An Integrated Approach for End-to-End Quality of Service Offering in Multi-domain Heterogeneous Environment

Invited paper

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ABSTRACT

Delivery of multimedia services over heterogeneous networks and terminals is facing an increased market demand. Multimedia applications have performance constraints that cannot be met in best-effort environment. Providing end-to-end Quality of Service (QoS) guarantees in multi-domain environment is still a big challenge. This paper highlights the problems and issues on offering QoS in heterogeneous environment and then presents an end-to-end solution for multimedia content offering, developed in ENTHRONE project[1], based on an Integrated Managemnet Supervisor (EIMS). It is an MPEG-21 oriented system, which deals with content generation, and handles content adaptation, QoS provisioning, and content distribution, as well as performing service monitoring and maintenance across QoS-enabled heterogeneous networks.

General Terms

Management, Design, Measurement, Standardization, Experimentation, Security

Categories and Subject Descriptors

H.3.4 [Systems and Software]: Distributed systems, Information networks, Performance evaluation (efficiency and effectiveness)

Keywords

MPEG-21, heterogeneous networks, Quality of Services, service management, SLA/SLS.

1. INTRODUCTION

Offering multimedia services in multi-domain heterogeneous environments is quite a big challenge. The increasing demand for multimedia content to be offered at large scale (i.e., the Internet), requires the provision of new Quality of Service (QoS) enabled mechanisms, techniques, and architecture to efficiently control, manage, and monitor services and networks. This poses a real challenge to research communities to tackle a number of main issues including:

- Access to various contents through diverse networked terminals with quality at agreed price is becoming necessary and widespread.
- QoS is expected at various levels and a mapping is achieved between these levels: Perceived QoS (PQoS) from user perspectives meeting user expectation, Application QoS (ApQoS) meeting application different requirements and Network QoS (NQoS) to achieve/determine certain performance across network domains.
- Deployment of QoS-based services across the large networks needs means to enable a large number of providers to co-operate in order to extend their QoS offerings over multiple domains.
- Service management becomes increasingly important for provisioning, offering, handling, and fulfilling variety of services.
- QoS monitoring is crucial to service providers for providing quantified QoS-based services and service assurance and to network providers for provisioning decisions and managing network resources at both intra and inter-domain levels.

Hence, an appropriate infrastructure is needed for allowing user and provider communities to interact in an interoperable way enabling access to multimedia content anywhere at anytime. Various business models can be considered to achieve this co-operation in offering end-to-end (E2E) services, involving a number of business entities such as *Service Providers (SP), Content Providers (CP), Network Providers (NP), Content*

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Consumers (CC), Access Providers (AC), Brokers/Resellers, etc. An SP provides the targeted services to the end-users and an NP manages an autonomous networking domain. The business model defines the roles and relationships between the business entities in terms of service delivery, information exchange, and financial settlements.

A complete architectural solution for multimedia content offering is currently proposed in ENTHRONE project [1, 2,3, 4]. It aims to cover the entire audio-visual service distribution chain, including content generation, protection, distribution across QoS-enabled heterogeneous networks and reception at diversed terminals. ENTHRONE is concerned with end-to-end QoS in terms of performance targets at the *user*, *application*, *terminal* and *network* levels and manages the mapping between these levels. It proposes an *Integrated Management Supervisor (EIMS)*, [3], [4] based on MPEG-21 standard, sitting at the top of a heterogeneous network infrastructure and manages the interactions among aforementioned business entities. The EIMS assures E2E QoS provisioning by achieving the required "horizontal" coherence of management and control activities, based on *Service Level Agreements/Specifications (SLA/SLS)* concepts. The QoS approach includes the content adaptation, i.e. the adjustment of the application to the network and terminal capabilities and/or to compensate for the deficiencies of the network.

The paper is organized as follows. Section 2 briefly presents an overview of related works. It provides then the ENTHRONE solutions , where the primary target is to generate, adapt, and transport media resources (multimedia contents) from CP's content servers (CS), through several domains up to regions where users (CCs) are located. Section 3 presents the ENTHRONE E2E QoS framework. Section 4 discusses content adaptation and cross-layer QoS mapping. Section 5 discusses the service management and resource provisioning and QoS-based service and network monitoring. The conclusions and future activities are presented in section 6.

