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SLA-BASED CONTENT ADAPTATION FRAMEWORK FOR OPTIMIZING QoE AND ENERGY CONSUMPTION

Mohd Norasri Ismail, Rosziati Ibrahim, Mohd Farhan Md. Fudzee and Muhammad Hanif Jofri
Software and Multimedia Centre (SMC), Faculty of Computer Science and Information Technology, Universiti Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, Johor, Malaysia
E-Mail: norasri@uthm.edu.my

ABSTRACT

Mobile device advancement and popularity has changed the way we consumed web content. However, the heterogeneity properties of mobile devices, subscribed network as well as its users lead to mismatch problem. The content adaptation system is the most viable solution for this issue. Most previous works in ADTE adapt the MPEG-21 Digital Item Adaptation (DIA) specification. However, only few work on optimizing energy consumption as well as quality of experience as a vision in Universal Multimedia Experience (UME). This paper proposes a framework of an adaptation decision-taking engine based on Service Level Agreement (SLA) and uses MPEG-21 Digital Item Adaptation specification. The SLA mechanism is integrated in this framework to enable more flexible decision-making process in the content adaptation system. This flexibility will support optimum QoE based on device current property status.

Keywords: content adaptation, adaptation decision-taking engine, quality of experience, energy-efficient, service level agreement.

INTRODUCTION

The consumption of today's web content which includes rich media content such as video streaming and 3D games is mostly done in a variety of devices (i.e. smartphone, tablet). Due to the heterogeneous nature, these devices differ in system software (what file format can they display), screen size (how the media content appearing), as well as battery (how long the media content can be played). Another factor is the connection to the Internet: they also varied in term of bandwidth, jitter, and reliability. Furthermore, the web content is also varied (modality, format, quality and size). Even the user also has different preferences while consuming web content (Quality of Service and Quality of Experience). Therefore, content adaptation is required to fit the media content to these heterogeneity contexts.

Content adaptation is one of the recent solutions to address content and context mismatch while viewing rich web content using heterogeneous device. This technique can either adapt web content to match the capabilities of the target device or adapt the resources of the target device to match the web content. However the first technique is widely used in the sense of the more practical adapting the content rather than adapting the resources.

Early content adaptation approaches are device-centric (based on the device capabilities), to enable access to multimedia content, regardless device context (Mohan *et al*., 1999). This vision is known as Universal Multimedia Access (UMA). In this approach, only targeted device capabilities is considered in content adaptation system. Therefore, it is most likely the highest adapted content quality (QoS) for the matched targeted device is produced. However, we also need to consider the user preference factor to ensure user satisfaction while viewing the adapted content. Recent research activities in content adaptation are moving towards user-centric approach referred as Universal Multimedia Experience (UME). This approach considers user preferences as an important factor with the goal to optimize user satisfaction by providing the best match adapted version of content to user preferences (Pereira and Burnett, 2003).

Although many content adaptation approaches have been proposed recently, only few concentrating on the energy consumption issues where the ability to manage limited mobile device energy resources to support UMA/UME efficiently (Moldovan *et al*., 2012; Kennedy *et al*., 2010; Zhang *et al*., 2009, Ismail *et al*., 2013). Thus, we need a mechanism that is, on the one hand, able to satisfy and negotiate users QoE and, on the other hand, optimize mobile device energy consumption (Ismail *et al*., 2013). Moreover, a generic and extensible approach is preferred in order to eliminate changes on main mechanism whenever any new kind of adaptation or new tools are offered in the future.

This paper proposes a framework for addressing the above-mentioned challenges. The contributions of this research are as follows.

Content adaptation framework. This paper introduces a framework for content adaptation system based on MPEG-21 standard. It describes the interrelated modules and components. Then, within the framework, we present the adaptation decision-taking engine architecture. This engine considers several factors in the decision-taking process to increase user QoE satisfaction and as well as energy consumption.

