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CONTENT ADAPTATION ON MOBILE DEVICES USING MPEG-21

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Content authors pursue the creation of mobile content that is ubiquitous in nature, i.e. published once only but being available anywhere, anytime, on any device. However, mobile content must accommodate varying resource constraints on different devices such as reduced resolution, processing power, memory and network bandwidth. In this chapter, we discuss those issues that are pertinent to multimedia content adaptation across different devices with reference to MPEG-21's Digital Item Adaptation for mobile devices. In particular, we consider how the range of aspects that affect a mobile usage environment, i.e. network, natural environment, device and user characteristics, could be used alongside a set of user-defined limitation and optimization constraints, to adapt content and thereby maximize quality of service.

Key words: MPEG-21, Content Adaptation, Adaptation Quality of Service, Mobile Devices
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1 Introduction

Whilst an emergent variety of pervasive terminals is gaining access to the Internet and other information resources, much of the rich multimedia content cannot be easily handled by the client devices with limited communication, processing, storage and display capabilities. Therefore, in order to improve content access, it is necessary to redesign the systems (i.e. content systems, proxy, QoS systems etc) to be able to utilize content adaptation mechanisms.

Content adaptation is one of the last phases in the multimedia delivery process and it aims to make the content accessible by anyone (Universal Multimedia Access). To achieve that, it is necessary to take into account various factors such as the terminal capabilities, network, user and natural environment characteristics since all these characteristics define different quality of service, bit rate, computing and presentation capabilities. Additionally, different users implies different preferences in terms of content type, quality etc. and different usage history [1][2]. Thus, the same content would be of different value to different end-users who may use different devices to access the same or different network infrastructures, access the content from different locations and at different times, and for diverse purposes.

The content type defines the possible set of adaptation operations. For instance, while video adaptation includes operations such as *transcoding*, *video summarization*, *replacement*, *synthesis* etc. [3], for audio the operations include *channel-dropping* and *scalable-audio* etc. [4]. Using each one of these operations, a content unit will provide different results which will most certainly yield a different level of satisfaction for each user based on his/her preferences and his/her current activities or location. However, the objective is usually not so simple since the result has to be optimized against various optimization constraints and has to satisfy various limit constraints; usually most of these are specified by the network infrastructure, device characteristics and the end-user preferences. Therefore, the selection of either a single or a combination of operations assumes a set of algorithms for (i) determining the best set of adaptation operations and the value of their input parameters (AO-Set), and (ii) adapting the actual content unit by applying the chosen AO-Set.

2 Video Adaptation Operations

There has been a wide variety of video adaptation operation approaches, such as transcoding, video summarization, selection/reduction, replacement and synthesis adaptation. *Transcoding* is the process of converting media content from one format to another. This operation can be applied using re-encoding, requantization, FD, CD, temporal condensation, resolution reduction (reduce bit-rate and spatio-temporal resolution) mechanisms. However, these mechanisms may not be feasible sometimes because of the computational complexity and the resulting quality reduction. *Video summarization* provides an abstract of a video for shortening both the navigation and browsing of the original video. There are two basic types of video summarization (i) the static video abstract, in which a collection of salient images or key-frames are extracted from the original video sequence and (ii) the dynamic video skimming which collects a number of associated audio-video sub-clips from a video sequence, but with much shortened length. *Selection/Reduction* is a video adaptation operation, also considered a form of transcoding and summarization, which selects and reduces some elements in a video entity like shots and frames in a video clip, pixels in an image frame, etc. Another approach is that of a *Replacement* operation that replaces selected elements in a video entity with less expensive counterparts. *Synthesis adaptation* provides a new content based on content analysis results and scalability and it operates by assuming that certain subsets of the total coded bit stream can still provide a useful representation of the original data if decoded separately.

Determining the appropriate adaptation operations needs searching huge spaces for optimal solutions, and considering each end-user's QoS individually. Also content adaptation involves a series of processes, such as selection of either a single or a combination of adaptation operations and population of their parametric values. Besides, the possible combinations of such operations are enormous since each combination will need to be optimized in consideration of the network and device characteristics. Each AO-Set will most certainly yield a different level of satisfaction for each user.

