Context-aware content adaptation: a systems approach

M.T. Andrade
INESC Porto
R. Roberto Frias 378
4200-465 Porto
Portugal
+351 22 2094000
mandrade@inescporto.pt

P.Bretillon
Telediffusion de France
1, Rue Marconi
F-57078 Metz cedex 03
France
+33 3 87207686
pierre.bretillon@tdf.fr

H. Castro
INESC Porto
R. Roberto Frias 378
4200-465 Porto
Portugal
+351 22 2094000
hcastro@inescporto.pt

P. Carvalho
INESC Porto
R. Roberto Frias 378
4200-465 Porto
Portugal
+351 22 2094000
pmc@inescporto.pt

B. Feiten
Deutsche Telekom
Goslarer Ufer 35
10589 Berlin
Germany
+4930 3497 2528
b.feiten@t-systems.com

ABSTRACT

The use of context information is fundamental for the implementation of useful and efficient content adaptation operations. These in turn are instrumental to enable the universal access to multimedia content, meeting usage environment constraints imposed by terminals and networks. From a systems' perspective, delivering content to heterogeneous clients through diverse networks and environments, requires the provision of the structural support to process context- and content-related metadata and subsequently perform content adaptation operations. In addition it is essential to effectively enable the interoperation of diverse terminals and of all entities participating in the multimedia content delivery service. In this paper we present the approach taken in the IST ENTHRONE project through its Integrated Management Supervisor system.

Categories and Subject Descriptors

H.3.4 [**Systems and software**]: *Current awareness systems (selective dissemination of information); Distributed systems; Question-answering (fact retrieval) systems; User profiles and alert services*

General Terms

Experimentation, Standardization, Verification

Keywords

Context awareness, content adaptation, heterogeneous networks, MPEG -21, Quality of Service (QoS), universal access

1. INTRODUCTION

To perform meaningful content adaptation operations that best serve the needs of end-users and applications, it is necessary to know the characteristics and capabilities of the complete context of usage including possible adaptation operations that can be performed upon the content.

While it is true that the current diversity of multimedia-enabled devices, of network connectivity and of compression-efficient encoding formats, greatly contributes to the universal access to content, it also imposes new challenges to the content/service provider who is faced with increased and personalized demand and increased competition. One way to address these challenges is to build content delivery systems that are able to adapt the content to match particular context characteristics or constraints. Figure 1 illustrates the present scenario of heterogeneity highlighting the role of content adaptation towards convergence.

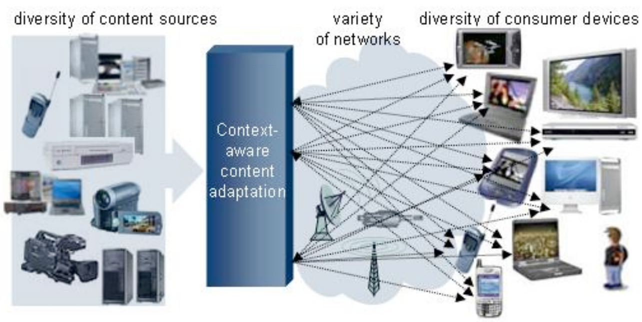

Figure 1 - converging within an heterogeneous world

This paper describes the solution implemented within the European project ENTHRONE[1] to enable multimedia services that transparently adapt to networks' conditions, terminals capabilities and user preferences. This is made possible through the use of a common framework, the MPEG-21 standard, to express and convey all the required metadata and of an architectural support implemented as a modular and distributed system, the ENTHRONE Integrated Management supervisor (EIMS). The EIMS is able to interoperate with multiple devices and applications, interpret and process this metadata, accordingly initiate a set of operations to adapt the content to context constraints and finally request the establishment of appropriate QoS-enabled network paths.

