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Educational Multimedia Adaptation for Power-Saving in Mobile Learning

by

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ABSTRACT

Limited-battery power is a major constraint in mobile learning. It is important to adopt battery power-saving mechanisms in mobile learning applications in order to extend the duration of learning activities. This thesis explores issues related to power-saving in mobile learning. Streaming of online educational multimedia on mobile devices is a power hungry activity due to large amount of wireless data transfer. A number of power-saving multimedia adaptation techniques for streaming multimedia have been developed in the past. Most of these existing approaches achieve power-saving by uniformly lowering the presentation quality of an entire multimedia stream. These generic techniques will typically lower the visual quality of an entire multimedia stream uniformly, without considering its impact on perceived loss of visual information at different points of the multimedia stream.

In this thesis, through a user study we suggest that reducing the quality of educational multimedia beyond a certain level - for power-saving adaptation - can cause perceived loss of visual information in quality-sensitive portions of a multimedia. This could have a negative impact on perceived learning effects and leave the resource unsuitable for learning. The results of the study suggest that different parts of a learning multimedia may have different lowest acceptable presentation quality requirements for avoiding perceived loss of visual information. The participants of the study were able to comprehend visual information in one fragment at a lower visual quality but could not comprehend visual information of some other fragments at the same quality level. To address this problem, we proposed a Content-Aware Power Saving Educational Multimedia Adaptation (CAPS-EMA) approach that suggests a way of delivering each portion of a multimedia in a lowest acceptable quality based on the visual contents of each fragment. We demonstrate an implementation of this approach using a prototype system called MoBELearn. The results of our evaluation studies suggest that the way CAPS-EMA adapts multimedia resources is acceptable to users in power-saving situations. CAPS-EMA requires some authoring processes in order to identify fragments and lowest acceptable quality constraints. An expert evaluation described the activities involved in the authoring process as easy to understand and perform.

Power-saving multimedia adaptation mostly results in some compromises in terms of visual quality and information content. Existing techniques offer users little control over the adaptation process and they are obliged to accept the consequences of the adaptation. We propose a Learner Battery Interaction (LBI) mechanism that suggests offering users power-saving options and relevant feedback about the expected compromises for each power-saving option. This would enable users to make informed choices about power-saving. We evaluated the concept of LBI through a user study. The results of the study suggest a positive perceived usefulness of the system and that mobile learning applications may benefit from the idea.

In the end, we propose a search mechanism for online adaptive learning resources that would help find a personalised learning resource that would fulfil the information needs of a learner in a battery-efficient way. This proposed mechanism is based on the concept of discovery of online open adaptive learning resources. For this purpose, we proposed an ontology model to describe adaptive learning resources, in terms of its adaptive features: learning and presentation features. This model could be used as a basis for implementing the proposed concept of the discovery of versions of adaptive learning resources in order to enable learners to engage in learning activities in a battery-efficient way by searching for online learning resources.

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DECLARATION OF AUTHORSHIP

I, Syed Muhammad Asim Jalal, declare that this thesis and the work presented in it are my own and has been generated by me as the result of my own original research.

Educational Multimedia Adaptation for Power-Saving in Mobile Learning

I confirm that:

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3. Where I have consulted the published work of others, this is always clearly attributed;
4. Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work;
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6. Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself;
7. Parts of this work have been published as:

    - Jalal, S.A., Gibbins, N., Millard, D., AL-Hashimi, B., and Aljohani, N.R., 2014. Energy-Aware Streaming Multimedia Adaptation: An Educational Perspective. In Proceedings of the 12th International Conference on Advances in Mobile Computing & Multimedia ACM, Kaohsiung Taiwan, In Press.
    - Jalal, S.A., Gibbins, N., Millard, D., AL-Hashimi, B., and Aljohani, N.R., 2013. Energy-Aware Adaptation of Educational Multimedia in Mobile Learning. In Proceedings of The 11th International Conference on Advances in Mobile Computing & Multimedia, Vienna, Austria, ACM pp.434-439.
    - Jalal, S.A., Gibbins, N.M., Millard, D., AL-Hashimi, B., and Aljohani, N.R., 2013 Content-Aware Power-Saving Multimedia Adaptation for Mobile Learning. In The 7th International Conference on Next Generation Mobile Apps, Services and

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- Jalal, A., Gibbins, N., Millard, D., and AL-Hashimi, B., 2012. Enabling the discovery of Adaptive Learning Resources for Mobile Learner. In The 11th World Conference on Mobile and Contextual Learning: mLearn 2012. Helsinki, Finland.

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Definitions and Abbreviations

UMA	Universal Multimedia Access
AEH	Adaptive Educational Hypermedia
QoE	Quality of Experience
MOS	Mean Opinion Score
SVC	Scalable Video Coding
DVS	Dynamic Voltage Scaling
CAPS-EMA	Content-Aware Power-Saving Educational Multimedia Adaptation
LBI	Learner-Battery Interaction
AH	Adaptive hypermedia
DASH	Dynamic Adaptive Streaming over HTTP
FEMM	Fragmented Educational-Multimedia Model
URI	Uniform Resource Identifier
RDF	Resource Description Framework
A-HBI	Application-Level Human-Battery Interaction
HBI	Human-Battery Interaction
FEMROM	Fragmented Educational Multimedia Resource Ontology Model
LOM	Learning Object Metadata
SKOS	Simple Knowledge Organization System
MoBELearn	Mobile Battery Efficient Learning
PMRV	Potential Most Relevant Version
ALRM	Adaptive Learning Resource Meta-Model
QIE	Quality-Information-Energy
PSI	Power-Saving Interface
PMRV	Potential Most Relevant Version

Chapter 1:

Introduction

Learning activities performed using mobile devices such as smart phones, tablets, Personal Digital Assistants (PDA) and any other portable devices, is termed as ‘mobile learning’ [1, 2]. In recent years, mobile learning has made considerable gains in popularity [3]. Mobile devices have become much more powerful; they come with increased processing capabilities, larger memory, bigger screen sizes, an ability to communicate with Internet services at much higher data rates, and other enhanced features and capabilities. These powerful mobile devices have also become increasingly affordable.

Improvements in wireless technologies have made it possible to connect these mobile devices with the Internet at higher data rates, enabling the use of high quality multimedia streaming content [4]. As a result, mobile users now have access to rich educational multimedia content anytime and anywhere [5]. This has led to mobile devices being increasingly used for online learning. Further opportunities for learning using mobile devices have been created by freely available educational resources including video resources by reputed institutions and individuals. Mobile learners now have control over what, when and where to learn, making learning using mobile devices increasingly popular [6-8].

There are, however, some challenges that still need to be addressed. There is wide diversity in mobile devices, network connectivity and learners’ needs [4]. Consequently the one-size-fits-all formula of providing same learning resource for all mobile learning situations, involving different learner needs and mobile device resources is unlikely to be appropriate. Adaptation and personalization techniques have been used to adapt learning resources in order to enhance and make the learning experience more efficient [9-12]. These adaptation and personalization techniques could be applied to the learner needs, preferences and device constraints for example. There has been much research in adapting learning resources to a learner needs and usage context [8, 12, 13]. The use of multimedia content poses many additional challenges in the context of mobile learning. Multimedia adaptation and personalization techniques have also been developed for mobile learning systems [6].

While other challenges arising from the diversity of devices and needs of learners have been addressed [13] [9] [14], little has been done regarding the problem of the limited battery power available in mobile devices. Battery technology in mobile devices has not seen as much advancement as other related technologies, such as processors, screen size, screen quality, memory, network connectivity and software applications [15]. Battery power is the lifeline for mobile learning, and limits on battery-power will restrict the duration of any learning activity. It is very important for mobile learning systems to consider techniques that would extend the battery life of mobile devices. In the following section, we discuss the main motivations behind the work done in this thesis, in the area of power-saving in mobile learning.

1.1 Research Motivation

The Content Adaptation and Universal Multimedia Access (UMA) [16] techniques have been used to adapt multimedia content based on the resource constraints of mobile devices. When accessed over a mobile network, online educational multimedia content quickly drains battery power as result of the size of the data transfers. The wireless interface of mobile devices consumes a major portion of the battery power during multimedia streaming [17-19]; streaming multimedia can consume up to two times more battery power than playing the same multimedia file locally [17, 20]. As a result, research efforts have been dedicated to improve battery efficiency and extend the battery life of mobile devices.

The existing battery-saving streaming multimedia adaptation techniques are mostly based on the approach of lowering the quality of an entire multimedia stream [17, 19, 21-29] in order to reduce the data size of the multimedia. A reduction in wireless data transfer results in reduced power consumption. These techniques are essentially based on the trade-offs between user experience and battery life. Multimedia quality may be lowered by reducing the encoding parameters like frames per second, bitrates, colours and resolution. These techniques degrade the quality of an entire piece of multimedia content uniformly without considering its impact on the visual information contents in different portions of the multimedia. Reducing the quality of educational multimedia resources beyond a certain level has the potential to leave the resource inappropriate for learning purposes, as some crucial quality-sensitive information could be lost due to lowered quality. This phenomenon is illustrated in Figure1-1, where two different fragments of the same educational multimedia are shown in three different presentation qualities. The visual information in video fragment 1 is not negatively affected after the multimedia quality is lowered. In case of video fragment 2, there is some visual information loss and is not properly comprehensible in the lower quality. This suggests that there is a need for energy-efficient educational multimedia adaptation techniques that would keep all parts of the adapted multimedia at a suitable quality. Mobile learning applications mostly have to rely on existing (generic) battery efficiency techniques. It is only recently that power-saving techniques have been recommended to be integrated in the mobile learning environments [30, 31]. In the mobile learning landscape we cannot see enough efforts towards battery efficiency. In this thesis, we investigate the impact of reduction of multimedia quality on perceived loss of visual information and propose an enhancement in power-saving multimedia adaptations that would address the issue of perceived visual information loss for educational multimedia. The major contribution of the thesis is proposing a power-efficient presentation environment of learning multimedia for mobile devices.

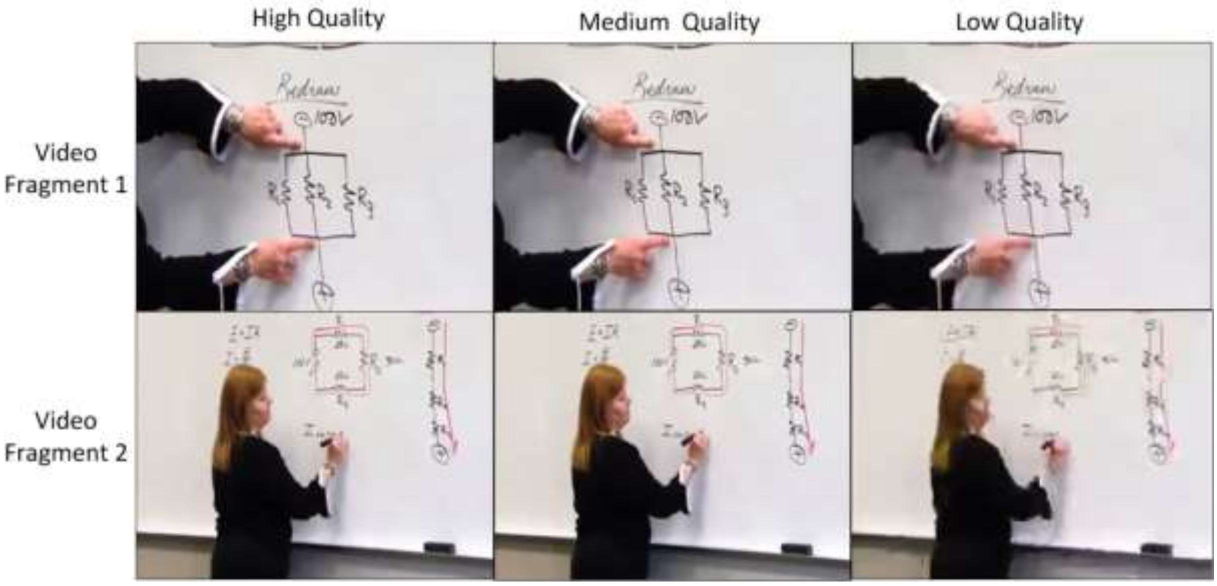

Figure 1-1: Video fragments in three qualities

The second issue that we aim to address in this thesis is about interaction mechanism in power-saving adaptive applications. The study of existing power-saving adaptation techniques reveals that users are not given enough options to control the adaptation process. We have discovered a lack of interaction and more of automation in these adaptive systems. Adaptation decisions that mostly result in a compromised user experience are made by adaptive systems without users' consent. Thus, users are not enabled to make informed decisions regarding these adaptations. A compromised experience is usually the consequence of degrading the presentation quality and reduction in the detail of information presented to users. For example, when a certain lower battery charge level is reached, the power saving mode - to perform adaptations - would be activated automatically. There is little work done that would allow users to take control of the adaptation process. The users are often provided with no options and relevant information to choose the extent of battery-power saving and the resultant compromise in experience.

Providing power-saving options and relevant information about each option in power-saving adaptive applications could be useful from usability point of view. A user may be interested in battery power-saving before a certain minimum power-level is reached, as the next recharging opportunity may not be very soon. For example, a user with fully charged battery may decide to start power-saving to extend the use of the device. On the other hand, the power-saving actions result in a compromised user experience and it should be the users who should be given the opportunity to decide if they are interested in any power-saving at any point and up to what extent. These choices may be based on the expected known compromises in experience. These interaction issues are the second focus of the research work in this thesis. We propose an interaction mechanism for adaptive learning application for allowing learners to choose the extent of power-saving based on information provided in the form of feedback for each power-saving option.

The area that we considered in this thesis is investigating the opportunities that adaptive learning resources could provide in search for power-efficient online learning resources. In the era of anytime-anywhere learning, learners may need to start a learning activity at any moment on some topic of interest. Learners receive great benefits from learning resources that are freely available on the Web. Moreover, using a search service is the easiest and preferred way to find learning information on the Web. There is, however, a lack of methods that would help a learner who is interested in completing a learning task in a battery-efficient way by finding an appropriate learning resource. There is a need for mechanisms that could incorporate battery-saving in the search process. Such mechanisms would enable learners to find battery-efficient and personalised learning resources, which would enable learners to engage in learning activities while consuming reduced battery-power. In this thesis, we attempt to address this challenge by proposing a way to search for learning resources that would enable learners to engage in learning activities using mobile devices in a battery efficient way.

1.2 Relationship to the Learning domain

In this section, we want to highlight the domain area and the scope of the work presented in this thesis. We want to clarify how and to what extent the work presented in this thesis is related to the learning domain. In this thesis, we are not investigating any pedagogical aspects of learning or learning theories. We are also not proposing any mechanism or technology that would improve learning or remembering information. Learning in the context of this thesis means that the information in a multimedia should be comprehensible without any perceived loss of information. The main contribution of this thesis is in the area of power-efficient presentation of multimedia learning resources. The connection of this thesis to the learning domain is based on the type of multimedia being selected as “learning” multimedia resources. We are investigating aspects of power-saving when online multimedia learning resources are used on mobile devices. It is important to clarify that this thesis is about processing already created learning resources and we are not proposing any new methods of instructional design for creating learning resources for improved learning.

We are distinguishing educational multimedia resources from any other kind of multimedia based on the objective and the nature of the contents of educational multimedia. It is more important for learning multimedia that its information contents – which are for learning purposes - are comprehensible after adaptation. As existing power-saving adaptation of streaming multimedia is mostly based on lowering the quality of multimedia, it could result in difficulty in comprehending visual content in a multimedia. This could result in perceived learning information loss if these techniques are applied on learning multimedia. So the main aim of the work in this thesis is to develop a power-saving adaptation approach that could reduce the perceived loss of visual learning information compared to when the existing approaches are applied to educational multimedia.

We want to design a learning multimedia adaptation mechanism for power-saving purposes, such that the learning information content remains comprehensible after adaptation. The aspect of learning is involved to the extent that if learning information contents are not properly visible or comprehensible due to power-saving adaptation then the multimedia would be considered as not suitable for a learning activity.

This thesis is related to the learning domain only to the extent that we are considering how to reduce or alleviate perceived learning information loss as a direct result of power-saving adaptation of multimedia educational resources. In this thesis, we have shown experimentally that the existing approaches of power-saving in this area could result in relatively greater perceived learning information loss.

In the final part of this thesis, we propose a search mechanism based on adaptive online learning resources for helping a learner find a learning resource that would enable learning activities in a power-efficient way. For this purpose, our contribution is presenting a metamodel of adaptive learning resources that could be used as a basis for discovering any existing learning resource fulfilling the information and power-saving requirements of a learner.

In short, this is a thesis on power-saving and adaptation of existing learning resources. This is not a thesis on pedagogy or the philosophical or psychological aspects of e-learning more generally.

1.3 Research Questions

We have identified the following research questions based on the problems defined in section 1.1.

- RQ1. Do different parts of the same educational multimedia have different minimum quality requirements for avoiding perceived loss of visual learning information?
- RQ2. Does the power-saving multimedia adaptation based on the approach of lowering the quality of entire multimedia result in perceived loss of visual learning information for educational multimedia?
- RQ3. How can we address the issue of perceived loss of learning information in a power-saving multimedia adaptation approach for educational multimedia?
    - a. How can we implement the enhanced power-saving multimedia adaptation mechanism for educational multimedia?
    - b. Would such a mechanism be acceptable for users (learners) for power saving?
    - c. Will the enhanced adaptation mechanism have any negative impacts on the coverage of the learning concepts included in the original multimedia?
    - d. Would the activities involved in the authoring process for the enhanced adaptation mechanism be acceptable for content authors (experts)?
- RQ4. How can we develop an interaction mechanism that would allow learners to choose the extent of power-saving based on the preferred level of resulting compromise?
    - a. How to learners perceive the usefulness of the interaction mechanism?
- RQ5. How can we develop a mechanism based on adaptive learning resources for searching online learning resources that will enable power-saving during learning activities?

1.4 Research Objectives

Based on the research questions identified in section 1.3, we have identified the following research objectives.

RO1. To establish through an experimental study if different parts of a learning multimedia could have different minimum acceptable quality requirements for reducing any perceived loss of visual learning information.

RO2. To establish through an experimental study the impact of lowering the presentation quality of entire learning multimedia uniformly on perceived loss of visual learning information.

RO3. To develop and implement a mechanism to enhance the quality reduction based power-saving adaptation approach to address the issue of perceived visual information loss due as a result of quality reduction during adaptation process.

RO4. To conduct experimental studies to evaluate the characteristics and functionality of the enhanced power-saving adaptation approach for learning multimedia with the relevant stakeholders i.e. Learners and Experts.

RO5. To design, demonstrate and evaluate an interaction mechanism for power-saving adaptive learning applications that will enable learners to make informed choices for power-saving by choosing the extent of compromise as a result of each adaptation option.

RO6. To propose a search mechanism based on adaptive online open learning resources to enable discovery of a personalised and battery-efficient learning resource in order to enable a battery-efficient learning activity.

1.5 Hypotheses

We have developed the following hypotheses the research presented in this thesis.

H1. Different parts of the same multimedia learning resource may have different minimum acceptable presentation qualities for avoiding any perceived loss of visual learning information.

H2. Battery-efficient adaptation mechanisms that lower presentation quality of entire multimedia for power-saving may result in visual information loss.

H3. A power-saving adaptation technique for streaming educational multimedia can be developed based on the lowest available acceptable qualities for different parts of a learning multimedia in order to avoid the perceived loss of visual information.

H4. An interaction mechanism for power-saving adaptive learning applications can be designed that gives users the control to make informed choices about choosing the extent of power-saving based on the level of acceptable compromise as a result of adaptation. This interaction mechanism would be considered as useful by the users.

H5. We can we design a search mechanism based on open online adaptive learning resources that would enable discovery of personalised and battery-efficient learning resource for engaging in a battery efficient learning activity.

1.6 Research Contributions

While addressing our research questions and objectives in this thesis, we have made the following contributions.

1. One of our key contributions is to expose the inadequacies of applying the commonly used power-saving adaptation approach of uniformly lowering the quality of entire multimedia on educational multimedia. We have highlighted through a user study that different portions of the same learning multimedia may have different acceptable minimum presentation qualities to prevent perceived loss of visual information and, therefore, it is inappropriate to uniformly lower the quality of multimedia during adaptation. This contribution challenges applying an adaptation technique based on uniformly lowering the presentation quality of an entire educational multimedia stream. The study results reveal that lowering quality uniformly may result in perceived loss of visual learning information, which could have negative impact on a perceived learning effect. This contribution highlights the need for enhancements in the power-saving multimedia adaptation techniques for adaptation of educational multimedia.
2. We propose an adaptation approach to avoid the problem of perceived loss of learning information during power-saving multimedia adaptation for online streaming educational multimedia. The proposed approach, Content-Aware Power-Saving Educational Multimedia Adaptation (CAPS-EMA), offers an enhancement to the quality reduction based power-saving adaptation approach. CAPS-EMA suggests considering the variations in the lowest acceptable presentation quality in the adaptation process that exists for different segments of a learning multimedia. As a result, the quality of each portion of a learning multimedia is not lowered to the extent that it will result in perceived learning information loss. This will enable maximum battery power-saving without any perceived loss of visual information due to adaptation, in a learning multimedia presentation environment. A framework and ontology metamodel for the implementation of the proposed approach are also developed.

3. This thesis presents a framework and an abstract data model for implementation of the proposed enhanced power-saving streaming multimedia adaptation approach. The framework specifies the key components in the proposed CAPS-EMA adaptation approach and their roles in the adaptation process. An abstract Fragmented Educational Multimedia Model (FEMM) is developed that describes the general structure and key aspects of the required metadata that is used by the CAPS-EMA approach. A prototype application MoBELearn system is developed by implementing the framework and the model.
4. This thesis presents perspectives of the main stakeholders of the proposed adaptation approach. Learners and Experts, the people who would perform the authoring process required for the CAPS-EMA approach, are the two main stakeholders of any learning multimedia systems. The authoring steps involve identification and generation of the multimedia fragments and their versions as well as generation of the needed metadata. The key characteristics of CAPS-EMA were evaluated through the MoBELearn application. The results of the evaluation studies suggest that the way CAPS-EMA approach addresses the problem of perceived loss of visual learning information in power-saving adaptation is acceptable to learners. Evaluation of the authoring process with experts suggested that the steps involved in the authoring process of multimedia and generation of the metadata for CAPS-EMA approach was easy to understand and the Experts in the role of multimedia author were able to perform the authoring tasks without any problems.
5. This study proposes Learner-Battery Interaction (LBI), which is an interaction mechanism for power-saving in learning multimedia applications. LBI suggests enabling users to control the power-saving adaptation process. This is done by providing users with explicit power-saving options and information about the resulting consequences of each option on the adapted multimedia. These options and information help them to make informed decisions about choosing from the available power-saving opportunities. The proposed concept is described using the LBI model. We have demonstrated and evaluated the concept using a prototype implementation. The results from user evaluation suggest that users have positive and high perceived usefulness opinions about the power-saving interface that implemented the Learner Battery Interaction model.
6. We have proposed a search mechanism based on online adaptive learning resources for enabling the discovery of personalised and battery-efficient learning resources allowing mobile learners to engage in a learning activity in a power-efficient way. Our main contribution in this area is presenting a framework that will enable this search mechanism.

Furthermore, we have developed a data model to represent adaptive resources and explain how it could be used as a basis for the proposed discovery mechanism.

1.7 Thesis Structure

In this section, we describe the structure of the thesis by giving a short description of the contents of each chapter.

In **Chapter 1**, we provide the context for the research work presented in this thesis. We discuss the main motivation behind this research work. We identify research questions and identified the research objectives that we want to achieve in the process to answering the research questions. In the end, we highlight generally our research contributions in the area of power-saving multimedia adaptation in the context of mobile learning.

Chapter 2 contains background literature about the related research areas including personalisation and adaptation, battery-efficiency techniques in mobile devices, multimedia adaptation techniques and battery-efficiency in mobile learning. We also highlight how the work discussed in this thesis is different from other research efforts in terms of objectives and methodology.

In **Chapter 3,** we try to understand the impact of using existing battery-efficient multimedia adaptation strategies, which are based on downgrading the presentation quality of entire educational multimedia uniformly. We present details of a user study we conducted to understand impacting of different lower presentation qualities on perceived loss of visual information in different fragments of a learning multimedia. The quality of multimedia was uniformly lowered following the approach of exiting power-saving multimedia adaptation approaches. The results of the study establish that different portions (or fragments) of a learning multimedia required different level of lower qualities as the lowest acceptable ones in order to avoid perceived loss of visual information. Based on these results we highlight the main short comings of existing commonly used power-saving adaptation approach for learning multimedia.

In **Chapter 4**, based on the results obtained in chapter 3, we present a Content-Aware Power-Saving Educational Multimedia Adaptation (CAPS-EMA) approach. The CAPS-EMA approach considers the perceived impact of multimedia adaptation on learning information contents. This strategy recommends determining the lowest acceptable quality for the various parts of a learning multimedia. During power-saving adaptation, the quality of any part of a multimedia is not downgraded beyond the identified constrained quality, for that portion of multimedia to prevent any perceived visual information loss. We also present a stakeholder analysis of the proposed adaptation approach. Furthermore, a framework for implementation of the proposed approaches is described along with implementation strategies in the context of multimedia streaming.

In **Chapter 5**, we present in detail an implementation of the proposed CAPS-EMA approach in the form of the MoBELearn (Mobile Battery-Efficient Learning) prototype system. In **Chapter 6**, we evaluate the CAPS-EMA approach using a quantitative experiment and a case study. We evaluated the impact of the characteristics of the CAPS-EMA adaptation approach. In **Chapter 7**, we discuss further evaluations with the main stakeholders, based on qualitative methods. Along with evaluation with learners, we also conduct an evaluation study with Experts (in role of multimedia authors) to understand their perception about the authoring process involved in the CAPS-EMA adaptation approach.

In **Chapter 8,** we propose an interaction mechanism, Learner-Battery Interaction (LBI), that would enable users to take control of the multimedia adaptation process. By LBI, we aim to empower users to make informed choices about battery power-saving by understanding the compromises in experiences that may result from the power-saving decisions of an adaptive system.

In **Chapter 9**, we extend the idea of battery-efficiency to performing learning activities through search for available online learning resources. We propose a search mechanism, which is based on adaptive online learning resources, for discovering a personalised and energy-efficient version from available adaptive learning resources. The proposed technique is aimed at enabling energy-efficient learning activity by searching for a learning resource on mobile devices. We propose a data model that will be used as a basis to implement the enhanced search mechanism.

Finally, in **Chapter 10,** we conclude the thesis by summarising the research work discussed in the thesis. We revisit our research questions and discuss how we addressed them using our research objectives and present the gathered evidence in this thesis. In the end, we mention our future research directions, some of which are based on the limitations of the research work described in the thesis.

1.8 Publications

Research work described in various chapters of this thesis has led to the following publications.

Chapter No.	Publications
Chapter 3	Jalal, S.A., Gibbins, N., Millard, D., AL-Hashimi, B., and Aljohani, N.R., **2014**. Energy-Aware Streaming Multimedia Adaptation: An Educational Perspective. In Proceedings of The 12th International Conference on Advances in Mobile Computing & Multimedia ACM, Kaohsiung Taiwan, In Press.
Chapter 4	Jalal, S.A., Gibbins, N., Millard, D., AL-Hashimi, B., and Aljohani, N.R., **2013**. Energy-Aware Adaptation of Educational Multimedia in Mobile Learning. In Proceedings of The 11th International Conference on Advances in Mobile Computing & Multimedia, Vienna, Austria, ACM pp.434-439.
Chapter 5	Jalal, S.A., Gibbins, N.M., Millard, D., AL-Hashimi, B., and Aljohani, N.R., **2013** Content-Aware Power-Saving Multimedia Adaptation for Mobile Learning. In The 7th International Conference on Next Generation Mobile Apps, Services and Technologies, Prague. pp. 256-261
Chapter 7	Jalal, S.A., Gibbins, N., Millard, D., AL-Hashimi, B., and Aljohani, N.R. **2014**, Learner-Battery Interaction in Energy-Aware Learning Multimedia Systems. In Proceedings of The 12th International Conference on Advances in Mobile Computing & Multimedia, ACM, Kaohsiung Taiwan, In Press.
Chapter 8	Jalal, A., Gibbins, N., Millard, D., and AL-Hashimi, B., **2012.** Enabling the discovery of Adaptive Learning Resources for Mobile Learner. In The 11th World Conference on Mobile and Contextual Learning: mLearn 2012. Helsinki, Finland.
Chapter 6	Evaluation of the Content-Aware Power-Saving Adaptation Approach (CAPS-EMA) – *draft*

1.9 Conclusion

In this introductory chapter, the context for the research work presented in this thesis is developed. The research questions and research objectives for the research work are identified. We also mention the research contributions and list the publications made so far on the basis of the work done in this thesis.

Chapter 2:

Literature Review

Personalization and adaptation techniques provide customized information to users based on their needs, preferences and context [32] [33] [34]. The process of adapting content to a specific user context involves content adaptation and content presentation. Content adaptation involves deciding what content is most relevant to the current user and how to structure this content in a coherent way, before presenting it to the user. Content presentation involves deciding how to most effectively adapt the presentation of the selected content to satisfy user hardware and network constraints as well as presentation preferences. Adaptation and personalization technologies gained more importance as a result of proliferation of mobile devices and continuous access of these mobile devices to the web making it easier to access information any time anywhere.

In this chapter, we now present an overview of the related literature and the concepts related to content adaptations followed by more detailed discussion on multimedia adaptation for power-saving from educational multimedia view point.

2.1 Adaptation and Learning Resources

In this section, we briefly introduce the concepts related to the adaptation of information resources. The major focus of this thesis is multimedia adaptation, but it would be useful to introduce the adaptation concepts that would also apply to the multimedia adaptation.

The traditional approach of one-size-fits-all of providing the same online learning resource to all types of learners, with each of these learners having different learner needs, having different learner needs is not considered as appropriate. The wide diversity in learners' devices and network connectivity [4] further complicates the situation. As a result, a lot of research efforts have been dedicated for adapting learning resources to learners' information needs as well as hardware and software resource constraints [9-12]. These personalization techniques adapt learning resources to learners' needs, preferences and their device constraints [8, 12, 13].

Different learners have different information needs and they have different preferences, goals, abilities and different background information. Typical systems which offer the same information to all users are inadequate. To address these issues, the adaptation of learning resources, based on the needs and background of the learners, has been suggested. Earlier efforts in the field of adaptation of educational resources have been performed using Adaptive Educational Hypermedia (AEH) [10, 35-37] based on Adaptive Hypermedia techniques.

Adaptive hypermedia (AH) is an area of research that attempts to increase the functionality of hypermedia applications by individualising their presentation in relation to individual users [35]. Adaptive Hypermedia (AH) systems can be beneficial in situations where the same system is used by different types of users. Brusilovsky defined AH as, "All hypertext and hypermedia systems which reflect some features of the user in the user model and apply this model to adapt various visible aspects of the system to the user. In other words, the system should satisfy three criteria: it should be a hypertext or hypermedia system; it should have a user model; it should be able to adapt the hypermedia using this model" [35]. An example of different users needing different information on the same topic is that of a novice and an advanced user. A novice user will need more descriptive information, while a more concise or summarised information will be enough for an advanced user. The use of adaptive techniques makes this possible. A user profile or a user model is required to capture information about the user to make adaptation possible.

One of the first adaptive hypermedia systems (AHS) models called Adaptive Hypermedia Application Model (*AHAM)* was described by Wu [38]. AHAM comprises of a domain model, a user model, an adaptation model and an adaptation engine[38]. A *Domain model* is a set of domain concepts and their relationships. A domain model describes how the information content of the application is structured in AH. A *User Model* is used to represent a user. Typically, it would store an individual user's characteristics, including for instance preferences, background knowledge, goals, navigation history and other relevant aspects which can be used to adapt content. A user model is a vital component of an AH system and the overall success of the system depends on this. Kavcic described three important aspects to be considered when designing a user model. First, the types of a user's information that needs to be captured and how it may be obtained. Secondly, how the information in the system can be represented, and thirdly, how the model can be constructed and updated [39]. There are two ways of capturing user information: explicit and implicit. In explicit methods, users are asked to provide the information using forms, mostly at the time of registration. In implicit methods the systems observes a user while he is using the system and captures the information from his behaviour. In this thesis, we have used explicit methods for user models, which are user preferences. An *Adaptation Model* normally contains rules that define relationships between a domain model and a user model to specify adaptation. The most common form of adaptation model is composed of "if <condition> then <action>" rules [38]. An *Adaptation Engine* executes the rules in the adaptation model to take the required action (i.e. presentation of links or fragments of hypermedia content pages).

Other reference models of AHS includes AHA [40] and LAOS [41]. We believe understanding the basic simple model AHAM describing AHS is enough for understanding the issues discussed in this thesis. A summary of other common AHS is given in [42]. The work included in this thesis is related to the Adaptive Presentation as described by Brusilovsky in [43] and [42] in their taxonomy of adaptive hypermedia technologies.

The process of adapting content to specific user needs comprises two sub processes: content adaptation and presentation. Content adaptation involves deciding what content is most relevant to the current user and how to structure this content in a coherent way, before presenting it to the user. The second sub process of content presentation involves deciding how to most effectively adapt the presentation of the selected content to the user [44].

De Bra [45] pointed out the distinction between adaptive systems and adaptable systems: both systems perform adaptation, but he argues that an adaptive system infers users' preferences automatically after observing their browsing process, while an adaptable system is one which offers users explicit choices through forms or questionnaires to capture preferences. In chapter of this thesis we argue that an adaptable system in case of power-saving in multimedia adaptation instead of adaptive system.

2.2 Adaptation for Mobile Learning

The focus of this thesis is around adaptation for power-saving for learning activities on mobile devices. In this section, we now discuss some related work to adaptation in the context of mobile learning. Adaptive mobile learning is a broader area that would include a variety of aspects of adaptation of learning content. Battery efficient adaptation in educational multimedia could be considered as an area of adaptive mobile learning.

In recent years, Mobile Learning has become increasingly popular, as a result of increased availability and significant improvement in the capabilities of mobile devices and network connectivity. Mobile learners have now access to rich educational multimedia content anytime and anywhere [5] and learners can now decide about what to learn, when to learn and where [6, 7]. Educational institutions and individuals around the world are now making their online learning videos available for free, opening further avenues for learning while being on the move. Online educational multimedia, however, still present some challenges in the resource constrained mobile environment, which need to be addressed.

The traditional one-size-fits-all approach towards learning resources is not suitable in the mobile learning paradigm, due to the diversity that exists in terms of mobile devices hardware and software features, network connectivity as well as learners' needs and context. Personalized learning resources can improve the efficiency of the learning process and help the learner take better advantage of the limited time and resource constrained device while on the move. Mobile devices have resource constraints in features like screen size, network characteristics, memory size and battery power. There has been much research in adapting learning resources to the learner's needs and usage context [13] [9] [14] . The use of multimedia content specially poses many challenges in the delivery of mobile Learning context. Multimedia adaptation and personalization techniques have also been developed for mobile learning systems [7].

Transforming learning resources in suitable versions in order to be efficiently delivered to meet the diverse needs of learners and constraints of mobile devices is a research area that is increasingly attracting a great deal of attention. Adaptive mobile learning uses content adaptation and personalization techniques to enable provision of multiple personalized versions of the same learning content [46] [13]. These techniques uses learner's preferences, knowledge level, learning styles, the learning context (e.g., location, time, current activity, etc.), and hardware resources and constraints including screen size, resolution, processing capacity, memory, software, and network connectivity to personalize learning resources.

Qing Tan in [9] Proposes a 5R adaptation framework, the aim of which is to provide a learning resource "at the right time, in the right location, through the right device, providing the right contents to the right learner". Some issues arising due to the diversity that exists in learning on mobile devices have been discussed in [47]. Over the years, many techniques have been proposed, to provide adapted versions of learning resources based on user preferences, devices characteristics and user needs. Some of these techniques can be found in [14, 48-51].

Moldovan et al in [52] present a generic architecture of an Adaptive M-learning System (AMLS) which adapts M-Learning based on learners profile and device characteristics. This architecture identifies the following components, illustrated in Figure 2.5.

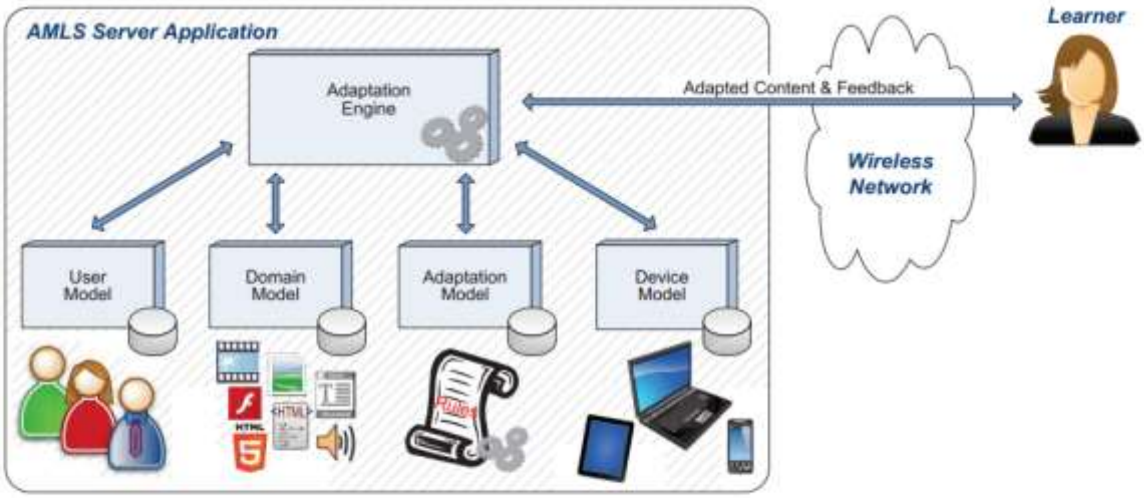

Figure 2-1 Generic architecture of an Adaptive M-learning System (AMLS) [52]

The *User Model* maintains information about learners, for example demographic data (name, gender, age etc.) knowledge level about study topic, goals, preferences and learning styles etc. This data can come explicitly or implicitly from learner interaction. The *Domain model* stores educational content and information or metadata about the content. It may be organized as learning objects and their relationships. The *Adaptation model* determines how to adapt learning content to a particular user model. The *Device model* stores information about capabilities and characteristics of devices used by learner. The *Adaptation Engine* performs the actual personalization of contents based on User, Domain and Device Models.

However, despite the fact that many adaptive solutions have been proposed to overcome learners' technological limitations, the available energy level mostly has not been considered as an input in the adaptation process. In this thesis, we propose approaches for power-saving using adaptive techniques for learning activities. In the context of adaptation in mobile learning we first propose a power-saving multimedia adaptation approach specifically for educational multimedia. In chapter 3 using a user study we first show how existing generic approach of multimedia adaptation approach is not suitable for educational multimedia and then build on the results we propose our context-aware multimedia adaptation approach. Existing approaches treat entire educational multimedia resource in same way without considering its impact on visual learning information in different fragments of the multimedia. We also discuss an interaction mechanism for power-saving adaptive educational systems. We argue in favour of adaptable system, where learners should be allowed to explicitly to choose the extent of power-saving based on any resulting comprise. Finally, we consider how we can devise a mechanism based on existing adaptive techniques to allow mobile learners to choose a version of any online adaptive learning resource that would consume minimum battery power while satisfying learners' information.

2.3 Multimedia Adaptation

In this section, we now discuss multimedia adaptation. The focus of this is more about streaming multimedia adaptation for power-saving in mobile devices. In the section (section 2.3) we aim to discuss various approaches used in multimedia adaptation in general. In section 2.5, we will discuss multimedia adaptation specifically for power-saving. Multimedia adaptation generally is used for adapting multimedia for various purposes, for example, network and screen sizes limitations. The major concept behind these multimedia adaptation techniques is quality reduction so that it would fit within the resource constraints. The same quality reduction approach is also used for multimedia adaptation power-saving purposes. In this section, we discuss the multimedia adaptation more broadly.

Due to the inherent resource limitation of resources of mobile devices (for example, low bandwidth, small screen size, low processing capability, small memory, limited hardware and software support and limited battery power) there are great challenges in the way of capitalising on the flexibility offered by the advancement in mobile technologies for information access. Most web content is currently designed for access through PCs and is therefore not suitable for access through mobile devices, due to the presence of multimedia content. Therefore, there is a strong need for special web content that can be used by mobile devices. Such content can either be specifically designed for mobile devices, or adapted from existing content.

In addition, different users of mobile devices have different needs at different places and times, or simply in different contexts. So adapting web contents to meet varying needs of users is the next level of challenge to be addressed, in order to get the maximum benefit from mobile technologies. The research area of content adaptation is addressing these issues.

Content adaptation involves identification and structuring of the content most relevant to the given user and their context, jointly called the interaction context. Other relevant characteristics include user preferences, interests and expertise level [44]. Lemlouma [53] defines the context from the content adaptation point of view as the set of information that has a direct relationship to the requested document. The World Wide Web Consortium (W3C) defines content adaptation as a process of selection, generation, or modification that produces one or more perceivable units in response to a requested uniform resource [54].

The terms *content adaptation* and *multimedia content adaptation* are now used interchangeably. Content adaptation techniques for mobile devices now also include Multimedia Content Adaptation techniques. By content adaptation we mean that the system is able to scale the content being delivered to the target device, based on the user's preferences, their device's capability and the network conditions [44]. Content adaptation includes, but is not limited to: format conversion, scaling of images as well as video and audio streams, media conversion (e.g. text to speech), omission or substitution of document parts (e.g. substitution of an image by a textual representation), document fragmentation, and language translation [55].

The process of adapting content to a specific user involves two sub-processes: Content Adaptation and Presentation [44]. Content adaptation is deciding what content is most relevant and how to structure the material in a coherent way before delivering the content. Content presentation involves deciding how to most effectively adapt the selected content to the user keeping in view the limitations of their device [44]. Content adaptation bridges the gap between device capabilities and content formats.

Multimedia content adaptation maximizes the return on the authoring investment, by increasing the diversity of the content consumption options, thereby allowing the content to reach a wider audience. Different summarization and visualization techniques have been developed, which are used for adaptation of content presentation for mobile devices [56, 57]. Universal Multimedia Access (UMA) [58] is another term that is being used for how different multimedia items should be adapted, so that they can be rendered to devices with different resource constraints. Content Adaptation on the other hand is a broader term and includes adaptations not only for devices, e-g. in UMA, but it also includes adaptation for a broader context, which also includes needs of the user based on his knowledge, location, time, activity and any other context feature, as well user preferences for particular content; for example, object of interest in some video, or interest in just audio, instead of video with audio. So UMA is also part of the whole content adaptation technique.

Multimedia content adaptation is the key for Universal Multimedia Access [59] as shown in Figure 2.2. The objective of the transformation of input multimedia content is to meet the diverse resource constraints and user preferences to optimize the overall utility of the multimedia content. Different types of adaptation process takes place at different levels, e-g: Server, Proxy, Router, Gateway or Client [59]

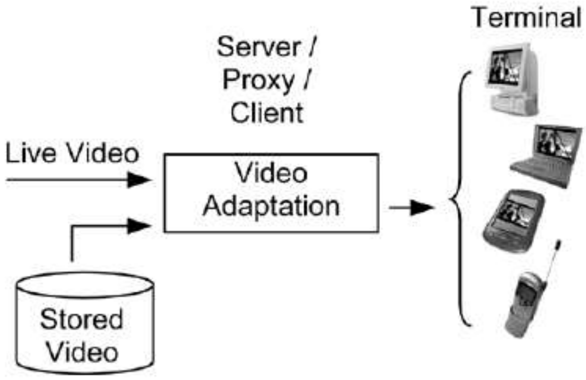

Figure 2-2 Concept of Multimedia Content Adaptation [59]

2.3.1 Types and Techniques of Multimedia Adaptations

Adaptation of Multimedia Content is performed using techniques like Adaptation by Selection, Adaptation by Transcoding, Layered Encoding (*transcaling*) and Rate shaping [60].

2.3.1.1 Adaptation by Selection

Adaptation by selection, or multiple encoding, is the earliest technique used for adaptation. The main concept here is to provide multiple versions of the same content in different forms and modalities and then select the most appropriate version, depending on the context of the client's request. The *InfoPyramid* framework [22] was among the first approaches of this adaptation technique. The *InfoPyramid* describes content in different modalities, at different resolutions and at multiple abstractions, so that it can be rendered to different devices. *InfoPyramid* is used by a customizer that selects the best version of the content item from it, to meet client resources and delivering the most value.

Li et al [61] describe the *InfoPyramid* as "a framework for aggregating the individual components of multimedia content with content descriptions, and methods and rules for handling the content and content descriptions. In addition, it defines methods for manipulating, translating, transcoding and generating the content". The *InfoPyramid* structure is shown in Figure 2.3, adopted from [58].

2.3.1.2 Adaptation by Transcoding

Zhang [60] defines Transcoding as the mapping of a non-scalable stream to another non-scalable stream with a different compression rate (for example, MPEG to H.263). Different techniques of this category can be found in [62]. Transcoding avoids the necessity of storing multiple versions of the same content, but is a very computation intensive technique.

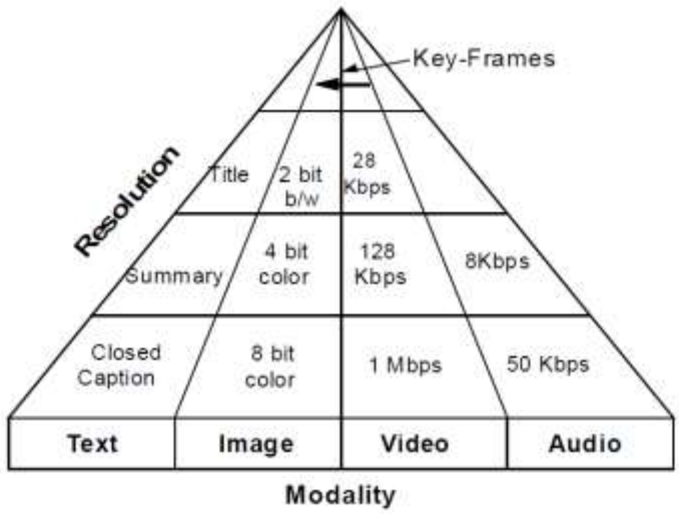

Figure 2-3 InfoPyramid [58]

2.3.1.3 Layered Encoding (*Transcaling*)

Layered Encoding is the most popular way to provide adaptation [60], by providing scalable media [63]. In this technique, one base layer with minimum quality and one or more enhancement layers are created. Media with enhanced layers are delivered depending on the available network and device resources. JPEG2000 [64] and MPEG-4 [65] are examples of scalable image and video formats, respectively.

2.3.1.4 Rate shaping

In the rate shaping technique, media encoder parameters such as image resolution and video frame rate etc. are changed by the application, to match the client resources.

Content negotiation takes place, in order to deliver the most relevant content to the user. Generally, a content negotiation solution requires the four basic components [53]. A d*escription tool* of context in which content is to be used, the server capabilities and the document profile. An *exchange protocol* for communication of control messages and user context. An *adaptation method* that adapts original content or selects one of the content versions. *A matching strategy* to select the appropriate content based on the context provided. Following are the two content negotiation techniques described by [66].

a) Offline Content Adaptation: This is to choose between variants available on the server for user. Here, many variations of the same content are prepared in advance for different contexts. This is also called Static Adaptation or Variant Selection.
b) Online Content Adaptation: In many situations, the available content can't satisfy the client needs. So the content has to be adapted on-the-fly, using any adaptation technique to meet user context and need. This is a much slower method of adaptation. Online Adaptation techniques are of two types [53].

The process of Content Adaptation can happen at Server, Client or any proxy [66]; each has advantages and disadvantages.

a). Server side adaptation: Server side adaptation requires additional software and hardware resources for the adaptations. One of the advantages of server side adaptation is that the server is in control of the adaptation process of its own content. Any other entity will have little knowledge about adaptation consequences.

b). Client side adaptation: In the client side adaptation, a client can specify its own preferences and can determine the scale of the adaptation itself. One major disadvantage is that not all client devices are powerful enough to perform adaptation. Another disadvantage is that there will be the need for different versions of the adaptation software for every different device.

c). Proxy based adaptation: Proxy server or intermediary adaptation is performed between the server and the client's terminal. This proxy can be provided by either the server, or by a third party. Proxy based transformation is very generic and doesn't put any additional load on server or client. However, it can have adverse impact on the original purpose of the content by the server, because only the server, or original author of the content, can have exact knowledge about what can be adapted and how.

Generally, proxy based transformation is a better solution for transcoding and quality control. However, knowledge based adaptation can only be performed by the server, with the input from the author about specific transformation rules. W3C Mobile Web Best Practices Working Group has therefore prepared guidelines for proxy transformation which are given in [67].

Surveys of some existing content adaptation techniques can be found in [66] and [68]. Zhang in [69] gives a brief overview of the issues involved in the web content adaptation for mobile devices. In the remaining section, we describe some content adaptation solutions that used distinct approaches for content adaptation.

R. Mohan et. al. [58] presents one of the first approaches based on the InfoPyramid framework. The proposed system was based on static adaptation and the original content was analysed and transformed into multiple version through transcoding at the server side. For example, a video was transcoded into different versions, with different resolutions and modalities. The resources of the client device were analysed and a decision about the selection of an optimum version was made. Adaption by selection approach is also used in [70], where multimedia content is created at five different quality levels and based on the context, one of the versions is delivered to the client. Weiss in [71] takes another approach to determine context of the user for delivering the adapted content. Authors propose a *situation*-based adaptations approach. In this approach, different situations are defined in the system. Each situation has adaptation rules that determine steps to be taken to adapt content. A user's current *situation* is determined based on the static device parameters, user preferences and the context of use and the corresponding adaptation actions are performed. For example, in a situation when a user is in a library, spoken words in a video are converted into subtitles, instead of audio. Herder et. al. propose an adaptation approach based on the concept of the trinity of context. In this approach, the user, the device and the context of use are called the trinity of context. The trinity of context is used to adapt navigational support to the continuously varying user model [72].

Seeman in [73] uses a proxy-based content adaptation technique. A decision engine is proposed. This decision engine takes as input the user request with the device information, applies a scoring scheme on various available versions of the content. Based on the scoring scheme, an optimal version for the user is computed. The approach is demonstrated using a PDF document adaptation system. The role of the semantic web in accessibility and device independence for adaptation for the people with disabilities has been explored in [74].

Distributed approaches for adaptation have been used in [53], [75], and [76]. Lemlouma in [53] presents a combined server and proxy approach of adapted content delivery. Here, the content has a document instance profile, which is matched against the client request. If they do not match, the server checks if any of the existing versions that matches client's requirements is available. If no such existing version is found, it checks the output of any adaptation methods, which would match the client's requirement; finally, if no match is found, the server sends a negative response to state that there is no available version for the context. Shahidi et. al. presents a distributed Content Adapter entity, is which is part of any Adaptation Management Framework (AMF) [75]. Adaptation Mechanisms (ADME) are adaptation services present at different locations in a network (at client, server or third party device) which may offer adaptation services. The Content Adapter makes use of one or more of the ADMEs to provide the adapted version of the content to the user. This claims to result in having many options for adaptations and not overloading any entity for the adaptation process. A Distributed Content Adaptation Framework (DCAF) has been presented in [76] for multimedia systems. This system takes client profile, network condition and content profile to create an adaptation graph from the list of available adaptation services provided by different third parties. The system selects an optimal adaptation path from graph to achieve the desired adapted content.

Hoque et al. [13] have also surveyed various multimedia adaptation solutions for wireless multimedia streaming in mobile devices. The authors focus on the wireless communication aspect and categories the existing solutions according to different layers of the Internet protocol stack they utilize. They also group the solutions based on the different traffic scheduling and multimedia content adaptation mechanisms. Beek in [77] takes a closer look at the use of metadata in UMA, in particular MPEG-7. UMA is universal or seamless access to multimedia content, by automatic selection and adaptation of content based on the user's environment [58]. Methods in this context may include selection among different pieces of content or among different variations of a single piece of content. Methods for adaptation include rate reduction, adaptive spatial and temporal sampling, quality reduction, summarization, personalization and reediting of the multimedia content.

More recently, a new streaming mechanism has been introduced, called Dynamic Adaptive Streaming over HTTP (DASH) [78]. DASH, is an extension of the HTTP streaming that performs content adaptation with a quite simple but effective approach. Instead of having one media file encoded at a single bitrate, the same media file is encoded at different bitrates, resolutions, etc. These multiple versions are then fragmented into smaller pieces. The fragment size is usually between two to ten seconds of video [79]. This enables the client to switch between different qualities, resolutions, etc. during the streaming session. DASH is able to automatically switch the video quality level according to the current network conditions. In [80], authors proposes a streaming technique that merges the scalable video encoding with the DASH approach.

2.4 Energy Efficiency in Mobile Devices

In this section, we briefly discuss energy efficiency in mobile devices. Mobile devices are run by limited battery power, it is therefore necessary to extend the mobile use time through energy efficiency techniques. In this section, we mention the broader aspects of this area and mention different approaches are used for this purpose. In section 2.5, we will discuss energy-efficiency (power-saving) in the context of multimedia adaptation.

Recent technological advances in mobile technologies have made mobile devices more common, more affordable and more powerful. Mobile devices now have more processing capabilities, increased memory capacities and better network connectivity with high speed internet. These mobile devices are now being used increasingly to retrieve high quality multimedia content from the web. These multimedia applications are extremely resource-hungry, including higher demand for battery power. Mobile devices are battery powered, but batteries have not kept up with the advances of other mobile technologies [15]. Today, battery power is a major constraint of these powerful mobile devices. As a result, a lot of research has been done on battery efficiency, in order to increase the battery life and run these multimedia applications for longer [81, 82]. CPU, Display and Network Interface are the biggest consumer of battery power.

Arghir [52] summarise the energy consumption characteristics of various components of mobile devices, that include display, CPU, RAM, Flash memory, WiFi, Cellular networks, Bluetooth, camera and other sensors and audio components. These energy consumption characteristics could be considered to develop energy-aware solution for mobile learning.

Battery Efficiency can be achieved a different levels, including hardware, network and application levels. Dynamic Voltage Scaling (DVS) [83] power management is a scheme that reduces the energy consumption, by changing processor speed and voltage at run-time, depending on the need of applications. Cornea et al. in [84] uses a DVS technique for run-time data aware optimizations for prolonging battery life. This system uses annotations for adding stream analysis data with the multimedia stream. These annotations capture patterns or trends in the data and this information is later used for run-time data aware optimizations. Acquiring this data at run-time on handheld devices is very difficult due to the time and processing requirements. The data analysis is, therefore, performed offline in advance. These annotations are also useful in estimating the required bandwidth for communication and estimating computation.

A power consumption reduction technique based on the dynamic adjustment of the backlight for a LCD is used in [85]. This technique also uses annotations for storing the luminance information for different scenes in the video and uses these annotations to dynamically adjust the backlight for LCD displays.

[86] provides a unified framework that integrates power saving optimizations techniques from low level architectural (CPU and memory) techniques, OS mechanisms (dynamic voltage scaling) and adaptive middleware techniques (transcoding and traffic shaping) to show that such an integrated approach can provide significant improvement at both system level and user experience. Authors have identified eight different quality levels for a hand held devices that user can distinguish. These quality levels provide transcoding parameters (bitrate, frame rate, video resolution).

In this thesis, we focus on power efficiency in multimedia streaming techniques; therefore, we discuss it in detail in section 2.5.

2.5 Energy Efficient Multimedia Adaptation

In this section, we discuss some relevant research work and issues related to multimedia adaptation for power-saving in mobile devices. Adaptation approaches, discussed in this section, are not related to any specific kind of multimedia content. These are generic adaptation approaches. By describing these approaches and techniques, our aim is to identify some problems that could result when these are applied to educational multimedia. To the best of our knowledge, there have been no efforts to develop or propose power-saving adaptation approaches specifically for educational multimedia.