Planning a multi-objectives adaptation-decision steps. The adaptation solutions is determined and executed as a mathematical model. The process started with the original required content descriptions, and ended whenever the content is adapted within user's QoE range for the given environment with minimum energy consumption. To achieve this goal, a set of adaptation operations identified after the decision-taking process is applied to the original content.

Service Level Agreement (SLA) mechanism in the ADTE. We notice that not all adaptation solutions can satisfy user's QoE and/or energy states of the user's device. Therefore, we implement the SLA mechanism to negotiate the agreeable solution, if such case happens.
We discuss the proposed framework and how MPEG-21 support content adaptation system in the next section. Then, we present the proposed architecture of the adaptation decision-taking engine architecture within the framework, followed by the service level agreement module. Then, the analysis of the proposed framework is discussed. The last section concludes the study.

MPEG-21 BASED CONTENT ADAPTATION FRAMEWORK

MPEG-21 is a multimedia standard endorsed in the ISO/IEC 21000 - Multimedia framework (MPEG-21) standard. It was defined by the Moving Picture Experts Group. The MPEG-21 standard aims to enable protected digital media access and delivery in interoperable infrastructure (Burnett *et al*., 2006). The tools defined in Part 7 of the MPEG-21 standard, which also known as the MPEG-21 Digital Item Adaptation (DIA) standards are meant for enabling content adaptation (Vetro and Timmerer, 2005). This research uses Adaptation Quality of Service (Adaptation QoS) tool, Usage Environment Description (UED) tool and Universal Constraint Description (UCD) tool.

The Adaptation QoS tool describes all possible parameters of the requested content. Optimal parameter for actual adaptation is based on these parameters. These parameters and its impact in the modules is referred as IOPins. The relationship of optimal parameter is known as modules.

The UED tool is used to describe the environment of the user. It includes device capabilities, natural surrounding, network characteristics, and user characteristics. For example, in terms of device capabilities, it describes the available codecs and display size.

The UCD tool specifies any constraints stated by the provider as well as the user. We used this tool to describe user Quality of Experience and energy states of the target device.

A mathematical model of adaptation solution can be produced using the three tools above. The adaptation solution can be decided by determining the most optimum IOPins values that are within user QoE range and do not violate the device capabilities and constraints. Finally, the actual adaptation is performed by using these IOPins values.

The proposed framework is adapted from Md Fudzee (2011). The framework is both utilizing user and device centric content adaptation, which can perform temporal and/or spatial adaptation of the video content in relation to energy efficiency. The framework's aim is to personalize media content in order to optimize QoE and device energy constraints specified by different types of users. The framework is a composed of the Adaptation Module and Service Level Agreement (SLA) Module as depicted in Figure-1.

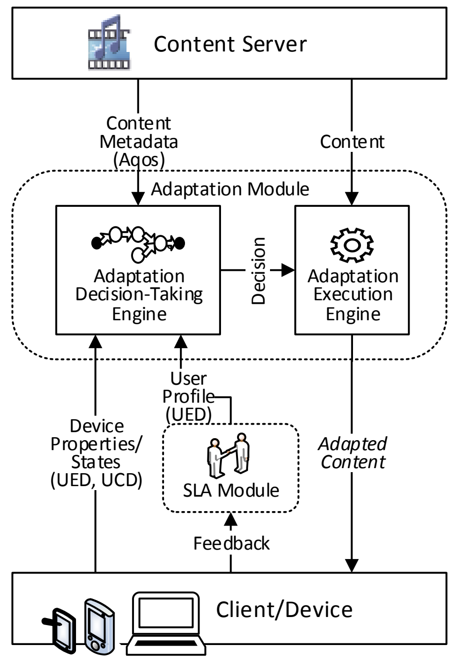

Figure-1. MPEG-21 based content adaptation framework.

