SLS Management Validation for End to End QoS Management in a Multidomain Testbed Environment

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Abstract — **This paper presents the validation of an end-to-end QoS integrated management system in a multidomain test-bed environment. The integrated management system was designed and implemented in the framework of the ENTHRONE European project. This paper focuses on the network service management validation at both the Service Provider and Network Provider. The Network Service Management is based on the SLS management: in the core network the pSLS management is used to deal with users aggregated services, while cSLS management is used to deal with individual users services. Both functionality and scalability tests for SLS management are presented**

Keywords-SLS, end to end QoS Management, testbed, functional and scalability tests.

I. INTRODUCTION

Today's high speed networks together with enhanced coding techniques for audio and video have made the real time delivery of multimedia services over internet possible. These real time multimedia services raise new challenges for the network regarding the quality of services (QoS) control in order to ensure the proper delivery of the services from content provider (source) to content consumer (destination). An integrated management system should exist, capable of managing the high level services with E2E (end to end) QoS guarantees, while preserving the independency of each network domain to be administrated autonomously in terms of its resources. This management system should also be capable to accommodate heterogeneous network technologies utilized today in the Internet.

An integrated end to end QoS management system has been designed, implemented and validated in the framework of ENTHRONE project (FP6 IST-507637 European project) [3][4][5][6][7]. The ENTHRONE Integrated Management Supervisor (EIMS) [5][6] is the main management entity designed according to the MPEG-21 standard, sitting at the top of a heterogeneous network infrastructure. The EIMS offers a unified management framework in the audio-visual distribution chain. It assures E2E QoS provisioning using service management 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.

Several works exist, dealing with end to end QoS management. The IMS solution for 3G mobile network has been standardized by the 3GPP consortium [13]. Also, for the IP world the TISPAN IMS architecture was proposed by NGN group [12]. Both are based on Integrated Services (Intserv) approach for QoS management. A separate signaling path-coupled session, crossing IP core domains, e.g., based on RSVP or NSIS approach, is run for each individual call. Such a solution could raise scalability problems.

The European projects CADENUS, TEQUILA, MESCAL and EuQoS [9][10][11], have also been dedicated to the E2E QoS issues. The projects have developed solutions to provision IP premium services. Efficient solutions have been proposed for services and resources management in single domain networks, while extension over multi-domain heterogeneous networking infrastructure is still an open issue.

CADENUS focused especially on service management. It did not get into details of how static and dynamic resource management is achieved. TEQUILA [11] and MESCAL [10] basically focused on QoS aware IP connectivity network services, intra-domain and inter-domain respectively. The MESCAL did not consider the end-user services or service creation, i.e., the process of (automated) service definition and service offering by the SPs, and the business-related aspects of high-level service offerings and the different roles of stakeholders. The EuQoS project developed and integrated an E2E QoS system to support QoS aware applications, but uses per-individual flow signaling for resource provisioning thus having scalability problems.