On one hand, advancements in battery capacity have lagged significantly compared to other capabilities of mobile devices [87] and on the other hand, the power requirements of mobile devices are continuously increasing, as mobile devices now come with increased processing capabilities, bigger screens and higher data communication rates.

Streaming of online multimedia is a power-hungry activity. Considerable research has been done to improve battery efficiency while using online multimedia content [19, 21, 22, 52, 88, 89].

Multimedia adaptation techniques commonly achieve power-saving by decreasing the multimedia quality, by modifying encoding parameters like frames per second, resolution, colour, bitrates [26], [17] and changing even the modality of content. The general principle behind these approaches is to reduce the data size of the multimedia that reduces the data transfer through the wireless interface and results in the use of less battery power.

Content adaptation has been an attractive solution for the ever-growing desktop-based Web content delivered to the user via heterogeneous devices. It has been demonstrated through numerous research efforts that content adaptation mechanisms have the capability to prolong battery life of the multimedia streaming clients [26, 82, 90]. A comprehensive survey of energy efficiency techniques for multimedia applications can be found in can be found in [19, 21, 22, 52, 88, 89].

Hoque et al. in [19] have surveyed various solutions for improving the energy efficiency of wireless multimedia streaming in mobile devices. They classify research work based on networks layers and adaptation techniques being used to give us an idea of how we can achieve battery efficiency at each network layer. This survey classifies power-saving multimedia adaptation techniques in application layers in Scalable Video Coding, Media Transcoding and Content Selection. All these techniques tend to reduce multimedia quality that help energy saving.

Zhang et al in [21] have focused on energy saving techniques for mobile multimedia delivery and group the solutions in power aware video coding and video delivery. The authors identify several challenges in designing energy efficient mobile multimedia communication devices. Based on the challenges identified authors conclude that due to the dynamics involved, enabling power-aware mobile multimedia is extremely challenging, and involves various trade-offs.

Ismael et al. in [88] classifies energy-aware content adaptation systems based on the mechanism used, strategy adopted, location of adaption of adaptation mechanism, purpose of user, context and technique used. This paper provides the following list of techniques used for multimedia adaptation for energy efficiency. Adaptation Streaming, Distillation, Content Selection, Scalable Video coding and colour.

Battery efficient adaptation solutions modify multimedia content in terms of presentation in order to minimize energy consumption as well as to fit content to resources of mobile devices. Content adaptation is used to trade streaming content quality for energy savings. While compromising quality of multimedia the user quality of experience (QoE) should also be considered while optimizing the energy consumption by adaptation mechanism.

As mentioned before adapting the fidelity of a content has an important role in battery saving adaptation mechanisms. At application level, commonly the quality of multimedia is reduced to achieve battery efficiency [17, 21-29]. Below we show how different adaptation mechanisms are used for battery saving purposes. Content Adaptation mechanisms that select appropriate quality of a video for power saving can be classified in to one of the following techniques.

2.5.1 Content selection

In this method, multiple versions in different qualities and modalities of each multimedia object is pre-processed and stored in the content server. Then, the best version for the desired battery efficiency is selected. One of the earlier content selection systems, InfoPyramid [58], used this mechanism. Chandra and Vahdat [29] measured the energy consumption of different media formats and stored the same media at different resolutions at the content server. They showed that switching to a lower fidelity stream at the server provides potential energy savings at mobile clients. Therefore, switching to a lower quality stream at the server provides energy savings at the client. Mohapatra et al. [91] transcoded a video stream with different parameters and generated multiple copies of the same video in a proxy or server. Then, they profiled the average power consumption of mobile clients for these transcoded streams and later used these profiled values for stream selection rather than transcoding. Two other approaches that select multimedia version based on the battery level of mobile devices are described in [90, 92].

2.5.2 Media Transcoding

Transcoding is another way that primarily deals with network bandwidth and device heterogeneity for multimedia streaming. In this approach, only one bit stream of high quality is stored at the server. In order to meet the user device or network requirements transcoding is performed at the server, at the access point, gateway or at some proxy server, which results in a new bit stream that fits the resource constraints. Shenoy and Radkov [93] introduced a streaming system which transcodes variable bit rate multimedia content in a proxy and then shape the resulting new bit rate media traffic into bursts at the proxy.

2.5.3 Scalable video coding:

Scalable Video Coding (SVC) [94] is also known as layered video coding. It provides the capability to encode a single video stream by using the bit rate of multiple transmission channels, by structuring the compressed data of video bit streams into layers. The base layer corresponds to the lowest bit rate stream having the minimum quality, frame rate and spatial resolution. The enhancement layers increase the quality of the stream by increasing the frame rate and spatial resolution. The number of layers to be transmitted to a streaming client at any time is determined by feedback received from the client. This technique, therefore, has potential to reduce power consumption at client mobile devices by transmitting a lower quality of multimedia by reducing the number of enhancement layers.

The dynamic scaling is achieved through any combination of three scaling mechanisms: temporal scalability, spatial scalability, and quality scalability. Using SVC, a scalable stream can provide dynamically different numbers of video layers (base layer and the different enhancement layers) to heterogeneous clients, according to the client's processing capability and importantly, the remaining battery-life of the device. The *temporal scalability* mechanism changes the frame rate of the received video stream by dropping whole frames. The *spatial scalability* mechanism changes the resolution of the video and the *Quality scalability* mechanism changes the quantization parameter of the video decoder. This has been proven to yield a 42% decrease in energy consumption during video decoding with a mere 13% quality degradation in the video [95].

Choi et al.[96] included SVC for an MPEG-4 FGS streaming system in which a mobile client can control its decoding capability according to the energy management policy. The mobile device sends its instantaneous decoding capability as a feedback message to the server and based on this information, the server determines the amount of data for a given frame to be sent to the mobile client. For instance, when the battery charge level of a mobile reduces to a predefined threshold, the power manager scales down the CPU frequency of the mobile client, in order to extend the battery life. They measured a 20% reduction in Wi-Fi energy consumption using this approach. A power aware streaming proxy (PASP) was designed by Rosu et al. [97] which uses scalable video coding to reduce the energy consumption of a mobile client.

2.5.4 Adaptive streaming:

Adaptive streaming refers to the process of detecting the users' bandwidth device or constraints in real time and then altering the quality of media stream. In [92] Kennedy et al. proposed and developed a simple algorithm that analyses the remaining stream duration and the remaining battery lifetime. The result from the algorithm is used to decide whether or not to send an adaptation request to the dynamic streaming server. When the remaining video stream duration exceeds the remaining battery life, the video is adapted to a lower quality, to ensure sufficient battery to display the remaining video stream.

In recent years, a new content adaptation method emerged known as Dynamic Adaptive Streaming over HTTP (DASH)[78]. In this case, a video service provider creates multiple versions of a video. Each version is then segmented in to smaller fragments of the same duration of a few seconds (2-10). The idea is that, during streaming, if some changes occur in network conditions, then the next segment is selected in suitable quality. This enables dynamic selection of video quality while streaming continues. Apple's HTTP Live streaming is an example of HTTP DASH where the duration of each segment is 10 seconds. The dynamic selection capability of this technique can be used exploited by battery efficient adaptation.

Lowering the presentation quality of multimedia has been used in many battery saving and energy efficiency multimedia adaptation research works. Some of these research efforts can be found in [17, 21-28]. Below, we briefly describe these systems and the approaches used by them. We can observe that all these approaches tend to uniformly decrease the presentation quality of streaming multimedia for power-saving in mobile devices. These approaches, however, are not content aware in the adaptation approaches. The quality of multimedia is lowered, without giving any consideration to the visual contents of the multimedia being adapted.

Zang et al in [21] discusses how selecting a multimedia in a lower quality can be used for power-aware mobile multimedia. Hoque et al. in [22] experiments with streaming services and power consumption by multimedia of different qualities, video players and video containers. Authors note that higher quality video consumed more battery power on Galaxy S3. Lian et al in [23] propose design of multimedia systems that will be power-aware. The basic idea behind their proposed mechanism is shown in Figure 2.4. It shows a different presentation quality and encoding parameters for different level of battery status. A higher quality media is delivered when the battery is full, while in a very low battery mode a very low quality media is delivered.

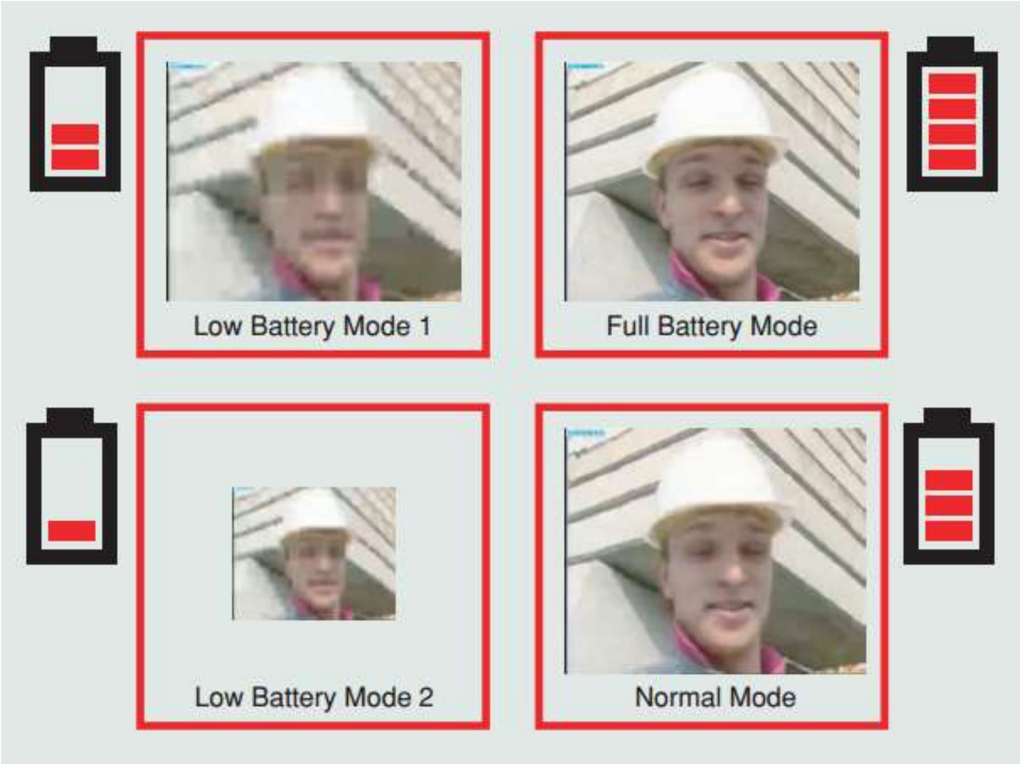

Figure 2-4 Video Presentation Quality for different Battery Levels[23]

Lui in [24] found through experiments that switching to lower quality in streaming the data transmission helped save battery-power. Trestian in a recent work [17] experimented with a 10 minute long Big Buck Bunny animated clip. A 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's work in [25] also shows experimentally that battery power consumption can be reduced by reducing bitrates and frames per seconds for video quality. They found the average growth rate of the energy consumption is 15.76% when frame rate is changed from 25 to 30 frames per second. Similarly, they find that 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. They also conclude that for a better picture quality, they can encode films with bigger bit rate with just a little increase of energy consumption. Otherwise, they will need to pay a great penalty if they try to have a better quality film by increasing the resolution instead.

Recently, Moldovan et al. in [26] presented a mechanism called bitDetect that uses objective video quality assessment metrics to detect content-specific decreased video bit rate levels that enable saving battery power while maintaining good user perceived quality. Adams et. al in [87] claims that batteries have not followed the exponential technological improvements of other mobile related hardware such as CPU, memory and wireless networking and present adaptation algorithms for power saving at data reception, decoding and playing stage of multimedia streaming stages. To save power in the decoding stage, the multimedia content was encoded at a lower bit rate.

McMullin et al. introduces a Power Save-based Adaptive Multimedia Delivery (PS-AMy) mechanism [90]. PS-AMy adapts multimedia streams in order to enable the streaming to last longer. The adaptation decision is based on the remaining battery life and packet loss. The client side sends the 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 [92] suggests Battery and Stream – Aware Adaptive Multimedia Delivery mechanism (BaSe-AMy), which 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 now briefly mention some other battery power-saving multimedia adaption techniques that are not based on lowering the presentation quality of multimedia. For example, Shenoy et. al. in [93] presents a proxy based technique that uses power friendly streaming transformation technique guided by client specified preference values for energy spending to limit the energy needs of the streams. This technique then uses intelligent network transmission. Both these techniques reduce the energy needs of the streams during transmission at the network interface and also at CPU during decoding and playback. The transformations take place at proxy.

It could be seen that the above mentioned multimedia adaptation systems lacks the ways to consider impact of quality reduction on the visual information contents of the multimedia. We argue that these multimedia techniques if applied on learning multimedia could result in visual information loss that may negatively affect the learning process. It is important to find a way of considering the impact on the visual content and keeping the multimedia in a form suitable for learning purposes.

In this section, we discussed some of the existing multimedia adaptation techniques developed for the purposed of power-saving in streaming applications. One common feature of these techniques is that they all use a common approach of lowering quality of entire multimedia uniformly without considering its impact on any visual information in different parts of the multimedia. The fact that these generic multimedia streaming techniques do not consider impact of quality adaptation on the learning information in multimedia creates certain problems when used for educational resources. We mentioned these problems in [31] and they will be discussed in Chapter 3.

2.6 Energy Efficient Adaptation in Educational Multimedia

Traditionally, Content Adaptation and Universal Multimedia Access (UMA) [16] techniques have been used to adapt multimedia content based on the resource constraints of mobile devices. Online educational multimedia, content when accessed over the mobile network, quickly drains battery power, as a result of huge data transfer. Battery power constraint is a great challenge in taking maximum advantage of mobile devices for learning and is a restricting factor. Since limited battery still is an important resource constraint in mobile devices, mobile learners are often forced to interrupt their learning activity because of low power situations.

Despite high dependency on battery power, little has been done to improve battery efficiency in mobile learning applications. However, most mobile learning applications depend on existing generic power-saving multimedia adaptation techniques that are not developed specifically for educational multimedia. Existing battery efficient multimedia adaptation techniques offer trade-offs between user experience and battery life. These techniques tend to degrade quality, in order to extend the battery life [19] [52]. These methods lower encoding parameters, like frames per second, bitrates, colours and resolution, to achieve battery efficiency.

In a recent survey, Moldovan et al in [52] 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. The authors further discuss various content adaptation mechanisms that can be used by mobile learning application to extend learning activities using mobile devices. The most important adaptation techniques are those at application level, which can be easily adopted by learning applications.

Moldovan et. al. in [27] and [7] are among the first works in the areas of power-efficient presentation of educational multimedia for mobile learning. They suggest that power-saving techniques need to be integrated with eLearning applications for mobile devices and adaptive e-learning environments should become energy-aware through power-saving techniques, in order to assist learners in a low power situation [27]. The authors recommend that it is better to provide multimedia educational content in lower quality, instead of affecting the learning experience, by stopping learning activities sooner, as a result of low power situations. This paper further presents an experimental evaluation of battery consumption and quality of multimedia encoding parameters. They perform subjective evaluation of using learning multimedia on mobile devices in different presentation qualities. The authors focus on better user experience, while recommending encoding parameters.

Moldovan et.al in [28] 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 learners to study for a longer duration. The authors conducted experiments to understand the impact of reducing the quality of the video for battery saving purposes on learning outcomes and learners' perceived quality. Subjective tests showed that the quality of the video could be reduced without significantly affecting the learning process. The authors conclude that for H.264 video compression, the bitrate of the educational multimedia clips can be significantly reduced, in order to save battery power, in a controlled manner, without significantly affecting learners' perceived quality.

In [98] a multimedia content management tool (MediaMTool) was presented, which automatically creates multiple versions of the multimedia clips based on a set of specified multimedia clip features. MediaMTool creates different versions of multimedia clips in order to support personalised and adaptive multimedia delivery that also enable battery saving streaming. To assess the battery saving capabilities, 16 clips corresponding to the 8 educational test media clips were selected. Each clip was encoded in two versions with lower and higher bitrates. All clips were streamed to an HP iPAQ 214 PDA and the device power consumption was measured for each case. Results showed that clips with lower bitrates extended battery life. The results also suggest that depending on the clip characteristics, between 13% and up to almost 17% increase in battery life can be achieved by reducing the bitrate from the reference bitrate to the threshold recommended by the BitDetect system proposed by the same authors [99].

2.7 Existing Approaches to Quality Reduction and Evaluation

It can be seen in the relevant literature, that no single standard approach has been followed for the quality reduction in existing multimedia adaptation approaches [17, 19, 21-29, 52, 82, 88-90]. The focus of these research works is on demonstrating and establishing that power-saving can be achieved by reducing the quality of multimedia. Quality reduction is done by changing the encoding parameters like frames per second (FPS), resolution and bitrates. The different approaches in existing literature modified the different encoding parameters in different manners to reduce the quality of a multimedia. Furthermore, the total numbers of lower quality levels are also different in different research works. For example, [17] used five quality levels using bitrates of 120,240,480, 960 and 1920 kpbs and used four 20 seconds clips, from different parts of the same video for evaluation, with no audio-only version. In [24], only two qualities of multimedia have been used for power consumption analysis. [25] used four quality levels with fixed video resolutions in different bitrates of 144, 288, 576 and 1152 Kbps. [86] used six quality levels, to measure battery consumption without any evaluation with users. Five quality levels of bitrates 400kbps, 800kbps, 1.2 Mbps, 1.6Mbps and 2 Mbps were used in [90] and analysis was done only with battery measurement for different streaming qualities with no evaluations with humans.

Subjective evaluation with users has not been widely performed in the quality reduction based power-saving multimedia adaptation literature, as can be seen in [19, 21-25, 27-29]. The focus of evaluations in these research works has mostly been power-saving measurements during streaming multimedia in different qualities. Few research studies, mentioned in [17], [26], [28], have used subjective evaluation. These studies were based on Quality of Experience (QoE) based methodology. In QoE based studies, the participants grade multimedia quality using Mean Opinion Score (MOS) (1 for Bad - 5 for Excellent) scale only.

Similarly, the power-saving multimedia adaptation research efforts in the context of educational multimedia used only two quality levels of a multimedia with the only subjective evaluation of rating multimedia clip using mean opinion score (MOS) methodology for Quality of Experience (QoE) measurement. A detailed difference with the work done in the educational multimedia context is explained in section 2.8.

2.7.1 Novelty in the Objective and Methodology Adopted in this Thesis

Both the user study (discussed in chapter 3) and the evaluation of CAPS-EMA (in chapter 6) follow existing power-saving multimedia adaptation approaches to the extent that the quality of a multimedia is lowered for power-saving purposes. However, the goal and methodology adopted in this thesis is different from any previous study in the existing power-saving multimedia adaptation literature. Firstly, the focus of this research is not on proving that reducing multimedia quality can help in power-savings. Earlier research efforts have already established that power-saving can be achieved by quality reduction. Secondly, the focus of power-saving adaptation is on 'educational multimedia' with emphasis on perceived learning information loss due to quality reduction.

The goal of our research work is to identify potential problems when existing approaches of power-saving adaptation are applied on educational multimedia and how could we address those problems. This has been done in Chapter 3 through a user study in demonstrating that uniformly lowering the quality of a multimedia may cause perceived loss of quality sensitive visual information. This has not been reported in any previous literature.

The goal of this thesis, in regards to the quality reduction of a multimedia, is about suggesting an approach for multimedia adaptation, whose output would be non-uniform quality adaptation for entire multimedia. This quality of multimedia would vary, based on the requirement of different parts of an educational multimedia.

As a result of evaluations, we do not aim to recommend any particular multimedia quality i.e. bitrate, resolution for an educational multimedia. The evaluation methodology has been devised for evaluating the particular features of the proposed content-aware power-saving approach.

2.8 Comparison with existing work on Power-Saving Learning Multimedia Adaptation

Our research work is more related in terms of the research domain to the work done by Moldovan et.al. in [26], [27] and [28], as they have also done their research in the area of power-efficient presentation of educational multimedia. Our work, however, is different from their work in terms of the objectives and the evaluation methodology.

The objective of their work is about demonstrating that lower quality in educational multimedia reduces battery-power consumption, and their proposed mechanism, BitDetect, suggests a lowered quality based on the temporal and spatial characteristics of multimedia. It is claimed that the BitDetect recommends are lower presentation quality that would offer good user experience. BitDetect suggests one single uniform quality for entire multimedia. The objective of our work is to propose enhancements in the quality reduction based power-saving adaptation approach for educational multimedia in order to minimise perceived visual information loss. Our work is not based on offering a better quality of experience. In the evaluations, Moldovan et. al. in [26] and [28] have selected 30 seconds clip from eight learning videos. Each clip was encoded in two qualities version. In their subjective evaluation, the participants were asked to rate multimedia clips using Mean Opinion Score (MOS) to show that their mechanism of detecting low quality thresholds for different video can offer battery power-saving with acceptable quality of user experience. In [27] Moldovan et.al used three different video qualities by varying only one encoding parameter and keeping the other two constant. Participants were asked to rate each quality using MOS methodology. Results indicated that lowered quality resulted in lower mean opinion score. The way different qualities were selected in these studies, however, did not follow any standard quality selection mechanism. In our evaluations, we have used five clips from each video with each clip encoded in four quality levels. We have explained these differences in detail in the coming sections.

2.8.1 Novelty in the Objective of the research

The objective of this thesis is not to demonstrate that lowering quality reduced power-consumption. Instead, we propose to lower quality based on the learning information requirements of different fragments of educational multimedia. We have conducted two user studies with different objectives than the Moldovan et. al. studies.

The focus evaluations by Moldovan et. al. was on evaluating the quality determined by the BitDetect system, which suggests to lower quality for power-saving with the resulting quality having good user acceptance. Furthermore, they also measured battery power-consumption for lowered quality of each video.

In our first study, discussed in Chapter 3, we aimed to understand if different segments of an educational multimedia had different lowest acceptable quality for avoiding perceived loss of visual information. We conducted this user study to see impact of uniformly lowering the quality of entire multimedia to a single uniform quality for power-saving. We wanted to see if the different fragments of a multimedia have different lowest acceptable qualities for conveying the learning information without any perceived loss of information. This makes our research study is very different from the Moldovan's work. The detail of our experimental methodology could be found in Chapter 3.

In the second evaluation (in Chapter 6), we performed evaluation of our proposed educational multimedia adaptation approach for power-saving (CAPS-EMA). Our proposed approach has commonality with Moldovan's work in the sense that both works aim to lower the quality of multimedia for power-savings. Moldovan's, like all other mentioned power-saving multimedia adaptation techniques, adapts multimedia to one single uniform multimedia quality for entire multimedia. Our work has differences from Moldovan's work in many ways. Firstly, our approach CAPS-EMA is not a mechanism for recommending characteristics of the lowered quality of the adapted multimedia. CAPS-EMA is an approach to multimedia adaptation that instead of lowering the quality of entire multimedia uniformly, suggests to lower the quality based on the perceived requirements of the individual portions of a multimedia.

2.8.2 Novelty in Methodology of the research

We now mention some more differences between the methodologies of our work and Moldovan's work.

- The focus of our user studies is on perceived information loss instead of Quality of Experience (QoE) in the adapted multimedia. The assumption behind this is the fact that poor video quality or even an audio version of a video can convey learning information, even though it will offer a lower QoE. The modality and the quality of a multimedia depend on the quality-sensitivity of visual information. Moldovan's work is based on quality of experience assessment only.

- In our studies, we have used four different multimedia quality levels including an audio-only version. The exact encoding parameters of each quality and the bitrate characteristics is for the purpose of demonstrating the concepts explained and are in no way strict recommendation of multimedia qualities for any specific type of multimedia. Moldovan's work is about proposing a mechanism that selects quality encoding parameters, e.g. bitrates, for videos based on the spatial and the temporal characteristics of the multimedia. Evaluations in Moldovan's work used only two multimedia qualities.

- In our evaluations, we have used an audio-only quality of multimedia. We believe, and our user studies suggest the same, that certain learning information could be conveyed in an audio-only modality, instead of video, without any perceived loss of information. Moldovan's work does not include any audio-only quality in their proposed mechanisms as well as in their evaluations, as they have used QoE criteria in their evaluations.

- Moldovan's work in subjective evaluation selects only one up to 30 seconds multimedia clip from each selected video for the study. We have selected five fragments of duration 20-25 seconds from each selected video. The reason for the selection of five fragments was that without this we could not have assessed the quality requirements for visual information at different fragments of the same multimedia.

- In our evaluation, we explicitly asked users about acceptance of each lowered power-saving multimedia quality for learning situations, when battery power-savings is desired. The evaluation in Moldovan's work used Quality of Experience based techniques that would make no distinction between situations where battery power-saving is not required and when it is required. We believe users would normally prefer a compromised version of a multimedia, offering a lower Quality of Experience, if that would help in preserving battery power when required.

We have seen that mostly QoE based evaluation is used during subjective evaluations of multimedia adaptations for power-saving. QoE deals with overall quality assessment of multimedia and a lower quality will always have low quality of experience as reported by [26] [27] [28]. In our subjective evaluations, we asked the participants to report perceived loss of learning information in the lower quality multimedia versions. In our evaluations, we also asked users about their opinions about the acceptance of each lower quality for learning purposes in a battery-power saving scenarios.

Overall, after the study of existing multimedia adaptation techniques, we can summarise that in these techniques, the impact of lowering the multimedia quality on the visual information contents is not considered in the adaptation process. We argue that the recommended single uniform quality by these approaches, as a result of adaptation, may be suitable for those short 30 seconds segments selected for evaluations, but there is no evidence that the same quality will be suitable for the entire multimedia, the duration of which may span up to hours in many cases. We believe that these adaptation techniques are not suitable for adapting learning multimedia as they do not consider the perceived learning effect in the adaptation process. In order to address the short comings of existing approaches, we have proposed the content-aware power-saving educational multimedia adaptation approach that would consider the impact of lowering the quality of multimedia on its visual information contents. We discuss this approach in Chapter 4.

2.9 Interfaces for Battery Power-Saving in Applications

Adaptation for battery power-saving mostly results in some compromises in the user experience, as we previously discussed in this chapter. In the context of multimedia adaptation, adaptation techniques usually reduce power consumption by lowering the presentation quality of streaming multimedia [17, 22, 26], changing modality and skipping some less important information contents to reduce the duration of multimedia. All these changes are aimed at reducing the overall data size of multimedia. This helps in reducing power consumption in wireless data transfer and processing, at the cost of some negative impacts on user experience and on learning activity [100] , in case the multimedia is of educational nature.

It is found from the study of the relevant literature of multimedia adaptation techniques [19, 21, 22, 52, 88, 89] that they lack options for users to control the adaptation process in terms of choosing any acceptable trade-offs or compromises. Furthermore, there is also lack of feedback to inform users about the form and characteristics of the adapted multimedia beforehand. Without these control options and information, users' (or learners' in the context of educational multimedia adaptation application) satisfaction is not guaranteed. Without such control options and feedback, users (learners) cannot choose the extent of the trade-off themselves and they would have to accept whatever the system chooses for them for adaptation. This means that the system itself decides about the resulting multimedia quality and would take the adaptation actions without the user's intervention and consent. While automatic selection of resulting compromise may also be desirable in certain situations, it would also be useful to provide multiple power- savings options to users with appropriate description about the resulting compromise for every power-saving option. A higher user satisfaction may be achieved if control is given to users and they decide themselves about either accepting the recommended (may be automatic) setting with resulting compromise or choose another option with a preferred degree of compromise or even aborting the activity completely. For example, only a learner will best know about their battery power-saving needs. A lower battery in a learner’s mobile device does not necessarily indicate that the learner will be out of battery-power soon and the current learning activity is going to be abandoned. A learner may have access to a charging facility for their mobile device or may be available in near future. Any automation in such situations, for example by reducing the content quality automatically and without the learner’s consent, may not provide a better user experience. We believe some control must also be given to the learner about the future lines of action regarding power-savings that would result in any compromise in user experience.

We suggest that multimedia learning systems should be adaptable instead of purely adaptive. De Bra [45] differentiates between adaptable and adaptive systems as follows: an adaptive system alters its behaviour automatically, while an adaptable system needs explicit interaction from the user. In this thesis we advocate for an adaptable systems for Learner-Battery Interaction, explained in the Chapter 7.

In this section, we discuss some research efforts that are in relation to power-saving and battery interfaces, to show the state of the art in relation to interfaces for power-saving. This literature review is about our work presented in the Chapter 8 of the thesis, where we introduce the concept of Learner-Battery Interaction (LBI) that would allow the learners to have some control over the power-saving adaptation mechanism. Learners could have control over the adapted version based on the feedback provided by the system. Feedback consists of the characteristics and the possible compromises of the adapted multimedia on the user experience and learning.

2.9.1 Human-Battery Interaction

The limited battery power in mobile devices has been a great usability concern recently [101]. Mobile devices are becoming more powerful and increasing in capabilities, but at the same time the more innovative and complex applications can become a burden on the limited available battery power in these devices. Improvements in battery power have not matched the corresponding developments in other mobile technologies [15], for example, processing capabilities, storage, displays, communication, etc. The usefulness of a mobile device is often proportional to its mobility, e.g., not being tied to a power source. Battery life has consequently become a major concern for mobile users.

Many research efforts have been directed at enhancing battery efficiency, however, little has been done regarding how human users deal with the limited battery lifetime [101]. A survey in [102] shows that 80% of mobile phone users took various measures to increase their battery lifetime.

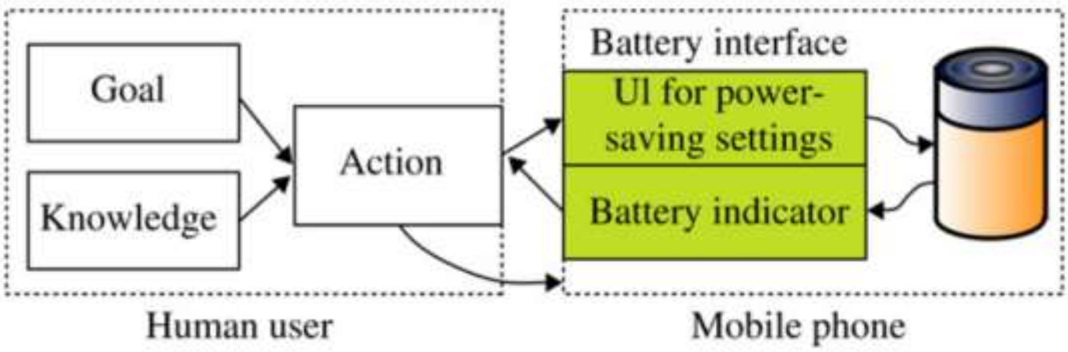

Figure 2-4: Conceptual model for human-battery interaction [103]

Rahmati et al. in [102, 103] proposed Human-Battery Interaction (HBI), which is the study and understanding of the users' charging behaviour, battery-indicators, the user interfaces for the power-saving settings, user knowledge, and the user reactions. A conceptual model of the human battery interaction is described in [103] has been illustrated in Figure 2.4. A user reads the battery indication and assesses the situation using the knowledge they have about the system, its power characteristics and their goal in using the mobile device. Based on their knowledge, the user interacts with the mobile device power settings, in a hope of meeting their activity goal. This model indicates that the study of the Human-Battery Interaction should include the understanding and the investigation of the user knowledge, how the users set their goals and prioritize different aspects of usability in the limited battery power, the design of the battery user interfaces, and how the users employ them.

Study results in [103] suggest that mobile phone users often have inadequate knowledge of the power characteristics of their mobile devices and that this exposes the inadequacy of the state-of-the-art battery interfaces. Some of their findings regarding user battery interfaces and the knowledge about battery interfaces are summarised below:

1. Users have inadequate knowledge on the system power characteristics
2. Many users are unaware of the existence of power-saving settings
3. Existing battery indicators are inaccurate and inadequate
4. A more accurate indicator with better feedback may enable users to charge phones more conveniently

5. Battery indicators of higher resolutions lead to higher user satisfaction
6. Battery indicator design must consider usage patterns and user goals
7. Power-saving settings remain largely unused
8. Current user-interfaces for power-saving settings are inadequate

It is worth noting that the HBI issues discussed by Rahmati et al. in [102] deals at the mobile operating systems level. They discuss the information and the power-saving settings provided by mobile device operating systems and do not refer to individual applications.

Heikkinen et al. in [104] also describe their user study aimed at understanding the user behaviour and expectation about battery management. Their results confirm the findings of Rahmati et al in [102, 103]. Ferreira et al. [101] conducted a study to understand user behaviour towards different applications and to report on users' experiences with a user-centred battery interface design, refining the knowledge of human-battery interfaces, and providing an insight for future battery interfaces. Their data gives an insight of how battery life was affected by users' interaction with their devices. Their study findings are given below.

1. Individual users exhibit very diverse patterns of behaviour, and it is challenging to capture this diversity to predict or explain battery usage in a battery interface.
2. Users have a reasonable battery mental model to explain their phone's battery lifetime and correlate the impact of their actions with foreground application usage, but not operating system processes or phone usage;
3. Despite this reasonable mental model of battery lifetime, some participants' phones 'died' frequently. In addition, users reported not knowing what to do to increase battery life, other than simply recharging their device or turning the Wi-Fi and Bluetooth on/off.
4. When presented with a list of applications running on their phones, users more easily identified applications they installed from the application store, than manufacturer applications.
5. Users are unable to assess reliably the battery left with the battery icon on the notification bar.

The findings of both studies reveal the need for further improvements in the user interface and providing explicit information, to help users understand better the current battery-power status and what steps they could take in order to extend the battery-life and the duration of use of the device.

Ferreira et al. [101] also extended the notion of Human-Battery Interaction to application level and developed a prototype, Interactive Battery Interface (IBI). IBI provides a user the information about the possible impact of each running application on the battery-life of their mobile device and allows them to abort any running application - if they wish - based on its impact. The impact of an application includes the extent of battery-power being consumed by each running application and how much can the battery-life be extended by aborting an application.

Truong et.al in [105] discusses a Task-Centred Battery Interface that provides users the information about how different applications affect battery usage and how long a combination of applications or individual tasks can be performed.

2.9.2 Advances in this thesis

We can see from the literature that human interaction with battery has been mostly discussed at interfaces provided at the operating system level. Research efforts have been focussed on understanding of the users' behaviour and improving existing battery indicators. Ferreira et al [101] and Truong et.al in [105], however, focused on interfaces that allow users to understand the impact of each running application on battery lifetime and enabling users to close any application, to extend battery lifetime. We have seen little research efforts that are focused on user interaction with the battery in an adaptive application, which would allow users to choose a power-saving option and hence choose a resulting, compromised experience from the adaptation of the application and its content.

In chapter 8, we advance the concept of Human Battery Interaction to power-saving adaptive applications and propose Learner-Battery Interaction (LBI) in the context of adaptation of educational multimedia. We discuss LBI model and show our implementation of the concept in the prototype MoBELearn application. We also discuss our evaluation results of the prototype interface.

2.10 Conclusion:

In this chapter, we first introduced basic adaptation and personalization concepts. We also mentioned some important research works in the field of multimedia adaptation, especially for battery power savings in mobile devices. The primary objective of this thesis is, however, to investigate opportunities for energy saving in educational multimedia and therefore we also mentioned some research efforts in this area. We have found that mobile learning multimedia applications would depend on generic multimedia adaptation techniques. These techniques do not consider the learning aspect of multimedia in the adaptation process. We, therefore, emphasize the need of multimedia adaptation techniques specifically developed for educational multimedia that also consider the effect of adaptation on the visual learning contents and perceived learning effects.

In this thesis, we argue that the perceived learning effects of a learning multimedia are dependent on its quality and modality. Lowering quality of multimedia beyond a certain level may have negative effects as a result of perceived information loss. We emphasize that adaptation techniques should be developed for educational multimedia that also take into account the impact of adaptation on perceived effectiveness of learning contents. We propose a power saving learning multimedia adaptation approach. Our proposed approach, published in [31], considers the perceived learning effects of a learning multimedia in the adaptation process. This approach ensures maximum battery efficiency while keeping the educational multimedia in an acceptable form for learning activity. We try to provide optimum power-saving while at the same time preventing any perceived negative effects on learning as a result of the adaptation.

Chapter 3:

Power-Saving Adaptation of Educational Multimedia

Mobile devices are increasingly being used to connect to the Internet. The advances in mobile and communication technologies have also opened further avenues of learning using mobile devices. Enhancements in mobile devices, like higher data rate internet connectivity, processing capability and higher resolution displays enable the use of online multimedia learning resources on mobile devices. Mobile learners can now access the rich educational online multimedia content anytime and anywhere [5].

Improvements in battery capacity have not matched the same advancements compared to other features of mobile devices. Limited battery power is a significant challenge in making better use of online educational multimedia resources. Online multimedia resources drain more battery power, as a result of a higher amount of wireless data transfer and therefore limiting learning opportunities on the move. We discussed battery efficient multimedia adaptation techniques in Chapter 2. These adaptation techniques tend to degrade multimedia quality in order to extend the battery life [19]. We pointed out that these existing techniques are generic techniques that do not consider perceived learning effect and we concluded that there is a need for designing battery power-saving mechanisms specifically for educational multimedia. These techniques would differ from generic techniques, in that they consider perceived learning effect aspects in their adaptation strategies and would focus on perceived information loss as result of adaptation.

This chapter addresses research question RQ1 and RQ2. In this chapter, we first present a conceptual model that will help us better understand the relationship between presentation quality of multimedia, the detail of information contents and energy consumed by multimedia, while streaming and playing on mobile devices. Later in this chapter, we describe a user study that we conducted, in order to get an insight into problems that may arise while applying generic adaptation solutions on educational multimedia. The result of the user study will be used to answer the research question RQ1.

3.1 Quality-Information-Energy Relationship Model

One aim of our research is to identify ways to improve energy efficiency in streaming multimedia on mobile device from learning activity point of view. In this section, we develop a conceptual Quality-Information-Energy Relationship Model that will show how energy consumed by a mobile device is related to the quality of a streaming multimedia resource and the detail of information contained in it.

We have studied existing literature on content adaptation from the aspect of improving energy efficiency for online multimedia content retrieval on mobile devices. Based on our study of Content Adaptation and Adaptive Hypermedia literature, we can say the following:

1. Every multimedia resource consists of two parts: information contents and its presentation.
2. Adaptation techniques can change the presentation quality of multimedia.
3. Adaptation techniques can change the detail of information in multimedia.

CPU, Network Interface and Display are the main power consuming components of handheld mobile devices. Wireless Network Interface (card) uses a large percentage of battery power – up to 50% on mobile devices [106]. Studies in [81] give an energy consumption model for downloading data (in bytes) over 3G, GSM and Wi-Fi networks. This suggests battery power consumption could be reduced by reducing the amount of data transfer on mobile devices. Reducing the total data size of the streaming multimedia would reduce the data transfer at the Wireless Network Interface that would lower the battery power consumption. Figure 3.1, from [81] shows energy in joules spent by each wireless technology to download different size of data (in KB).

A multimedia stream of higher quality has bigger data size than the same multimedia in a lower quality. Another factor that increases the total size of data of a multimedia resource is the duration of multimedia. For example, an abridged version of a resource will have a smaller data size than the original longer version. So reducing the quality and the detail of information in a resource reduces the size of a multimedia resource and can be used to achieve energy efficiency.

We can, therefore, say that there are two ways in which we can achieve energy efficiency in the context of streaming learning multimedia:

1. Reduce the presentation quality of the multimedia.
2. Reduce the detail of the information in the multimedia.

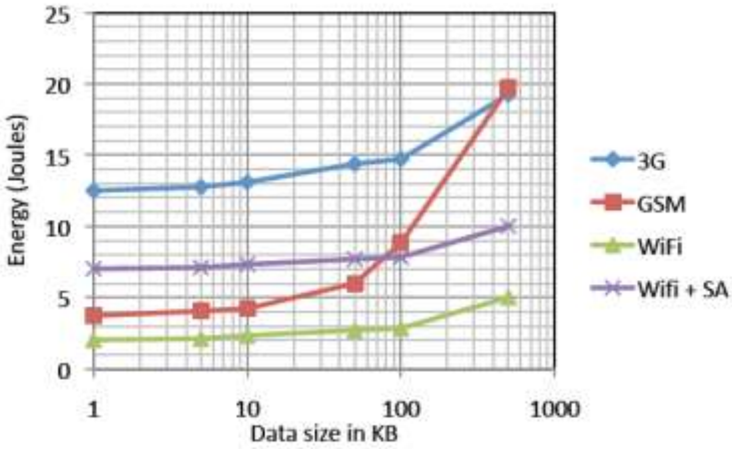

Figure 3-1 Relationship between data downloaded and energy consumption [81]

3.1.1 Reducing the presentation quality

Degrading the quality of multimedia reduces the total data size (bytes) of the content, and therefore can reduce the energy needed during data transfer to a mobile device. Multimedia quality can be lowered in many ways up to different levels, resulting in different levels of battery-power saving. For example, we can change resolution, frames per second, bitrate, number of colours and modality of content, to save battery-power.

Reducing the quality of content beyond a certain point can have a negative impact on the visual information contents and may result in perceived information loss. For example, reducing the bitrate beyond a certain limit would degrade the quality to the extent that some visual information content may be perceived to be incomprehensible. In the context of learning multimedia this may have negative impact on the perceived learning effect. Similarly, a video converted into much reduced frames per second as a sequence of images may not convey the same information, if the information is contained in motion of one or more objects in the original video. Furthermore, a coloured graph or diagram that visualises information in different colours can convey more information than the same graph in black and white. As a more extreme example, reducing the resolution of a video beyond a certain limit will render the video completely incomprehensible.

We can say that there is always some lowest acceptable quality for different kinds of visual information contents. This concept is explained diagrammatically in the Figure 3.2.

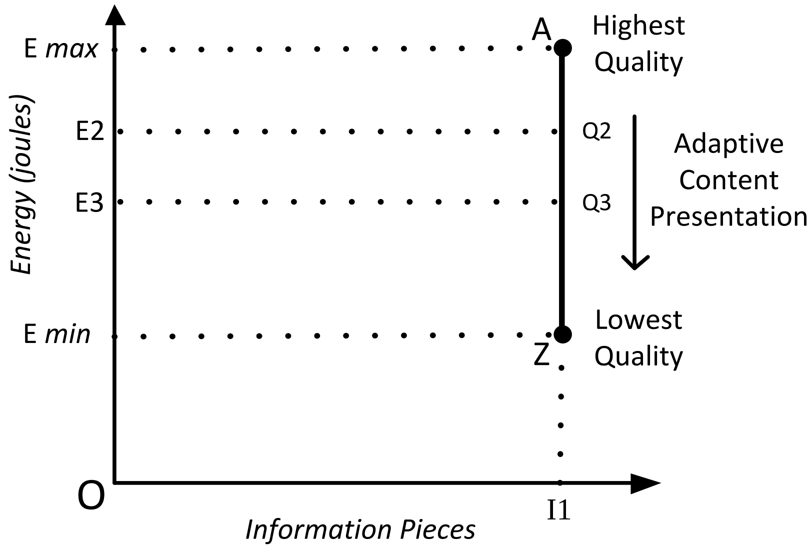

Figure 3-2 Battery-Power Saving using Adapting Presentation

Figure 3.2 represent the impact of reduction in multimedia quality on energy consumption. Point A represents complete multimedia of full duration consisting of all information content in the highest available quality that would require maximum energy E_{max}, among the available options. By moving from point A to point Z, we reduce the presentation quality, keeping the same detail of information or total multimedia duration. Point Z represents the lowest acceptable quality of the multimedia that will not result in any perceived information loss. The presentation quality at point Z depends on the nature of visual information in multimedia. For example, if the visual information is quality sensitive, then this lowest quality will be higher than in case of a multimedia where visual information is not quality sensitive. We can see E_{min} is the energy consumption that will be consumed if the entire multimedia is delivered in the lowest available acceptable quality. Q2 and Q3 represent multimedia in intermediate qualities, which would consume energies E2 and E3, respectively. It is important to mention that for any multimedia the exact values of E_{max} and E_{min} (in joules for example) are not fixed. The exact energy consumption values depend on many factors, including the kind of mobile device, network connection type and available signal quality.

3.1.2 Reducing the detail of information

Another way to achieve energy efficiency is to consider the reducing detail of the information presented in a multimedia content. This means removing parts of the content that are less important or not relevant for the current user. Existing Adaptive Hypermedia techniques uses this technique to personalize content for different users based on a User Model – which include the users' background knowledge - and the prerequisites for that information.

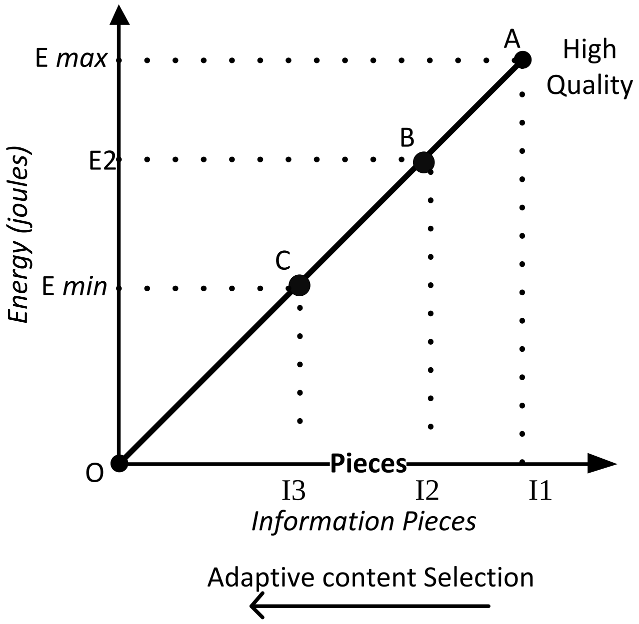

Figure 3-3 Battery-Saving using Content Selection

For example, if a user has some background knowledge about a topic, then they would like to skip those portions of the resource that defines and explains basic introductory concepts. This would reduce the overall data size of the resource and would need lesser energy during data transfer at mobile device. Deleting some content fragments reduces the entire size and duration of use of the content – which will need less time to retrieve and play back as well, resulting in a saving of battery power. This method though needs considerable input from authors of the content in the form of metadata.

Figure 3.3 shows the relationship between the detail of information in multimedia and energy consumption. Line A-O represents how the energy requirement is reduced as we decrease the amount of information pieces in a multimedia. Point A on the line represents the entire multimedia with all information in the highest quality; this content will consume maximum energy E_{max}. Point B represents the reduced information level I_2 after skipping lesser important multimedia pieces of the same quality. This would reduce the energy consumption to E_2. Similarly, point C has further reduced information content I_3 and would require less energy. I_3 represent the minimum information that must be contained in the multimedia for learning purposes. Any further reduction in the multimedia duration would not convey sufficient learning information.

Content reduction can be achieved by selecting fewer content pieces. Skipping content pieces could be done on the basis of knowledge level of user or relative importance of the content pieces. The most important content fragments are selected first followed by lesser important content fragments for the user. In reality we cannot select amount of information at any random point. We can only select a subset of fragments from the whole set of fragments in order of importance. It is important to mention that in reality the energy consumption is not a linear function and the straight line AO is only representation for understanding purposes.

Content reduction or Adaptive Content Selection may be done using adaptive hypermedia techniques represented by 'inserting/removing fragment' by Brusilovsky in [43]. Adaptive Content Generation means selection of content fragments based on a user model to produce the final content. Presentation quality reduction may be achieved using techniques called Adaptive Content Presentation in adaptive hypermedia terminologies. Adaptive Content Presentation is changing the quality parameters to meet some constraints.

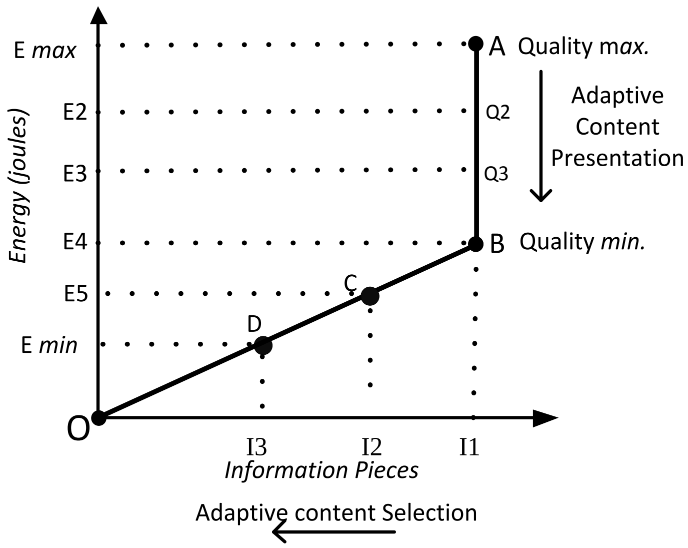

Figure 3-4 Combined Quality and Information Adaptation

In Figure 3.4, we combine content reduction with quality reduction. From point A to B we save battery power by reducing presentation quality of multimedia. From point B to D we can further save battery power by reducing the number of fragments in the multimedia based on a certain defined criteria. Point D represents multimedia content in the lowest acceptable of the available presentation qualities with minimum possible information.

In Figure 3.5, we show how a battery efficient learning multimedia system should work and display some usage scenarios. Figure 3.5 shows how different users with different preferences receive different versions of the same content.

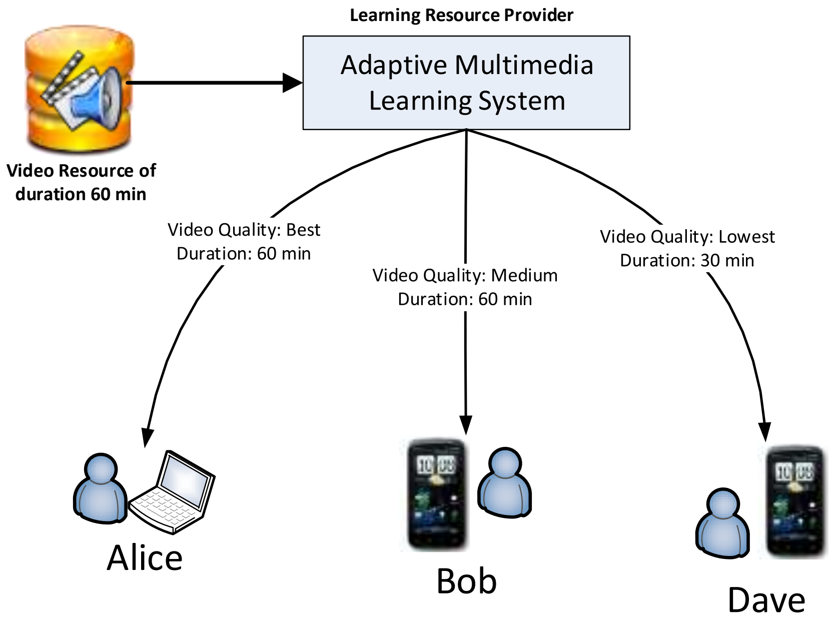

Figure 3-5 Battery Saving Scenarios in Learning Multimedia Adaptation

For example, Alice, Bob and Dave are students of the same class and are interested in a learning video about the concept of Inheritance in C++ programming. They all have studied a course in Object Oriented Programming using Java. Alice has a laptop; Bob and Dave have smart phones with Wi-Fi connections. They all use an adaptive mobile learning system to get the desired multimedia. Alice has laptop and can receive high quality content and she is not interested in saving laptop battery power. Bob is also not interested saving mobile phone battery. Dave wants **to save battery power** while using this learning content. Based on the preference and constraints of the devices, the following versions of the content were delivered to each user.

Alice’s laptop could afford to display high quality content in highest resolution so she receives high quality content of full duration (60 min). Bob has mobile phone and cannot play high quality content, so he receives medium quality content of full duration. Dave has same mobile and background knowledge as Bob and could afford to play medium quality content. But his preferences show that he is interested in battery power-saving, therefore, Bob received the lowest quality Content of lesser duration based on his background knowledge.

Based on the discussion, illustrations and explanations, we now present a conceptual model, Quality-Information-Energy relationship Model.

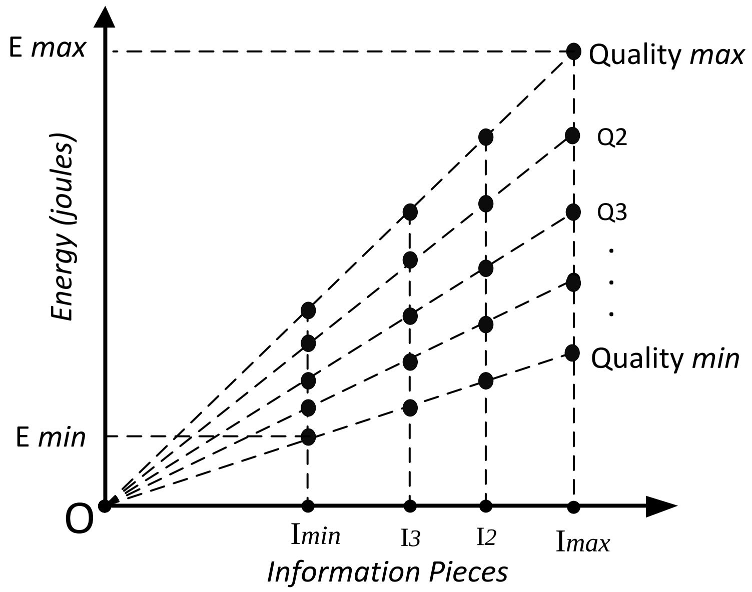

Figure 3-6 Quality-Information-Energy Relationship Model

In Figure 3.6, we present the complete Quality-Information-Energy relationship model. All the bold dots on dashed lines represent entire selection space for a learning multimedia. A dot represents a specific number of multimedia pieces in a specific quality. We see a multimedia can be delivered in a number of available qualities ranging from $Quality_{max}$ to $Quality_{min}$. Each multimedia can have specific information that consists of a number of multimedia fragments. We can see E_{max} is maximum energy consumption and E_{min} is the minimum possible energy consumption in the context of the figure.

We can now have some further explanatory examples. Figure 3.7 shows how for a given energy budget E_i we can have different options. We can choose to deliver different details of information in different presentation qualities. We can choose multimedia with least detail I_4 in a highest quality Q_1, a little more detailed information of level I_3 in slightly reduced quality Q_2 or complete multimedia in Q_4.

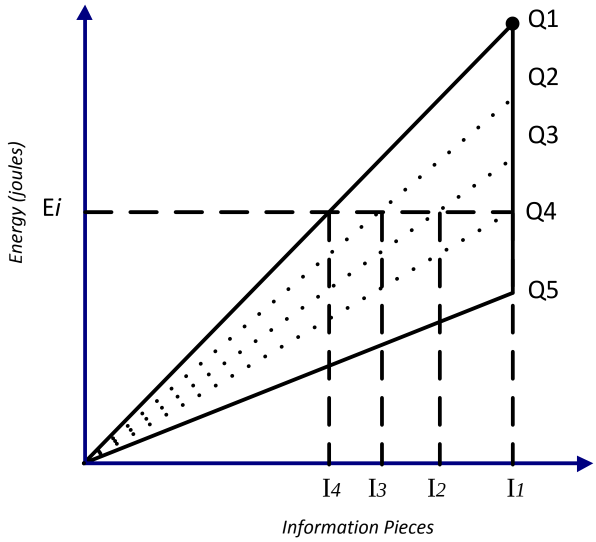

Figure 3-7 Example 1

In the same way Figure 3.8 shows how a multimedia of given information level I_n can be delivered in multiple energy budgets. If we chose higher quality then we will be spending maximum energy E_1, or if we want to save further battery power then we can choose Q2, Q3, Q4 or the lowest acceptable quality Q5 which will save maximum battery power at energy level E_5.