For selecting and utilizing the AO-Set, the process needs also to be capable of analyzing the content. Video analysis is mainly classified to semantic video analysis, structural video analysis, hybrid video analysis. *Semantic video analysis* defines that, shots, frames, video segments which have different value to different users can be modeled in MPEG-7 by content providers, authors or through dynamic content analysis. With the application of video analysis and consideration of user preferences each video can be evaluated separately for each user and score values provided for different shots, frames and segments. Thus, the results of video semantic analysis can define the type of adaptation needed. *Structural video analysis* is another method for video analysis, which provides information about the structure elements of the video rather than the semantic elements. Hence, the scores would be on the video structure. Another method to use is code representation without video analysis, for example, decoding from one format to another without any content or video analysis. Combination of all of the above can provide different level of adaptations.

The following section discusses how the MPEG-21 standard accommodates the above requirements and provides a dynamic content adaptation framework.

3 MPEG-21

In order to model, filter and personalize multimedia units across the network infrastructure for use by different users, the MPEG group introduced the MPEG-7 and MPEG-21 open standards. The MPEG-7 Multimedia Description Scheme (MDS) provides the necessary tools for building multimedia content models. MPEG-7 concentrates on the description of multimedia content and enables quick and efficient searching, identification, processing and filtering of multimedia material [5] [6]. The MPEG-7 standard provides a huge amount of audio-visual descriptions in order to cover aspects such as content based searching/filtering and access to multimedia content. These descriptions are based on catalogue (e.g., title, creator, rights), semantic (e.g., who, what, when, where about information on objects and events) and structural (e.g., image colour histogram) features of the AV content and leverages on AV data representation defined by MPEG-1, 2 and 4. MPEG-7 uses XML Schema as the language of choice for content description [7].

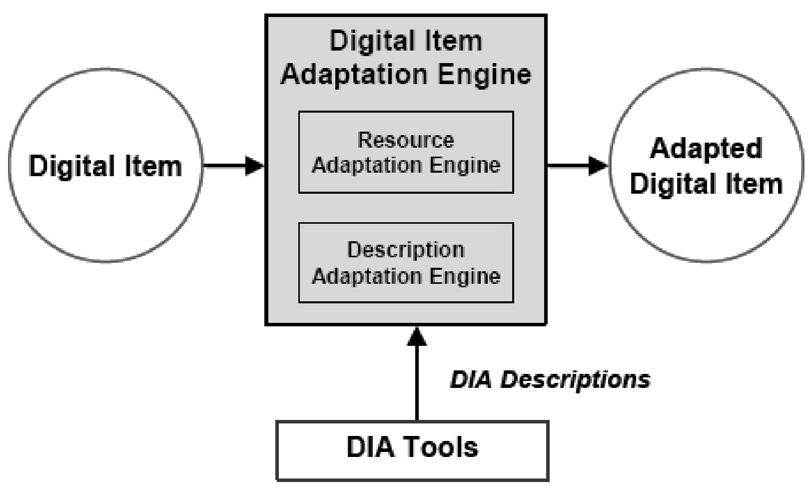

Figure 1: Concept of Digital Item Adaptation

On the other hand, MPEG-21 provides a number of tools, which enable the use of multimedia resources across a wide range of networks and devices [1]. A Digital Item is a structured digital object with a standard representation, identification, and associated metadata within the MPEG-21 framework

[8]. This entity is the fundamental unit of distribution and transaction within this framework [9]. One of the goals of MPEG-21 is to achieve interoperable transparent access to (distributed) advanced multimedia content by shielding users from network and terminal installation, management, and implementation issues. To achieve this goal requires the adaptation of Digital Items [2]. MPEG-21 part 7 describes various tools pertinent to the Digital Item Adaptation. A Digital Item is subject to a resource adaptation engine, as well as a description adaptation engine, which together produce the adapted Digital Item (figure 1).

The standard specifies only the tools that assist with the adaptation process (figure 2), not the adaptation engines themselves. These tools are clustered into three major categories (i) Usage Environment Description, (ii) Digital Item Resource Adaptation and (iii) Digital Item Declaration Adaptation Tools.

