Energy-Aware Streaming Multimedia Adaptation: An Educational Perspective

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ABSTRACT
As mobile devices are getting more powerful and more affordable the use of online educational multimedia is also getting very prevalent. Limited battery power is nevertheless a major restricting factor as streaming multimedia drains battery power quickly. Many battery efficient multimedia adaptation techniques have been proposed that achieve battery efficiency by lowering presentation quality of entire multimedia. Adaptation is usually done without considering any impact on the information contents of multimedia. In this paper, based on the results of an experimental study, we argue that without considering any negative impact on information contents of multimedia the adaptation may negatively impact the learning process. Some portions of the multimedia that require a higher visual quality for conveying learning information may lose their learning effectiveness in the adapted lowered quality. We report results of our experimental study that indicate that different parts of the same learning multimedia do not have same minimum acceptable quality. This strengthens the position that power-saving adaptation techniques for educational multimedia must be developed that lower the quality of multimedia based on the needs of its individual fragments for successfully conveying learning information.

Categories and Subject Descriptors
H.5.1 **[Multimedia Information Systems]:** Video
I.3.6 **[Methodology and Techniques]**: Device independence
K.3.1 **[Computer Uses in Education]:** Distance learning

General Terms
Design, Performance, Experimentation, Human Factors, Theory

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1. INTRODUCTION
In recent years mobile learning has become very popular. Powerful mobile devices with enhanced capabilities are now becoming more affordable. Furthermore, the tremendous improvements in wireless technologies have made it possible to connect these mobile devices to the internet at higher data rates, enabling the use of high quality multimedia content. As a result mobile users can now also have access to rich educational multimedia content anytime and anywhere [4]. Further opportunities of learning using mobile devices have been created by the free availability of a great number of educational videos by reputed institutions and individuals. Mobile learners now have control over what, when and where to learn, making learning using mobile devices increasingly popular [2; 22]. There are, however, some challenges that still need to be addressed.

There is a big diversity in terms of mobile devices, network connectivity as well as mobile learners' needs. This makes the traditional one-size-fits-all approach unsuitable for mobile learning resources. Adaptation and personalization of learning resources have been used to enhance and make the learning experience more efficient. It is important to facilitate mobile learners in taking better advantage of the limited time and resource constrained devices they possess while on the move. There has been much research in adapting learning resources to the learners' needs and usage context [23] [24] [32]. The delivery of multimedia content in particular poses many challenges in mobile learning. To address these challenges multimedia adaptation and personalization techniques have also been developed for mobile learning systems [22].

Content Adaptation and Universal Multimedia Access (UMA) [28] techniques have been used to adapt multimedia content based on the resource constraints of mobile devices. Battery technology has not seen as much of an improvement as other features of mobile devices. Mobile devices have limited battery power which restricts learners from learning for longer durations. Educational multimedia content on the web when accessed over mobile networks quickly drains battery power as a result of large data transfer. The wireless interface of mobile devices consumes a major portion of battery in multimedia streaming. Streaming multimedia can consume up to two times more battery power than playing the same multimedia file locally [25; 26]. Energy efficient multimedia adaptation techniques tend to degrade multimedia quality in order to extend the battery life [6] and are therefore based on a trade-off between user experience and battery life. Multimedia quality is lowered by reducing the encoding parameters like frames per second, bitrates, colours and resolution.

The power-saving streaming multimedia techniques degrade the quality of multimedia content uniformly without considering any impacts on the different portions of the multimedia. Reducing the quality of entire educational multimedia resources beyond a certain point can leave some portions of the multimedia resource - containing crucial visual quality-sensitive information - unsuitable for learning due to the loss of visual information. There is need for energy efficient educational multimedia adaptation techniques that keep multimedia suitable for learning after the adaptation. In our earlier work [11], we proposed a Content-Aware Power Saving Educational Multimedia Adaptation (CAPS-EMA) approach that achieves battery efficiency without risking the learning process. We believe existing techniques are not suitable for adapting educational multimedia as they do not consider learning factors in the adaptation process. It is only recently that power-saving techniques have been recommended to be integrated in mobile learning environments [11; 20].

Our hypothesis is that different parts of a same learning multimedia have different minimum acceptable visual qualities for conveying learning information without any perceived loss of information. In this paper we conduct an experimental study to test this hypothesis.

The paper is organized as follows. In sections 2 and 3 we discuss some existing research work in battery efficient multimedia adaptation and power-saving educational multimedia adaptation. Section 4 discusses the need for adaptation techniques for educational multimedia. Section 5 describes the experimental design and the results are discussed in section 6. Finally in section 7 we briefly discuss our prototype implementation for battery efficiency educational multimedia.

