A scalable platform for context-aware and DRM-enabled adaptation of multimedia content

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Abstract: Future Media Internet will allow new applications to be realised with support for ubiquitous media-rich content service technologies. Virtual collaboration, in which users with diverse geographical locations, terminal types, connectivity, environments and preferences will access and exchange pervasive yet protected and trusted content, is one of them. These multiple forms of diversity require content to be transported and rendered in different forms, which requires the use of context-aware content adaptation. This avoids the alternative of predicting, generating and storing all the different forms required for every item of content. This paper describes a platform that has been developed within the VISNET II Network of Excellence (NoE) project, for context-aware adaptation of multimedia content that has been governed using Digital Rights Management (DRM). The platform has a modular architecture to ensure scalability and well-defined interfaces based on open standards for interoperability as well as portability. The platform makes use of ontologies during the adaptation decision taking stage to enable semantic description of real-world situations. The decision taking process is triggered by low-level contextual information and works by applying rules provided by the ontologies. It supports a variety of adaptations that can be dynamically configured. The paper provides the insights into the interfaces required between the aforementioned modules and the sequence of events that take place while performing DRM-based adaptation for a particular user or group of users in specific situations.

Keywords: Context-aware content adaptation, ontology-based and DRM-enabled ADE, adaptation authorisation, AE, MPEG-21, Web Services-based interfaces, virtual collaboration.

1 Introduction

Future media Internet will allow new applications to be realised with support for ubiquitous media-rich content service technologies. Virtual collaboration [1] is one of them, which allows remotely located partners to meet in a virtual environment using state-of-the-art communication and audiovisual technologies. All remotely located partners should feel the sensation of being in a single room regardless of their true geographical location. A large fixed-terminal acts as the main control/command point and serves for a group of co-located users and other large, medium and small size terminals including mobile devices are used by other groups and individuals. Users located in remote and heterogeneous environments, not only consuming but also producing new contents, access and exchange pervasive yet protected and trusted content. However, given the diversity of scenarios and usage environments in these types of applications, access to content is likely to pose significant challenges, which need to be addressed through the use of context-aware content adaptation. The challenges arise, as each combination of location, terminal scale, connectivity, user preferences and other local usage environment factors may require a different source and channel coding format for the content. It is clearly impossible to pre-generate and store all of these formats for every item of content, and so real-time adaptation of a very limited set of formats (probably only one) is required.

A number of context aware content adaptation frameworks and platforms have been presented in the literature [2-7]. Most of them were developed within the mobile services application domain. They tried mostly to explore context to improve usability aspects by sensing how the available devices were being used. Generally, they reacted directly to the sensed low-level contexts. They usually lacked flexibility, as they did not make use of ontologies or made a rather static and limited use of ontologies. Therefore, they did not explore the inter-relations among different types of low-level contextual information; thus did not sufficiently address the aspects of interoperability, scalability and security/privacy. In fact, earlier research was typically application-centric, overlooking the aspects of gathering different types of contextual information from different spaces and interoperability in heterogeneous environments. Likewise, aspects concerning security of content and context metadata, and ensuring the privacy of users have only recently started to be addressed.

A wide variety of research work has been conducted on privacy and DRM [8] as well as on adaptation [9][10] to date. However, such work has been essentially carried out independently, without any significant exchange of information between the different groups addressing each of the two topics. Nonetheless, adaptation is an operation to be performed upon the content. Accordingly, and as long as the content is governed or protected, the content adaptation operation should also be subjected to certain rules and rights. Therefore, it is inevitable that these two separated communities cross the boarders eventually and start to work together.

In light of these facts, this paper proposes a scalable platform for context-aware and DRM-enabled adaptation of multimedia content. The rest of the paper is organised as follows: Section 2 briefly introduces the use of ontologies within the adaptation decision process. The proposed platform architecture, its main strengths and details of its modules are described in Section 3. Section 4 presents the interfaces between the modules. Finally, we present our concluding remarks and directions for future work in Section 5.