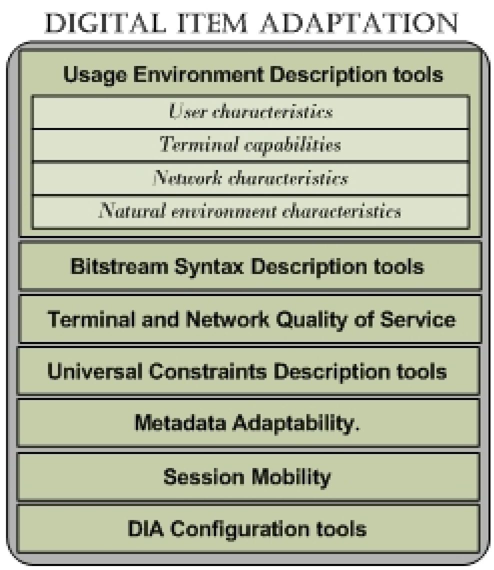

Figure 2: Digital Item Adaptation Tools

The usage environment description tools describe the terminal capabilities, user network and natural environment characteristics. Terminal capabilities are further subdivided to codec (encoding and decoding capabilities), device properties, which include power, storage and data I/O characteristics, and input-output characteristics, which include display and audio output capabilities. Terminal capabilities may be considered when determining the kind of adaptation of the digital item; for instance, transmission of a news clip at a full frame rate for a long period of time to a mobile device with low battery capacity may be ineligible. However, content summarization could satisfy both mobile device constraints and user preferences. On the other hand, user characteristics specify tools describing user characteristics related to user information, usage preferences such as audiovisual content and presentation preferences, accessibility, mobility, usage history and user's preferences related to multimedia segments etc. Network characteristics specify tools in terms of network capabilities and conditions, including utilization, delay and error characteristics. Finally natural environment describe the real natural environment by providing information about the audiovisual environment (noise level and noise frequency spectrum), location, time etc [10]. These various usage environment properties can be used for Digital Item Adaptation.

Digital item Resource Adaptation tools consist of the Bitstream Syntax Description [11] [12], Terminal and Network QoS and Metadata Adaptability tools. Terminal and Network QoS addresses the problem of media resource adaptation to constraints imposed by terminals and/or networks for QoS management. Terminal and Network QoS (Adaptation AQoS) is described in greater detail in the next section. Finally, Digital Item Declaration Adaptation Tools consists of the session mobility and the DIA configuration tools. In DIA, session mobility refers to the transfer of configuration - state information that pertains to the consumption of a Digital Item on one device to a second device [13]. This enables the Digital Item to be consumed on the second device in an adapted way. During this transfer, application-state information, which pertains to information specific to the application currently rendering the Digital Item, can also be transferred.

Terminal and network quality of service aims to assist in maximizing the quality of service by selecting the optimal adaptation parameters. Thus, the AdaptationQoS tool describes the relationship between Quality of Service constraints (e.g., on network bandwidth or a terminal’s computational capabilities), possible adaptation operations that may satisfy these constraints, and associated media resource qualities that result from adaptation. This set of tools [1] provides the means to trade-off these parameters with respect to quality so that an adaptation strategy can be formulated and optimal adaptation decisions can be made in constrained environments. The AQoS tool has been designed in a modular way, and therefore an instance of AQoS can be constructed using a number of interconnected modules of *UtilityFunction*, *LookUpTable* or *StackFunction* (table 1).

Table 1: AQoS Module Types

UtilityFunction	Distribution of three key factors involved in media resource adaptation: • constraint (e.g., bandwidth, power, display resolution) • adaptation operation (e.g., frame dropping, spatial size reduction) • utility (e.g., objective or subjective quality, such as PSNR, Distortion Index (DI))
LookUpTable	Matrix representation of data and their relationship (axes and content). Although it is written as a MxN matrix it can represents multidimensional matrixes, in which elements might be strings, integers, floats and/or Booleans.
StackFunction	Mathematical relationships between the variables (IOPins). An expression is written as a sequence of stack operations and arguments.

