Assessing Power Saving Techniques and Their Impact on E-learning Users

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Abstract—**As mobile devices are constantly improving, they have started to be used for online learning. If the delivery of educational content involves multimedia streaming, additional pressure is put on the battery life, causing it to discharge faster. Running out of battery life during a learning session can have a negative impact on the learner's Quality of Experience. This paper suggests the fact that adaptive e-learning environments should become energy-aware and power saving techniques should be considered in order to assist the learner in a low power situation. The impact of various factors on the battery life was analysed and the results show that significant power saving can be achieved by applying different techniques during the multimedia streaming process. However, subjective tests conducted on a small group of participants show that some of these techniques have a negative impact on end-user perceived quality and may not be suitable for an e-learning environment.**

Keywords—***power saving; e-learning; multimedia content adaptation; subjective quality evaluation***

I. Introduction

Over the past few years, technology has become a part of our life like never before. More and more people use it as a way to stay in touch with friends, to access information, to work, to study, or for entertainment. With the help of the new technologies, e-learning has become an increasingly important form of education, and many educational institutions have extended their activity on the Internet.

At the same time, users in general, learners in particular, have already become more oriented through mobility. A recent study report published by the Educause Centre for Applied Research shows that laptop ownership increased among undergraduate students from 65.9% in 2006 to 82.2% in 2008 [1]. The study was conducted in 44 universities and colleges in the USA.

Mobility comes with a lot of advantages for the learners but also with a number of limitations. A major limitation is that, while on the move, learners rely mainly on the mobile device battery power supply. Given the fact that an increasing number of e-learning environments have included multimedia content in their applications, accessing a course over the wireless network can quickly drain the power from the battery. If learners have to stop their activities due to low power situations, not only their Quality of Experience (QoE) is affected, but also the learning outcome may be significantly reduced.

In this context, e-learning environments have to become energy aware and to assist the learners in maximising their learning outcome. Therefore, power saving techniques must be integrated with the e-learning applications. Battery life will be extended by personalising the educational multimedia content depending on the available power resources of each particular mobile device that is used.

This paper presents an experimental evaluation of some of the factors that have an impact on the battery power consumption when multimedia content is delivered to mobile devices. It also looks at different actions that can be taken in order to reduce the power consumption. These actions can be integrated into a power saving mechanism which will extend the functionality of the adaptive e-learning systems.

Considering the fact that users are becoming increasingly quality-aware, a subjective testing was conducted on a group of participants in order to assess how their perceived quality is impacted when power saving actions are applied.

The paper is structured as follows. Section two consists of a literature review of the existing power saving techniques in the wireless communication area and previous research in the area of adaptive learning. The paper continues with experimental results assessing the impact of various factors on battery power consumption, but also with the results of the subjective evaluation. In the end conclusions are drawn and future directions are presented.

II. Related Work

In the last decade, adaptation and personalisation have gradually been brought to the forefront of research and as a result a large number of applications in the technology-enhanced learning area have been proposed. Various aspects were investigated as important input in the personalisation of the course material and learning process.

Content personalisation may be driven by the needs of individual learners, their preferences, goals [2], knowledge level [3] or cognitive preferences [4]. Personalisation of the learning process may be driven by the user's abilities, motivation and their previous interaction with e-learning environment, as well as by the learner's concentration level and frequency of disruptions [5].

Most of the research in the area of adaptive e-learning has concentrated on delivering personalised educational content based on learner characteristics. More recently research focused on proposing solutions for multimedia content adaptation according to learner device type and characteristics [6], [7], network type and conditions [8] and user Quality of Experience (QoE) [9].

Although much research was performed in this area and there are clear evidences that the available power of the mobile device could affect the learning process, no study has considered the learner device battery level in the personalisation process of the multimedia content, apart of other characteristics.

Batteries have improved over the last few years, but still a combination of multimedia tasks that are using at the same time multiple components simultaneously (such as screen and speakers, CPU, memory and the Wireless Network Interface Card (WNIC)) may drain the battery power quickly.