2 Ontologies in context-aware content adaptation

Context-awareness in content adaptation can be defined as the ability of a system to adapt the content to the characteristics and constraints of the consumption environment and user's preferences [11]. The use of contextual information is instrumental in the successful implementation of useful and meaningful content adaptation operations that enhance the quality of the user experience while also increasing the system usability [12]. Context information is required to decide how and when to adapt content, so as to meet users' expectations and satisfy usage environment constraints.

An ontology is used to define the knowledge about a domain, which enables a formal description of specific situations in that domain [13]. In practice, an ontology is a hierarchical description of a set of concepts, logical statements that describe what the concepts are and how they are (or can be) related to each other (properties and their relationships) and a set of inference rules. Decision taking operations driven by the conditions and characteristics of real-world situations can greatly benefit from the use of ontologies [12]. Low-level contextual information gathered from sensors can be used to trigger the adaptation decision process. The context-aware ontology provides the definition of concepts and inference rules to evaluate the validity of the sensed data, which is used for reasoning and inferring higher-level contexts, thus enabling a context analysis closer to real-world situations. Accordingly, the adaptation decision has higher chance of satisfying user expectations.

Different real-world situations for multimedia content consumption are likely to have a common knowledge denominator (common concepts and rules). However, they will also have specific knowledge only relevant for the application in view. Accordingly, our approach for the use of ontologies relies on a two-layer ontology model shown in Figure 1. This model is developed using the Web Ontology Language (OWL) [14].

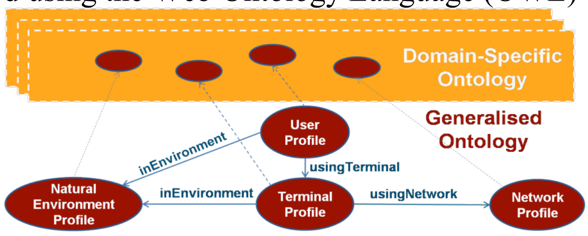

Figure 1: Context ontology overview

The generalised ontology layer provides descriptions of generic concepts and rules that can be used in any virtual collaboration application scenario. This layer is based on MPEG-21 Digital Item Adaptation (DIA) [15], in particular the Usage Environment Description (UED) tool, and is divided into four main profiles. Figure 2 represents the conceptualisation of these profiles. The second layer, *i.e.,* domain-specific layer, provides rules dedicated to a given application. Multiple domain-specific ontologies can thus co-exist in this layer. For example, the virtual classroom-specific layer provides the means of reasoning various adaptation options to help the user understand the classroom session better.

