Content Adaptation Decision to Enhance the Access to Networked Multimedia Content

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Abstract This paper presents the concepts and functionality of a distributed context-aware content management system to enable the customised access to multimedia content from diverse client devices. Its core architecture, composed of multiple software components, is based on the MPEG-21 specifications. It transacts multimedia content packaged as MPEG-21 Digital Items, and performs content adaptation operations according to the MPEG-21 standard when such is revealed necessary to meet specific usage scenarios characteristics and limitations. The adaptation decision adopts a quality-based strategy, trying to maximise the perceived quality given constraints imposed by terminal capabilities, network conditions and user preferences. The exchange of information between the different and distributed components of the system is mostly done via MPEG-21 DIDs, carried in SOAP messages, adopting a services-oriented architecture and offering a standardised method for interconnecting entities participating in a multimedia content delivery service.

1 Introduction

Nowadays, consumers can access multimedia content using a variety of terminals with a wide range of capabilities. The ubiquity of networks allows consumers to access multimedia content from almost anywhere and makes networked access to multimedia content increasingly popular. However, due to the diversity of network characteristics and capacity, to the different preferences and requirements of different users and to the varied capabilities of available multimedia terminals, the access to the same content from different users is not done in an homogeneous way. This paper introduces the Integrated Management Supervisor (IMS), a software system developed in the context of the ENTHRONE [1] IST project [1], focussing on its content adaptation decision functionality. ENTHRONE tries to provide a solution for the access to multimedia content with end-to-end quality of service in heterogeneous environments. Our focus is on two aspects that we consider essential to meet this challenge while coping with the referred above diversity in terminals, networks and users. First, on a service oriented architecture that facilitates the inter operation between the different components of the system and that makes it easy to be deployed in a wide range of scenarios. Second, on content adaptation mechanisms that are able to understand and use information about the context of usage, including network characteristics and conditions, terminal capabilities, user preferences and possibly environmental conditions. In the described system, this is achieved through the use of the MPEG-21 specifications. This paper is structured as follows: section 2 provides a brief description of the IMS architecture and functionality. Section 3 describes in more detail the strategy adopted and components developed to perform content adaptation decision operations. Finally section 4 draws the concluding remarks.

2 IMS Architecture

In networked environments, to ensure end-to-end quality of service each component along the delivery path must provide a QoS-based service (content sources and adapters, networks and network-related equipment, terminals). ENTHRONE's tenet is that the integrated management of these components allows a better use of the available resources, making it possible to achieve the best quality given the existing constraints. The IMS [2] is the system designed and developed in ENTHRONE to achieve such an integrated management. It comprises different subsystems to interface with the different components along the content delivery chain. Figure 1 illustrates the high-level architecture of the IMS. The kernel of the IMS is the *IMS-Dispatcher*. This is the subsystem responsible for taking global, system-wide decisions

[1] ENTHRONE, IST-507637 is and Integrated project approved in the 1st call of IST-FP6 in June 2003. ENTHRONE stands for *End-to-End QoS through Integrated Management of Content, Networks and Terminals.*