2. POWER EFFICIENT MULTIMEDIA ADAPTATION

On one hand advancements in battery capacity has lagged significantly compared to other capabilities of mobile devices [1] and on the other hand the power requirements of mobile devices are continuously increasing. Mobile devices have now increased processing capabilities; they come with bigger screens and can communicate at higher data rates. All these enhancements require more battery power. Streaming online Multimedia is one also a power hungry activity. Considerable research has been done to improve battery efficiency while using online multimedia content. Multimedia adaptation techniques achieve power-saving by lowering visual quality. This is done by altering media parameters like frames per second, resolution, colour, bitrates [18], [26] and changing even the modality of content. The general principle behind this approach is to reduce the data size of multimedia which reduces the data transfer through wireless interface. This results in reduced consumption of battery power. It is proven that content adaptation mechanisms have the capability to prolong battery life of the multimedia streaming clients [5; 16; 18]. Content adaptation has been an attractive solution for the ever-growing desktop-based Web content delivered to the user via mobile devices.

Comprehensive surveys of energy efficient techniques for multimedia applications can be found in [6] [29] [7; 8; 21; 31]. Hoque et.al in [6] surveyed various solutions for improving the energy efficiency of wireless multimedia streaming in mobile devices. They classify research work based on different networks layers and adaptation approaches. This gives us an idea of how we can achieve battery efficiency at each network layer. The survey classifies power saving multimedia adaptation techniques in application layers into Scalable Video Coding, Media Transcoding and Content Selection. Each of these application layer mechanisms reduce multimedia quality and bitrates that helps in energy saving. Wang et.al in [29] provide list of techniques that can be used in mobile networks for green mobile communication or energy efficiency. Zhang et al in [31] have focused on energy saving techniques for mobile multimedia delivery and group the solutions in power aware video coding and video delivery. They identify several challenges in designing energy efficient mobile multimedia communication. Ismail et al in [8] classifies energy aware content adaptation systems based on the mechanisms used, strategies adopted, location of adaptation mechanism, purpose of user, context and the technique used. These systems modify visual presentation of multimedia content in order to fit it to mobile devices and minimize energy consumption. While compromising on visual quality of multimedia the quality of experience should also be considered while optimizing the energy consumption by adaptation mechanism.

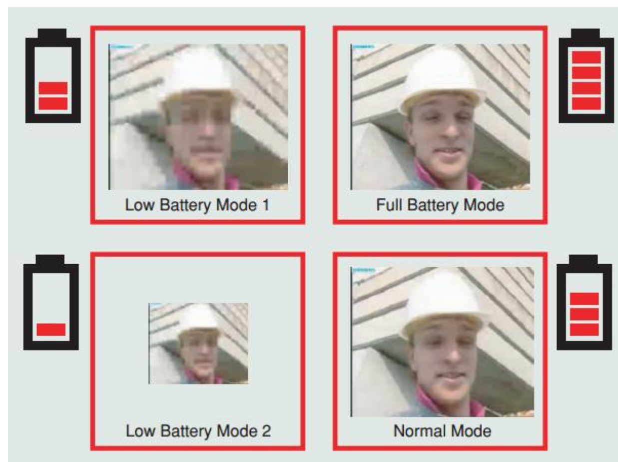

Figure 1: Video Presentation Quality for different Battery Levels[13]

Adapting the fidelity of content has an important role in battery saving adaptation mechanisms. At application level mostly the quality of multimedia is reduced to achieve battery efficiency [3; 7; 13-15; 17-19; 26; 31]. Below we show how different adaptation mechanisms are used for battery saving purposes. Zang et al in [31] discusses how lower quality adaptation mechanisms can be used for power-aware mobile multimedia. Hoque et al in [7] experiments with streaming services and power consumption by multimedia of different qualities, video players and video containers. They report high battery power consumption for high quality video on Galaxy S3 mobile device than low quality videos. Lian et al in [13] propose a design of multimedia systems that is power-aware and delivers multimedia in different quality and encoding parameters for different level of battery status, as shown in Figure 1.

Liu et al in [15] found in experiments that switching to lower quality in streaming the data transmission is reduced that helped save battery power. Trestian et al in [26] experimented with The

Blender Foundation's 10 minute long Big Buck Bunny animated clip. High quality version of the clip was transcoded at five different quality levels (QL1-QL5) with video frame rate reduced from 30 fps in QL1 to 10 fps in QL5. Their results show that by decreasing the video quality level, they could achieve energy savings from 6.7% (for a QL1 to QL2 drop) up to 62.7% (for a QL1 to QL5 decrease) on the wireless interface only.

