

AN INTEGRATED HETEROGENEOUS NETWORK MANAGEMENT SYSTEM ARCHITECTURE PROPOSAL

Eduardo Bertassi (Escola Politécnica da Universidade de São Paulo, São Paulo, Brasil)

– eduardo.bertassi@poli.usp.br

Rodrigo Filev Maia (Escola Politécnica da Universidade de São Paulo, São Paulo, Brasil)

– rodrigo.maia@poli.usp.br

Ian Korolkovas (Escola Politécnica da Universidade de São Paulo, São Paulo, Brasil)

– ian@larc.usp.br

Denis Gabos (Escola Politécnica da Universidade de São Paulo, São Paulo, Brasil)

– dgabos@larc.usp.br

Nowadays, the convergence of heterogeneous technologies presents new research opportunities due to the diversity of challenges to be faced. The combination of Digital TV with mobile communication technologies enables the development of new paradigms concerning the distribution of digital content and interactive multimedia services. Although different business models and processes can be engineered from such paradigms it is important to notice that the QoS control in the resulting heterogeneous networks will play an important role for the success of the digital content and interactive multimedia services delivery. Therefore, this paper presents a network management system architecture proposal for the implementation of QoS control in an integrated heterogeneous network environment based on traffic engineering concepts.

Keywords: Convergent Networks; Traffic Engineering; QoS Management and Control; Mobility.

I. Introduction

In the last decade the rapid evolution of microcircuits manufacturing processes and the decline of production costs have increased the demand for portable devices over the years: cellular phones, personal digital assistants, laptops, tablet PCs, among others, became not only a merely fashionable appliance but also an important tool to aid people in different day by day situations.

With the advent of wireless communication and the wide spread of broadband digital services provision, portable devices will become indispensable in the near future due to the possibilities that can be offered to its users in terms of digital services: digital TV, videoconferences, B2C, among others. However, some issues must be addressed in order to make all these services feasible.

Metropolitan networks are heterogeneous by nature. It is very common to have content providers and service providers operating in different network domains, transmitting its contents, or services, to different broadcasters that turn out to be located in different networks. The situation gets even more complicated when the contents and services are transmitted by the broadcaster to users with portable wireless devices. Therefore, in such heterogeneous communication environment it is necessary to have appropriate and efficient means to manage and control this information traffic, otherwise the Quality of Service (QoS) of the services that can be provided to the users will be severely compromised.

This work intends to show the efforts that have been made towards the development of a Network Management System (NMS) architecture for an integrated heterogeneous network environment and it is organized as follows: section 2 presents the related works developed in Europe, section 3 outlines the network and system considered for the development of the architecture, section 4 addresses the main objectives that should be reached with this work, section 5 outlines how the network management system is composed, section 6 briefly describes the network management operation process, section 7 presents the integrated heterogeneous network management system architecture proposed and section 8 contains some comments about the research that is currently being done using the developed architecture.

II. Related Works

There were several works in the European Community regarding broadcast/telecommunication convergence aspects that served as basis for the present work.

The INSTINCT Project (IP-based Networks, Services and Terminals for Convergence Systems) (INSTINCT, 2007) was the main reference for this work and was build on past projects such as: CONFLUENT (Enabling Commercial Application of Convergent Services in Collaborative Networks of UMTS and DVB-T Systems) (CONFLUENT, 2007), CISMUNDUS (Convergence of IP-based Services for Mobile Users and Networks in DVB-T and UMTS Systems) (CISMUNDUS, 2007), and SAVANT (Synchronised and Scalable AV Content Across Networks) (SAVANT, 2007).

Although the later projects were focused on content and service creation (as well as its delivery), INSTINCT Project (among other aspects) was rather concerned with the

implementation of an environment that should deal with the aspects of a convergent network. These aspects were, mainly, QoS Control and Network and System Management.

Some other initiatives, like DAIDALOS Project (Designing Advanced Interfaces for the Delivery and Administration of Location independent Optimised personal Services) (DAIDALOS, 2007), ENTHRONE Project (End-to-End QoS through Integrated Management of Content, Networks and Terminals) (ENTHRONE, 2007), EUQOS Project (End-to-end Quality of Service Support Over Heterogeneous Networks) (EUQOS), EVEREST Project (Evolutionary Strategies for Radio Resource Management in Cellular Heterogeneous Networks) (EVEREST, 2007) and GST Project (Global System for Telematics) (GST, 2007) are also related with QoS aspects in several different situations and environments.

In this work, the requirements, reference scenarios, specifications, and tools were not only transferred and adapted from the INSTINCT's European telecommunications scenario but also complemented to ramp-up the core development of the INSTINCT Project, contributing to its innovative activities.

III. Network and System Overview

The objective of this section is to make clear how INSTINCT's architecture was designed to aim a convergent broadcast in a mobile system infrastructure (BERG, 2004). Therefore, an outlined view of the systems that compose this architecture is needed for the understanding of the Integrated Heterogeneous Network Management System Architecture (IHNMSA) shown in this work.