The rest of the paper is organized as follows. Section II presents the background and related work. Section III discusses the requirements in terms of metadata and describes the framework for establishing the relationship between quality, adaptation operations and constraints imposed by the usage environment. An overview of EIMS is outlined in Section IV. The systems' support for quality-based content adaptation decision is detailed in section V. Section VI presents some experimental results. Finally, Section VII draws the concluding remarks.

[1] ENTHRONE IST-507637, "*End-to-End QoS through Integrated Management of Content, Networks and Terminals*". The project is now entering a second 2-year period

2. BACKGROUND AND RELATED WORK ON CONTENT ADAPTATION

Content adaptation has already gained a considerable importance in today's multimedia communications and will certainly become an essential functionality of any service, application or system in the near future. Adapting content can be seen as an efficient solution to allow the consumption of a meaningful variation of that content, under network, terminal and environment conditions which prevented the previous consumption of the original content.

Research activity regarding techniques and approaches to operate varied forms of transformations upon the content [1],[2], to quantify the quality of the adapted content [3] and also to allow describing the context of usage [4], has been conducted during the last years and still is today. Standardisation bodies have also been quite active in this field, notably MPEG [5]-[7], ITU [8] and W3C [9]. At the systems level, research has been focused on locating and efficiently managing available resources (such as CPU processing power, amount of memory or network bandwidth availability) and on providing QoS to high-end applications [10],[11]]. Although the proposed solutions provide the end-to-end functionality and interaction with heterogeneous devices, they do not address the aspects of manipulating content and context metadata in a unified way to transparently adapt the content to the current context constraints. Despite these important advances, further steps are still required to arrive to complete systems operating in heterogeneous content delivery environments and providing the necessary architectural support to actually offer the desired functionality to its users. It is in particular necessary to address aspects to fully understand context, as well as to assess the degree of satisfaction of the users towards the delivered service and feed this information back into the system.

The ENTHRONE project has focused on the development of a solution to provide this kind of structural support for multimedia content delivery services.

3. METADATA AND QUALITY-BASED FRAMEWORK

3.1 Metadata requirements

Context-aware, quality-based adaptation requires the availability of engines that take decisions about the need to perform adaptation, which in turn require the availability of meaningful descriptions about the content and the context of usage, providing a measure of the service quality.

Content-related metadata should include not only description about the content itself, but also regarding the type of operations that can be performed upon it and the result that is obtained. Context-related metadata should provide a characterization of the environment where the content is to be delivered and consumed. Examples are the capabilities of the terminal or the characteristics and conditions of networks. Also very important is another type of context metadata closely related with the content, which relates to the capabilities and operating points of available adaptation engines. This metadata is generated and used in ENTHRONE in accordance to the MPEG-21 standard.

3.2 MPEG-21 DIA

MPEG-21 DIA [7] specifies a set of tools to assist the adaptation of multimedia content in the form of Digital Items (DIs). It provides the means to characterize the context of usage and to relate the quality of A/V signals to application parameters (eg. of available encoders or adaptation engines) and to the required resources, such as bandwidth, network losses or display dimensions. It does not however specify the way to obtain the values of these descriptors not the relation between them. In ENTHRONE we have developed mechanisms to generate the required values and a specific tool to express the relation. These mechanisms are described in the next sections. From the available MPEG-21 DIA tools, the EIMS uses the Usage Environment Descriptor (UED), the Adaptation Quality of Service (AQoS) and the Universal Constraints Descriptor (UCD) to provide the system with the required metadata support for context-aware, quality-based adaptation decision functionality. Fr details on these tools the reader is encouraged to refer to [6] and [7]. UED provides the mechanisms to describe the characteristics of the environment in which the content is to be consumed, notably terminal capabilities, characteristics of the network and information regarding the user and his/her surrounding natural environment. UCD can be used to express the characteristics of the environment in terms of constraints. It enables the transformation of the current conditions of the usage context conveyed as UED, into the form of constraints. AQoS provide the means to express the relation between resources or constraints, adaptation operations and quality. The combined use of these tools and of on-line quality measurement mechanisms, allows to decide which (a-priori or reactive) measure to endorse when a given quality is selected or a quality degradation is detected.