While the above modules operate differently, a generic interface to all instances is provided through Input/Output Pins (IOPins). Each IOPin is a uniquely identifiable variable globally declared and referenced from within a module. The example of table 2 demonstrates a *utilityFunction* having as constraint the bandwidth and as adaptation operation the media color (IS_COLOR) and resolution (SCALE). The two adaptation operations define a adaptation domain space for the entire video clip. Therefore, a desirable video adaptation solution will be the one, which satisfies the limitation constraints and optimizes the optimization constraints.

Table 2: AQoS Example – Exemplifying the *utilityfunction*


```
  <DIA>
  <Description xsi:type="AdaptationQoSType">
  <Module xsi:type="UtilityFunctionType">
   <Constraint iOPinRef="BANDWIDTH">
    <Values xsi:type="IntegerVectorType">
     <Vector>1510 1359 1200 1071 1000 842 744 600</Vector>
    </Values>
   </Constraint>
  <AdaptationOperator iOPinRef="IS_COLOR">
  <Values xsi:type="IntegerVectorType">
  <Vector>1 0 1 0 1 0 1 0</Vector>
  </Values>
  </AdaptationOperator>
  <AdaptationOperator iOPinRef="SCALE">
  <Values xsi:type="IntegerVectorType">
  <Vector>4 4 3 3 2 2 1 1</Vector>
  </Values>
  </AdaptationOperator>
  <Utility iOPinRef="PSNR">
  <Values xsi:type="FloatVectorType">
  <Vector>34.47 32.48 31.58 28.62  27.53 26.49 23.44 23.36</Vector>
  </Values>
  </Utility>
  </Module>
  <!- .... Definition of Modules -->
  </Description>
</DIA>
```


The Universal Constraint Description tool (UCD) describes limitation constraints and optimization objectives on the AQoS parts that affect the adaptation decisions (e.g. on an adaptation operation, on a quality, or constraint). This tool is indented to be used by a consumer or a provider so as to specify their specific constraints and objectives for each digital item during the adaptation [14]. The UCD can make reference to user environment description data, AQoS data and video metadata.

The collection, preparation, delivery and consumption chain of content (or digital item) is very long and ambiguous process that begins with the author and usually ends up with the user. A number of actors are involved in the process such as the author, the publisher, the content provider, the content consumer. In addition, many factors and parameters affect that chain, such as the network environment, natural environment, device and user. Whatever device is used (e.g. a normal PC, a mobile phone, a pocket pc, a handheld device, etc) the content must be able to plug-and-play on that device. Therefore, the specific device characteristics must be collected for tuning the content according to these.

4 MPEG-21 Adaptation architectures and Mobile Applications

Each content adaptation architecture proposed until now uses selectively some of the MPEG-21 tools, since the standard does not imply which tools must be used, how or when during the adaptation cycle. Thus, it allows algorithmic diversity in order to implement pioneering architectures. Based on what tools are used and how they are used, different designs of adaptation architectures are possible. For instance, content adaptation architectures can be implemented at various network locations (i) at user devices as client content adaptation architectures, (ii) at intermediate nodes of network infrastructure, such as router and proxy servers and (iii) at content provision systems as server adaptation architectures. Several distinguished characteristics of video adaptation processing, allow also the classification of video adaptation architectures as (i) real-time/on-the-fly architectures (adapting streamed content at minimum latency), (ii) non-real time/on-the-fly (adapting stored content at minimum latency) and (iii) non-real time/offline (adapting stored content)[15].