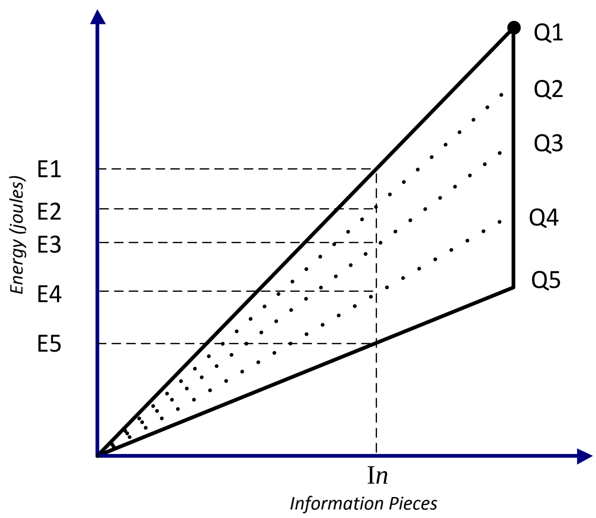

Figure 3-8 Example 2

3.2 Problems in Existing Multimedia Adaptation Solutions

Existing adaptation techniques are susceptible to perceived information loss as a result of quality of reduction. Such losses can negatively affect the perceived learning effect and may jeopardize the learning process. We have observed that Educational Multimedia mostly relies on existing generic adaptation mechanisms for adaptation in order to meet resource constraints in mobile devices including battery power. There is a lack of specific multimedia adaptation mechanisms for educational multimedia. We believe it is important as educational multimedia has specific learning objectives and adaptation mechanisms must consider this additional factor in adapting educational multimedia.

Existing generic multimedia adaptation mechanisms degrade quality of multimedia content uniformly without considering the nature of visual contents in different videos segments. Evaluation of these multimedia adaptation techniques are based on evaluating parts of videos (mostly of few seconds durations) and not on complete video or different representative segments. Most of educational videos do not comprise of the uniform or similar kind of information. Various segments or parts of videos differ in nature and detail of visual information. A selected lowered quality of video may be suitable for one segment but may not necessarily be suitable for another part to successfully convey visual information with any perceived loss in information. The learning visual information, therefore, may not be comprehendible and the objective of learning multimedia may be compromised. The following are the possible problems when generic 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 perceived learning effect. These methods are not content-aware. This means that quality degradation decisions are enforced irrespective of the contents of the multimedia. This may make the multimedia content unhelpful for learning purpose if the learning content was quality sensitive and required a higher quality for avoiding perceived loss of information.
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 as a result it either may not remain fully useful for learning due to some perceived loss of information or provide lesser than the achievable (maximum possible) power efficiency. The description of these issues is given below.

a. *Battery efficiency at cost of compromising learning:* Parts of an educational video content that contains quality sensitive visual information might require a higher quality than the selected one for successfully conveying information without any perceived loss of information. Moreover, it is not possible that a generic method could decide about acceptable presentation qualities for all educational multimedia. Such systems would achieve power-efficiency with unpredictable consequences for perceived learning effects and may be negatively impacting the educational value of resources as a result.

b. *Reduced Power efficiency:* This problem has the following two dimensions.

   i. It may be possible that only few segments from the entire multimedia require a higher presentation quality for safely convey the learning information without any perceived loss of information. The remaining parts multimedia may convey the learning information in a lower quality. In order for acceptable perceived learning effect, these few segments must be delivered in a higher quality. As the entire resource could only be delivered in one uniform quality, the entire multimedia would be delivered in a higher quality. This would result in spending more battery power than the required extent. Most of the resource could be delivered in a lower quality. A fragmented approach would be helpful in this case. In this way, only the fragments needing higher quality would be delivered in higher quality and the rest could be delivered in a lower quality saving battery power.

   ii. It may also be possible that the selected lower quality - selected based on the acceptable user experience - may still be high enough for learning. The same information contents may be delivered safely without any perceived information loss in further lower quality version without compromising on the perceived learning effect. A good example is a learning video where there is no significant visual information; the audio version in this case would provide the same learning information. So the video version even if in a very lower quality would be a waste of battery power if power-saving was desired.

We conducted a user study in order to investigate the above mentioned issues and to understand if different parts of the same multimedia resource have same minimum presentation quality requirements or if it differs for different parts in order to avoid perceived information loss. This study would help us know if a single uniform quality for entire multimedia as output of an adaptation technique has any negative impact on perceived learning effect. In Section 3.3, we present details of the user study.

3.3 User Study

3.3.1 Research Design

This user study was designed to investigate if the entire multimedia learning resource can be delivered in a uniform lowered quality without negatively impacting any visual information. This means that we wanted to understand if at different temporal points of the same multimedia – that would have visual information with varying characteristics – may have different requirements in terms of minimum presentation quality for conveying the learning information. For this purpose, in this study we presented different short clips from learning multimedia from different portions with multiple visual quality versions to the participants of the study and asked if they could comprehend learning information in specified fragment versions. It is important to note that, we did not ask participants to actually engage in any learning activity. The whole objective was to see if there is any variation or differences in acceptance of lower qualities at different points. This was an information comprehensibility exercise instead of a learning exercise, where participants would tell us if they think they could comprehend the visual information or if a higher quality was needed to comprehend the information due to the perceived visual information loss.

3.3.2 Research method

We designed the study as a quantitative study. We received ethical approval from the University of Southampton Ethics Committee to undertake these evaluation studies under reference number **4301**. We selected three freely available educational videos on the following topics: Ohm's Law, C++ and the Semantic Web. These videos were different in terms of the way visual information was presented. The video on Ohm's law (Video 2) was a recording of a teacher with a white board. The video on C++ (Video 2) was a mix of slides and practical activity like writing code in some editor. The video on the Semantic Web (Video 3) was consisted of slides only, with slides varying significantly in the level of detail of visual information on each slide. We selected five fragments from each video with visual information of varying nature. All selected fragments were of duration 15-20 seconds and they differed from each other in terms of the type and detail of the visual information. This difference can be observed from the screenshots of the video fragments given in the Figures 3.9, 3.10 and 3.11.

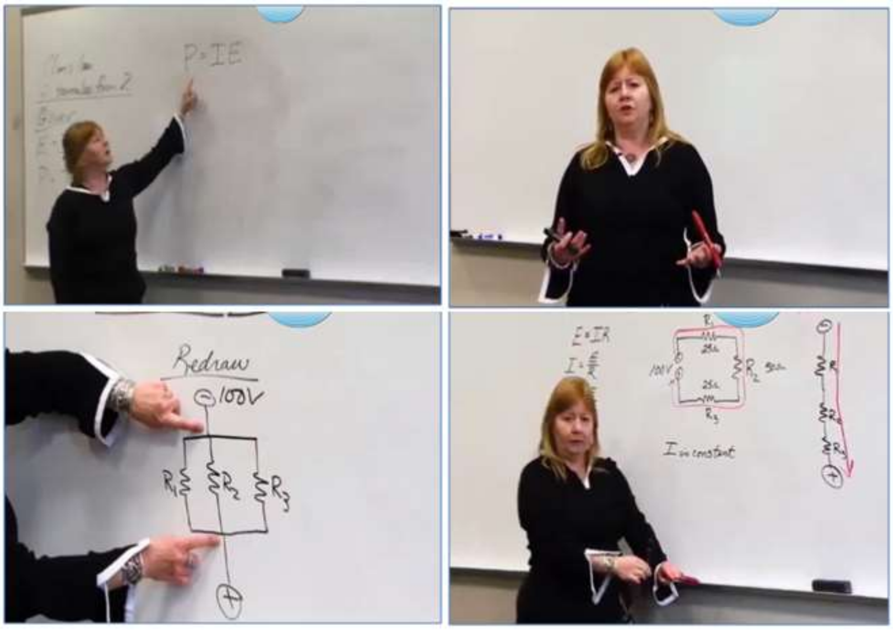

Figure 3-9 Fragments from Video 1 (Ohm's Law Clip)

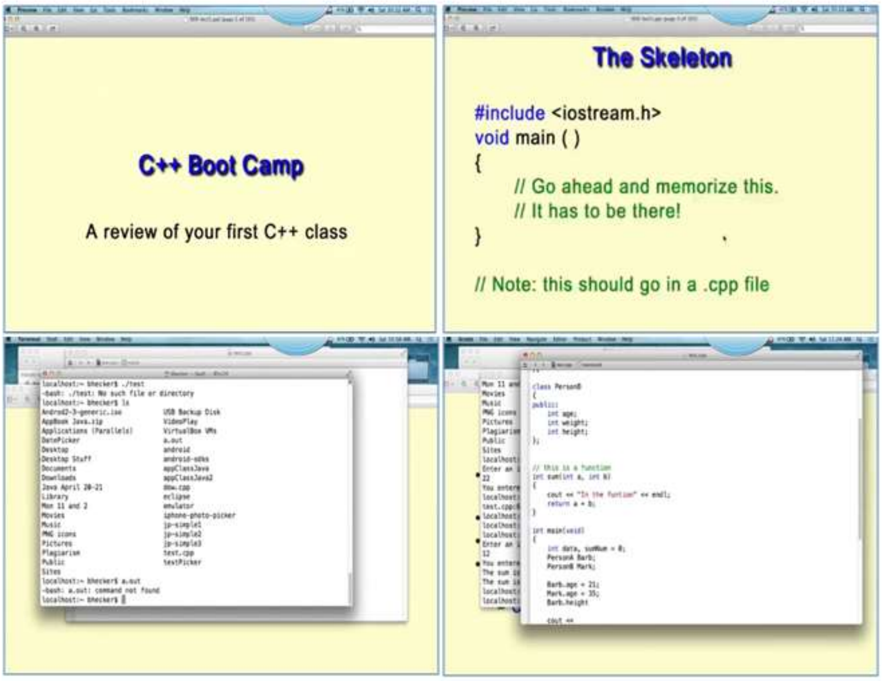

Figure 3-10 Fragments from video 2 (C++ clip)

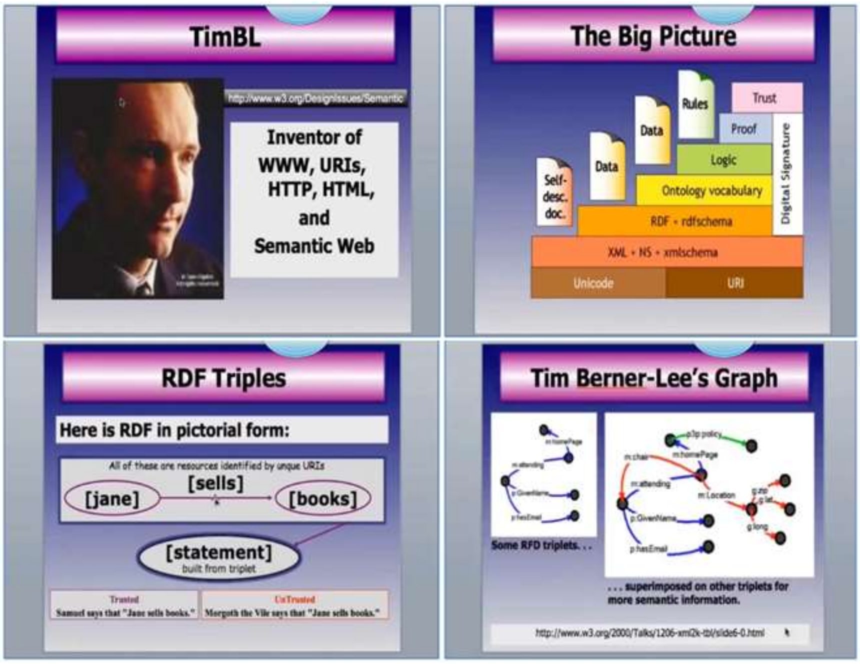

Figure 3-11 Fragments from Video-3 (Semantic Web Clip)

The major difference between our study and other content adaptation experiments, especially the one with educational multimedia, is that we did not a take a one small clip from the entire learning multimedia for the purpose of evaluations, as done in [26], [27] and [28]. We, instead, took five fragments from different parts of each learning multimedia with different visual characteristics of the information contents. We made sure that the selected fragments vary in visual presentation and the visual nature of information contents. The details of visual information were different in each fragment.

As we mentioned earlier, the objective of this study was not to ask participants of the study to perform any learning activity. We were interested to know in the participants' perception about any visual information loss and opinions about which visual quality they think resulted in the perceived loss of visual information in any fragment. We chose to take multimedia fragments of smaller duration and asked participants to identify any perceived loss of visual learning information. By including audio-only fragment versions, we wanted to know if the participants of the study believed that they could comprehend the information without any support of visual information in some clips.

It is also worth mentioning that these smaller clips (20-25 seconds) do not relate to the concept of fragments that we refer to in the proposed CAPS-EMA adaptation approach to be discussed later in Chapter 4. These smaller clips are used for evaluation only to correspond to different temporal points of multimedia. The selected clips may belong to a larger fragment of multimedia and may span up to duration. It is important to further clarify that we do not suggest in any way, that learning could be performed from clips of such smaller duration.

We encoded all clips at four different qualities (Q1 – Q4), with one (Q4) in audio-only quality. Quality encoding parameters for all qualities are described in Table 3.1. We had a total of 20 video clips for each learning video and a total of 60 clips for all the three videos. The video versions of the clips were encoded without audio, in order to allow participants to focus on visual information only without any help from audio. This would ensure that audio will not compensate any loss of visual information. This was done to help us to know exactly if the visual information was comprehensible in any quality or not. The bitrates of the video clips in qualities Q1-Q3 with video with audio would be higher than the mentioned figures. The total bitrate of Q1, Q2 and Q3 with a medium quality audio would higher by at least 128 or 64 kbps then the given bitrates. The audio quality (Q4) version was encoded with single channel minimum bitrate, which is only 32 kbps.

Table 3-1 Description of Presentation Qualities

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

We have chosen four quality levels at the lower end of qualities. So the highest quality Q1 is much lower than what would be considered as higher quality in practice in normal circumstances. High quality streaming multimedia in practice would be 1000 kbps or more. Furthermore, the qualities selected are not based on the literature that evaluates multimedia quality from the Quality of Experience (QoE) point of view. As we discussed in section 2.7 of the literature review section, there is no standard way of reducing multimedia quality. We have mentioned in the section 2.7 that different researchers used different number of quality levels with different encoding parameters and bitrates.

As mentioned in section 3.2, we could not find any standard way of degrading quality in the researches focused on power-saving multimedia adaptation. Furthermore, we would not be following any QoE based methodology for our study, as the purpose of our study was not to provide better QoE in terms of perceived quality of multimedia. Instead this thesis is focused on comprehension of visual information and on perceived loss of visual information.

We did not include multimedia clips in their original high qualities versions in the user study and only considered their encoded lower quality versions. Original qualities of the multimedia we selected were of higher qualities, and mostly there are no visual information issues. We chose to focus our study on the lowered qualities as it is the lower adapted multimedia qualities where the problem of visual information loss could occur due to adaptation process. Our investigation, therefore, is limited to see the impact of lower qualities on comprehending learning information.

In the user study, our objective was to gather participants' feedbacks about each version of each multimedia clip, and then analyse which multimedia clips were acceptable in which multimedia version for information comprehension. As Different clips of the same multimedia resource represents different temporal points of the multimedia, the results will suggest if different qualities were acceptable for information comprehension at different points in multimedia.

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

3.3.3 Procedure

During the study only one participant was used at a time. We briefed each participant before starting the study about the procedure. The participants were not told about the purpose of the study. The participants were guided about how to provide opinion 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 versions of the clips. The statements for video and audio versions are given in Table 3.2 and Table 3.3, respectively. Each participant was asked to provide their opinion after watching each clip. The participants were requested to specify their opinion on a four-point likert scale from Strongly Agree (4) to Strongly Disagree (1) with no neutral opinion. Below we explain the purpose of the questionnaire statements.

Table 3-2 Questionnaire statements for video clips

Clip ID: BC3	**Strongly Agree**	**Agree**	**Disagree**	**Strongly Disagree**
Visual information that is focused in this clip is visible.				
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.				
If I **DO NOT** need battery power saving, I am still comfortable with this visual quality.				

Table 3-3 Questionnaire Statements for Audio Clips

Audio Clip ID: BD4	**Strongly Agree**	**Agree**	**Disagree**	**Strongly Disagree**
Information in this Audio clip was understandable without requiring visual support.				
If I **NEED** to save battery power, I am happy to have this information in Audio instead of spending more battery power on video.				
If I **DO NOT** need battery power saving, I am still comfortable to have this information in Audio instead of Video				

3.3.4 Explanation of Questionnaire statements

The statement 1, mentioned in Table 3.4, is about understanding if a specific version of a clip is suitable to convey the desired learning information without any perceived loss. For the video versions we asked about the visual information that is presented or being displayed in the clip. We expected participants to agree with this statement, if a video version of a clip was in a visual quality that was good enough for comprehending the visual information without any perceived loss. If the version was in audio-only quality then the participants should agree to the statement if the version (audio) of the clip could successfully convey the intended information in audio without any need for visual support. For example, if a clip is lower quality version of any clip and a participant feels that the visual information that is being displayed is not comprehendible then we expect users to disagree with the statement.

Similarly, if the audio was just a verbal explanation of some concept and did not refer to any visual information which was available in video, then audio should be acceptable for this piece of information. Otherwise if the visual content was required to understand the information contents of the audio then the audio version was not acceptable for such clip.

Table 3-4 Statement 1 for Video and Audio Clips

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 any support in visuals.

Table 3-5 Statement 2 for Video and Audio

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.

Statement 2, mentioned in Table 3.5, is about battery power-saving scenario. We want to understand about participants' opinion if a video clip version was acceptable to them for learning purposes, in case, they wanted to save battery power or if participants would prefer to spend more battery power to have the clip in a higher presentation quality. For example, if a learner wants to preserve battery-power, then it means a learner should receive a video clip in a quality that serves the purpose of comprehending the information without any loss of information while consuming a minimum of battery power. If a participant agreed to this statement, that would mean the participant was not willing to spend more battery power by having the information in a higher quality and that there was no perceived loss of information.

Similarly, statement 2 for the 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 agreed to the statement for the audio version of a clip, that would mean the audio quality was good enough for the learning information in that clip and the participant would like to save battery power, instead of spending more battery power on the video quality.

Table 3-6 Statement 3 for Video and Audio Clips

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

Statement 3, mentioned in Table 3.6, is about a scenario where the participants would not be interested in battery power-saving. We want to know about users' acceptance opinion about the quality of a version of a clip, in the situation where battery power-saving is not desired, that is, the participants could spend more battery power on a higher quality if they want. Responses to this statement would help us to understand responses to statement 2 in a better way, and may reflect any compromise on quality due to battery power-saving preferences.

3.3.5 Results

We now present the participants' opinions about each clip version of each video. From the results we will try to understand the acceptance of each clip version of each video clip. We present results for each experimental video separately and discuss the opinions for each of the three statements.

Video 1

In Figure 3.12, we present a summary of the participants' opinion about the video 1 clip. In the figure Q1, Q2, Q3 and Q4 represent the video qualities, with Q1 being of highest quality and Q4 in audio quality. F1, F2, F3, F4 and F5 mean video fragments (clips). Results for each video include three tables, one for each statement. The values in the table are the total number of positive responses. Seven participants viewed each clips, so each value is out of a total of 7. The value 7 in a box means all of the participants responded positively for that statement about a clip, while 0 mean no participant responded positively, that is, nobody agreed to the statement. Boxes in green shade represent the lowest quality with all positive responses for that clip. All green shaded boxes have all positive responses for statement 1 and 2, except for statement 3, where not all participants gave positive responses about acceptance of the quality of the clip where battery power-saving was not required. For statement 3, for all videos, we have green shades in boxes where maximum participants (5 or 6) responded positively. Overall, we consider the green shaded box as the lowest acceptable of the four qualities for a 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	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

Lowest quality with maximum acceptance   Not acceptable for majority

Figure 3-12 Summary of Results for Video 1 (Ohm's Law Clip)

We can see in the figure for Statement 1 that the lowest quality that successfully conveys the information varies significantly. Information in F2 could be conveyed in Q4 which is Audio. This means F2 can convey its information in all four qualities. On the other hand, information in F3 could only be comprehended in Q1 (the highest quality) only, we can see delivering F3 in any lower quality will result in perceived information loss for many participants.

For statement 2, we can see the responses were similar to statement 1. We see that in order to save battery life of mobile devices, the participants were willing to receive multimedia in the lowest quality that can successfully convey the contained information without any perceived loss. The lowest quality for each fragment can be seen in responses for statement 1.

Statement 3 is about the situation when battery power-saving was not desired. We can see that the participants clearly wanted a higher quality for all clips. This shows there was a compromise in the expected battery-saving situation.

Video 2

Figure 3.13 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 clip to clip. For statement 3, responses for F1 and F2 show that Q3 was acceptable, even when battery saving was not an issue. In case of statement 3 for video 1, acceptable qualities were only Q1 and Q2.

	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

Lowest quality with maximum acceptance   Not acceptable for majority

Figure 3-13 Summary of Results for Video-2 (C++ clip)

Video 3

Figure 3.14 shows responses for Video 3 for all the three statements. We can see similar pattern in responses like clips from video 1 and video 2. Minimum quality varies from clip to clip. There is no single lowest acceptable quality for all clips of the video 3.

	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

Lowest quality with maximum acceptance   Not acceptable for majority

Figure 3-14 Summary of Results for Video-3 (Semantic web clip)

3.4 Discussion

The results confirm that there was no single lowest of the available qualities for all different clips of the same multimedia in order to convey the contained information without any perceived loss of some information. The participants' opinion suggested different minimum quality levels, from the available qualities, for different clips, if they were to achieve power-saving by accepting a lower power-efficient quality.

Hence, the results suggest that different clips of the learning videos have different lower qualities as acceptable minimum qualities. These results support the position that adaptation techniques for educational multimedia must consider the aspect of perceived visual information loss, due to lowering the presentation quality. Our results suggest that this may cause perceived visual information loss, which may have negative impact on perceived learning effects.

For example, in video-1, if an adaptation mechanism selected Q3 for the entire video, then we can see that there could be perceived information loss problems in clips F3, F5 and other similar parts of the video. Even for Q2 there will be problems in clip F3 and other similar portions of the video-1 which actually require Q1 for avoid perceived loss in visual 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 entire video in order to keep the learning information of multimedia in a comprehensible form, then we can see in case of video-1 that we would be delivering multimedia in higher quality then the acceptable ones for clips F1, F2, F4, F5 and all other portions of the multimedia that would be similar to these. This will result in less than optimal power-savings.

Based on the discussion, we can conclude that any adaptation mechanism that adapts an educational multimedia should consider the impact on learning information contents in the adaptation process. This can be done if the adaptation is performed on a fragment by fragment basis. This can be achieved by using some metadata about each portion (fragment) to specify the lowest acceptable quality constraints for those portions (or fragments). These quality constraints in the metadata would then guide the adaptation process. Such adaptation mechanism can be called a content-aware adaptation mechanism. Metadata created by multimedia authors or subject experts has an important role to play in such adaptation approach. In Chapter 4, we propose an adaptation technique for educational multimedia. This proposed solution is aimed to address the objections we have raised on the commonly adopted generic adaptation solutions.

3.5 Conclusion

The main aim of this chapter is to identify the potential problems when the commonly used power-saving multimedia adaptation approach is used for adapting educational multimedia by lowering the quality of entire multimedia uniformly. Firstly, we explain how reducing the presentation quality and detail of information helps in reducing the battery power consumption in streaming multimedia. Based on these descriptions we develop a Quality-Information-Energy model. This model may be helpful in understanding power-saving in multimedia streaming through adaptation. We identified potential problems of using the approach of uniformly decreasing the presentation quality of the entire educational multimedia for power-saving.

This chapter then presented a user study aimed at understanding if there exists any variation in the minimum multimedia quality requirements for different portions of the same multimedia, in order for learners to successfully comprehend the visual learning information. The results of our study show that different parts of the same educational multimedia may require different lowest qualities for comprehending the information contents. These results strengthen the case for a content-aware power-saving multimedia adaptation approach, specifically for learning multimedia where it is vital to convey learning information without any perceived information loss. Such enhanced adaptation approaches would degrade the presentation quality of different parts, while considering the minimum quality requirement of each part of the multimedia. We present our proposed enhanced content-aware power-saving adaptation approach in Chapter 4.

Chapter 4:

Content-Aware Power-Saving Educational Multimedia Adaptation (CAPS-EMA)

4.1 Introduction

Battery efficient multimedia adaptation is different from other multimedia adaptation techniques; other adaptation techniques tend to provide users with the best possible user experience and the best possible quality that their device can use under the constraints of the device resources. On the other hand, the objective of power-saving multimedia adaptation is not to provide the best possible user experience and the multimedia quality, but a lowered quality with a 'compromised' user experience, in order to extend battery life. This has been discussed in the literature review chapter. The basic principle is that a mobile device might be able to use higher quality content, but in order to preserve battery-power, a lower quality is delivered that would consume less battery-power. This, however, must not be done at the cost of compromising the whole purpose of any multimedia. Successfully conveying learning information is the objective of any learning multimedia. An adaptation process applied to educational multimedia must keep the information in the adapted multimedia understandable and comprehensible.

Existing power-saving multimedia adaptation techniques are generic techniques, which are not designed in a way that consider the aspect of perceived loss of visual information during the adaptation process. These adaptation techniques are based on the approach of 'uniformly' lowering the quality of entire multimedia. It means that a single multimedia quality is selected for entire multimedia, irrespective of the information contents in various portions of a multimedia. Our study results in section 3.3.5 showed that such adaptation could lead to some problems for educational multimedia. It either may result in negatively impacting the perceived learning effect by causing perceived loss of visual information or may not achieve the achievable power-savings without loss of visual information. We discussed these problems in detail in section 3.2.

In this chapter, we address the research question RQ3. In this chapter, we introduce a power-saving content-aware adaptation approach that aim to address the issues in generic power-saving multimedia adaptation, identified in Chapter 2. The output of our proposed adaptation strategy would not be in one uniform quality for entire multimedia; instead, the output would be multi-quality and multi-modal, depending on the information contents in different portions of the learning multimedia. The output quality would be multi-quality, as the each of portion of multimedia that has visual information of different nature would be delivered in a quality suitable for those particular portions. The basic idea is that, in order to consume minimum battery power, a learner device should not consume more battery power than what is necessary for conveying the information contents in an acceptable quality, i.e. the visual information should be comprehensible without any perceived loss of information. Every segment of multimedia is delivered in the minimum quality that is good enough to comprehend the information. We recommend that this additional information about the lowest acceptable quality for each portion is stored as metadata at multimedia authoring stage. For example, if decreasing the resolution or the bitrate beyond a certain point makes the visual information in some portions of a multimedia not comprehensible, then the proposed adaptation strategy suggests delivering that portion of multimedia in a higher quality, to keep the information comprehensible. Similarly, if a video segment converted to audio to achieve battery efficiency might leave the entire resource unusable for information purposes, as this will remove important visual information, then this adaptation mechanism will make sure that the output modality for that piece of multimedia is never audio. All this is possible with the help of additional metadata that will enable to put constraints on different portions of the multimedia. We refer to this as the content-aware adaptation strategy.

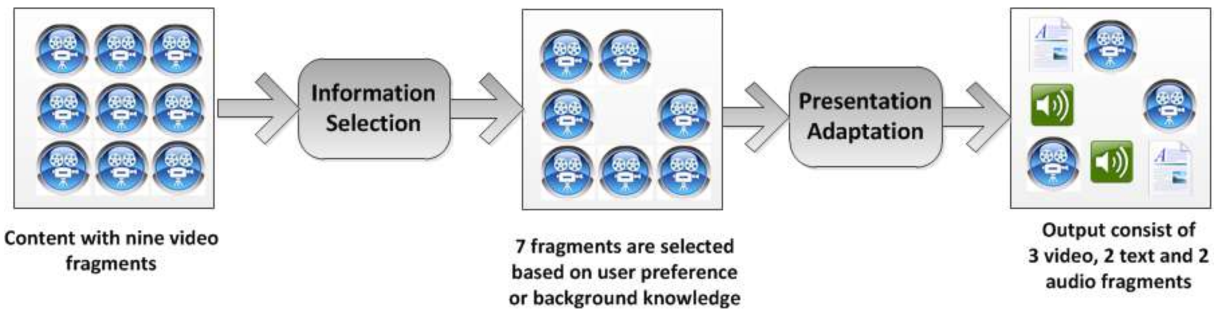

Figure 4-1 Content-Aware Adaptation

A content-aware battery power-saving method may replace some portion of a video by some text if it can convey the desired information. A content-aware strategy may also decide to skip some media fragments if they are not important for a specific learner. Such a content-aware adaptation strategy is represented in Figure 4.1, which represents a scenario in which a multimedia content having nine video fragments was adapted into a set of three video clips having different qualities, two audio clips and two text fragments based on some energy consumption preferences and learner's needs. We now introduce our proposed adaptation strategy, which we call Content-Aware Power-Saving Educational Multimedia Adaptation (CAPS-EMA).

4.2 Content-Aware Power-Saving Educational Multimedia Adaptation (CAPS-EMA)

In order to address the identified shortcomings in existing generic multimedia adaptation techniques, we present Content-Aware Power-Saving Educational Multimedia Adaptation (CAPS-EMA) mechanism. This approach aims to provide battery efficiency through multimedia quality reduction while keeping all portions of the adapted multimedia in an acceptable form, by avoiding perceived loss of information in any portion of the multimedia. This approach proposes the lowered quality during an adaptation should be determined based on the requirement of each portion of a multimedia. The entire multimedia, therefore, has to be accessible as fragments, where each fragment is available is multiple quality versions. CAPS-EMA does not recommend any minimum or maximum duration of a fragment. This is one of the distinctions from generic existing approaches where entire multimedia is available in multiple quality versions. Storing multiple versions requires extra storage space on server, but this investment enables a much useful form of adaptation. Storing multiple quality versions in adaptation approach is not new and this has been discussed in the literature on multimedia adaptation in Chapter 2 in detail. In CAPS-EMA we propose storing multiple versions of each fragment. Storage of multimedia as fragments and that too in multiple versions is not a new approach. Adaptive streaming techniques also store multimedia as fragments and in multiple versions. So it is widely adopted approach in adaptation mechanisms. This is also used in a more recently introduced adaptation mechanism Dynamic Adaptive Streaming over HTTP (DASH) [78]. The only difference is that in DASH, the fragments are of smaller fixed durations. Apple Live Streaming and Microsoft Smooth Streaming also use fragmented and versioned storage of multimedia.

In CAPS-EMA, we propose to identify the lowest of the available presentation qualities, during the authoring stage, which could safely convey the information contents in a fragment without any perceived information loss. This lowest acceptable quality is put as a constraint quality for that fragment in a metadata. This process of identifying and putting constraint qualities for each fragment could be performed during authoring phase, by the multimedia author using some authoring tool that implements CAPS-EMA. We have not yet developed any authoring tool in this thesis and metadata has been added manually after observing multimedia fragments in different versions. The focus of the thesis is on proposing CAPS-EMA approach, and demonstrating how it can be used to deliver multimedia adapted in multiple qualities and modalities with the aim of minimising the overall energy consumption.

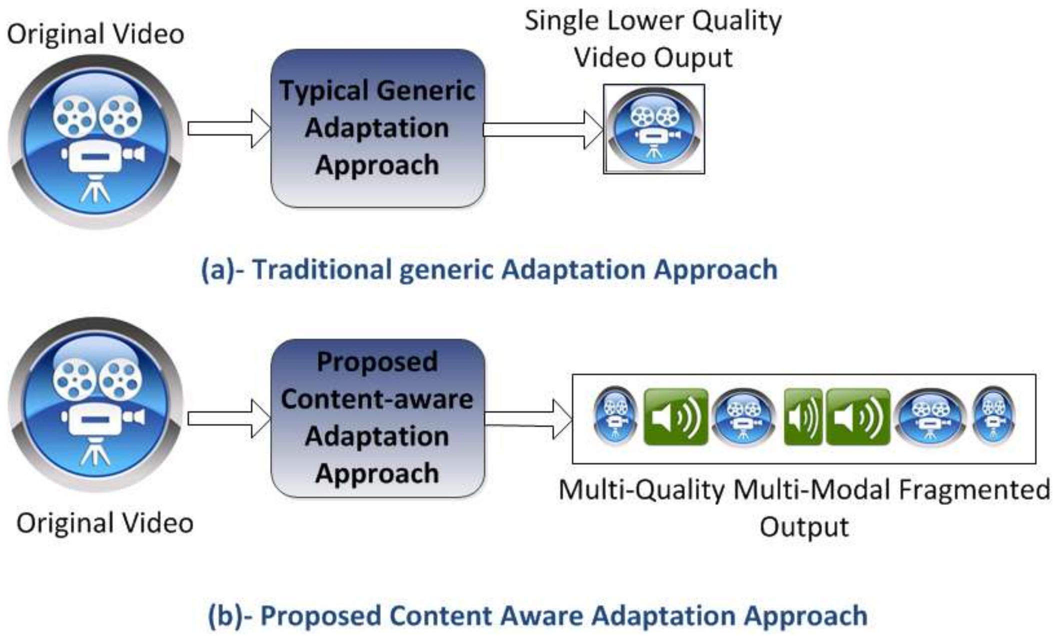

Figure 4-2 Comparison of Traditional and our Proposed Approaches

If a fragment of multimedia has quality-sensitive visual contents, then we would assign it a higher quality constraint after observing the content manually. This observation could be done using some tool. On the other hand, if a fragment of a video does not contain any important visual information at all and all the information content is verbal, then the presentation constraint for such fragment could be as low as audio-only quality. Most learning videos present visual information of different extents at different temporal points in a multimedia resource. Our proposed approach considers the effect of quality reduction on the information that is contained in each temporal fragment, by imposing quality constraints. This makes the delivery of each fragment in a different quality possible. The lowest acceptable quality varies from fragment to fragment. A fragment in our solution's context is a portion of multimedia segment in the temporal dimension that would have the same lowest presentation quality constraint to effectively convey the learning information without any perceived loss. The output of our proposed approach is a fragmented, multi-quality and multimodal format. Figure 4.2 shows the difference between our approach and a generic multimedia adaptation approach.

According to the CAPS-EMA approach, the compromised quality for power-saving is determined by the nature of the content of a multimedia on a fragment-by-fragment basis. This results in some segments of a multimedia to safely present the information contents without any perceived loss of information in a low quality. In the same lower quality, however, some other parts of the same multimedia could result in perceived information loss and, therefore, must be delivered in a higher quality. In the same way, we can have some other parts of the same resource that is delivered in audio without causing any perceived loss in information.

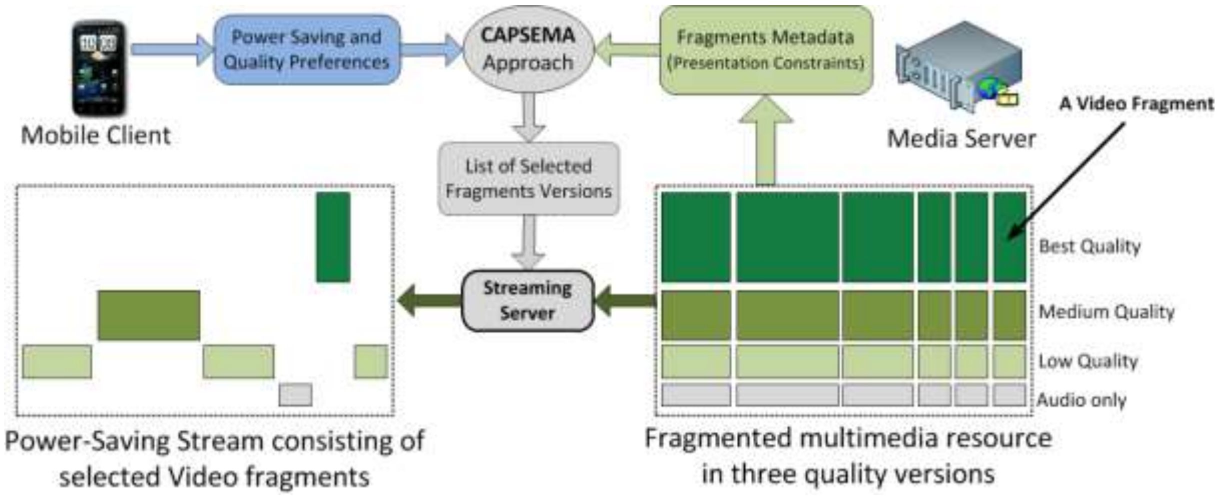

Figure 4-3 CAPS-EMA Process

This approach has twofold benefits. On one hand, it preserves the potential of adapted multimedia to remain effective in perceived learning effect by avoiding any perceived information loss and on the other hand, it opens opportunities for even more power-saving than can be achieved using existing generic approaches. The process of CAPS-EMA is shown in Figure 4.3. In the figure, the number of quality versions as four is only for illustration purposes, and it could be any number. CAPS-EMA does not recommend any number of possible quality versions. We explain the individual components in more detail in sections 4.3 and 4.4. On the server side, we have multimedia in fragmented form with each fragment stored in different presentation quality versions. This fragmentation is done on the basis of the nature of contained visual information. Metadata for the multimedia is generated, which also contains information about presentation constraint on each fragment. User preferences about desired extent of power-saving and presentation quality could be accommodated and retrieved. Based on the metadata and power-saving user preference, the adaptation algorithm selects a list of different fragments versions. This list is then provided to the streaming server to stream all the fragments to the client device.

4.3 Requirements for CAPS-EMA

Following are the main requirements to implement CAPS-EMA adaptation approach.

4.3.1 Storage of Multimedia in Fragments and Versions

The CAPS-EMA content adaptation strategy is based on multimedia in fragmented form with each fragment having multiple quality versions. CAPS-EMA does not recommend any fixed number quality versions for each fragment. Learning multimedia should be accessible by streaming system as fragments. A fragment of multimedia is a piece of multimedia that has similar visual information contents and would, therefore, have the same lowest acceptable multimedia quality for avoiding perceived information loss. Hence there is no limit on the duration of a fragment. The duration of a fragment completely depends on the lowest quality requirement for a piece of multimedia. We can associate metadata with each fragment to store the information about the lowest acceptable quality for each fragment. We can also add importance information about each fragment, which will help in situations where we want to skip some less important fragments to reduce the duration of multimedia. It is important to note that fragmentation depends on the implementation of the adaptation system.

Fragments can be logically defined or split in multiple files. Logical fragments are the ones where the entire multimedia is stored as a single file and the fragment identification information is stored as a metadata in terms of start and end-times of multimedia. For example, a fragment can be defined by specifying that a fragments starts at 100th seconds and ends at 190th seconds of the multimedia. Each fragment should also be available as multiple quality versions, with different encodings parameters. The decision to use logical or real fragments is determined by the entire streaming system and multimedia encoding format.

4.3.2 Metadata Representation

Metadata [107] plays a central role in our proposed adaptation strategy. We should be able to represent metadata in a suitable way to describe important information about media fragments. This metadata is needed for selection of fragments and their versions. The primary information that we require from the metadata are the presentation quality constraints for every fragment. The presentation constraint basically, as described earlier, is a quality level. If a fragment is delivered in lower quality than the specified constraint quality, then it may result in significant perceived loss of information.

In this thesis, our focus on quality constraint is only for successfully comprehending learning information. Just like traditional approach of lowering quality of entire multimedia for power-saving, the proposed CAPS-EMA approach can also be adapted in many ways. CAPS-EMA is not a software system, it is only an adaptation approach based on quality constraints for each fragment. The proposed CAPS-EMA approach can be used for other constraints, based on user models or usage context, but that is beyond the focus of this work. This idea of constraint-quality based adaptation strategy could be used for any approach that could identify multiple constraint-qualities based on multiple usage contexts. This multiple constraints-qualities based approach, however, is beyond the scope of the thesis.

We can also add some other educational features in the metadata, but it is optional in the context of the objectives of this thesis. This means specifying degree of importance of each fragment for all or specific set of learners based on background knowledge level or many other criteria.

4.3.3 User Preferences

A learner should be able to describe her preferences about the adapted multimedia. These preferences can be about acceptable compromise of quality level, desired battery power-saving and any background knowledge level about the topic. These preferences can guide the adaptation strategy to select the right fragments and right versions. Device constraints like screen size, network type and condition and other processing capabilities can also be treated as preferences in adaptation mechanism. Device constraints also guide the adaptation process.

4.3.4 Adaptation Strategy

Adaptation Strategy deals with decision-making about selecting final set of fragment versions that would make up the final adapted multimedia. Fragments are selected based on the fragments metadata, learner preferences and device constraints. An adaptation strategy has two parts: Information Selection (fragments selection) and Presentation Selection (version selection). The CAPS-EMA based adaptation strategy could performs adaptation by first selecting a set of fragments based on needs and importance and then every selected fragment is selected in the most appropriate version. In thesis, however, we are not considering skipping of any fragments – instead we select only fragment versions of all fragments.

4.3.4.1 Fragments Selection

Fragment Selection means selecting the suitable set of multimedia fragments based on importance of information content to meet the learner's information needs. Each fragment contains certain learning information. Some learning information is critical for understanding some concepts while some information may be just additional explanation or just very basic information that is not needed by many advanced learners. Fragment selection is similar to Adaptive Content Generation in Adaptive Hypermedia terminology.

It is however important to remind the reader that the Fragments Selection is not part of the objectives of this thesis. Fragment Selection is just an additional capability that the CAPS-EMA approach could offer. In the context of this thesis, we assume all fragments of a learning multimedia as equally important and we are implementing or evaluating the knowledge based selection of fragments.

4.3.4.2 Version Selection

Version Selection means selecting the right version of all selected fragments for the final adapted multimedia. Version selection is done on the basis of preferences for power-saving and visual quality constraints. For maximum power-saving each fragment is selected in the lowest acceptable presentation quality, which would not result in any perceived loss of visual information. In this thesis, we have focused on Version Selection as we have not implemented or evaluated any fragments selection based on the learner's knowledge and context.

4.4 CAPS-EMA Framework

In Figure 4.4, we present a framework for Content-Aware Power-Saving Educational Multimedia Adaptation (CAPS-EMA) approach. The framework allows us to understand different components that enable CAPS-EMA. These are generic components and can be implemented in variety of ways.

The System Interface allows interaction with the learner. The *System Interface* would be used by user (learner) to initiate any adaptation process. It is worth clarifying, that we are not recommending any specific set of actions or options to be provided to the learner in *System Interface*. The exact options would depend on specific implementation and the extent to which the approach of the CAPS-EMA approach is modified. In a complex system CAPS-EMA could be modified for accommodating any preferences from the learner using the interface, for example, about any preferable compromised quality etc. The interface would also be delivering the adapted multimedia from the multimedia store.

An Educational Media Store would store educational multimedia resources. The multimedia resources would include a multimedia file in original quality as well as in fragmented form with different versions of each fragment. The exact number of fragments and number of versions of each fragment depend on the way the CAPS-EMA would be implemented. We have no recommendations for that.

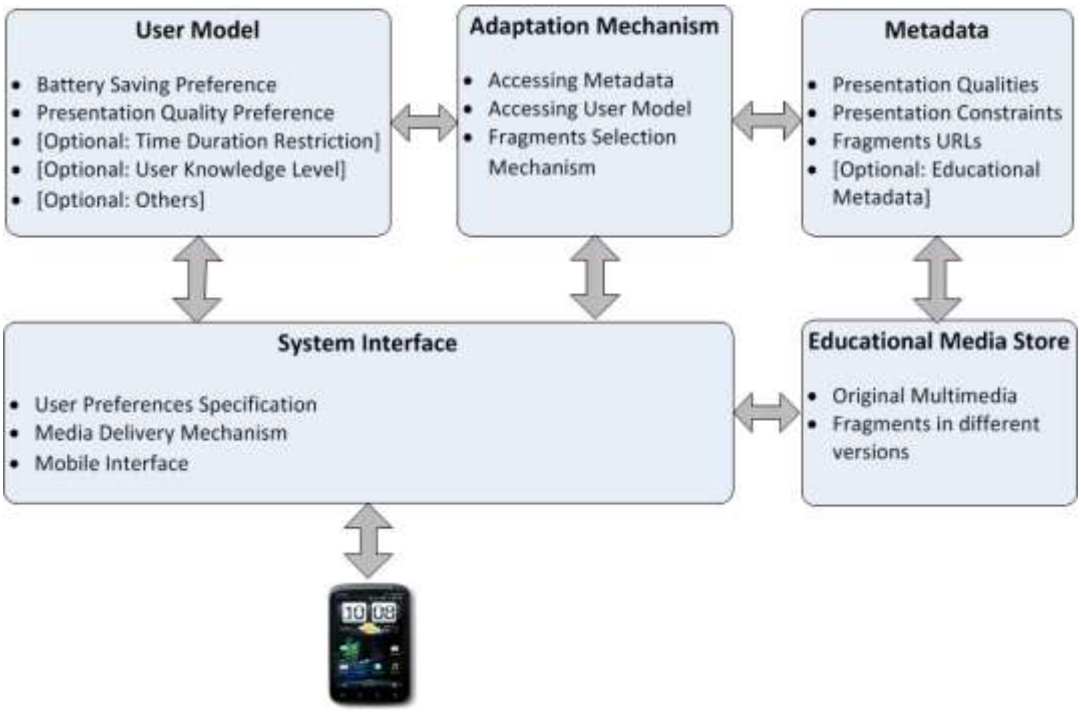

Figure 4-4 A Conceptual Framework for CAPS-EMA Implementation

The *Metadata* component stores metadata about multimedia resources. The metadata would include information about each fragment, its version and quality and other constraints. The metadata could also include educational metadata – it is however not the focus of the work in this thesis. A whole array of educational metadata could be included if needed, for example, suitability for different level of users and constraints for specific usage context. In this thesis we are not going into any specific scenarios or specific usage context. The exact nature and number of educational features would depend on the specific needs of the implementation. In this thesis, we have focused on introducing an adaptation approach for power-saving that would avoid perceived loss of visual information through quality constraints.

The *Adaptation Mechanism* is the process of determining multimedia fragments in specific versions based on the constraints identified in the metadata, user preferences (if any) and usage context (beyond scope of this thesis). The selected list of fragment versions can then be streamed to the learner device using the interface.

The User Model could contain information about learner's preferences about power-saving and quality of multimedia. Depending on the exact implementation, it could include additional information, like preferences for duration of use, background knowledge level etc. All this information could be used by an appropriately implemented *Adaptation Mechanism*. The User Model is used by the *Adaptation Mechanism* along with Metadata in the adaptation process.

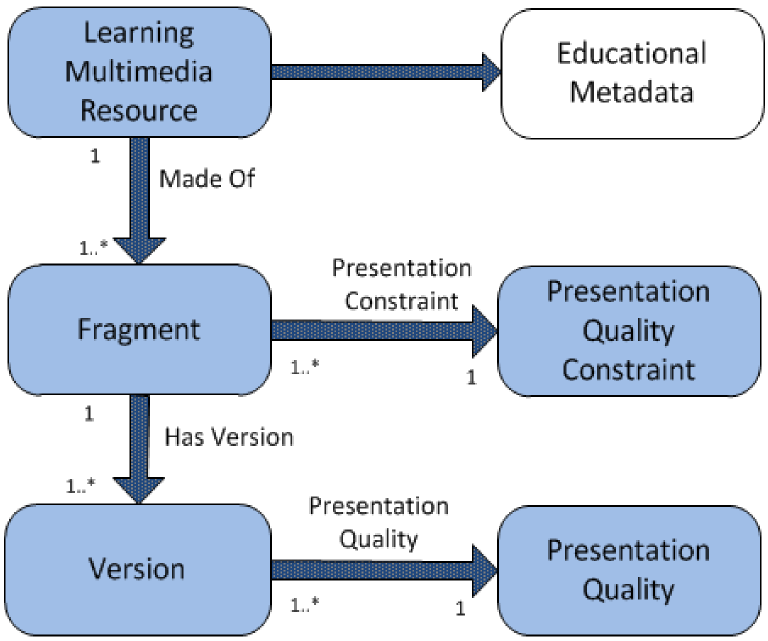

Figure 4-5 Abstract Fragmented Educational-Multimedia Model (FEMM)

4.5 Fragmented Educational-Multimedia Model (FEMM)

In this section, we present the Fragmented Educational-Multimedia Model (FEMM) that would guide the process of the metadata development for the implementation of the CAPS-EMA approach. This purpose of this abstract model is to guide the creation of the needed metadata, and we are not recommending any final set of metadata features. The model can be used to include any set of features, especially educational metadata features. FEMM is given in Figure 4.5.

A learning multimedia resource is made of one or more *Fragments*. Each *fragment* has one or more versions. The metadata scheme should be able to describe these relationships. Each v*ersion* of a fragment has a specific multimedia quality represented by *Presentation Quality*. The *Presentation Quality* could further be described in terms of encoding parameters. We could include a quality number for each quality. In this thesis, we have associated a quality number for each quality level. We have not investigated about any efficient representation of quality information in the metadata. The exact implementation detail for representing multimedia quality is left for implementers. As CAPS-EMA approach is based on quality constraints on various fragments, each *Fragment* has a *Presentation Quality Constraint* for that purpose in the model. This quality constraint will prevent that fragment of multimedia being delivered in a lower quality preventing any perceived visual information loss.

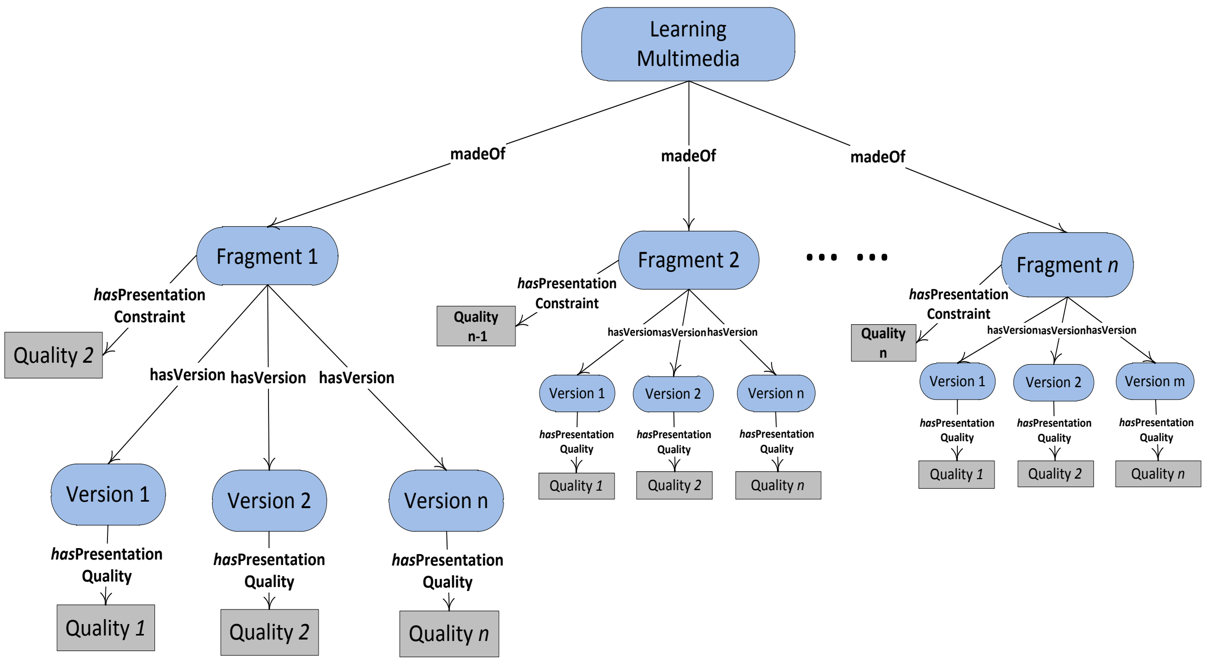

Figure 4-6: An example of Fragmented Educational Multimedia Model

Figure 4.6 shows an explanatory example of this model. The hypothetical educational multimedia described in the figure has *m* fragments (Fragment$_1$, Frament$_2$ .. Fragment $_m$). Each fragment has *n* versions (Version$_1$, Version$_2$, .. Version $_n$). Each version has specific quality (Quality$_1$, Quality$_2$ .. Quality$_n$). We can see that each fragment also has a *Quality Constraint*, which is *Quality$_2$* in case of *Fragment1*. In the figure, we have used different quality constraints for each fragment just for the purpose of illustration. In real application there could be many fragments that would have the same quality constraints. The quality constraints do not have to be different. We can implement metadata about a multimedia in any existing standards for example XML or RDF [107].

4.6 Possible Implementation Strategies for CAPS-EMA

In this section, we now describe some implementation options for CAPS-EMA approach. The objective is to discuss these strategies to highlight the existing streaming techniques that could be used to implement CAPS-EMA. The aim is to suggest that we do not require any new kind of streaming techniques for implementing the CAPS-EMA approach. All these techniques are mature enough and have been used in research and commercial applications for multimedia adaptation.

4.6.1 Content selection

Content Selection is the simplest and easiest way to manage multimedia resources. It has been discussed in section 2.5.1. In order to implement CAPS-EMA using content selection, multimedia resources would be divided into pieces of variable duration based on the nature of the visual information contents. Metadata about each fragment is stored in a separate file. Each fragment has a separate URI and the adaptation process in this case is selection of the URIs of the appropriate fragments versions. The list of selected URIs is forwarded to a system interface, to stream them to the client device. We applied this strategy developing a prototype application (discussed in Chapter 5) in this thesis. The Content Selection process is shown in Figure 4.7.

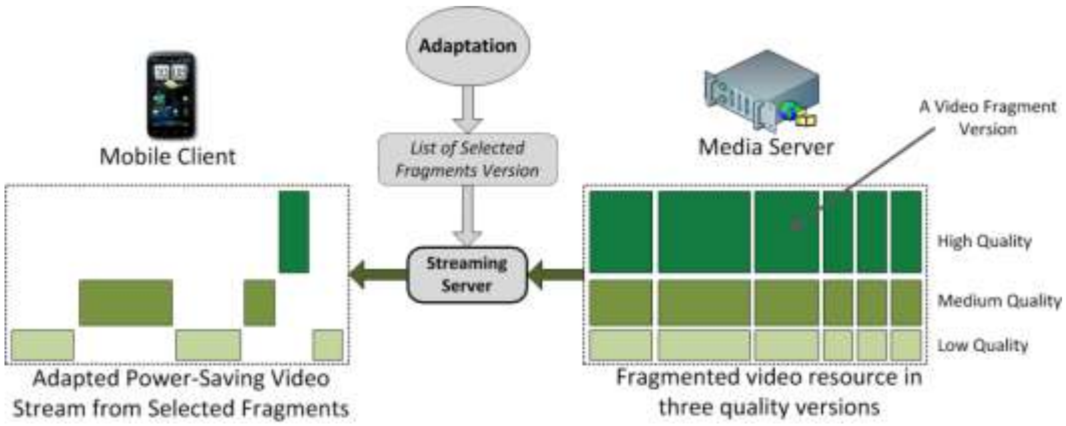

Figure 4-7 Content Selection based CAPS-EMA

4.6.2 Media Fragments URI

Another approach that could be used in implementing CAPS-EMA is the recently proposed Media Fragments URI [108] by W3C Media Fragment Working Group (MFWG). The objective of the proposed specification is to improve the support for the addressing and retrieval of sub-parts of media resources (e.g., audio, video and image).