Lin et al in [14] also shows experimentally that battery power can be reduced by reducing bitrates and frames per seconds for video quality. They find the average growth rate of the energy consumption is 15.76% when frame rate is changed from 25 to 30 frames per second. Similarly, the average growth rate of the energy consumption is 22.44% when the resolution of the film is changed from 320 × 240 to 384 × 240. This paper also concludes that for a better picture quality, we can encode films with bigger bit rate with just a little increase of energy consumption. Otherwise, we will need to pay a great penalty if we try to have a better quality film by increasing the resolution instead.

McMullin et al. introduced a Power Save-based Adaptive Multimedia Delivery (PS-AMy) mechanism [16]. PS-AMy adapts multimedia streams in order to enable the streaming last longer. The adaptation decision is based on the remaining battery life and packet loss. The client side sends a feedback about the remaining energy and packet loss while the server side adjust the data rate dynamically to save energy while maintaining acceptable user-perceived quality. Kennedy et. al. in [12] suggests Battery and Stream – Aware Adaptive Multimedia Delivery mechanism (BaSe-AMy). BaSe-AMy considers mobile device remaining battery level and energy at WNIC (physical layer), remaining video stream duration (Application layer) and Packet loss rate (Transport layer) to decide the bitrate for the video in order to extend the battery life of the wireless device.

We have observed that these streaming multimedia adaptation techniques do not consider impact of reducing visual quality on the loss of visual information during the adaptation process. The loss of visual information may negatively impacts the efficacy of multimedia for learning. These problems have been discussed in detail in [11].

3. POWER SAVING IN EDUCATIONAL MULTIMEDIA

Battery power constraint is a great challenge in taking maximum advantage of mobile devices for learning and is a big restricting factor. Battery life is still a constraint for mobile devices; mobile learners are often forced to interrupt their learning activity because of low power situations. Online educational multimedia content when accessed over the mobile network quickly drains the battery power as result of huge data transfer. Despite high dependency on battery power little has been done to improve battery efficiency in for mobile learning purposes. Mobile learning applications depend on existing generic power saving multimedia adaptation techniques that are not developed specifically for educational content. Existing battery efficient multimedia adaptation techniques offer trade-off between user experience and battery life. These techniques tend to degrade quality in order to extend the battery life as discussed in section 2.

In a recent survey, Moldovan et al in [21] presented a detailed survey of methods and techniques that can be used to achieve energy efficiency in mobile learning. They discuss energy consumption characteristics of components in mobile devices and identify ways to address battery power savings. It discusses various content adaptation mechanisms that can be used by mobile learning applications to extend duration of learning activities. The most important of such content adaptation techniques are those at application level which can be easily adopted by learning applications.

[17] suggested to integrate power saving techniques in mobile learning applications. They argue that it is better to provide multimedia educational content in lower quality rather than affecting learning experience by stopping learning activities earlier as a result of low power situations. This paper further presents experimental evaluation of battery consumption and quality of multimedia encoding parameters and performs subjective evaluation of using learning multimedia on mobile devices in different presentation qualities. The focus, however, is on better user experience and user experience matrices are used while recommending encoding parameters.

Moldovan et al in [19] suggest Eco-Learn an mLearning system for saving battery power by adapting educational multimedia. Eco-Learn also consider the learner profile and device characteristics in order to provide battery efficient multimedia content. In order to support adaptation, metadata is added to the content and adaptation rules are defined using an authoring tool. EcoLearn delivers adaptive educational multimedia clips, by decreasing the bitrate, with the goal to save the battery power on the learner mobile device, thus assisting the learners to study for a longer period of time. They conducted experiment to understand the impact of reducing quality of video for battery saving purposes on learning outcomes and learner perceived quality. Subjective test in this paper shows that quality of video can be reduced without significantly affecting learning process.

In our previous work [11], we presented an approach for educational multimedia adaptation for power saving . The objective of this adaptation mechanism was to prevent any portion of learning multimedia from delivering in a quality that is not suitable for learning due loss of visual information loss. We also demonstrated a prototype implementation in [9].

4. USER EXPERIENCE VS LEARNING-AWARE ADAPTATION

We have observed from the study of existing literature that existing generic adaptation mechanisms are used for adapting educational multimedia in order to meet resource constraints in mobile devices including battery power. These techniques either lower multimedia quality without considering any additional usage aspect or are based on user experience only. In both cases, if the educational aspect is not considered in the adaptation process, it may result in negative impacts on either battery efficiency or effectiveness of multimedia for learning. There is a lack of specific multimedia adaptation mechanisms for educational multimedia. We believe it is important because educational multimedia has specific learning objectives and adaptation mechanisms must consider this additional educational factor in adapting educational multimedia.

