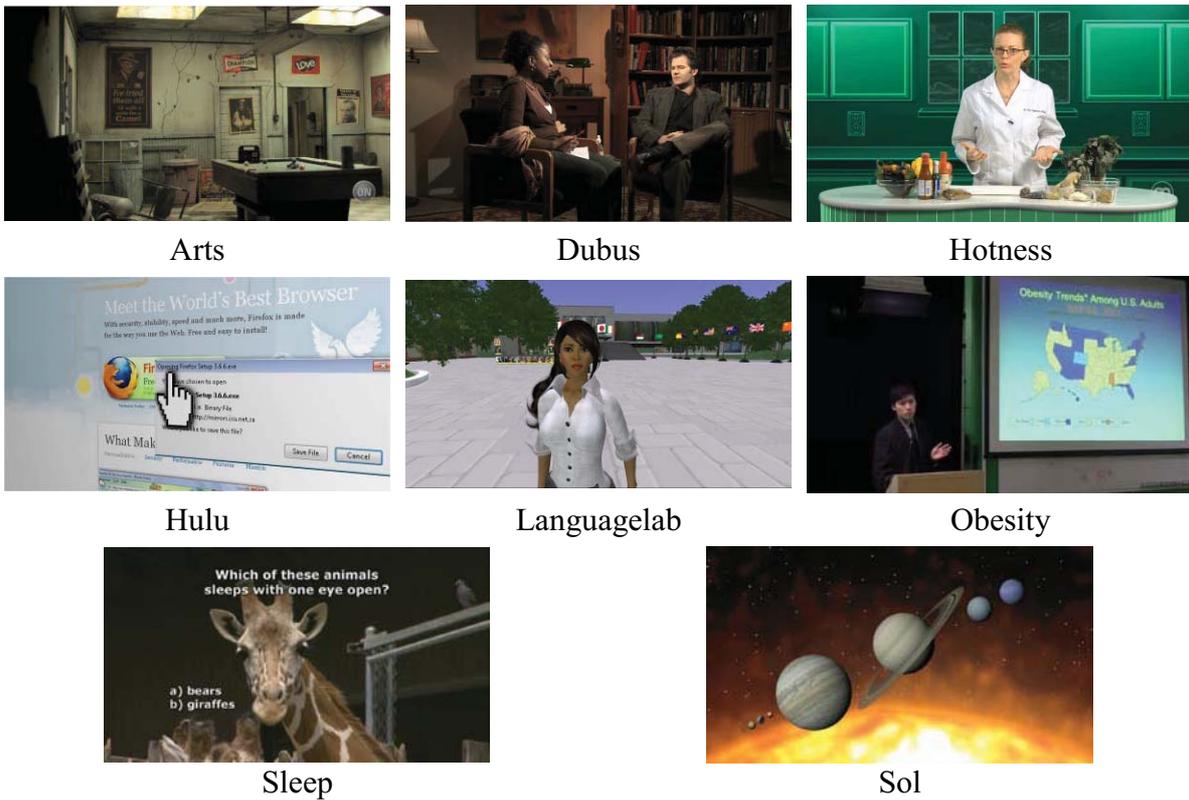


Figure 3: Representative frames for the eight video test sequences

Battery Power Saving Assessment

In order to assess the battery power saving capabilities of the proposed solution, an experimental network was created for streaming the multimedia clips to the PDA device. A laptop with a 2 GHz Intel Core 2 Duo processor and 3 GB of DDR2 SDRAM memory running Microsoft Windows 7 Professional was used as streaming server.

Videolan VLC⁵ multimedia framework was used for streaming the test video sequences and the streaming protocol of choice was HTTP. The videos were streamed wirelessly, in which case both the server and the PDA client were connected to the same wireless Access Point (AP) as in Figure 3. Each video sequence was streamed one at a time, in loop for duration of one hour. The battery was 100% charged before streaming each sequence. During streaming, device battery information (e.g. battery level, battery voltage, etc.), was logged for further processing using the BattLog⁶ program. To determine the maximum battery power that can be saved while maintaining a good quality level, the power consumption was measured for each video sequence at the two bitrates considered, the reference one and the minimum threshold one.