Adaptation module

The role of this content adaptation system is the following: given a video and a user, it tries to provide an adapted version of the video that satisfies user and device constraints while maximizing the QoE within the available device energy. It consists of two engines: Adaptation Decision Taking Engine (ADTE) and Adaptation Execution Engine (AEE). ADTE retrieve all necessary information (content metadata, device properties, device current states and user QoE preference) and list all possible adaptation solutions. ADTE then will identify the best adaptation solution based on current constraints and capabilities. The selected adaptation solution is then sent to the AEE for execution. The AEE takes the video from the database and launches the appropriate available adaptation tools according to the chosen adaptation solutions. This framework allows any third-party adapter to be easily plugged into the system). Any transcoding tools and services can be registered at the AEE with specific functionalities. Upon receiving an adaptation task, the AEE dynamically decides the most appropriate service and redirects the task to the selected service. Finally, the result of this process is kept internally as an XML file. This enables optimizing the delivery of adapted content by reusing previous adaptation plans (Bayou, Coquil and Kosch, 2011).

The task of the ADTE is the most challenging, since the content can be adapted in different ways. The decision-taking process may encounter two or more

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optimal set of adaptation operations that could satisfy user's QoE and device constraints (i.e. energy consumption). It also plans for optimal energy-efficient adaptation strategy. The adaptation decision making process is the major focus of this study.

Service level agreement module

The SLA Module is mainly used to guarantee the user to get the required content version, delivered within the agreed QoE and availability of mobile device energy resources. The role of this module is to manage any agreement and negotiation set by the content provider and the user. This module also manages user QoE profiles (e.g., display quality preference, cost, and tolerable response time).

The negotiation process will be initiated whenever one or more constraint cannot be satisfied by the selected solution identified by ADTE. As an example, if energy left on a mobile device is 900 mW and the user requested to play a 10 minutes of adapted streaming video which requires 1000mW of energy. It is not sufficient to play the whole video as needed. Therefore, the negotiation process will be triggered. There are two mechanisms of negotiation that can be used: independent and dependent negotiation.

The process of decision making in independent negotiation is done without user intervention. The ADTE will recalculate the adaptation solution to identify the optimum solution based on the new constraint. Whereas, user intervention is needed in the dependent negotiation mechanism. We propose to use both mechanisms in our framework based on the specific situation. Let say the acceptable range of QoE stated by the user in QoE profile is 10%. If the difference of adapted content QoE is less than or equal to 10%, then the independent mechanism will be chosen. However, if it is more than 10%, then dependent mechanism will be used to negotiate QoE level.

ADAPTATION DECISION-TAKING ENGINE ARCHITECTURE

Original content is adapted based on the decision provided by ADTE. In our proposed framework, the decision is based on user QoE, device capabilities and current energy level. The proposed architecture is adapted from Kofler *et al*. (2007) depicted in Figure-2.

The metadata handling process is separated from the actual optimization process to conform with the MPEG-21 standard, which standardizes the XML content descriptions (Arnaiz *et al*., 2011; Kofler *et al*., 2007). This process is handled by Profiler. The Profiler first extract all capabilities and constraints in the form of UCD and UED. It includes the description of user QoE preferences, target device capabilities and constraints (includes current energy status), network, natural environment. These descriptions formulated as a threshold profile.

The Solution Resolver main task is to process the threshold profile and generates all possible adaptation solution set based on the stated threshold (Jofri *et al*., 2015). This step is done to ensure that the only adaptation solution that is within the stated threshold filled in the solution space. These solutions are in the form of mathematical representation consists of the IOPins and Modules (i.e. interrelationships of IOPins). We introduce the request context to represent the user's desire towards the content. Meanwhile, for mapping the constraints/resources based context (e.g. Client profile, network parameters, and user QoE preferences), utility context and accessibility context, we can easily incorporate (Lum and Lau, 2003; Hsiao *et al*., 2008; Virgilio *et al*., 2007), (Prangl *et al*., 2007) and (Yang and Shao, 2007; Yang *et al*., 2008) work, respectively.