Multimedia adaptation mechanisms degrade the quality of multimedia content uniformly without considering the nature of visual content in different videos segments. Evaluation of these multimedia adaptation techniques are based on evaluating parts of the video (mostly of few seconds duration) and not on complete video or different representative segments. Educational videos may not contain similar visual detail of information and may differ in nature and detail of visual content. A selected lowered quality of video may be suitable for one segment but may not necessarily be suitable for another segment to successfully convey visual information. The learning visual information, therefore, may not be comprehensible and the objective of learning multimedia may be compromised. Following are the possible problems when the general purpose adaptation techniques are applied on educational multimedia.

1. The first problem with existing generic techniques is that they do not have any mechanism to consider the effect of quality degradation on the intended learning outcome. These methods are not content-aware or learning-aware. This means that quality degradation decisions are enforced irrespective of what the contents of multimedia are. This may make a multimedia content unhelpful for learning purposes if the learning content was quality sensitive.
2. The second problem with these power-saving adaptation techniques is that they select a single lower quality for the entire educational multimedia. Learning multimedia is adapted to a single quality. This may result in two problems. Firstly, the multimedia may not remain fully useful for learning if the selected quality is lower than the minimum acceptable to successfully convey information. Secondly, it may provide less than the achievable power efficiency if the entire multimedia is selected in a higher quality to preserve the quality sensitive portions of the multimedia.

We conducted a user study in order to understand if different parts of the same multimedia resource have the same minimum presentation quality requirements or if it differs for different parts of multimedia for successfully conveying learning information. This study would help us know if single uniform quality for entire multimedia as output of an adaptation technique may cause any negative impacts on learning. The major difference between our study and other content adaptation experiments is that we did not take a single random segment from entire learning multimedia for evaluation. Instead we took different segments that are representative of the whole multimedia in terms of visual detail. They comprise of segments of varying types and extents of visual information. We now present the details of the user study we conducted.

5. RESEARCH DESIGN

This study was designed to understand minimum acceptable presentation qualities of learning multimedia resources. We are interested to know if a multimedia learning resource can be delivered in a single lower quality or if different segments needed different minimum presentation qualities, for conveying learning information without any information loss.

5.1 Research method

We designed a quantitative study. For this purpose three freely available educational videos were selected on the topics of Ohm's Law, C++ and Semantic Web. Video 1 (Ohm's Law from Dunwoody College Youtube channel) was a recording of a teacher and a white board. Video 2 (C++ from Barbara Hecker's online lecture) was a mix of slides and practical activity like writing codes. Video 3 (semantic web lecture from http://WebExplorations.com) consisted of slides only where slides vary in detail of visual information on each slide. We selected five fragments from each video so that they were representative of the entire video in terms of visual information contents. Screenshots of different fragments of each video are given in Figure 2, Figure 3 and Figure 4. Each fragment was of duration 15-20 seconds and differed from the others in terms of type of visual information. The screenshots of the video fragments are given in the Figures 2, 3 and 4. We encoded all fragment in to four different qualities (Q1 – Q4), with one (Q4) in audio only quality. Quality encoding parameters are described in Table 1. We had a total of 20 video clips for each video and a total of 60 clips for all the three videos. The video versions of the fragments were encoded without audio, so that participants could focus on visual information contents only to comprehend visual information without. This will help us to know exactly if the visual information was visible enough in a particular quality or not.

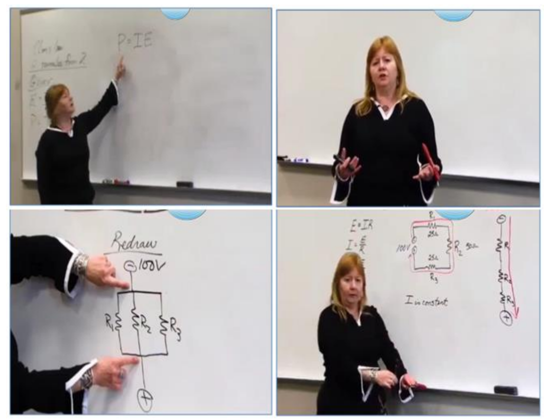

Figure 2: Fragments from Video 1 (Ohm's Law Clip)

Table 1: description of presentation qualities

Quality Level	Video Bitrate (kbps)	Audio Bitrate (kbps)	Resolution	FPS
Q1	150	-	640 x 480	15
Q2	50	-	480 x 360	10
Q3	10	-	320 x 240	5
Q4	-	32	-	-

We did not include original high qualities of videos in evaluation. We also did not include other higher bitrate qualities as we believe these high quality videos do not cause problems in understanding. We chose to focus our study in lower qualities as it is lower qualities where problems occur. Q4 is audio only quality encoded at 32 kbps with single channel.

We aimed to have participants' feedback about each video fragment in each quality. We recruited 28 volunteers for the study. Participants were PhD students from the School of Electronics and Computer Science, University of Southampton. Each participant viewed one version of each video fragment. In this way each video fragment version was viewed by exactly 7 participants. All participants were provided with a HTC Sensation phone for viewing clips. The viewing order was selected in such a way that no participant will view multiple versions of the same video fragment. Each participant was given a total of 15 different clips including 3 or 4 clips in audio quality.