However, battery life is not a new issue and many power saving techniques in wireless communications have been proposed over the time. For the particular case of multimedia streaming, the proposed solutions can be classified in the following categories:

1) *Power saving in the reception stage* of the multimedia stream. These solutions look at sending and receiving data and mainly focus on maintaining WNIC in a low power state for a longer period. A proposed solution is to send video frames in a bulk based on the network traffic shape instead of sending them individually. Thus data waiting time for the device is reduced [10]. Another proposed solution uses periodic bulk transfer of the video data in order to reduce the working time of the wireless card, combined with a decrease of the video quality at an intermediate proxy node [11]. Existing research shows that significant improvements in the battery life can also be achieved by extending the power saving mechanism, already built in the IEEE 802.11 standard [12]. This solution uses 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 to the mobile station after several attempts to receive it.

2) *Power saving in the decoding stage*. A study [13] has proposed to use dynamic online feedback for setting the average frame decode rate to the same value as the display rate in order to save power in the decoding stage.

3) *Power saving in the playing stage*. The majority of the solutions that have been proposed for saving power in the reception stage have focused on the device screen. Battery power consumption can be reduced by optimising the backlight power consumption [14], or by extending the Dynamic Luminance Scaling (DLS) to cope with transflective LCD panels that can operate with or without backlight [15] depending on the battery level and ambient luminance. Power save can also be achieved by adjusting screen brightness and volume level but since the user has control on these settings, little research has been performed in this area.

Literature review shows that numerous power saving techniques with good results have already been proposed. The novelty of this research consists of the fact that it will bridge the well researched area of personalised e-learning with the power saving in the wireless communications and will look not only to increase the battery life, but also to improve the learning process.

III. Factors That Influence Battery Power Consumption of The Mobile Devices

Playing multimedia educational content on a mobile device is an energy intensive task, especially when this is streamed over a wireless network. In this situation significant power is consumed by the WNIC for retrieving and processing the multimedia stream, in addition to the power consumed by other components for decoding and playing the audio-video sequence. The multimedia streaming process can be seen as consisting of three different stages: data reception, decoding and playing. Each of them contributes more or less to the overall battery consumption of the mobile device.

Various experimental tests (see Table I) were conducted in order to investigate the impact of each of the three stages on the battery power consumption. Different factors specific to each stage were also considered. For testing purposes, a video clip with a reduced degree of motion content, was used. Various versions of the studied video clip that have different values of the encoding parameters were created. This set of videos can be classified according to the encoding parameter that is studied. Any two videos corresponding to a specific encoding parameter have different values for that parameter. The rest of the encoding parameters are constant and their values are in the following groups: video compression - H.264 encapsulated in the MP4 multimedia container, resolution - 320 x 240 pixels, frame rate - 24 fps and average video bit rate - 384 Kbps.

Depending on the performed test, each video was streamed to the mobile device and/or played locally in a loop until the battery was completely discharged. To

TABLE I
EXPERIMENTAL TESTS PERFORMED

Test	*Stages Involved*	*Parameter Category*	*Studied Parameters*	*Parameter's Values*
Streaming and Local Playback	Reception, Decoding, Playing	Encoding Parameters	Video Compression	H.264, WMV 9, MPEG4 Part2, H.263
			Video Resolution	480 x 360, 320 x 240, 240 x 180
			Video Frame Rate	24 fps, 20 fps, 16 fps
			Average Video Bitrate	512 Kbps, 384 Kbps, 192 Kbps
Local Playback	Decoding, Playing	Device Settings	Volume Level	100%, 50%, 0%
			Screen Brightness	100%, 50%
			CPU Clock Speed	520 MHz, Auto Speed, 208 MHz

maximize the accuracy of the results, similar conditions were kept between any two different tests. The only applications running on the mobile device were the media player and the program used for tracing information on the battery power consumption. For the case when a video was streamed, the mobile device was maintained in a fixed position where the wireless signal strength was high and constant. For the case when the video was played locally the WNIC was switched-off. To ensure that the battery degradation in time has a minimum impact on the results, the tests corresponding to the same parameter were performed consecutively with a minimum time necessary to charge the battery between them. All the tests were performed in a laboratory where the temperature was constant.