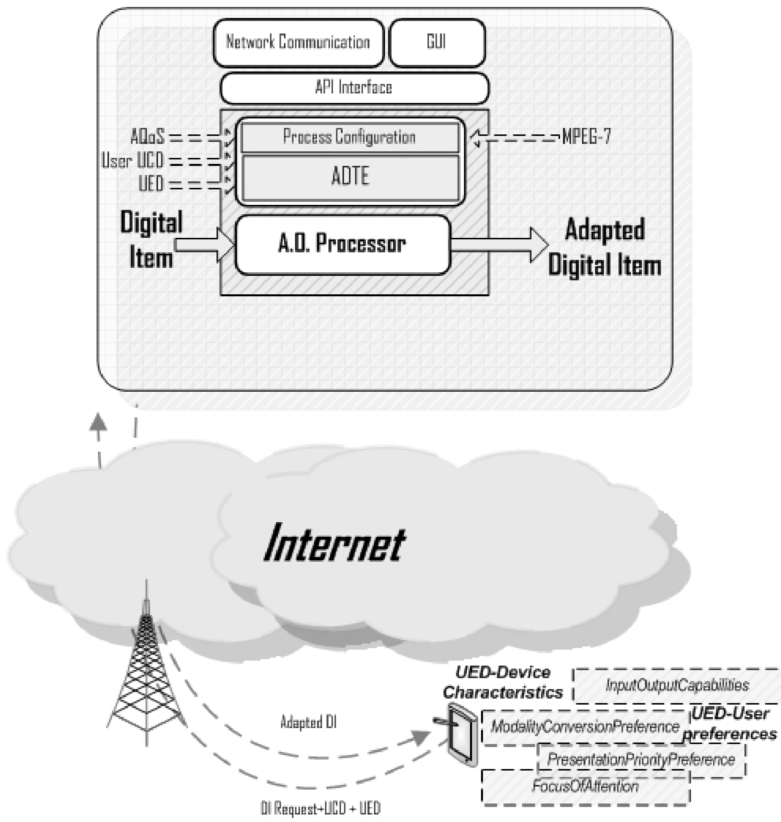

Figure 3: MPEG-21 adaptation architecture with network communication module and Adaptation operation processor

Modern adaptation architectures encounter unpredictable environments mainly due to user mobility and varying resource availability. To adapt, systems must identify the need for a change, decide on the change and implement it in a timely manner. For instance in the case of streaming media, adaptation can take place in the application layer by increasing the compression, decreasing image size or transcoding the stream to mono. At the middleware layer, the server source for the stream could be changed or frame filtering could be introduced into the path. The adaptation process repeats a cycle of estimating, deciding and acting with the use of observation variables, which capture relevant aspects of the system status. Figure 3 is an extension of the basic DIA Engine of figure 1. The network communication of the adaptation architecture is handled by a network communication module. An adaptation operation processor will apply an adaptation description solution to the original Digital item so as to transform it to the adapted digital item. The adaptation decision taking engine (ADTE) provides the adaptation description solution based on a set of input data, such as the AQoS instance, the UCD and UED of the user, the MPEG-7 instance that describes the movie etc. The solution, yielding the decision, can then be computed by a universal process independent of what the variables represent. The MPEG-21 framework allows the ADTE to be implemented with several designs taking into account the different sequential logical segments as adaptation units (frame, shot scene etc). A multidimensional space which represents all possible adaptation solutions has to be searched and each solution must be validated against the constraints (including those set by the user) and for its optimality. The best solution will be applied to the original Digital item in order to adapt it. The final result will depend much more on individually-weighted variables that constitute possible solutions-operations. Therefore, the initial weight assignment will influence the final solution. A problem that arises is how to normalize, prioritize and also weigh variables which can only be assigned by the end user.

Usually, video adaptation problems require identification of video content entity and the spaces of ARU. In [16] as in [3] as well, the authors used the term “adaptation operation, resource and utility (ARU) spaces” in order to emphasize the multidimensional constrained problem during the adaptation process. To be more precise, given a particular content unit, adaptation operation space relates to the existence of many adaptation methods that can be applied, such as transcoding, summarization, etc. Furthermore, resource space is defined by the multiplicity of the device and network characteristics related with the content delivery and consumption, such as bandwidth, device computational capabilities, display dimensions, etc. The utility space is quite nearer to the quality of service concept, as it is measuring in its multiple dimension space the user’s likings and preferences. Therefore, a point at adaptation space (e.g. marked by a defined adaptation operation such as transcoding) is associated with specific resources and utility values which are represented by corresponding points in the resource space and the utility space respectively. Although the above seem to formulate a complete framework for dynamic adaptation, however, during dynamic adaptation, the main problem lies with the fact that the utility value can not be easily measured. Therefore, for a given resource-constrained utility maximization optimization problem, the result of the adapted content can not be easily evaluated without the human factor. In addition, during the searching for the appropriate adaptation operation and its parameters, it is very difficult to know the result of each selection without exercising it at that point of time.