2. THE CONTEXT AND BACKGROUND

Large user communities exist today, with various QoS preferences, accessing services over heterogeneous networks via different terminals (from mobile phones to high definition TVs). Access networks can be diverse, wire-line/wireless (e.g., xDSL, WLAN, WMAN, GSM, 3G, etc.), connected to various backbone networks (e.e., IP, DVB). All these are different in bandwidth and quality of service (QoS) that they can support. In addition, users have different content/presentation preferences and intend to consume the content at different locations, time, and under changing circumstances.

Research and standardization targeted to *Universal Multimedia Access (UMA)* [6, 7, 8], tempt to comply with the scenarios indicated above. UMA is not a last hour concept, but it has only been recently that this concept gained momentum. First, UMA enables heterogeneous terminals with limited capabilities to access rich media resources. UMA addresses the delivery of multimedia resources under different and varying network conditions, diverse terminal equipment capabilities and specific user or creator preferences and needs. This is to provide the best possible QoS or Quality of Experience to the user with regard to the actual usage environment by adapting the media resources. The access should be transparent and convenient, i.e., the user does not need to trigger or even does not notice that content negotiation, adaptation, and/or personalization has to take place to enable high quality media consumption under the given circumstances.

MPEG-21 [9] is the ISO/IEC standard (divided in 18 parts) currently under development in MPEG. It focuses on the development of an extensive set of descriptions and tools to facilitate the transactions of multimedia content in heterogeneous network environments. MPEG-21 is a vehicle towards the implementation of UMA, notably via its parts 2 (Digital Item Declaration Language, DIDL) [10], 3 (Digital Item Identification, DII) [11] and 7 (Digital Item Adaptation, DIA) [12]. One of the basic concepts of MPEG-21 is the Digital Item (DI): a structured object with standard representation, identification, and associated metadata. It is the unit that is acted upon; managed, described, exchanged, collected, etc. Each DI has associated to it, apart from media resources and descriptions, an XML document that enables the declaration of the structure and parts of the DI. This XML document is the MPEG-21 Digital Item Declaration (DID) expressed according to part 2 of the standard (DIDL). Part 7 of the standard (DIA) provides a set of tools to assist content adaptation operations. In particular, the tools Usage Environment Descriptor (UED), Adaptation Quality of Service (AQoS) and Universal Constraints Descriptor (UCD), define a set of descriptors and methodologies to describe the context of usage, the operations that can be performed upon the content and the result that can be expected in terms of quality. These tools can be used to analyse the current status of the consumption environment, decide upon the need to perform adaptation and finally notify adaptation engines, to adapt the stream to particular usage constraints (e.g. available network bandwidth or terminal display capabilities) and to user preferences (e.g. removal of undesired objects from an MPEG-4 stream or retrieval from the server some of the media components of a stored DI only). Systems adopting this approach, upon the same query, are able to produce different results according to the diverse usage environment constraints and/or user preferences/profiles. Figure 1 shows the layout of the functional architecture of an adaptation framework based on the MPEG-21 concepts.

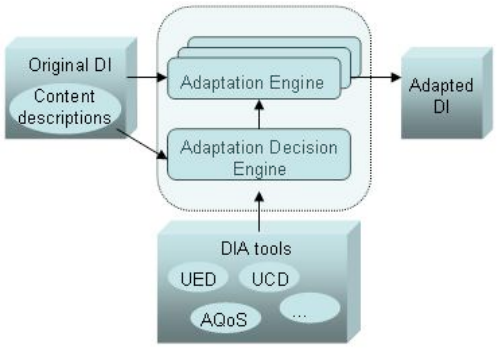

Figure 1: MPEG-21 adaptation.

MPEG-7 [13] in addition to providing description schemes to encode low-level features and high-level semantics of audio/video (A/V) content, specifies descriptions schemes to express preferences of the user and to provide content adaptation hints. MPEG-21 user preferences can be expressed using the relevant MPEG-7 descriptions. Research groups worldwide are investigating the use of the MPEG-21 and MPEG-7 tools to develop efficient adaptation engines with the goal of

implementing UMA-enabled systems [8]. In addition to MPEG, other standardisation bodies have also conducted work towards the support of context-aware applications and universal access. That is the case of the World Wide Web Consortium (W3C) or the Internet Engineering Task Force (IETF), both of which have delivered related specifications in the last years. In particular the W3C has been quite active in the field of context-aware applications, having delivered the Composite Capability/Preferences Profiles specification [14]. It provides the means to specify client capabilities (i.e. the "user agent" information) and user preferences using Uniform Resource Identifiers (URIs) and Resource Description Framework (RDF) text sent in HTTP requests. The user agent specifies the preferences of the user in the header of the client HTTP request, such as versions of content or languages, and is empowered with negotiation capabilities. Many of the current specifications and approaches being studied or developed towards the implementation of content adaptation operations in particular in mobile environments rely on the use of W3C technologies.