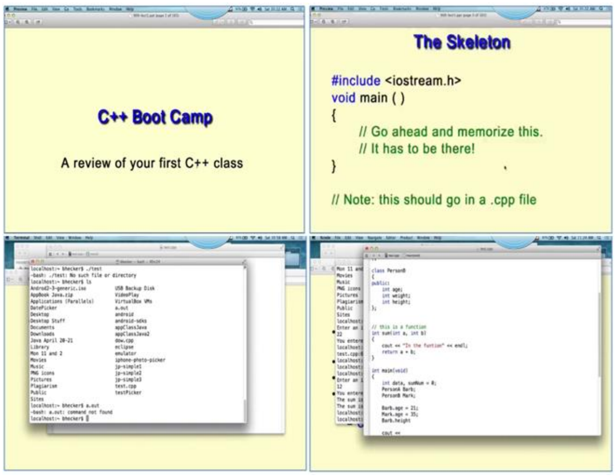

Figure 3: Fragments from video 2 (C++ clip)

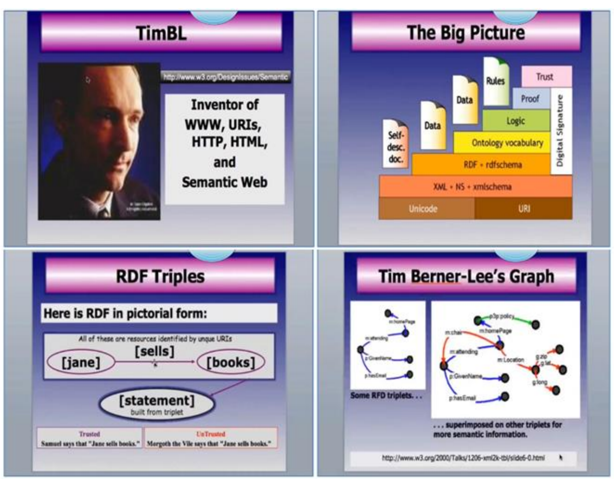

Figure 4: Fragments from Video-3 (Semantic Web Clip)

5.2 Procedure

Only one participant was used at a time in the study. Participants were given a preliminary brief about the study procedure. The questionnaire was explained and participants were guided about how to provide opinions about each statement. The questionnaire consisted of the same set of three statements for all video clips and another set of statements for all audio clips. Participants were requested to provide their opinion after watching each clip.

Participants could specify their opinion on a four point Likert scale from Strongly Agree (4) to Strongly Disagree (1). We considered 4 or 3 (Strongly Agree and Agree) options as positive responses and 2 or 1 (Disagree and Strongly Disagree) as negative responses in the results analysis. Below we explain the purpose of the questionnaire statements.

5.3 Explanation of Questionnaire Statements

Statement 1, mentioned in Figure 5, is about knowing if the specific version of a fragment is suitable to convey the intended learning information. For the video versions (Q1, Q2 and Q3) we enquired about visual information that was presented in the clip. It was expected that participants would respond positively to the statement if the fragment version is in a visual quality that is good enough to comprehend the visual information. If the fragment version is in the audio only quality (Q4) then participants should agree to the statement only if the audio version of the fragment can successfully convey the intended information without any need for visual support. For example, if a clip is a lower quality version of a fragment and the participant feels that the visual information being displayed is not comprehensible then we expect them to disagree with the statement. Similarly, if the audio version is just a verbal explanation of some concept and does not refer to any visual information which is not available in the audio version, then audio should be acceptable for this piece of information. Otherwise, if there is a need for some missing visual content in order to understand the conveyed information then such a fragment should not acceptable in audio only quality.

Statement 1	
For **Video** Versions	Visual information that is focused in this clip is visible
For **Audio** Versions	Information in this Audio clip was understandable without requiring visual support.

Figure 5: Statement 1 for video and audio clips

Statement 2, mentioned in Figure 6, is about a battery-power saving scenario. We want to understand about the participants' opinion if a fragment version is acceptable to them for learning purposes in situations where they would want to save battery power or if participants would prefer to spend more battery power in order to have the clip in a higher quality.

Statement. 2	
For ***Video*** Versions	If I NEED to save battery power, I would prefer video clip in this visual quality instead of spending more battery power on a higher quality.
For ***Audio*** Versions	If I need to save battery power, I am happy to have this information in Audio instead of spending more battery power on video.