MPEG-21 defines the structure of digital item which can be consumed by client devices with the appropriate digital rights. Thus, various functionalities must be implemented by client devices. Mobile client applications that will support full MPEG-21 DIA processing and consumption must at least support (i) digital item retrieving via wireless channels such as GPRS, (ii) digital Item browsing, (iii) presentation of DI sub-items and (iv) IPMP DIDL protected Digital Item processing[17] [18] [19]. To provide maximum portability across devices of varying specifications and to facilitate extensibility, these mobile applications need to be modular and decoupled [20]. On the other hand, users need to define their preferences and characteristics such as content and presentation preferences (figure 4a), or their likings for the modalities and genres (figure 4b).

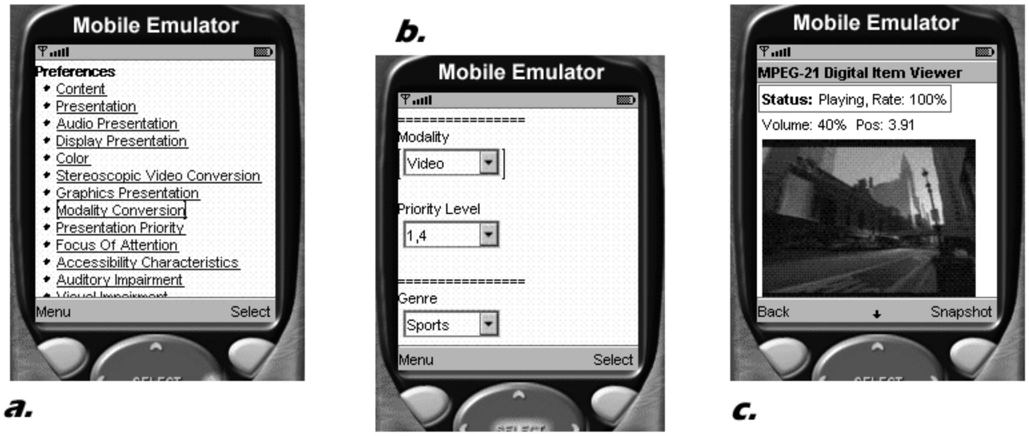

Figure 4: (a) MPEG-21 User Preferences. (b) Modality Priority (c) MPEG-21 Digital Item Viewer

The mobile client software (e.g. interactive browser) must be able to send the usage environment characteristics (UED) to the MPEG-21 content adaptation architecture. The browser should comprise of various components so as to enhance the optimization of the content adaptation process, since during communication with the middleware it will need to automatically provide information about the mobile device and network characteristics. It will also need to identify the user, and load user preferences during initialization. Furthermore, a user should be able to update his/her preferences at any time. User characteristics include general user information, content preferences, presentation preferences, accessibility characteristics, mobility characteristics and destination. While some of these have to be inserted manually (since most preferences can only be extracted from the user), some other can be determined and inserted automatically by the client software (e.g. user location).

A user profile consisting of user characteristics and preferences guides the content adaptation. When a person uses a different mobile device or terminal, his/her preferences may not change. That kind of action requires making a user's profile portable, which implies either a number of algorithms for moving intelligently the profile each time a user changes a device or storing each user profile centrally online. In addition, with regards to customizing preferences for each device, there will be few differences to opting for a fresh specification. The user profile may be saved in repositories [21] or in databases [22].

The following table shows a sample priority preference set for general resources, where a user wishes to have high video QoS by assigning a *priorityLevel* of 1.5 to video resources. The user is also interested in Sports and gives a *priorityLevel* of 1.6 to this genre. So, the resources of video modality and Sports genre, especially the Sport videos, should have better qualities after adaptation. Note that the user already knows the default *priorityLevel* of resources is 1.0. However, the same user would specify different weight values under different circumstances e.g. when he is in his/her car and he wants the content in less elapsed time. The *priorityLevel* is defined within user characteristics and is filled manually by a user. Conversion preferences allow a user to specify the relative order of each conversion of an original modality and the numeric weight of each conversion. The weights of conversions may help the selection process to determine when conversion should be made.