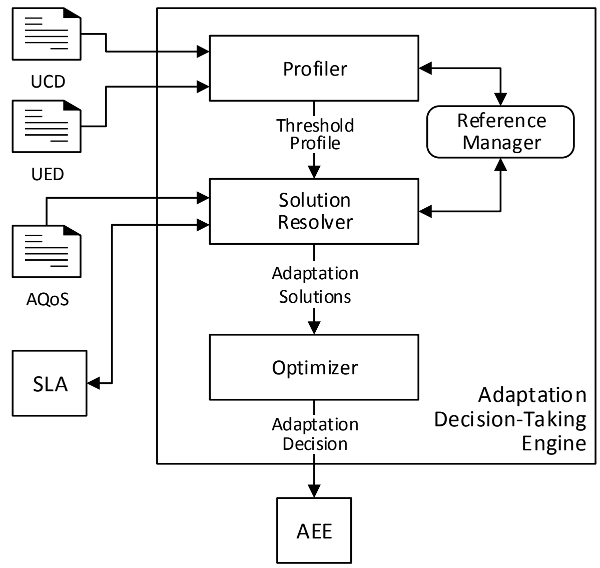

Figure-2. The ADTE architecture based on MPEG-21 DIA.

Generally, we can describe the overall semantics of related terminologies as below:

Definition 1: Adaptation Factor. These values are also known as adaptation constraint (i.e. terminal constraint, user constraint, network constraint) which is in the form of UED and UCD descriptions. It can be defined as a set of parameter for adapting particular content as follows:

$adapt_{\text{factors}} = \{factor_1, factor_2, factor_3, factor_4, \ldots, factor_n\}$

Example:

$adapt_{\text{factors}} = \{QoE_{\text{preferences}}, energy_{\text{status}}, device_{\text{profile}}, network_{\text{parameters}}\}$

Where each factor has certain attributes:

$factor_n = \{attrib_1, attrib_2, attrib_3, \ldots, attrib_n\}$

Example

$QoE_{\text{resolution}} = \{excellent\}$

$energy_{\text{status}} = \{joule\}$

$device_{\text{profile}} = \{screen\_size,\ supported\_format\}$

$network_{parameters} = \{bandwidth\}$

There are many contributing factors to measure QoE of a system. For high level factors, it includes efficiency, system usability, reliability, suitability, and content consumption experience. Apart from that, low level factors can also be considered, for instance the sharpness of the video, clarity, naturalness, readability of text, blurriness and blockiness which are much related to human perceived quality in case of video contents (Jumisko-Pyykkö *et al*., 2007).

QoE preferences are important to facilitate the user immediate desire, as illustrated in these statements (not limited to):

- "I want to play the video in high quality" because he need the details.
- "I want to view this 10 minute video for at least 5 minutes" because his phone battery almost empty.

However, to retrieve these desires is a challenging task. To measure QoE, there are many possible approaches such as using objective quality metrics and using pseudo-subjective quality metrics. It includes, the structural similarity metric (SSIM) or video quality metric (VQM) (Zinner *et al*., 2010). Then, these considered metrics values are matched to the mean opinion score (MOS) scale to measure user QoE (refer Table-1).

Table-1. Mean Opinion Score.

MOS	Quality	Impairment
5	Excellent	Imperceptible
4	Good	Perceptible but not annoying
3	Fair	Slightly annoying
2	Poor	Annoying
1	Bad	Very annoying

As such, assuming that we already captured the user's QoE desire based on previously described statements using SLA:

Condition 1: $QoE_{resolution} = \{excellent\}$
Condition 2: $QoE_{view\_time} = \{fair\}$

Definition 2: Quality Dimension. Define the set of properties for a particular media content where it forms the QoE values.

$QoE_{media} = \{parameter_1, parameter_2, \ldots, parameter_n\}$

Example:
$QoE_{video} = \{resolution, framerate, quality\}$

Definition 3: Quantization Steps (*qstep*). Each parameter in quality dimension has certain quantization steps. It defines the scale where each quantization can be represented by a certain value.