Figure 6: Statement 2 for video and audio clips

For example, if a learner wants to preserve mobile battery power then the learner should receive a video clip in a quality that serves the learning purpose while consuming minimum battery power. If a participant agrees to this statement that would imply that the participant is not willing to spend more battery power by having the information in a higher quality and the visual information is comprehensible. Similarly, statement 2 for audio version means that if a participant would like to spend more battery power to have the clip in a video version instead of audio. If a participant agrees to the statement for the audio version of a fragment that would indicate that the audio quality was good enough for learning information in that fragment and the participant would like to save battery power instead of spending more battery power on video quality.

Statement 3, mentioned in Figure 7, is about a scenario when a participant is not interested in battery power saving. We want to know about the participants' acceptance opinion about the quality of a version of a fragment in a situation where the battery power saving is not desired. In this case, participants can spend more battery power on a higher quality if they want. Responses to this statement will help us understand responses to statement 2, and may reflect any compromise on quality due to battery power saving.

Statement. 3	
For ***Video*** Versions	If I DO NOT need battery power saving, I am still comfortable with this visual quality.
For ***Audio*** Versions	If I DO NOT need battery power saving, I am still comfortable to have this information in Audio instead of Video

Figure 7: Statement 3 for video and audio clips

6. RESULTS

In this section we present the study results. We show the participants' opinions about each fragment version of each video. From the results we try to understand acceptance of each fragment version of each video clip. We present results for each video separately and discuss them for each of the three statements in the questionnaire.

6.1 Video 1:

In Figure 8, we present a summary of participants' opinions about fragments of video-1. In the Figure Q1, Q2, Q3 and Q4 represent video qualities where Q1 is the highest quality and Q4 is the lowest audio only quality. F1, F2, F3, F4 and F5 represent the five video fragments. Results for each video include three tables one for each statement. The numbers in the table are the total number of the positive responses for a statement for a given fragment version. Exactly 7 participants viewed every fragment version; therefore each number in the table is out of 7. A number 7 in a cell means all participants, who viewed the represented fragment version, responded positively for a statement about the fragment version. While 0 means no participant responded positively, that is, nobody agreed to the statement about the fragment version. Cells with green colour represent the lowest quality with the maximum number of positive responses for that fragment. We take this as minimum acceptable quality for a fragment. Cells in red lines pattern represent the quality that is not considered as acceptable by participants for the fragment in the specific quality.

	Statement 1					Statement 2					Statement 3				
Quality	F1	F2	F3	F4	F5	F1	F2	F3	F4	F5	F1	F2	F3	F4	F5
Q1	7	7	7	7	7	7	7	7	7	7	5	5	7	6	5
Q2	7	7	3	7	7	7	7	6	7	7	2	6	3	7	4
Q3	7	7	2	7	0	7	7	2	7	4	3	5	0	5	0
Q4	2	7	1	0	1	2	7	5	0	0	0	0	0	0	0

Figure 8: Summary of Results for Video 1 (Ohm's Law Clip)

We can see in the Figure 8 for Statement 1 that the minimum quality that successfully conveys the information varies significantly. Participants' opinions show that information in F2 could be conveyed in Q4, which is audio only. This means F2 can convey the information contents in Q4 and all the three higher qualities. On the other hand information in F3 could only be transferred in the highest quality Q1 only. Delivering F3 in any lower quality will cause information loss. For statement 2, which was about battery saving scenario, responses were similar to statement 1. In order to extend the battery life of mobile devices, participants were willing to receive multimedia in the lowest quality that can successfully convey information. The lowest quality for each fragment can be seen in responses for statement 1. Statement 3 is about a situation when battery power saving is not desired. It can be seen that participants clearly wanted a higher quality for all fragments. This shows there was a compromise on visual quality in the battery saving situations.

6.2 Video 2:

Figure 9 shows responses for fragments of video 2. We can see for both statements 1 and 2 that minimum quality is not the same for all fragments of the video and vary from fragment to fragment. For statement 3, responses for F1 and F2 show that Q3 is acceptable even if battery saving is not an issue. In case of statement 3 for video 1, acceptable qualities were only Q1 and Q2.

6.3 Video 3:

Figure 10 shows responses for video-3 for all the three statements. We can see similar pattern in responses like fragments from video-1 and video-2. Minimum quality varies from fragment to fragment. There is no single minimum acceptable quality for all fragments.