The two devices were maintained at a fixed distance of the AP in direct sight. No other traffic existed in the experimental network and the 54 Mbps speed of the AP allowed for a smooth playback of the streamed clips. Constant settings were also maintained on the PDA

⁵ VideoLAN - VLC media player - Open Source Multimedia Framework and Player, <http://www.videolan.org/vlc/>

⁶ BattLog 0.2.3.130 (Beta) - xda-developers, <http://forum.xda-developers.com/showthread.php?t=444920>

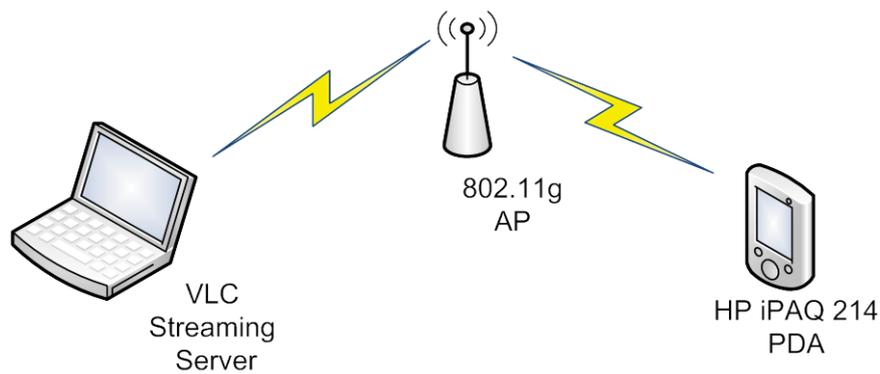


Figure 4: Experimental setup for battery testing

device. The screen brightness and volume level were set to 100% and all the power saving settings were disabled to avoid the device going to sleep or dimming the screen brightness, thus influencing the results. Headphones were plugged in and the only applications running were the multimedia player and the program used for logging battery related information.

Subjective Assessment

The goals of the subjective assessment were:

- To assess learners perceived quality of the multimedia educational content having degraded quality;
- To assess if the low quality level supports the learners in achieving the knowledge presented through the visual information.

In this sense, for each test video sequence, the subjects were asked to rate the overall video quality on a five level quality scale (1- Bad, 2 – Poor, 3 – Fair, 4 – Good, 5 - Excellent), and to answer one question related strictly to the visual information being presented. The Absolute Category Rating (ACR) method specified in the ITU-T P.910 Recommendation for video quality assessment of multimedia applications (ITU-T 2008) was used for this purpose. In this case for each test sequence only the low bitrate version was displayed a single time. The subjects were informed to grade the quality and answer the question only after watching the clip. To allow sufficient answer time, the subjects were free to choose when to proceed to the next video sequence.

The same PDA device as for the case of battery power assessment was used, and the subjective tests were conducted with one participant at a time. Similar laboratory conditions, with constant level of luminosity were maintained for all the participants. To control the background noise, the participants were provided with headphones.

21 (13 male, 8 female) non-expert subjects have participated in the subjective assessment. Their ages ranged between 21 and 37 years old (average age 27.14). All the participants have reported that they had normal vision or have corrected to normal vision (they were wearing glasses).

Battery Power Saving Results

Since the goal of this study was to assess improvements in terms of battery power saving when multimedia bitrate is reduced, while maintaining a good perceived quality, the mobile device power consumption was measured for each of the eight test sequences in two scenarios. In the first scenario, the video bitrate of the streamed clip was set at the reference value of 1200 Kbps. For the second one the video bitrate was set at the minimum threshold computed by the proposed adaptive mechanism (see Section 3.2). The "Sleep" video sequence had 512 Kbps, while the other seven sequences had 256 Kbps.

Figure 5 shows the battery discharge characteristic for the test sequence "Dubus" in the two scenarios. As one can note, apart of a short sudden drop in the beginning of streaming, the battery has a linear discharging. Because the transitory period persisted for all the measurements conducted, the log data for the battery discharge from 95% to 75% (20% battery discharge) was analysed.