The mobile device consisted of a Dell Axim PDA with an IEEE 802.11b wireless card and a 520 MHz ARM processor, running Microsoft Windows Mobile. Additionally, a laptop with 2 GHz Intel Core 2 Duo processor and 2 GB of RAM memory, running Microsoft Windows Vista was used as a streaming server when the videos were streamed to the mobile device. Additional details on the test setup can be found in [16].

A. The Impact of WNIC on the Battery Life

In the reception stage, most of the power is consumed by the for network related tasks, such as receiving the data packets and processing them. In order to assess WNIC's effect on the battery power consumption, a number of comparative tests were performed when the same versions of the multimedia clip were first streamed from the server to the mobile device via an Access Point (AP), and then stored and played locally on the PDA.

The results presented in Fig. 1.a-d show that when the multimedia clips were streamed, the battery discharged in half of the time required when the same clips were played locally. Only the times needed to discharge the battery from 50% battery charge to 1% battery charge were considered in the comparison. For example, in the case of the H.264 video with a frame rate of 16 fps, the battery life was reduced by 52%, from 84.22 minutes when the video was played locally to 40.4 minutes when it was streamed and played in real time (see Fig. 1.c).

The conclusion that can be raised is that WNIC is responsible for approximately 50% of the total battery consumption when retrieving the streamed multimedia clip and the reception stage is where significant power can be saved, by applying different techniques.

B. The Impact of Encoding Parameters on Battery Life

Before it can be played, a multimedia clip has to be decoded according to the encoding scheme used. CPU and memory are the main components responsible for the power consumption at this stage. In order to assess the effect of the encoding scheme on battery power consumption, following multimedia clip parameters were considered: video compression technique, video resolution, frame rate and bitrate. Comparative results (see Fig. 1.a-d) show that the battery life can be increased by changing the video compression technique to a more energy efficient one or by reducing the values of other encoding parameters.

Fig. 1.a shows that an increase in battery life of 21.53% can be achieved, by changing the video compression technique from H.264 to H.263 (encapsulated as a Flash video), when the videos were played locally on the device. The improvement was even higher when the same videos were streamed to the mobile device (27.6%).

As opposed to the video compression technique, reducing the quantitative encoding parameters will have a higher impact on the battery life if the videos are played locally, rather than streaming them. For example, by reducing the resolution from 480 x 360 pixels to 240 x 180 pixels, the frame rate from 24 fps to 16 fps and the average video bitrate from 512 Kbps to 192 Kbps, the battery life increased with 25.66%, 15.31% and 14.67% respectively, when the videos were played locally, and with 15.93%, 10.94% and 7.27% respectively, when the videos were streamed to the PDA (see Fig. 1.b-d).

Concluding this, one can say that battery power can be saved by varying the encoding parameters of the multimedia clip being delivered, but the amount of power saved is significantly smaller than that in the reception stage of the multimedia streaming process.