The media flows transport through networks can significantly influence the perceived QoS seen by the end user. Nowadays the IP based networks are extended over other traditionally non-IP environments (e.g. DVB and other access networks) and become a ubiquitous *multi-service multi-domain heterogeneous network*. Therefore, QoS related technologies, mechanisms and their integration are still subject to further investigation, especially in multi-domain environment, considering *heterogeneity of networks, QoS-based service management* QoS-enabled intra- and inter-domain *resource management*, and the need for *independence* of network providers in managing and controlling their networks, etc.

A number of European research projects have dealt with end-to-end QoS intra-domain and inter-domain issues (AQUILA, TEQUILA, CADENUS, MESCAL, EuQoS, etc.) [15, 16, 17, 18, 19, 20, 21]. While proposing viable solutions for E2E QoS, their scopes are rather limited. AQUILA did not consider the roles of different stakeholder roles at service, access, and network planes. Neither TEQUILA nor MESCAL is concerned with end-user services or service creation, i.e. the process of (automated) service definition and service offering by the SPs. Neither project developed an end-user application service framework taking into account the business-related aspects of high-level service offerings and the different roles of the stakeholders such as APs, SPs, CPs, CCs, etc. CADENUS is more service oriented but it does not get into details of how static and dynamic resource management and traffic engineering is achieved at the network level and the use of MPEG-21 at service level. EuQoS is limiting his scope to end-to-end network resource management.

Here, the ENTHRONE project proposes a complete integrated, scalable, and deployable solution for transport of media resources across heterogeneous multi-domain networks, by taking into account both service and resource provisioning to fulfil the MPEG-21 vision and requirements.

3. END-TO-END QoS IN ENTHRONE

Figure 2 presents the high-level ENTHRONE architecture from two perspectives. First, it is vertically structured into two "macro-layers", i.e., '*Application and Service Layer'* and '*Transport Layer'*. The figure also shows on the top the business actors co-operating in the E2E service offering. This approach follows the recent architectural trends, which aim at decoupling the applications and services from transport technologies, in order to allow transport heterogeneity in the core and access. The upper macro-layer contains *Applications,* which may use *Services.* Second, the system is traditionally divided into *Management Plane (MPl)*, *Control Plane (CPl)* and *Data Plane (DPl)*. The *Data Plane (DPl)* is responsible to process (e.g., traffic classification and conditioning in Diffserv) and transfer the multimedia flows. For instance, at Application and Service Layer macro-layer, the *DPl* may run mechanisms to adapt/transform media flows under control of *Media Control Middleware (MCM)*. At transport layer, *DPl* runs network level data flow mechanisms for traffic control and QoS assurance (e.g., DiffServ for IP, MPLS, DiffServ-like for DVB, etc.). The *MPl* performs long-term functions related to service management at the Application and Service Layer macro-layer and resource and traffic management at Transport layer. The *CPl* performs the short-term control functions as well as routing. At Application and Service Layer macro-layer it accomplishes the service and session control. The ENTHRONE specific *Media Control Middleware* (MPEG-21 oriented) controls all media flow related actions such as content preparation, handling, adaptation and consumption. The *Service Management* establishes appropriate SLAs/SLSs among the operators/ providers/ customers. In multi-domain environment the *MPl* and *CPl* are logically divided in two sub-planes, intra- and inter-domain.

A fundamental architectural requirement for ENTHRONE management system [1], [2], [3], [4] is to assure compatibility with different legacy management systems of SP, NP, and CPs. Therefore, as presented in Figure 2, the EIMS implements only the upper layers of the architecture (see the Figure 2 dashed rectangle marking the EIMS scope), while the intra-domain management, control and data plane functions can be left intact in each autonomous domain.