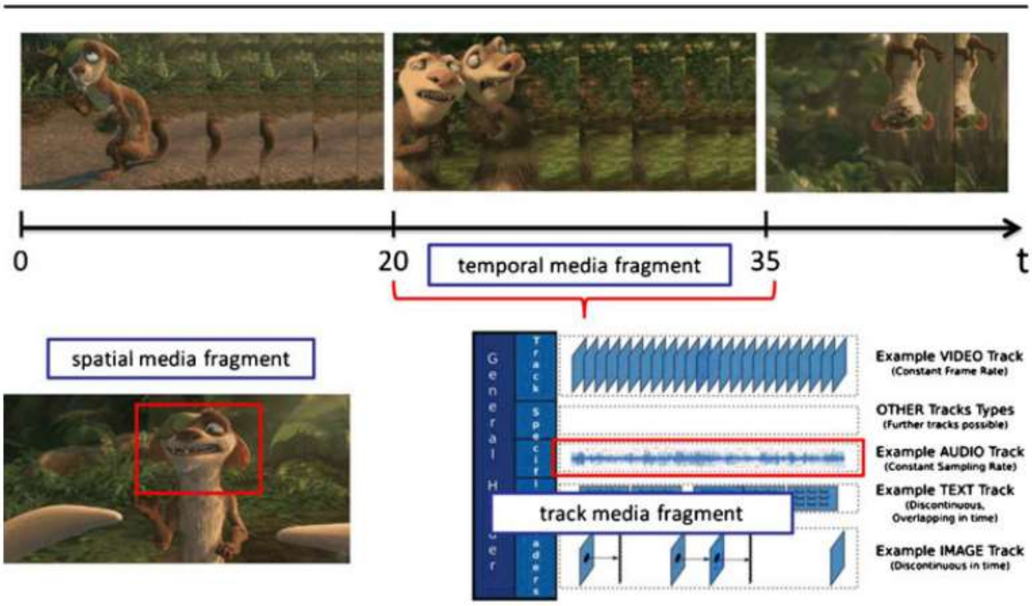

Figure 4-8 Media Fragment Types [109]

The Media Fragments 1.0 specification supports three different axes for media fragments: temporal (i.e., a time range), spatial (i.e., a spatial region), and track (i.e., a track contained in the media resource) as shown in the Figure 4.8. [109]. Such media resources usually include multiple tracks of data all parallel along this uniform timeline. These tracks can contain video, audio, text, images, or any other time-aligned data [110]. There can be multiple video and audio tracks. For example, we can have multiple audio tracks in different languages. We can have a URI for fragment in each of these dimensions. For example, for a fragment in temporal dimension we can have a URI like:

http://foo/media.mp4#t=10,30

This URI identifies the fragment with time range 10 to 30 seconds of media.mp4.

We can also have a URI for a track. For example:

http://foo/media.mp4?track=HighVid

This URI identifies the high quality video track of media.mp4. Each track can be represented by a track name.

In order to implement and deploy a system able to deal with Media Fragment URIs, the key requirement is to have a module that is able to translate media fragments (i.e., expressed in time or tracks) into fragments expressed in terms of bytes (i.e., byte ranges) [111]. The NinSuna platform [112] is a format-independent media delivery platform that is able to perform fragment extraction.

One possible application of Media Fragment URI, that is of interest to us, is multiple bit rate delivery [113]. A media resource can also be characterized by a number of tracks with different bitrates (i.e., qualities). For example, consider a media resource *LearningMedia.mp4* having the following tracks of multiple bitrates.

- HighQVTrack: H.264/AVC video (1,000 kbit/s)
- MidQVTrack: H.264/AVC video (500 kbit/s)
- LowQVTrack: H.264/AVC video (100 kbit/s)

The format of URIs that we could use in our proposed adaptation approach would be the one that could select a temporal fragment in a specific quality track. We could generate a Media Fragment URI for a piece of video of 60 seconds duration, with its start time in a multimedia from the 40th second until the100th second of the video in the medium quality track.

http://example.com/LearningMedia.mp4#t=40,100&track=MidQVTrack

We have not addressed the spatial dimension in out adaptation technique; however, it can be used. Spatial dimension is a specific region of interest in a video. Selecting a specific region also results in reduction of the total data size of multimedia, which helps in power-saving during data transfer. The metadata in this case can use Media Fragment URIs and the adaptation process will actually be the process of selecting the appropriate Fragment URIs, as shown in the Figure 4.9. It should be noted that the tracks in this case would be fragmented logically, using Fragment URIs, which requests the server to extract the identified fragments from the parent resource.

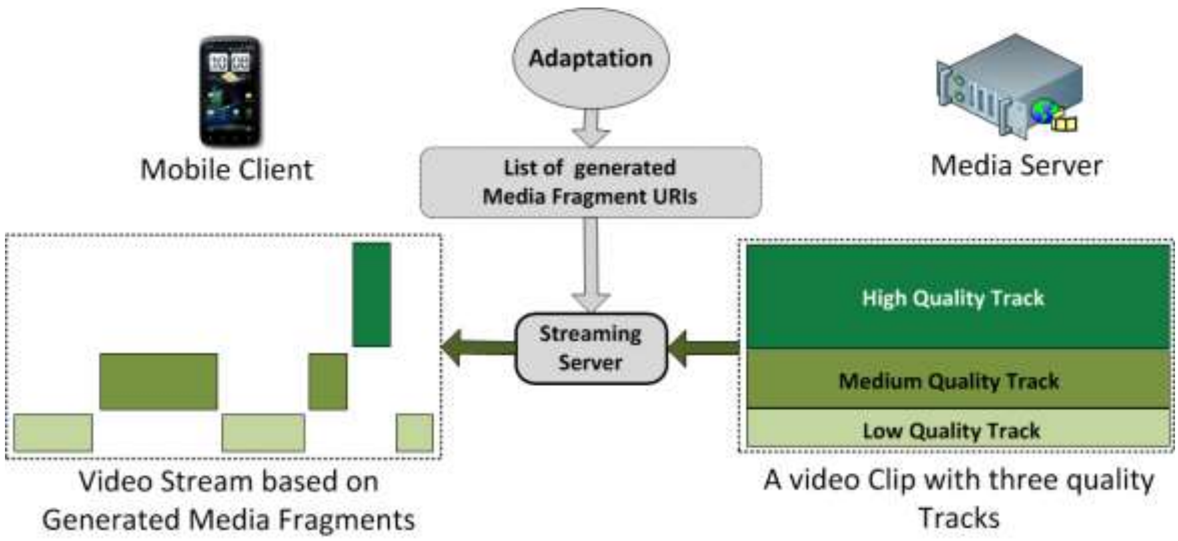

Figure 4-9 Media Fragment URI based CAPS-EMA

4.6.3 Dynamic Adaptive Streaming

We can also use an Adaptive Streaming Mechanism to implement CAPS-EMA. This, however, requires some modifications for some control on the streaming process and would be a complex choice to implement CAPS-EMA. The Dynamic Adaptive Streaming over HTTP (DASH) [78] is one implementation of the Adaptive Streaming. DASH dynamically changes media streaming quality based on client device network conditions. Instead of having one media file encoded at a single bitrate, the same media file is encoded at several bitrates, resolutions, etc. These multiple versions of the same media are then chopped into segments of equal durations that could be individually addressed through HTTP. The normal DASH adaptation process is shown in Figure 4.10.

We can exploit this adaptive bitrate characteristic for power-saving. Instead of adapting the output quality based on feedback of network conditions from the client side, we can direct the streaming media server to change the output quality at a specified time to a specific quality. This time and quality is determined by the adaptation engine. For example, we can provide a list of temporal points and media quality (bitrate) for each temporal point. The media server can then stream media based on the list. At each temporal point, the server should change the output quality to the specified one. This list will be generated as part of the adaptation process, with the help of metadata. Fragments will be defined logically in terms of time information. This possible implementation is depicted in Figure 4.11.

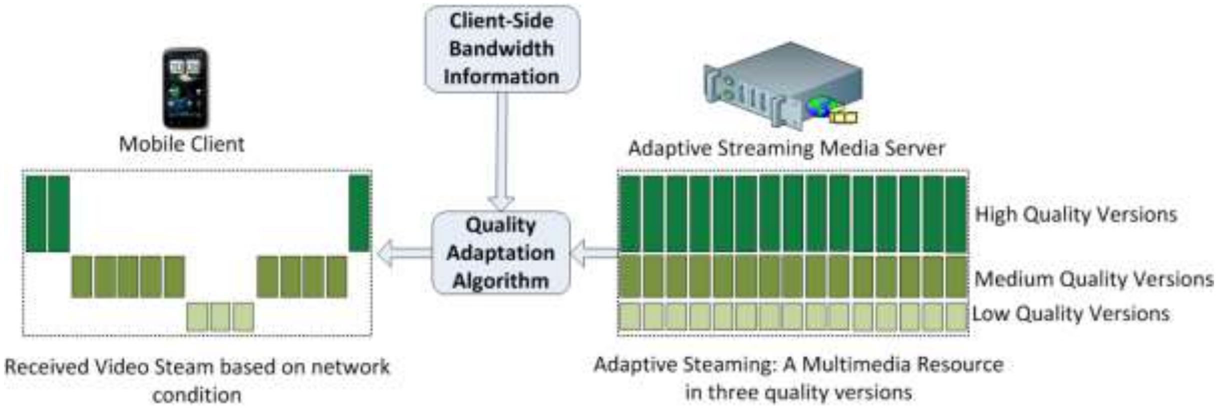

Figure 4-10 Adaptive Streaming

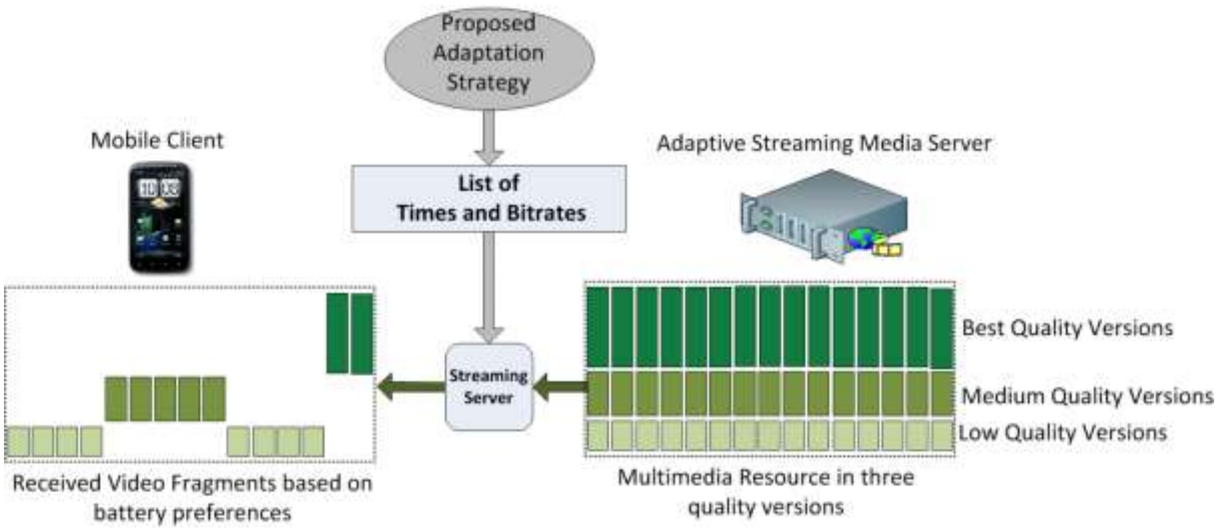

Figure 4-11 Adaptive Streaming based CAPS-EMA

4.7 Issues regarding Implementation Issues

We now highlight some issues regarding implementation of the CAPS-EMA approach.

4.7.1 Implementation Possibilities

In section 4.6, we have suggested possible implementation strategies. We discussed some established existing multimedia streaming techniques that could be used to implement the CAPS-EMA adaptation approach. All those techniques are established and have been used by other researchers and implemented in commercial applications.

4.7.2 Practicality of metadata driven adaptation

Metadata driven multimedia adaptation has been used in other researches [77, 114-116]. Metadata driven multimedia adaptation has also been used in the Distance Learning application [117]. Different multimedia adaptation strategies would require different metadata. It is generally agreed in the context of adaptation that there is extra effort and extra resources required. These extra efforts are associated with the benefits that adaptation offers.

4.7.3 Poor multimedia quality and learning

Adaptation by reducing the quality of multimedia for the purpose of meeting any device constraints, network constraints or limited battery-power constraints, always negatively impacts the Quality of Experience. Moldovan in [27] suggests that reduced quality for learning is acceptable for learners without negatively impacting learning outcome significantly. Despite this, the multimedia adaptation for meeting resource constraints and power-saving purposes has been widely suggested. In this thesis, we argue that the impact of lowering quality is severe only if it results in perceived loss of visual learning information. CAPS-EMA is therefore proposed to take advantage of power-saving adaptation without causing perceived loss of visual information during adaptation.

This thesis, however, also focuses on the importance of giving learners the options to control the adaptation process and not just receive the adapted multimedia without the learners' will. We discuss this concept of Learner Battery Interaction (LBI) in chapter 7. The LBI concept is not related to the CAPS-EMA approach of adapting multimedia. LBI focus only on the interaction mechanism for power-saving adaptive applications.

4.8 Stakeholder Analysis

In this section, we do the stack holder analysis of the CAPS-EMA approach. Like any other adaptation approaches, end users who will consume the adapted multimedia are the main the stakeholders. In our case, as the target multimedia type is educational multimedia, therefore learners are the main stakeholders. Other stakeholders of the CAPS-EMA approach are the people who would be performing the authoring process, that is, multimedia authors. Multimedia authors could be instructors.

The research work discussed in this thesis directly addresses learner stakeholder. The main objective of the thesis is to achieve power-saving at learner's mobile device, without any perceived negative impacts.

4.8.1 Learners

A Learner is an important stakeholder in the adaptation system that would implement the CAPS-EMA approach. Learners would normally have the following main interests, with respect to the adaptation approach.

- Learners would be using the educational multimedia adapted using the CAPS-EMA approach in situation where they need to save battery power.
- It is important for Learners that the learning information in the adapted multimedia is comprehensible for without any perceived loss of information.
- Learners would also need some interface providing options to invoke the power-saving mode in the system implementing CAPS-EMA.

4.8.2 Multimedia Processing Experts (Multimedia Authors)

The multimedia authors would have the following interests in CAPS-EMA.

- The author of the multimedia will be performing the fragmentation of multimedia content.
- The multimedia author will need a tool to perform this fragmentation. A tool that suggests points of fragmentation will be very useful for the author.
- The multimedia author will decide about quality constraints.
- The multimedia author will require a tool that can show various fragment in various quality where they can select a possible constraint quality for each fragment
- The multimedia author will also be interested in a tool that could generate metadata for a learning multimedia automatically based on the selection of fragment point and quality constraints for each fragment.

4.9 Conclusion

In Chapter 3, we discussed some shortcomings of existing generic multimedia adaptation techniques when applied to education multimedia for mobile devices. We conducted a user study to understand these problems. In Chapter 4, we introduced the Content Aware Power-Saving

Educational Multimedia Adaptation (CAPS-EMA), as a way of tackling the identified shortcomings in existing approaches. By using the proposed CAPS-EMA approach, we can control any negative impact of adaptation on learning experience, mainly due to perceived loss of visual information. Each portion of a multimedia would not be delivered in a quality that is not suitable for proper comprehending of the information contents. We presented a conceptual framework that would guide development of any system implementing CAPS-EMA for adaptation. An abstract model of educational multimedia is also discussed, that would be helpful in generating useful metadata to be used by the CAPS-EMA approach. In the end, we discuss some enabling technologies that can be considered to implement CAPS-EMA. We have shown in this chapter the possible approaches and available technologies that could be used to implement CAPS-EMA.

Chapter 5:

MoBELearn System

In Chapter 4, we introduced the CAPS-EMA adaptation approach. The CAPS-EMA approach aims to consider the impact of reducing presentation quality for power-saving purposes on the visual information contents of multimedia. Instead of reducing the presentation quality of the entire multimedia to a single uniform quality, the CAPS-EMA approach suggests to determine the lower quality based on the visual contents on fragment-by-fragment basis. Chapter 4 also described a framework for implementation of the CAPS-EMA approach and suggested some possible implementation strategies in section 4.6. These strategies are based on established multimedia adaptation and streaming techniques that include content selection, dynamic adaptive streaming and media fragment URIs.

This chapter addresses the research question RQ3-a. In this chapter, we describe the MoBELearn application, which is a prototype implementation of the CAPS-EMA approach. We also explain a fragmented learning multimedia ontology metamodel that is used in the prototype implementation.

5.1 MOBELEARN

The MoBELearn (Mobile Battery Efficient Learning) system is a prototype implementation of the proposed battery power-saving CAPS-EMA adaptation approach. MoBELearn is based on the CAPS-EMA framework and Fragmented Educational Multimedia Model (FEMM) discussed in Chapter 4. MoBELearn is a format-agnostic multimedia adaptation system that is based on Semantic Web technologies. It is format-agnostic because the adaptation mechanism is not dependent on any particular multimedia format and the approach can be applied on multimedia in any format. The MoBELearn system demonstrates the functionality of the CAPS-EMA approach. Furthermore, we use the same prototype system for the evaluation of CAPS-EMA. The evaluation results are presented later in Chapter 6.

The architecture of the MoBELearn system is given in Figure 5.1. The ***System Interface*** component of the system interacts with the learner's device. A learner can specify battery power-saving preferences and retrieve learning multimedia. The interface component is developed using HTML5, Mobile JQuery and is deployed on the Apache webserver. The interface component provides the learner with a number of options for power-saving. Each option contains information about the extent of possible power-savings and its impact on the resultant multimedia in terms of presentation quality. Higher power-saving preferences result in more compromise on the multimedia quality.

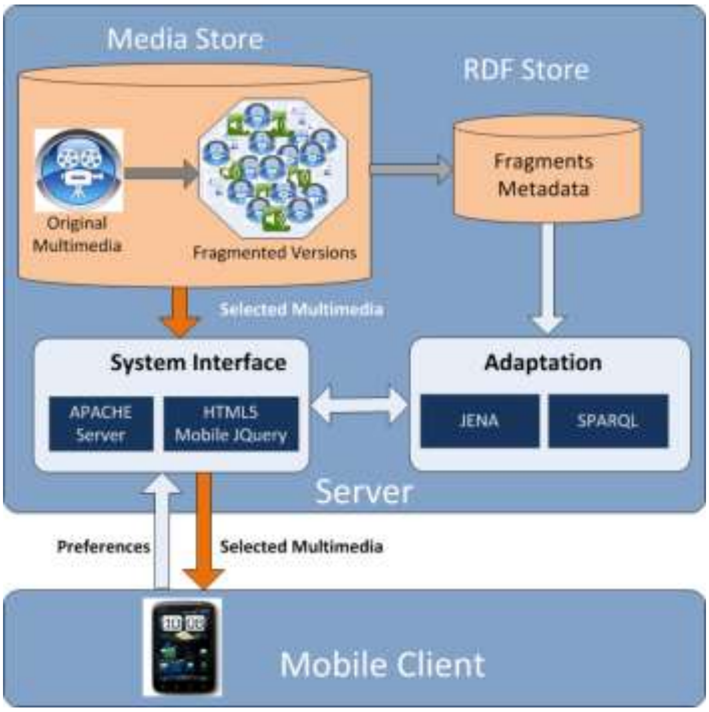

Figure 5-1: MoBELearn Architecture

The ***Media Store*** contains the multimedia content in both the original quality as well as in fragmented and versioned forms. The ***Adaptation*** module decides about the final multimedia fragments and their versions based on the learner preferences. It should be noted that learner preference is an optional part of the CAPS-EMA approach. CAPS-EMA is designed to adapt multimedia by providing each portion of a multimedia in an acceptable lowest available quality, in order to achieve the greatest possible power-saving. Users, however, could be provided options to choose a compromised quality that is higher than the lowest acceptable quality. This could happen, for example, in situations when a learner is not interested in certain very low qualities (for example, presence of audio clips in the adapted version). We have implemented these preferences in the MoBELearn system as part of our work discussed in Chapter 8 of the thesis and therefore they are not directly relevant in the context of CAPS-EMA. The ***Adaptation*** module generates SPARQL queries that would retrieve the URLs of the selected multimedia fragments. The ***System Interface*** component interacts with the ***Adaptation*** module to retrieve the list of fragments to be delivered to the user. The ***Media Store*** streams the selected multimedia fragments to the learner's device. One fragment version for each selected fragment is selected during the adaptation process. For the prototype system, the original videos are manually fragmented and encoded into different versions. It can be a good future research direction to investigate how can we automatically fragment multimedia resource based on similar lowest acceptable qualities and create suitable versions. The ***RDF Store*** component stores the multimedia metadata. Metadata is stored in the Resource Description Framework (RDF) format. RDF has been chosen as semantic web technologies, such as RDF and OWL, will often enhance the interoperability among metadata standards for multimedia content [112] and they are often easily extendable. The multimedia Metadata component is a major component of our adaptation approach. The RDF store is a MySQL database and the Jena API is used to save and retrieve RDF data. Jena API is used to create RDF models in the database and is used to populate the model from RDF triples. We further discuss our metadata model and its implementation in Section 6. The ***Adaptation*** component performs the adaptation process after taking input from both the *System Interface* and the *RDF store*. It takes learner preferences from the System Interface and fragments metadata from the RDF Store. The adaptation process generates the SPARQL Query that will select URLs of the most appropriate fragment versions. This list is then provided to the System Interface for streaming the content from the Media Store.

5.2 MoBELearn Working

The Figure 5.2 shows the user interface of the MoBELearn system. A slide-bar is used to allow the user to specify their power-saving preferences. Each option in the slide-bar provides a brief feedback about the form of the adapted learning multimedia as a result of that option. For example, the user preference in the left screenshot will result in no battery power-saving, in which case, the learner will be provided the original high quality video as one continuous fragment. In the right screenshot, option specifying the user preference for the most battery power-saving is selected. This will result in each fragment being delivered in its lowest of the available acceptable qualities, achieving the most energy efficiency. It illustrates that approximately 75% battery-power-savings can be achieved during wireless data transfer. This power-saving value in the prototype has been computed beforehand for these options with the help of the PowerTutor android app [118]. Power-saving values were calculated by streaming both the original and the adapted multimedia and energy consumption for wireless data transfer and browser were recorded through the PowerTutor app for both versions. The percentage of power-saving values was then calculated. It is important to note that we are not interested in exact values of energy consumption (in Joules) as the exact values vary in different situations and are affected by several other factors including, type of wireless technology (GSM, 3G, LTE, WiFi), carrier’s properties and strength of the wireless signals [17]. Various battery consumption models have been proposed, to measure energy expenses in terms of data transfer. A battery consumption model could be used to approximately compute battery consumption and determine efficiency. These models are based on the size of the data transfer.

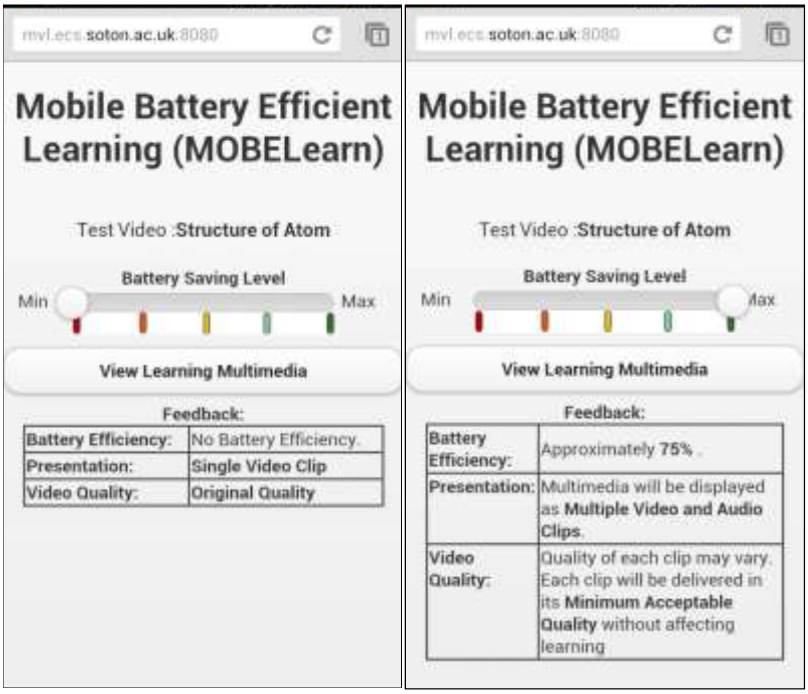

Figure 5-2: MoBELearn Interface

In our test case, we used an openly available learning video titled “The Structure of the Atom”[1]. The learning multimedia was fragmented into eight fragments. Each fragment was encoded in four different qualities, including one audio-only quality. The quality constraints were determined after observing the contents of the video fragments and were placed in the metadata. The detailed data model of the multimedia is discussed in the Section 5.3.

Figure 5.3 shows a adapted output for the preferences specified in Figure 5.2. Figure 5.3 (Left) shows a fragment being delivered in audio quality. Figure 5.3 (Right) shows a fragment being delivered in very lower quality. This Low Quality version is being compared against the original version in Figure 5.4. We can see the difference in both video qualities. The video on the left has a bitrate of 124 kbps, 30 Frames per Second and stereo audio quality while the video fragment on the

[1] Derek Owens channel on YouTube.

right has bitrate of 39 kbps, 5 frames per second and mono-quality audio. The energy savings would be even greater if the quality (bitrates) of the original video was higher than 370 Kbps.

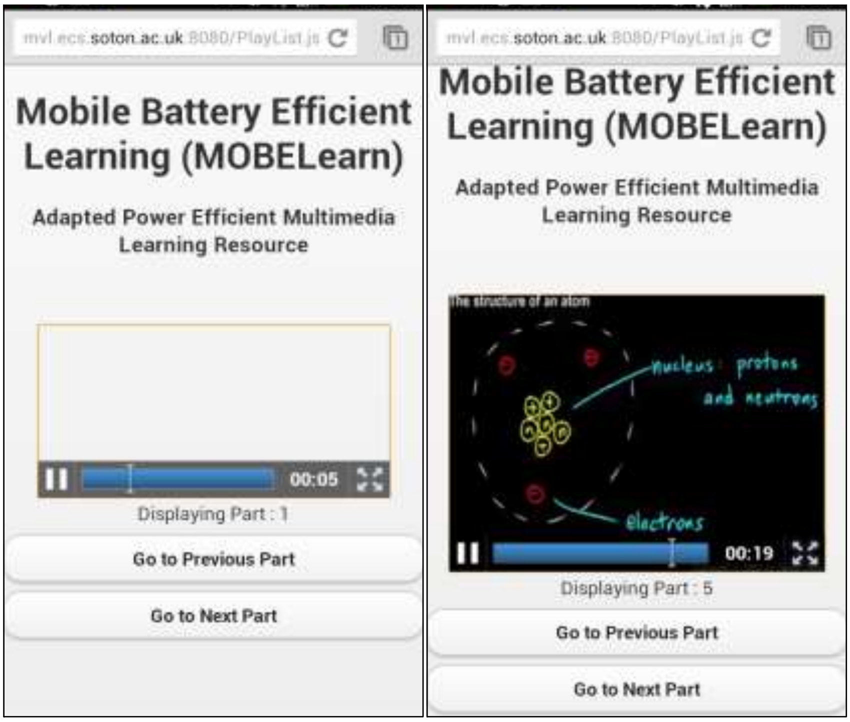

Figure 5-3: Screenshots of the prototype System

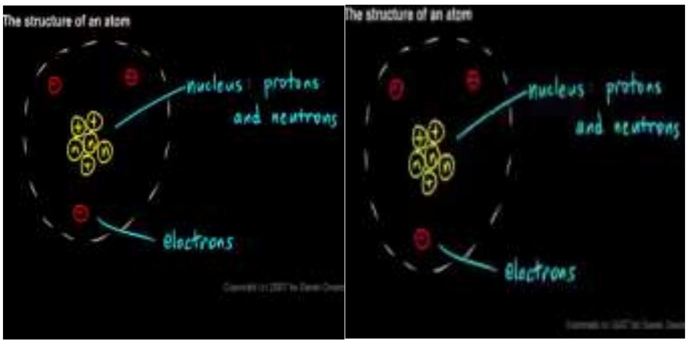

Figure 5-4: Comparison of Original and Adapted Content

5.3 Fragmented Learning Multimedia Resource Model

As illustrated in the Figure 5.1, MoBELearn is a metadata-driven multimedia adaptation system. The Fragmented Educational Multimedia Resource Ontology Model (FEMROM) has been developed for this purpose, which is based on the FEMM conceptual model presented in section 4.5. The model in the MoBELearn system is implemented as an RDF ontology model. The structure of the proposed metamodel is based on the relationships that exist between those features of a fragmented learning multimedia that are required for the adaptation purposes. In the context of the objectives of the thesis as well as for the purpose of simplicity, we have used minimum features in the model and did not use those features of multimedia that has no direct role in the CAPS-EMA adaptation process.

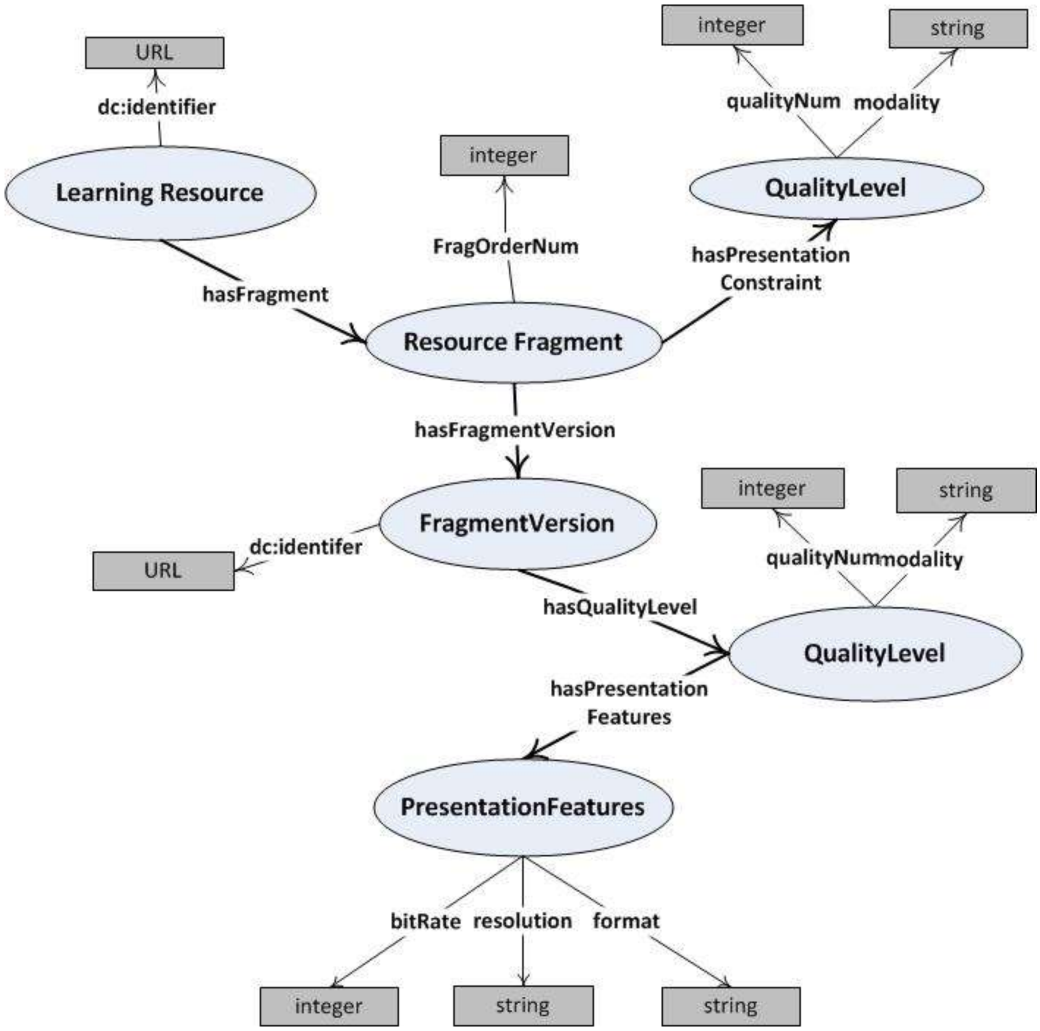

Figure 5-5: Fragmented Educational Multimedia Resource Ontology Model

Each learning multimedia has a *URL*, a *creator* (author of the content) and a *title*. In the context of CAPS-EMA, a learning multimedia is in a fragmented form and it, therefore, consists of one or more multimedia fragments. Each fragment has a certain sequence number based on its order in the multimedia. The most important aspect of the proposed CAPS-EMA adaptation strategy is the presentation quality constraints for each fragment from the available presentation qualities. Each fragment, therefore, also has some quality constraint information attached to it. The concept of constraints has been discussed in detail in Chapters 3 and 4. A fragment might not be appropriate for learning purposes due to perceived loss of visual information, when a quality is reduced beyond a certain level; therefore, the lowest quality - that would not cause perceived information loss – is taken as a constraints quality. Each fragment is supposed to have few versions in each available presentation quality. A presentation quality (level) could be described in terms of multimedia presentation features like bitrates, frames per second, and resolutions etc. We have modelled these aspects of the fragmented educational multimedia in the proposed model. Figure 5.5, illustrates the FEMROM metamodel.

In the model a *LearningResource (*Multimedia Learning Resource*)* is has *ResourceFragment*s. Each *LearningResource* has a URL modelled by *dc:identifier* from the Dublin Core[1] vocabulary. It is recommended to reuse existing ontologies instead of recreating alternative vocabulary [119]. To represent the order of fragments in the entire resource we have a data property for the fragment sequence number (*FragOrderNum*). This would help arrange the fragments in the right order in the adapted multimedia. As each fragment of multimedia has fragment versions in each available presentation quality, this is represented in the model by *ResourceFragment* having *FragmentVersions* using *hasFragmentVersions* property. Each *FragmentVersion* has a certain different *QualityLevel* and *modality*. Each *FragmentVersion* has a separate identifier (URLs). During the adaptation process, one of these fragment version *URLs* will be selected for each fragment. Quality parameters for each *QualityLevel* are described using *PresentationFeatures* property that contains attributes like bitrate, Resolution and FPS (frame per Second). Presentation quality constraint is associated with each fragment using the *hasPresentationConstraint* property. This property associates a *QualityLevel* with each *ResourceFragment*.

In Figure 5.6, we show an example of the model. It illustrates the model of the multimedia resource we have shown in Figure 5.3. The learning multimedia in this prototype implementation was fragmented into 8 fragments with varying durations. In total five fragments were of duration more than 60 seconds. We have not recommended any minimum or maximum duration for each fragment. We believe smaller fragments might have negative impact on the user experience and may require further research to identify the constraint on the minimum duration of a fragment for an acceptable user experience.

Each fragment in the prototype implementation was encoded in four different qualities, including an audio only quality. The original quality of the multimedia was 370 Kbps. The bitrates of the

[1] http://dublincore.org/documents/dcmi-terms/

encoded video qualities were 124 Kbps, 70 Kbps and 35 Kbps. The audio only quality had the bitrate of 32 Kbps. We identified the presentation quality constraint by observing the learning multimedia in the four available qualities, by playing the role of learning resource authors. We put presentation constraints and information about fragment versions in the metadata. The quality constraints for fragments 1,3 and 6 was quality 4, which is an audio only quality. The quality constraints for fragments 2, 4, 5 and 8 was quality 3 (35Kbps) while fragment 7 required quality 2 (70Kbps) as a quality constraint. Due to the space limitation, we could not illustrate the entire model in the graphical form. Figure 5.7 represents a piece of the RDF code of the implementation of this model.

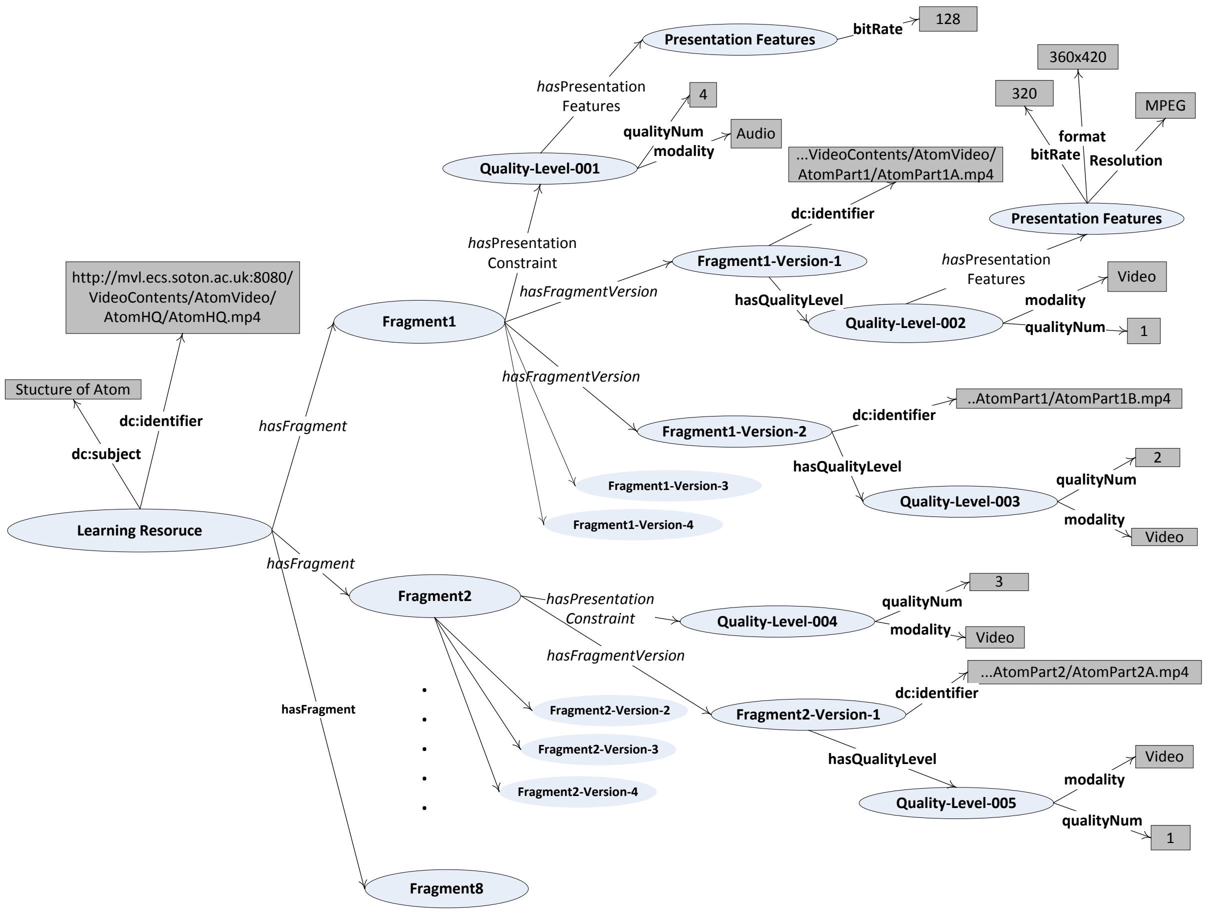

Figure 5-6: Example Learning Multimedia Model

MoBELearn uses RDF-driven content adaptation [112]. RDF-driven adaptation is based on executing SPARQL queries over instances of the model for media fragments. This makes our adaptation format-agnostic. Adaptation happens at the level of selection of the fragments and their versions. This selection is done on the basis of the user preferences (User Model) about the extent of desired power efficiency and the multimedia metadata. User Preferences help in generating an appropriate SPARQL query which is then executed over the RDF store to retrieve URIs for the multimedia fragments. The URI's of the fragments are delivered to an HTML 5 video player on a learner's mobile device as a playlist using Mobile JQuery.

```
<rdf:Description rdf:about="http://mvl.ecs.soton.ac.uk:8080/VideoContents/AtomVideo/Atom.mp4">
  <dc:identifier>http://mvl.ecs.soton.ac.uk:8080/VideoContents/AtomVideo/AtomHQ/AtomHQ.mp4"</dc:identifier>
  <acm:hasFragment>
  <rdf:Description rdf:about="http://mvl.ecs.soton.ac.uk/VideoContents/AtomVideo/AtomPart1/AtomPart1A.mp4">
    <acm:orderNum  rdf:datatype="http://www.w3.org/2001/XMLSchema#int">
    1
    </acm:orderNum>

    <acm:hasPresentationConstraints>
    <rdf:Description>
        <acm:qualityNum rdf:datatype="http://www.w3.org/2001/XMLSchema#int">4</acm:qualityNum>
            <acm:modality>Audio</acm:modality>
        </rdf:Description>
    </acm:hasPresentationConstraints>

    <acm:hasFragmentVersion>
        <rdf:Description rdf:about="http://mvl.ecs.soton.ac.uk:8080/VideoContents/AtomVideo/AtomPart1/AtomPart1A">
            <acm:size rdf:datatype="http://www.w3.org/2001/XMLSchema#int">385</acm:size>
                <dc:identifier>/VideoContents/AtomVideo/AtomPart1/AtomPart1A.mp4</dc:identifier>
                <acm:hasQuality>
                <rdf:Description>
                    <acm:qualityNum rdf:datatype="http://www.w3.org/2001/XMLSchema#int">1</acm:qualityNum>
                    <acm:Modality>Video</acm:Modality>
                </rdf:Description>
                </acm:hasQuality>
        </rdf:Description>
    </acm:hasFragmentVersion>
    <acm:hasFragmentVersion>
        <rdf:Description rdf:about="http://mvl.ecs.soton.ac.uk:8080/VideoContents/AtomVideo/AtomPart1/AtomPart1B">
            <acm:size rdf:datatype="http://www.w3.org/2001/XMLSchema#int">202</acm:size>
            <dc:identifier>/VideoContents/AtomVideo/AtomPart1/AtomPart1B.mp4</dc:identifier>
            <acm:hasQuality>
                <rdf:Description>
                   <acm:qualityNum rdf:datatype="http://www.w3.org/2001/XMLSchema#int">2</acm:qualityNum>
                   <acm:Modality>Video</acm:Modality>
                </rdf:Description>
            </acm:hasQuality>
        </rdf:Description>
    </acm:hasFragmentVersion>
```

Figure 5-7: A portion of the model implementation

On mobile devices, the HTML 5 Video Player's *autoplay* feature is disabled, therefore, in our system, the learner has to click on the each media fragment explicitly to start playing a fragment. This explicit clicking action to start multimedia could be a user experience (UX) concern. We realised this limitation in mobile operating system at a very late stage of implementation. This limitation, however, does not exist in laptops (or PC) on which all the fragments could be played using '*autoplay'* without any user explicit interaction for each fragment. For the evaluation purposes, this was a bias *against* our approach and not in the favour of our proposed CAPS-EMA approach. For implementation, we would recommend a programming approach that would seamlessly start playing the next fragment without any user intervention.

In Figure 5.8, we show a sample SPARQL query that selects multimedia media fragments in the lowest available acceptable quality to achieve most power-saving. The prefix 'f:' in Line 3 refers to our proposed ontology. In Line 4, we select ***?FragVerId*** that represents URLs of each fragment version. In Line 7 we limit the results of fragment versions to only those resources where ResourceID is http://mvl.ecs.soton.ac.uk:8080/VideoContents /AtomVideo/Atom.mp4 only. This results in selecting fragments from our requested multimedia content resource. The metadata repository may contain metadata about other multimedia resources as well. ?pConstQNum in Line 10 represents the quality number of the presentation constraint quality. In Line 14, we enforce the selection of fragment versions to those where the quality number (?QN) is the same as the number of the presentation constraint quality (?pConstQNum).

```
1  PREFIX dc:<http://purl.org/dc/elements/1.1/>
2  PREFIX rdf:<http://www.w3.org/1999/02/22-rdf-syntax-ns#>
3  PREFIX f:<http://www.fragmentmodel.com/elements/1.1/>
4  SELECT DISTINCT ?FragVerId
5  WHERE {
6  ?LearningRes dc:identifier ?ResourceID.
7  FILTER regex(?ResourceID,"http://mvl.ecs.soton.ac.uk:8080/
   VideoContents/AtomVideo/Atom.mp4","i").
8  ?LearningRes f:hasFragment ?LRFrag.
9  ?LRFrag f:hasPresentationConstraints ?pConstraint.
10 ?pConstraint f:qualityNum ?pConstQNum.
11 ?LRFrag f:hasFragmentVersion ?FragVer.
12 ?FragVer dc:identifier ?FragVerId.
13 ?FragVer f:hasQuality ?Quality.
14 ?Quality f:qualityNum ?QN. FILTER(?QN = ?pConstQNum)
15 }
16 ORDER BY ASC(?FragVerId);
```

Figure 5-8:SPARQL query selecting fragments in lowest acceptable qualities

We have also made provision in our metamodel to design a system that would offer further power-saving, by selecting only the most important media fragments for a certain user level and exclude those fragments that were determined as optional, based on the existing user knowledge level. It is, however, important to clarify that these additional possibilities of the metamodel is not part of the

CAPS-EMA approach itself. CAPS-EMA is about not delivering the whole multimedia in a lower quality and instead delivering different portions of multimedia in a minimum quality that would convey the information contents without any perceived loss. Multimedia resource authors or the subject experts would generate the additional metadata needed for this. Practicality of metadata based multimedia adaptation has been discussed in section 4.8.2. We have also mentioned in the stakeholder analysis in section 4.7.1 that multimedia author will require a tool to perform the metadata generation. Without specialised tools for this purpose, the process will be least feasible and will have obvious scalability issues.

5.4 Extending the model with educational Attributes

The metadata model presented in Figure 5.5 does not include any educational attributes. The objective of the metamodel was to model the fragmented multimedia in terms of minimum features that would be enough to perform the CAPS-EMA based adaptation of educational multimedia. Being a model of educational multimedia, it is important that the proposed model could be extendable with relevant educational attributes. In this section, we show an extension of the metadata model with educational attributes. There are numerous educational metadata standards that are being used with educational resources. IEEE Learning Object Metadata (LOM), Simple Knowledge Organization System (SKOS), Dublin Core are example of some commonly used standards. We have tried to extend the metamodel with attributes from these vocabularies. The SKOS vocabulary is used for representing the domain concepts. We show how our proposed model fits with these existing educational metadata standards. It is, however, important to mention that these educational attributes making extension of the model is optional for CAPS-EMA based adaptation. These educational attributes have their own role in learning systems and not related to power-saving.

The extended version of the model is given in Figure 5.9. The portion of the model in green colour represents the extension with educational attributes. We have added *EducationalAttributes* with each *ResourceFragment.* Each resource fragment has attributes like typical learning time and difficulty level. These are modelled by reusing IEEE Learning Object Model attributes *TypialLearningTime* and *Difficulty*. We have also added importance information with educational attributes to represent the importance of a fragment for different user background knowledge level (beginner, advanced etc.). This is based on the notion, that some fragments may be more suitable for learners with specific background knowledge of the topic. For example, some fragments may be optional for a user with advanced background knowledge about the topic. This information about *importance* is modelled using a pair of attributes of *Imp_value* and *userLevel*. *userLevel* can have values like Beginner, Intermediate and Advanced while *Imp_value* can have 1 (important) or 0 (optional) values. In order to shows what concepts were covered by each fragments, we used the SKOS Concept attribute. Each SKOS concept has label, described by *skos:prefLabel* attribute. Using the SKOS Concept feature, we can link the model with the domain concepts. SKOS metadata specification is used for describing domain concept maps.

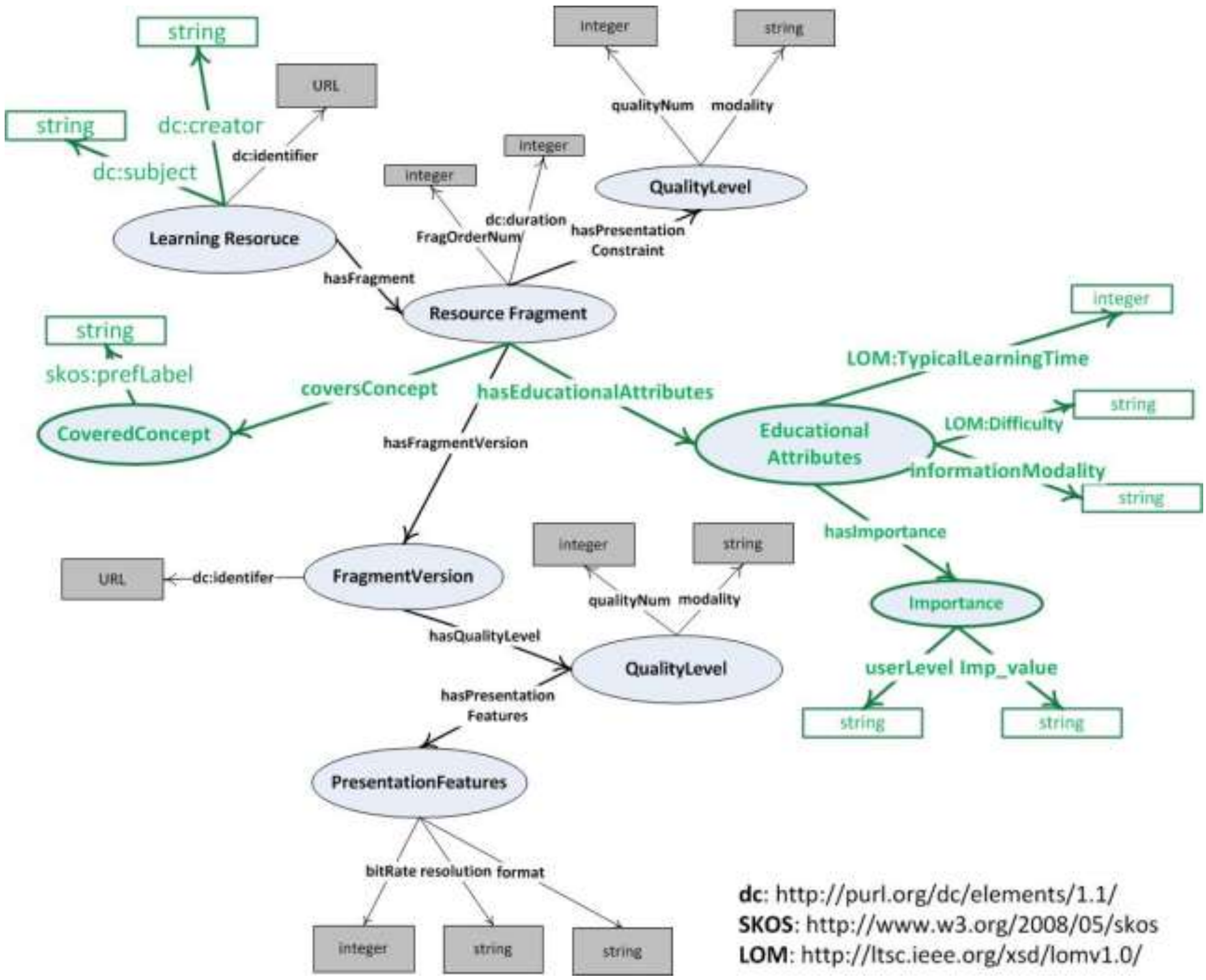

Figure 5-9: Model extension with educational attributes

Figure 5.10 shows an example of the extended metamodel and shows how it is linked with the SKOS Concept map. This example is related to the learning video about the Semantic Web that we have used for evaluation in chapter 6. The green shaded portion of the figure represents an example

SKOS concept map, mapping concepts of Semantic Web. In the figure, we can see that *fragment1* fragment covers two concepts of *Tim Berners Lee* and *The Semantic Web Idea*. The fragment2 fragment convers the concept of *The Semantic Web Layers*.

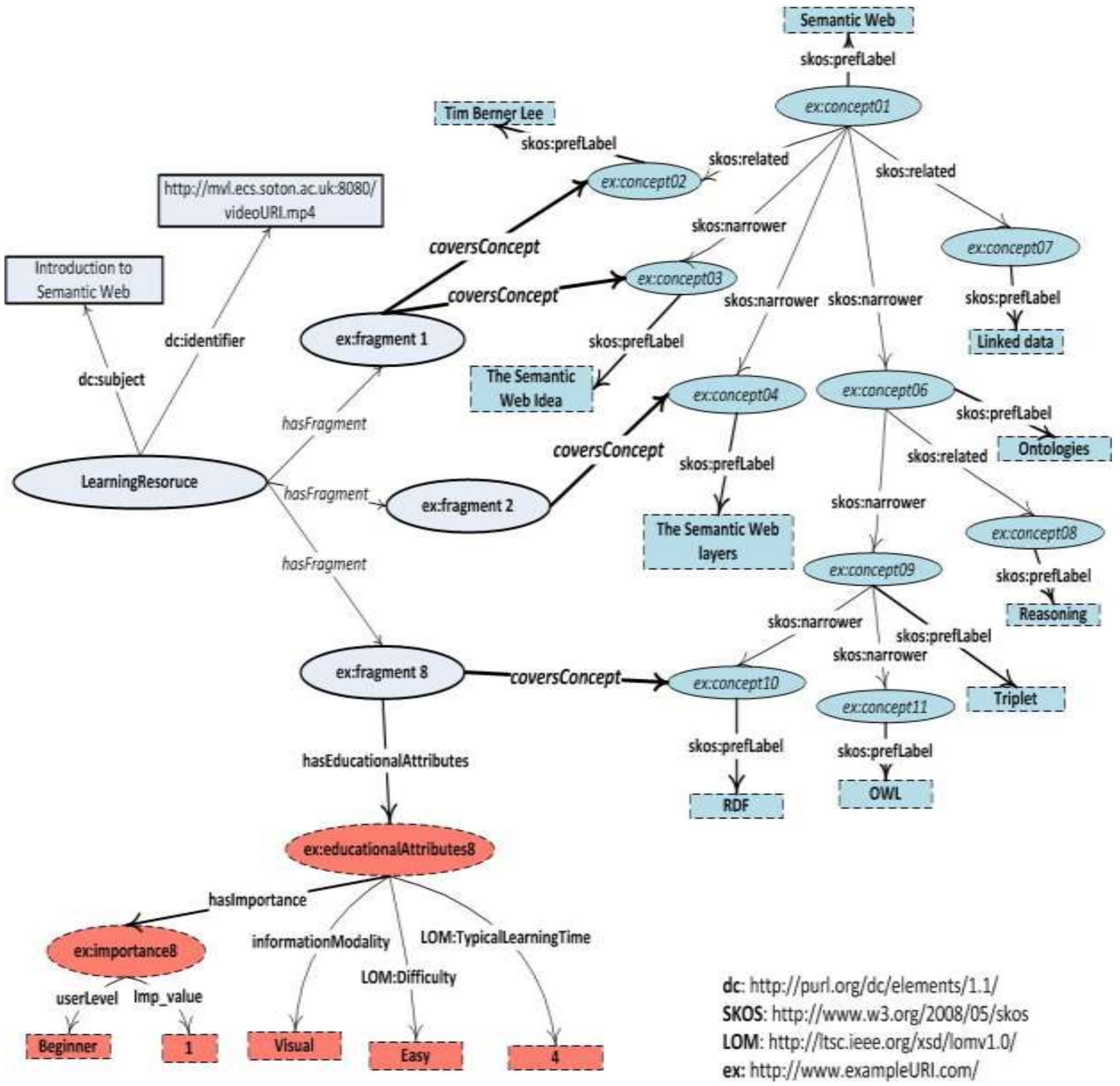

Figure 5-10: An example of the metamodel with educational features

5.5 Testing the metamodel

In this section, we test the Fragmented Educational Multimedia Resource Ontology Model (FEMROM) using some scenarios, from the assumed range of situations. We considered a hypothetical learning multimedia and generated metadata in RDF. Testing is performed to see if we can get the desired fragment versions by generating SPARQL queries for each scenario from the developed metamodel.

In this section, we are not considering the scenarios based on the situations that required adaptation based on educational attributes. Such scenarios include selecting fragments based on the learner's background knowledge. Omitting some fragments for advanced level learners would save further battery-power, but doing such adaptation is beyond the scope of CAPS-EMA and the objective of the thesis. The work in this thesis is about selection of fragments in the lowest acceptable quality from the available qualities and does not adapt multimedia for power-saving based on any educational metadata. Those scenarios, that require educational features based adaptation, are placed in Appendix E.

The example multimedia considered for testing in this section has four fragments and each fragment has three versions; High Quality Video, Low Quality Video and an Audio Only Quality. These qualities are labelled as 1, 2 and 3, respectively as shown in Table 5.1.