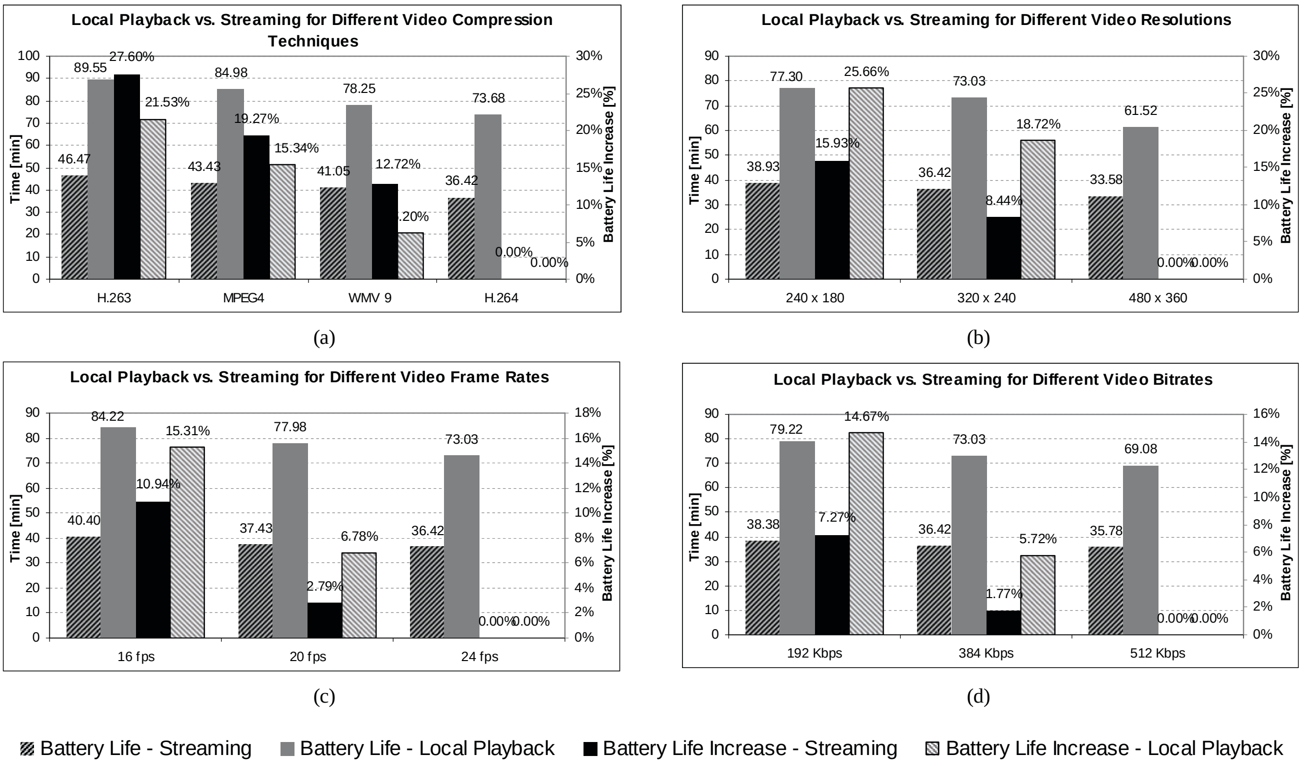


Fig. 1. Battery life and battery life increase (comparing with the less energy efficient case from the group), when videos with different encoding parameters are streamed and played locally on the mobile device: (a) the effect of video compression technique on battery life; (b) the effect of video resolution on battery life; (c) the effect of video frame rate on battery life; (d) the effect of average video bitrate on battery life.

C. The Impact of Device Settings on the Battery Life

Depending on the type of multimedia content, the device screen and speakers are the main components responsible for the power consumed when the multimedia clip, previously decoded, is played to the user. A new set of tests were carried out in order to assess the effect of device components and especially their settings on the battery life. Each test consisted of playing locally the same video file until the battery was completely discharged. The WNIC was switched-off to eliminate its effect on power consumption and to increase the contribution of the component whose settings were changed.

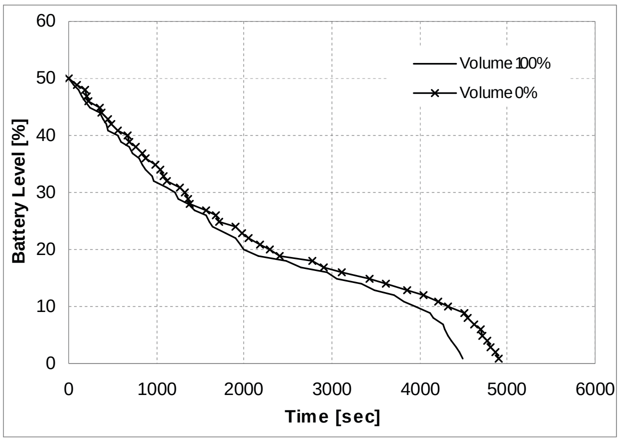
To assess the effect of the speakers on the battery life, the volume was set to three different levels and the time needed to discharge the battery was measured. The levels considered were 0%, 50% and 100%. Fig. 2.a shows that if the media clip that is being played consists in an audio-video sequence, the sound playback by the speaker has a small contribution to the overall power consumption of the mobile device. Turning the sound OFF will increase the battery life only with 9% comparing with the case when the volume is set to 100% both in the media player and in the Operating System. Since no important benefit was noticed when the volume level was set to 50%, the case was not plotted on the graph.