$parameter_n = \{qstep_1, qstep_2, qstep_3, \ldots qstep_n\}$.

Example
resolution = {128x96, 176x144, 256x192, 320x240, 352x288}
framerate = {15fps, 20fps, 25fps, 30fps}
quality = {28dB, 32dB, 40dB, 44dB, 48dB}

All *qstep* values will be normalized into a numerical value that ranges from 0 to 1. For instance the highest resolution value of original content is mapped to 1. The equation for mapping the i^{th} *qstep* values into numerical values is as follows:

$qsval_i = (qstep_i \,/\, qstep_{max})$

where $qstep_i$ represent the i^{th} quantization step, while $qstep_{max}$ represent the maximum quantization step within the respective dimension of quality (i.e. full scaling factor). These values, then represented as the following vector:

$qval_{parameter} = \{qsval_1, qsval_2, qsval_3, \ldots, qsval_n\}$

Example
$qval_{resolution} = \{0.12, 0.25, 0.48, 0.76, 1\}$
$qval_{framerate} = \{0.25, 0.5, 0.67, 0.83, 1\}$
$qval_{quality} = \{0.58, 0.67, 0.83, 0.91, 1\}$

Definition 4: Quantization step value (*Qsv*) is all possible combinations of quantization parameter. To derive *Qsv* we use the Cartesian Product as follow:

$Qsv = (qval_1 \times qval_2 \times qval_3 \times \ldots \times qval_n)$
$Qsv = \{(a,b,c) \mid a \in qval_1, b \in qval_2, \text{and } c \in qval_3\}$

Example
$Qsv = \{(0.12, 0.25, 0.58), (0.12, 0.25, 0.67), \ldots, (1,1,1)\}$

Definition 5: QoE threshold (*Qt*). Means the limit of acceptable user QoE preferences, which is agreed in the SLA. For every adaptation solution set, the user QoE preference threshold is assigned to each parameter. We use the nine-grade numerical quality scale (refer Table-2) which is an extension of the MOS scale to define user QoE preferences using SLA. Then we map the user QoE preferences numerical values that ranges from 0 to 1 to set the threshold (*T*) based on Table-2.

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Table-2. Nine-grade numerical quality scale (ITU-T P.910).

Grade	Quality
9	Excellent
8	
7	Good
6	
5	Fair
4	
3	Poor
2	
1	Bad

$Qt = \{T_1, T_2, \ldots, T_n\}$

Example:
$Qt = \{0.7, 0.7, 0.9\}$

From *Qt*, we define the weight of user QoE, *w* that will be assigned to each parameter. Total sum of weight must be 1. It can be expressed in the following expression for $n + 1$ parameters:

$$\sum_{j = w_n} w_j = 1$$

Example:
$w = \{0.3, 0.3, 0.4\}$

Definition 6: Solution space (*Sol*). Define the adaptation solution set that is met with *Qt*. Each possible adaptation solution is analysed. First, all *Qsv* that is met with device constraint are selected. Then, these *Qsv* is compared with *Qt*. The result can be TRUE or FALSE. It depends on the requirement of the QoE by the user. For positive monotonic QoE (e.g., quality), the *Qsv* must be equal or greater than (i.e., ≥) the stated *Qt*, whereas for negative monotonic QoE, the *Qsv* must be equal or less than (i.e., ≤) the stated *Qt*. For positive monotonic QoE, if $s_i = \{Qsv_k \geq Qt_k\}$ is met, then the selection is TRUE, vice versa. On the other hand, for negative monotonic QoE (e.g., frame rate), if $s_i = \{Qsv_k \leq Qt_k\}$ selection is TRUE, vice versa. TRUE is equal to 1 while FALSE assertion is 0. If all results of the comparison for each parameter are TRUE, then the solution set is in full-compliance. This solution set is selected into solution space. The solution set is in partial-compliance when only some parameters are satisfied while non-compliance is stated when all of the parameters are not satisfied.