	Statement 1					Statement 2					Statement 3				
Quality	F1	F2	F3	F4	F5	F1	F2	F3	F4	F5	F1	F2	F3	F4	F5
Q1	7	7	7	7	7	7	7	7	7	7	7	7	6	6	7
Q2	7	7	6	7	5	7	7	7	7	5	7	6	5	6	4
Q3	7	7	1	0	0	7	7	1	1	0	7	7	0	0	0
Q4	7	0	0	0	3	7	0	0	0	1	0	0	0	0	0

Figure 9: Summary of Results for Video-2 (C++ clip)

	Statement 1					Statement 2					Statement 3				
Quality	F1	F2	F3	F4	F5	F1	F2	F3	F4	F5	F1	F2	F3	F4	F5
Q1	7	7	7	7	7	7	7	7	7	7	6	7	7	6	6
Q2	7	7	7	7	5	7	7	7	7	5	7	7	7	5	3
Q3	7	5	7	3	0	7	3	7	4	1	4	3	6	2	0
Q4	7	2	4	1	0	7	2	6	1	0	0	0	0	0	0

Figure 10: Summary of Results for Video-3 (Semantic web)

6.4 Discussion

The results of this study show that there is no one minimum quality for different parts of the same multimedia for conveying visual information without any problems. Participants accepted different minimum qualities for different fragments in order to save battery power. These results mean that different fragments of learning videos may have different acceptable minimum qualities. This proves our hypothesis as positive and support our position in [11] that the adaptation techniques for educational multimedia must consider learning aspect in the adaptation mechanisms. It means during quality selection for adapted multimedia the learning efficacy of the adapted multimedia should be considered. For example, in video-1 if an adaptation mechanism selected Q3 for entire video then we can see that there will be negative consequences on understanding problems in fragments F3, F5 and other similar parts of the video. Even for Q2 there will be problems in fragment F3 and other similar portions of the video-1 which actually require Q1 for conveying learning information. We can see the same problems in results for video-2 and video-3.

On the contrary, if we select a higher quality Q1 for the entire video in order to keep the learning efficacy of multimedia, then in case of video-1, we will be delivering multimedia in higher quality than the minimum acceptable for four fragments F1, F2, F4, F5 and others parts similar to these in the entire multimedia. This will result in reduced battery power-saving. Based on the discussion we can conclude that any adaptation mechanism that adapts an educational multimedia should consider the impact on learning outcome in the adaptation process. This can be done if the adaptation is performed on fragment by fragment basis and using some metadata about each fragment that guides the adaptation process. The metadata is used for representing quality constraints on fragments. Such adaptation mechanisms can be called content-aware adaptation mechanisms. Metadata created by content authors of multimedia or other subject experts has an important role to play in such adaptation strategies. In [9] we proposed an adaptation technique for educational multimedia. This proposed solution tries to address the objections we raised on typical generic adaptation solutions.

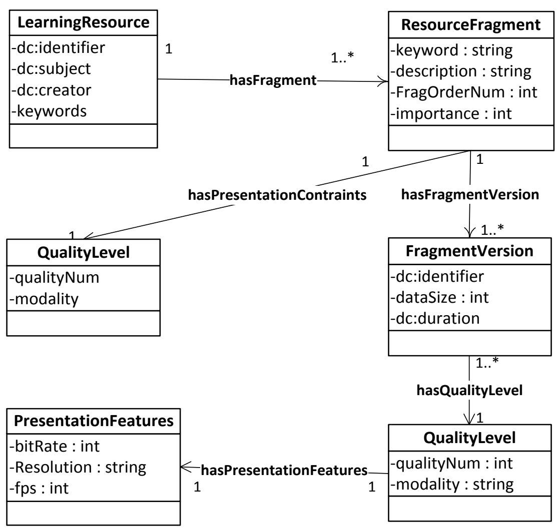

Figure 11: Fragmented Educational Multimedia Resource Ontology Model [9]

7. MoBELearn SYSTEM

Results of the study confirmed the problems identified in section 4 about using generic multimedia adaptation techniques for educational multimedia. To address these problems we developed an adaptive educational metadata model called Fragmented Educational Multimedia Resource Ontology Model (FEMROM) [9]. Details of this model can be found in [9]. This model is implemented as RDF ontology. We chose RDF because Semantic Web technologies such as RDF and OWL enhance the interoperability among metadata standards for multimedia content [27] and they are extendable. FEMROM model is given in Figure 11. This model is based on fragmented multimedia with multiple versions for each fragment. We can devise adaptation mechanisms for educational multimedia based on this model that can avoid the problems due to visual information loss and can help achieve maximum power saving in streaming multimedia. The model allows placing presentation quality constraints on different parts of the multimedia fragments. An adaptation mechanism, therefore, is able to not deliver a multimedia portion in a quality that is lower than the identified constraint quality for that portion.

Based on this proposed model, we developed an adaptation approach Content-Aware Power-Saving Educational Multimedia Adaptation (CAPS-EMA) [11]. We implemented CAPS-EMA approach and the model in a MoBELearn (MObile Battery Efficient LEARNing) prototype system [9]. MoBELearn is a metadata-driven multimedia adaptation system and considers the educational aspect of multimedia in the adaptation process. Details of the MoBELearn system can be found in [9].