To investigate the effect of the device screen, on the battery consumption, two levels were considered for the screen brightness: 100% and 50%. Fig. 2.b shows that in comparison with the sound volume, screen brightness has a higher impact on power consumption. An increase in battery life of approximately 31% is achieved when the screen brightness is reduced to half of its maximum level.

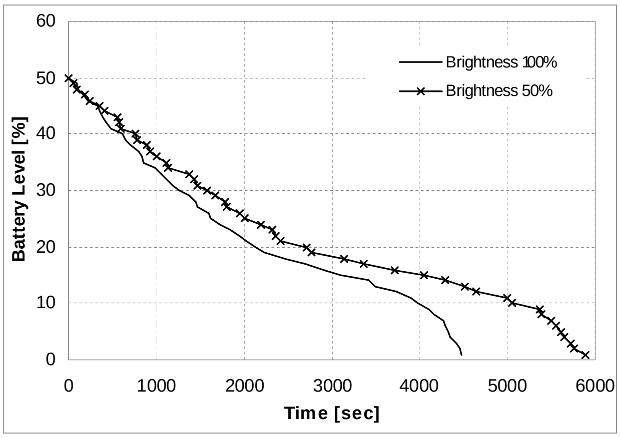
A last set of experimental tests was conducted in order to investigate the effect of CPU on the battery power consumption. For this, the CPU clock speed was set to three different values: 520 MHz, auto speed and 208 MHz. Fig. 2.c shows that comparing with the case when the clock speed is set at 208 MHz, changing this speed to 520 MHz will increase the battery consumption by 25%, while letting the system to choose the optimum speed, reduces the battery life by 17%.

D. Reflections on the Results

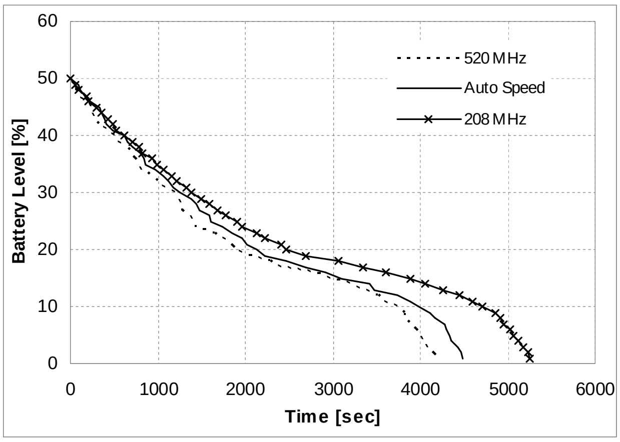
The experimental results presented above show that during the streaming process of a multimedia clip, there are multiple options for extending the battery life. By turning ON the WNIC to retrieve the multimedia content from the network, the battery consumption increases with up to 50%. So is at this stage where significant battery power can be saved. The longer the time that WNIC spends in a low power state before retrieving data, the higher the amount of



(a)



(b)



(c)

Fig. 2. Battery life when changing different settings of the mobile device: (a) the sound volume level; (b) the screen brightness; (c) the CPU clock speed.

power that is saved. Solutions for extending this time must be found without introducing delays that can impact negatively the learning process.

By changing the encoding parameters of the streamed multimedia clip, additional power can be saved. There are two possible options to do this. First, advance creation of multiple versions of the multimedia content which differs in terms of encoding parameters. This method requires more storage space on the server side, but this is not a serious issue as over the last years, the storage devices have exponentially increased in capacity and their price has drastically dropped. A second option makes use of transcoding, reducing the required storage space and enabling real time modifications of the encoding parameters to be performed easier. The disadvantage of this solution is that requires high processing power on the server side, especially when a high number of users are accessing the application at the same time.