Definition 7: Energy estimation (*Ee*). Means the estimated energy usage for each solution in *Sol*. In order to evaluate our model, we use another power consumption model, which is based on the assumption that power consumption is linearly proportional to the frame rate (Yu *et al*., 2014).

$Ee = \{e_1, e_2, e_3, \ldots, e_n\}$

Example:
$Ee = \{120, 220,300, 380, 420\}$

Definition 8: Modified solution space (*mSol*). Define the adaptation solution set that is met with $energy_{\text{status}}$. Each adaptation solution in *Sol* is compared with $energy_{\text{status}}$. The *Ee* for each adaptation solution must be equal or less than (i.e., ≤) the $energy_{\text{status}}$. If $s_i = \{Sol_{\text{Ee}} \leq energy_{\text{status}}\}$ selection is TRUE, vice versa. This solution set is selected into modified solution space, *mSol*.

There is possibility that the solution space is empty (i.e. no available solution meets the threshold profile). In this case, the negotiation process will be invoked. This process is done outside the ADTE by SLA mechanism. The outcome of this negotiation is either to quit the adaptation or to negotiate with lower *Qt* to proceed with the adaptation process.

Definition 9: Optimal solution (*Op*). The optimal solution is the optimal option of *mSol* that satisfies user QoE and device energy status as well as other specified UED and UCD constraints. For every solution set in *mSol*, there are weights assigned to the parameter, based on, *Qt*. The optimal solution can be identified after the weights are assigned to each of the solutions in *mSol*. The maximum value is selected as the optimal adaptation solution (*Op*). The result of this process is expressed by the following expression:

$Op = Max\,(mSol_i \times w)$

Finally, the output of this component is derived as values for the IOPins that is optimal. The output is sent to AEE as parameters for the actual adaptation process.

SERVICE LEVEL AGREEMENT

SLA is used to express commitments, expectations and restrictions in a transaction between two parties. Specifically, the main objectives of SLA in content adaptation are (a) to facilitate two-way communication between negotiating parties that include an understanding of needs, priorities, and specifications, (b) to protect against expectation creep that includes the identification and negotiation of service levels, (c) to have mutually agreed standard, and (d) to gauge service effectiveness that includes the basis for performing an assessment. In our context, it provides clients with the platform to specify their QoS/QoE requirements and ensures the QoS/QoE offered by the selected service providers are delivered accordingly. Figure-3 depicted the SLA management framework.

The SLA management framework consists of three interrelated phases: creation, monitoring and

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enforcement. Brokers and providers have the mechanism to establish SLA. A broker, on behalf of the client, negotiates SLA with service providers. These newly created SLA clearly expresses the required QoS/QoE to be maintained till the end of service execution, the required content object level to be delivered, the penalties in case of failure to provide the offered QoS/QoE and the actions of resolution in case of a conflict.

After the successful creation of SLAs, providers are tasked to perform the adaptation. These services executions are monitored using the specified monitoring apparatus to ensure offered QoS/QoE and required content adaptation are obeyed. The monitored QoS/QoE levels are compared with SLA created. If the SLA for the service is being delivered accordingly, the SLA is in compliance; otherwise the SLA is in non-compliance form. When a non-compliance case detected, the enforcement phase is invoked.

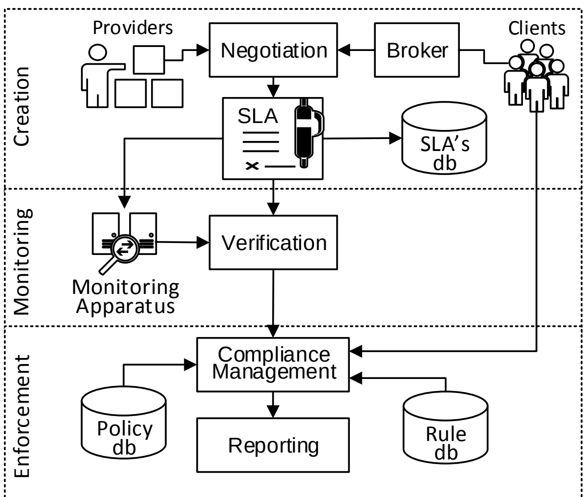

Figure-3. SLA management framework for content adaptation (Fudzee and Abawajy, 2012).