Table 5-1 Fragment Version Qualities

Version	Quality
1	High Quality Video
2	Low Quality Video
3	Audio Only Quality

The lowest acceptable qualities as constraints for fragments 1 and 3 were selected as *Audio*. Fragment 2 and Fragment 4 were assigned *Low Quality Video* and *High Quality Video* as constraints, respectively. This thesis is about adaptation based on power-saving policy and not based on any other educational requirements. We have, however, added some educational metadata, primarily related to the importance of each fragment for different user background level, as shown in Table 5.2. This is done with the aim to only suggest possibilities of CAPS-EMA extension. We have used beginner and advanced level background knowledge levels. The value 1 represents that a fragment is required for that knowledge level, while 0 represents that a fragment is optional for a background knowledge level. The suggestion here is that some fragments could be skipped based on the learner educational profile to achieve further power-saving.

Suppose the original video multimedia is hosted at the following URL: http://www.videoLectures.com/videoLecture.mp4

Table 5-2 Fragments Quality Constraints and Importance Information

Fragment ID.	Fragments Quality Constraints	Importance	
		for Beginner Level	for Advanced Level
Fragment 1	3 *(Audio)*	1 (compulsory)	1 (compulsory)
Fragment 2	2 *(Low Quality Video)*	1 (compulsory)	0 (optional)
Fragment 3	3 *(Audio)*	1 (compulsory)	0 (optional)
Fragment 4	1 *(High Quality Video)*	1 (compulsory)	1 (compulsory)

Due to the space limitation, this representation does not contain all information about all multimedia fragments. Each fragment version has a URL as shown in Table 5.3.

Table 5-3 Example of multimedia fragments version

Fragment	Quality	URL	
Fragment 1	HQ Video	URL	http://www.videoLectures.com/videoLecture1HQ.mp4
	LQ Video	URL	http://www.videoLectures.com/videoLecture1LQ.mp4
	Audio	URL	http://www.videoLectures.com/videoLecture1Audio.mp4
Fragment 2	HQ Video	URL	http://www.videoLectures.com/videoLecture2HQ.mp4
	LQ Video	URL	http://www.videoLectures.com/videoLecture2LQ.mp4
	Audio	URL	http://www.videoLectures.com/videoLecture2Audio.mp4
Fragment 3	HQ Video	URL	http://www.videoLectures.com/videoLecture3HQ.mp4
	LQ Video	URL	http://www.videoLectures.com/videoLecture3LQ.mp4
	Audio	URL	http://www.videoLectures.com/videoLecture3Audio.mp4
Fragment 4	HQ Video	URL	http://www.videoLectures.com/videoLecture4HQ.mp4
	LQ Video	URL	http://www.videoLectures.com/videoLecture4LQ.mp4
	Audio	URL	http://www.videoLectures.com/videoLecture4Audio.mp4

This multimedia model is illustrated graphically in Figure 5.11.

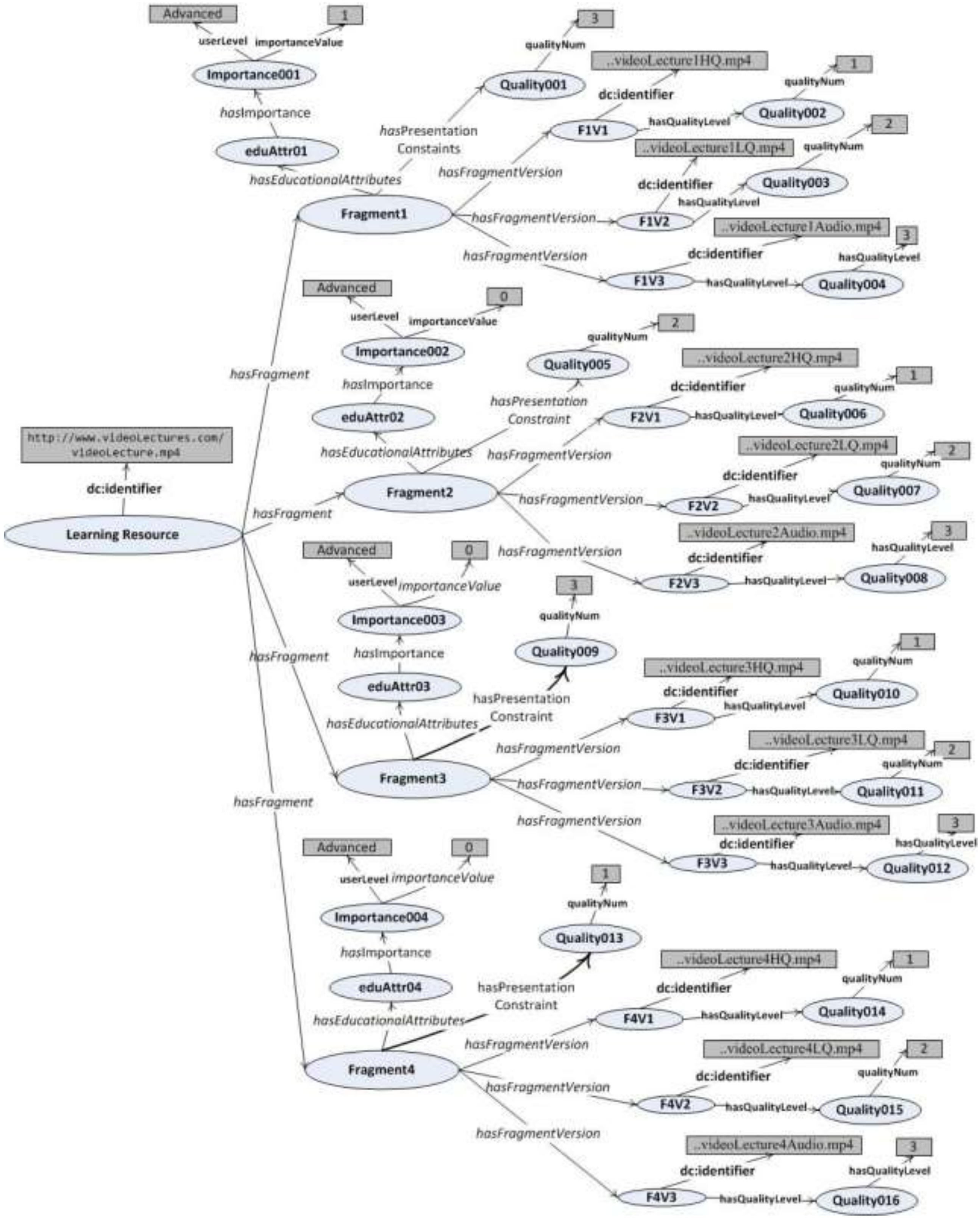

Figure 5-11: Graphical Representation of an example learning multimedia model

Scenario 1:

A learner is interested in using the multimedia but desires maximum possible power-saving.

In this scenario, the learner should be provided with all multimedia fragments and all fragments should be delivered in the lowest acceptable presentation quality. The lowest acceptable quality may vary from fragment to fragment, as represented by constraint quality. SPARQL query in this case should retrieve each fragment in a quality determined as the constraint quality for each fragment in the metadata. In this scenario, there is no role of any educational attributes. We represented this scenario with the SPARQL query given in Figure 5.12 to see the resulting selection of fragment versions:

```
1  PREFIX dc:<http://purl.org/dc/elements/1.1/>
2  PREFIX rdf:<http://www.w3.org/1999/02/22-rdf-syntax-ns#>
3  PREFIX f:<http://www.fragmentmodel.com/elements/1.1/>
4  SELECT DISTINCT ?FragVerId WHERE {
5  ?LR dc:identifier ?ResId.
6  FILTER regex( ?ResId, "http://www.videoLectures.com/videoLecture.mp4","i").
7  ?LR f:hasFragment ?LRFrag.
8  ?LRFrag f:hasPresentationConstraint ?pConstraint.
9  ?pConstraint f:qualityNum ?pConstQNum.
10 ?LRFrag f:hasFragmentVersion ?FragVer.
11 ?FragVer dc:identifier ?FragVerId.
12 ?FragVer f:hasQuality ?Quality.
13 ?Quality f:qualityNum ?QN. FILTER(?QN = ?pConstQNum)
14 }
15 ORDER BY ASC(?FragVerId);
```

Figure 5-12: SPARQL query for scenario 1

In the above given SPARQL query in line 13, we use the filter to select only those fragment versions where the fragment quality is same as constraint quality for that fragment. The output of the query is given below.

Output:

```
http://www.videoLectures.com/videoLecture1Audio.mp4
http://www.videoLectures.com/videoLecture2LQ.mp4
http://www.videoLectures.com/videoLecture3Audio.mp4
http://www.videoLectures.com/videoLecture4HQ.mp4
```

We can see that each fragment is selected in a version that is declared as constraint quality. Presentation constraint qualities are the lowest acceptable qualities from the available options. We can see Fragment 1 and 2 are in Audio, Fragment 2 in lower quality and Fragment 4 in high quality video.

Scenario 2

A learner is interested in using the multimedia but is not interested in any battery power-savings. The learner prefers to watch the multimedia in highest quality.

In this scenario, a learner is not interested in any battery saving and interested to watch the entire multimedia resource in the highest quality. In this case the highest quality should be selected – i-e Quality 1. The following SPARQL query is used to select all fragments in highest quality (quality 1). Practically, for highest quality content when power-saving is not required, the original multimedia file in original quality and as one file should be selected. We here only included this scenarios for the purpose of showing the SPARQL query generation process only.

```
1    PREFIX dc:<http://purl.org/dc/elements/1.1/>
2    PREFIX rdf:<http://www.w3.org/1999/02/22-rdf-syntax-ns#>
3    PREFIX f:<http://www.fragmentmodel.com/elements/1.1/>
4    SELECT DISTINCT  ?FragVerId WHERE {
5    ?LR dc:identifier ?ResId.
6    FILTER egex(?ResId,"http://www.videoLectures.com/videoLecture.mp4","i").
7    ?LR f:hasFragment ?LRFrag.
8    ?LRFrag f:hasFragmentVersion ?FragVer.
9    ?FragVer dc:identifier ?FragVerId.
10   ?FragVer f:hasQuality ?Quality.
11   ?Quality f:qualityNum ?QN. FILTER(?QN = 1)
12   }
13   ORDER BY ASC(?FragVerId);
```

Figure 5-13: SPARQL Query for scenario 2

This is a simple SPARQL query where in line 11 we filter to select all fragments with highest quality - that is, quality value as 1.

Output:

```
http://www.videoLectures.com/videoLecture1HQ.mp4
http://www.videoLectures.com/videoLecture2HQ.mp4
http://www.videoLectures.com/videoLecture3HQ.mp4
http://www.videoLectures.com/videoLecture4HQ.mp4
```

We can see in the output of the query that all four fragments are selected in High Quality. In this section, we used two scenarios to test the metamodel used for MoBELearn system implementing

MoBELearn system. We could see that we could retrieve the desired fragments in the appropriate versions using the generated SPARQL queries.

5.6 Conclusion

This chapter introduced the MoBELearn system. MoBELearn is an implementation of the CAPS-EMA approach, which was introduced in Chapter 4. The MoBELearn is a prototype application that implements the CAPS-EMA framework. This chapter describes the architecture of the MoBELearn system and shows how the system is designed and what components are involved. MoBELearn uses fragmented multimedia and their associated metadata to produce the adapted multimedia, that is, power-efficient as well as retains the multimedia in an acceptable form for learning purposes i.e. no without any perceived loss of information. We also present a Fragmented Educational Multimedia Resource Ontology model, which is implemented as RDF. The metadata used by the MoBELearn to describe the fragmented multimedia is based on this model. We test the model using an example multimedia resource. For this purpose, a hypothetical multimedia learning resource was defined and metadata was generated. Later, SPARQL queries for two representative usage scenarios were generated and checked if we could receive the expected fragment versions. We found that we could successfully generate SPARQL queries to perform the desired adaptation for possible scenarios.

In chapter 6, we would describe evaluation of the CAPS-EMA approach using the MoBELearn system. A case study and an experiment were designed to evaluate the proposed approach. These studies are aimed to understand if the CAPS-EMA approach is acceptable for users for battery power-saving purposes in streaming learning multimedia applications. We would also assess if the CAPS-EMA approach could reduce the problems of perceived visual information loss in multimedia adaptation.

Chapter 6:

CAPS-EMA Evaluation

6.1 Introduction

In Chapter 4 we discussed the proposed Content-Aware Power-Saving Educational Multimedia Adaptation (CAPS-EMA) approach and in Chapter 5 we described a prototype implementation of this approach. This chapter addresses the research questions RQ3-b and RQ3-c. We will discuss in this chapter evaluation of the CAPS-EMA technique. We performed this evaluation in two different ways. In the first evaluation, we performed a Between-Groups experimental study. A separate case study was performed as a second evaluation. The experiment was aimed to understand the differences of opinions between two groups of participants about the two power-saving versions of the learning multimedia. The participants in the first group were provided with a multimedia in lower quality, according to the commonly used existing power-saving approach. The participants of the second group were provided with multimedia adapted using the CAPS-EMA approach, as a battery efficient version. In the case study, we were interested to investigate any possible negative impacts of the characteristics of CAPS-EMA on user acceptance, satisfaction and learning activities. The specific characteristics that we evaluated are fragmented output, difference in visual qualities of different fragments and replacing those video clips by audio versions, where there is no visual information. We received ethical approval from the University of Southampton Ethics Committee to undertake these evaluation studies under reference number 4301.

In section 6.2 we present details of our experimental study. We discuss the methodology for evaluation, the experimental setup and the complete process we followed in this experiment. In section 6.2.2 we present results of the experiments using descriptive analysis. Section 6.3 explains the case study we conducted. We discuss results obtained in 6.3.3 followed by discussion in detail in section 6.3.4. Section 6.4 concludes this chapter by presenting a summary of Chapter 6.

6.2 Experimental Evaluation

In this section, we describe in detail the experimental study we conducted for evaluation. We discuss in detail the methodology used and steps involved in this experiment.

6.2.1 Methodology

This experiment was designed as a Between-Groups quantitative study. Group 1 was provided with lower quality of multimedia as a battery-efficient version, like any traditional approach. A traditional approach is considered as the one which provides battery efficient multimedia version by lowering the quality of multimedia without considering any impacts on learning or information loss. While Group 2 was provided the battery-efficient version adapted using the CAPS-EMA approach. The lowered quality for Group 1 was the same as the lowest video quality used for Group 2. We have discussed the selection and number of lowered multimedia qualities in section 2.7 of Chapter 2. Questionnaires were used for gathering quantitative data mostly in the form of a likert scale. This experiment was designed to understand any differences of opinion between both groups about the following aspects of their respective adapted battery-efficient versions.

1. User satisfaction of the quality of the adapted multimedia
2. Perceived loss of any visual information observed due to low quality
3. Extent of the perceived visual information loss
4. Acceptance of the adapted multimedia for learning purposes
5. Acceptance of the adapted multimedia for power-saving situations

This experiment will help us understand if the participants faced any problems due to lowered multimedia quality and if those problems may impact learning activities. Furthermore, we want to know if the CAPS-EMA approach may perform any better compared to a traditional adaptation mechanism.

For the purpose of this experiment, we recruited 28 PhD students from the School of Electronics and Computer Science, University of Southampton. The participants were randomly assigned to two groups, with each group having 14 participants. This is one of the thesis limitations that the participants selected for the evaluations purposes do not belong to broader range of learner levels. The participants of each group were not told about details of which group were they assigned to. All the participants had experience of using smart phones and other mobile devices.

Most of the participants in this experiment were different from the participants used in the previous experiment. There was a gap over 6 months between the two experiments, and both experiments were different in their nature. We could, therefore, assume that any bias in final results due to any repeated participant would not be significant. The final results of the study also did not suggest any significant and observable bias.

To remove any positive bias in the results, the majority of the PhD students recruited for the experiment did not belong to our particular research group. Furthermore, it was ensured that only those PhD students from our own group are recruited who were not aware of the research.

We selected one learning video from the three videos we used in our first user study (described in Chapter 3). This learning video was on the topic of "Semantic web". Our plan was to provide two different battery-efficient versions of the multimedia to each group. We used the Samsung Note-2 mobile phone for the experiment for both groups, to view their respective multimedia versions using a Wi-Fi connection.

Figure 6-1 Screenshot of main screen for Group 1 Setup

6.2.1.1 Setup for Group 1

We selected a lower quality version of the entire video as the battery efficient version for Group 1. This was done according to any traditional approach that uses a lower quality of multimedia for battery efficiency without any further consideration for information loss or impact on learning. We selected Quality-3 for this video as described in Section 3.3.1. Quality-3 was the lowest quality of multimedia that was in video modality. Quality-4, which was even lower quality, was with Audio modality. The video was presented as a single clip with an entire duration of five minutes. This multimedia was uploaded on a webserver and streamed to mobile device. Figure 6.1 shows the starting screen for Group 1. Figure 6.2 shows some screenshots of the multimedia in Quality-3 at different points and each screenshot does not represent a separate fragment.

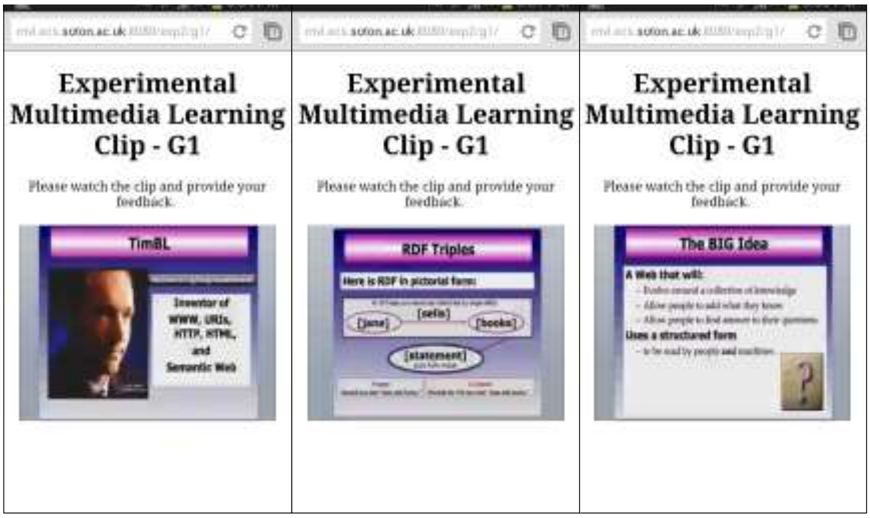

Figure 6-2 Screenshots from Group 1 Setup

6.2.1.2 Setup for Group 2

We used the CAPS-EMA approach to generate battery efficient versions for Group 2. We configured our MoBELearn system to deliver the CAPS-EMA version as a battery efficient version to the participants in Group 2. We generated the metadata to be used by the CAPS-EMA approach (MoBELearn system) based on the results obtained from our experimental study for the video in Chapter 3. From that study we could get the key parts of metadata, that is, information about what were the lowest acceptable qualities for different fragments of the video.

Table 6-1 Screenshots from Group 1 Setup

Fragment	**Presentation Quality**
Fragment 1	Quality 4 (*Audio only*)
Fragment 2	Quality 3
Fragment 3	Quality 3
Fragment4	Quality 2
Fragment 5	Quality 1

The CAPS-EMA version of the adapted multimedia was a set of five fragments in different levels of presentation quality. Different qualities were selected based on the constraints identified in the metadata. In Chapter 4, we discussed in detail about the CAPS-EMA approach and role of the metadata. We show selected qualities for each fragment in Table 6.1. In total 3, out of 5 fragments were selected in the same or reduced quality than the quality of multimedia for Group 1. Therefore, for the group 2 we did not select a major portion of multimedia in a better quality than the multimedia provided to Group 1.

The starting screen for Group 2 setup is shown in Figure 6.3. We can see that the MoBELearn system is configured to provide only one button for participants to start using multimedia. This "*Watch Learning Multimedia*" button implements the maximum battery power-saving option of the original MoBELearn system.

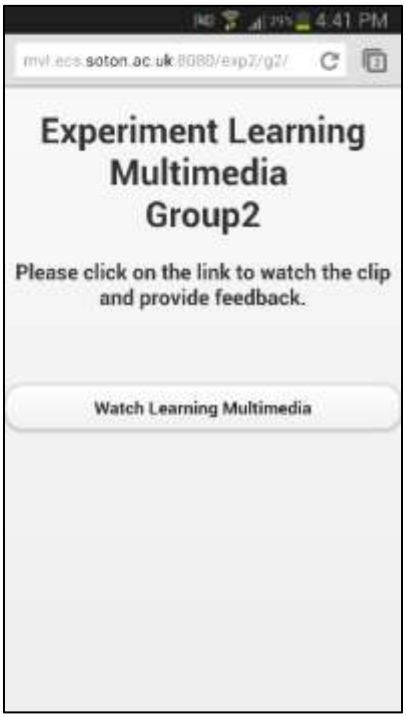

Figure 6-3 Screenshot of main screen for Group 2 Setup

Figure 6.4 shows other screenshots of the system while multimedia is being used. Due to editing and resizing of the screenshots, the content shown does not represent the actual quality of the multimedia that was being viewed. We can see the first multimedia fragment is being delivered as an audio only fragment.

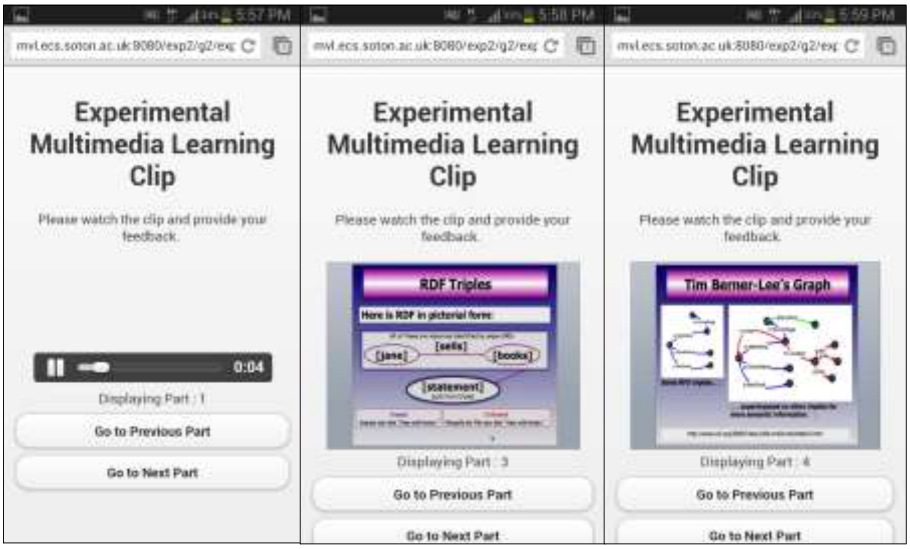

Figure 6-4 Screenshots from Group 2 setup

6.2.1.3 Procedure

We used only one participant at a time in the experiment and all participants were provided similar environmental conditions, e.g., similar levels of lighting, free of distractions. Each participant was briefed before the start of the experiment and was guided about all the steps involved in the experiment and the expected way of providing feedback using questionnaires.

The experiment consisted of four major steps as shown in Figure 6.5. As a first step we provided each group with their respective battery-efficient version of multimedia. We requested participants to focus on the perceived loss of visual information, so that they may be able to provide their opinions later through questionnaires. After the participants used the multimedia, in the second step they were provided with Questionnaire A for their opinion. Questionnaire A was designed to get the participants' opinion about the visual quality of multimedia and if they thought there was any loss of visual information, the extent of the loss of information if any, and their acceptance of the multimedia for learning purposes.

After this, in the third step, we allowed participants to watch the original multimedia. This was done to enable them to see any differences between the first (or adapted) version and the original multimedia. This would help confirm any problems in the adapted version. This would allow participants to figure out any differences in visual information contents and the extent of problems will be exposed. It is worth noting, that we were interested in the visual information that was visible without any problem in the original one but the same was missing or not properly visible in the battery-efficient multimedia version.

Step	Group1	Group 2
1	LOW QUALITY multimedia provided as Battery Efficient Version	CAPSEMA Approach used to provide Battery Efficient Version
2	Group-1 was asked to provide feedback about Low Quality Version in Questionnaire –A	Group-1 was asked to provide feedback about CAPSEMA Version in Questionnaire –A
3	Both Groups were asked to watch original version to observe any differences	
4	Group-1 was asked to provide feedback on differences between Low Quality version and Original version using Questionnaire-B	Group-2 was asked to provide feedback on differences between CAPSEMA version and Original version using Questionnaire-B

Figure 6-5 Different Steps in the Experiment

In the last step, we provided Questionnaire B to the participants to have feedback about any differences they observed and reconfirm their opinion in Questionnaire 1 with respect to original multimedia, especially regarding perceived loss of visual information. We used a different set of questions in Questionnaire B, most of them were to confirm their previous responses.

6.2.1.4 Questionnaires

We now briefly discuss the two questionnaires. We designed two questionnaires; the first one would give us insight into the participants' opinion about the adapted battery-efficient version. We used the second questionnaire after allowing them to view the original multimedia. The statements in Questionnaire B were selected in a way to reconfirm their opinion about the adapted multimedia, after observing differences from the original multimedia.

The questionnaires were designed in order to get the participants feedback about the following aspects (as identified earlier in section 6.2.1):

1. User satisfaction of the quality of the adapted multimedia
2. Loss of any visual information observed due to low quality
3. Extent of the visual information loss
4. Acceptance of the adapted multimedia for learning purposes
5. Acceptance of the adapted multimedia for power-saving situations

Both questionnaires used four point Likert scales (*Strongly Disagree, Disagree, Agree and Strongly Agree*). Two statements S3 and S4 in Questionnaire A used different scales. In S3 we were interested to know about the perceived extent of visual information loss and in S4 we asked about perceived presentation quality of multimedia. We reported results for those two statements separately from the rest.

Firstly, we were interested to know if any perceived loss of visual information was observed by the participants. Secondly, we were interested in the extent of the loss of any visual information as well. We were especially interested to know about the participants' view on the extent of information loss due to lowered quality of multimedia. The extent of the perceived visual information loss will have another dimension as well. It will determine if we selected the appropriate lower quality for the battery-efficient version of the multimedia for Group 1. For example, if for Group 1 the entire multimedia had a very poor quality that caused loss of visual information in the majority parts of the multimedia, then this could raise objection on the quality selected for the multimedia for Group 1. The study design in that case would be considered as biased towards Group 2. We asked participants about the satisfaction of presentation quality to understand if there is any compromise involved in acceptance for battery efficiency. We included statements about the suitability of the adapted version for learning purposes.

In Questionnaire A, we did not ask about any aspect of the battery efficiency or if a multimedia was acceptable for battery-efficiency. We did not want to provide hints about the purpose of the study. This was done to avoid any bias in the answers. We focused only on understanding if the participants think that the information was successfully conveyed or not. We were more interested in Questionnaire A about the perception of information loss due to lower quality and perceived negative impact of the extent of information loss for learning purposes. We asked about the acceptance of the multimedia as a battery-efficient version of the original multimedia only at the end of Questionnaire B.

We mostly used Questionnaire B for confirmation of participants' opinion in Questionnaire A, allowing the participants of both group to watch the original versions of multimedia. Comparing visual qualities of the original and the adapted version was not important for evaluation purposes. The original quality will always be better than the battery-efficient version, but it is also more expensive in terms of the battery-power cost.

6.2.2 Experiment Results

We now report results from our experimental study. We have used descriptive analysis of results. The participants' opinions for Questionnaire A for both groups are given in Table 6.2 and Table 6.3. We also report the mean values and standard deviations. Abbreviations SD, D, A and SA in the table represent Strongly Disagree, Disagree, Agree and Strongly Agree, respectively. We also report results by positive and negative responses in Table 6.4, where we also report percentages of the opinions for positive (Agree, Strongly Agree) and negative (Strongly Disagree, Disagree) responses.

Table 6-2 Results for Questionnaire A

	Questionnaire A Statements	Control Group - Group1						CAPSEMA - Group2					
		SD	D	A	SA	Mean	S.Dev.	SD	D	A	SA	Mean	S.Dev
S1	Some information was not properly visible for understanding			7	7	3.50	0.52	11	3			1.21	0.43
S2	I could view all visual learning contents explained in the multimedia	3	10	1		1.93	0.73			7	7	3.5	0.52
S5	I am satisfied with the presentation of the multimedia	1	5	7	1	2.57	0.76	1		8	5	3.21	0.80
S6	I think a higher quality was required to view some visual learning information			6	8	3.57	0.51	5	8	1		1.79	0.80
S7	Generally, the extent of visual information loss you observed is acceptable for educational multimedia	2	9	3		2.07	0.62			6	8	3.57	0.51
S8	Generally, the extent of visual information loss you observed can have negative impact on a learning activity	1	2	5	6	3.14	0.95	10	4			1.29	0.47

Table 6-3 Results for Questionnaire A (statements S3, S4)

	Statements	Control Group - Group1				CAPSEMA Apporach - Group2			
S3	Up to what extent in the whole multimedia did you observe any Information Loss due to low quality	No Parts	Few Parts	Most Parts	All Parts	No Parts	Few Parts	Most Parts	All Parts
		0	10	4	0	10	4	0	0
S4	Visual quality of the multimedia presentation in your view was	Bad	Poor	Good	Excellent	Bad	Poor	Good	Excellent
		3	9	2	0	0	12	2	0

6.2.2.1 Perceived Visual Information Loss

The statements S1 and S2 were about opinions about the perceived visual information loss the participants have observed. In S1, we asked the participants if the battery efficient version had any perceived visual information loss. There was a clear difference between responses from both groups. The mean of responses for Group 1 is 3.50 with 100% participants agreeing while mean for Group 2 is 1.21, and 100% of participants responded with negative responses. In S2, we asked participants about the same issue in a different way. We asked if they think they could view all learning material. The responses to S2 confirmed results from S1. Group 1 responded with 93% in disagreement and 100% of Group 2 responses were positive, as can be seen in Table 6.4. Responses from both S1 and S2 show that battery efficient version in case of Group 1, had some information not visible for understanding, while no such problem was reported from the participants' in Group 2. From responses to S1 and S2 we cannot get any idea about the extent and severity of the issue in the visual information problem, if any. We, therefore, wanted to confirm this in the next statement S3. This would also justify the selection of the quality of the multimedia for the experimental setup.

Table 6-4 Questionnaire A Results Summary

	Questionnaire A	Control Group - G1		CAPSEMA Group - G2	
		Disagreement	Agreement	Disagreement	Agreement
S1	Some information was not properly visible for understanding	0 0%	14 100%	14 100%	0 0%
S2	I could view all learning visual content that was explained in multimedia	13 93%	1 7%	0 0%	14 100%
S5	I am satisfied with the presentation of the multimedia	6 43%	8 57%	1 7%	13 93%
S6	I think a higher quality was needed to view some learning visual content	0 0%	14 100%	13 93%	1 7%
S7	Generally, the extent of visual information loss you observed is acceptable for educational multimedia	11 79%	3 21%	0 0%	14 100%
S8	Generally, the extent of visual information loss you observed can have negative impact on a learning activity	3 21%	11 79%	14 100%	0 0%

6.2.2.2 Extent of the perceived Visual Information Loss

In S3 (Table 6.3), we asked the participants about the extent in whole multimedia that had the perceived loss of visual information. For Group 1, 10 participants responded that **Few Parts** had problem, while the remaining four responded with **Most Parts**. This suggests that a majority agreed that only few parts of the entire multimedia suffered from the perceived information loss and the selected multimedia quality of the adapted was not totally inappropriate for most parts of the multimedia. For Group 2, 10 participants responded with **No Parts** had perceived visual information loss.

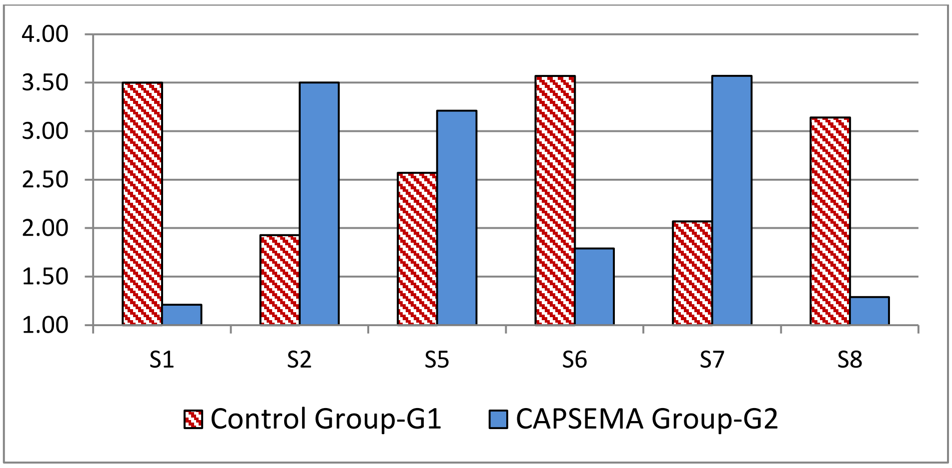

Figure 6-6 Summary of Mean values of both Group1 and Group2

6.2.2.3 Presentation of Multimedia

Statements S4 and S5 were about the presentation of multimedia. For S4, 85.7% of both groups (i-e 12 participants in each group) responded that the quality of presentation was either bad or poor. This shows that the presentation quality of the multimedia for Group 2 adapted using CAPS-EMA was not significantly better in terms of overall quality than Group 1. Despite this, Group 2 agreed that there was no perceived loss of visual information. Responses to S5 show that participants in Group 2 were more satisfied with overall multimedia presentation with mean value of 3.21 of (93%) than Group 1 with mean value of 2.57 (43%).

When asked if they think a higher quality was needed to display some visual learning information (S6), Group 1 responded positively with 100% participants agreeing to the statement with a mean value of 3.57. Group 2 responded in disagreement with 93% participants disagreeing (mean value of 1.79) that a higher quality was needed to convey learning visual information.

6.2.2.4 Impact on Perceived Learning Effect

In S7 and S8, we wanted to know what the participants think about the potential impact of the extent of the perceived information loss, if any, on a perceived learning effect. Both questions are targeted to know participants' perception about similar issues, that is, impact of the extent of any perceived visual information loss on the perceived learning effect. The objective of S8 was to reconfirm S7 in a different way. In Group 1 a total of 11 of the 14 participants (79%) responded that the extent of perceived visual information loss they observed is generally not acceptable for educational multimedia (S7) and that loss of this type of visual information could have negative impact on perceived learning effect (S8). On the other, hand all participants from Group 2 were of the view that the perceived visual information loss, if any, was acceptable for educational multimedia (S7) and that there will be no negative impact on the perceived learning effect (S8). Figure 6.6 shows a summary of means for Likert scale statements in Questionnaire A for both groups.

In order to see the statistical significance of the results, we conducted an independent Mann-Whitney U Test. Results of the U-test are given in the Table 6.5. It can be seen that the significance values for all statements are less than .05 ($p < .05$) showing the difference between two groups are highly significant.

Table 6-5: Mann-Whitney U-Test results for questionnaire A

	Questionnaire A Statements	**Sig. (p-value)**
S1	Some information was not properly visible for understanding	.000
S2	I could view all visual learning contents explained in the multimedia	.000
S3	Up to what extent in the whole multimedia did you observe any Information Loss due to low quality	.000
S4	Visual quality of the multimedia presentation in your view was	.000
S5	I am satisfied with the presentation of the multimedia	.035
S6	I think a higher quality was required to view some visual learning information	.000
S7	Generally, the extent of visual information loss you observed is acceptable for educational multimedia	.000
S8	Generally, the extent of visual information loss you observed can have negative impact on a learning activity	.000

6.2.2.5 Questionnaire B Results

We now discuss the results obtained from Questionnaire B. Questionnaire B was used after the participants were asked to use the original multimedia in original quality, to observe any differences in the quality and visual information contents, and afterwards provide opinion about the differences they found in both versions. In Table 6.6 we put detailed results with participants' answers for each option, mean value and standard deviation. All options in Questionnaire B were based on four-point Likert scale from Strongly Agree to Strongly Disagree with no neutral option. In these statements, the "*first version*" refers to the adapted version of the multimedia, which the participants viewed before Questionnaire A. The original version viewed after Questionnaire A is referred to as the "*second version*" or the "*original version*". In Table 6.7, we summarize results and include the percentage of the participants that responded positively (Strongly Agree or Agree) and those responded negatively (Strongly Disagree and Disagree).

Table 6-6 Questionnaire B Results

	Questionnaire B Statements	Control Group - Group1						CAPSEMA - Group2					
		SD	D	A	SA	Mean	S.Dev.	SD	D	A	SA	Mean	S.Dev.
S9	There is no difference in Presentation Qualities of both versions	10	4	0	0	1.29	0.47	0	10	2	2	2.43	0.76
S10	First version of multimedia had No information loss.	4	10	0	0	1.71	0.47	0	1	7	6	3.36	0.63
S11	I could find some visual information in the original video that was not visible in the first multimedia.	0	0	5	9	3.64	0.50	7	4	2	1	1.79	0.97
S12	The second version of multimedia has extra visual information to learn from.	0	1	9	4	3.21	0.58	4	10	0	0	1.71	0.47
S13	I found it difficult to learn from the first version.	1	4	4	5	2.93	1.00	6	8	0	0	1.57	0.51
S14	I can confirm first version negatively effects learning process.	0	3	5	6	3.21	0.80	10	4	0	0	1.29	0.47
S15	The first version is acceptable for learning if it helps battery power saving and I need to preserve battery power.	2	8	4	0	2.14	0.66	0	0	3	11	3.79	0.43

In S9, we requested the participant for their opinions about any noticeable differences in the presentation qualities of both versions. The mean of Group 1 was 1.29 and Group 2 was 2.43. All members of Group 1 disagreed that there was no difference while 71% of Group 2 disagreed. This means a majority of both groups observed differences between the presentation qualities of the adapted and the original versions.

In S10, we were interested in understanding if the participants believe that there was no perceived information loss with respect to the original version of the multimedia. The mean of responses from Group 1 was 1.29 with all participants (14) responding negatively. The mean value for the responses from Group 2 was 3.36, with all participants (14) responding positively.

In S11 and S12 we asked about the same issues in different ways. We were interested to know if the participants think there were some visual information contents in the original version that was missing in first (adapted) versions. The participants' results from Group 1 show that 100% agreed to S11 and 79% agreed to S12. This suggests that Group 1 found additional visual information contents in the original version; they confirmed that the first version had missing information. The participants in Group 2 responded negatively to both questions with 79% responding in disagreement to S11 and 100% participants disagreeing to S12.

Table 6-7 : Questionnaire B Results summary

	Questionnaire B	Control Group - G1		CAPSEMA Group - G2	
		Disagreement	Agreement	Disagreement	Agreement
S9	There is no difference in Presentation Qualities of both versions	14 100%	0 0%	10 71%	4 29%
S10	First version of multimedia had No information loss.	14 100%	0 0%	1 7%	13 93%
S11	I could find some visual information in the original video that was not visible in the first multimedia.	0 0%	14 100%	11 79%	3 21%
S12	The second version of multimedia has extra visual information to learn.	1 7%	13 93%	14 100%	0 0%
S13	I found it difficult to learn from the first version.	5 36%	9 64%	14 100%	0 0%
S14	I can confirm first version negatively effects learning process.	3 21%	11 79%	14 100%	0 0%
S15	The first version is acceptable for learning if it helps battery power saving and I need to preserve battery power.	10 71%	4 29%	0 0%	14 100%

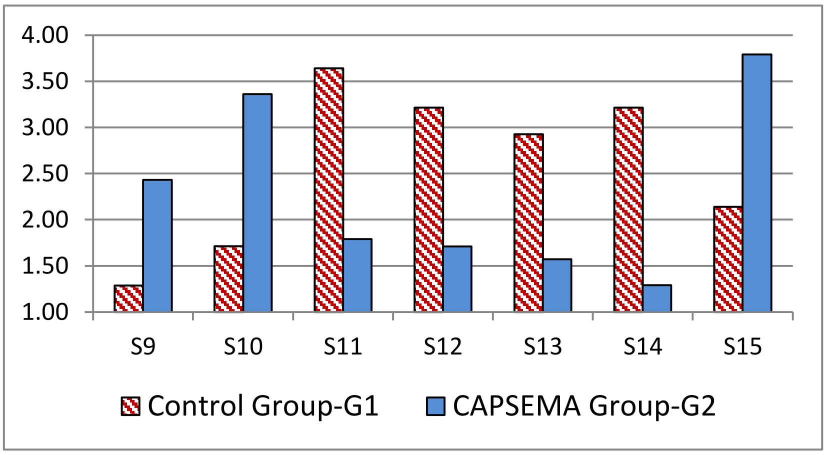

Figure 6-7 : Summary of Mean Values of Questionnaire B

S13, S14 and S15 were related to the impact of visual quality on perceived learning effect. In S13, 9 participants from Group 1 (64%) believed that it was difficult to engage in a learning activity from the first (adapted) version, while no participant from Group 2 believed that it was difficult to engage in a learning activity from the adapted version of multimedia. For S14 in Group 1 79% participants (11) agreed that the first version can negatively affect the learning process while no participant agreed to this from Group 2. In S15, we asked the participants about the adapted multimedia from battery power-saving scenario point of view. We enquired if the adapted version of the multimedia was acceptable as a battery efficient version in a situation where they would like to save battery power. In Group 1, 10 participants out of 14 disagreed that it was acceptable while no participant disagreed in Group 2. The CAPS-EMA version of the multimedia was accepted by all members of Group 2 for battery efficiency.

To check the statistical significance of the results of the questionnaire, we conducted an independent Mann-Whitney U Test. The results of the U-test in Table 6.8 confirm that the differences of opinions of both groups are significant. The significance values for all statements are less than .05 ($p < .05$) suggesting highly significant differences.

Table 6-8: Mann-Whitney U-Test results for questionnaire B

	Statement	Sig. (p-value)
S9	There is no difference in Presentation Qualities of both versions	**.000**
S10	First version of multimedia had No information loss.	**.000**
S11	I could find some visual information in the original video that was not visible in the first multimedia.	**.000**
S12	The second version of multimedia has extra visual information to learn.	**.000**
S13	I found it difficult to learn from the first version.	**.001**
14	I can confirm first version negatively effects learning process.	**.000**
S15	The first version is acceptable for learning if it helps battery power saving and I need to preserve battery power.	**.000**

6.2.3 Further Discussion

In this section, we do further discussion on the results from the experimental study. We are trying to generalise conclusions from combined results of both Questionnaires A and B.

6.2.3.1 Visual Information loss

The results suggest that the participants in Group 1, had problems in comprehending some visual information due to the lowered quality while participants in Group 2 did not face this problem. The results of the S1 suggest perceived visual information loss in the adapted multimedia for participants in Group 1. All the participants in Group 1 reported perceived loss of visual information while all the participants in Group 2 did not report any perceived loss of visual information. The responses to S2 by both groups also suggest the same phenomenon.

The same was also confirmed by Questionnaire B, where participants reported their opinion after watching the original multimedia. The responses to S10, S11 and S12 show that participants of Group 1 believed that their version of multimedia suffered from perceived visual information loss, while Group 2 did not report any such loss of visual information.

The responses to S6 help us to understand better the results so far, that suggests that the visual information loss in the low quality version was due to the reduced quality of the multimedia and not for some other reason. It clarifies, for example, that there were no problems with the visual information in the original high quality version. We think it was important to confirm that the original version of the multimedia was free from any problems with respect to visual information loss. Otherwise, if the original version suffered from any perceived visual information loss, it would obviously reflect in the adapted version too.

These results alone do not reflect any improvements that could be made by our proposed CAPS-EMA approach. These results must be viewed under the following observations that suggest that there was no big difference in the visual qualities to a large extent in the multimedia for both groups. If there were perceived information loss in complete or most parts of the multimedia in Group 1, then it would point to the fact that may be that selected quality was much lowered and was not appropriate. The results of the experiment would not support the potential benefits for our adaptation approach. We therefore, inquired the participants of the study to report on up what extent of the whole multimedia had any issues of information loss. The results of S3 show that the visual information problems in Group 1 occurred only in a few parts of the multimedia and not in the most parts or entire multimedia. 71.5% of participants in Group 1 believed that problems were only in few parts. This suggests that most parts of the selected multimedia were fine in the selected lowered quality for the majority of participants, and that problems were limited to few portions. This fact also helps this position that only 2 out of 5 fragments of multimedia for Group 2 were in higher quality than the quality chosen for multimedia of Group 1. It is also important to remind ourselves that 1 fragment in the Group 2 multimedia was in lower quality then the Group 1 multimedia, which was in Audio only format.

An equal number of participants from both groups (85.7%) described their version of multimedia as “bad” or “poor” in S4. This means that the quality of multimedia adapted through CAPS-EMA for Group 2 was not better than the adapted version for Group 1 by a great extent. Despite this, we have seen that Group 1 reported perceived visual information loss and that Group 2 did not report such information loss. Furthermore, the participants in Group 1 were less satisfied than Group 2 (S5). This strengthens the claim on which we proposed our adaptation technique, that though there may be visual information loss at few points in the entire multimedia, the adapted multimedia will have lesser user satisfaction for learning purposes. We discussed this problem in section 1.2.1.2.

6.2.3.2 Acceptance for Learning Purposes

Group 2 was positive about the acceptance of their (adapted) version of multimedia for learning purposes, while Group 1 declared their version of multimedia as not suitable for use for learning, even when power-saving is required (S13). Group 1 in S7 and S8 decided that the degree to which the visual information loss was observed is not acceptable for using for learning purpose and they were of the opinion that the extent to which the visual information loss was observed could have negative impact on perceived learning effect. On the other hand, all participants of Group 2 decided that their version of multimedia is acceptable for using it for learning activity and did not think that there was any possible of negative implication on the perceived learning effect.

In the results of Questionnaire B, after watching the original multimedia, the opinions of both groups confirms their previous opinions provided for Questionnaire A. A majority of Group 1 reported that it was difficult to learn from their version of multimedia and reported that it was not suitable for learning purposes. Group 2, however, unanimously responded against this view.

6.2.3.3 Acceptance for Battery Efficiency

Group 1 did not approve their version of the multimedia for learning purposes even if it offered battery power-saving in a situation they had to save battery power (S15). The reason was that they do not want to compromise on learning information loss at the cost of battery-power-saving. Only 4 participants (28%) suggested that they would accept this multimedia as a power efficient version in situations where they have to save battery power. On the other hand all participants of the Group 2 would accept their version of the multimedia for learning purposes in the situation they have to preserve battery power.

6.3 Second Evaluation: Case Study

In the second evaluation, we tried to evaluate the specific characteristics of a multimedia adapted through the CAPS-EMA approach. We wanted to understand the impact of those characteristics on user satisfaction, acceptance for learning purposes and for battery power-saving scenarios. This is important for us to understand, as we believe these features are not commonly expected and not found in a multimedia resource adapted through any other approach. These specific characteristics are fragmented output, adapted multimedia in multi-quality and multi-modal form. We wanted to know about any possible negative impacts these features may have on user satisfaction or acceptance for learning purposes.

6.3.1 Characteristics of CAPS-EMA for Evaluation

In this section, we describe those particular characteristics and aspects of the CAPS-EMA adaptation approach that we are interested to evaluate.

6.3.1.1 Fragmentation

The CAPS-EMA approach is based on fragmented multimedia. The output of the CAPS-EMA is fragmented, where each fragment is supposed to be delivered in the lowest acceptable quality. We were interested to know about the participants' opinions about the impact of fragmented output on the user satisfaction and acceptance for learning purposes. We also wanted to know if the participants would accept fragmentation in the adapted multimedia for battery power-saving purposes.

6.3.1.2 Adapted Multimedia in multiple qualities

The second feature of a multimedia adapted through CAPS-EMA is that the output is in multiple qualities. Different fragments could have different presentation qualities. We would be evaluating the impact of this multi-quality output on its acceptance for learning purposes, on user satisfaction and acceptance for power-saving.

6.3.1.3 Output with Audio Fragments

The third distinctive feature of our proposed adaptation technique is the way we could replace some video fragments by an audio-only version, when the learning information is not in visual. In such situation the learning information is in verbal and audio only quality could convey the information without any loss in visual information. We wanted to understand the participants' opinion about this feature, as to how it may impact on user satisfaction, perceived learning effect and if it is acceptable for battery power-saving.

6.3.2 Methodology

For the purpose of evaluation, we selected the participants of Group 2 in our earlier experimental study discussed in section 6.2. As that group already has viewed the battery efficient version using the CAPS-EMA approach, we decided to use the same group for evaluation and provided them with additional Questionnaire C after the first experiment was finished. The entire process of filling Questionnaire C took an additional 5-10 minutes after the end of the experimental. We requested the participants to provide their opinion on the first version of the multimedia. We divided a total of 11 statements in Questionnaire C into three categories; user satisfaction, Impact on perceived Learning effect and acceptance for battery power-saving. We used a five-point Likert scale (Strongly Agree – Strongly Disagree including a Neutral option) in Questionnaire C. Questionnaire C was mostly based on personal preferences and acceptance, instead of reporting on comprehensibility of visual information, therefore, the neutral option in Likert scale was also included.

To achieve further reliability in terms of impact on actual learning process and learning outcomes, it would be useful to allow participants a much longer period of time (months) to use multimedia adapted through CAPS-EMA and allow them to perform real learning activities with actual testing of their learning. In the current evaluation, however, we are interested to assess the participants' perception about suitability of the characteristics in which CAPS-EMA adapts multimedia. We believe that the methodology adopted for this case study can successfully achieve this objective.

6.3.3 Results

We now discuss the results gathered from the participants' opinions. We used descriptive analysis for analysis purposes. Mean values are reported on a scale of 1-5. In statements S1 to S5, we were interested to understand the participants' satisfaction of overall experience, while using multimedia adapted using the CAPS-EMA approach. For these five statements, we present mean values of participants' responses in Table 6.9 while a summary of the results in terms of positive, negative and neutral responses is given in Table 6.10. Figure 6.8 summarise mean values of the participants' responses to the questionnaire as a bar graphs.

Table 6-9 : Mean values of participants User Satisfaction responses

No.	Statement	Mean	Std Div.
S1	I could observe difference in video qualities of different clips	3.29	1.07
S2	I am comfortable with multimedia being presented as multiple clips	3.79	1.12
S3	I am satisfied with different segments of multimedia being presented in different visual qualities	3.93	0.73
S4	I am comfortable with multimedia learning resources have some parts in audio	3.71	0.83
S5	There was no problem for understanding concepts explained in each clips	4.5	0.52

In S1, we were interested to know if the participants could observe the difference in the visual qualities of different fragments in the adapted multimedia. The mean value of responses was 3.29. Overall, 42.9% agreed that that they could observe the difference, 28.6% disagreed and 28.6% remained neutral. This suggests that the majority of participants (57.1%) could not observe any differences in the visual qualities of different fragments in the adapted multimedia.

Table 6-10 : User Satisfaction Responses Summary

	Disagreement		**Neutral**		**Agreement**	
S1	4	28.6%	4	28.6%	6	42.9%
S2	2	14.3%	4	28.6%	8	57.1%
S3	0	0%	4	28.6%	10	71.4%
S4	2	14.3%	1	7.1%	11	78.6%
S5	0	0%	0	0%	14	100%

In S2, S3 and S4, we asked about the impact of CAPS-EMA features on satisfaction. In S2, 57.1% agreed (mean value 3.79) that they are comfortable with the adapted multimedia being delivered as a combination of fragments and only 14.3% participants responded that they were not comfortable with fragmented multimedia. 28.6% remained neutral. It is important to mention that the prototype we implemented had fragmentation explicitly observable. One reason was that fact that the *autoplay* feature is disabled in mobile operating system and its effect was well-defined. We believe that user satisfaction would increase if CAPS-EMA is implemented using adaptive streaming technique where the quality of a multimedia can be changed seamlessly without obvious breaks. Even an implementation that would allow the play fragments in an *autoplay* - without asking users to click for starting new clip - will be very helpful in increasing user satisfaction.

When asked in S3 if they were comfortable with differences in visual qualities of different fragments in multimedia, no participant responded negatively. The mean value was 3.93 with 10 participants (71.4%) agreeing and the rest remained neutral. 11 participants (78.6%) agreed to S4 that they have no problem with a mix of audio and video clips with mean value 3.71. Only 2 participants (14.3%) disagreed and 1 (7.1%) chose neutral option. All participants responded positively to S5 which said there was no problem in understanding of the concepts contained each clip.

In S6, S7 and S8, we inquired about the impact of the CAPS-EMA features on perceived learning effect and comprehension of the information contents. The opinion results are given in Table 6.11 and Table 6.12. The participants' responses were very positive with mean values of 4.21 for S6 and S8 and 4.29 for S9. The perception of the participants was that the evaluated features would have no negative impact on the perceived learning effect. 13 participants of the total 14 (92.9%) responded positively for each of these three statements with 1 neutral opinion for each statement.

Table 6-11 : Result of Responses to Impact on Learning

	Statement	Mean	Std Div.
S6	Multimedia presented in multiple clips does not negatively impact learning	4.21	0.579
S7	Learning multimedia composed of clips of different visual qualities does not negatively affect learning	4.29	0.611
S8	Presentation of multimedia fragments in Audio has no negative impact on learning	4.21	0.579

Table 6-12 Summary of Responses to Impact on Learning

	Disagreement		Neutral		Agreement	
S6	0	0%	1	7.1%	13	92.9%
S7	0	0%	1	7.1%	13	92.9%
S8	0	0%	1	7.1%	13	92.9%

In S9, S10 and S11, we were interested in understanding the participants' opinion about acceptance of CAPS-EMA features for the battery power-saving situation. We asked if each of the three statements were acceptable to the participants if done for the sake of battery power-saving in a situation when they want power-saving. The participants' opinions were very positive. Mean values for S9, S10 and S11 were 4.29, 4.36 and 4.64, respectively (Table 6.13).

Table 6-13 : Results of Responses to Acceptance for Battery Efficiency

	Statement	Mean	Std Div.
	Are the following acceptable to you in this multimedia presentation if done for battery saving in a situation you needed to save battery power?		
S9	Receiving learning multimedia as multiple clips	4.29	0.726
S10	Receiving clips in different video qualities	4.36	0.633
S11	Receiving audio version of a video portion that has no important visual information	4.64	0.497

A summary of the responses to the participants' acceptance of the features of the adapted multimedia for battery efficiency is given in Table 6.14. In S9, we asked about the acceptance of the fragmented multimedia for battery power-saving. 12 participants (85%) responded positively for this statement and only 2 responded with neutral option. No participant responded negatively. In S10, we inquired about the acceptance of the battery-efficient adapted multimedia in multi-quality with fragments in varying visual qualities. 13 participants (92.9%) responded positively and 1 participant responded with the neutral option. In the last statement S11, we asked if a mixture of audio and video clips was acceptable for battery power-saving purposes. All participants responded positively.

Table 6-14 : Summary of responses to Acceptance for Battery Efficiency

	Disagreement		Neutral		Agreement	
S9	0	0%	2	14.3%	12	85.7%
S10	0	0%	1	7.1%	13	92.9%
S11	0	0%	0	0%	14	100%

In Figure 6.8, we present a summary of participants' responses for each statement in a bar graph.