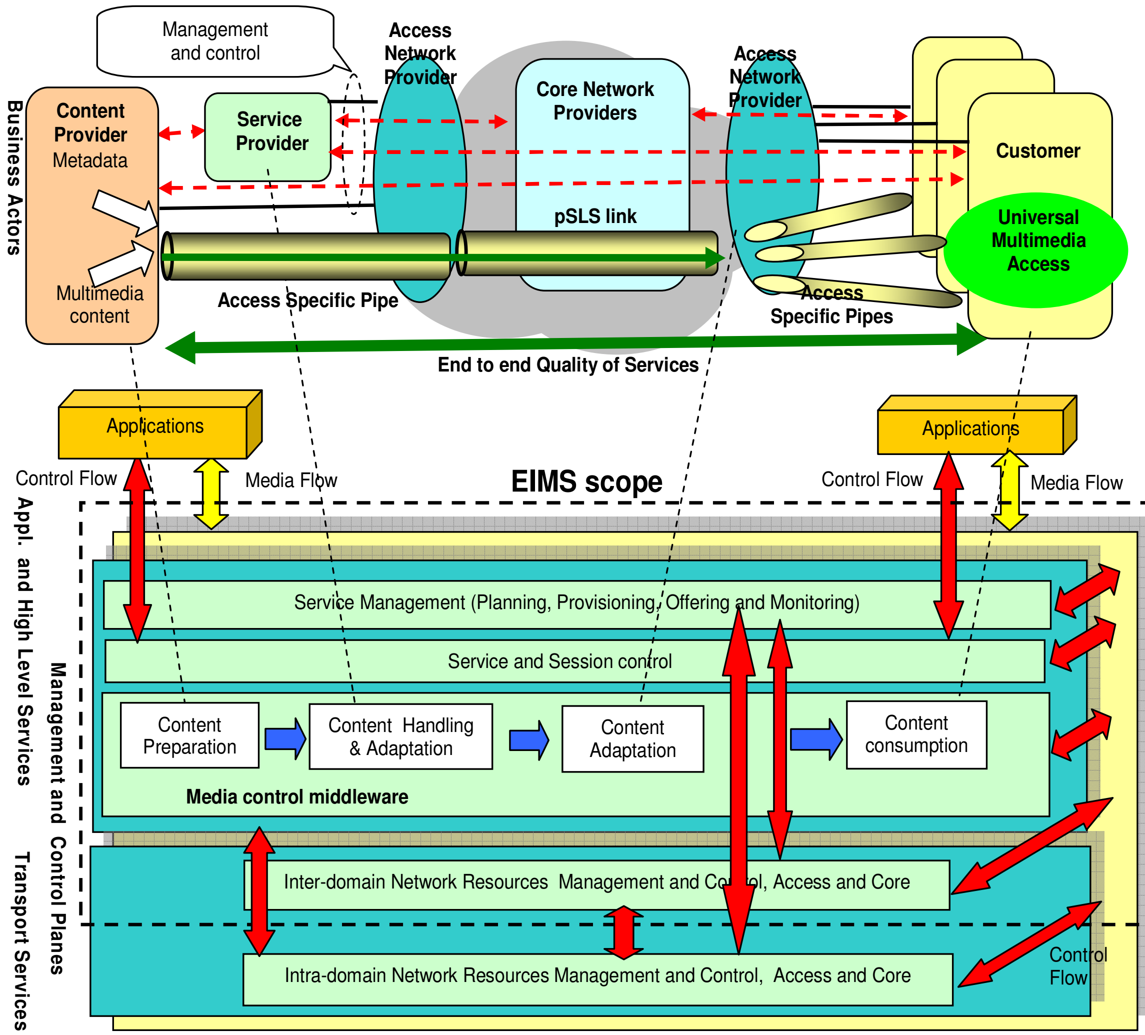

Figure 1. Multiple plane high level view of the ENTHRONE architecture

ENTHRONE architecture deals with both service level and resource management. Its EIMS is independent of network technology and harmonizes the inter-domain functioning while the network domains are autonomic in terms of resource management.

The ENTHRONE EIMS supports different business models and entities having their own resources and capabilities, but cooperating to offer value-added services for end-users. These business entities are: Service Providers (SP), Content Providers (CP)-owning Content Servers (CS), Network Providers (NP), Content Consumers (CC), Access Network Providers (ANP), Brokers/Resellers, etc., [3][4][5][6][7][8]. The SP provides high level services to the end-users, while the NPs manage their autonomous network domains. The ANPs manage the Access Networks.

ENTHRONE testbeds are set-up in several countries, that are interconnected in order to build an international pilot. Each testbed consists of a networking infrastructure (core IP domains, various access networks) and hosts having installed the relevant software components, corresponding to the business entities (SP, NP, ANP, CC, CP/CS). The testbeds are aimed at several objectives to be fulfilled: the development and validation of the software components to be integrated in the management and control system; validation of the transport services management (or IP level network services) in both access and core IP part of the network; validation and deployment of the high level services. Both functional (i.e. correctness) and scalability aspects are targeted in the test campaigns. Appropriate scenarios are specified for each kind of test.

This paper presents the implementation and infrastructure of a complex multiple domain testbed developed at University "Politehnica" of Bucharest (UPB), based on the ENTHRONE architecture. Examples are given of functional validation results.

The paper is organized as follows. Section 2 shortly presents the ENTHRONE network service management framework. Section 3 describes the Pilot set up at University "Politehnica" of Bucharest. Section 4 presents samples of scenarios for functional and performance level testing.

Section 5 presents the test results and Section 6 contains the conclusions.

II. ENTHRONE ARCHITECTURE AND NETWORK SERVICE MANAGEMENT SUMMARY

ENTHRONE has defined an E2E QoS multi-domain *ENTHRONE Integrated Management Supervisor (EIMS).* The service management (SM) is a part of the EIMS. It considers all actors mentioned above and their contractual service related relationships, *Service Level Agreements (SLA)* and *Service Level Specifications (SLS),* as defined in [3][4][5][6][7][8]. The SM is independent on particular management systems used by different NPs in their domains. The SM entities should cooperate to realize the E2E chain. They are present in different amounts in SP, CP, NP CC entities, depending on the entity role in the E2E chain. The SM located in NPs should cooperate with each domain manager and also with other actors in the E2E chain.

The QoS control is accomplished at the service level by logical QoS enabled aggregated pipes, built through the domains crossed by the path from source to destination, and logical QoS enabled individual pipes, built for each user in the access network. Several individual QoS enabled pipes are included in an aggregated pipe at the core network level.

The pSLS is a contract performed at the Management Plane, and established by horizontal negotiation signaling between two peer managers, e.g., SM@NP, in which the requested NP agrees or does not agree to offer to the requester the QoS-enabled service (in the terms of QoS enabled pipes). Negotiations are required to establish an end-to-end pipe.

The EIMS architecture at NP (EIMS@NP) contains four functional planes (Figure 1): the *Service Plane (SPl)* establishes appropriate SLAs/SLSs among the operators/ providers/customers. The *Management Plane (MPl)* performs long term actions related to resource and traffic management. The *Control Plane (CPl)* performs the short term actions for resource and traffic engineering and control, including routing. In a multi-domain environment the *MPl* and *CPl* are logically divided in two sub-planes: inter-domain and intra-domain. Therefore, each domain may have its own management and control policies and mechanisms. The *Data Plane (DPl)* is responsible to transfer the multimedia data and to set the DiffServ traffic control mechanisms to assure the desired level of QoS.

The main task of the EIMS@NP is to find, negotiate and establish a QoS enabled pipe, from a Content Server (CS), belonging to a Content Provider, to a region where potential clients are located. This unidirectional pipe is referred as pSLS pipe, and it could cross multiple domains. Each pipe is established and identified by a chain of pSLS agreements between successive NP managers. The forwarded cascaded model is used to build the pSLS pipes [7]. The pipes are unidirectional ones. An end to end negotiation protocol is used to negotiate the pSLS pipe construction across multiple network domains [7].

The process of establishing a pSLS–link/pipe is triggered by the SP. It decides, based on market analyses and users recorded requirements, to build a set of QoS enabled pipes, with QoS parameters described by a pSLS agreement. It starts a new negotiation session for each pSLS pipe establishment. It sends a pSLS Subscribe request to the EIMS@NP manager of the Content Consumer network domain. The EIMS@NP manager performs the QoS specific tasks such as admission control (AC), routing and service provisioning. To this aim, it splits the pSLS request into intra-domain respectively inter-domain pSLS request. It also performs intra-domain routing, to find the intra-domain route for the requested pSLS, and then it performs intra-domain AC. If these actions are successfully accomplished, and if the pSLS pipe is an inter-domain one, then the manager uses the routing agent to find the ingress point in the next domain, does inter-domain Admission Control and then send a pSLS Subscribe request towards the next domain. This negotiation is continued in the chain up to the destination domain, i.e., the domain of the CC access network. If the negotiation ends successfully, the QoS enabled pipe is considered logically established along the path from source to destination.