In the enforcement phase, a specific decision-making mechanism is used to decide whether a non-compliance case is a direct violation, a conflict or a result from bypassing conditions. Based on the determined result, it enforces the necessary action and to provide a real-time compliance reporting to clients. In case of any violation or any conflict, the enforcement mechanism is activated to penalize the provider or to resolve the conflict, respectively. The broker sends a real time report to the client for each service consumed including the compliance status.

In order to pass and adapt the content between service proxies, a mechanism to connect and manage the proxies (both the broker and service) is required. In the following section, we will elaborate on how this is achieved.

DISCUSSIONS

In this section, we will evaluate the framework using available standard video sequence and the discuss the analysis of the framework.

Framework evaluation

To prove the performance of the proposed framework, we use the JSVM 15.1 encoder (Reichel *et al*., 2007) to generate scalable bitstreams. Video sequence, ‘akiyo’ from the standard video database, is chosen for the test. The videos are originally at CIF (352×288) spatial resolution with a frame rate of 30fps, and each sequence is 8-second long (240 frames). One bitstream is generated with five temporal layers, and each temporal layer in turn has five quality layers created using the coarse grain scalability with quality values equals to 41dB, 44dB, 45dBb, 47dB and 48dB, respectively. The GOP size is 16 frames in all cases. In our case, we have 4 frame rate (15, 20, 25 and 30 fps) and 5 quantization step (16, 25, 40, 64 and 102).

For our test, we consider the following Quality Dimension of ‘akiyo’ sequence:

QoE_{video} = {*resolution, framerate, quality*}

The qstep for each above parameter can be considered as follows:

resolution = {128x96, 176x144, 256x192, 320x240, 352x288}
framerate = {15fps, 20fps, 25fps, 30fps}
quality = { 28dB, 32dB, 40dB, 44dB, 48dB}

Then we normalize each *qstep* values into a numerical value that ranges from 0 to 1:

$qval_{\text{resolution}}$ = {0.12, 0.25, 0.48, 0.76, 1}
$qval_{\text{framerate}}$ = {0.25, 0.5, 0.67, 0.83, 1}
$qval_{\text{quality}}$ = {0.58, 0.67, 0.83, 0.91, 1}

From the *qstep* values, we can generate a total of 80 possible combinations of quantization parameter or possible adaptation solution, *Qsv*.

Qsv = {(0.12, 0.25, 0.58), (0.12, 0.25, 0.67),…, (1,1,1)}

The more possible combination will enable more accurate adaptation decision with targeted terminal and environment conditions.

For this test, we consider this scenario; a user wishes to play the ‘akiyo’ sequence at high quality. The users also need the resolution of the sequence as big as possible. However, the user considers frame rate as not important. From the stated requirement, he set its QoE preferences using SLA as *User Preference A*. Let’s consider his mobile device battery is nearly depleted and he only has 600mW left. Using the Nine-grade numerical quality scale, we can set the *Qt* for *User Preferences A* as follows:

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Qt = {0.9, 0.7, 0.9}

Therefore, the value of *w* is:

w= {0.36, 0.28, 0.36}

After analysing each of the possible solutions, there are only 4 solution set that is met with *Qt*:

Sol = {(1, 0.83, 0.91), (1, 0.83, 1), (1, 1, 0.91), (1, 1, 1)}

The next step is to identify estimated energy usage, *Ee* for each solution in *Sol* and define it as *mSol*. Table-3 shows the results of the adaptation solution in *mSol* of 'Akiyo' sequence using our proposed framework. We only consider energy constraint on this test for simplicity and clarity. For real world situation there are many constraints can be considered using our proposed framework.