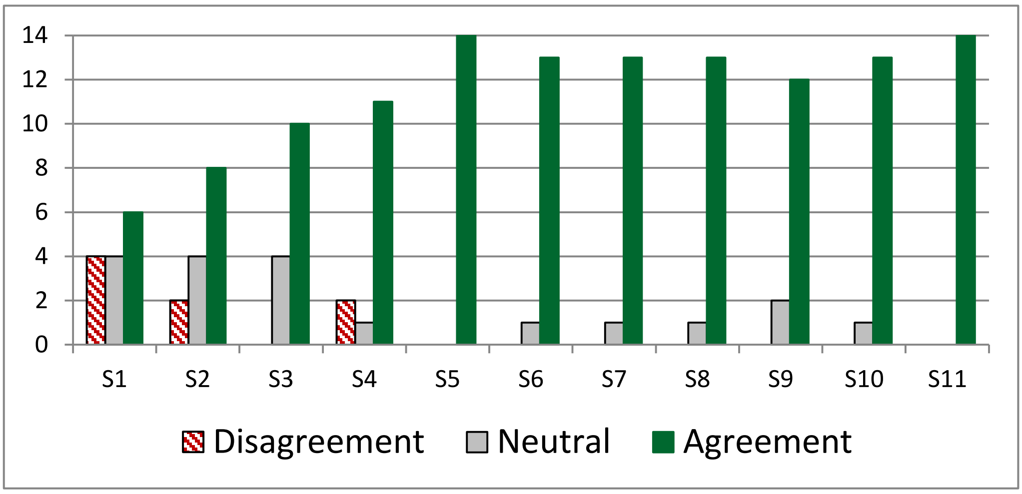

Figure 6-8: Detail of Responses for Questionnaire C

6.3.4 Discussion

We performed this second evaluation in order to understand if there were any perceived negative impacts of the specific characteristics of the multimedia adapted through the CAPS-EMA approach, may have on user experience and perceived learning effect. The results of the case study were positive. As we can see in Figure 6.8 the mean values are high and the participants were comfortable with these features. Mean values are especially higher for acceptance of the features of the adapted multimedia for battery-power-saving situations.

The results of S1 suggest that the majority of the participants of the study could not observe the differences in video qualities of different fragments in the multimedia. Eight participants (Disagreed: 4, Neutral: 4) could not observe the difference in visual qualities of different fragments. This suggests an important point that only a slight and less noticeable increase in visual qualities of only few fragments could help in reducing the visual information loss. This, however, may not always be the case. The difference in video qualities may be more pronounced for any other video. This, however, will not impact the efficiency of our proposed technique.

The responses for S3, S7 and S10 show that the differences in the video qualities of different clips do not have any negative impacts on the user satisfaction, perceived learning effect or acceptance for battery-efficiency. This was the not an unexpected outcome. We thought we should evaluate every aspect of the CAPS-EMA approach and, therefore, evaluated this feature too for its impact.

The responses to S2, S6 and S9 show, that the participants thought that there were no negative impact of the adapted multimedia in fragmented form on the user satisfaction, perceived learning effect or on the acceptance for battery efficiency. Only 2 participants responded that they were not satisfied with the use of fragmented multimedia. However, no participant reported any negative impact of fragmented multimedia on perceived learning effect and no participant disagreed with its acceptance for battery efficiency. The responses to S6 suggest that participants were of the view that the fragmented multimedia would not negatively impact the learning process. This is because all of the learning information was conveyed without any perceived learning information loss. The responses to S9 reveal that fragmented multimedia is acceptable for battery saving purposes. Only 2 participants (that make up 14.3% of all participants) opted for the neutral option while the remaining 12 (85.7%) agreed for use of fragmentation for battery efficiency.

The opinion results for the statements S4, S8 and S11 also suggest that it is acceptable to deliver the audio version of a video piece, when there is no visual information in some specific part of a learning multimedia. Only 2 participants reported that they were not comfortable with audio clips replacing video clips in a learning multimedia. The responses to S8 also show that it will have no impact on perceived learning effect, if we replace the video clips with audio, where the information is in verbal. No participant disagreed in S8 (Agree: 92.9%, Neutral: 7.1%) where we asked about their views on the perceived negative impact of incorporating audio clips in the adapted multimedia on learning process. All participants agreed that it is acceptable for audio clips to replace video parts when there is no visual information for battery-saving purposes.

Based on the evidence gathered from the results of the case study, we could say that the CAPS-EMA adaptation characteristics were overall acceptable for the participants. There is no evidence from the opinion of the participants that any of these characteristics had any perceived negative impact on the learning activities.

6.4 Conclusion

In this chapter, we discussed the two studies we conducted for the evaluation of the CAPS-EMA approach. This evaluation was conducted in two ways. First we conducted an experimental study based on a Between-Group experimental methodology. The experiment was aimed at investigating differences in opinion of the two groups. One group was provided a power-saving version of a multimedia adapted using traditional approach of lowering uniformly the presentation quality of the entire multimedia. Another group was provided a battery with efficient version of a multimedia, using the CAPS-EMA approach. The results of the experiment suggested that there were significant differences in the opinion of both groups. The group using the traditional approach of battery power-saving for the streaming multimedia reported problems of perceived visual information and believed that the adapted multimedia would not be suitable for using for learning. The group that used the CAPS-EMA approach was satisfied with the adapted multimedia and believed that the adapted multimedia had no impact on the perceived learning effect. The second evaluation was based on a case study. The case study was aimed at evaluating the characteristics of the CAPS-EMA approach to understand if those characteristics posed any problems for learning activities, have negative impacts on user satisfaction and they were acceptance for battery-efficiency purposes. These characteristics include fragmented nature of the adapted multimedia using the CAPS-EMA approach, replacement of those video portions of a multimedia which did not contain any visual information by their audio version and the difference in the visual qualities of different fragments. The results of the case study reveal that the participants did not report any issues with these features and declared those features as acceptable.

Chapter 7: **Further Evaluations**

This chapter primarily addresses research questions RQ3-c and RQ3-d. In order to gain further insights regarding the important characteristics and issues surrounding CAPS-EMA, we arranged two further studies for evaluation with more focus on qualitative data and analysis. We identified learners and learning content authors (could be instructors) as the two main stakeholders of the CAPS-EAM adaptation approach in chapter 4. In this chapter, we first discuss our study aimed to evaluate the main features (steps) involved in the authoring process of producing the multimedia in the required format and generation of the needed metadata that will be enable implementation of the CAPS-EMA approach. We designed the study with experts (non-students) in the role of content authors, which are important stakeholders. The main focus of this evaluation was on understanding viewpoints about the main aspects of the authoring process through qualitative data using open discussion and interviews. Furthermore, in the second evaluation, we arranged another study with participants in the role of learners to assess the impact of the adaptation on the concepts covered in the original multimedia. This was done through qualitative data gathering and analysis. In these evaluations with learners we discovered some new insights - regarding about the way CAPS-EMA adapts multimedia - that were not highlighted in earlier experiments.

Before we describe the first evaluation study with experts in detail, it is important to first describe briefly the authoring process that would generate the multimedia in required format and the metadata for the CAPS-EMA adaptation approach and identify the characteristics of the authoring process that would be evaluated.

7.1 Characteristics of the authoring process

The work discussed in this thesis has not included any specific multimedia authoring tool for processing a learning multimedia according to the framework developed for the CAPS-EMA adaptation approach (Chapter 4). The framework could identify the main tasks that should be implemented by an authoring tool to be developed for the CAPSEMA adaptation approach. The actual development of any authoring tool is left for the future work and is not discussed in this thesis.

In this section, we briefly identify and describe those activities and tasks involved in the authoring process for the CAPS-EMA approach. These actions or tasks will be performed by the content author (or instructors) as part of the authoring process.

7.1.1 Generating multimedia version in different presentation quality

One task of the authoring tool would be to enable generation of multimedia versions in different presentation qualities. The generated multimedia versions would be used to determine quality constraints, as discussed in the following sections.

7.1.2 Viewing the multimedia in multiple presentation qualities

The authoring process includes viewing the multimedia in multiple presentation qualities, in order to identify presentation quality constraints among the available qualities for different portions of multimedia. Viewing the multimedia in different qualities helps the content author to assess the impact of lower qualities on the information contents to observe any potential perceived information loss. This would help in the fragmentation process and identifying quality constraints on fragments.

7.1.3 Observing the impact of lower qualities

This means content authors should be able to observe and understand any potential impacts of the lowered presentation qualities on comprehension of the visual information contents due to any perceived loss of visual information. This would help in identifying the quality constraints on various multimedia fragments. The constraint quality is the lowest available quality that would not cause any perceived loss of visual information as a result of the lowered quality. This is a major task in the processing of a multimedia and thereafter metadata generation for the CAPS-EMA adaptation approach.

7.1.4 Identifying fragments

As mentioned before, viewing learning multimedia in multiple available qualities to observe any perceived loss of visual information due to lowered presentation qualities would help in identifying the quality constraints for different portions of a multimedia. This process forms the basis of identifying fragments in a multimedia and is the main aim of the multimedia processing or the authoring process. A fragment in the context of the thesis is a piece of educational multimedia that has similar visual minimum quality requirements for conveying the contained information. A constraint quality would be assigned to each fragment. These constraint qualities are then used by the adaptation process.

Identifying fragments essentially means identifying the start and the end times of a portion of a multimedia which will have the same constraint quality. This requires the same multimedia content to be viewed in different qualities for visual inspection of the possible impact in order to assist the content authors to determine the quality version that would be determined as the lowest acceptable quality for a piece of multimedia. There is no limitation as such on the duration of a fragment or identifying fragments based on any other specific characteristics. However, it is believed and it is also obvious that fragments of a very small durations (few seconds) could result in poor user experience and may not be as battery-efficient due to the involved overhead of fragmentation. It would not be, therefore, worth considering such portions of multimedia of such small duration as a fragment in the context of the CAPS-EMA approach. We have identified the need for further research into the matter to investigate the minimum acceptable fragment length or duration in order to provide power-saving as well acceptable user experience. On the other hand, a full educational multimedia could be considered as one fragment if there is no variation in the lowest acceptable quality for avoiding perceived information loss.

7.1.5 Annotating fragments with quality constraints

After fragments are identified, the next important task in the authoring process would be to annotate the fragments with quality constraints for each fragment. The lowest acceptable quality is identified during the fragmentation process, where content authors are allowed to inspect the multimedia in different qualities. This lowest acceptable quality constraint for different fragments is the key aspect of the CAPS-EMA approach for adaptation.

7.1.6 Annotation with educational and other metadata

The multimedia fragments could be annotated with educational metadata. The role of educational metadata in adaptation is beyond the scope of the thesis. The scope of the thesis is adaptation for power-saving through multimedia quality reduction only. The exact use of the educational multimedia depends on the nature of the metadata and its objective. Some possible uses of an educational metadata could be to include difficulty level of the content in each fragment, suitability of each fragment for various user knowledge levels or including concepts covered by each fragment etc. One potential use of such educational metadata in the context of this thesis could be to exclude some multimedia fragments based on difficulty level or suitability for certain user knowledge level, to achieve further power-saving for those specific knowledge levels.

7.2 Evaluating the Authoring Process

In this section, we now discuss the evaluation of the process of multimedia authoring and metadata generation for CAPS-EMA, with experts - in the role of multimedia authors. Different activities involved in the authoring process are identified in Section 7.1. In order to conduct this evaluation study, we received ethic approval with ethics reference number 16151. The same ethics approval was also received for the second part of the evaluation with participants in the role of learners. This second study is described in the section 7.3.

7.2.1 Experiment Objective

The objective of the evaluation study is to evaluate the processes involved in the authoring process that will lead to generation of multimedia and metadata in the required form for the CAPS-EMA adaptation approach. As we have not yet developed any authoring tool, we would be evaluating the authoring steps performed manually. We requested the experts to go through the processing tasks involved in the authoring process manually. We manually created different versions of a selected learning resource and requested participants to perform the tasks over them.

We aimed to understand views of the experts about different aspects of the authoring process. We were interested to know how easily they could perform various tasks involved in the authoring process. We wanted to know how much the participants understood the process and criteria of the fragmentation process, if they could identify fragments and on what basis the participants decided about fragments. We wanted to investigate if the participants could easily identify lowest available quality constraints for each fragment. Furthermore, we want to know what the participants' think about how easy the process of associating the educational metadata with each fragment is. The aim is to gather qualitative data about the above mentioned aspects of the authoring process.

7.2.2 Experiment Design

We designed a semi-structural interview for this qualitative evaluation. We selected three experts for the purpose of this experimental study, from Electronics and Computer Science, University of

Southampton. Two of the three experts were university level teachers with minimum 5 years of teaching experience. We also chose one post-doc researcher who extensively worked on development of e-learning tools for educational multimedia. The same researcher also did research and have publications in the area of multimedia fragments. We developed a set of open ended questions to get insight into the aspects of evaluation that we were interested to investigate.

First, we briefed each participant about the procedure of the evaluation. We discussed with each participant the idea of fragments based on the concept of lowest acceptable presentation quality. We then requested each expert to identify fragments in the learning multimedia provided to them. For this purpose, we selected a video on the topic of the Semantic Web. The selected video is the extended version of the learning multimedia used in the previous experiments. We enabled each participant to view the multimedia in the same four different presentation qualities including audio version. This was done by creating a webpage where they were provided all multimedia in the four versions and they could play and pause each multimedia version. We used the same presentation qualities for the four versions that were used in earlier experimental studies discussed in chapter 3 and 6. We requested the participants to think-aloud during the fragments identification. We recorded entire interview sessions for evaluation purposes.

7.2.3 Findings

We now discuss findings of the evaluation.

7.2.3.1 Executing the authoring process

As mentioned in the experimental design section, we requested participants to think aloud during going through the authoring process. The process involved identification of the potential fragments based on the available minimum quality requirements of the visual information contents and declaring the lowest acceptable presentation quality among the available four qualities. Below we present our findings and also mention some important comments of the participants.

- ***Understanding the process of fragmentation***

  We noted the participants had little trouble with understanding the overall process and the concept of fragmentation to meet the requirements of the CAPS-EMA approach. The participants were able to identify potential fragments. The fragments identified by the participants along with the identified lowest acceptable quality are given in Table 7.1.

Participant 1 commented during the study that "*For this part quality 3 is not appropriate but (quality) 2 is better*". This suggests that the participant understood the process and decided to consider that specific portion of the multimedia as a fragment with Quality 2 as a constraint. Another participant, Participant 2 commented during the process about a different portion of the multimedia as "*Q3 is not bad but Q2 is needed for this information.. so Q2 is better*". Participant 3 commented about another segment as "*this one should be Quality 1in high quality*".

Identifying the lowest available quality that is suitable for a particular portion of multimedia is the basis of the fragmentation. During executing the authoring process the participants were able to identify fragments and understood the fragmentation process.

- ***Understanding the impact of quality reduction***

We noted from the comments and the list of identified fragments by the participants did not face any problems in understanding the impact of quality reduction. When the participants were able to see the same multimedia in different qualities they were able to observe the differences in the presentation qualities and they could decide about any negative impacts of the quality reduction on the information contents of the multimedia. Furthermore, the participants were quick to identify the features causing the problem of perceived information loss due to quality reduction. Below we have put some comments of the participants that reflect that the participants were able to assess the impact of quality reduction on information.

Participant 1 commented on the impact of lowered quality on text in the video as "*You can see some blurring on the text there, but that's fine. Where there is text only it appears to be fine. Lets compare it to the above one (higher quality)…*". The same participant thought that a diagram which had some text in smaller font size should be displayed in the highest quality and commented as "*This is a diagram and it should be (quality) number. 1.*"

Participant 1 referring to a portions of multimedia where there was little difference in visual information due to quality reduction said, "*You can see there is slight degradation between (quality number) 2 and 3 but not much*" and "*.. there appear to be no difference between three of them*"

The Participant 2 also pointed out that the graph in the multimedia should be in the highest quality as in any lower quality there was some perceived loss of visual information in smaller text and said "*It is not so bad (in Quality 2), but Quality 1 for the graph is better".* The Participant 3 referring to some portion of multimedia containing a graph said, "*This definitely can't be audio… quality 2 for this diagram.. I think".*

- ***Identification of fragments with Audio-Only as lowest quality***

  We noted that the participants agreed that some parts of the multimedia could be conveyed in audio, as the visuals in those parts were not essential. All participants were able to identify such fragments of the multimedia where they thought the audio-only version could convey the essential information. For example, Participant 1 said on one occasion, "*For that last slide (portion) you could use audio as there is nothing (visual) in the slide that could help. Now again, that portion or that sort of example slide doesn't need to have visuals… that could be in audio*". Similarly, the participant 2 said, "*The first part can be in audio…as the photo is not needed*" "*This can be audio as there is nothing special in the visuals*". The Participant 3 referring to some part with audio-only quality as acceptable said, "*This one will lose some information but it is ok, because you don't have to know (see) this. So audio is good for this part".*

7.2.3.2 Fragmentation

The participants of the study were able to identify fragments with some quality as lowest quality constraint. The entire multimedia was of duration 13 minutes 15 seconds. All the participants did not identify the same fragments. There were few differences in the portions of the multimedia identified as fragment as well as some differences in the lowest quality constraints for a fragment. This suggests that identifying fragments is a subjective process, and the same multimedia can be fragmented in multiple ways depending on the perception of the author. Table 7.1, shows the output of the authoring process by the three participants. The output includes the start and end times of identified fragments and their respective quality constraints. We got ten fragments from the entire multimedia based on the decisions of the participants during the authoring process. At least two of the three participants suggested each of the given fragments in the table, where all three participants did not suggest the same fragment.

Table 7-1: Output of the fragments Identification

Fragment #	Start Time	End Time	Duration	Quality Constraint
1	00:00	01:07	01:07	4-*Audio*
2	01:08	02:50	01:40	2
3	02:51	04:03	01:15	4-*Audio*
4	04:04	05:09	00:54	3
5	05:10	05:52	00:42	4-*Audio*
6	05:53	08:01	02:05	3
7	08:02	08:45	00:42	4-*Audio*

8	08:46	11:07	02:19	2
9	11:08	12:42	01:34	1
10	12:43	13:15	00:32	2

To understand the participants' perception about the difficulty or any problems in the fragmentation process, we enquired them about their views. They were of the view that there was not something very difficult in the process and that it was easy. The Participant 1 responded when asked if the process was simple and easy by saying, "*Yes quiet easy. Very easy… really easy*". The process is time consuming, however, authoring phase of any adaptive learning resource that offer some sort of personalisation takes more time at the authoring stage, than a one-size-fits-all resource.

It has also been observed that it was easier to make decisions about the portion of multimedia where the information was mostly in textual form than when graphs or figures were involved. One participant mentioned that in lower qualities there may be difficulties in choosing one. The participant 2 said, "*It is not difficult. It is an easy task. Only in some portions there may be difficulties (in making decisions) in some low qualities"*. The participant 3 also point out that the difficulty level of the authoring process will not be the same for all multimedia and it depends on the nature of a multimedia. Especially, if the visual contents of the multimedia is fast moving and keep drastically changes with quick intervals, may make the process further time consuming and the decisions will take more time. The participant 3 said, "*It is not difficult I think. For this video it was very easy. But for any other video it may be different"*. This suggests that the fragments identification also depends on the nature of information contents in a video.

7.2.3.3 Basis of fragmentation

We also wanted to know on what basis the experts would consider a portion of multimedia for a fragment. We, therefore, enquired the participants about the factors on the basis of which they would identify fragments. It was revealed during the discussions that fragments are identified based on observing the visual contents of a multimedia, the perceived importance of the visual contents and quality requirements of the different parts of the video. A new fragment is supposed to start when there is significant change in the visual contents. The difference should be significant enough to cause change in the lowest quality requirements. Over all, the following themes emerged from the discussion.

- Visual appearance of the information contents
- Change of slide, where multimedia consists of slides

- Change of plot
- Significant change in presentation of visual information

One participant said about the basis of the fragmentation, "*Just the visual appearance of the information or text, especially the text on labels on the graphs or images… not only normal text but on graphs and diagrams. Especially, in the links and labels on the figures. In low quality video there were difficulties (to comprehend them)*". Another participant talked about more generalised patterns and said "*Fragments could be defined by change of screen, change of plot etc. in different ways. In this video mostly it was change of slide*".

7.2.3.4 Lowest quality constraint identification

The most important feature of the CAPS-EMA approach is the identification of lowest acceptable quality from the available qualities as a constraint quality. During the experimental procedure, we allowed each expert to view the multimedia in different qualities at the same time. They could pause and play any version at any time – in order to observe the information contents. It is important to know about how the experts would decide about the selecting the lowest acceptable quality for a piece of multimedia. We, therefore, enquired the experts about the basis on which they decided about the lowest acceptable quality for different fragments. We were further interested to know about their perceived easiness of the process of selecting the lowest acceptable quality.

The experts believed that the process was easy and straightforward. One participant mentioned, "*No, it is not difficult. it was easy". *Another participant said, "*The process is simple. It was easy. If I can't read it (in some quality) then there is problem (with that quality)".* The lowest acceptable quality was determined by observing the visual information. The following themes emerged during the discussion, on the basis of which lowest quality constraints were determined.

- **Text Size**
  The role of text size is vital. If the text is larger in size then it is usually fine to deliver that portion in a very lower quality. A portion of video with text in smaller size results in perceived visual information loss in lower qualities.
- **Figures and graphs**
  Figures and graphs are very important elements that determine the suitable minimum quality. Figures and graphs usually have smaller labels that may cause problems in lower presentation quality.

- **Storytelling and additional explanation**
  If there is any storytelling in any part of the video, that portion could be delivered in audio. Furthermore, any additional explanations could be considered as candidates for audio only contents.
- **Introducing new concepts**
  It was highlighted that introducing new concepts should be done with visuals. Visuals in that case can help in focusing on the learning information even if the information could be delivered in audio version.

Participant 1 said about the lowest acceptable quality decision for the video, "*So for me the rational is anything with pictures tends to level two (Quality 2) but sometimes level one (Quality 1). Anything with large text or design (tends to) level 3. Anything that is descriptive narrative story telling should be audio only. Not when describing diagrams or new concepts. Otherwise just audio is fine"*. Participant 2 identified the textual information for constraint quality decisions and said "*the visual appearance of the information or text, especially the text on labels on the graphs or images*". Participant 3, while talking about what helped him decide about the audio quality said, "*Just by looking at the visual information, I can decide about what information can be audio"*. The same participant further said, "*If there is any visual things that I want to see or that will help me in understanding, if not, I can just hear audio ..."*. The same participant mentioned another interesting point that the audio only information could be sometimes useful and said "*... visuals could be sometimes be distracting (if not properly used)".*

7.2.3.5 Associating educational metadata

A part from associating quality constraints metadata with a multimedia, another potential useful aspect of the proposed metamodel scheme is its potential for extension with educational features. The metamodel we presented for power-saving in the MoBELearn application itself does not use the educational features in the adaptation process. The educational features if incorporated could be used for further types of adaptations. We have, however, evaluated the annotation of fragments with educational metadata. The asked the experts about their views for identifying and annotating the multimedia with the educational features that we used for extension of the metamodel in section 5.4. This basically involves annotating the fragments with the SKOS concepts covered by the multimedia, specifying the difficulty level of the information in each fragment (IEEE LOM '*Difficulty*' feature), and designating the importance of each fragment for different learners' background knowledge levels (Beginner, Intermediate or Advanced). We asked the experts about how easy they thought the process was and what factors were involved.

Over all, the experts were of the view that the process of annotating fragments was easy; however, it is dependent on the subject knowledge of a person doing the annotation. Anyone with expert level knowledge of an area can annotate the educational features very easily. The participant 1 said*, "Yes that is pretty straight forward. I can do that quiet easily"*. The Participant 2 mentioned, "*I can do that easily if I have the background knowledge. I think it depends on the video. If I have the appropriate knowledge level about the topic I can do that"*. Participant 3 was of the similar opinion and said "*Not difficult at all*. *It depends on the knowledge of the area... an expert of the subject matter can decide it"*.

7.2.4 Discussion

Based on the discussion, we believe that the participants understood the overall authoring process and the task involved. The participants executed the authoring process and performed the completed the relevant tasks. They were able to identify fragments based on the quality requirements of each portion of multimedia.

The experts were able to understand the impact of quality reduction on the visual information contents of the multimedia. They were also able to identify the features that were causing perceived information loss due to quality reduction, for example, text size, labels in figures etc. Furthermore, the participants also determined few fragments that could be delivered in audio-only quality. In the end, we got a list of fragments that the participants could identify with respective quality constraints.

The participants of the study identified the factors that are important in identifying fragments. These factors included visual appearance of the information; change of slide and change of scenes. These factors could be used to identify potential fragments.

With regards to identifying lowest quality constraints among the available qualities, the participants determined that text size play crucial role in quality constraints. The figures and graphs needed higher qualities than other contents. The participants highlighted that storytelling could be used in audio-only modality. One useful point that emerged was the fact that even though in introductory material there may not be very crucial visual information but they still should always be presented in visual quality in order to engage learners at that crucial stage.

The expert participants were of the view that the process was easy. It was, however, pointed out that the process depends on the nature of the video to be processed. Any video with higher screen dynamics with quickly changing contents could be challenging, while multimedia explaining contents in a presentation slide format would easier for the authoring process. Regarding associating educational metadata, the experts were of the view that the process itself would be very easier if the multimedia author has good knowledge of the subject matter and annotating fragments with any sort of metadata would be an easier process.

7.3 Evaluation with learners

The quantitative studies discussed in Chapter 6, were mainly focussed on the perceived visual information loss and to understand if the way CASP-EMA adapts educational multimedia was acceptable for learners. The results of the studies suggested that the group of participants that used CAPS-EMA adapted multimedia did not observed any visual information loss and they believed their version of multimedia had no negative impacts on the perceived learning effect. The experiments did not evaluate the perceived learning experience and any impact of adaptation on the included learning concepts – not just visual information at different temporal point in a multimedia.

In this section, we now describe our another evaluation study with participants in the roles of learner with focus on qualitative evaluations using interviews to get further insight into any impacts of the adaptation, through the CAPS-EMA approach, on the coverage of concepts in the adapted multimedia.

7.3.1 Experiment Objectives

The objective of this new experiment is to explore if and how the adaptation using CAPS-EMA would impact the coverage of the concepts in the original multimedia. The aim is to explore how clearly the concepts covered by the original multimedia are perceived after adaptation. This study would evaluate the impact of the CAPS-EMA approach more broadly as a whole experience in order to gain insight. In this study, we will not measure learning of the participants – instead we asked them to identify the concepts covered in original and adapted multimedia and requested their opinion about their perception.

7.3.2 Experiment design

We designed a mixed method experiment to get some quantitative as well as qualitative data. We were interested to do the evaluation with non-PhD students at the University of Southampton as we recruited PhD students in our previous experiments. Due to end of the term time and summer vacations, however, we were unable to recruit non-PhD students. There were a few masters students who were trying to meet project submission deadlines and were not willing to participate. We, therefore, decided to use PhD students in our experiment again. We, however, did not recruit students who were already used before and those who had any slight knowledge about the project.

We applied for ethics approval for this experiment along with the other experiment. Our ethic approval application with ID 16151 was approved after some modifications, we intended to use audio recording in this study.

We divided the 12 selected participants randomly in two groups, with each group had 6 participants. One group was provided multimedia without any adaptation for power-saving, while the other group was provided multimedia with power-saving through the CAPS-EMA approach. We asked both groups to identify the concepts from a list that they think were covered by the multimedia, followed by asking them to give their opinion about the way they think those concepts were covered by their version of the multimedia.

7.3.2.1 Procedure:

We conducted the experimental study with individual participants, one at a time. This was preferred as we had to conduct and record their interviews. We randomly assigned participants to two groups. Group 1 was provided with multimedia without the adaptation treatment, while Group 2 was provided with multimedia adapted using the CAPS-EMA approach. Each participant was briefed about the procedure of the study after they would arrive at the designated room for the study. They were informed that they could leave the experiment at any time, if they wish. They were also aware that the interviews will be audio recorded for analysis.

After each participant would view the multimedia they would be given a questionnaire first. We asked them to identify the concepts from a given list that they thought were covered by the multimedia. We further asked them to rate their satisfaction about the way the identified concepts were covered and how adequately they think the concepts were presented. We then asked some open-ended interview questions about how well they thought that the identified concepts were presented successfully and if they found any problems with the multimedia presentation that negatively impacted the way concepts were covered. We asked follow-up questions to the answers to further clearly understand the participants' views.

7.3.3 Experiment Finding

In this section, we discuss the findings of the study. We gathered both qualitative and quantitative data. The major finding that we discovered in this study, which was not discovered in our earlier studies, is about the use of audio fragments in the adapted multimedia to save battery-power. Most of the participants that used the adapted multimedia reported that they do not prefer to have audio portions in the adapted multimedia. It was suggested that the audio portions / fragments will be specially creating problems when a new topic is being introduced. They, however, pointed out to the instances where audio-only content will not be a problem.

First we report on how the participants responded to concepts identification. We provided a list of concepts related to the topic covered by the multimedia (i.e. Semantic Web) and requested them to identify the concepts they thought were covered by the multimedia. We provided the list of concepts given in the Table 7.2. The list contains concepts covered in the multimedia as well some other related concepts that were not covered in the multimedia. The table shows result from both groups. Group 1 used the power-saving multimedia adapted through the CAPS-EMA approach while Group 2 used original quality multimedia. The concept titles in the ***grey shaded cells*** are the ones covered by the multimedia. The numbers in the table show the number of participants that identified the concepts as *covered* by the multimedia. We can see that participants of both groups could correctly identify majority of the concepts that were covered. In Group 1 there were only two closely related concepts that were not covered by the multimedia, but the few participants thought it was covered. The reason for this mistake may be the fact that these concepts were very closely related and had similar titles.

Table 7-2: List of Concepts

Concept titles	Group 1	Group 2
Semantic Web idea	6	6
SPARQL		
Linked Data		
Triplet	6	5
RDF	6	6
Reasoning		
Who proposed semantic web?	6	6
Resource Description Framework	6	6
Ontology	2	1
Semantic Web Layers	6	5
Google search and the Semantic Web	5	6
Triple Store		
Resource in RDF	6	6
Jena API		
XML implementation of RDF	6	6
SPARQL End Point		
RDF Schema	1	
Tim Berner-Lee's Graph	6	6
OWL		
Web Ontology Language		
Protégé		
RDF Graph	6	6

(grey)	Concepts covered in the multimedia
(white)	Concepts NOT covered in the multimedia

We then asked the participants of both groups to rate their satisfaction about the way the identified concepts were covered by the multimedia. We requested the participants to respond using a 4-point likert scale from *Very Satisfied* to *Very Dissatisfied*. The opinion of the participants from Group1 and Group 2 to this question is given in Table 7.3. The numbers in the tables shows the number of participants choosing that option.

Table 7-3: ***Rate your satisfaction about the way the identified concepts were presented.***

	Very Satisfied	Satisfied	Dissatisfied	Very Dissatisfied
Group-1	0	6	0	0
Group-2	2	3	1	0

The results in the table suggest that the participants of Group 1 that used the multimedia adapted using the CAPS-EMA approach were satisfied from the way the adapted multimedia covered the included concepts. The group that used original quality multimedia had 1 participant dissatisfied. When asked later about for the reason, it was revealed that the reason for dissatisfaction was due to the way the information was structured and the presentation of the multimedia was not an issue.

We further asked the participants about how adequately they think that the concepts, discussed in the multimedia, were presented. The participants were asked to respond to this question on a 5-point likert scale. The results of the participants of both groups for this question are given in Table 7.4.

Table 7-4: ***How adequately you think the concepts, discussed in the multimedia, were presented?***

	Not at All	Very Little	Somewhat	Quite well	To a Great Extent
Group-1	0	0	1	5	0
Group-2	0	1	1	3	1

The results suggests that the responses of Group-1 that used CASP-EMA approach were not bad than the Group-2 that used the original multimedia. One participant of the Group-2 responded with "Very Little" option. This participant did not like the way information was structured instead of the presentation of multimedia.

In the open ended interview questions, we tried to discover further issues around the impact on the coverage of the concepts due to the adaptation of the multimedia using CAPS-EMA. We asked questions about the how well they thought the multimedia presented the identified concepts successfully and if they had found any issues that prevented the concepts from being properly covered or presented.

7.3.3.1 Findings from Group 1 interviews

We discovered the following themes from the data from Group-1, which used the adapted multimedia. We discovered some new issues with CAPS-EMA that could not be discovered in our earlier experiments. The main problems that were discussed about the CAPS-EMA adaptation approach were around the presence of the audio clips in the adapted multimedia. However, no such issues were highlighted due to any impacts of the two other characteristics of the CAPS-EMA approach, i.e. fragmented and the multi-quality nature of the adapted multimedia. Overall, we could identify the following themes from the discussion with Group 1.

7.3.3.1.1 No problem with coverage of the concepts

The participants were of the view that the (adapted) multimedia covered the concepts well. This was also reflected in the likert scale questions. There were some issues regarding the way the instructional material was designed, this issue has been covered by a separate theme discussed separately. One participant was noted as saying "*I think the package (adapted multimedia) was good*" and "*Its presentation of the concepts was fine. It was nice*". Another participant mentioned, "*Over all I think the information delivered was quiet clear. Especially the basic concept was quiet clearly explained*". Over all the perception regarding coverage of the concepts was positive.

7.3.3.1.2 Audio information understandable

The participants of the study did not complain at any moment about any problems in understanding the information content in the audio only fragments. All participants, however, preferred video content, instead of audio-only. One participant said, *"I would say video is always preferable but the information provided in just audio was (also) comprehensive enough and I would definitely understand"*. Another participant commented about the audio portions as "*In each instance of the audio I could understand what it was saying… but recalling which is a problem for me"*. Another participant complained about not being able to focus on the audio-only contents in the multimedia and said *"Although I understand what speaker is saying I would sometimes switch off (lose concentration)*".

7.3.3.1.3 Video gets more attention

As we mentioned in the previous section, the participants preferred to receive the video content instead of audio. The results of the discussion suggest that the video content was easy to follow and focus on. Below are some of the comments that reflect this insight.

- "*I think if I would have chosen something to be different, it would be to change some audio into video*".
- *"For me you need pictures as well – not just sound, as people can pay more attention".*
- *"I found that the portions with visuals were easier to follow".*

- *"In my experience some audio and some video is not good. I want video all the time, even if I decide not to look at it."*

Our results suggests that the overall experience of the learning from a video content is much better than learning from audio-only content, as one participant commented *"… because the audio part does not give you that (very) experience*".

7.3.3.1.4 Visuals more useful for remembering

During the discussion it was also mentioned that visuals (video content) are useful for remembering the information content, as one participant commented, *"I understood the audio parts very well, but I can remember the visual things more than the audio only portions…. recalling which (the information in audio-only) is a problem for me"*.

7.3.3.1.5 New topic should not be in audio only

It was suggested during the discussion that audio should not be used while introducing a new concept. A participant mentioned this as, *"..if it was totally unrelated or a new idea in audio it would be more challenging for me"*. This was probably believed because of what was referred to earlier that audio content is difficult to focus on and visuals help in remembering things. As the introduction is usually critical and forms the basis of further more detailed information.

7.3.3.1.6 Audio depends on the background of the learner

Another point that came up in the discussion is that audio contents could be appropriate for someone who already has some background knowledge on the relevant topic. This point is also closer to the previous theme, that new topic should not be introduced using audio only content.

One participant referred to this idea by saying, *"… specifically for the initial multimedia, because it would be for someone not having enough knowledge, need to be in video".* Another participant said something similar, who had no problem with audio but was of the view that it might be because he had some background knowledge about the topic. The participant said, *"I didn't feel the need for any visuals but if you ask someone from a different background they may not understand*".

7.3.3.1.7 Lecturing was not good

Some participants were not satisfied from the way the learning content was designed and the style of teaching. Our research work is not related to that aspect of multimedia, as it is about teaching methodology. One participant for example said, *"The idea was not explained well"*. The participants in Group 2 highlighted this point a lot more than Group 1.

7.3.3.2 Findings from Group 2 **interviews**

The participants of the Group 2 used original multimedia. Group 1 mostly discussed about the audio portions in the adapted multimedia and its potential negative impacts. Over all, Group 2 participants did not find any problems in the way the concepts were covered. The participants of Group 2, however, observed more that the method of instruction could have been better and that it was not very professional. Group 2 also highlighted that the text size of some of the information was very small. Group 1 did not report this observation though. May be Group 1 had other very obvious issues (for example, audio only content) that is why Group 1 did not focus on the issue of smaller text size or quality of instruction. We now briefly discuss some of the themes identified by Group 2.

7.3.3.2.1 Concepts were covered successfully

Participants of Group 2 were of the view that the concepts were covered well by the multimedia. Some issues were raised about the instruction style. We are discussing instruction style under separately theme below. The important point was that the participants did not find any problems due to multimedia presentation. This was expected, as the original multimedia was in high quality without any adaptation.

One of the participants mentioned about the coverage of the included concepts as, "*They were explained in details and quite clearly. The examples helped in explaining the concepts clearly"*. Another participant said, "*In general, the multimedia was successful in presenting the basic idea of the presentation"*. One other participant said, "*The multimedia gave a fairly comprehensive overview of the topics covered in a clear and concise way*".

7.3.3.2.2 No problem with multimedia presentation

The participants of Group 2 did not complain about the presentation of the multimedia and reported it to be in good quality. This was also expected as the multimedia was in the original high quality. One participant said, "*The multimedia quality was quite good. I had no problem in viewing (information in) the multimedia. The image quality was good; the diagrams were clear and legible*".

7.3.3.2.3 Some information contents were of smaller size

As there were fewer problems in the original quality to discuss and focus on, as compared to the adapted multimedia, the participants of Group 2 identified other issues that were not identified by Group 1. One such issue was reporting about the smaller size of text in the multimedia. It was highlighted that the size of text could be increased specially in the figures (diagrams). One participant referred to this as "*The objects and writing in the slide are too small but acceptable since the presenter highlights the main things of the idea of it*". Another participant described similar issues and said "*…however, the labels on graphs in the video are sometimes difficult to identify*".

7.3.3.2.4 Could improve instructional aspects / lack of professional instruction

Another aspect that Group 2 participants emphasised more than Group 1 was the quality of instruction. The participants thought the way of instruction could improve. This aspect, however, is not relevant to the CAPS-EMA based adaptation approach. As we mentioned earlier the reason of this being mentioned could be because the original quality multimedia provided to group 2 had less problems in terms of presentation. Below we quote some quotations of the participants in Group 2.

- *"It was not clear to me; more explanation was required".*
- *"The appearance gave the impression of a non-professional resource. In principle, aesthetics has is not relevant to content quality. However nowadays Youtube has changed the expectations. The users expect flashy and aesthetic content that looks pretty".*
- *"… but the use of animations or a greater number of visuals may have helped clarify certain points and help to keep the user's attention".*
- *".. fairly well described but a worked example of a use case could have been useful".*

7.3.4 Discussion

We conducted this last evaluation study to get insight into any impacts of the CAPS-EMA adaptation approach on the way concepts were covered by adapted multimedia. We already evaluated the CAPS-EMA approach quantitatively to understand the impact of perception of information loss; however, in this evaluation we were interested to gather some qualitative data using interviews and focus more on the way the original concepts were covered in the adapted multimedia.

Overall, the results of this evaluation confirms findings of the previous evaluation of the CAPS-EMA approach that learners did not find any major issues with the adaptation approach, with respect to suitability of the adapted multimedia for learning purposes. Nevertheless, we discovered some problems being reported about the inclusion of the audio fragments in the adapted multimedia. The use of audio-only fragments was suggested to be limited.

Our findings show that the participants of both groups successfully identified the covered concepts. This suggested that the Group 1 that used CAPS-EMA adapted multimedia had no significant problems as far identifying the covered concepts were concerned. Furthermore, 5 out of 6 participants in Group 1 thought that the multimedia presented the concepts “Quite Well”, suggesting the way the adapted multimedia covered the concept was acceptable. One participant in Group 2 – that used original multimedia – was not satisfied from the multimedia. The qualitative data suggested that the participant was not happy with the way concepts were explained mentioning non-professional resource. It is obvious that in this thesis we were not considering any aspect of the teaching itself.

During interviews the participants were of the view that there was no problems in the way concepts were covered in both original and adapted multimedia. No problems or issues were highlighted by the participants of Group1 using adapted multimedia about fragmentation or multi-quality video contents. The difference in visual qualities of different fragments was not observed by 5 out of the 6 participants. The one aspect of the CAPS-EMA approach that received some criticism was inclusion of the audio fragments in the adapted version. It was highlighted that including audio fragments should be avoided as it can cause several problems. It was discussed that visuals get more focus and attention than the information in audio. It was also highlighted that information in visuals helps in remembering the information. If audio-only quality has to be used then it should be avoided at places where new topics or concepts are being introduced in fragments. Audio-only fragments could also be used without any problem when learners have some background knowledge about the topic.

7.4 Conclusion

In this chapter, we discussed further evaluation studies related to CAPS-EMA adaptation approach. First, we discussed the study aimed for evaluating the CAPS-EMA authoring process. The major features of the authoring process consist of processing the multimedia to identify fragments and generate the required metadata that will enable the CAPS-EMA approach. The authoring process will be performed by experts and not by learners. Experts would include instructors or multimedia authors who would be using some multimedia processing tool that is developed to implement CAPS-EMA. In this thesis, we have not developed any multimedia authoring tool; however, we manually evaluated the main activities involved in the authoring process. We tried to understand if experts would be able to understand the basic concepts behinds the CAPS-EMA adaptation, that is, the ideas of a ‘fragment’ and ‘quality constraint’. We wanted to know if experts could identify fragments and quality constraints for fragments. Furthermore, on what basis would they do these tasks? Our evaluation results suggest that the expert participants in the study agreed that the authoring process is easy to understand and perform. They could successfully identify fragments for a given multimedia and determined quality constraints.

In our second evaluation, we tried to get insight in to how well the adapted multimedia would cover the concepts covered in the original multimedia. Hence, the main aim was to see any impact of the adaptation on the concepts included and not just on perceived visual information. We also wanted to qualitatively evaluate the way CAPS-EMA would adapt the multimedia. Through interviews we asked the participants (in the role of Learners) about their views on the adapted multimedia. One new insight that we got through this evaluation was that audio-only fragments were not always preferred. The participants were of the view that audio-only fragments should specifically be not used while introducing new ideas or concepts, and that suitability of audio-only fragments also depends on the background knowledge of a learner about the topic being covered.

Chapter 8: **Learner Battery Interaction**

8.1 Introduction

Using online multimedia learning resources is a very power-hungry activity. It drains battery power quickly, due to the large amount of wireless data transfer. To address this problem, many power-saving multimedia adaptation techniques have been proposed. Some of these techniques are discussed in Chapter 2. For reducing power consumption, these techniques use approaches like reducing the quality of the multimedia content, changing the modality, reducing the details of information content and duration of the multimedia. Chapters 3 and 4 described a power-saving adaptation mechanism for educational multimedia. We have discussed the role of the users' preferences and options for battery power-saving in chapter 4 and 5.

This chapter addresses research question RQ4. In this chapter, we try to address another dimension of power-saving adaptation in mobile applications, i.e. an interaction mechanism for power-saving options. We discuss this in the context of power-saving multimedia adaptation systems. Power-saving adaptation is mostly based on modifying some aspects of an application, for example, lowering the presentation quality of multimedia [17, 22, 26], changing modality and skipping some less important information contents to reduce the duration of multimedia. This modified behaviour of the application results in some compromises in the user experience. This compromise in experience increases with increasing demand for power-saving. We noticed this phenomenon in Chapter 2 in terms of multimedia quality reduction.

The study of existing power-saving adaptation techniques [19, 21, 22, 52, 88, 89] reveals that users are not given enough options to control the adaptation process. This means that the adaptive applications mostly do not provide options to user for choosing the extent of power-saving based on the level of acceptable compromised experience. The power-saving adaptation is usually triggered automatically when a certain level of remaining battery life is reached. Hence there is more automation and a lack of interaction mechanisms for users. Furthermore, we have found lack of feedback to inform the users in advance about the form and characteristics of the adapted multimedia. Without such control options and information, satisfaction of users is not guaranteed. Without such control options and feedback, users cannot choose the extent of the trade-off themselves. As a result users have to accept whatever the system chooses for them. This means that the system itself decides about the resulting multimedia quality and would take the adaptation actions without the user's intervention and consent. We emphasise in this chapter that users (or learners in the context of the thesis) should be provided such options to choose themselves the degree of power-saving based on acceptable compromised experience with the help of feedback from a system.

We believe that learners should be given control of the adaptation process and be allowed to make informed decisions about battery power-savings. For example, only a learner will best know about their battery power-saving needs. A lower battery in a learner's mobile device does not necessarily indicate that the learner will be out of power soon and the current learning activity is going to be abandoned. A learner may have access to a charging facility for their mobile device. Any automation in such situations, for example by reducing the content quality automatically and without the learner's consent, may not provide a better user experience. We believe control must always be given to the learner about the future lines of action regarding power-savings.

In section 2.9, we discussed some research efforts related interfaces for battery and power-saving and identified the latest work done in the area. We introduced Human-Battery Interaction (HBI) [102, 103] and some other studies already done in the area. In this chapter, we extend the notion of HBI and introduce the concept of the Learner-Battery Interaction (LBI). We will introduce a conceptual model that addresses the interaction in the domain of power-saving educational multimedia adaptation. We highlight some important aspects of the LBI and discuss what options and information must be made available to the learners that will help them to choose the appropriate power-saving options. We then discuss a prototype system developed based on this concept, highlighting the options that should be provided to the learners and how these would facilitate in choosing the power-saving options. This chapter also describes an evaluation in the form of a user study. The experimental user study was conducted to evaluate the prototype system in order to understand the importance and the effectiveness of the proposed model in a multimedia learning scenario.

8.2 Learner Battery Interaction

We have seen in section 2.9 that the study of Human-Battery Interaction (HBI) has been limited to the interfaces provided by mobile operating systems and applications that allow information about the battery consumption of all running applications. Furthermore, the only application level options that HBI addresses are interaction for aborting an application altogether, as discussed in [101]. HBI did not refer to provide any options within an application regarding battery consumption.

In this chapter, we make an effort to further extend the notion of Human-Battery Interaction and propose an interaction with the battery at an inside-application level. We refer to interaction at this level as Application-Level Human-Battery Interaction (A-HBI). A-HBI includes the understanding and the study of user interaction with the power-saving interfaces in an application. It includes providing the appropriate information to users that would increase their understanding about the battery consumption aspects of applications and enable them to make power-saving decisions at an application level. Furthermore, it also includes identifying the aspects of an application that could be changed (adaptation) for achieving power-saving. This concept, however, applies only to those applications that can perform power-saving adaptation. It means that an application should be able to save battery-power by modifying certain aspects of its behaviour, change in the output or the way of interaction, for example, changing backlight, colours, extent of interactivity, modality and quality of multimedia content, omitting irrelevant or less important details from information, etc. Different kinds of applications may use different kinds of power efficient adaptation. We identify the following requirements for applications using A-HBI:

- The applications should be adaptable for battery power-saving.
- The applications should provide power-saving interfaces that allow users to select power-saving options.
- The applications should increase user knowledge about the situation, by providing information in the form of feedback for each power-saving setting and enable them to make decisions.
- Feedback should include details of change in the characteristics of the application for each power-saving setting. This should help users understand any trade-offs involved.
- Feedback should include information about the extent of power-savings and extension in the possible duration of use of mobile device.

In this thesis, we discuss the notion of Application-Level Human-Battery Interaction from the power-saving educational multimedia adaptation point of view. The role of learners' preferences about battery efficiency has been discussed in detail in chapters 3 and 4. These chapters also discussed the importance of the feedback for power-saving settings. This feedback would enable users in choosing the available options. We here propose the concept of Learner-Battery Interaction

(LBI). Learners on mobile devices interact with learning applications; therefore the Learner-Battery Interaction considers both the educational and the power-saving aspects of learning applications.

Multimedia learning contents are getting popular in mobile learning. Multimedia resources as discussed in Chapter 2 are very costly in terms of battery-power consumption. There has been lot of research work – discussed in chapter 3 - in developing techniques for energy efficiency in multimedia streaming applications. Most of these techniques are based on reducing the multimedia stream quality. We have shown in the experimental study in Chapter 03 that the generic multimedia power-aware adaptation techniques are not adequate for educational multimedia. We identified the need for adaptation techniques specifically designed for educational multimedia. These adaptable applications need to employ Learner-Battery Interaction described in this chapter. The study of existing literature shows that, despite availability of many power efficient multimedia adaptation techniques, little has been done to involve user in the adaptation process. These techniques mostly consider existing battery power levels in decision making for the output quality to extend the battery life. Battery power-saving settings are one of the aspects addressed by the LBI. It is argued that learners must be provided enough information to enable them to make informed decisions regarding power-saving settings. Choosing power-saving setting that would save battery power will always result in some trade-offs in terms of presentation quality or the detail of the information contents. Learners must be aware about the extents of these possible compromises before they choose any power-saving option. This is especially important in educational multimedia applications. With some energy-aware adaptation techniques, the lowered quality of the multimedia would impact the learning experience. This possibility must be clearly conveyed to users.

The adaptation decisions to decrease the presentation quality or reduce the information content are taken without any involvement of users (learners). Users need to be aware of all options along with the resulting compromises in the user experience or the learning experience. This will help learners to choose a compromised experience by themselves, based on their goals. We believe this would offer a satisfying experience. Minimal interfaces are not sufficient for the user to understand what is happening to the battery nor to take action based on limited information [102, 103].

8.3 Learner-Battery Interaction (LBI) Model

This section describes the Learner-Battery Interaction model. This conceptual model is illustrated in Figure 8.1. This model is based on the requirements of mobile learning applications with focus on learning multimedia. It gives an insight into what types of battery interfaces should be provided that would allow users to interact with power-saving settings in learning multimedia mobile applications. This also helps in understanding the types of information that should be provided to learners to make them make informed battery-saving decisions in order to achieve their immediate learning goals. We find that at the moment the mobile learners lack these opportunities.

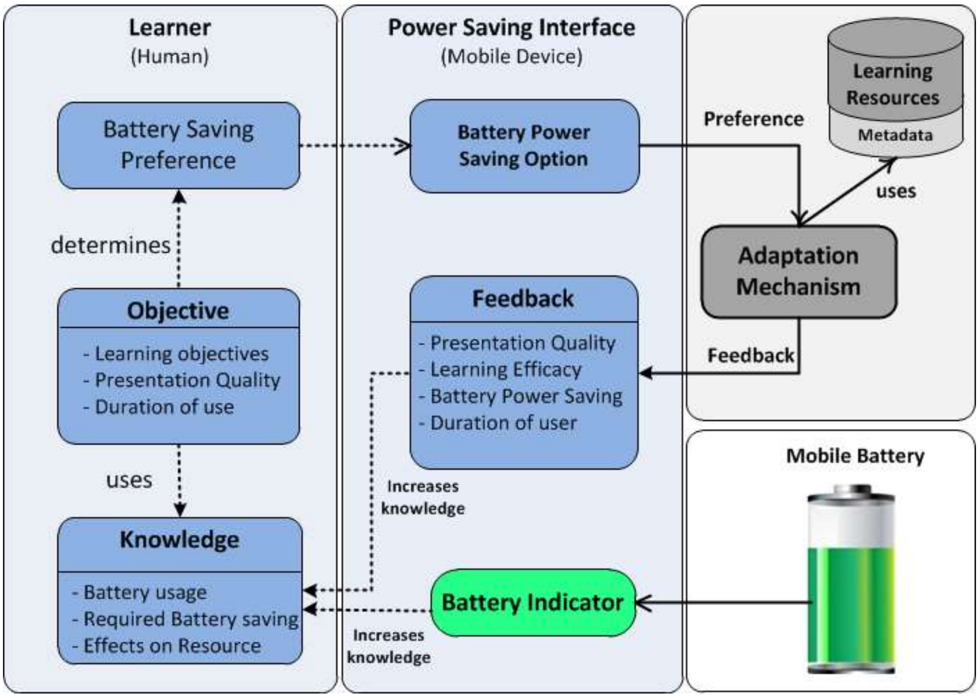

Figure 8-1 : Learner-Battery Interaction Model

In the Learner-Battery Interaction system, the Power-Saving Interface (PSI) provides power-saving options. Each power-saving option results in some trade-offs and may alter some of the characteristics of the learning application. The aim of PSI is to enable the selection of the options and provide a feedback about each option. A learner chooses a particular power-saving option based on their *Objective* and the knowledge the user has about the battery consumption and battery power-saving options. The first piece of the *Knowledge* that the learner gets is from the current battery charge indicator. This gives the user an idea about if they require any power-saving. The second factor that contributes in assessing the needs of battery power-saving is the *Objective* of the learner, in terms of what the leaner wants to learn, the available time duration and any preferences for the presentation of the learning resource. If a user then wishes to select a power-saving option from the Learner-Battery Interface, from the feedback provided, the learner acquires more knowledge and becomes well informed about the power-saving options. The *Knowledge* coming from the feedback may cause the user to alter her objective (and preference) about the learning activity. The learner may decide to compromise on the quality of presentation preference, modify the learning objective and reduce the duration of the learning activity.

Some tentative aspects of the information a learner could be interested in the form of feedback are:

- Which option will help most in completing the learning activity?
- How will any option affect presentation quality?
- How much battery saving can be achieved with each option?
- How much will any option extend the battery life?
- Will any option result in negative impact on the learning process?

This is not an exhaustive list of the information learners may be interested as feedback. There is a need for a study to identify the types of information that learners' would need. An appropriate way for conveying this information can also be developed that could convey the resulting compromises and benefits. The feedback is the main source of updating learners' knowledge about the battery consumption and possible savings. Different power-saving options may be affecting the quality up to different levels. We now describe different components of our proposed model.

8.3.1 Battery Power Indicator

The *Battery Power Indicator* provides learners with an idea of the remaining battery charge in the device. As mentioned in [102], these indicators cannot provide accurate information about the remaining duration of use; however, they provide useful approximate information. Battery indicators are mainly part of the mobile operating system and are visible all the time. This provides initial knowledge to a learner about the remaining battery power and helps them to plan ahead, based on the power status indicated by the *Battery Indicator*.

8.3.2 Objective

The objective of a learner in simple terms is the goal and preferences of the learner for the intended learning activity. It may include the learning objective, the presentation quality preferences, the approximate duration available for the learning activity, etc. The objective of a learner might not be clearly specifiable; it can be a tentative idea in their mind. The *Objective* of the learner may subsequently change, depending on the knowledge they gain from the feedback that the system may provide about the remaining battery life and battery-saving options.

8.3.3 Knowledge

The *Knowledge* means the extent of information a user has about the different aspects of the battery, including the battery consumption by various applications and the power-savings opportunities using Learner Battery-Interaction. The importance of this *Knowledge* has been identified in previous Human-Battery Interaction studies [101, 103, 104]. Human-Battery Interaction is driven by user's knowledge of battery [102]. User studies show that mobile users obtain such knowledge from multiple sources. We include feedback in battery power-saving interface as a main source of learners' knowledge about battery consumption characteristics.

8.3.4 Battery Power Saving Options

This is an important component of the Learner-Battery Interface (LBI). It provides the learner with certain options about power-savings. Each power-saving option will result in a certain amount of battery power-saving at the cost of some compromise or trade-off in certain aspects of the application and the learning activity. For example, it may result in reduction in the presentation quality, change of modality, duration of the learning session, skipping of some less important information, etc. All possible changes must be clearly conveyed to the learners with appropriate descriptions. In our system, we incorporate an explicit learner interface for power settings that provide detailed and clear feedback about each power-saving setting.

8.3.5 Power Saving Preference

This represents the option that a learner has currently selected from the set of given options. The Learner may select an option just to know about what behaviour and level of compromise to expect for a particular option. Based on the feedback and the goal, the learner may try another option, before committing to one final option.

8.3.6 Adaptation Mechanism

The *Adaptation Mechanism* is another major component that actually performs battery efficient adaptation in an application. It decides about what actions can be performed and which aspects of the application to adjust in order to reduce battery consumption. The Power-aware adaptation mechanism takes power-saving preferences, reads metadata and provides feedback about the eventual adapted content as a result of the current option. The learner will have the opportunity to understand any trade-off and decide about whether to continue with this setting or change it.

8.3.7 Feedback

As mentioned in 8.3.4, each power-saving option results in offering some compromises in certain aspects of the application and the learning activity, for example, reduction in presentation quality, modality, duration of learning session, skipping of certain information etc. The purpose of Feedback is to convey all these compromises or trade-offs to a learner in a detailed and precise manner so that the learner can make an informed decision that would result in a better satisfaction.

8.3.8 Learning Resources and Metadata

The *Interface* itself cannot adapt content. It is the multimedia and the learning content adaptation mechanisms that enable the power-saving adaptation process. Learning Resources would have suitable metadata that are used in the process of generating the adapted content. In order to have a better feedback, detailed and suitable metadata is required. For example, metadata can describe which sections of the learning resource are more important and which sections could be skipped for a particular learner, in which alternative modalities etc.