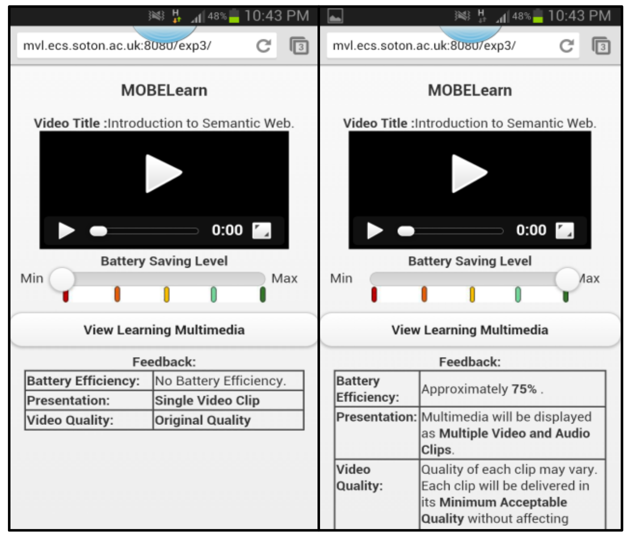

Figure 12: MoBELearn Interface

Figure 12, shows the user interface of the system. A Slide-Bar is used to allow user to specify their power saving preferences. Each option in the slide-bar provides a brief feedback about the adapted learning multimedia that will be generated as a result. For example, the user preference in the Figure 12 (Left) screenshot will result in no battery savings. In this case learner will be provided the original high quality video as one clip. In the Figure-12 (Right) screenshot, user preference for the maximum battery power saving is selected. This option will result in each fragment being delivered in its minimum acceptable quality. Figure-12 (Right) shows approximately 75% power savings can be achieved during wireless data transfer. The power-saving values in our prototype has been computed beforehand for each options using PowerTutor android app [30]. It is important to note that we are not interested exactly in the values of energy consumption. The exact values vary for different situations and is affected by several factors including, type of wireless technology (GSM, 3G, LTE, WiFi), carriers properties and strength of wireless signals [26]. Various battery consumption models have been proposed to measure energy expenses in terms of data transfer. Battery consumption models could be used to approximately compute battery consumption and determine efficiency. We have evaluated the interface of the MoBELearn system using a user study. Details of this evaluation can be found in [10].

In the test case shown in Figure 12 and Figure 13, we used an openly available Semantic Web lecture from http://WebExplorations.com. The multimedia was fragmented and each fragment was encoded in different qualities. Quality constraints were determined after observing the content manually. These constraints were placed on each fragment in the metadata. Figure 13 shows a sample adapted output of preferences in the Figure 12. Figure 13(Left) shows a fragment being delivered in Q4 which is audio only quality. Q4 was decided as the minimum acceptable quality in the metadata for this fragment. An audio is acceptable when the information is verbal only and visual information is not needed for comprehension. In Figure 13 (Right), screenshot displays the low quality version of Fragment 5.

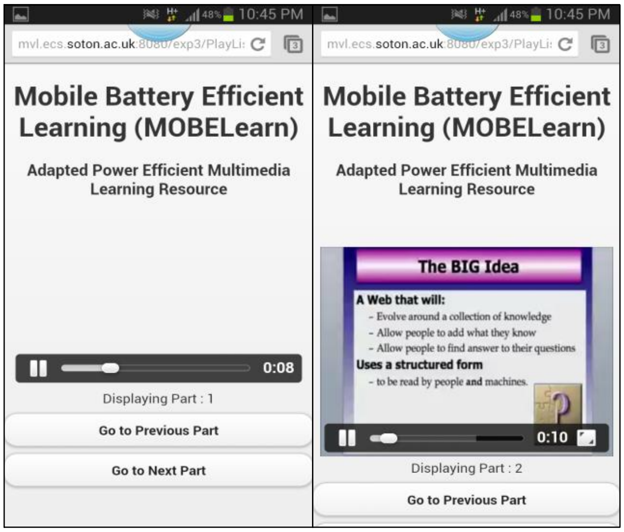

Figure 13: Screenshots of the prototype System

8. CONCLUSION

In this paper, we discussed how the commonly used approach of uniformly lowering presentation quality of entire streaming multimedia for power-saving may not be suitable for adapting educational multimedia. Some segments in multimedia may suffer from visual information loss in the adapted low quality form, if they required a higher quality for correctly conveying information. This may have negative impact on the learning, if the visual information was crucial for learning. We conducted an experimental study to support our argument. Our results confirm the position that different segments of the same learning multimedia have different minimum acceptable qualities for conveying information. Based on the results we emphasize the need for multimedia adaptation techniques to be designed specifically for educational multimedia, which also consider the learning aspect of the multimedia adaptation process and lowers quality of different multimedia segments based on the information contents in individual segments.

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