The Network Service Management (NSM) is the EIMS subsystem offering network connectivity service to the applications. The NSM manages the services and network resources by using an overlay based approach. This means that a network domain is abstracted with a virtual domain and the services and domain resources management is performed based on the virtual domain information. Each domain has its own local manager, called Intra-domain Resource Manager, which is in charge with the local domain management. Also it applies the decisions taken at the virtual level in the managed domain [7][15].

The network connectivity service is first built at the overlay level. This is done during the pSLS Subscription phase, which is performed using pSLS negotiation between the SP and the NP of the first domain and between the successive NPs along the service path. The negotiation result is an aggregated pipe built for the service traffic between the content source and the destination access network. During the pSLS Invocation phase, the pSLS pipe is installed on the network equipments of each domain, crossed by the aggregated pipe, by the associated Intra-domain Resource Managers. The pSLS pipe resources could be invoked totally or partially, depending on the amount of traffic estimated for the pSLS associated services in the following time period.

With the pSLS pipe built, the SP can now offer the service to the users by allocating pSLS pipe slices, cSLS pipes, to the individual users' calls. These cSLS pipes are built at the access network level. In this way the ENTHRONE solution avoid per flow signaling in the core domain.

III. ROMANIAN PILOT TOPOLOGY

The Romania Pilot island (RPI) general infrastructure consists of three sections:

- Core IP – The Core IP network consists of three autonomous domains, each managed by the ENTHRONE EIMS at Network Provider subsystem. The Core network is linked via GEANT with the other ENTHRONE pilots;
- Access Networks – We have implemented several type access technologies i.e., IP/Ethernet; wireless - WIMAX 802.16d, and DVB-T. For the WiMAX access based network we have developed, in ENTHRONE project, a WiMAX Resource Manager which is integrated with the ENTHRONE EIMS. It is capable of cSLS management inside the WiMAX network;
- ENTHRONE Terminals with wired or wireless access based on WLAN-802.11b/g. They are supporting the ENTHRONE signaling via the Terminal Device Manager, which is used to connect the terminal to the ENTHRONE EIMS system.

This infrastructure allows experimentations of full ENTHRONE scenarios locally, but can be interconnected to other countries' pilots too. The terminals can be fixed or mobile, with single mode or hybrid mode access. The ENTHRONE business entities supported are CC, CP, SP, NP. The relevant EIMS entities are located in: Core IP; Access (Aggregation) Networks; User Terminals; Content Providers hosts.

The UPB pilot was focused on the SLS management validation, both pSLS and cSLS management. In Figure 9 the simplified version of the pilot topology, showing only the components involved in the validation tests, is presented. There are three core IP network domains NP1, NP2 and NP3, each one managed by its own *NetSrvMNgr@NP* (in the current implementation it includes also the Inter-domain Network Resource Manager). The Intra-domain Resource Manager (*IntraResMngr@NP*) manages the resources at the local domain level. In particular, the access network technology used in our example is IEEE 802.16d/WIMAX, [5]. The AN is managed by its Resource Manager (*ResMngr@ANP*), which reserves resources on the WiMAX links at SP requests.

The structure of the core network is detailed: the allocated IP addresses, the name of the border routers and the applications installed on the testbed. The core routers are implemented using the Linux machines and the resource control in the data plane is done using the Linux Traffic Control application. The network management modules are communicating using the Web Services technology, the interfaces between them are defined using the WSDL description language [7][18][19].

The NP1 domain has four border routers (*border_an*, *border_elcom*, *border_as1as2* and *border_as1as3*). The *border_elcom* router is connected through the GEANT backbone with other ENTHRONE pilots. The AN connected to *border_an* router contains the EIMS SP machines and also the CP machines. The EIMS SP and CP machines are implemented using virtual machines.

The NP2 domain has two border routers (*border_as2as1*, *border_an103*). The WiMAX AN is connected to the *border_an103*. In this network we have the ENTHRONE terminal and player. The NP3 domain contains only one machine, with a simulated virtual domain containing three border routers (*border_as3as1*, *border_as3as2*, *border_an105*).

The main ENTHRONE components and their placement are shown in Figure 9. In red are highlighted the modules involved in the network service management: Network Service Manager at Service Provider and Network Provider (*NetSrvMngr*), the Intra-domain Network Resource Manager at Network Provider and the WiMAX Resource Manager at Access Network. A detailed description of the ENTHRONE modules could be found in [3][5][7][16]. The main task of the Network Service Manager is to find, negotiate and establish a QoS enabled pipe from a Content Server to a Content Consumer. The following components are installed at each IP domain:

- Network Service Manager at Network Provider
- Intra-domain Resource Manager: specific blocks of NP for resource management and traffic engineering
- Node monitoring and Network Monitoring

The assembly of these components provides the service and resource management for support of the network connectivity in the core network.

The overall goal of the UPB testbed was the deployment, validation and demo for a subset of the ENTHRONE general functionalities. Specifically, we targeted to test and validate the network IP connectivity QoS enabled services over several core IP domains and heterogeneous access networks (ANs), in unicast and multicast mode.

Appropriate scenarios have been defined to provide the necessary framework for functional and performance system validation. Each scenario defines the test environment and a sequence of actions (inputs, internal actions and expected outputs) to perform. We define *Operational Scenarios* (in terms of functionality), technically-oriented (correctness, scalability, stability, etc.), and usability-oriented (cost/benefit to provider and end-user) relatively to a given subsystem to be tested; *High level services Scenarios*- oriented towards services like VoD, streaming, E-learning, etc., aimed to measure the related performance and benefits seen from user perspective [20].