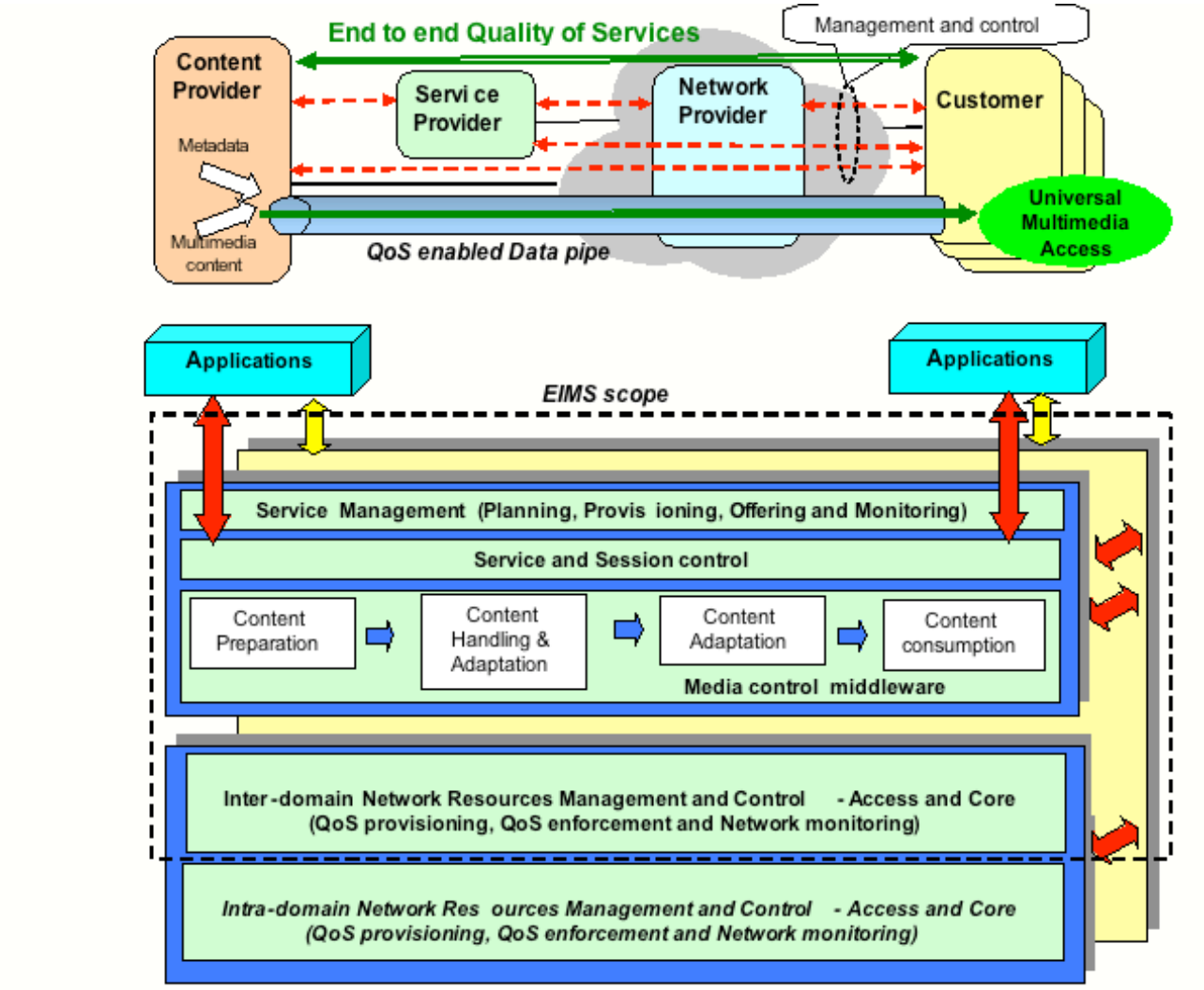

Figure 2: High level view of ENTHRONE architecture in the 3G UMA perspective.

The EIMS performs a number of functions: *Content preparation* (the EIMS-Content Manager@CP with the generation of DIDs and subsquent publishing on a data base; *Content handling* (the EIMS-CM@SP for the storage and access to the content data bases and repositories; the EIMS Dispatcher when processing the content to analyse the metadata); *Content adaptation* (the EIMS Dispatcher takes decisions to adapt; the EIMS-CM@CP receiving the adaptation parameters and passing them to the TVMs); *Content consumption* (the IMS-Terminal Device Manger reporting terminal capabilities, user preferences and PQoS alerts to the Dispatcher; the Em3w running on the terminal and passing the DIDs to the DIBrowser or invoking/controlling the media player; the EIMS taking reactive measures during the service consumption in case of quality degradation). All these functions have been represented as *Media Control Middleware.*

The end-user selects a service with a given or chosen QoS, based on subscription to services either with published/well known SLAs, or dynamically negotiated SLAs which are translated by a provider into a set of SLSs, required for network configurations. The service provisioning is accomplished using SLS, defined in a specific way dependent on low level QoS technology.