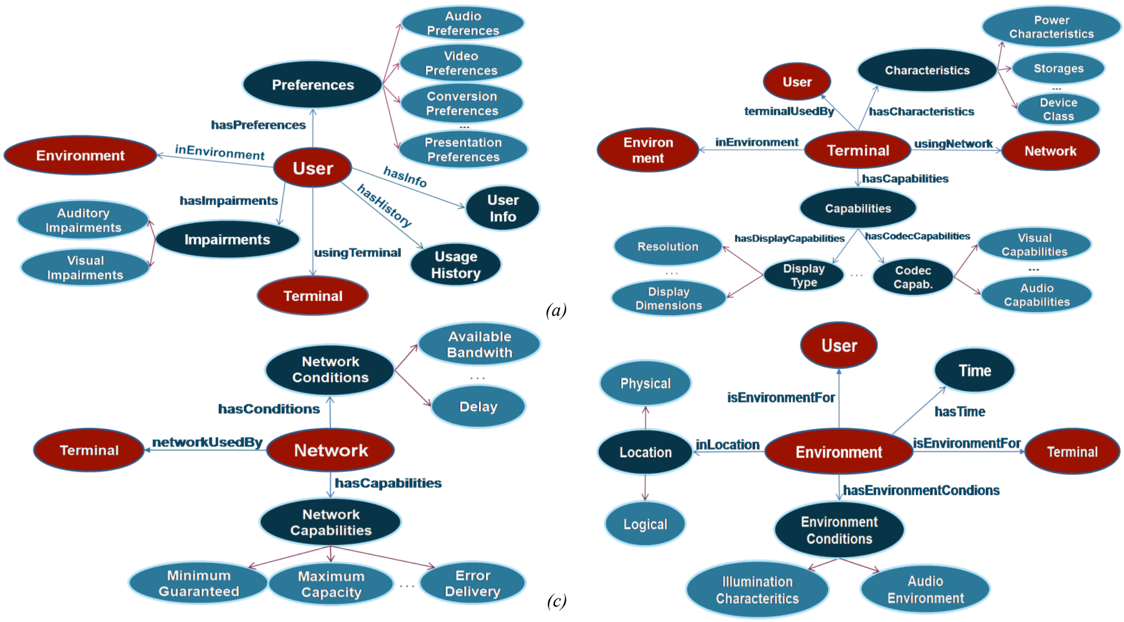

Figure 2: The conceptualisation of (a) user, (b) terminal, (c) network, and (d) natural environment ontologies

3 Proposed Architecture

The proposed context-aware adaptation platform for a virtual collaboration application [1], which is conceptually illustrated in Figure 3, consists of the following four major modules: (1) Adaptation Decision Engine (ADE), (2) Adaptation Authoriser (AA), (3) Context Providers (CxPs), and (4) Adaptation Engine Stacks (AESs) comprising Adaptation Engines (AEs) within. These modules are developed as independent units that interact with each other through Web Services-based interfaces.

The distributed modular architecture of the proposed platform ensures scalability. Well-defined interfaces based on open standards also guarantee interoperability and flexibility of freely adding, removing and migrating modules. The use of ontologies in the ADE, while being also a vehicle for interoperability, provides the platform with context-aware analysis capabilities closer to real-world situations. The AA ensures the governed use of protected content through DRM. The only standardisation initiative to integrate DRM and adaptation is the Amendment 1 of MPEG-21 DIA, named Conversion and Permissions [16]. It offers the possibility of extending MPEG-21 REL [17] licences with more fine-grained descriptions of the permitted conversions and their associated limit constraints. An extract from an example of conversions and constraints for a selected application scenario can be seen in Section 4. Flexible AEs enable the execution of a variety of adaptations that can be dynamically configured and requested on the fly. The next subsections briefly describe the functionality of each module of this platform.

Figure 3: Context-aware content adaptation platform in a virtual collaboration scenario

3.1 Context Providers (CxPs)

Contextual information can be any kind of information that characterises or provides additional information regarding any feature or condition of the delivery and consumption environment. Entities, either software or hardware, that are able to generate and provide this explicit contextual information are designated as CxPs. The low-level contextual information generated by these entities, once acquired and represented according to a standard format, will be used to infer higher-level concepts, and thus assist the adaptation decision operation.

The standardised format used in this work is the MPEG-21 DIA specification. The use of standards is instrumental to enable interoperability among systems and applications, and across services. MPEG-21 DIA specifies appropriate XML schemas to represent the low-level contextual information. In particular, the MPEG-21 UED tool provides four main types of descriptors: *User*, *Terminal*, *Network* and *Natural Environment*. Based on this division, four context profiles have been created, as illustrated in Figure 4. With these profiles, each CxP needs only to know and implement its own sphere of action resulting in a level of interoperability enhancement.

The CxPs can be various in a complex application scenario. A few of the examples for such CxPs are network operators (through the network equipment), content providers (through databases, media repositories, streaming servers, encoders etc); equipment manufacturers (through terminal devices, sensors such as cameras, microphones etc); and users (via the terminal device being used or via databases holding user profiles). The proposed platform exposes an Application Programming Interface (API) based on MPEG-21 distinguishing the different profiles as identified in this paper, which are expected to be used by these CxPs accordingly.