8.4 Prototype System

This section discusses a proof of concept prototype interface of the MoBELearn system that implements the Learner-Battery Interaction model. The MoBELearn system [120] is explained in Chapter 5. MoBELearn is an adaptive mobile multimedia learning system that implements the CAPS-EMA approach [31] for power-saving in mobile devices. Screenshots of the prototype MoBELearn interface are given in Figure 8.2.

These screenshots illustrate the concept of Learner-Battery Interaction. Using the Power-Saving Interface (PSI), learners can select their desire level of battery efficiency based on the immediate feedback about each available option. Learners can select these options using a slide bar and the feedback is updated immediately. Feedback is provided about the extent of battery savings to be achieved by this application, about the structure and presentation quality of adapted multimedia. Feedback in the prototype interface consists of messages that correspond to the adapted multimedia for each power-saving option. The battery-saving percentage values in the current prototype interface are not real time values. They are fixed values and are displayed for the evaluation purposes only, to illustrate the concept of our proposed system only. The objective was to show in the different components of the Feedback in the interface and gather the perception of participants about the proposed interface. For this purpose it is not important if the numbers are real-time. In Human Computer Interaction, it is common to use even paper or wireframe prototypes for evaluation purposes. In our case, the whole interface experience was real with exception of using values that are not computed in real-time. In real systems, these values should be actual approximate values that are generated automatically in the feedback. Implementing this functionality is beyond the scope of this research work. Calculating real battery power-saving values requires some further research efforts and could be done with the help of reliable battery consumption models. Battery consumption models are created for estimating battery consumption based on different situations. Once a learner is happy with any option, the learner can go ahead with that option and start learning from the multimedia resource.

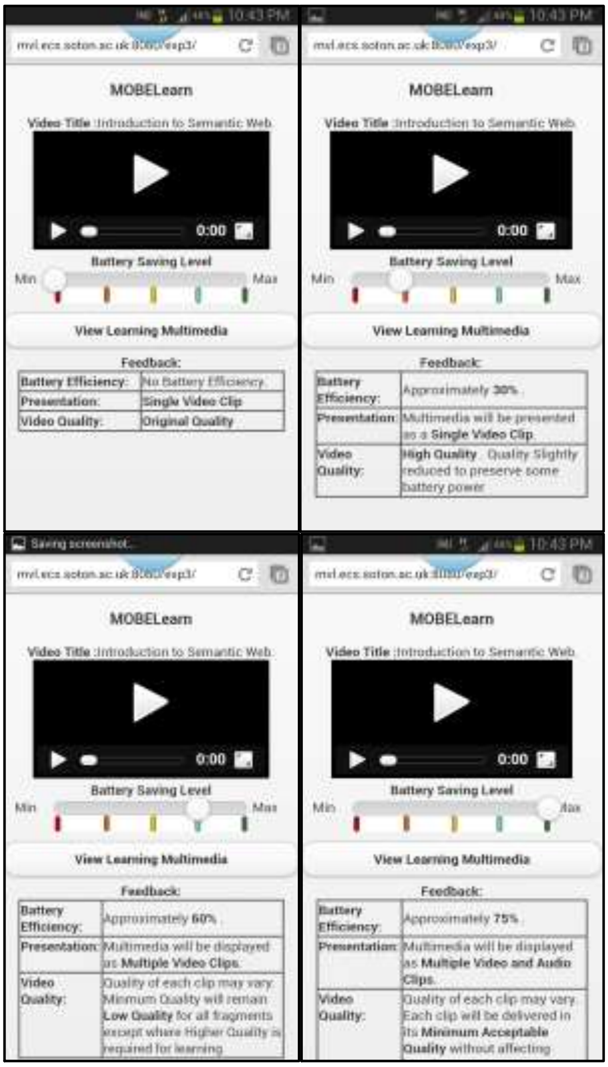

Figure 8-2 : Screen shots from the MoBELearn System

8.5 Experimental Study

The aim of the user evaluation study was to know the importance and usefulness of the concept of the Learner-Battery Interaction (LBI). In this study, the MoBELearn interface was evaluated for this purpose. It was aimed to evaluate usability of the interface, usefulness of the LBI concept and the importance of the feedback in such systems. We recruited 15 participants from the School of Electronics and Computer Science at the University of Southampton. All participants were PhD students with experience of using smart phones.

8.5.1 Study Design

This study involved allowing participants to interact with the system and user interface, and then report their experience using the questionnaire. The statements in the questionnaire were designed to understand participants' perception about some aspects of usability, understanding, usefulness and importance of feedback in LBI. Only one participant was used at a time in the study and all participants were provided with the same mobile device. We used a Samsung Galaxy Note 2 mobile phone. Participants were requested to use the system, try different options and understand the feedback for each of the option. We asked them to use adapted learning multimedia with different options. Participants were given a questionnaire to provide their views about 15 statements about different aspects of the system. Responses were recorded in the form of a Likert scale with Strongly Disagree (1), Disagree (2), Neutral (3), Agree (4), Strongly Agree (5) options.

8.5.2 Participant Responses and Results

The responses of participants about our battery saving interface and the proposed system were overall very positive. The responses of Strongly Agree and Agree are reported as positive responses while Disagree and Strongly Disagree as negative responses.

Table 8-1 : Statement 1 Responses

	Statement	Strongly Disagree 1	Disagree 2	Neutral 3	Agree 4	Strongly Agree 5	Mean	Std Div.
S1	I have used similar systems before	9 **60%**	6 **40%**	0	0	0	1.4	.57

We wanted to know if the participants had seen any other similar systems; 100% responded with disagreement to the statement regarding this as shown in Table 8.1. These results support the novelty of our proposed concept of Application Level – HBI and Learner-Battery Interaction.

With the next statement, we asked if the participants were aware about any techniques that they may use for power-saving. The results for this are given in Table 8.2, 26.6% (4 of 15) participants agreed to this statement. They reported the use of manual techniques like reducing screen brightness and disabling WiFi/data connection to save battery power. No participant reported using any available lower quality of multimedia. We found that there is not enough awareness among users about the impact of video quality on battery life.

Table 8-2 : Statement 2 Responses

	Statement	Strongly Disagree 1	Disagree 2	Neutral 3	Agree 4	Strongly Agree 5	Mean	Std Div.
S2	I am aware of other methods that can help me save battery power in mobile multimedia streaming applications.	6 40%	5 33.3	0	2 13.3	2 13.3	2.27	1.486

The ease of interaction with the interface and understanding the purpose of application was also evaluated. We asked the participants to report their views about the four statements regarding usability. We asked if the purpose of the application was clear, if the interface was easy to use and about the use of a slider control for choosing battery saving options. All participants responded positively with only one participant responding in neutral for one statement (statement 5) as shown in Table 8.3. The mean of responses ranged from 4.4 to 4.67, showing the system interface was perceived to be easy to understand and usable on mobile devices.

Table 8-3 : S3-S6 Responses

	Statement	Strongly Disagree 1	Disagree 2	Neutral 3	Agree 4	Strongly Agree 5	Mean	Std Div.
S3	I understand the overall purpose of this application	0	0	0	5 33.3%	10 66.7%	4.67	.488
S4	This application is easy to understand.	0	0	0	7 46.7%	8 53.6%	4.53	.516
S5	This application is easy to use on touch screen mobile devices.	0	0	1 6.7%	7 46.7%	7 46.7%	4.4	.632
S6	I am comfortable with use of Slider Control for selecting battery saving options	0	0	0	9 60%	6 40%	4.4	.507

We were also interested in knowing about the perception of the participants about such battery power-saving systems. We wanted to know if they would prefer to use such an application in situations when they need to save battery-power on mobile devices while streaming learning multimedia. The results, in Table 8.4, show that all participants were positive (53.3% Agree, 46.7% Strongly Agree) about the usefulness of the system for multimedia learning application. When asked if they like the way our system addresses the problem of power-saving in a multimedia learning, 86.7% (13 of 15) were positive and 13.3% (2 of 15) were neutral. 80% responded positively when asked if such systems should be integrated in mobile learning applications and 20% were not sure and responded neutral. Similarly 93.3% responded that they would use the system in the future if they need power-saving in such scenarios.

Table 8-4 : S7 - S10 Responses

	Statement	Strongly Disagree 1	Disagree 2	Neutral 3	Agree 4	Strongly Agree 5	Mean	Std Div.
S7	This application is useful for preserving mobile battery power in multimedia learning	0	0	0	8 53.3%	7 46.7%	4.47	.516
S8	I agree to the way this system addresses the problem of battery consumption in learning multimedia	0	0	2 13.3%	10 66.7%	3 20.0%	4.07	.594
S9	Such application should be integrated in mobile learning systems.	0	0	3 20.0%	8 53.3%	4 26.7%	4.07	.704
S10	I would use such a system in situations where I need to save battery power.	0	0	1 6.7%	9 60.0%	5 33.3%	4.27	.594

The feedback for each battery saving option is an important aspect of our proposed Learner-Battery Interaction model. We also evaluated this feedback aspect of the system to know if the participants think it is helpful in making battery power-saving choices and if they require more information in the feedback for properly choosing from the options. The results are given in Table 8.5, where 86.7% agreed (Agree: 9, Strongly Agree: 4) that the feedback provided by the system was easy to understand while two participants (13.3%) responded with neutral options. Regarding if knowing about the impact of power-saving choices on adapted multimedia is important for such systems, 93.3% (14 participants) agreed (Agree: 10, Strongly Agree: 4). When specifically asked about if the feedback provided by our system is helpful in selecting a power-saving options, 86.6% were positive with 14 participants responded positively while 1 responded with a neutral answer.

We wanted to know if the participants thought that they need more information in the feedback for power- saving options. A total of 5 participants (33.3%) agreed that they need more information. Three participants (20%) did not think they need any further information in the feedback while 7 (46.7%) neither agreed nor disagreed. Some participants highlighted they need additional information in terms of impact on the duration of use as a result of each power-saving option. Reliable battery consumption models can help in getting such information.

Table 8-5 : S11- S15 Responses

	Statement	Strongly Disagree 1	Disagree 2	Neutral 3	Agree 4	Strongly Agree 5	Mean	Std Div.
S11	Feedback provided is easy to understand	0	0	2 13.3	9 60.0%	4 26.7%	4.13	.640
S12	Knowing impact of battery saving choices on multimedia through feedback is important	0	0	1 6.7%	10 66.7%	4 26.7%	4.13	.743
S13	Feedback provided by this application is helpful in making informed decision about battery saving choices	0	0	2 13.3%	8 53.3%	5 33.3%	4.20	.676
S14	I am satisfied with feedback provided by the system	0	0	1 6.7%	11 73.3%	3 20%	4.13	.516
S15	I need more information in feedback	2 13.3%	1 6.7%	7 46.7%	5 33.3%	0	3.00	1.00

Based on the results of the study it could be said that the participants of the study were having a favourable and positive perception about the system and the proposed idea of Power-Saving Interface that provide proper feedback about the impact of each option. The Participants thought that such interfaces are important and it should be included in learning systems. We have summarised the responses of participants for all statements in Figure 8.3, which contains the means of the responses to all statements. We also asked participants some optional open questions to get further insights into their perception about the system. We mention answers to some open ended questions by participants below.

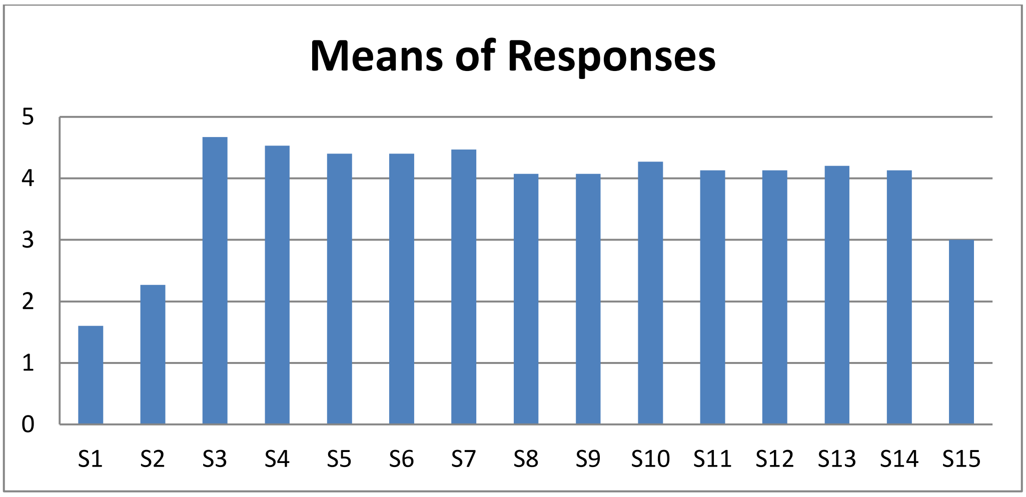

Figure 8-3 : Responses Mean

1. What other Information would you be interested as feedback?

- "Preview of video quality".
- "Extension in time or duration of use."
- "Time remaining for battery and detail of (presentation) quality."
- "It would be more useful if app read my current battery status and recommend what would be the best option for me."
- "Remaining life of the battery after the video is played."
- "Size of clip can be helpful and time"

2. What is your overall impression about this system?

- "Positive". "End user will not need as much feedback as we have at present"
- "A very useful application with immediate effect upon the implementation of educational use of digital devices. High usability value."
- "Very good technique. It might be helpful if I can see the preview of the quality while I select the battery level."
- "It is useful to have such application when you are away on train and you want to have lecture on a topic. I'd use the app, especially for the selecting an audio out of video."
- "Learners should be able to change the quality of the video while they are watching it."
- "Introduced me to the possibility of saving battery when watching video. Very practical."

- “Easy to use. Feedback is clear.”
- “The feedback provided by the app gives me information to make choices. This is helpful when I want to save battery power.”
- “Very good, I would like to have more feedback on the network speed my battery level after the video finishes.”

Most participants did think the information in the feedback was enough; however, some participants raised important issues. For example, they need some sort of preview for each quality as a textual description was not enough. Some more technical people would prefer at least some encoding parameters. But this need to be investigated that what is the most appropriate way for communicating this feedback. Feedback in terms of time duration was also desired by some. For example, the participants wanted to know how much a particular option might extend the battery life. The overall impression of the system was reported as positive and participants understood the benefits and opportunities in learning systems.

8.6 Conclusion

This chapter concludes all aspects of the proposed Content-Aware Power-Saving Multimedia Adaptation Approach and its implementation in the form of MoBELearn system. We explained Human-Battery Interaction (HBI) and described various aspects of HBI mentioned in the relevant literature. We highlight how most of the efforts regarding HBI are limited to battery interfaces provided by mobile operating systems. We extend the concept of HBI to battery interfaces at application level. We advocated that it is would be useful for those applications that perform power-saving adaptation to consider application level battery interfaces for users. We incorporated this idea to multimedia mobile learning applications capable of power-saving multimedia adaptation and introduced the concept of Learner-Battery Interaction (LBI). LBI interaction proposes to provide explicit power-saving options to mobile learners with appropriate feedback about the consequences of each option. Through a user study, we find that this would help mobile learners in making informed choices using power-saving options. The aim of LBI is to focus on both battery power-savings and the educational aspect of the user interaction with battery power-saving interfaces.

In the next chapter, we will discuss another potential role of online adaptive learning resources in the context of battery-efficient mobile learning using online search for learning resources. The Web has become a major source of learning information. Mobile learners connected with the Internet can now use their mobile devices to search for online learning resources. In this respect, we will discuss how we can develop a mechanism based on available online adaptive learning resources, to help mobile learners in finding a learning resource that is personalised to their needs and would consume minimum battery power when used on mobile devices. The objective of the proposed concept would be to reduce battery consumption at both the search stage and the use of learning resource stage. Battery consumption during a search process would be reduced by finding a resource that meets a learner's needs and preferences in a time efficient manner. This would reduce the use of mobile device in search process. Furthermore, by finding a learning resource that would consume less battery power when used for learning process on mobile devices would result in a power-saving during the use stage.

Chapter 9:

Discovery of Adaptive Online Learning Resources for Power-Saving on Mobile Devices

9.1 Introduction

In Chapters 3 to 6, we addressed issues related to power-saving educational multimedia adaptation. In Chapter 7, we proposed an interaction mechanism for power-saving mobile learning applications in order to be able make informed power-saving choices. This chapter is related to the research question RQ5 and we discusses another dimension to introduce power-saving in the context of mobile learning. We extend the concept of power-saving to online search systems for learning resources.

The Web is becoming a major source of learning information and increasingly used by all kinds of learners to fulfil their learning needs. Advances in mobile technologies and connectivity have opened further avenues of anytime-anywhere learning activities on the go [1, 2, 5, 8]. Learners can now engage in both formal and informal learning activities using mobile devices anytime through available online learning resources. It is important to develop mechanisms that has potential to provide opportunities to these learners with mobile devices - who would search online for relevant learning resources - to meet their learning needs in a battery efficient way.

Online search systems are becoming increasingly important for finding learning resources. We believe it would be useful to incorporate battery power-efficiency in search mechanisms. This means potential learners with Web enabled mobile devices should be able to discover suitable learning resources that would fulfil both their learning needs as well as power-saving preferences. This would include discovering and providing learners with personalised learning resources that would enable the learning activity in a battery-efficient manner. Our envisioned enhanced search mechanism – discussed in this chapter - is aimed at addressing this mechanism.

This enhanced discovery or search mechanism could be implemented in two ways. One way is to search for static non-adaptive content and provide it to the learners. The other way would be to make use of adaptive technologies, and make this discovery based on adaptive open learning resources. Adaptive learning resources could be delivered in multiple personalised versions based learners' requirements. In the context of this thesis, we focus this enhanced discovery mechanism from an adaptive learning resources view point.

A typical learning activity based on searching normally consists of the search process for an appropriate learning resource followed by the learning process itself.

In this chapter, we present a data model to represent online adaptive learning resources that could be used as a basis for the proposed discovery mechanism of online learning resources that would enable performing learning activities in a power-efficient manner.

This chapter is organised as following. In section 9.2, we describe the basic motivation behind the envisioned mechanism. In section 9.3 we explain the concept of the discovery of adaptive resources, and in section 9.4 we explain how it can help in battery efficient learning. In section 9.5, we discuss a framework for implementation of the proposed mechanism. In section 9.6 we discuss features of the adaptive learning resources and how we can make use of them for power-saving in learning activity based on online resource. In section 9.7, an Adaptive Learning Resource Model - based on the identified feature of adaptive learning resources - is proposed and the model is evaluated using an example scenario. Section 9.8 describes how an implementation of the proposed mechanism would look like. Finally, section 9.9 concludes this chapter.

9.2 Motivation

Limited-battery power is a big usability concern in mobile devices based learning. The problem is especially acute when learning is performed by first searching for online learning resources. The search activity is an additional activity, where a learner uses any search service and then browses the search results to select the one that looks appropriate. It is difficult to go through the contents of all learning resources returned in the search results, and then select the one that is perceived to be appropriate. It is clearly a time consuming activity, resulting in increased mobile device usage and hence increased battery-power consumption in the search stage. Additionally, a generic search system does not provide any services to search for a battery efficient learning resource. There is a need for a search mechanism that would help learners using mobile devices to find a learning material that would consume less battery-power during learning activity while satisfying their information needs.

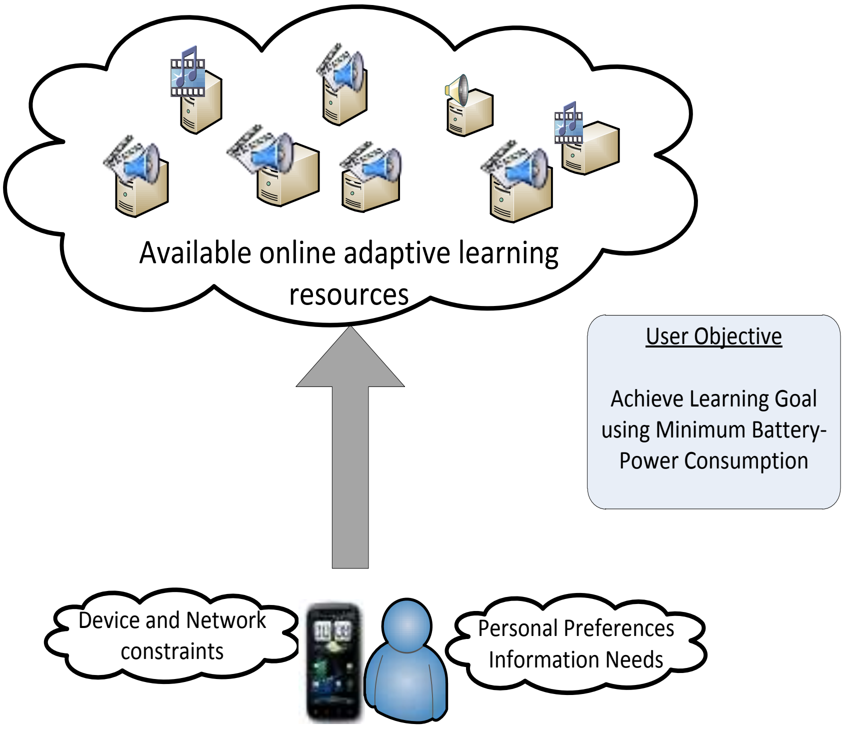

Figure 9-1 : Motivational Scenario

9.2.1 Motivational Scenario

The main motivation behind this work is described in the following scenario that is also depicted in Figure 9.1.

> *Alice is interested in finding a freely available online learning resource to learn about some topic of interest using her mobile device. She wants to spend minimum battery power during the searching process and the learning activity based on the discovered learning resource. She needs a searching service that is able to find a learning resource to satisfy her information needs that would consume less battery-power during the learning activity.*

In the given scenario, the learner requires a search system that would discover for her a *battery-efficient learning resource* on the topic of interest in a short time without requiring a lot of browsing through the search results. The learning resource that is selected would consume less battery power while using it in the learning activity and would satisfy her *personal learning needs*. With the help of such a system, learners with mobile devices could extend the battery life of their mobile devices. For this purpose, we envision a search mechanism that is based on adaptive open learning resources. This mechanism is aimed at enabling the discovery of a personalised version of one of the online open adaptive learning resources that would result in lower power being consumed during a learning task. We discuss this envisioned mechanism in the following sections.

9.3 Scope of the work

As discussed in the introduction section of this chapter, we are focusing on how to make use of the adaptive learning resources to offer power-saving for learning activities performed by searching for online learning resources on mobile devices. There are four challenges in this regard.

1. How adaptive learning resources are created?
2. How to create the metadata to represent adaptive learning resources in terms of its adaptive features?
3. How to implement the whole system to implement the proposed idea of discovery of adaptive learning resource?
4. Finally, how to represent user preferences that would be compared against the representation of adaptive learning resources?

These four challenges are related to the areas identified in the Figure 9.3, where each rectangle is related to each of the challenge identified here.

The first challenge has been addressed by existing adaptation and personalisation techniques. We have discussed in detail these techniques in Chapter 2 [8, 12, 13]. These techniques are mature enough and they are being used to develop adaptive learning systems for many years.

In this chapter, we focus on the second challenge, that is, the description of adaptive learning resources. Description of adaptive resources, in the form of metadata, is very important. This metadata will be the basis for a complete search system that would match the described learning resources against user preferences. We develop a representation metadata of adaptive learning resources that could be used as a basis for an enhanced discovery mechanism.

For challenge 3, we only propose a framework that could be used to implement the discovery mechanism. The exact implementation of the complete system that would demonstrate the idea of discovery of adaptive learning resources is not discussed in this thesis and is left for the future work. The challenge 4 is about user modeling and user preference representations. User modeling techniques are already being used by adaptive learning systems as well as in search systems [11, 35, 121].

The major contribution of this chapter along with proposing and identifying a mechanism based on the adaptive learning resources that could implement power-saving options in the search mechanism is the metamodel representation of adaptive learning resources that could be used as a basis to implement the proposed discovery mechanism.

9.4 The concept: Discovery of Online Adaptive Learning Resources

In this section, we explain the concept of the discovery of adaptive learning resources. For many years research has been done to develop personalization and content adaptation techniques (Section 2.1). These techniques have successfully addressed the issues arisen due to the diversity in the users' needs, devices and connectivity. The adaptation of learning resources is performed on the basis of the learner's needs, preferences and resource constraints of the user device [46, 49, 122, 123]. Adaptive Hypermedia [10, 11, 36], Content Adaptation [69] and Context-awareness techniques [13, 34] have all played a useful role in addressing the issues arising from the one-size-fits-all problems. Personalized information retrieval techniques enable learners to find relevant information that fulfils their specific needs [121].

Adaptive resources provide personalised versions of some resource to diverse user types. Personalisation is done in many different dimensions. It can be done on the basis of user's knowledge background, specific preferences, context of use and the device's resource constraints. During personalisation either information, presentation of information or both may be adapted to serve users in a better and in an efficient way resulting in increased user satisfaction.

We have found in the literature that these techniques have limited scope and are applied to resources within specific systems in the information retrieval or learning domains. Little work has been done to exploit the potential benefits of the adaptation and personalisation techniques on a wider scale on the Web. It would be useful if adaptive resources could be available openly for all users - without requiring registration with specific offline systems - and the possible adapted versions of these resources were also available for search. We discuss this potential further useful role of these adaptive information resources on the Web in the context of battery power-saving and providing personalised learning contents.

There have been many research efforts to create useful metadata schemes aimed at the discovery of learning resources [124, 125]. These metadata schemes, however, lack the ability to represent adaptive learning resources [126]. There is a need for developing metadata standards that could be used to represent adaptive learning resources. Furthermore, search mechanisms need to be developed that could find a learning resource offering a personalized version that suits the learner's background knowledge, matches their preferences and device constraints. This means that every possible deliverable version of an adaptive resource should be made searchable through the Web. An adaptive content is different from a static content. A static content has one version and is easily searchable using existing common search mechanisms. An adaptive content can be offered in multiple versions. All the versions may differ in characteristics like modality, quality and duration. These versions serve several different types of information needs and constraints.

The commonly used search techniques (e-g: keyword based techniques) for discovering static contents cannot be used for discovering a version among the set of possible adapted versions of an adaptive resource. Adaptive resources are adapted in two dimensions: The information dimension and the presentation dimension. We explain these two dimensions in Section 9.7. The challenge in the discovery of these adapted versions is representing these adaptive resources in terms of the adaptive characteristics. This means to represent features of all possible versions that the adaptive resources can offer. If we could do this representation, we may then use these representations in the discovery process. We can compare the user search context, consisting of user preferences and resource constraints, against these representations and select the one adaptive resource that provides a version matching the requirements.

The process of the discovery of adaptive resources is illustrated in Figure 9.2. It illustrates three adaptive multimedia resources provided by different providers. Each adaptive resource can be adapted and provided in various adapted versions. These adapted versions include adapted video, audio and text versions. One of these providers may have the Potential Most Relevant Version (PMRV). A Potential Most Relevant Version (PMRV) is the version that closely matches the user's information needs, preferences and devices capabilities. It is only possible through an Adaptive Resource Discovery Service (ARDS) to find out the PMRV. An ARDS needs metadata representing all possible adapted versions by an adaptive resource. Figure 9.2 shows that a user with a mobile devices used ARDS to find a version that satisfies their needs. This service is based on the metadata or the profiles of adaptive resources.

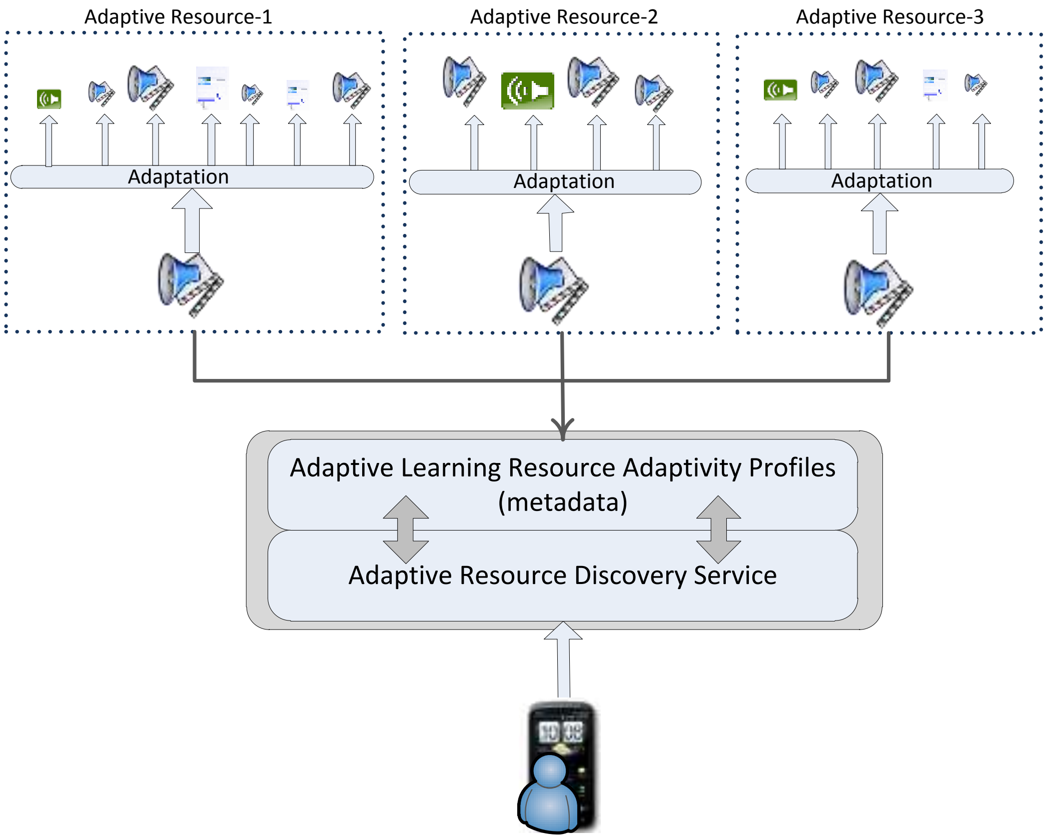

Figure 9-2 : Proposed Solution of Discovery of Adaptive Resource Versions

9.5 Discovery of Adaptive Learning Resources for Power-Saving

In this section, we describe our proposed mechanism for enabling Battery-Efficient learning activity using search for online learning resources. We describe how the discovery of adaptive learning resources could help in power-saving in mobile learning and we highlight the opportunities provided by existing technologies and techniques that could be used for this purpose.

Adaptation and personalization techniques are being developed for many years that successfully perform personalisation of learning resources. These techniques are deployed in specialised learning and information retrieval systems, where they are accessible to users registered with the system only. Furthermore, developing suitable mechanisms for the discovery of the personalised versions of adaptive resources has gained little attention.

There is a need for mechanisms that could expose the deliverable adapted versions for searching. If content providers could deploy these adaptation and personalisation techniques and make features of all possible adapted resource versions available, the desired enhanced searching mechanism could be implemented. This enhanced search mechanism could address battery-efficient in the context of mobile learning using search in the following ways.

1. If we could enable the discovery of a battery-efficient version from all available versions of all available adaptive resources provided by different providers, which satisfies the learner's information needs. The battery-efficient version here means the version of any learning resource that would consume lesser battery power during data transfer phase.
2. A typical search process involves browsing through the search results one by one to ultimately discover the one that is perceived to best suit the learner's needs, interests, preferences and resource constraints. This is a time consuming and therefore battery consuming process. If we could discover a learning resource that suits their personal needs in quickly in less time, it may reduce the time needed for browsing and identifying the appropriate resource. This would result in reduced battery power consumption at the discovery of information resource phase.
3. If we could provide the learner with a personalised version of an adaptive resource that closely satisfies their needs, it will result in time efficient learning activity. Such a version of a learning resource will fulfil the objectives of a learner in shorter time resulting in reduced consumption of mobile battery power during the learning activity.

In Figure 9.3 illustrates how existing techniques fit in the proposed mechanism. The adaptive learning resources use adaptation techniques. On the user side, user and context modeling techniques could be used to represent what is required by a user. This includes user preferences and device constraints. We need to develop a mechanism to represent their versions. These version descriptions can then be used by matching techniques to find the versions that satisfy the users' needs.

9.6 A Framework for the Discovery of Adaptive Online Learning Resources

In this section, we describe a framework to enable the proposed mechanism for the discovery of versions of the adaptive resources. The framework is presented in Figure 9.4. This framework shows the major components that constitute the proposed system. *Adaptive Learning Resources* are provided by different resource providers. These resources are openly accessible on the Web. The *Adaptive Learning Resources* have *Adaptive Learning Resource Profiles*. These are metadata about the adaptive resources that describe them in terms of their adaptive features. The *Adaptive Learning Resource Profile* of an *Adaptive Learning Resource* represents the number of ways that resource could be delivered in as (adapted) versions. These descriptions must follow some standard *Adaptive Resource Model* in order to have a common vocabulary and structure for metadata. This common

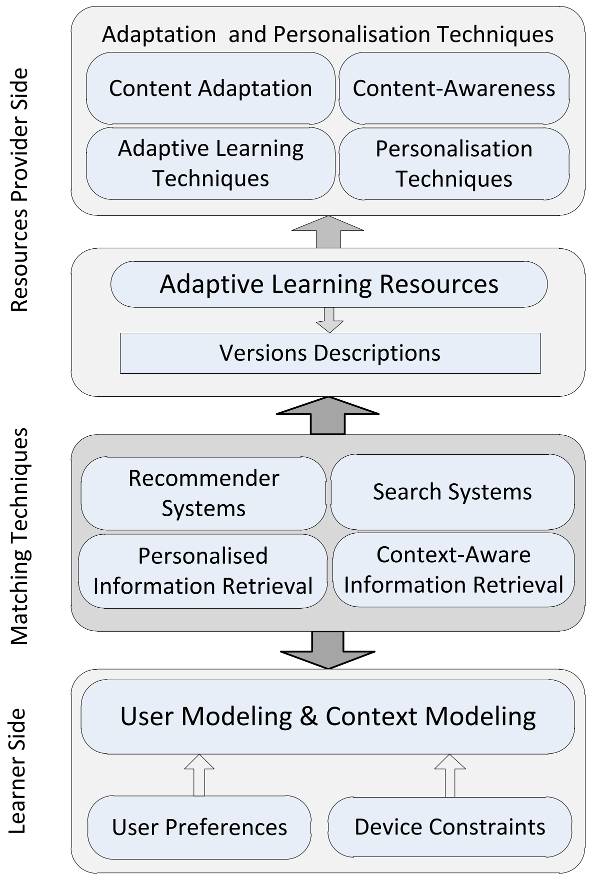

Figure 9-3 : Existing techniques within the context of the proposed mechanism

metadata model will be used by all resource providers to describe their adaptive resources consistently. The *Search Service* uses only the *Adaptive Learning Resource Profiles* (or the metadata) for searching and recommending learning resources. The *Search Service* uses the Context of the user to recommend appropriate resources. The Context is constructed from the *User Preferences* and the *Resource Constraints* of the device and network connectivity. Users can specify their preferences using a user interface while resource constraints can be determined from the device and network information. A user may be offered to specify the information needs in terms of topic of interest and preferences about the desired content in the form of modality, format, duration of use, power-saving preferences etc. User Preferences and Resource Constraints that make up the Context are matched against the *Adaptive Learning Resources Profiles* to select the *Most Relevant Version* available among many on some topic.

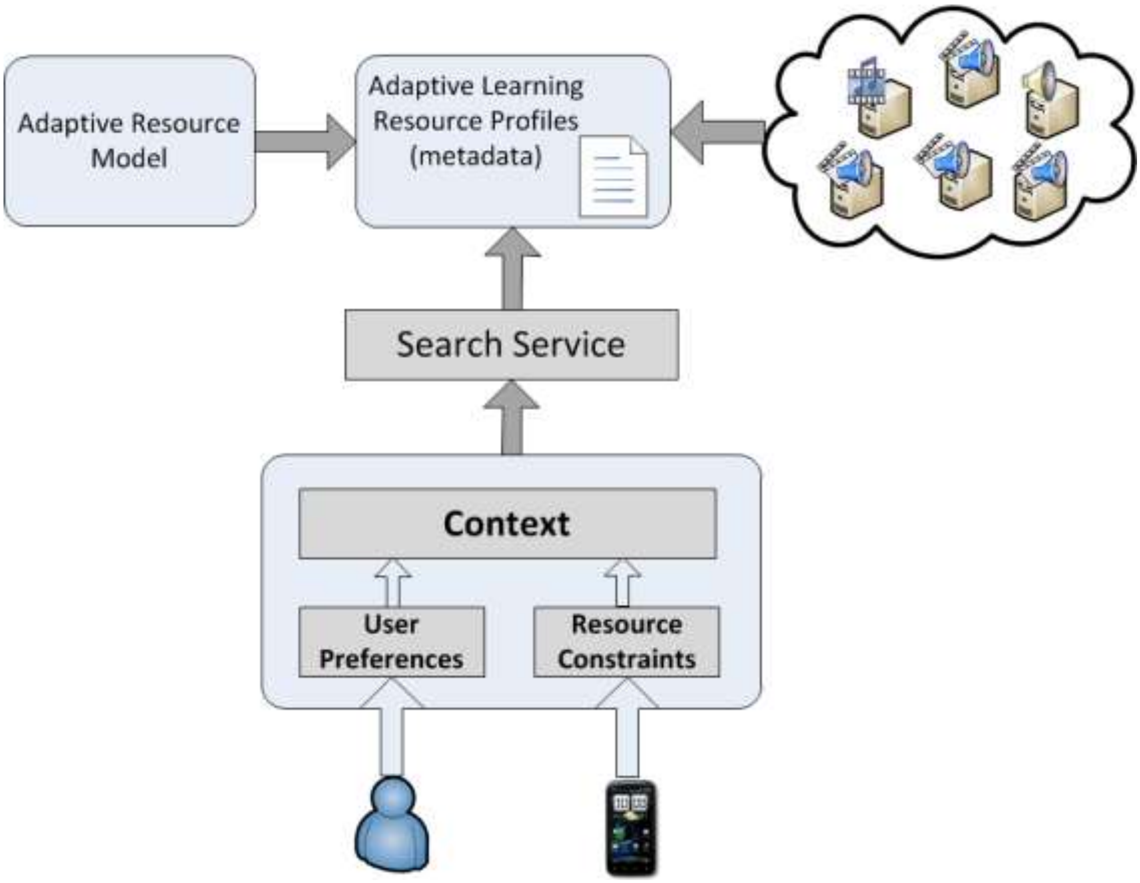

Figure 9-4 : Framework for the Discovery of Adaptive Resources

9.7 Adaptive Features of Adaptive Learning Resources

As we have been discussing in this chapter, an adaptive learning resource can be offered in several different versions, satisfying many several preferences and constraints. Each version differs from others in terms of the information and presentation features. The Information features include any feature that deals with information contents of the resource, for example, topic, language, background knowledge requirements, details about the concepts covered, duration of use, etc. The Presentation features deals with content format and presentation, for example, encoding parameters of a multimedia resource i.e. frames per seconds, bitrates, resolution, modality. These features are important for matching resource constraints as well as power-saving viewpoints.

Figure 9.5 shows a conceptual model of Adaptive Learning Resources in terms of their adaptive features. This model helps in understanding the process of modeling and representing adaptive resources for the discovery purposes. The figure illustrates that an adaptive Learning Resource has adapted resource versions. Each adapted resource version has *Educational Features* and

Presentation Features. These features combine can be matched against learners' needs, preferences and the device and connectivity constraints.

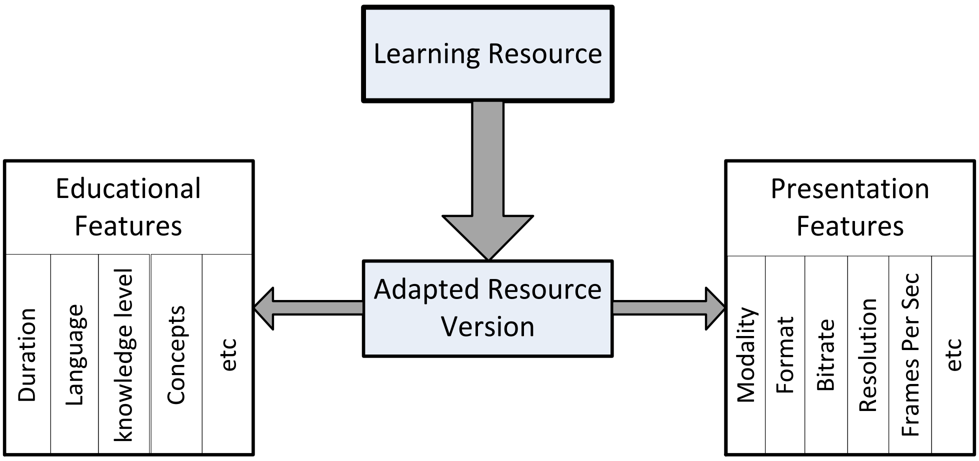

Figure 9-5 : Conceptual Model of Adaptive Learning Resource (MALR)

The *Presentation Features* along with the duration of use can determine a Battery-Efficient version. For example, a shorter version in a lower presentation quality that suits a learner a learners needs might be considered as battery efficient against other versions which are of longer duration or in a higher presentation quality. The Audio and Text modalities are also considered as a lower quality than video for this purpose. Selection of Text, Audio or Video modalities can be decided based on the user preferences for modality. The details of matching and ordering of search results can be determined by individual application. In Section 9.8, we describe a data model that implements Adaptive Learning Resource Model that could be used as a basis for implementation of our proposed concept of discovery of adaptive learning resources.

9.8 Adaptive Learning Resource Model

Existing metadata schemes for learning resources are not suitable to describe adaptive learning resources [126]. In this section, we present a metamodel that would be able represent metadata for describing an adaptive resource. This adaptive learning resource metamodel would describe possible adapted versions of an adaptive learning resource. This data-model could be used as a basis of the discovery mechanism. As mentioned earlier in this chapter, benefit of such a search mechanism includes finding a learning a version of an adaptive resource that is suitable for the user's information needs and satisfy mobile device constraints as well reduction in browsing time during searching process. Both of these benefits results in reduction in battery-power consumption.

The proposed model, Adaptive Learning Resource Meta-Model (ALRM), models adaptive resources in terms of their adaptive features. As discussed in section 9.7, adapted versions of adaptive resources differ in two dimensions: the Information dimension consisting of Learning Features, and the Presentation dimension consisting of Presentation Features. Learning Features relate to information characteristics of a resource version and are relevant to the information needs of a learner. Presentation features describes the visual aspects of a resource, for example, for a video resource Presentation Features are the video encoding parameters. These parameters are related to device constraints and also useful in determining a battery efficient version.

Learning Features include information suitability level in terms of knowledge (for example: Beginner, Intermediate, and Advanced levels), approximate time duration needed for a learning activity for a resource and language of information contents. Presentation Features include modality and format of content, resolution and bitrates. Presentation features and durations combined can determine which versions are battery-efficient.

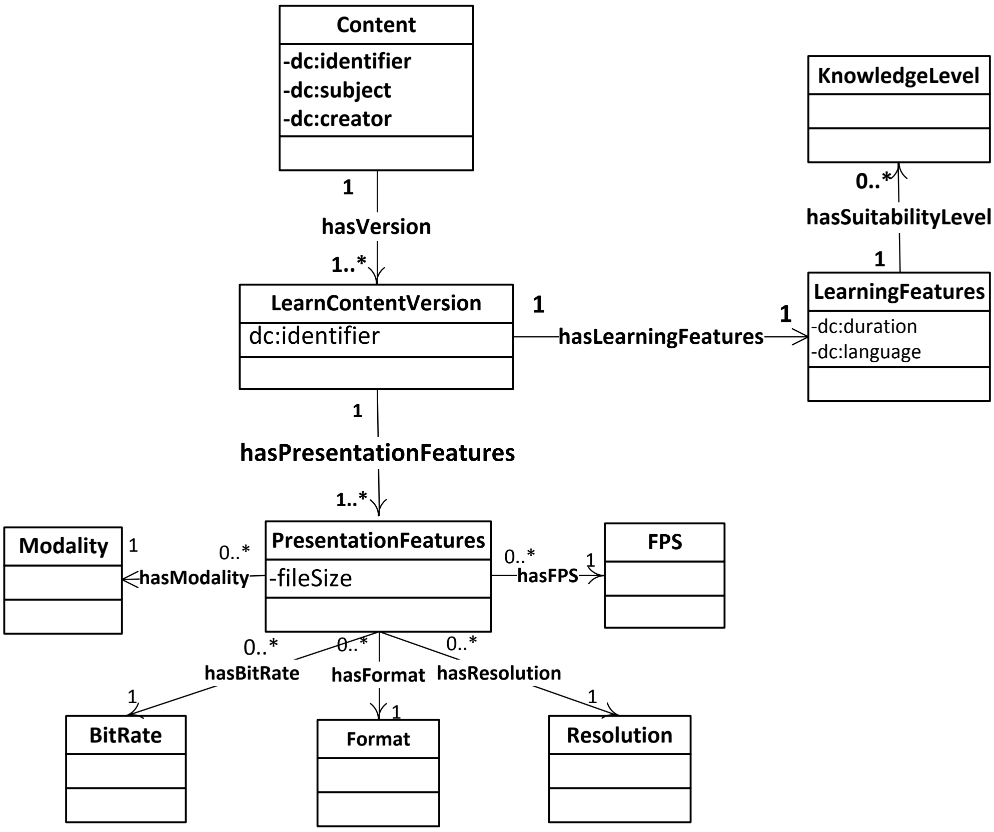

Figure 9-6 : Adaptive Learning Resource Model

We modelled Adaptive Learning Resource Meta-Model (ALRM) as ontologies and implemented as the Resource Description Framework (RDF) model. We used ontologies for modelling as they are extendable, reusable and convey semantic information. This model is shown in Figure 9.6. An adaptive learning resource or **LearningContent** has **LearningContentVersion**. **LearningContentVersion** describes one deliverable version of the adaptive Learning Content. A **LearningContent** has data properties like *dc:identifier*, *dc:subject,* and *dc:creator* to represent URL, topic of learning resource and author of the content, respectively. We have reused Dublin Core (dc:) vocabularies in our model. Reusing existing vocabularies is a recommended practice in designing ontology models, instead of creating a new vocabulary. These features are the same for the entire adaptive content and are common to all versions. **LearningContentVersion** has **PresentationFeatures** and **LearningFeatures** using *hasPresentationFeatures* and *hasLearningFeature* properties. ***PresentationFeatures*** represents the presentation features of a version. Presentation Features includes features like - *Modality*, *BitRate*, *Format*, *Resolution*, *FramesPerSecond*. Modality can be Audio, Video, Text or Image. If a resource is in Audio or Video format then the **PresentationFeatures** contains both *BitRate* and *Format* of content. Video content has also FramesPerSecond fearure. Image and Video both can have the *Resolution* feature. **PresentationFeatures** contains one data property which is *dataSize*. **Learning Features** includes *dc:duration* and *dc:language.* **LearningFeatures** *hasSuitabilityLevel* data property to link **KnowledgeLevel**. **KnowledgeLevel** categorises the background knowledge of the learner about the topic, and has instances of **Beginner**, **Intermediate** and **Advanced**, as shown in Figure 9.7. The *dc:duration* property represents the duration of a learning resource in minutes and language property represents the language of the learning resource.

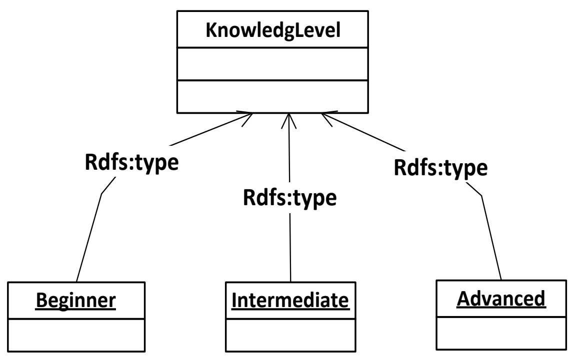

Figure 9-7 : Learner Background Knowledge Level

The **Modality** of a content has four instances Video, Audio, Text and Image, as shown in Figure 9.8.

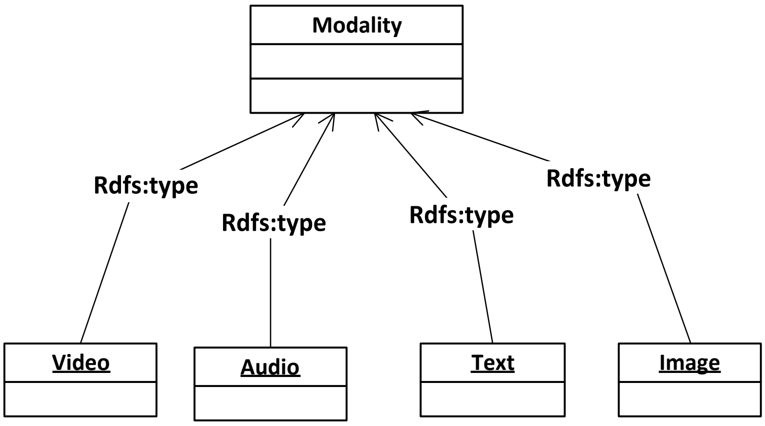

Figure 9-8 : Content Modality

The features specified in the model are not exhaustive, and this model can be extended. The model in existing form, however, helps in clarifying the whole concept of describing an Adaptive Learning Content. In Figure 9.9, we present an example model of an adaptive resource. The resource described is an adaptive video resource at an example URL "*www.abcTutorial.com/semanticweb.mp4*" by instructor *"James D."* that explains the concept of *"Semantic Web"*. This resource can be delivered in four versions. Version 1 and Version 2 are in English language for Beginner Level. Version 1 is in Video quality in 320 kbps bitrate and duration is 50 minutes. Version 2 is also of 50 minutes duration but in audio mp3 format. Version 3 and Version 4 are abridged versions for intermediate level in English language. Abridged versions are of duration 30 minutes. Version 3 is in Video while Version 4 is in audio quality.

9.9 Testing

We performed testing of the Adaptive Learning Resource model. Implementing a search system based on the proposed concept and evaluating its effectiveness could not be performed due to time limitations and the limited scope of the thesis. We tested the ontology model for its functionality. For this purpose, we setup a simple system to perform the testing. The architecture of the test setup is illustrated in Figure 9.10. The metadata was created about an example adaptive learning resource and was stored as RDF models in MySQL database. Jena API was used for this purpose to interact with MySQL database for the persistent storage of the models. A simple client interface was developed that would allow to specify for a search topic, selection of learning and presentation

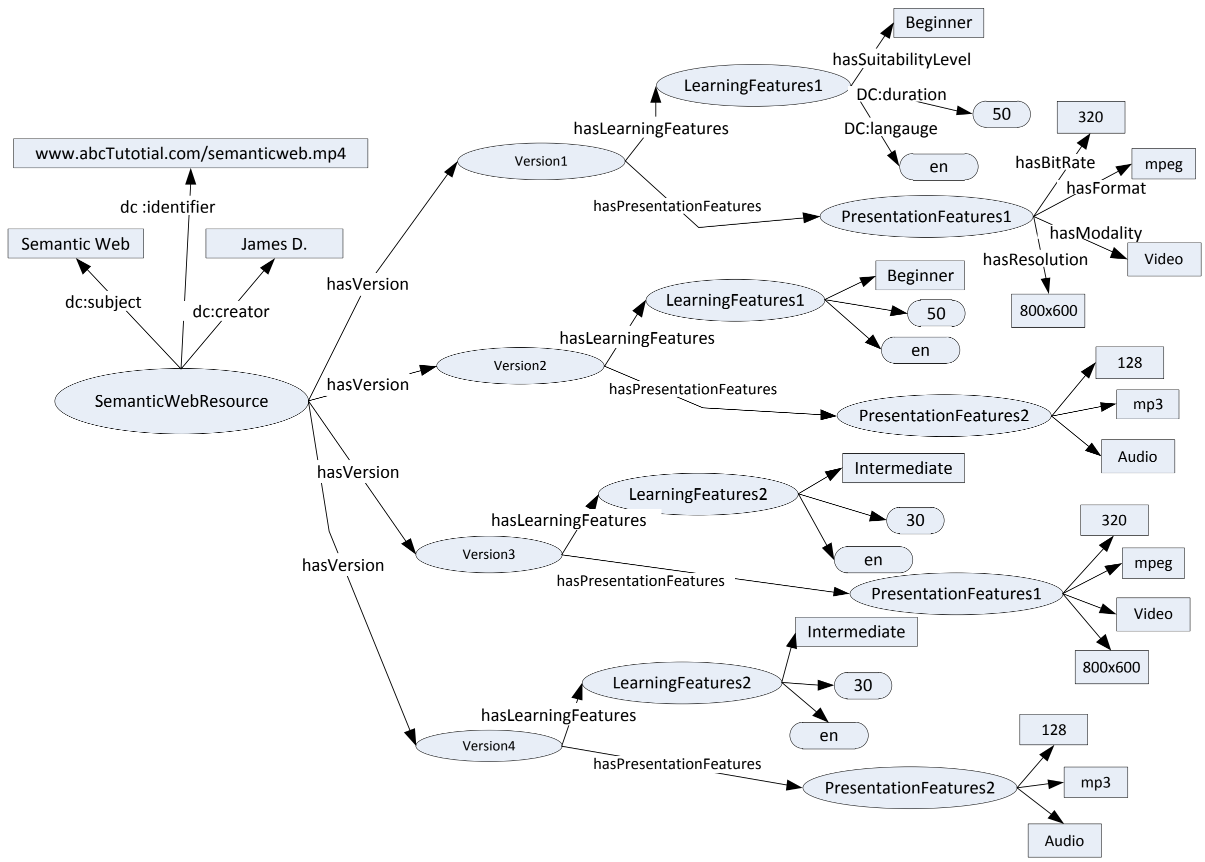

Figure 9-9 : Example Adaptive Resource Model

features. In a real implementation of the system some presentation features would be determined from the device profiles and network constraints. The interface would send the selected learning and presentation constraints to the server along with the topic of interest. The java servlet on the server would generate a SPARQL query based on the preferences and features. The resulting SPARQL query was executed with the help of Jena API to query the MySQL database for matching records. If there are any matching resources, the result of the SPARQL would be containing list of resource providers URLs. We noted that the system was returning the appropriate URLs based on the preferences and features selected.

In next sections, we demonstrate the behaviour of the envisioned system that would be implementing the proposed concept of the discovery of adaptive learning resources for power-saving on mobile devices. We consider one usage scenario and illustrate the behaviour of the system and describe the SPARQL query based on the model for this scenario.