IV. SCENARIOS FOR NETWORK CONNECTIVITY SERVICES FUNCTIONAL VALIDATION

In this section we will present samples of operational scenarios to validate the inter-domain negotiation signaling and processing for the pSLS-links (in core IP domains) and cSLS-links (in AN) installation in the network.

These tests are aimed at validating the correctness of the EIMS Network Service Manager (NSM) implementation behavior, relative to p/cSLS subscription and invocation, in a multi-domain environment for unicast case.

The Figure 2 shows an example of a message sequence launched by SP in order to install in the networks (three IP domains) a pSLS-link. The pSLS-link invocation phase is considered. It is supposed that the pSLS-link has been already subscribed, through a similar sequence of actions. The EQoS-pSLS negotiation protocol has the task to transport the negotiation messages between entities [6][8]. This protocol has been implemented as Web Services, [7][18][19]. The pSLS subscription invocation scenario main phases are described below. The modification and deletion scenarios derive from this one.

1 The SP administrator decides, based on current needs data, to invoke, partially or totally, a previously subscribed pSLS-link. It configures the pSLS parameters in the web management interface and then it triggers the subscription of a new pSLS link. See action 0 on Figure 2. The SLS parameters specify among others, the bandwidth required, delay, and class of services associated to this request.

2 The *NetSrvMngr@SP* starts an invocation signaling session. So, it sends the pSLS invocation request, using the EQoS client, to the first *NetSrvMngr@NP*(action 1).

3 The negotiation is carried in cascaded forwarding mode between the *NetSrvMngrs@NPs*, down to the last core IP domain where the potential CCs are located. See actions 2, 3.

4. It is assumed a successful scenario where all resource checks are successful, therefore vertical commands are given by each *NetSrvMngr@NP* to its *IntraResMngr@NP* in order to install the pipe in the network (actually configuration of the Diffserv LINUX Traffic Control for the associated QoS class is done). See (4,5; 7,8; 10,11) actions.

5. Responses are returned to the upstream *NetSrvMngr@NPs*, (6, 9, 12) and then, finally, to SP Admin.

The Figure 3 shows a scenario in which a client (CC) browses a website (which can be based on a Digital Item Description -DID) which offers the latest Digital Items for consumption. The module Customer Service Manager (CustSrvMngr) is in charge with the high level service management. It is the main subsystem which coordinates all the other subsystems of the Service Provider. Then the following message sequence is performed in order to allow users access to the ENTHRONE services:

1 The CC chooses a specific DI and sends a request for it to *Service Provider Frontend* (SP-FE)

2 The SP-FE forwards it to C*ustSrvMngr*. The parameters are: the content ID, class of service, the initial (i.e., the static) usage environment (UED) of the client (Terminal Capabilities, User Characteristics/ Preferences, Natural Environment Characteristics and Network Characteristics), IP address of the client.

3. *CustSrvMngr@SP* selects a content variation list (in cooperation with other EIMS blocks not shown here)

4. The *CustSrvMngr@SP* queries the *NetSrvMngr@SP* about the available pSLS(s) between each content variation and the CC. Then (4.1, 4.2) *NetSrvMngr@SP* queries the repository to obtain a list of the appropriate pSLSes

5. *NetSrvMngr@SP* returns a list with available pSLSs, between the content sources and the access network, to the *CustSrvMngr*

6. After getting pSLS status, the *CustSrvMngr* performs other actions. Among others, it selects an appropriate pSLS link.

7. *CustSrvMngr@SP* requests cLS subscription to *NetSrvMngr@SP*. Then a sequence of actions denoted with 7.1-7.6 follows: *NetSrvMngr@SP* checks for available resources on the pSLS link, then negotiate with the access network resource manager (*ResMngr@ANP*) to reserve resources for the cSLS link in the access network. If all these actions are successfully accomplished, then the *NetSrvMngr@SP* updates the resources status and records the cSLS agreement.

8. *NetSrvMngr@SP* responds to *CustSrvMngr@SP* with the new cSLS subscription data. Other actions may be performed by the *CustSrvMngr@SP*- not detailed here.

9. 10 *CustSrvMngr@SP* responds to the CC, via *SP-FE,* about the success of the DI selection.

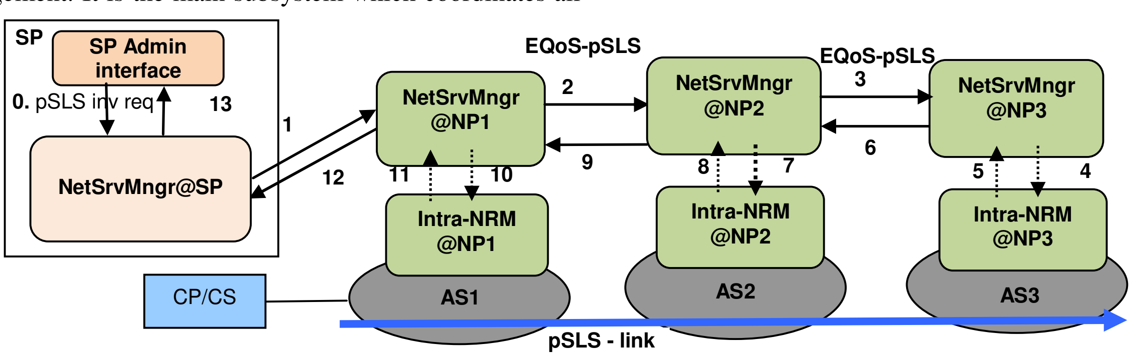

Figure 2. Basic pSLS invocation chain of signalling (3 IP domains).