4. THE EIMS ARCHITECTURE

4.1 Concepts, requirements and technology

The EIMS [12], is a content management and mediation platform based on MPEG-21 [6] and distributed technologies. Its goal is to provide transparent access to multimedia content and services, offering a quality-controlled delivery.

To achieve this, it needs, on one hand, to process and interpret content- and context-related metadata: the former to locate the useful content and learn its characteristics and the operations possible to be performed upon it; the later to learn about the terminal and networks characteristics and user preferences. Only in possession of this information it may adapt the content to meet the context constraints. To allow its operation in heterogeneous environments, a single common framework was selected to express and convey all this metadata - the MPEG-21 standard.

On the other hand, the EIMS needs to interact with different entities, namely content providers, network operators, service providers and end-users. For this reason the EIMS is composed of different sub-systems with well-defined functionality, offered as services. The EIMS thus presents a services-oriented architecture facilitating its usage in different environments and contexts and effectively enabling the access of multiple, heterogeneous client devices to multiple heterogeneous sources of content. Simple Object Access Protocol (SOAP) is used to exchange messages between sub-systems or external applications. Web Services Description Language (WSDL) is used for the specification of service interfaces. EIMS functionalities can be directly accessed and combined to support the requirements of different applications (e.g. VoD, multicast NVoD, file downloading, real-time streaming, news-on-demand, broadcast iTV, etc).

4.2 EIMS sub-systems

The architecture of the EIMS from the sub-system level down to the component level is illustrated in Figure 2. The major sub-systems are the EIMS Dispatcher and the EIMS Content Manager (EIMS-CM). These modules directly manipulate both the content resources and the metadata. Nevertheless all subsystems play an important role towards the fulfillment of the context-aware content adaptation functionality of the EIMS.

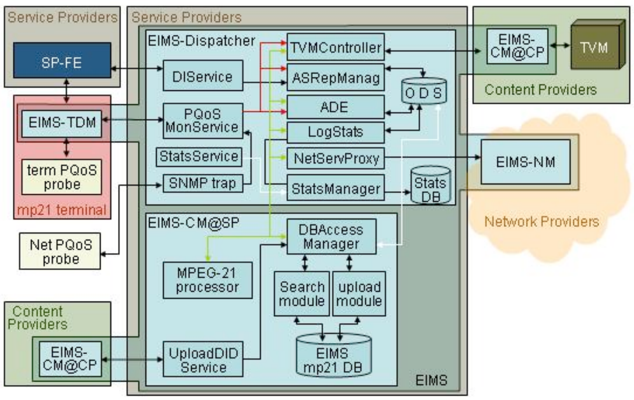

Figure 2 - Architecture of the EIMS at the component level

1) EIMS Dispatcher

This is the coordination subsystem of the EIMS. Its functionality is explained in more detail in section 5.3.

2) EIMS Content Manager (EIMS-CM)

It is typically a distributed system, deployed at two different sites. The EIMS-CM@CP is located at the Content Provider (CP) premises. It provides the support for the integration of metadata, generation and publishing of DIDs, as well as for local configuration of adaptation engines (ENTHRONE TVMs). The EIMS-CM@SP is located at the Service Provider (SP) site. It offers a service for the upload of metadata in the form of MPEG-21 DIDs It performs content searches based on semantically meaningful keywords (currently TVA Program Information metadata) and MPEG-21 Identifiers. It maintains a repository of the received DIDs and of each item.

3) EIMS Network Manager (EIMS-NM)

Provides an interface with network-level mechanisms. It performs pSLS management, including negotiation, invocation and monitoring, as well as network cSLS invocation [13]. It passes to the Dispatcher, upon request, required network information to build the network UEDs.

4) EIMS Terminal Device Manager (EIMS-TDM)

This subsystem provides a platform-neutral interface to various kinds of terminals. Its main purpose is to report back to the Dispatcher the characteristics of the terminal and to perform local QoS management, license management and event scheduling.