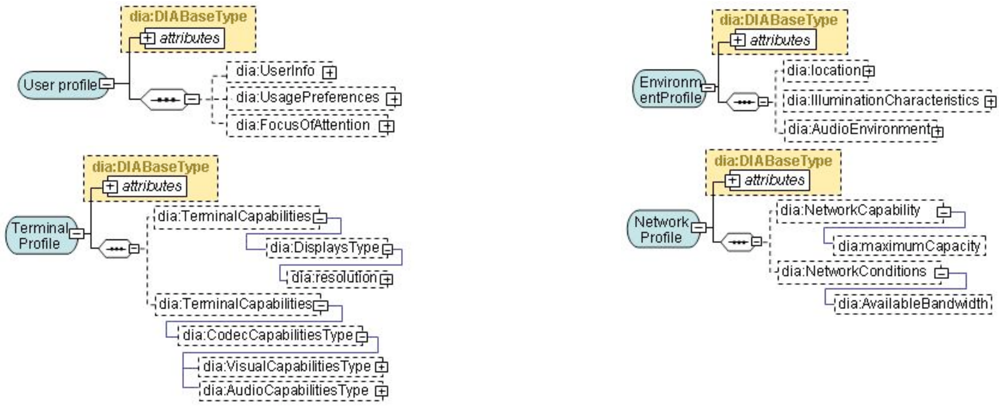

Figure 4: Virtual collaboration context profiles

3.2 Adaptation Decision Engine (ADE)

The ADE is the module responsible for taking decisions regarding the actions to perform to maximise the user's quality of experience when the contextual information is available. The architecture of the ADE being designed in VISNET II is illustrated in Figure 5 [12]. In this architecture, a central coordinator interacts with dedicated modules responsible for sensing low-level context generated by the CxPs, such as terminals, networks, electronic equipment, and other required content-related metadata (media characteristics) and rules for reasoning specific to the application in view. The acquired context is processed by these modules and formatted into the identified UED, using the context profiles described in the previous section.

The greatest challenge in the design and development of the ADE relates to the *Reasoner*. Whenever rules, together with new or updated contextual information, are available, the *Reasoner* is invoked by the *ContextServiceManager* and interacts with the *DecisionTaking* module to select the most appropriate adaptation and corresponding service parameters. This will be done through the use of ontologies, as described in Section 2. This ontology will have a virtual classroom-specific layer providing the means for the ADE to infer the state of the user, such as the type of user, the location or activity in which he/she is engaged, the degree of satisfaction being experienced, the type and characteristics of the terminal being used, or the environment and network conditions. In this way, the ADE will be able to describe real-world situations, which, together with low-level contextual information, drive the adaptation decision taking process.

3.3 Adaptation Authoriser (AA)

In general terms, the main role of an AA in a governed system is to allow (or disallow) adaptation operations based on whether they violate any conditions expressed in the licenses. In this paper, we present an innovative proposal for the implementation of an AA. Within the proposed modular platform, the AA acts as a new "CxP", which converts licenses into adaptation constraints. Complementing those presented in Section 3.1, a novel context, namely *Authorisation Profile* is developed for this contextual information, which comes from the AA, as shown in Figure 6. The AA looks into the DRM repository (Figure 3) to find all the licenses associated with a certain resource and user, and passes relevant adaptation constraints to the ADE, so that it can take an appropriate adaptation decision.

3.4 Adaptation Engine Stacks (AESs)

The AESs considered in this platform are capable of performing multiple adaptations, as illustrated in Figure 7. The service initialisation agent is responsible for initialising each component in the AES. After initialising the AES, the registering agent communicates with the ADE to register its services, capabilities and required parameters. It is also responsible for renewing the registered information in case of any change in its service parameters. The adaptation decision interpreter processes the adaptation decision message from the ADE requesting the adaptation service. Based on this information, it also decides the appropriate AE to be invoked and its configurations. The progress of the adaptation operation is monitored by the AE monitoring service and if necessary, it informs the progress back to the ADE.