The power saving techniques related to the reception and the decoding of the multimedia stream can be implemented on the server side, or between the server and the client. The users have reduced control on how data is received and on the amount of resources necessary to decode and play the multimedia content that is being sent. If the e-learning environment allows them, they have the option to download the multimedia content and view it afterwards, saving power at the same time. In this case the reception is controlled by the users but is efficient only if there is enough network bandwidth available to allow them to download a clip in a much shorter time then needed to stream it. On the other hand, the users have a high level of control on the device settings. Changing these settings in order to save power can have a negative impact on users' satisfaction.

It is worth mentioning that in the case of this particular device, the battery has a nonlinear discharge characteristic (see Fig. 2.a-c), but with several sections approximately linear (50% to 20%, 20% to 10% and 10% to 1%). Also a significant interval from the total battery life increase, achieved by changing a specific parameter, corresponds to the section when the battery life decreases from 10% to 1%. A power saving algorithm must consider the discharge characteristic of the battery model corresponding to the mobile device that is being used to access the multimedia content, but also the battery level at which the device is set to turn off, usually between 5% and 10% for laptops or PDAs.

IV. PRELIMINARY SUBJECTIVE EVALUATION

This section presents preliminary results of subjective tests that have been carried out in order to assess the impact of some of the actions that can be taken to increase the battery life, on end-user perceived quality of the multimedia clip. A small number of participants have attended and further tests are ongoing. The evaluation addressed only the encoding parameters because their variation is easier to be controlled and is directly reflected in the final quality of the multimedia clip.

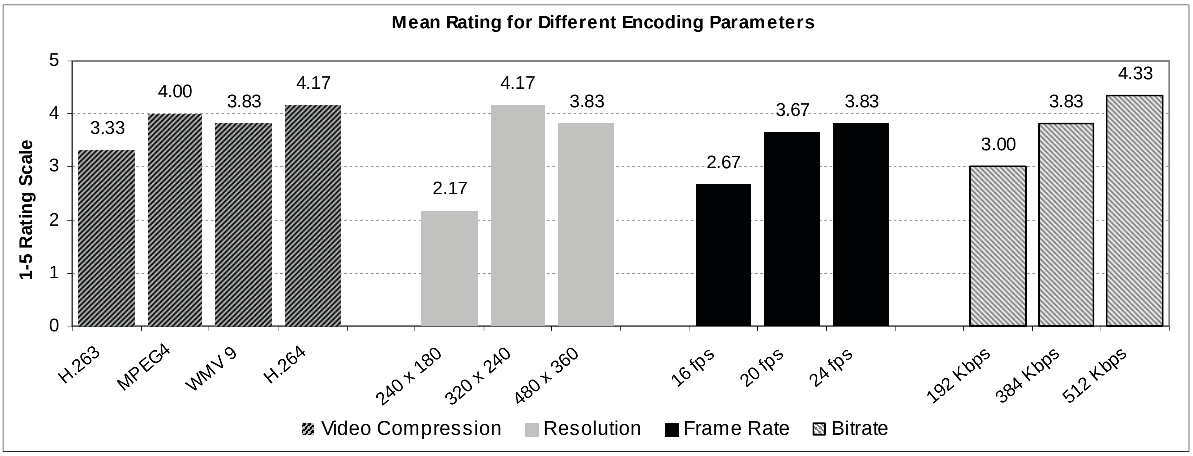


Fig. 3. End-user perceived quality when varying the encoding parameters.

A. *Evaluation Setup*

Four sets of short video sequences were created, one for each of the encoding parameters whose impact on battery life was previously studied. In particular, each set consisted in a number of three or four video sequences with different values for the parameter associated with that set, and constant values for the rest of the parameters.