The EIMS also processes user requests. This comprises the support for content search and service-level management and control. It also performs monitoring functions including the adaptation decision making process both at service request as well as throughout the service delivery. A high-level block diagram of the EIMS is depicted in Figure 3.

The Dispatcher sub-system is the core to EIMS for coordinating the management of services, user requests, and monitoring the agreed services. Cooperating with other sub-systems, it processes user requests to search and consume the adapted multimedia content with a given quality and monitors the service throughout its lifetime. It uses content and context metadata, mostly MPEG-21 descriptions, related with the request and initiates a set of operations accordingly. In a simplistic way, all the EIMS subsystems can be seen as providing services to EIMS Dispatcher, more specifically to its Adaptation Decision Engine (ADE) subsystem, with the metadata it requires to take its adaptation decisions, and to convey these decisions to lower level components, for example transcoders. EIMS Dispatcher is service oriented and normally reside at the SP premises.

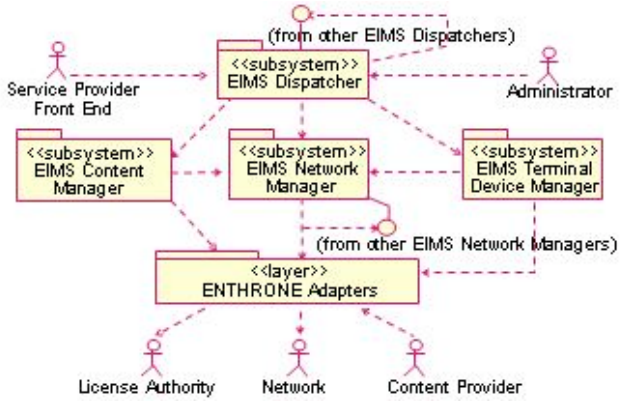

Figure 3: EIMS subsystems

The EIMS Netwok Manager (EIMS-NM) provides a bridge between the content/user-oriented service environment at the SP side and the transport-oriented world at the NP side. Whilst the SP and its EIMS-Dispatcher operate in the MPEG-21 world, the IMS-NM functions at networking level for both service and resource management. The EIMS-NM at NP also includes a service management part which deals with the interactions with other NPs or SP.

The EIMS-Terminal Device (TD) Manager provides a platform-independent interface to various types of terminals, enabling their seamless interaction with the EIMS Dispatcher. It collects and passes onto the EIMS Dispatcher, information concerning the terminal, the user and the surrounding environment and notifies the occurrence of PQoS alerts generated by PQoS probe/s installed at the terminal. (when the measured value of perceived quality drops below a given threshold). The PQoS probes are explained in more detail in the section 5.

The EIMS Content Manager is responsible for the storage, access to and handling of multimedia metadata and resources; provides search and upload functionality. It is responsible for content publishing in the form of MPEG-21 DIs, containing all the content-related metadata as required by the EIMS Dispatcher. It also enables the local configuration of diverse adaptation engines.

4. CONTENT ADAPTATION AND QoS CROSS-LAYER MAPPING

4.1 Content Adaptation

The ultimate goal of the ENTHRONE system is to provide QoS-controlled multimedia services to end-user terminals having different capabilities. The capabilities of the terminal and the user preferences are encoded as MPEG-21 descriptions using the UED tool and passed to the EIMS Dispatcher together with the user service and quality requests. The EIMS Dispatcher incorporates an ADE that uses the AQoS tool specified in MPEG-21 DIA. Network characteristics and the capabilities of available adaptation engines are also encoded in the form of UED. The AQoS tool is used for describing the characteristics and quality of the multimedia content, the operations that can be performed upon it and the result in terms of quality. For each available DI, an AQoS description is generated and incorporated into the associated DID during the content generation and metadata aggregation processes. Using PQoS probes, several sets of content attributes/encoding parameters/quality are generated and included in the DID as AQoS descriptions. These descriptions basically provide the information regarding the expected quality of a DI for different encoding operating points, so as to optimise the quality and encoding parameters taking into account the parameters present in the UED description.