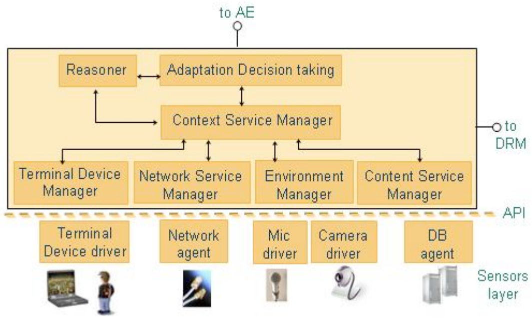

Figure 5: Adaptation Decision Engine

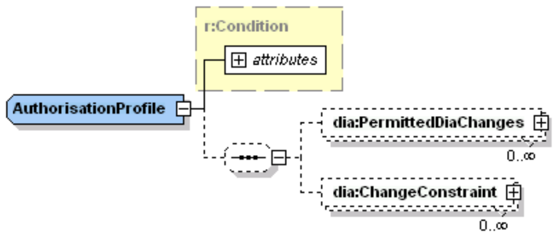

Figure 6: Authorisation profile

4 Interfaces between modules

This section provides the insights into the interfaces required between the previously described modules and the sequence of events that take place while performing DRM-based adaptation for a particular user or group of users. Figure 8 represents the functional architecture of the proposed platform, in which the interfaces between modules are illustrated. For this distributed environment, the exchange of messages should be addressed using Simple Object Access Protocol (SOAP), a simple and extensible Web Services protocol [18]. The sequence of messages transferred between each module is summarised in the sequence chart shown in Figure 9, and relevant messages are explained in Table 1.

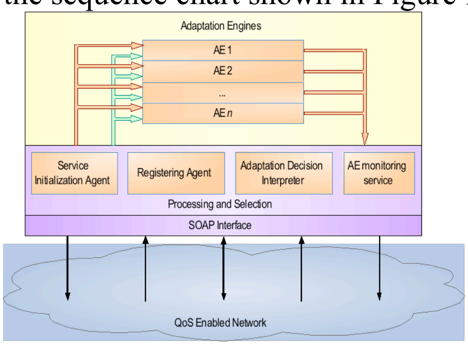

Figure 7: Organisation of an AES

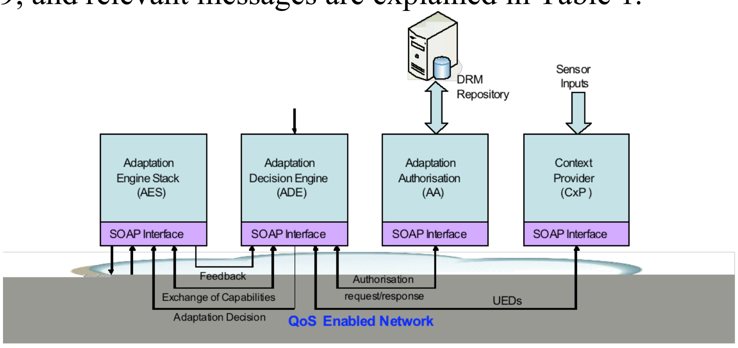

Figure 8: Functional architecture of the proposed platform for context-aware and DRM-enabled multimedia content adaptation