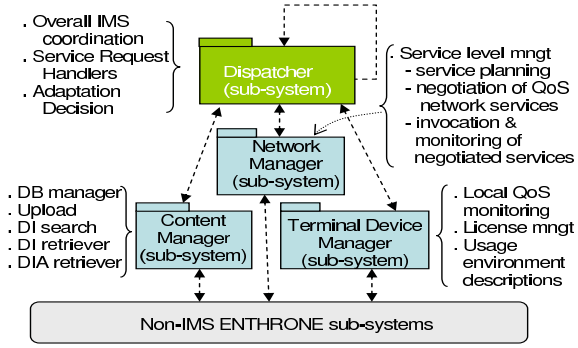

Fig. 1 High-level IMS architecture

and performing the management of user requests. Other IMS subsystems, with more service-specific functionality, provide the interconnection with non-IMS systems. The *IMS Network Manager* (IMS-NM) is the subsystem responsible for the aspects related to the management of the network service. The *IMS Terminal Device Manager* (IMS-TDM) is the subsystem responsible for the management of terminals. Among other tasks, it is responsible for monitoring the perceived quality and for collecting information concerning the terminal capabilities. The *IMS Content Manager* (IMS-CM) is the subsystem responsible for the storage, access to and handling of multimedia metadata and resources. Overall the IMS is a distributed system, having also some of its sub-systems implemented in a distributed fashion. The IMS-CM is typically a distributed sub-system. It has specific modules installed and running at the Content Provider side together with the sources of content, codecs and adaptation engines. It also has other modules installed at the Service Provider side, managing the access to metadata and resources using a data base and repository. The *IMS-Dispatcher* performs service-level management functions. It attends user requests, processes content and context metadata related with the request and accordingly initiates a set of operations. The metadata is instantiated from information retrieved from the IMS data base, previously gathered by the IMS, or from information dynamically requested by IMS subsystems to external components (as in the case of network conditions). Using this metadata, the *IMS-Dispatcher*, via its *Adaptation Decision Engine* (ADE), decides if and what kind of adaptation is required to fulfill the customer's request with the best possible quality. In a simplistic way, all the IMS subsystems can be seen as providing services to feed the *IMS-Dispatcher*, or better the ADE subsystem, with the metadata it requires to take its adaptation decisions, and to convey these decisions to lower level managers. The generation of the adaptation-related metadata and the adaptation decision taking process are explained in more detail in section 3.

Each of the IMS subsystems was developed as providing a service to other subsystems, leading to a service-oriented architecture. Many of those services are implemented as Web Services, exchanging information using SOAP [5]. For example, MPEG-21 metadata to assist the IMS to take decisions on how to instruct external resource managers. SOAP is a particularly convenient technology. First, both SOAP and MPEG21 are based on XML. Second, the use of Web Services facilitates the interoperability of applications developed for different platforms and deployed across the Internet. Other alternatives are not that universally supported, e.g. Java RMI is language dependent, or are not that universally available, e.g. Corba. Additionally, SOAP supports also a document-based style of communication. Given that the ADE, and many other MPEG21 tools, take XML documents directly as input, the use of SOAP with a document communication style is especially well suited. Additionally, the operands are regarded as XML documents and therefore are opaque to the communications subsystem.

3 Adaptation Decision Support

The use of common and standard data formats, and of content adaptation decision capabilities was identified as essential for the IMS to meet its challenges. Nowadays multimedia content can no longer be seen as a single item but rather as a set of resources of different media types accompanied by a variety of descriptions. A mechanism is needed to enable the declaration of the parts that make up each set and how they are structured. Among the available emerging standards, MPEG-21 [3, 4, 6, 7] can be considered as one of the most advanced, complete and flexible. Because MPEG-21 also provides support for content adaptation, in addition to a number of other functionalities, it was chosen to be used in ENTHRONE. MPEG-21 DIA [4, 6, 7] specifies a set of tools to assist the adaptation of Digital Items. These tools can be used to describe transmission and consumption environment constraints, as well as Quality of Service. In particular, the tool referred to as *Adaptation-QoS* (AQoS), allows describing the relationship between QoS constraints (e.g., on network bandwidth or a terminal's computational capabilities), feasible adaptation operations satisfying those constraints and the quality that can be expected when applying those adaptation operations. It provides the means to formulate a quality-based adaptation strategy under constrained environments. The tool *Usage Environment Description* (UED) allows the description of the environment in which the content is to be consumed, notably the capabilities of the terminal, the characteristics of the network and information regarding the user and surrounding natural environment. The tool *Universal Constraints Description* (UCD) can be used to express optimization constraints. These are essentially the MPEG-21 DIA tools that are