4.3 EIMS functionality

Overall the functionality delivered by the EIMS can be described through its use cases and interfaces. Figure 3 shows the use case model of EIMS, comprising only the use cases with implications at the architectural level. Actors can be persons or applications.

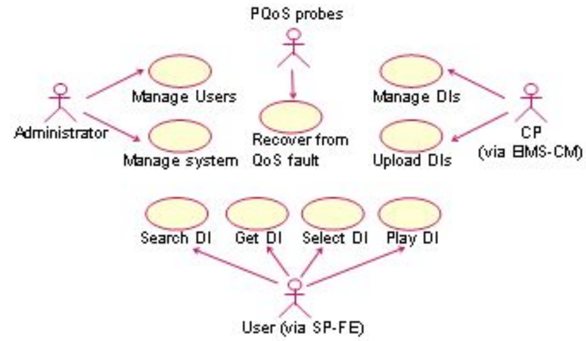

Figure 3 - EIMS use case model

The 4 use cases assigned to the actor "User" are in fact initiated by an application, the Service Provider Front End (SP-FE). This subsystem acts as a Web portal, announcing available multimedia services to end-users, authenticating users and forwarding their requests to the relevant EIMS. Bellow a short description of the most relevant use cases is provided.

Table 1 – Description of some EIMs use cases

Use case	SearchDI
Actors	SP-FE on behalf of the user
Purpose	To allow end-users to search for content using semantically meaningful keywords
Overview	The SP-FE after having authenticated the user, forwards the search request to the EIMS Dispatcher. The request is an XML search query with semantically meaningful keywords. The Dispatcher contacts the EIMS-CM@SP that performs an Item-wise search into the mp21 database. All the Items that match the query are retrieved and a DID is built to wrap them. This new DID is returned back to the user.

Use case	SelectDI
Actors	SP-FE on behalf of the user
Purpose	To allow end-users to select a given resource for consumption.
Overview	The user, after browsing through DIDs, "clicks" on the name of a resource to consume. A "SelectDI" command is sent to the Dispatcher, carrying a unique mp21 identifier and a UED string describing the terminal's capabilities, the quality selected by the user and the time at which the user wants to consume the resource. The Dispatcher gathers required AQoS and network UED metadata and obtains an adaptation decision from the ADE. Data generated in this process are stored with a unique identifier ("service_id"). A response is sent to the user as a DID. If the ADE did not find suitable adaptation operations satisfying the usage constraints, the response will accordingly notify the user.

Use case	PlayDI
Actors	SP-FE on behalf of the user
Purpose	To allow end-users to receive and consume a previously selected resource
Overview	The user selects for playing a previously agreed service (upon a successful completion of a "SelectDI"). The SP-FE passes to the Dispatcher the "PlayDI" command, having as a parameter the "service_id" returned by the "Select_DI". The Dispatcher fetches the required service parameters to configure the adaptation engine (an ENTHRONE TVM). It

	passes these parameters to the IMS-CM@CP, which performs the local TVM configuration. It sends to the terminal a response DID with status data and the service end-point (i. e., the location of the source of content).

5. SYSTEM SUPPORT FOR CONTEXT-AWARE CONTENT ADAPTATION

5.1 PQoS probes

Controlling the degree of satisfaction of the end-user is a major interest of adaptation. User satisfaction results from a complex combination of various service parameters from different levels. ENTHRONE accounts for this quality of service from the user perspective by using Perceived QoS (PQoS) in adaptation decisions. PQoS probes are designed to match the quality assessment provided by a panel of users [14], performing analysis on decoded audio and video signals as shown in figure 4.