Table 3: MPEG-21 Presentation Priority ***[1]***

```xml
<DIA>
<Description xsi:type="UsageEnvironmentType">
<UsageEnvironment xsi:type="UserCharacteristicsType">
<UserCharacteristics xsi:type="PresentationPreferencesType">
<PresentationPriority>
<GeneralResourcePriorities>
<ModalityPriorities>
<Modality priorityLevel="1.5" href="urn:mpeg:mpeg21:2003:01-DIA-ModalityCS-NS:1">
<mpeg7:Name>Video</mpeg7:Name>
</Modality>
</ModalityPriorities>
<GenrePriorities>
<Genre priorityLevel="1.6"
href="urn:mpeg:mpeg7:cs:GenreCS:2001:1.6">
<mpeg7:Name>Sports</mpeg7:Name>
</Genre>
</GenrePriorities>
</GeneralResourcePriorities>
</PresentationPriority>
</UserCharacteristics>
</UsageEnvironment>
</Description>
</DIA>
```

Finding an optimal operation means finding one that will provide the best QoS for a user given their preferences and characteristics. The goal of content adaptation is to maximize a set of optimization constraints given by various actors while satisfying various limit constrains. Digital item quality could be guaranteed to the user based on any criteria, including distortion quality measures. A user may use the mobile interactive browser for evaluating the adapted content.

Measuring video quality or image quality is a complex process, even with the aid of human factor, since quality has not been defined effectively for dynamic environments. Approaches for quality evaluation are using the objective quality, which requires a number of computing algorithms, or the subjective quality, which requires manual effort [23]. UCD allows the specification of quality threshold (as a constraint) under which it is declared that no acceptable experience can be provided. However, an optimization constraint in the same description could request that providers shall always try to deliver the best possible experience [24]. The next section discusses the subjective and objective quality video metrics.

5 Subjective and Objective Quality Measurements

Quality is an essential factor for evaluating, specifying and comparing video communication processes. However, measuring video quality and specifically measuring image quality is difficult due to the many factors that affect the results. While a number of strategies for coding images and videos have been deployed recently during “lossless” and “lossy” coding, quality has not been addressed adequately [25].

Subjective quality measurement is related with a number of complex entities of the human visual system such as brain and eyes. Although, the opinion of visual quality is influenced by human visual system factors and how clearly parts of the scene can be seen and whether motion appears natural and 'smooth', a viewer's opinion of 'quality' is also affected by other factors such as the viewing environment, the observer's state of mind and the extent to which the observer interacts with the visual scene. In addition, a user carrying out a specific job that requires attention on part of a visual scene will have quite different needs for 'good' quality than a user who is passively watching a movie[23].

Another way for measuring the quality of video relies heavily on the so-called objective quality measures (algorithmic approach). For image quality, SNR and PSNR metrics are used. Signal-to-noise (SNR) measures are estimates of the quality of a reconstructed image compared with an original image. The basic idea is to compute a single number that reflects the quality of the reconstructed image. The actual metric used to compute the quality is the peak signal-to-reconstructed image measure called PSNR.

6 Conclusions

While the growth of the technology in the area of communication infrastructure has enabled access from almost anywhere and anytime, multimedia content keeps increasing at an exponential rate. Moreover, mobile content must accommodate varying resource constraints on different devices such as reduced resolution, processing power, memory and network bandwidth. Adaptation operations vary and can be mainly classified based on which content type can be applied and the end results. Additionally, each adaptation operation can be initialized and applied with various input arguments making the adaptation domain a huge search space. MPEG-21 mobile client applications must allow a user to define his/her preferences and at the same time include mechanisms for retrieving and sending device and network information to the adaptation systems. These systems must be able to take into account the user preferences, device and network constrains. The paper elucidates how a range of elements, retrieved by the existing mobile usage environment (i.e. network, natural environment, device and user characteristics) formulate, along with a set of user defined limitation and optimization constraints, an adaptation framework requiring strategies for selecting and applying a solution so as to maximize the quality of service. It is very essential to note that the MPEG-21 framework is still under development. MPEG-21 provides only the schema tools for describing the digital items, the environment, the end user's devices and the network. In addition it provides tools and mechanisms for allowing the digital item adaptation, storage, processing and interaction of digital items. Therefore, research practitioners can deploy their own innovative architectures and designs.

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