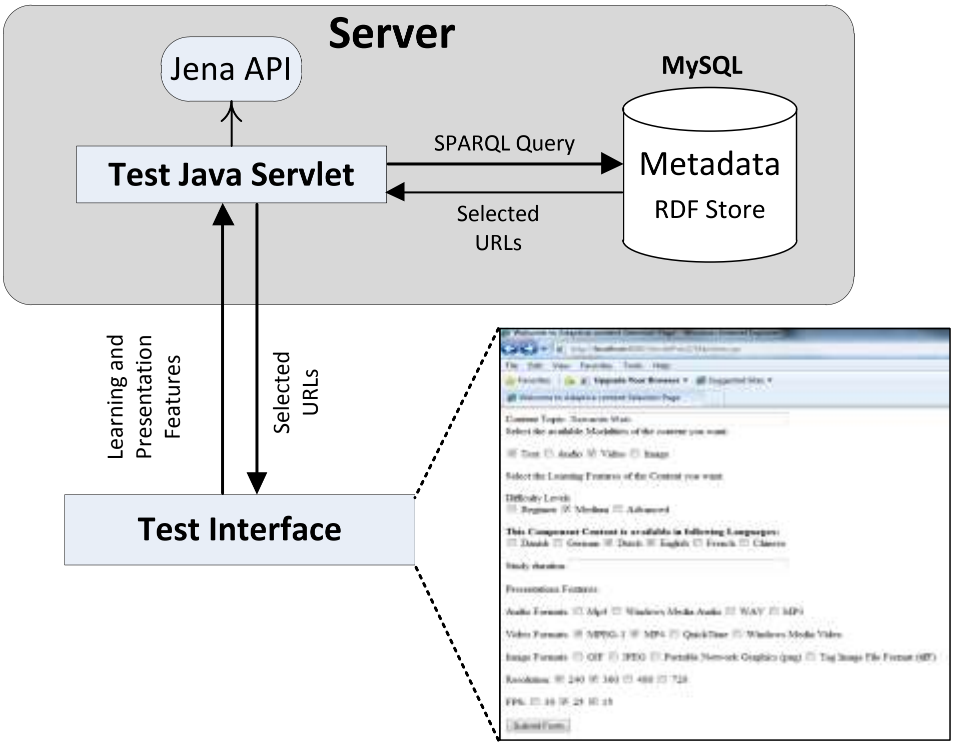

Figure 9-10: Architecture of Testing Setup

9.9.1 Example Scenario:

Bob has a job interview in 40 minutes and is waiting in the waiting area. The job specification requires a good understanding of Semantic Web technologies. Bob has some knowledge of the Semantic Web technologies but he wants to know more about the topic to improve his chances of success in the interview. Bob has a mobile phone connected to the internet. He is interested in a tutorial about the Semantic Web technologies in English or French language. He has 30 minutes to learn. By looking at the remaining battery life of his mobile, Bob thinks that the video will drain the battery power quickly so he should look for an audio version instead. Bob uses the Adaptive Learning Content Search system, and searches for a tutorial in Audio suitable for Intermediate level knowledge of 30 minutes duration. He receives a link for an adaptive resource that can provide an audio content of 30 minutes duration, which is a shorter version in audio of an original full video lecture in English of duration 60 minutes.

System Behaviour

Bob uses the Adaptive Content Search System's Interface to specify a topic to search and his preferences. Bob specifies his topic of search as **Semantic Web** and the preferred duration of the content as **30 minutes**. He is specified preferred languages as **French** or **English,** background knowledge level on the topic as **Intermediate** and the acceptable modality of the content as **Audio**. Bob does not specify format preferences or presentation quality. The system decides about the format and bitrates that is for best suited for the usage context including hardware and software resources. The system retrieves the device hardware and software information to decide that Bob can play **mp3** audio. The system generates SPARQL query based on the following information.

```
Topic: Semantic Web
Modality: Audio
Language: French, English
Duration: 30 min
Knowledge Level: Intermediate
Format: mp3
```

```
PREFIX dc: < http://purl.org/dc/elements/1.1/>
PREFIX ALRM: <http://users.ecs.soton.ac.uk/smaj08r/ontology/ALRM.owl#>
SELECT DISTINCT ?content WHERE {
?content dc:subject ?topic . FILTER regex( ?topic, "Semantic Web", "i")
?content ALRM: hasVersion ?learnCVersion.
?learnCVersion ALRM:hasLearningFeature ?learnFeatures .
?learnCVersion ALRM:hasPresentationFeature ?presentFeatures .
?presentFeatures ALRM:hasModality ALRM:Audio .
?learnFeatures ALRM:hasSuitabilityLevel ALRM:Intermediate .
{ ?learnFeatures dc: language "en" . } UNION
{ ?learnFeatures dc: language "fr". }
?learnFeatures dc: duration 30 .
?presentFeatures ALRM:hasFormat ALRM:AudioMp3 .
}
```

Figure 9-11: Example Test SPARQL Query

The system would display only those adaptive resources that have a version that matches the above requirements. A SPARQL query is used to search models of all adaptive resource in the RDF repository. Suppose in our example scenario, only the content described in Figure 9.11 matches the criteria. In this example, `Version 1` and `Version 3` are not selected as they are of Video Modality, while `Version 2` was of `50 minutes` duration for `Beginner level`. `Version 4` was selected because the mobile phone was able to play an `mp3` file and internet connection was good enough to play the audio of 128 kbps. In Figure 9.11 we describe the SPARQL query that is generated for the search.

9.10 A Proposed Architecture for the Adaptive Resource Search System

As mentioned earlier, we have not implemented a complete system here due to the limited time and scope of the thesis; however, we here propose some guidelines for the system in the form of an architecture given in figure 9.12. A learner interacts with system using the **Interface** and provides Search Topic, **Presentation Preferences** (Modality, Quality etc), **Learning Preferences** (background knowledge, duration, language etc.) and battery power-saving preferences. The system retrieves **Device Profile** of the user device and determines minimum quality. If the desired quality could not be provided to the due to limited resources or data connection limitation, then a minimum quality for the context is computed. A set of learning and presentation features are finalised and SPARQL **Query Generator** generates the SPARQL query.

The query is executed by **Query Executer** against all the RDF models of Adaptive Resources stored in the **Metadata Store**. The query result is processed by a **Result Processor**. The result processor can perform any filtering or sorting based on some criteria. The final sorted and filtered result set is provided to the user via System Interface. If there is no exact match of resources for user preferences, the closest available versions could be selected based on some criteria and presented to the user. For example, if the exact match of the requested duration is not found then the closest approximation will be provided. Any Intelligent algorithm can be used to determine the nearest match.

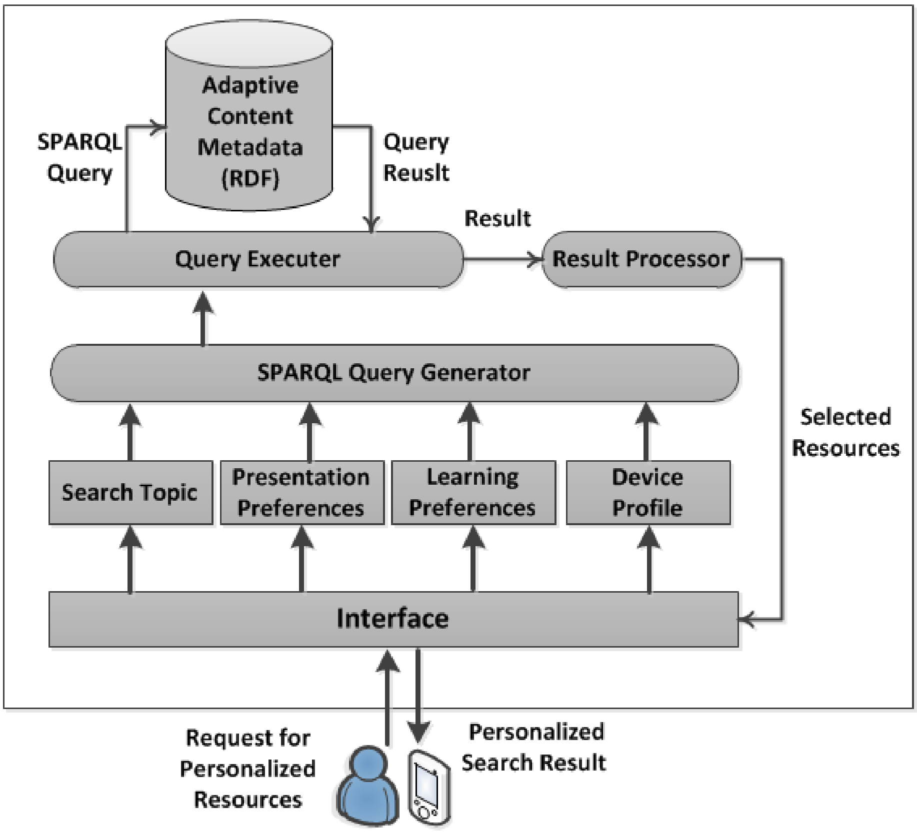

Figure 9-12 : Proposed Architecture for Adaptive Learning Resource Search System

9.11 Conclusion

In this chapter, we discussed the last of the three aspects of the battery-efficient mobile learning we considered in this thesis. Chapters 3 to 4 discussed our research work related to power-saving educational multimedia adaptation. We discussed Content-aware Power-Saving Educational Multimedia Adaptation (CAPSEMA) approach aimed at addressing some shortcomings of existing power-saving multimedia adaptation approaches. In chapter 7 the Learner-Battery Interaction (LBI) mechanism was proposed for power-aware mobile learning systems. The aim of the LBI was enable mobile learners make informed power-saving choices in power-aware mobile learning applications. In this chapter, we aimed to extend the notion of power-saving to search systems for online learning resources. We proposed a search mechanism, based on adaptive learning resources, aimed at discovering online learning resources on the desired topics that would help learners perform battery-efficient learning activity. This would help a learner with a mobile device to save battery-power during search for the learning material and the learning activity. The mechanism would select the learning resource from the available online resources that would consume less battery-power during the learning activity and would also be personalised to suit information needs of a learners. We have presented a data model that could be used as basis for implementing the proposed mechanism. The model was designed as an ontology model and implemented in RDF. In the end, we also presented a framework for the discovery of adaptive learning resources to enable the proposed solution.

Chapter 10: **Conclusion**

10.1 Research Overview

In this chapter, we summarise the research work presented in this thesis. We will discuss how we addressed the research questions mentioned in Chapter 1. We will highlight the evidence gathered in this thesis for answering those questions. We also summarise our research contributions made through research work presented in this thesis. In the end, we will highlight some limitations of this study and identify some future research work and directions.

This thesis addresses issues related to battery power-saving while performing learning activities on mobile devices (mobile learning). In particular, we focused on adaptation for battery power efficiency while using streaming learning multimedia resources on mobile devices. The following were the main motivations behind the work done in this thesis.

- Reducing the presentation quality of entire streaming multimedia is an approach that is commonly used for power-saving by existing adaptation techniques. These techniques are not designed in a manner to consider any negative impacts of the presentation quality reduction on perceived loss of information contents in a multimedia. Perceived information loss in a multimedia could have negative impacts on a learning activity. In this thesis, we investigated the impact of applying quality-reduction based power-saving multimedia adaptation on learning multimedia. We tried to establish if uniformly lowering the quality of entire multimedia could result in any perceived information loss as a result of reduction of quality. As a result, we wanted to suggest an enhancement to the quality reduction based power-saving multimedia adaptation approach, so that it would consider perceived information loss in the adaptation process.

- Existing power-saving adaptation techniques do not offer users enough control over the adaptation process. Power-saving adaptation usually results in some compromised behaviour of adaptive applications. It could, therefore, be useful to provide users options to select the extent of the power-saving based on the acceptable compromise level in the behaviour of an application. The power-saving adaptation is usually triggered automatically when a certain lower power-level is reached. For example, in power-saving multimedia adaptation techniques users are unable to select the extent of power-savings and choose any acceptable resulting compromise due to power-saving. We have considered this aspect in the context of power-saving learning multimedia application. We proposed an interaction mechanism that would allow users to control the adaptation process. This would make multimedia adaptation more satisfactory in a way that users themselves would be selecting the extent of power-saving based on the expected trade-off in quality of multimedia.

- The final objective in this thesis was to investigate how can adaptive and personalisation techniques be used in the context of open online learning resources to develop an online search mechanism for enabling discovery of learning resource to engage in a learning activity on some topic in a power-efficient way.

We started our research by studying existing power-saving multimedia adaptation techniques. In Chapter 2, we reviewed some popular power-saving adaptation approaches. We also highlighted work done related to the power-saving adaptation in the context of mobile learning. We noted in the literature review that power efficiency in streaming multimedia was mostly achieved by reducing the presentation quality of entire multimedia. This approach reduces the data size of the adapted multimedia and saves battery-power in the wireless data transmission. Most of these techniques do not consider the impact of quality reduction on the information contents of the multimedia. With the help of existing literature, we identified how there is a need for power-saving adaptation mechanism for streaming educational multimedia in order to avoid perceived visual information loss.

We investigated through a user study the impact of the power-saving adaptation approach of uniformly reducing the quality of entire multimedia. This investigation is presented in Chapter 3. We were especially interested to establish if it could result in perceived visual information loss or not. The results of the user study confirmed that it is possible that existing approach of uniformly lowering the quality of entire multimedia may result in perceived visual information loss and that different parts of the same educational multimedia may need different minimum available presentation qualities for avoiding the perceived visual information loss. Based on the results of the user study, a Content-Aware Power-Saving Educational Multimedia Adaptation (CAPS-EMA) approach was proposed in Chapter 4. This approach suggests delivering each portion of a multimedia in lowest acceptable presentation quality that would not result in any perceived visual information loss. The proposed CAPS-EMA adaptation approach is based on a metamodel of fragmented learning multimedia. The objective of the metamodel is used to identify the lowest available presentation quality constraint for each fragment. We also presented requirements for CAPS-EMA adaptation approach and presented a framework for its implementation. In order to demonstrate the proposed adaptation approach, we implemented CAPS-EMA adaptation approach using a prototype application called MoBELearn. This prototype system has been explained in Chapter 5. We followed the framework presented in Chapter 4 for implementing the prototype. As part of the implementation, we developed ontology metamodel to represent the fragmented multimedia learning resource.

In Chapter 6 and Chapter 7, we evaluated the proposed CAPS-EMA adaptation approach. CAPS-EMA was evaluated with main stakeholders i.e. Learners and Experts (Instructors/Multimedia Authors). Overall the objectives of evaluation were to understand if the way CAPS-EMA adapts a learning multimedia for power-saving is acceptable for Learners and how the adaptation impacts the concepts included in the original multimedia. Further, we wanted to understand the perception of Experts, in the role of multimedia authors, regarding the authoring process involved as a pre-processing for enabling the CAPS-EMA based adaptation. Evaluation studies in Chapter 6 are purely quantitative studies and are performed with Learners. Chapter 6 consists of two user studies. The first experimental study was based on comparing the CAPS-EMA approach to the commonly adopted alternative power-saving approach in terms of perceived visual information loss and impact of the adaptation on the perceived impact on learning. In the second user study, we aimed to understand the participants' acceptance of the characteristics of the CAPS-EMA adaptation approach. These characteristics include output of the adapted multimedia in fragmented form, variation in presentation quality of different portions of multimedia and delivering some portions in audio format when the visual information is not considered significant. The evaluation results suggest that the CAPS-EMA adaptation approach could reduce the perceived loss of visual information for power-saving. The participants that used multimedia adapted through existing approach reported negative impact on perceived learning effect and considered the adapted multimedia unsuitable for learning purposes due perceived information loss. Furthermore, the results also suggest that the way in which the CAPS-EMA adapts learning multimedia is acceptable for learners in order to save battery-power.

In Chapter 7, we performed further evaluations of the CASP-EMA with focus on qualitative in-depth analysis. We performed evaluation with both Learners and Experts (Instructors). We evaluated the main aspects of the activities involved in the authoring process for the CAPS-EMA with Experts in the role of content authors. We wanted to understand their perception about the authoring process. We did not implement any authoring tool for the CAPS-EMA, however, we evaluated the authoring steps manually without any tools. The results of the evaluation suggest that the authoring process was not considered as difficult and the users (in the role of authors) could understand the main ideas behind the authoring process. The experts were of the view that the required metadata could be easily generated and that educational metadata generation part was also easy as long as the authoring is performed by somebody who had expert-level background knowledge of the subject matter. Results of the evaluation with users in the role of Learners suggest that the multimedia adapted through the CAPS-EMA is acceptable for them and they did not report any negative impact of the adaptation on the coverage of concepts included in the original multimedia. However, learners were mostly not in favour of the presence of the audio clips. It was revealed that audio clips should specifically be not used when new concepts are introduced in a multimedia.

In order to address the problem of lack of user control on the power-saving adaptation process in adaptive applications, we presented a Learner-Battery Interaction (LBI) mechanism in Chapter 8. As power-saving adaptation results in some compromised experience, it is important that users should be provided a mechanism to control the adaptation process based on the acceptable compromised experience. LBI proposes to provide users power-saving options and information about the resulting compromise so that users can make informed power-saving decisions. We demonstrated the concept in the MoBELearn application. We presented a framework for LBI. We evaluated a prototype implementation of the proposed LBI mechanism through a user study. The results of the evaluation suggest that users had a high perceived usefulness of the proposed system.

Finally in this thesis, we addressed the issue of how adaptive open online learning resources would allow us to create a learning resource discovery mechanism that would enable learners using mobile devices to engage in learning activity in battery-efficient way. In chapter 9, we presented a data model for adaptive learning resources that could be used a basis for the proposed learning resource discovery mechanism. The data model models adaptive learning resources in terms of its adaptive characteristics. The adaptive characteristics could be used to select a version of an adaptive learning resource among many potential learning relevant resources on the topic of interest that could provide opportunity for battery-efficient learning activity.

10.2 Revisiting Research Questions

In this section, we revisit the research questions and discuss how we addressed them. We further summarise how we achieved our research objectives.

1. ***Do different parts of the same educational multimedia have different lowest quality requirements for avoiding perceived loss of visual learning information?***

   This research question was addressed through research objective RO1. In order to answer this research question, we conducted an experimental study. This study is given in detail in Chapter 3. In this study, we asked the participants to report any perceived visual information loss in different quality versions of five different fragments of the three selected educational multimedia. We created four versions of each fragment in four different qualities. The results of the study suggested that different fragments of the each multimedia had different lowest acceptable qualities for avoiding perceived loss of visual information. For some fragments the lowest quality (Q4) was acceptable while for some only the highest quality (Q1) was determined as the lowest acceptable quality. This proves our hypothesis H1 as correct and answers our research question as ‘Yes’. Detailed results of the study are given in figure 3.12, 3.13 and 3.14.

2. ***Does the power-saving multimedia adaptation based on the approach of lowering the quality of entire multimedia result in perceived loss of visual learning information for educational multimedia?***

   This research question is about studying the impact of the existing commonly used approach of lower the quality of entire multimedia for power-saving purposes. This research question was addressed through research objective RO2. We answered this research question through our experimental study discussed in section 6.2, where we evaluate the CAPS-EMA approach. In the study, we provided multimedia adapted by lowering quality of entire multimedia uniformly to Group 1. The results of the opinions from Group-1 revealed perceived loss of visual information in the adapted multimedia. All participants of Group 1 reported that they observed loss of visual information and 13 out of 14 of participants (93%) disagreed that they could view all visual information explained in the multimedia. The participants of Group 1 also reported that due to the extent of the perceived loss of visual information, the adapted multimedia required a higher quality and that it was not suitable for learning activities.

   These results answered **RQ2** and tested positively the hypothesis **H2**.

3. ***How can we address the issue of perceived loss of learning information in a power-saving multimedia adaptation approach for educational multimedia?***

We addressed this research question through research objective RO3 by proposing an enhanced adaptation technique, Content-Aware Power-Saving Educational Multimedia Adaptation (CAPS-EMA), in chapter 4. CAPS-EMA enhanced existing approach by delivering each fragment of multimedia in a lowest presentation quality that does not cause any perceived loss of visual information. This technique is based on the metadata that identifies the lowest acceptable quality among the available qualities for different fragments of a learning multimedia. The proposed concept has been demonstrated using a prototype application, MoBELearn. We have discussed the implementation of CAPS-EMA in Chapter 5. Designing CAPS-EMA and successfully implementing the approach through a prototype implementation answer this research question and it also tests positively the hypothesis **H3**.

a. How can we implement the enhanced power-saving multimedia adaptation mechanism for educational multimedia?

This sub-research question has been answered by developing a prototype implementation of the proposed enhanced power-saving educational multimedia adaptation approach. This implementation has been discussed in chapter 5.

b. Would such a mechanism be acceptable for users (learners) for power saving?

This research question was answered through research objective RO4. We conducted user studies in order to evaluate CAPS-EMA with Learners both quantitatively and qualitatively. In first user study described in section 6.2, we conducted a between-group experiment where we provided Group 2 of the participants with multimedia adapted through the CAPS-EMA approach. The results of the participants' opinion – mentioned in Table 6.3 – suggest that 93% of the participants (13 out of 14) were satisfied with the presentation of the adapted multimedia. Moreover, all the participants of Group 2 believed that the way multimedia was adapted through CAPS-EMA was acceptable for learning activities and that they didn't believe that it would cause any negative impact on a learning activity.

In a separate study mentioned in section 6.3, we evaluated the impact of the specific characteristics of the CAPS-EMA approach i.e. fragmented output, multi-quality output and presence of audio fragments in the adapted multimedia. We aimed to understand any impact of these characteristics on user satisfaction, acceptance for learning activity and acceptance for power-saving. The results of the study show positive responses from the participants. Majority of the participants were not dissatisfied from the CAPS-EMA characteristics (Table 6.9 and 6.10). As shown in Table 6.11 and 6.12, 13 out of 14 participants believed that these characteristics would have no negative during learning activities. Finally, we could see that none of the participants responded that with disagreement for acceptance of the CAPS-EMA characteristics for power-saving purposes. The results from these studies (in section 6.2 and 6.3) answer the research question as ‘Yes’.

c. ***Will the enhanced adaptation mechanism have any negative impacts on the coverage of the learning concepts included in the original multimedia?***

One of the main objectives of the mixed method studies with Learners, discussed in Chapter 7, was to understand any negative impacts of the CAPS-EMA mechanism on the concepts included the original multimedia. We aimed to understand how well the adapted multimedia covered the learning concepts in the original multimedia. During the evaluation, Learners were able to identify the concepts successfully and they believed that those learning concepts were covered well without any problems for perceived learning effect. These results have been discussed in section 7.3.3. Hence the results of study answer this research questions as ‘No’.

d. ***Would the activities involved in the authoring process for the enhanced adaptation mechanism be acceptable for content authors (experts)?***

We also evaluated the CAPS-EMA with participants in the role of content author. We selected experts for this experiment. We aimed to gather experts’ opinion about the authoring process involved in the metadata generation for CAPS-EMA adaptation. Although, we did not develop any complete authoring tool as part of the research in this thesis, we allowed the experts to go through the activities involved in the CAPS-EMA authoring process and report about their views about the authoring process. The results, as discussed in section 7.2, show that experts believed that authoring process was easy. The expert participants could understand the process of fragmentation and selecting the required metadata. The experts could identify the basis on which they would fragment a multimedia and then assign quality constraints. Regarding the educational metadata, it was reported that the process of generating educational metadata itself is an easy process, with the condition that the person generating the metadata should have subject knowledge. These results, as discussed in section 7.2.3, suggests that the authoring process is acceptable for experts, and this answers the research question RQ3.c as ‘Yes’.

4. ***How can we develop an interaction mechanism that would allow learners to choose the extent of power-saving based on the preferred level of resulting compromise?***

a. *What is learners' perception about the usefulness of the interaction mechanism?*

We addressed RQ4 and RQ4-a through the research objective RO5 in Chapter 8, where we proposed Learner-Battery Interaction mechanism (LBI). In Chapter 8, we identified the need for such a mechanism that would allow users to select a power-saving option themselves with the help of a feedback provided about the extent of a compromise as a result of each power-saving option. We considered a power-saving adaptive learning application. We developed a framework to implement this proposed mechanism. We demonstrated a prototype implementation of LBI in the form of MoBELearn interface.

We also conducted a user study to understand the perceived usefulness of the proposed LBI approach. The results of the evaluation study – as mentioned in Tables 8.3 and 8.4 – suggests that the users had high perceived usefulness of the proposed interaction mechanism in adaptive power-saving applications.

By proposing the LBI mechanism and implementing it in a prototype system we answer the research question RQ4. The results of our evaluation study suggest that users' perception about the usefulness of the system is positive; this answers the sub-research question RQ4-b.

5. ***How can we develop a mechanism based on adaptive learning resources for searching online learning resources that will enable power-saving during learning activities?***

This research question was addressed though research objective RO6. In Chapter 9, we proposed a mechanism based on open adaptive learning resources that will enable search for a learning resource enabling power-saving during learning activities. For this purpose, we presented a data model of adaptive learning resources. This data model models adaptive learning resources in terms of its adaptive characteristics and acts as a basis of the proposed discovery mechanism. The proposed mechanism answers the research question RQ5.

10.3 Research Contributions

1. We have established through experimental study the inadequacy of existing power-saving streaming multimedia adaptation approaches of uniformly reducing the quality of multimedia for educational multimedia. The results of our study (in Chapter 3) – which is the first of its kind - suggest that different portions of a learning multimedia may require different lower qualities as lowest acceptable qualities for avoiding perceived loss of learning information during adaptation though existing generic adaptation mechanisms. Uniformly lowering the quality of entire learning multimedia, therefore, could result in perceived information loss in learning information. In our other study (Section 6.2), users in the roles of learners reported perceived loss of visual learning information when learning multimedia was adapted through uniformly lowering the quality of entire multimedia. They reported that the lowered quality was not suitable at some places due to perceived loss of information.

   This contribution is important as it challenges the use of the commonly adopted power-saving approach of uniformly lowering the presentation quality of an entire multimedia stream for educational multimedia resources and highlights the need for enhancements in adaptation mechanisms specifically for learning multimedia.

2. Another key contribution of this research is proposing an approach to avoid the problem of perceived loss of learning information during power-saving multimedia adaptation for educational multimedia. The proposed adaptation approach, Content-Aware Power-Saving Educational Multimedia Adaptation (CAPS-EMA), proposes not to reduce the quality of entire multimedia uniformly. Instead CAPS-EMA suggests to reduce the quality of each portion of multimedia to an acceptable lowest level that will not result in perceived loss of learning information. This is achieved through placing lowest (acceptable) quality constraints on different portions of a multimedia. These constraints would be identified during the analysis of the multimedia in the available lower qualities for different portions of a multimedia. These quality constraints are put in the form of metadata, and the adaptation process make adaptation decisions based on these quality constraints in the metadata.
3. One key contribution of this research work is in presenting a framework (in section 4.4) that will guide the implementation of the enhanced proposed adaptation approach and an

abstract model, Fragmented Educational Multimedia Model (section 4.5), that describes the general structure and key aspects of the metadata that would be required as part of the CAPS-EMA implementation. The framework identifies key components of CAPS-EMA and how are they are related to each other. The unique feature of the framework is using fragments of multimedia and metadata associated with those fragments.

The Fragmented Educational-Multimedia Model (FEMM) describes the general structure of the metadata. This generic abstract model also clarifies the role of the metadata in the proposed approach for adaptation. FEMM illustrates the concepts of fragments, their versions in different qualities and presentation quality constraints in the context of the proposed CAPS-EMA approach. The model also shows that there is possibility of annotating the multimedia with educational multimedia depending on the need of a particular implementation.

The proposed framework and the FEMM model have been implemented in the form of prototype MoBELearn system (Chapter 5). The MoBELearn system shows how the framework and the FEMM model could be implemented. In the prototype system, the metadata about the fragmented multimedia was implemented using RDF and used SPARQL queries in the adaptation engine.

4. This thesis presents perspectives of the key stakeholders of the educational multimedia adaptation system (Learners and Multimedia Authors) regarding the proposed power-saving adaptation approach through evaluation studies. This is an important contribution as it answers some key questions regarding acceptance of the approach by main stakeholders and would encourage implementation of the CAPS-EMA adaptation approach.

   Our evaluation studies suggested that Learners believed there were no problems with using learning multimedia adapted through CAPS-EMA, and yet it reduced the problem of perceived visual information loss in learning multimedia as compared to the traditional approach of uniformly lowering the quality of entire multimedia. We evaluated the impact of the key characteristics of a multimedia adapted through CAPS-EMA, that is, multi-quality fragmented output with the possibility of the presence of audio fragments instead of video on acceptance for power-saving in learning activities. The results suggest that the resulting compromises due to adaptation were acceptable for power-saving purposes.

We also show through evaluation with Experts in the roles of multimedia author that the activities involved in the authoring process for CAPS-EMA adaptation – i.e. fragmenting multimedia and metadata generation – was considered easy and acceptable. During evaluation the Experts participants were able to understand the objectives of the authoring process and the ideas of fragments and constraint quality. As part of the evaluation, the Experts participants were able to generate fragments and needed metadata for a learning multimedia.

5. This research suggests that an enhanced interaction mechanism, for application with power-saving adaptation, based on providing explicit options to control power-saving and feedback for each option about the resulting compromises is perceived to be very useful. This enhanced interaction mechanism, Learner-Battery Interaction (LBI), has been proposed for mobile learning applications that offer power-saving adaptation. The unique feature of LBI is enabling users to control the extent of power-saving through informed decision making about adaptation, instead of allowing an adaptive application to make automatic power-saving decisions on their behalf. LBI suggests to provide users with explicit multiple power-saving options for different degree of power-saving and providing information about the resulting consequences of each power-saving option on the adapted content and behaviour of the application.

   A Learner-Battery Interaction Model is presented, that illustrates how both the feedback from power-saving options and battery indicator can increase the knowledge and understanding of a user about the situation at hand in terms of the remaining battery life of a mobile device. This helps user decide and amend the objective of the learning activity. This also helps a user decide about choosing the right option from the available options provided for power-saving.

   The results of the evaluation study reveal that users /learners had positive and high perceived usefulness about the power-saving interface implementing LBI.

6. In this thesis, we have presented a data model of adaptive learning resources that could be used as a basis for an approach that would enable discovery of versions of open online adaptive learning resources based on the power-saving and personalised information needs. The developed metamodel models an adaptive resource in terms of the adaptive characteristics of an adaptive learning resources.

While the available online keywords based searching facilities is based on static single versioned non-adaptive information resources, the work related to the envisioned discovery of adaptive learning resources for power-saving, in Chapter 9, proposes to develop a search mechanism that would allow selection of open adaptive information resources based on the characteristics of the different versions it can adapt to. Such a mechanism would extend the useful role of adaptive resources from closed systems – where users register to interact with adaptive resources - to be openly available on Web.

We have discussed the proposed search mechanism and its framework in the context of power-saving that will enable learner discovery of personalised and battery-efficient learning resources allowing mobile learners to engage in a learning activity in a power-efficient way. We suggest extending the concept of adaptation to open educational resources that are searchable on the Web.

The discovery mechanism would enable the learner to find a resource version among the many available online from different providers that would be suitable for a user's information needs and would be expected to consume less battery power during the learning activity. A resource version is considered battery efficient if it suits the learner's information needs and background knowledge as well as the duration of the expected learning activity with a resource and total data size of the learning resource.

10.4 Research Limitations

In this section, we mention some limitations of our work discussed in this thesis.

10.4.1 Research Design Limitations

There are some limitations related to the experimental design of the studies that we conducted. While addressing research objective RO1, we did not select a huge number of learning videos on a variety of topics in the user study (Chapter 3). A larger number of videos would have given more strength to the results. The design of the user study involved fragmenting each video into five fragments of durations about 20-25 seconds and then creating four different quality versions of each fragment. In total, we had 60 multimedia clips for evaluation from just three videos. A larger number of videos would have resulted in a much complex study design and would require a bigger number of participants.

Furthermore, we recruited a limited number of participants from a specific group; all participants were PhD students from Computer Science and Computer Engineering disciplines. This may constrain the generalizability of the results.

10.4.2 Battery Measurements

We did not implement a functionality to measure the real-time battery-power consumption in the developed system. The battery consumption values were computed beforehand and were used in the experiments. This is due to the limited scope of the research questions addressed in this thesis. The thesis is aimed at addressing some shortcomings of the existing power-saving streaming multimedia adaptation approaches and proposes some enhancements to overcome those shortcomings. Battery consumption varies significantly due to many different factors, for example, wireless signal strength, the type of wireless network technology used and features of the mobile device.

10.4.3 Impact of Fragmentation Overhead

In this thesis, we did not calculate the extent of the impact of any overhead resulting from fragmentation of the multimedia on battery power consumption. Streaming fragmented multimedia is not the same as single complete piece of the multimedia. We did not address the impact of this difference on power consumption and user experience. Our current implementation also suffered from an HTML 5 specific limitation on mobile devices. The '*autoplay'* feature of HTML5 is disabled in mobile operating systems. Users were obliged to explicitly interact with the system by pressing the "start" control for playing each fragment. The impact of successfully addressing this problem is also expected to further improve user satisfaction. This possible overhead could be lowered if the dynamic adaptive streaming discussed in section 4.6.3 is adopted for implementation.

10.4.4 Optimal Fragments Duration

In this thesis, we did not address the following issues regarding the optimal multimedia fragment size.

- What is the minimum fragment duration that would be acceptable for users?
- What is the minimum fragments duration that is feasible for battery-saving purposes? For example, for what minimum duration of a fragment it would be feasible to deliver a bigger

fragment instead of delivering it as two smaller fragments in different lowest acceptable qualities?

- What is the minimum acceptable fragment size for each reduced quality level? We believe fragment sizes depend on the selected quality level. We intuitively think we would require less number of fragments as we increase the preference for minimum presentation quality. This is further explained in 10.5.1.

10.4.5 Implementation and Evaluation of Battery-Efficient Search Mechanism

As discussed in section 9.8, due to the limitation of time and scope of the thesis, we could not develop a complete system implementing the proposed mechanism of battery-efficient learning through discovery of online adaptive resources. We as a result could not evaluate effectiveness of the concept.

10.5 Future Research Directions

We have identified some future research directions based on the work done in this thesis. Some of these future research directions are based on the limitations and limited scope of the current study.

10.5.1 Updating the Fragmented Learning Resource Ontology Model

The Fragmented Educational Multimedia Resource Ontology Model (FEMROM) that we have presented in this thesis has been developed keeping in view the requirements for maximum battery-efficiency only. For the maximum possible battery-efficiency, usually the lowest acceptable quality is selected. We believe this model may not be the efficient one for scenarios where less than the maximum possible battery efficiency is desired. This can be the case as result of preferences for a slightly a higher quality than the constraint quality. We need to update the fragmented multimedia model in a way to accommodate those scenarios. We believe the total number of fragments (and, therefore, their durations) depends on the preferred lower quality level. We expect to require fewer fragments of the multimedia when we prefer a higher quality.

To explain this slightly complex situation, we give an example in Figure 10.1 based on results from section 3.3.5, which is a portion extracted from the Figure 3.12. As described in section 3.3.5, the green boxes represent lowest acceptable quality level for corresponding fragments. The red boxes represent the quality levels not acceptable for those fragments, as it would cause loss of visual information. For maximum battery efficiency, when quality Q4 is acceptable, we require five fragments, as each consecutive fragments have different minimum quality requirements. However, if quality Q3 was preferred by a user as lowest acceptable quality instead of lowest possible Q4, then both F1 and F2, as one bigger fragment, would be a more efficient option. This combined larger fragment would overcome possible fragmentation overhead, making the total number of required fragments as four. Similarly, if a further higher quality Q2 is desired as lowest quality, then we can have only three fragments, that is, F1 and F2 as one fragment of quality Q2, F3 of Q1, and F4 and F5 as one fragment of quality Q2. So the fragmentation overhead is expected to be reduced. We need to consider this further for updating the model to accommodate these issues.

Quality	F1	F2	F3	F4	F5
Q1	7	7	7	7	7
Q2	7	7	3	7	7
Q3	7	7	2	7	0
Q4	2	7	1	0	1

Figure 10-1 : Acceptable Minimum Quality levels for different fragments of Multimedia for video 1 in the user study

10.5.2 Implementation using Adaptive Streaming Technique

We would be interested in investigating ways of implementing CAPS-EMA using adaptive streaming techniques, as discussed in section 4.6.3. An adaptive streaming technique does not require actual splitting of the media file for fragmentation by content authors, instead identifying the start and end times of the fragments in the original multimedia stream as metadata are enough. This is known as logical fragmentation. This would be a more intuitive way of implementing the CAPS-EMA. It is believed that it would also address some possible inefficiencies, as a result of physical fragmentation, as identified in 10.5.1. An adaptive streaming implementation requires a scalable video encoding format. The resultant implementation would enable a smooth and seamless transition between different fragments, while the multimedia is being played.

10.5.3 Authoring tool for Metadata Creation

One other issue of our interest for future study is to investigate how we can design an authoring tool that can facilitate content authors in the creation of the metadata for the CAPS-EMA approach.

Some requirements for such a tool might be to identify potential fragments based on the similarity of visual contents and identifying presentation quality constraints.

This could be done by displaying each potential media fragment in different presentation qualities for observation by a human operator, who would be looking for perceived information loss. Another option could be to investigate using advanced video processing methods to objectively detect the minimum acceptable qualities for each detected fragment.

10.5.4 Working Prototype for Battery Efficient Search System

We are interested to explore further the mechanism of discovery of adaptive learning resources and identify the potential ways to implement it. We aim to get an insight into how and in what ways it could offer better learning experiences to mobile learners. This would also help us to evaluate the effectiveness of the concept, a limitation in the thesis that is identified in section 10.4.5.

10.5.5 Change in User Behaviour through LBI

Due to the limited scope of this thesis, we could not identify the potential behaviour change of learners as a result of using the Learner-Battery Interaction (LBI) mechanism. We would be interested to investigate if the Learner-Battery Interaction interfaces might encourage learners to increase the use of mobile devices for learning purposes and if it might influence users' charging patterns.

10.6 Conclusion

The main focus of the research study in this thesis was achieving battery power-saving in the context of mobile learning. The higher data rate connectivity of these mobile devices with the Internet has opened further learning opportunities for using online learning resources. Using online multimedia resources on mobile devices, however, is a very power hungry activity that drains the battery power quickly. Power-saving adaptation techniques for streaming multimedia have been developed to address the high battery power consumption problem. This thesis studied the impacts of these existing power-saving multimedia adaptation techniques when applied to learning multimedia. The results of our study reveal that the commonly used power-saving approach of uniformly lowering the presentation quality of entire multimedia may negatively affect a learning activity due to perceived visual information loss. Moreover, preventing these information losses would result in battery power inefficiency, if current approaches were used. To address these negative implications, this thesis proposed a Content-Aware Power-Saving Educational Multimedia Adaptation (CAPS-EMA) approach. This approach recommends lowering the presentation quality of multimedia depending, on the presentation quality requirements of each piece of that multimedia. The CAPS-EMA approach was demonstrated in a prototype implementation in the form of the MoBELearn application. The evaluation results suggest that the CAPS-EMA approach would improve the user satisfaction, by reducing the problem of visual information loss.

The thesis also proposed a Learner-Battery Interaction (LBI) mechanism that proposes to provide users with control options for power-saving adaptation activity. An evaluation study shows that users reacted positively to the interaction mechanism. Users should be enabled to make informed decisions about the extent of power-saving, based on information provided about possible compromises in the adapted multimedia.

This thesis proposes an enhanced search mechanism for the discovery of online learning resources that enable battery efficient learning. The battery-efficient learning activity is learning when the mobile usage duration and the wireless data transfer is reduced helping in reduced consumption of battery power. Furthermore, battery efficient learning is facilitated by a learning resource that is personalised to the learners needs. The proposed search mechanism is based on adaptive learning resources and would enable the discovery of an online adaptive learning resource that can offer a personalized version that would consumes less battery power during the learning activity, while satisfying the information needs of a learner.

Appendix A : Questionnaire used in user study 1

A portion from the questionnaire used in user study 1 (describe in chapter 3). The same group of statements were repeated for all video clips.

Participant ID: [ ] GROUP: 1 1/4
Thank you for participating in this study

Please provide the feedback after viewing each multimedia clip.

Clip ID: AA1	**Strongly Agree**	**Agree**	**Disagree**	**Strongly Disagree**
Visual information that is focused in the clip is visible.				
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.				
If I **DO NOT** need battery power saving, I am still comfortable with this visual quality.				

Clip ID: AB2	**Strongly Agree**	**Agree**	**Disagree**	**Strongly Disagree**
Visual information that is focused in the clip is visible.				
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.				
If I **DO NOT** need battery power saving, I am still comfortable with this visual quality.				

Clip ID: AC3	**Strongly Agree**	**Agree**	**Disagree**	**Strongly Disagree**
Visual information that is focused in the clip is visible.				
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.				
If I **DO NOT** need battery power saving, I am still comfortable with this visual quality.				

Clip ID: AE1	**Strongly Agree**	**Agree**	**Disagree**	**Strongly Disagree**
Visual information that is focused in the clip is visible.				
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.				
If I **DO NOT** need battery power saving, I am still comfortable with this visual quality.				

Clip ID: BA1	**Strongly Agree**	**Agree**	**Disagree**	**Strongly Disagree**
Visual information that is focused in the clip is visible.				
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.				
If I **DO NOT** need battery power saving, I am still comfortable with this visual quality.				

The same group of statements were repeated for all audio clips.

Participant ID: [ ] GROUP: 1 4/4

Thank you for participating in this study

Questions about Audio Clips

Audio Clip ID: AA4	**Strongly Agree**	**Agree**	**Disagree**	**Strongly Disagree**
Information in the Audio clip was understandable without requiring visual support.				
If I **need** to save battery power, I am happy to have this information in Audio instead of spending more battery power on video.				

Audio Clip ID: BD4	**Strongly Agree**	**Agree**	**Disagree**	**Strongly Disagree**
Information in this Audio clip was understandable without requiring visual support.				
If I **need** to save battery power, I am happy to have this information in Audio instead of spending more battery power on video.				

Audio Clip ID: BE4	**Strongly Agree**	**Agree**	**Disagree**	**Strongly Disagree**
Information in this Audio clip was understandable without requiring visual support.				
If I **need** to save battery power, I am happy to have this information in Audio instead of spending more battery power on video.				

Audio Clip ID: CD4	**Strongly Agree**	**Agree**	**Disagree**	**Strongly Disagree**
Information in this Audio clip was understandable without requiring visual support.				
If I **need** to save battery power, I am happy to have this information in Audio instead of spending more battery power on video.				

Appendix B : Questionnaires used in experimental study for CAPS-EMA evaluation

Questionnaire A: Used after participants used the adapted multimedia.

Participant ID: [ ] 1
Thank You for Agreeing To Participate In This Study

Please provide feedback about your experience of using the learning multimedia

No.		Strongly Disagree	Disagree	Agree	Strongly Agree
S1	Some information was not visible to view for understanding	Strongly Disagree	Disagree	Agree	Strongly Agree
S2	I could view all learning visual content that was explained in multimedia	Strongly Disagree	Disagree	Agree	Strongly Agree
S2.1	*Please briefly elaborate if your response to S2 is Strongly Disagree or Disagree.*				
S3	Up to what extent of whole multimedia did you observe Information Loss due to poor visibility	No Parts	Few Parts	Most Parts	All Parts
S4	Visual quality of the multimedia presentation in your view was	Bad	Poor	Good	Excellent
S5	I am satisfied with presentation of the multimedia	Strongly Disagree	Disagree	Agree	Strongly Agree
S6	I think a higher quality was needed to view some learning visual content	Strongly Disagree	Disagree	Agree	Strongly Agree
S7	Generally, the extent of visual information loss you observed is acceptable for educational multimedia	Strongly Disagree	Disagree	Agree	Strongly Agree
S8	Generally, the extent of visual information loss you observed can have negative impact on learning	Strongly Disagree	Disagree	Agree	Strongly Agree
S8.1	*Please briefly elaborate if your response to S8 is Agree or Strongly Agree.*				

Questionnaire B: User to after participants watched the original version of the multimedia.

Participant ID: [ ] 2

Thank You for Agreeing To Participate In This Study

After watching the second version of the multimedia, please provide your opinion about the any differences you think exist.

No.		Strongly Disagree	Disagree	Agree	Strongly Agree
S9	There is no difference in Presentation Qualities of both versions	Strongly Disagree	Disagree	Agree	Strongly Agree
S10	First version of multimedia had No information loss.	Strongly Disagree	Disagree	Agree	Strongly Agree
S11	I could find some visual information in the original video that was not visible in the first multimedia.	Strongly Disagree	Disagree	Agree	Strongly Agree
S12	The second version of multimedia has extra visual information to learn from.	Strongly Disagree	Disagree	Agree	Strongly Agree
S13	I found it difficult to learn from the first version.	Strongly Disagree	Disagree	Agree	Strongly Agree
S14	I can confirm first version negatively effects learning process.	Strongly Disagree	Disagree	Agree	Strongly Agree
S15	The first version is acceptable for learning if it helps battery power saving and I need to preserve battery power on a mobile device	Strongly Disagree	Disagree	Agree	Strongly Agree
S15.1	*Please briefly elaborate if your response to S15.*				

Appendix C : Questionnaire used in the user study for CAPS-EMA characteristics evaluation

Q: [C] Participant ID: [ ] 1

Thank You for Agreeing To Participate In This Study

No.		Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
	User Satisfaction					
S1	I could observe difference in video qualities of different clips	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
S2	I am comfortable with multimedia being presented as multiple clips	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
S3	I am satisfied with different segments of multimedia being presented in different visual qualities	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
S4	I am comfortable with multimedia learning resource having some parts in audio	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
S5	There was no problem in understanding concepts explained in each clip	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
	Impact on Learning					
S6	Multimedia presented in multiple clips does not negatively impact learning	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
S7	Learning multimedia composed of clips of different visual qualities does not negatively affect learning	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
S8	Presentation of multimedia fragments in Audio has no negative impact on learning	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
	Acceptance for Battery Efficiency					
	Are the following acceptable to you in this multimedia presentation if done for battery saving in a situation you needed to save battery power?					
S9	Receiving learning multimedia as multiple clips	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
S10	Receiving clips in different video qualities	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
S11	Receiving audio version of a video portion which has no important visual information	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

Appendix D: Questionnaire used in LBI evaluation

Q [D] Participant ID: [ ] 1

Thank You for Agreeing To Participate In This Study

Feedback refers to the textual description for each battery power-saving option that you can select using the slider control in the application interface.
Battery Power-Saving Options refer to each option that you can select using slider control in this application

S1	I have used similar systems before	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
S2	I am aware of other methods that can help me save battery power in mobile multimedia streaming applications.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
S3	I understand overall purpose of this application	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
S4	This application is easy to understand.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
S5	This application is easy to use on touch screen mobile devices.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
S6	I am comfortable with use of *Slider Control* for selecting battery saving options	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
S7	This application is useful for preserving mobile battery power in multimedia learning	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
S8	I agree to the way this system addresses the problem of battery consumption in learning multimedia	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
S9	Such application should be integrated in mobile learning systems.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
S10	I would use such a system in situations where I need to save battery power.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
S11	The feedback provided is easy to understand.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
S12	Knowing impact of battery saving choices on multimedia through feedback is important	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
S13	Feedback provided by this application is helpful in making informed decision about battery saving choices.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
S14	I am satisfied with feedback provided by the system	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
S15	I need more information in feedback	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

Q [D] Participant ID: [ ]

2

Thank You for Agreeing To Participate In This Study

S16	What other Information would you be interested in the feedback?
S17	What other systems or techniques you are aware of to use for similar purpose?
S18	What is your overall view or impression about this system?

Appendix E：Fragmented Metadata Model testing for some scenarios based on educational metadata

In this section, we present further scenarios from the assumed situations where the adaptation requires educational attributes. As the work in this thesis is not related to multimedia adaptation based on any educational attributes we separated these scenarios from the ones mentions in chapter 5.

Scenario 1:

A learner with advanced level of background knowledge is interested in battery power-saving by receiving a shorter version by not having the portions of multimedia that would contain details not important for his level. The learner prefers highest multimedia quality.

In the above-mentioned scenario, the learner wants to achieve some battery efficiency by asking for a multimedia of reduced duration. User should be provided with fewer fragments in the highest quality. By looking at the specification in Table 5.2, the learner should be given only two fragments that are compulsory for advanced level learners. The following SPARQL query should returns us the desired fragments versions.

```
1    PREFIX dc:<http://purl.org/dc/elements/1.1/>
2    PREFIX rdf:<http://www.w3.org/1999/02/22-rdf-syntax-ns#>
3    PREFIX f:<http://www.fragmentmodel.com/elements/1.1/>
4    SELECT DISTINCT ?FragVerId WHERE {
5    ?LR dc:identifier ?ResId.FILTER regex(
6    ?ResId,"http://www.videoLectures.com/videoLecture.mp4", "i").
7    ?LR f:hasFragment ?LRFrag.
8    ?LRFrag f:hasEducationalAttributes ?eduAttr.
9    ? eduAttr f:hasImportance ?Importance.
10   ?Importance f:UserLevel ?uLevel.FILTER regex( ?uLevel, "Advanced" , "i").
11   ?Importance f:importance ?ImpValue.FILTER (?ImpValue = 1 ).
12   ?LRFrag f:hasFragmentVersion ?FragVer.
13   ?FragVer dc:identifier ?FragVerId.
14   ?FragVer f:hasQuality ?Quality.
15   ?Quality f:qualityNum ?QN. FILTER(?QN = 1)
16   }
17   ORDER BY ASC(?FragVerId);
```

In the above SPARQL query, the lines 10 and 11 filters fragment versions for selecting those fragments version where for user level (?uLevel) has value “Advanced” and the importance values

(?ImpValue) is 1. ImpValue of 1 represents compulsory for that user type. In line 15 filtering is done to select fragment versions where ?QN is 1 – that is – highest quality. Output of the query execution is given below:

Output:

```
http://www.videoLectures.com/videoLecture1HQ.mp4
http://www.videoLectures.com/videoLecture4HQ.mp4
```

We can see that the generated SPARQL successfully selects the expected fragments that both Fragment 1 and 2 in high quality.

Scenario 2

A beginner level learner wants battery power-saving but prefer video-only multimedia content.

In this scenario, the learner is interested to achieve a power-saving but does not want any audio-only content in the adapted multimedia. In this case, the learner should be provided with all fragments in their lowest acceptable qualities except where audio is the lowest acceptable quality. In that case where audio is the lowest quality, Low Quality video should be provided. So the SPARQL query should be created that should select fragment version in their lowest acceptable quality or if the lowest acceptable quality is Audio quality then select the fragment in Low-Quality instead. The following SPARQL query should give the desired selection of fragments:

```
1   PREFIX dc:<http://purl.org/dc/elements/1.1/>
2   PREFIX rdf:<http://www.w3.org/1999/02/22-rdf-syntax-ns#>
3   PREFIX f:<http://www.fragmentmodel.com/elements/1.1/>
4   SELECT DISTINCT ?ResId ?FragVerId ?QN ?size  WHERE {
5   ?LR dc:identifier ?ResId.
6   FILTER regex(?ResId,"http://www.videoLectures.com/videoLecture.mp4","i").
7   ?LR f:hasFragment ?LRFrag.
8   ?LRFrag f:hasPresentationConstraints ?pConstraint.
9   ?pConstraint f:qualityNum ?pConstQNum.
10  ?LRFrag f:hasFragmentVersion ?FragVer.
11  ?FragVer dc:identifier ?FragVerId.
12  ?FragVer f:hasQuality ?Quality.
13  ?Quality f:qualityNum ?QN.
14  FILTER( ?QN = IF (?pConstQNum < 2, ?pConstQNum, 2 ) ).
15  }
16  ORDER BY ASC(?FragVerId);
```

In the above SPARQL query the line 14 performs this complex selection process. It does the quality number selection. The quality number is determined as 2, which is low-quality, the constraint quality is not a High-Quality i-e 1. For all remaining fragments the quality is determined as 2 – i-e Low-Quality.

Output*:*

```
http://www.videoLectures.com/videoLecture1LQ.mp4
http://www.videoLectures.com/videoLecture2LQ.mp4
http://www.videoLectures.com/videoLecture3LQ.mp4
http://www.videoLectures.com/videoLecture4HQ.mp4
```

As we can see in the results of the selection fragment versions, three fragments are selected in Low-Quality and Fragment 4 is selected in High Quality. Fragments 2 and 4 are selected in lowest acceptable qualities, however, Fragment 1 and 3 is selected in Low Qualities even though they have Audio as constraint qualities in the metadata, which can be seen in Figure 5.2.

Scenario 3:

A learner with advanced level background knowledge is interested in maximum possible power-saving. The learner would also accept a shorter version of multimedia by skipping less important fragments for his level. The learner has no preference for modality or multimedia quality.

In this scenario, the learner is interested to achieve maximum battery saving by reducing both quality and contents of the multimedia. Fragments optional for advanced level learners can be skipped. This would be done by selecting compulsory fragments for an advanced level learner in their lowest acceptable presentation qualities. The following SPARQL query is generated for this scenario.

```
PREFIX dc:<http://purl.org/dc/elements/1.1/>
PREFIX rdf:<http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX f:<http://www.fragmentmodel.com/elements/1.1/>
SELECT DISTINCT  ?FragVerId  WHERE {
?LR dc:identifier ?ResId.
FILTER regex(?ResId, http://www.videoLectures.com/videoLecture.mp4","i").
?LR f:hasFragment ?LRFrag.
?LRFrag f:hasEducationalAttributes ?eduAttr.
? eduAttr f:hasImportance ?Importance.
?Importance f:UserLevel ?uLevel.FILTER regex( ?uLevel, "Advanced" , "i").
?Importance f:importance ?ImpValue.FILTER (?ImpValue = 1 ).
?LRFrag f:hasPresentationConstraints ?pConstraint.
?pConstraint f:qualityNum ?pConstQNum.
?LRFrag f:hasFragmentVersion ?FragVer.
?FragVer dc:identifier ?FragVerId.
?FragVer f:hasQuality ?Quality.
?Quality f:qualityNum ?QN. FILTER(?QN = ?pConstQNum)
```

```
18  }
    ORDER BY ASC(?FragVerId);
```

In the above given SPARQL query, filtering is done in the lines 10 and 11 to retrieve fragments where user level is "Advanced" and importance value is '1'. The line 13 accesses the quality number of the constraint quality for each fragment and in the line 16 filtering is done to retrieve fragments where the quality number is same as the constraint quality.

Output:

```
http://www.videoLectures.com/videoLecture1Audio.mp4
http://www.videoLectures.com/videoLecture4HQ.mp4
```

We can see that in the output only Fragment 1 and 4 are selected as both fragments are declared as compulsory for advanced level learners. Furthermore, both fragments are selected in their corresponding lowest acceptable presentation qualities.

Scenario 4:

A learner with advanced level background knowledge is interested in maximum battery power-saving. The learner would accept a shorter version of the multimedia but prefer only video content.

This scenario is similar to scenario 5, except that the learner is also willing to get a shorter version by omitting any fragments that are optional for advanced level. In this scenario the learner is interested to achieve maximum battery power-saving in video only adapted multimedia. This means the learner should be provided only those fragments identified as important or compulsory for Advanced Level learners, in the lowest acceptable qualities except where Audio is the lowest acceptable quality.

```
1   PREFIX dc:<http://purl.org/dc/elements/1.1/>
2   PREFIX rdf:<http://www.w3.org/1999/02/22-rdf-syntax-ns#>
3   PREFIX f:<http://www.fragmentmodel.com/elements/1.1/>
4   SELECT DISTINCT  ?FragVerId   WHERE {
5   ?LR dc:identifier ?ResId.
6   FILTER regex(?ResId,"http://www.videoLectures.com/videoLecture.mp4", "i").
7   ?LR f:hasFragment ?LRFrag. "+
8   ?LRFrag f:hasEducationalAttributes ?eduAttr.
9   ? eduAttr f:hasImportance ?Importance.
10  ?Importance f:UserLevel ?uLevel.FILTER regex( ?uLevel,"Advanced", \"i\").
11  ?Importance f:importance ?ImpValue.FILTER (?ImpValue = 1 ).
12  ?LRFrag f:hasPresentationConstraints ?pConstraint.
13  ?pConstraint f:qualityNum ?pConstQNum.
```

```
14 ?LRFrag f:hasFragmentVersion ?FragVer.
15 ?FragVer dc:identifier ?FragVerId.
16 ?FragVer f:hasQuality ?Quality.
   ?Quality f:qualityNum ?QN.FILTER(?QN=IF(?pConstQNum <2,?pConstQNum, 2) ).
17 }
   ORDER BY ASC(?FragVerId);
```

In the above-mentioned SPARQL query, the lines 10 and 11 filters for fragments compulsory for "Advanced" level users. The line 17 select fragment in the right quality. It selects quality as constraint-quality, if the constraint quality is greater than Low-Quality (value=2), and Low-Quality (value=2) for the rest of fragments.

```
Output:
http://www.videoLectures.com/videoLecture1LQ.mp4
http://www.videoLectures.com/videoLecture4HQ.mp4
```

We can see that this SPARQL query gave desired output. It selected only the important fragments for advanced level user. The first fragment is selected in Low Quality – as the constraints quality was Audio but Audio was not preferred. The other compulsory fragment 4 was selected in high quality as the constraints quality was High-Quality.

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