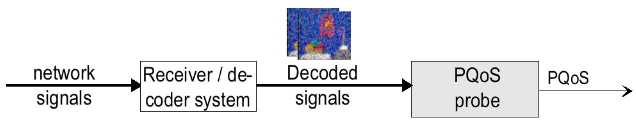

Figure 4 – "no reference" PQoS probe measurement

PQoS probes analyze content signals to detect specific impairments introduced by the delivery chain. A perceptual model that accounts for human sensitivity is used to evaluate their perceptible impact on PQoS. In ENTHRONE, where video content is encoded using the MPEG-4 specification and transmitted over lossy networks, typical impairments include block artifacts, blur, freezing and motion jerkiness.

PQoS probes are used in two steps: off-line, for the generation of AQoS descriptions, and on-line, for the monitoring of the instantaneous perceived quality

AQoS data is required to establish the relation between the targeted user quality (PQoS), the application parameters (bit rate, frame rate, aspect ratio, etc) and the network level quality (NQoS) parameters. An experimental approach is used, relying on a database of video streams generated using a wide range of content types (such as studio, sports, news or advertisements), various encoding configurations (data rate, frame rate, resolution, etc.) and transmitted over IP under several loss profiles. The analysis of correlation between PQoS measurements, using probes or standard assessment sessions [8], encoding parameters and network conditions provides the PQoS to NQoS mapping rules. These results are used to generate AQoS metadata as it will be explained in the next sub-section.

In a second step, PQoS monitoring is performed during service delivery, triggering EIMS adaptation reactions by generating PQoS alarms. PQoS monitoring is implemented at two locations along the delivery chain: 1) in the user terminal and 2) in the network. Terminal PQoS probes provide feedback to the EIMS concerning the final user experience. Network PQoS probes provide node or domain level measurements regarding a single or aggregated flow. They can be used to detect SLS/SLA violations and determine fault location [13]. The terminal PQoS probe interacts with the output of the MPEG-4 player to measure the perceived quality of the decoded A/V sequence. The probe is initially set to the agreed PQoS value. Whenever it detects degradation on the quality, it sends an alert to the EIMS, describing the current PQoS level and the new context. These alerts are conveniently filtered by the PQoS monitoring service of the EIMS Dispatcher in order not to trigger unnecessary adaptation decision operations.

5.2 AQoS Description generator

This component generates metadata useful for quality-based adaptation decisions in the form of DIA AQoS descriptions.

The biggest challenge when generating AQoS descriptions is to obtain an accurate match between perceived quality and the adaptation operations, including possible sets of parameters, that can be performed upon the content to yield such quality. In ENTHRONE these quality values are generated per classes of DIs, obtained off-line using different subjective and instrumental measurement tools and kept in a database. Examples of subjective tools are the ones described in the previous sub-section. Classes are distinguished through the use of an MPEG-7 codec classifier, the bit rate and the genre. Table 2 summarizes some of the input parameters (based on the MPEG-7 MediaFormatType [5])

Table 2 - AQoSDescriptionGenerator input parameters

Name	Example	Description
CodecClassifier	urn:mpeg:mpeg7:cs:VisualCodingFormatCS:2001:3.1.2	Unique classifier for the specific codec type MPEG-4 Visual Simple Profile @ Level 1
GenreClassifier	urn:enthrone:cs:2005:GenreQuality:1.	E.g. Speech, Music, Football, Al
qualityMeasure	urn:mpeg:mpeg21:2003:01-DIA-AdaptationQoSCS-NS:1.2.1	A measure of the perceptual quality of a video signal using PSNR
Bitrate	64	Net bitrate of the streams in kbit/s
BitrateRange	32-1500	Net bitrate of the streams in kbit/s
imageSize	320x240	Picture size in pixels