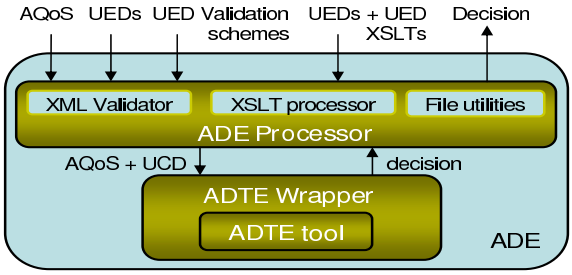

Fig. 2 The ADE functional architecture

```
<dia:TerminalCapability xsi:type="dia:DisplaysType"
    ...
    <dia:Resolution horizontal="720" vertical="576"/>
    ...
</dia:TerminalCapability>
```

UED to UCD

```
...
<Description xsi:type="UCDType">
    ...
<AdaptationUnitConstraints>
    ...
<LimitConstraint>
<!-- Horizontal Resolution -->
    ...
    <Value>720</Value>
    ...
    <Operation operator=":SFO:38"/>  <!- is less or equal ->
    <Operation operator=":SFO:24"/>  <!- boolean AND ->
...
```

Fig. 3 Conversion between UED and UCD

being employed in ENTHRONE to assist the adaptation decision operations of ADE. A specific component described in section 3.2, the *AQoSDescriptionGenerator*, was developed within ENTHRONE to generate the AQoS descriptions, essential to the ADE operation.

3.1 Adaptation Decision Engine (ADE)

The ADE is the module of the *IMS-Dispatcher* that takes DI adaptation decisions to provide the best quality given usage environment constraints (on the terminal, networks and encoders) and user preferences. It can be invoked both before and during content streaming. The latter can happen in case the measured perceived QoS falls below a pre-configured value. In both cases it determines the set of service parameters that provide the best quality, given the above mentioned constraints. Figure 2 illustrates the structure of the ADE.

The ADE takes as inputs DIA descriptions (UEDs and AQoS). In a first stage, the ADE processor module validates the received descriptions and then transforms UEDs into UCDs. This way, the capabilities of terminals and the user preferences, the characteristics of available adaptation engines and the capacity of the network are transformed into constraints, which are fed along with AQoS metadata into the Adaptation Decision Taking Engine (ADTE). Figure 3 shows a small excerpt of an UED with terminal characteristics and the corresponding excerpt of the UCD produced by the ADE processor.

The ADTE is the module of the ADE that performs the actual decision taking and is based on open soft-

```
<DIA>
 <DescriptionMetadata>
   <ClassificationSchemeAlias alias="AQoS"
 href="urn:mpeg:mpeg21:2003:01-DIA-AdaptationQoSCS-NS"/>
 </DescriptionMetadata>
 <Description xsi:type="AdaptationQoSType">
    <Module xsi:type="UtilityFunctionType">
       <Constraint iOPinRef="BANDWIDTH">
                <Vector>100000  500000  1000000</Vector>
       <Utility iOPinRef="DVQ">
                <Vector>75  88  98</Vector>
       </Utility>
    </Module>
    <IOPin semantics=":AQoS:1.1.1" id="BANDWIDTH"/>
    <IOPin semantics=":AQoS:1.2.x" id="DVQ"/>
 </Description>
</DIA>
```

Fig. 4 An example of an AQoS description

ware submitted to the official MPEG software repository [10]. The AQoS descriptions can be expressed in three different modes - *UtilityFunction*, *StackFunction* and *LookupTable*. These three modes essentially provide different ways of establishing the relationship between the operating point and the result in terms of resources (e.g. bit rate or spatial resolution) and in terms of quality. The ADTE can use any of these modes to implement a quality optimization algorithm. The ADE output is a set of "name-value" pairs selected among the AQoS descriptors originally provided. This output is used to configure different resources, including the encoding parameters of the streamer. In the current implementation, this configuration is done using different Web Services and associated SOAP messages. The use of XSLT endows the ADE of great flexibility, decoupling the ADE from other components. For example, it is possible to seamlessly replace the ADTE and/or accept different UEDs or use different transformations of UEDs into UCDs.