To eliminate the influence of other factors, such as fluctuations in the available network bandwidth, on the final perceived quality, the video sequences were stored and played locally on the mobile device. Also, to keep a uniform testing environment, all the participants used the same PDA device for viewing the video sequences. The screen brightness was set to 100% and the volume level was set at an adequate level for the laboratory environment where the testing was conducted. None of the participants changed the mobile device settings, even if they were allowed to do so.

The subjective tests were performed with one participant at a time and before starting, he/she was introduced to the test environment and to the method of assessment. A five-grade quality scale (i.e. 1 - Bad, 5 - Excellent) was used for this purpose. The participant was asked to rate his/her overall impression given by each sequence in part, and to mark the corresponding checkbox on a form that was provided. Code names were associated with the video sequences so that the viewers were not aware of the parameters being analysed. The overall duration of the test session, including introduction, viewing and rating, was planned to last less than 20 minutes. A different order of displaying the video sequences was chosen for each participant to the subjective test.

B. *Preliminary Results*

Fig. 3 presents the mean scores, achieved by each particular sequence. Preliminary results show that, changing the video compression technique has a lower impact on end-user perceived quality, than decreasing the resolution, the frame rate or the bitrate. Significant battery power can be saved by changing the video compression, while maintaining a good quality level. For example by changing the video compression from H.264 to MPEG4 Part 2, there is an improvement in battery life of 19.27% when the video is streamed to the mobile device and 15.35% when the video is played locally (see Fig. 1.a). At the same time a good level of quality was maintained, the sequence encoded using MPEG4 scored an average rating of 4 out of 5, whereas the sequence encoded using H.264 scored an average of 4.17 out of 5.

Results also show that by reducing other encoding parameters to levels that offer a good energy saving, the user perceived quality is significantly reduced. At the same time, a slight decrease which maintains a good level of quality, may not have real benefits in terms of power saving. For example by reducing the frame rate from 24 fps to 16 fps, an increase in battery life of 10.94% could be achieved for the case when the videos are streamed, but the quality was significantly reduced, the corresponding video sequence scored an average of 2.67 out of 5. Reducing the frame rate to 20 fps, the quality is still good, but the increase in battery life that can be achieved is only 2.79%.

As it can be seen in Fig. 3, the video sequence with a resolution of 320 x 240 pixels, achieved a higher score than that with a resolution of 480 x 360 pixels, when the contrary was expected. This is explained by the fact that device screen had a resolution of 320 x 240 pixels and additional tasks were required for scaling down the video, negatively influencing the user perceived quality.

If e-learning users are in the middle of a learning activity and an interruption occurs due to insufficient battery power, their QoE can be negatively impacted. This can also happen if the quality of the multimedia content is reduced too much, even if by doing this sufficient power is saved to allow them to complete the learning activity. To maximise the learning outcome, a power saving solution for e-learning environments must find the right balance between the amount of power saved and the user QoE.

V. CONCLUSION AND FUTURE WORK

The goal of this paper was to assess the factors behind the battery power consumption when multimedia content is streamed and played on a mobile device. A number of experimental tests were carried out, which have shown that during the multimedia streaming process, data reception accounts for half of the total power consumption of the mobile device. Results have also shown that battery power consumption is influenced by the encoding parameters of the multimedia clip and by the settings of the mobile device. However, their contribution is found to be significantly smaller than that of WNIC.

Preliminary subjective testing was conducted in order to assess the impact of encoding related to the power saving actions on the end-user perceived quality. The conclusion drawn from these tests was that changing the encoding parameters, while at the same time maintaining a good quality, may not save enough power to improve the learning process. Therefore most of the effort must be concentrated to save power in the reception stage of the multimedia streaming. Encoding related techniques should be used when the power saved in the reception stage is still not enough to maximise the learning outcome.

Future work will address the deployment of a power save mechanism that will incorporate various techniques specific to different stages of the multimedia streaming process. Further experimental testing will be conducted on various mobile devices, in order to propose a battery independent discharge model that estimates with accuracy the remaining battery life.

Elaborate subjective testing will also be conducted on a large number of participants in order to assess the benefits of the proposed solution in terms of battery power save, end-user satisfaction and learning improvement.

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