Upon receiving the description of the context of usage (content adaptation metadata, networks and usage environment constraints and user preferences), the EIMS Dispatcher invokes the ADE to select the appropriate adaptation operation and service parameters. If different versions of the selected content already exist in a media repository, the ADE identifies the variation or version of the content that is able to satisfy all the constraints. If it needs to be generated on the fly (e.g. adapted by transcoding), the ADE obtains the values of the encoded parameters that need to be passed to the adaptation engine to obtain the desired version of the content. In addition, the system uses PQoS measuring tools (PQoS probes) placed at the user side as well as along the network path. Such tools are used to monitor the end-user perception of audiovisual quality of the content being delivered and send alerts to the EIMS Dispatcher. An alert is issued when quality becomes unacceptable, e.g. when it drops below an agreed level. These alerts are used to trigger new adaptation decision operations in light of the new restrictions (mainly in terms of bandwidth). As a result, a new set of system parameters is obtained and passed to the adaptation engine.

4.2 Cross-layer QoS Mapping

The QoS mapping are carried out in two directions. First is called *PQoS to NQoS mapping*. Targeted PQoS for end-user perception of audiovisual quality is mapped to application quality (ApQoS) and then to network-level quality (NQoS) using top-down cross-layer approach. In the translation process, the AQoS tool metadata are used twice: first, to map PQoS to ApQoS and second to map the ApQoS to NQoS.

```
        (via AQoS)              (via AQoS)
PQoS --------------> ApQoS ----------------> NQoS
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The parameters associated with NQoS determine the networking requirements of user requested media content. The desired values of NQoS parameters guide the SP/NP in order to utilize, which QoS-enabled aggregated pipe for this media stream (see section V.A).

Second is called *NQoS to PQoS mapping*. Different techniques can be used to derive values of PQoS parameters from NQoS measurements. The mapping result is used as feedback to SP's IMS Dispatcher in its decision-making process. It is used also as an input to the ADE to compute a new adaptation if necessary.

ENTHRONE considers an experimental approach to establish *PQoS to NQoS mapping* in both directions (such as encoding and network parameters), which allow to generate AQoS descriptions. A database of video streams is generated using a wide range of content types (studio, sports, news, and advertisements), various encoding configurations (data rate, frame rate, resolution, etc.) and transmitted over IP under several loss profiles. Then, the PQoS of video streams is evaluated using PQoS probes described in the next section, and/or during standard assessment sessions involving no less than 15 persons, [22]. The analysis of correlations between PQoS and encoding and network conditions provides PQoS to NQoS mapping rules. The analysis of ENTHRONE results has shown a strong variability with content

type, which suggests that a good mapping should take content type into account; general mapping rules have been set up, translated to AQoS metadata, and inserted in the DID. This approach has been successfully implemented and applied to content adaptation. Future investigations are being carried out to enhance the PQoS to NQoS mapping function.

5. QoS PROVISIONING AND MONITORING

5.1 Service and Resource Management

Delivery of QoS enabled services over multi-domain heterogeneous networks requires to provision QoS enabled paths over multi-domain networks. A *management system* is employed in each business entity (SP, CP, NP, CC – see Figure 2 and 3). In particular in NP, the management system is composed of *service management (SM)* and *resource management (RM),* the latter including the *traffic engineering (TE)* functions. The SM is part of EIMS-NM and deals with QoS enabled service offering to customers and it is transport technology independent. The RM manages and controls the networking resources, optimising their usage while offering desired level of QoS to the media flows. NPs can use their own existing RM systems for managing/controlling their networking resources or use the resource management offered at EIMS-NM.

Delivery of services in multi-domain environment raises inherent scalability problems. One approach to this [1], [2], [15], [16] is to establish, (based on forecasted data and prior to transmission of individual media streams), long-term, logical aggregated pipes that each can be utilised for a defined QoS class service. ENTHRONE assumes a small number of well-known QoS class services to which these pipes belong. The pipes are established through negotiation of *SLA/SLS* contracts between providers *(pSLA/pSLS)*.