Table-3. ADTE result of Akiyo sequence.

Solution No.	Resolution	Frame Rate	Quality	Energy Estimation	Score
User preference A: *Qt* = {0.9, 0.7, 0.9}					
1	1	0.83	0.91	600	0.95
2	1	0.83	1	650	0.95
6	1	1	0.91	600	0.97
User preference B: *Qt* = {0.7, 0.7, 0.9}					
1	0.76	0.83	0.92	600	0.84
2	0.76	0.83	1	650	0.88
6	0.76	1	0.92	600	0.89
7	0.76	1	1	650	0.93
21	1	0.83	0.92	600	0.92
22	1	0.83	1	650	0.95
26	1	1	0.92	600	0.97

From Table-3, we can identity that the most optimal solution for *User preference A* with energy constraint of 600mW chosen by this framework is Solution No. 6. Although the highest quality value is Solution No. 2, the estimated energy consumption is not met with energy constraint.

Let consider another scenario; if a user prefers to view the same video sequence with high quality, but for him resolution and frame rate are not important (*User preference B*) with energy constraint of 650mW. The solution chosen will be Solution No. 22. Although Solution No. 26 have the higher score, Solution No. 22 have higher quality value.

We can make a conclusion from the result of the test, that adaptation decision-taking for optimizing QoE and energy consumption can be made using the proposed framework.

Analysis of framework

In this section, we justify the strength of our proposed design in terms of reliability, scalability, extensibility, simplicity and portability.

In the application architecture perspective, reliability is viewed as the degree to which the architecture is susceptible to failure at the system level in the presence of partial failures within components, connectors, or data (Fielding, 2000). As such, this approach improves reliability by enabling negotiation process between the user and service provider when a certain objective cannot achieve.

In addition to scalability, extensibility is also important. Extensibility is defined as the ability to add functionality to a system (Pountain and Szyperski, 1994). In our design, extensibility is induced by allowing new services to be listed in the adaptation registry dynamically, without restructuring the architecture. New adaptation engine or data types can be facilitated as long as it is introduced.

In our design, simplicity of the architecture is also considered. We refer simplicity as simplifying the functionality of each component in the architectural design. We induce simplicity by applying principle of separation of concerns to the allocation of functionality within components (Fielding, 2000). As such, each main component is separated into independent modules (e.g., ADTE, AEE, SLA). Moreover, each service provider can externally facilitate a particular adaptation task, thus enabling delegation of tasks. Web Services provide specific services, offer better adaptation services and becoming intelligent (Malik and Bouguettaya, 2009).

Finally, we discuss the strength of the architecture in term of portability. Software is portable if it can run in different environments (Ghezzi *et al*., 1991). As such, we induce portability by the mean of platform neutral and providing message-oriented interface for public interaction. The use of MPEG-21 standard also contributes the portability of this architecture as it promotes standard descriptions using XML.

CONCLUSIONS

This study builds on and contributes to work on content adaptation, as it is becoming important in the emerging mobile and pervasive computing. In this paper, we present a content adaptation framework for optimizing Quality of Experience and energy consumption as well as different network environment and user devices in an interoperable and efficient way. This framework uses the MPEG-21 standard to ensure interoperable solution. The components of the proposed framework were discussed accordingly. The proposed ADTE will enhance decision-making process by considering user satisfaction in term of Quality of Experience as well as device energy consumption. The decision-making process also supported by the SLA mechanism to ensure agreeable decision thus increase satisfaction. The SLA is needed in the adaptation decision-taking process because there is a possibility that no adaptation solution that can meet with user QoE

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preferences and/or sufficient available energy to view the content. Therefore the system may negotiate with the user to proceed with content adaptation. Future works of this research are to develop and implement the proposed ADTE and the SLA to appropriately experiment the outcome of the framework. We will also conduct a subjective assessment of this framework to further improve the QoE requirements in the ADTE. Another future work is to accurately measure energy usage estimation of the content as well as measuring energy availability estimation of the target device.

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