The example in Figure 5 illustrates a possible AQoS description. The utility for describing the perceived quality is the DVQ measure developed in Enthrone [14]. The *AQoSDescriptionGenerator* can be used off-line as a Web Service, delivering its output upon request through SOAP messages. DIA metadata can be inserted in DIDs at the EIMS-CM upon the publishing of the multimedia content as MPEG-21 DIs, or can be passed standalone to the EIMS Dispatcher

```
<DIA>
  ...
  <Description xsi:type="AdaptationQoSType">
    ...
    <Module xsi:type="UtilityFunctionType">
      ...
      <Constraint IOPinRef="BANDWIDTH">
        <Vector>100000 500000 1000000 1500000</Vector>
      </Constraint>
      <Utility IOPinRef="DVQ">   <!-- Digital Video Quality -->
        <Vector>75 88 98 99 </Vector>
      </Utility>
    </Module>
    ...
    <IOPin semantics=":AQoS:1.1.1" id="BANDWIDTH"/>
    <IOPin semantics=":AQoS:1.2.x" id="DVQ"/>
  </Description>
</DIA>
```

Figure 5 - Excerpt of an ENTHRONE AQoS

5.3 Service-level functionality of EIMS

The EIMS-Dispatcher through its Service Manager module illustrated in Figure 6, implements all the functionality required at the application layer to support context-aware quality-controlled access to content.

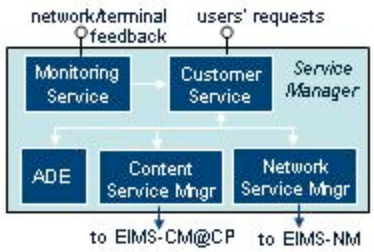

Figure 6 - Block diagram of the Service Manager

1) Customer Service Manager

Receives the user request and collects required metadata to process it. It takes the decision regarding the need to initiate an adaptation. It relies on the Adaptation Decision Engine (ADE) to implement the quality-based content adaptation decision.

2) Monitoring Service

Provides an interface towards PQoS probes, supporting different protocols, namely SNMP and SOAP. Probes are initialized with the quality value agreed at negotiation phase. Whenever a loss of quality is detected, an alert is sent back to the EIMS-Dispatcher. This alert is further processed by the Monitoring Service and may initiate a new content adaptation decision process.

4) Content Service Manager

It is responsible to establishing communication with external adaptation engines, passing them the new service parameter values. This communication is done via SOAP.

5) Network Service Manager

This module communicates with the EIMS-NM to obtain information concerning network conditions, which are essential for the adaptation decision taking process and to request and invoke QoS-enabled paths.

3) Adaptation Decision Engine, ADE

The ADE takes DI adaptation decisions to provide the best quality given usage constraints. It can be invoked before and during content streaming. The latter can happen in case of PQoS alerts. In both cases it determines the set of service parameters that provide the best quality under the constraints. Figure 7 shows the structure of the ADE. The ADE is fed with useful descriptions as described in section 3.2.

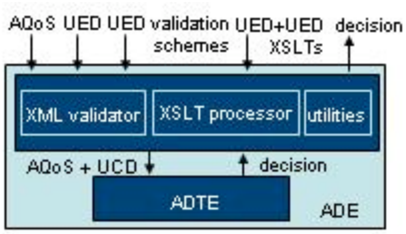

Figure 7 - High-level architecture of the ADE

UEDs are transformed into UCDs, such that the terminal capabilities, user preferences, characteristics of available adaptation engines and capacity of the network may be transformed into constraints. Figure 8 shows an excerpt of a terminal UED and the corresponding UCD produced by the ADE processor and passed to the ADTE. The ADTE receives also ordered sets of encoding parameters and quality values expressed in the AQoS description. It selects the first set that satisfies the constraints expressed in the UCD description.

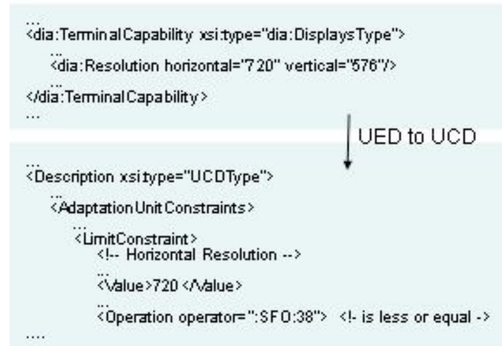

Figure 8 - UED to UCD conversion example

Figure 9 shows examples of AQoS values highlighting the best possible choice. The ADE output is a set of "name-value" pairs selected among the AQoS descriptors originally provided.