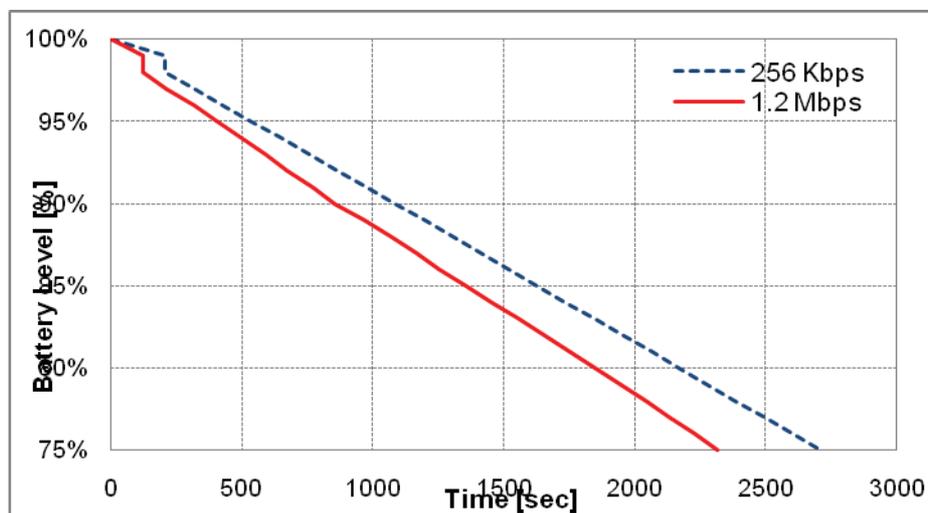


Figure 5: Battery discharge characteristic for video test sequence "Dubus"

An analysis of the results for the eight test video sequences for the two scenarios is presented in Table 3 and Figure 6. The results show that by reducing the video bitrate from the reference value of 1200 Kbps to the minimum threshold, a time improvement of 14.71% in average was obtained. While for the first scenario 20% of the battery charge offered in average 31.66 minutes of streaming time, for the second scenario the same amount of battery power lasted for 4.66 additional minutes.

Figure 6 shows that for the same bitrate, there are little variations in terms of the streaming time between the different test sequences. In both scenarios, the minimum streaming time corresponds to the sequence "Sleep". This can be explained by the higher dynamicity and in the case of the second scenario by the higher bitrate threshold (512 Kbps vs. 256 Kbps).

Test Sequence	Time [sec]		Time [min]		Time Difference		
	256 / 512** Kbps	1.2 Mbps	256 / 512** Kbps	1.2 Mbps	[sec]	[min]	[%]
Arts	2180	1882	36.33	31.37	298	4.97	15.83%
Dubus	2176	1912	36.27	31.87	264	4.40	13.81%
Hotness	2224	1936	37.07	32.27	288	4.80	14.88%
Hulu	2224	1906	37.07	31.77	318	5.30	16.68%
Languagelab	2162	1909	36.03	31.82	253	4.22	13.25%
Obesity	2193	1908	36.55	31.80	285	4.75	14.94%
Sleep**	2085	1845	34.75	30.75	240	4.00	13.01%
Sol	2188	1898	36.47	31.63	290	4.83	15.28%
MIN	2085	1845	34.75	30.75	240	4.00	13.01%
MAX	2224	1936	37.07	32.27	318	5.30	16.68%
AVG	2179	1900	36.32	31.66	280	4.66	14.71%
STDEV	44	27	0.73	0.44	25	0.42	1.28%