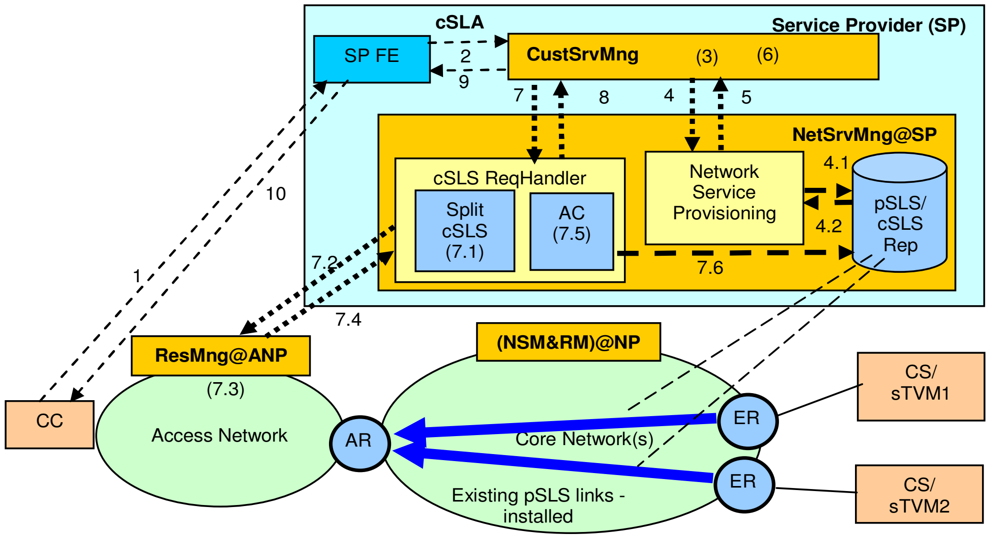

Figure 3. Message Sequence showing the pSLS status query and cSLS subscription related actions

The Figure 9 shows, in graphical form, on the testbed diagram, the results for the two scenarios above, aiming to construct a pSLS-link in the NP1 and NP2 IP domains and complete it with a cSLS-link, as a last mile installed in the WiMAX AN network. The pSLS link is subscribed spanning from *Border_an* up to *Border_an103.* The concatenated pipes at the left side (subscription phase) represent the pSLS-link subscribed. This is done at EIMS overlay level in each domain; EIMS knows only the ingress and egress points in each domain and the inter-domain links. The inter-domain route selection [21] is not the subject of this paper. The actual path established in invocation phase within each IP domain is different from the overlay one; e.g., in NP1 the path is A1, E4 and E3. The arrows 1, 2, 3, 4 represent the horizontal signaling actions between *NetSrvMngr@SP* and *NetSrvMngr@NPs* for pSLS subscription. The arrows 5,6,7,8 represent the similar actions for pSLS invocation. The arrows 6’ and 7’ represent the vertical commands given by the *IntraNetResMngr@NP* to routers in order to install the pipes (i.e. Traffic Control parameters configuration). The arrows 9, 10 and 11, 12 represent respectively the signaling actions between the *NetSrvMngr@SP* and *ResMngr@AN* to subscribe and invoke the cSLS-link in the WiMAX segment. The arrow 11’ represents the command given to the WiMAX Base Station (BS) to install the associate service flow between BS and Subscriber Station (SS). The thick line in the Figure 9 represents the path of the future media flow through the domains, form CP up to the CC. A lot of experiments for other different scenarios are reported in [17].

V. Tests Performed in the UPB Testbed

The testbed focused on validating the SLS management as standalone functionality and also integrated with the overall ENTHRONE end to end QoS management system. Functionality and scalability tests were done for the SLS management [1][2][16][17].

A. *Functionality tests*

1) *pSLS management*

In this section there are presented some functionality tests performed. The complete description of tests suit performed in UPB testbed can be found in [16].

The first suit of functionality tests refers to the pSLS subscription. The pSLS subscription request is triggered by the Service Provider’s Network Service Manager in order to reserve resources, at the overlay (virtual domain) level, in the core network. As a result of the pSLS subscription a logical pipe, pSLS pipe, is built in the core network. We made tests for intra-domain and inter-domain pSLS subscription and invocation.

As an example, for intra-domain case it was built a pSLS pipe between the *border_an* and *border_elcom* border routers (Figure 9). For inter-domain case a pSLS pipe was subscribed between the *border_an* machine (on NP1 domain) and *border_an103* machine (on NP2 domain). The *border_an* machine is the border router for the Content Server access network, and *border_an103* is the border router for the access network containing the ENTHRONE terminal. The pslsSubscribe operation was triggered from the *NetSrvMngr@SP* installed on the SP virtual machines. In the negotiation were involved the *NetSrvMngr@NP1* and *NetSrvMngr@NP2*.

In Figure 4 there are presented the messages exchanged between the *NetSrvMngr@SP* and the *NetSrvMngr@NPs* for the inter-domain pSLS subscription case. For the *NetSrvMngr@NP1,* the messages exchanged between the main modules involved in pSLS management are also detailed: pSLS provisioning, pSLS split and pSLS admission control. For the second domain a similar suit of messages will be exchanged in order to fulfill the request.