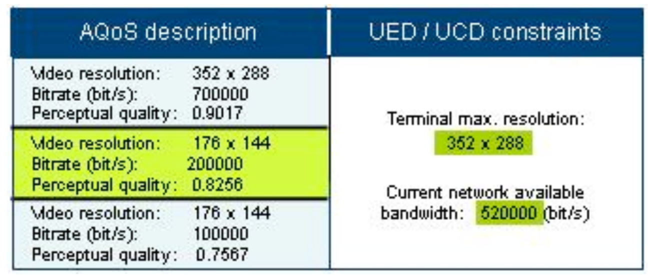

Figure 9 - Sets and selection of AQoS values

The required metadata is instantiated from information retrieved from the EIMS data base, or from information dynamically gathered by the EIMS-Dispatcher from external components. The later is the case of network conditions and PQoS alerts. Terminal UEDs are generated by the EIMS-TDM and passed onto the EIMS-Dispatcher as a parameter in a user request. In addition, whenever alerts are generated due to quality degradation, a new UED is generated, reflecting the new conditions. Network UEDs are generated when the ADE is invoked as they should reflect the current conditions on the network. They are generated by the Network Service Manager upon request of the Customer Service Manager. AQoS descriptions arrive to the EIMS inside the DIDs, being subsequently extracted and stored in the EIMS database.

6. EXPERIMENTS

Different demonstration scenarios were developed to experiment the adopted approach. Figure 10 illustrates a Video on Demand (VoD) service over a co-operating DVB/UMTS network to mobile terminals embedded in vehicles. The user may select a PQoS level that the system tries to enforce depending on the context conditions. Content can be live encoded in MPEG 4 format using the service parameters determined by the EIMS. Alternatively, different versions may exist stored on servers. In both cases the content is transmitted over a real DVB network. The terminal is currently based on a laptop PC having a PQoS probe integrated. It emulates different terminal display sizes (CIF, QCIF) and network throughputs (250 kbit/s to 1,5 Mbit/s).

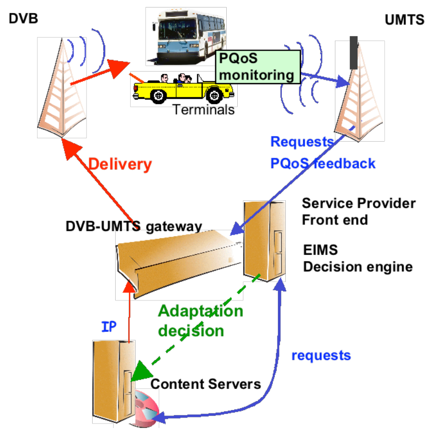

Figure 10 - Video to mobile devices with QoS adaptation

6.1 QoS adaptation at service invocation

The user connects himself via UMTS to a Web portal (the ENTHRONE SP-FE) and initiates a search for content, based on keywords. The EIMS locates useful content in the MPEG-21 repository and sends back to the user a DID with all the matching results. The user browses through this MPEG-21 DID looking for the desired content. He/she finally selects the content to consume, indicating the desired quality. Using all the available metadata as described in the previous section, the EIMS, through its Service Manager, determines the best set of service parameters. The user will eventually get the quality he/she has selected depending on the current context conditions. If it is not possible to deliver the chosen quality, an error message will be sent. Once the service parameters are obtained, they are passed via the EIMS-CM to the adaptation engine, an MPEG-4 real-time encoder board. Likewise, the terminal PQoS probe is set with the agreed PQoS value via the EIMS-TDM. Finally, content is played in the terminal via DVB.