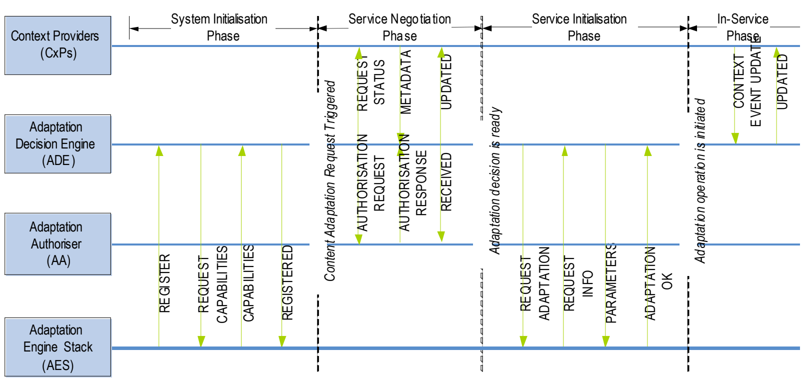

Figure 9: Sequence chart of messages exchanged between each module

Table 1: Description of messages exchanged among the modules

Message	Interface	Semantic Meaning
REGISTER	ADE-AES	In this message, the AES notifies the ADE that there is an available AES to perform content adaptation.
REQUEST CAPABILITIES	ADE-AES	The ADE confirms the reception of the request for registration from the AES, and enquires on its adaptation capabilities.
CAPABILITIES	ADE-AES	The AES provides information about its adaptation capabilities, *i.e.,* the available AEs.
REGISTERED	ADE-AES	This message comprises the ADE's confirmation of the reception of the AES's registration request, and this finalises the registration of the AES.
AUTHORISATION REQUEST	ADE-AA	This message is sent by the ADE to request information about the adaptation authorisation associated with a content and User.
AUTHORISATION RESPONSE	ADE-AA	The AA provides the authorisation information – a list of permitted adaptation operations and associated constraints.
RECEIVED	ADE-AA	An acknowledgement message from the ADE.
REQUEST STATUS	ADE-CxP	ADE invokes the contextual information to be extracted by the CxPs.
METADATA	ADE-CxP	The contextual information is sent by the respective CxPs.
UPDATED	ADE-CxP	ADE sends an acknowledgement message to inform that the contextual information has been received correctly.
REQUEST ADAPTATION	ADE-AES	When the decision is taken and authorised, the ADE informs the registered AES that an adaptation is needed.
REQUEST INFO	ADE-AES	The available AES informs that it is ready to respond to the specific adaptation request.
PARAMETERS	ADE-AES	The appropriate parameters are passed from the ADE to AES to assist the adaptation process.
ADAPTATION OK	ADE-AES	The AES has received the parameters and informs the ADE that it is capable of performing the requested adaptation operation.
CONTEXT EVENT UPDATE	ADE-CxP	The CxP sends the respective new contextual information to the ADE.

4.1 ADE-CxPs Interface

To obtain low-level context information, the ADE can either query CxPs or listen for events sent by CxPs depending on the service status. During the service negotiation phase, the ADE queries the CxPs, as shown in Figure 9. The received contextual information is formatted in standard MPEG-21 DIA UED descriptors, and registered in the ontology model. During the in-service phase, the CxPs work in a "push" model notifying the ADE when a new context is available via the context update message. In this way, the ADE is enabled to react to any significant changes in context, and adjust the adaptation parameters accordingly to maximise the user satisfaction under new usage environment conditions.

4.2 AES-ADE Interface

While designing the interface between the AES and ADE, factors such as ability to have multiple AESs operating within the system and their ability to join, leave and migrate seamlessly are considered. In order to provide the aforementioned flexibility, a dedicated service initialisation phase, which is initiated by the AES, is introduced. The parameters exchanged in this phase are mostly related to the AES's capabilities. Therefore, the AES informs its adaptation capabilities and necessary metadata related to those capabilities, *e.g.,* maximum and minimum bit rates, maximum spatial resolution etc, along with the registration request message. In order to conclude the registration on the ADE database, the AES should also inform the ADE of its IP address and the service identifier. Once the registration is completed, the AES is ready to perform adaptation operations in response to the relevant ADE requests.

After taking an adaptation decision, the ADE invokes the service initialisation operation, as shown in Figure 9. During the service initialisation phase, the ADE requests from the AESs to invoke the selected adaptation operations on the original Digital Item (DI) and forward the adapted DI to the user. This request also contains the related adaptation parameters including the source DI, desired adaptation operations and associated metadata.

4.3 ADE-AA Interface

When dealing with protected content, the ADE's content adaptation decision is preceded by an authorisation request, which identifies the *User* that consumes the adapted content and the *multimedia* resource, which is going to be adapted by its DI Identifier. The AA responds to this request with all the adaptation related information contained in the license associated to the referred *multimedia resource* and *User*. This information includes the permitted adaptation operations as well as the adaptation constraints associated to those operations. Both the permitted adaptation operations and related constraints are expressed in a format compatible to MPEG-21 DIA.

An extract from a possible authorisation response from the AA is shown in Table 2. Here, we considered a use case of the virtual classroom application [12], in which a student wishes to attend a virtual classroom session using his/her PDA over a 3G mobile network.