Table 3: Battery Tests Results

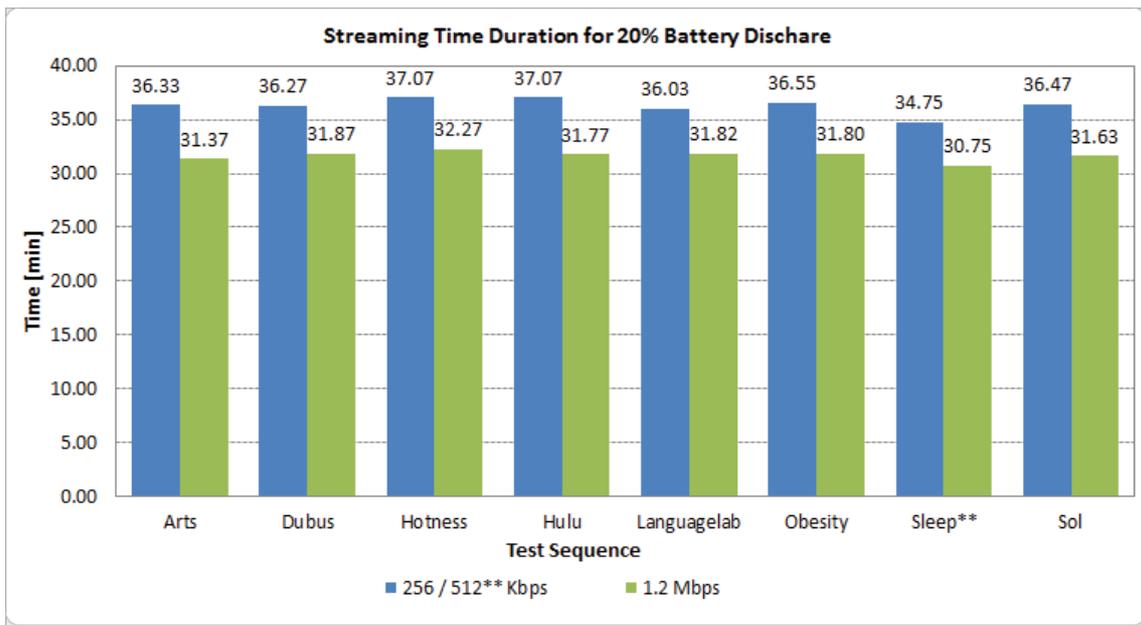


Figure 6: Streaming time duration for the eight video sequences during a 20% battery discharge

Subjective Testing Results

Subjective Video Quality Assessment

Subjects were asked to grade the video quality of each sequence on a 1-5 grading scale and the MOS scores were computed for each of the test sequences.

The results summarised in Table 4, show that six video sequences scored over 4, corresponding to "Good" on the MOS scale and two have scored less than 4 (3.9 for Obesity" and 3.6 for "Languagelab"). The average MOS score across for the eight video test sequences is 4.1.

The subjective quality assessment results have confirmed the results of the objective metrics ($MOS_{PSNR} = 4.5$ and $MOS_{SSIM} = 4.75$) and showed that the proposed mechanism can be used for detecting minimum bitrate thresholds that still offer a good quality level.

The conclusion that can be drawn is that for H.264 video compression, the bitrate of the educational multimedia clips can be significantly reduced, in a controlled manner, without significantly affecting learners' perceived quality. This is due to the fact that often educational clips have low levels of dynamicity. Also, very often the information changes only in a part of the video frame (e.g. a projected slideshow, cursor on a screen, demonstrator hands, etc.).

<i>Test Sequence</i>	<i>MOS</i>	<i>MOS_{PSNR}</i>	<i>MOS_{SSIM}</i>
Arts	4.0	4	5
Dubus	4.5	5	4
Hotness	4.5	4	5
Hulu	4.0	4	5
Languagelab	3.6	4	5
Obesity	3.9	5	5
Sleep	4.0	5	4
Sol	4.5	5	5
Average	4.1	4.5	4.75

Table 4: Comparison of subjective MOS scores with equivalent MOS of the objective metrics

Learning Assessment

The second goal of the subjective assessment was to assess the learning capability provided by the EcoLearn system. The learners answered eight questions related to the information presented in the eight video test sequences. Six questions were of "multiple choice" type with only one answer correct, one question was "yes/no" type, and one question were "short answer".

The average results across the 21 participants are summarised in Table 5. The majority of the subjects were able to answer correctly the majority of the questions for all the multimedia sequences under test, whereas the average correct response rate was 91% Statistical analysis shows that there is little correlation between the MOS scores and the average correct answers for the eight video sequences ($r = -0.374$).

<i>Test Sequence</i>	<i>Avg. Correct Answers [%]</i>
Arts	95
Dubus	100
Hotness	95
Hulu	86
Languagelab	100
Obesity	95
Sleep	90
Sol	67
AVG	91

Table 5: Average correct answers for the eight video test sequences

Conclusions

This chapter has introduced EcoLearn, an adaptive m-learning system supports learners to study for longer by decreasing their mobile device battery power consumption. A mechanism to adapt the educational type multimedia content is proposed and examples of adaptation rules are presented.

Two studies were conducted to assess the benefits of the proposed solution in terms of battery power saving, and its impact on the learning process. The results of an experimental study have shown that in average more than 14% extra study time can be achieved by using the proposed method. Furthermore, the results of a subjective study conducted on 21 participants have showed that the battery power saving is not done at the expense of the learning process. The participants were able to provide correct answers to questions related to the educational content being presented in 91% of the cases, and in average the perceived quality of the test sequences was graded with 4.1 corresponding to Good on a 1 to 5 subjective scale.

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