6.2 In-service QoS adaptation

To experiment content adaptation during the service lifetime, we simulated network congestion by injecting extra traffic in the network during service delivery. The congestion on the network caused the PQoS to drop bellow the agreed value and consequently the generation of PQoS alarms. These alarms were passed to the EIMS Dispatcher and conveniently processed. With the new context constrains descriptions, the ADE was invoked and new service parameters calculated. These were then passed to the TVM via the EIMS-CM@CP. The EIMS thus provided a quality-controlled delivery, by adjusting the service parameters in a way that minimized the degradation perception.

7. CONCLUDING REMARKS

The experiments performed in ENTHRONE with its EIMS, have shown the suitability of MPEG-21 to enable the transparent adaptation of content to different context constraints. The use of Web Services has proved to be quite efficient and easy to use to enable the interoperability among heterogeneous users and applications. Tests have shown that the latency of the system in delivering useful results upon a user query and the time to take an adaptation decision were low and considered acceptable by the users of the system. Nevertheless more thorough tests need to be conducted, as the response times may significantly vary with the size of the data base and with the amount of adaptation metadata needed to process in the adaptation decision. In addition, more work is planned along different axes, notably concerning QoS models and cross-layer mechanisms to support adaptation.

8. ACKNOWLEDGMENTS

This work was in part supported by the EC through the programme FP6-IST. The authors would like to thank their colleagues of the ENTHRONE project for their fruitful collaboration in the development of the work here described.

9. REFERENCES

[1] A. Tripathi and M. Claypool, “Improving Multimedia Streaming with Content-Aware Video Scaling”, Proc. of the Second Int. Workshop on Intelligent Multimedia Computing and Networking (IMMCN) Durham, USA, March, 2002.

[2] S. Chattopadhyay, K. Li, S. Bhandarkar, “FGS-MR: MPEG4 Fine Grained Scalable Multi-Resolution Video Encoding for Adaptive Video Streaming”, Proc. of the NOSSDAV 2006, Newport, USA, May, 2006.

[3] Y. Wang, S.-F. Chang, A. C. Loui. “Content-Based Prediction of Optimal Video Adaptation Operations Using Subjective Quality Evaluation”. Columbia University ADVENT Technical Report #202-2004-2, January 2004.

[4] W. Lum and F. Lau, “A context-aware decision engine for content adaptation”, IEEE Journal of Pervasive Computing, 2002.

[5] MPEG-7 Part-5: ISO/IEC 15938-5, “Multimedia Content Description Interface, Part 5 Multimedia Description Scheme", 2001.

[6] I. Burnett, F. Pereira, R. Walle, and R. Koenen (eds.), “The MPEG-21 Book”, John Wiley and Sons Ltd, 2006.

[7] MPEG-21 Part-7: ISO/IEC 21000-7, Information technology - Multimedia Framework - Part 7: Digital Item Adaptation, Oct. 2004.

[8] ITU-T Rec. BT.500-12, “Methodology for subjective assessment of the quality of television pictures”.

[9] W3C Rec. 15, “Composite Capability/ Preference Profiles (CC/PP): Structure and Vocabularies 1.0, January 2004.

[10] P. Bellavista, A. Corradi, and C. Stefanelli, “An Integrated Management Environment for Network Resources and Services”, IEEE Journal on Selected Areas in Communications, Vol. 18, No. 5, May 2000.

[11] Foster, I., Fidler, M., Roy, A., Sander, V. and Winkler, L., End-to-End Quality of Service for High-End Applications, Elsevier Computer Communications Journal, vol. 27, no. 14, pp. 1375-1388, 2004.

[12] ENTHRONE Deliverable D07, “IMS Implementation", December 2005. Available at http://www.enthrone.org/ in the area {reports – deliverables}.

[13] ENTHRONE Deliverable D24, “Specification of protocols, algorithms, and components, the architecture, and design of SLS Management” December 2005.

[14] ENTHRONE Deliverable D25 “Perceived Quality Meters and Agents”, July 2005.