3.2 AQoSDescriptionGenerator Component

This component generates metadata useful for quality-based adaptation decision operations in the form of DIA AQoS descriptions. It is used off-line as a Web Service, delivering its output upon request through SOAP messages. The AQoS descriptions arrive to the IMS inside the DIDs, being subsequently extracted and separately stored in the IMS data base. Upon solicited, the ADE receives and uses this information to take an adaptation decision that will result in the best estimated quality given a set of usage constraints. As referred above, AQoS provides a means to relate different codec operation points, constraints and operators' values to achieve a given perceived quality. The example in Fig 4 illustrates a possible AQoS description. The utility for describing the perceived quality is the DVQ measure developed in Enthrone [8].

The biggest challenge when generating AQoS descriptions is to obtain an accurate match between perceived quality and the adaptation operations that can be performed upon the content to yield such quality. The Enthrone *AQoSDescriptionGenerator* is designed around

Table 1 Some of the most relevant input parameters to the *AQoSDescriptionGenerator*

Name	Example	Description
Codec Classifier	urn:mpeg:mpeg7: cs:Visual CodingFormatsCS: 2001:3.1.2	Unique classifier for specific codec types, eg. MPEG-4 Visual Simple Profile @ Level 1
Genre Classifier	urn:enthrone: cs:2005: GenreQuality:3.1	Quality related genre classifier, i.e., Footbal
Quality Measure	urn:mpeg:mpeg21: 2003:01-DIA-AdaptationQoSCS-NS:1.2.x	Classifier that identifies the measure for the perceptual quality, eg. DVQ for assessing the video quality
Bitrate	64	Net bit rate of the stream in Kbit/s
Bitrate Range	32-1500	Range of net bit rate of streams
ImageSize	320x240	Picture size in pels

a database that holds the perceived quality of a variety of codecs, obtained off-line using different subjective and instrumental measurement tools. Having measurement results stemming from different sources increases the reliability of the final estimate used in the AQoS description. Examples of two such subjective tools are the ones developed or improved within ENTHRONE and described in [8]. Accurate quality estimates require that the perceptual quality of A/V signals is assessed for each set of encoding parameters. This would however lead to a huge effort. In ENTHRONE we have adopted an approach where AQoS metadata is generated per classes of DIs. Classes are distinguished through the use of an *MPEG-7 codec classifier*, the *bit rate* and the *genre*. Classification schemes for codec type, genre and AQoS are used to provide a system wide common definition of identifiers. Table 1 summarizes some of the most relevant input parameters, which are based on the MPEG-7 MediaFormatType [9].

AQoS is used by the IMS to set up the initial system parameters for a given user request and throughout the duration of the service, in case of quality degradation alerts. When an A/V service starts, the PQoS probes along the transmission path are initialized with the value of perceived quality chosen by the IMS among those contained in the AQoS description. When the measured DVQ values fall below that initial value, an alert is triggered. The IMS then contacts the adaptation engine to adapt the service, for example by increasing the redundancy.

4 Concluding remarks

This paper provides an overview of the concepts and architecture of the IMS system developed in the ENTHRONE project. It describes in more detail its functionality to support multimedia content adaptation. Major strengths of the described system rely on its extended coverage and use of MPEG-21 tools and its ability to support QoS- and context-aware universal access to multimedia content. Nonetheless, full use of the MPEG-21 potential is still far from being achieved. Support for more elaborated forms of content adaptation is envisaged. In particular, it is possible to develop adaptation mechanisms based on scalable encoders and on the use of binary descriptions of the bit stream. The later can be used to perform less demanding adaptation operations, which can be done by general-purpose engines in a distributed fashion. Another very important aspect is the verification of the digital rights associated to the content before actually deciding upon adaptation operations. Finally, further study is required to efficiently use the feedback information coming from the PQoS probes to enhance the IMS operation under dynamically varying conditions.

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