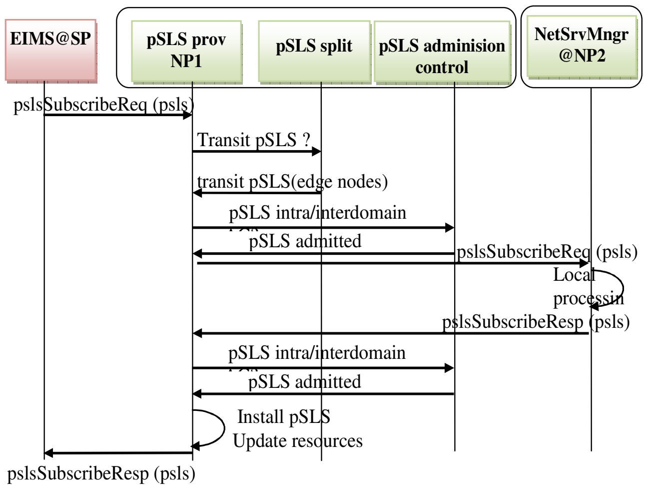

Figure 4. MSC for the inter-domain pSLS

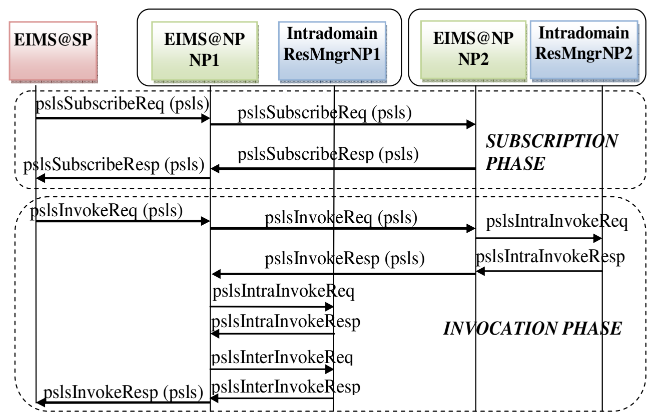

Figure 5. The MSC for pSLS subscription and invocation

For the pSLS pipe subscribed it has also tested the invocation phase. Both the invocation for intra and inter-domain case were considered.

There were triggered invocation requests from the *NetSrvMngr@SP*. In the negotiation phase, the following entities were involved: the *NetSrvMngr@NP1*, *Intra-domainResMngr@NP1* modules for intra-domain and *NetSrvMngr@NP1/NP2*, *Intra-domainResMngr@NP1/NP2* for inter-domain pSLS invocation. As a result the pSLS pipe resources were reserved on the Linux routers along the path. The bandwidth resources were reserved in the Linux router using the Traffic Control application. The reservation was performed successfully. The system was able to prioritize the pSLS traffic against a noise traffic generated in order to test the invocation result.

In Figure 10 one can see a screen capture with two movies, one whose stream is treated as best effort traffic, while the packets for the second one are transmitted through the pSLS pipe in the core network. One can see that the second movie's quality is much better than for the first movie. The traffic classes created by Traffic Control application, for best effort and for the pSLS pipe, and the noise traffic generated with Iperf application are also shown.

The operations for modifying and closing the Invocation and for closing the pSLS subscription were also performed successfully.

2) cSLS management

For the cSLS management it was performed both standalone tests, using a Customer Service Manager test module used to trigger cSLS subscription and invocation requests, and tests using the whole ENTHRONE end to end QoS management system. In this section we will present the whole ENTHRONE signaling mechanism with focus on the cSLS management.

After the pSLS subscription and invocation phases, a pSLS pipe will be established in the UPB testbed. The pSLS pipe, which is crossing both the NP1 and NP2 domains, is built from the 192.168.202.200 server to the 10.242.103.0 access network. The 192.168.202.200 server has the Adaptation TVM installed on it. In the 10.242.103.0 access network we have an ENTHRONE terminal with the ENTHRONE Player and Terminal Device Manager Client installed on it. After the pSLS pipe was built between the aTVM content server and the access network containing the ENTHRONE Terminal, the ENTHRONE end to end scenario can be run. The cSLS pipes requested by the users will be associated with the pSLS inter-domain pipe. In the 10.242.103.0 access network we have a WiMAX based network, managed by an ENTHRONE Resource Manager at Access Network Provider (*WimaxMngr@ANP*), installed on *border_an103* machine. We will be able to test the subscription and invocation phases, for the cSLS pipes, at the access network level.

After the ENTHRONE end to end overall scenario will be run, the cSLS/pSLS pipes will be installed in the access network. At the WiMAX access network level the cSLS pipe is installed as a service flow on the BS-SS WiMAX link.

The traffic streamed from the Adaptation Terminal towards the ENTHRONE Terminal will be inserted in the pSLS pipe, while crossing the NP1 and NP2 domains, and in the Service Flow associated with the cSLS pipe, while crossing the access network. In NP1 domain and in the access network the links crossed by the user's traffic were flooded with some noise traffic from a traffic generator. As a result of the resource reservations performed during the invocation phases, the users are able to see the movie with a good quality (Figure 10).

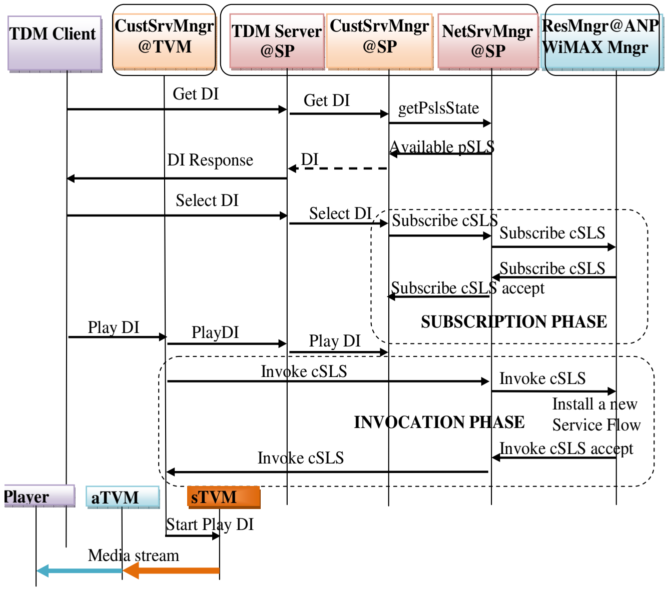

Figure 6. cSLS invocation and subscription phase in the overall end to end ENTHRONE scenario

In Figure 6 the messages exchanged during the overall end to end QoS management scenario are shown. The cSLS subscription and invocation phases' placement in the message sequence is also shown.

In Figure 6, by DI we noted Digital Item which is defined in the MPEG 21 standard; by CustSrvMngr we refer the Customer Service Manager either Service Provider or at TVM and by TDM the Terminal Device Manager [3][5][6][7][16] [17].