The construction of pipe is initiated by SP via SM at the EIMS Dispatcher, based on its knowledge about location of CPs content servers and location of potential customers. The SP makes a request for a pipe to the SM of appropriate NP/s. The pipe could be set-up uni- or bi-directionally by the RM of NPs. The peering relationship between SP and NPs could be a star/hub one, or a *cascaded* one, [8]. The latter has been selected by ENTHRONE as more scalable because an SP does not need to interact with all NPs in the E2E chain, but only with the first one situated at the entrance of the desired path. Each pSLS request contains [1], [2] all desired NQoS parameters (bandwidth, delay, jitter, loss rate, etc.). The pipes are requested by SPs and they are agreed between SP- and an NP or an NP- and another NP during the *subscription* phase. The scope of pipes is from CSs access points up to regions where potential users are located. The actual resource allocation at the network level for these pipes can be done immediately at subscription instants, or later, based on agreed scheduling. This is called aggregate pipe service invocation.

Distinction is made, [1] between subscription and invocation of the aggregated pipes and individual user service subscription and/or invocation. After aggregated pipes are installed across network domains by NP's RM, the SP is able to offer services to individual media flows (e.g., VoD), therefore, these services can be advertised to the users. The QoS-based services using the aggregated capacities are "sold" in retail manner, to many customers, through individual contracts *customer-SLA (cSLA)* between the SP and each interested customer. The final goal is to assure for each individual flow, the desired set of E2E QoS guarantees. This approach avoids per flow signalling at inter-domain scale where signalling occurs only at the edges.

The lifetime of aggregated pipes is medium or long term. They can be redefined in some resource provisioning cycles (RPC) [15], [16], [17] run for network dimensioning purposes. The RPC denotes the time period to adjust the anticipated demand and network availability estimates. ENTHRONE also developed a suite of protocols as vehicles to transport information for: service related negotiation process between the SM of peering domains (*EQoS-SLA/SLS-NP*), resource reservation (EQoS-RA) and QoS monitoring and reporting (*EQoS-RM*), [2].

5.2 QoS Monitoring and Maintenance

QoS monitoring is crucial to SPs for providing quantified QoS-based services and service assurance and also to network providers for managing network resources (intra and inter-domain). A QoS-based monitoring system should: 1) assist SPs to verify whether the QoS performance guarantees committed in SLAs are in fact being met (e.g., PQoS monitoring) 2) assist NPs (i.e., NQoS monitoring). in making provisioning decisions for optimizing the usage of network resources (intra and inter-domain) In multi-domain environment, it is essential for providers to co-operate based on an agreed framework formulating the configuration of monitoring elements and services, the execution of measurements, the composition of results, and the exchange of measurement data. In addition to perceptional service monitoring, PQoS monitors provide to IMS Dispatcher information for content adaptation.

PQoS monitors address end-user perception of audiovisual quality and service performance at the application level. PQoS measurements are an estimation of subjective quality assessments. The subjective quality measurement involves playing a sample audiovisual content to a number of human participants for acquiring their judgment on the quality, [22]. ENTHRONE PQoS monitors provide the quality of audio and video using automated procedures, by performing the analysis of decoded signals only, [5]. In order to ensure E2E measurement consistency, a single scale set of user oriented parameters, and calibration is used, [22].

PQoS meters can be positioned in the user terminals and in the network. Terminal PQoS monitors are managed by the SP. For scalability reasons, the probes feedback is activated in few user terminals or in terminals dedicated to monitoring. In the network, PQoS monitors provide node or domain level measurements. They are installed in specific points (e.g. at the domain edges, where individual flows can be extracted) and managed by the network provider to provide measurements on specific flows. PQoS monitors can be used to detect SLS/SLA violations, locate violating domain/s, and drive appropriate EIMS adaptation actions. NQoS monitors offer various network measurements at the network or E2E levels. A detailed description of Enthrone developed QoS monitoring system, its implementation, and obtained results are given in [23].

6. CONCLUSIONS

In this paper, we have described an integrated management system MPEG-21 oriented, for providing end-to-end QoS over heterogeneous terminals and networks.. First, we considered a

business model that allows formulating the roles and relationships between the respected business entities in terms of service delivery, information exchange, and financial settlements. We developed an integrated management system dealing with the content generation, adaptation, provisioning, distribution, and monitoring. We discussed the system capabilities especially in content adaptation, cross-layer QoS mapping, service and resource provisioning and QoS-based monitoring at both service (perceived) and network levels. In summary, we believe that the presented approach is scalable and can contribute towards operationally optimized services and networks. Currently, the Enthrone consortium is validating the proposed system as well as enhancing it by adding more features.

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