Table 2: An extract from an MPEG-21 DIA authorisation response

```
<dia:permittedDiaChanges>
   <dia:ConversionDescription xsi:type="dia:ConversionUriType"> <-- Adaptation of TemporalResolution -->
      <dia:ConversionActUri uri="urn:visnet:TemporalResolutionScaling"/>
   </dia:ConversionDescription>
   <dia:ConversionDescription xsi:type="dia:ConversionUriType"> <-- Adaptation of the Bit Rate -->
      <dia:ConversionActUri uri="urn:visnet:BitRateTranscoding"/>
   </dia:ConversionDescription>
   <-- Further ConversionDescription would go here -->
</dia:permittedDiaChanges>

<-- These constraints apply whether or not the image is adapted -->
<dia:changeConstraint>
   <dia:constraint>
       <dia:AdaptationUnitConstraints>
         <dia:LimitConstraint> <-- Minimum limits for the TemporalResolution -->
            <dia:Argument xsi:type="dia:SemanticalRefType"
               semantics="urn:mpeg:mpeg21:2003:01-DIA-MediaInformationCS-NS:20"/>
                  <-- 20 refers to TemporalResolution -->
            <dia:Argument xsi:type="dia:ConstantDataType">
               <dia:Constant xsi:type="dia:IntegerType">
                  <dia:Value>10</dia:Value>
               </dia:Constant>
            </dia:Argument>
            <dia:Operation operator="urn:mpeg:mpeg21:2003:01-DIA-StackFunctionOperatorCS-NS:13"/>
                  <-- 13 refers to the operator ">" -->
         </dia:LimitConstraint>
         <dia:LimitConstraint> <-- Bit Rate minimum limit -->
            <dia:Argument xsi:type="dia:SemanticalRefType"
               semantics="urn:mpeg:mpeg21:2003:01-DIA-MediaInformationCS-NS:7"/>
               <-- 7 refers to Nominal Bit Rate-->
            <dia:Argument xsi:type="dia:ConstantDataType">
               <dia:Constant xsi:type="dia:IntegerType">
                  <dia:Value>30000</dia:Value>
               </dia:Constant>
            </dia:Argument>
            <dia:Operation operator="urn:mpeg:mpeg21:2003:01-DIA-StackFunctionOperatorCS-NS:13"/>
               <-- 13 refers to the operator ">" -->
         </dia:LimitConstraint>
      </dia:AdaptationUnitConstraints/>
      <-- Further constraints would go here -->
   </dia:constraint>
</dia:changeConstraint>
```

To the best of our knowledge, the platform presented here could be the first practical implementation of adaptation authorisation based on MPEG-21 DIA. To date, DRM systems are mostly based on MEPG-21 REL or OMA DRM [8], and allow a limited governance of adaptation operations. However, the fine granularity of detailed descriptions included in our approach offers an added value to the governance of adaptations, as it allows, for example, controlling the usability of the adapted content.

5 Conclusions

In this paper, we have presented the concepts and architecture of a proposed scalable platform for context-aware content adaptation, especially suited for virtual collaboration applications. The innovative character of this platform is brought out by addressing different aspects concerning the delivery of networked multimedia content simultaneously. This has been demonstrated with the proposed platform by combining the use of ontologies and low-level context to drive the adaptation decision process; verifying and enforcing usage rights within the adaptation operations; incorporating multi-faceted AEs; and being able to deliver on-the-fly, on-demand, different adaptation operations that suit various dynamic requirements. It is envisaged that the definition of such a modular architecture with well-defined and standards-based interfaces will greatly contribute to interoperability and scalability of future content delivery systems. Besides the virtual collaboration (e.g., classroom) application, the proposed content adaptation platform can also be used in several other multimedia applications, such as mobile video, video-on-demand, e-learning, e-health, gaming etc. Current state-of-the-art research on context-awareness systems is investigating many of the aspects covered in this paper, although typically these tend to be dealt with in an isolated manner, as opposed to the platform presented here. The future work will investigate issues, such as user privacy (context protection) and protection of the adapted content as well as incorporation of new adaptation technologies into the platform.

Acknowledgements

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