B. *Scalability tests*

Besides the functionality tests, which were used to validate the ENTHRONE functional architecture, the correct behavior of the ENTHRONE modules, we have tried to determine the scalability of the ENTHRONE Network Service Manager's modules. Because the Service Provider has to deal with user's requests, which are greater in number than the requests for pSLS pipe establishment triggered by the Service Provider before the service offering, we have considered that scalability problems could be generated by the Network Service Manager at the Service Provider module, when it should answer to the cSLS subscription and invocation requests.

In order to test the scalability for the NetSrvMngr@SP module we have used a CustSrvMngr test module to generate cSLS subscription and invocation requests. The test module was used on a terminal situated outside the university campus. In order to connect to the testbed we have used a VPN connection. So, the requests have to travel initially through the Internet before reaching the UPB testbed, simulating in this way the real case where the users connects to the Service Provider via Internet.

Several successive requests were generated and the time required to fulfill all the requests was measured. The following cases were considered:

- Several cSLS subscription requests (Figure 7)
- Several groups of cSLS subscription and invocation requests (Figure 8). In this case, because the number of the cSLS invocation is large, we have used a dummy WiMAX manager module which did not install the service flows on the WiMAX equipment, but just returned a positive answer.
- Several groups of cSLS subscription, invocation and invocation close requests (Figure 8). In this case we have used the real WiMAX manager, because in this case, after the service flow is installed, it is also removed afterwards.

From the picture one can see that the NetSrvMngr@SP could serve 200 requests suites cSLS subscription, cSLS invocation, cSLS invocation close in less than 20 seconds. Taking into account that the cSLS requests are for video on demand services, we believe that serving speed is satisfactory. We didn't perform yet tests with the case when the requests are coming from different machines.

VI. CONCLUSION AND FUTURE WORK

A testbed for an integrated E2E QoS management system validation, developed in the framework of the ENTHRONE Project, is briefly described. Several tests were presented, both functionality and scalability tests, aimed to validate the SLS management and the ENTHRONE overall system.

Scalability tests are in progress. Some basic scalability tests for the pSLS/cSLS negotiation were done. Further tests have to be done for the scalability in the case of requests coming from different hosts. Also we should do tests in order to measure the scalability for the entire system, with all the ENTHRONE modules integrated.

The tests have proved that ENTHRONE is a functional, flexible, feasible solution for E2E QoS management for multimedia streams delivery. While functionality test were successfully, a difficult part is to prove its scalability. Some tests in this direction were started, but there is still lot of work in this direction. We stressed the system with some automatically generated requests and the serving rate was acceptable.

The ENTHRONE system is designed for multimedia delivery, but it has no support for VoIP services and for audio/video conferencing/chat. Because of the long term nature of the pSLS aggregated pipes they are not well suited for the dynamic and diversity of these interactive services. Future work will be done to enhance the ENTHRONE system and also to adapt it to some new services link requiring QoS, like VoIP and videoconferencing.

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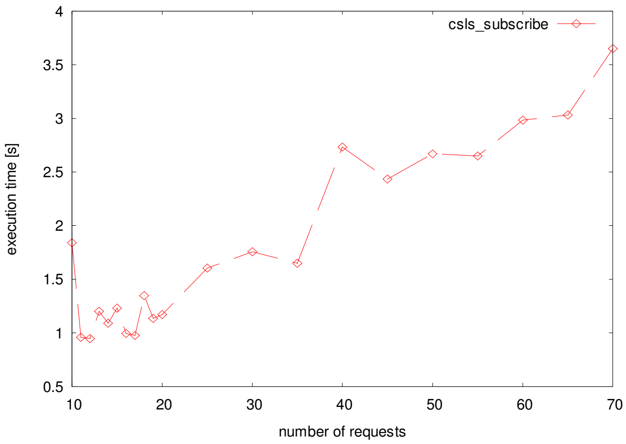

Figure 7. The execution time for cSLS requests

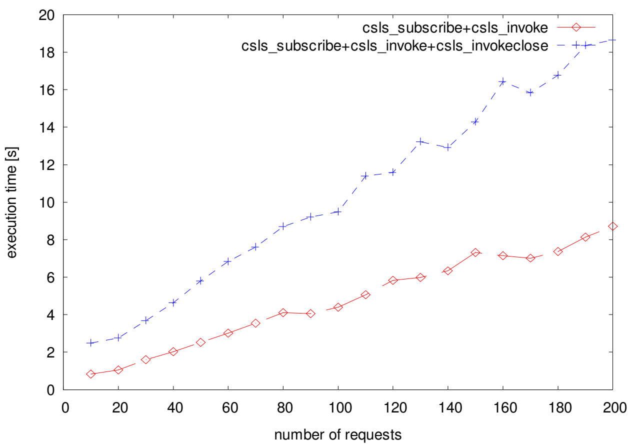

Figure 8. The execution time for *cSLS subscribe*, *cSLS invocation* suite and for *cSLS subscribe, cSLS invocation, cSLS invocation close* suite

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LEGEND FOR FIGURE 9:

- TVM – Multimedia TV processor (source TVM and adaptation TVM),
- EIMS@SP- ENTHRONE Integrated Management System at Service Provider,
- NetSrvMngr@SP/NP – Network Service Manager at SP/NP,
- IntraResMngr@NP – Intra-domain Resource Manager at NP,
- WiMAXmngr – Resource Manager at AN for the WiMAX access network

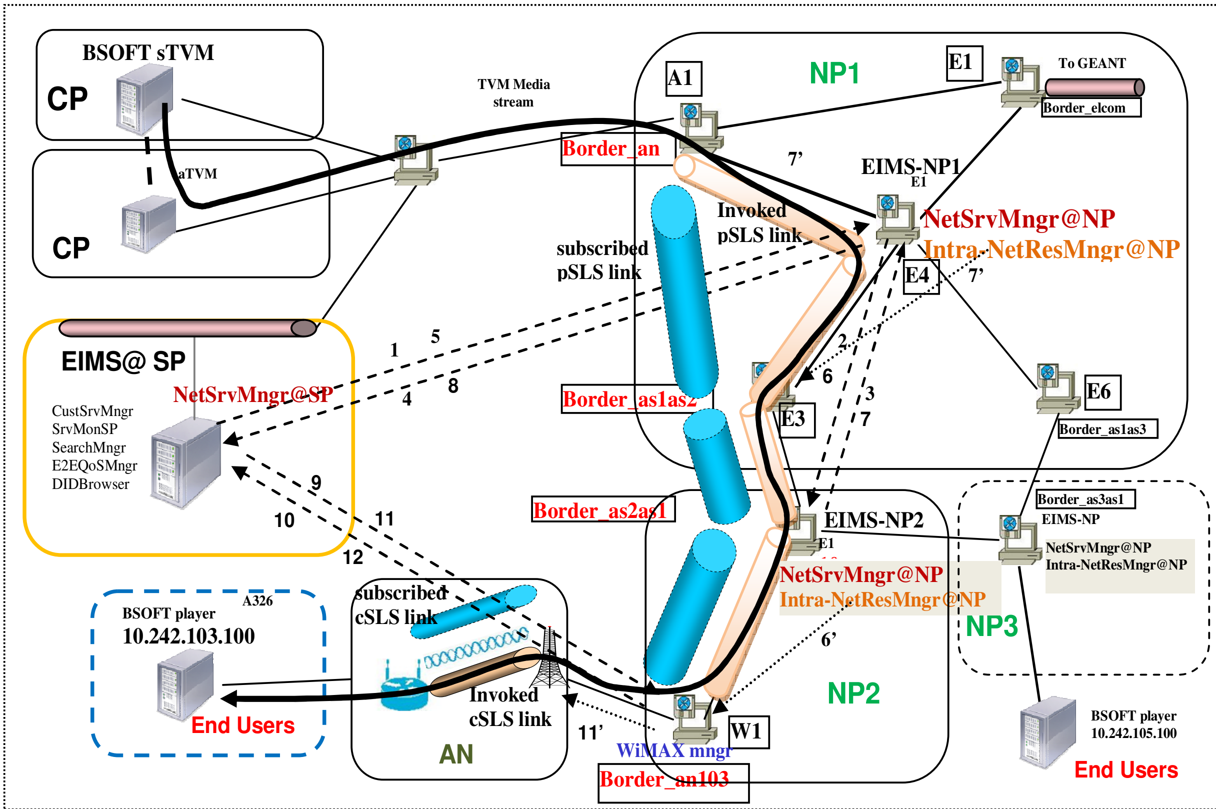

Figure 9. UPB testbed infrastructure: installation of pSLS link and cSLS link in NP1, NP2 and in WiMAX Access Network.

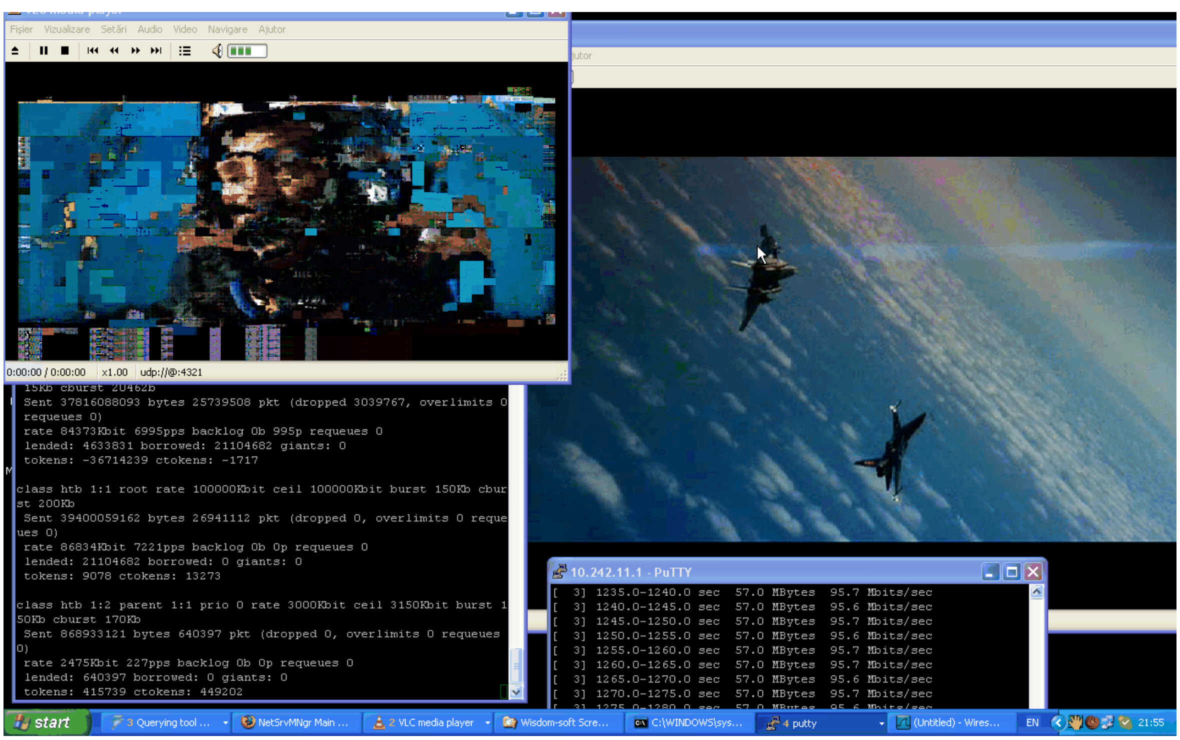

Figure 10. The result of the cSLS/pSLS invocation.