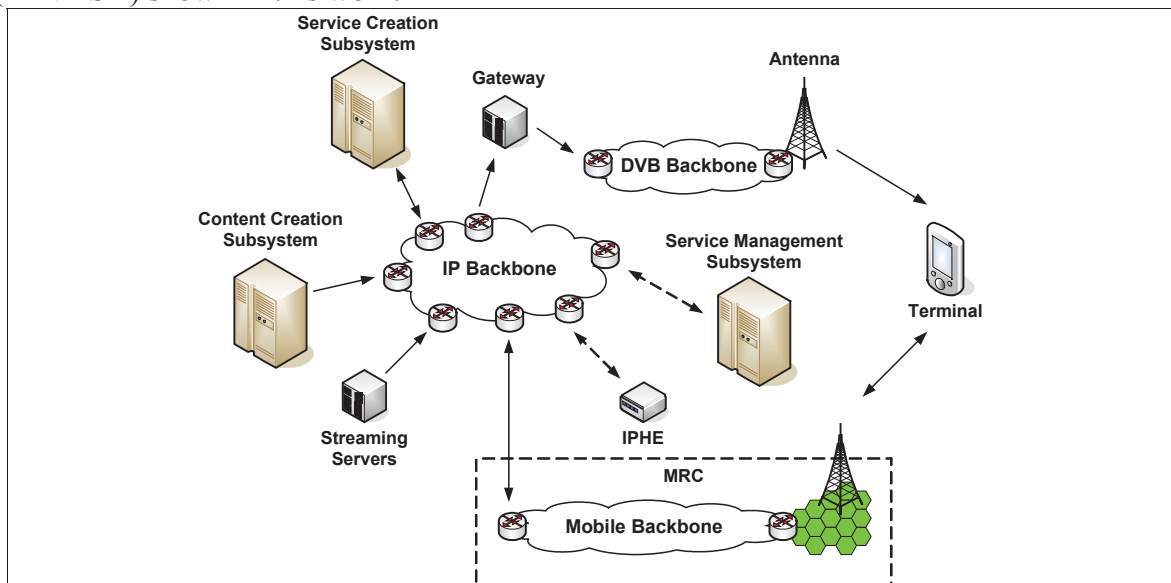


Figure 1. INSTINCT's Heterogeneous Network Environment (BERG, 2007)

A system and network infrastructure that intends to deploy services through Digital TV broadcasting considering the user's mobility and interactivity has a high degree of complexity due to the following reasons:

- It is a new concept that involves broadcast with mobility and interactivity;

- It deals with an heterogeneous network environment, involving Digital TV Broadcast Networks, IP Backbones in Metropolitan Area Networks (MANs) and Wide Area Networks (WANs), Mobile Networks, among others;
- It intends to offer multimedia services over data communication networks, thus requiring QoS monitoring and control.

As shown in Fig 1, such heterogeneous network environment can be divided in its main subsystems and components for a better understanding:

- **Content Creation Subsystem (CCS):** Encodes video and audio content from a studio to DVB-T (Terrestrial Digital Video Broadcasting) and/or DVB-H (Digital Video Broadcasting for Handhelds);
- **Service Creation Subsystem (SCS):** Receives the content from one or more CCS and aggregates them into a single Transport Stream (TS). It gets the terminal requests and responses through the Mobile Return Channel (MRC) via GSM (Global System for Mobile), UMTS (Universal Mobile Telecommunications System) or any other mobile telecommunications technology. It might create user service interfaces using a standard framework like MHP (Multimedia Home Platform) or DASE (Digital TV Applications Software Environment);
- **Gateway (GW):** Its main role is to encapsulate IP data coming from several sources in the DVB flow. It is configured by the IP Head-End (IPHE) system;
- **Antenna:** Responsible for transmitting the TS that was generated at the SCS through air to the Terminal;
- **Mobile Backbone:** Some mobile transmission technologies can be assumed here, such as GSM, UMTS, CDMA (Code Division Multiple-Accesses), among others. The Mobile Backbone enables the interactivity between the Terminal and the INSTINCT's network. Furthermore, it could be used as an alternative downstream channel;
- **Terminal:** A mobile device that allows the user to access the services and contents transmitted from the DVB Backbone antenna or from the Mobile Backbone antenna. It also permits interaction with the content and service providers;
- **Streaming Server (SS):** Provides content that was previously generated, recorded and encoded. It acts similarly to the CCS;
- **Service Management Subsystem (SMS):** Represents the SMS from INSTINCT's architecture. It is responsible for coordinating the service scheduling, SLAs (Service Level Agreements), QoS requirements, among others, according to the business rules established between the key players (content and service providers, broadcasters, among others);
- **IP Head-End (IPHE):** The IP Head-End system has the role of adapting the IP services to the DVB world. Its main functionality is to configure the GW in order to allow it encapsulating data. Therefore, the IPHE needs to exchange information with the SMS and other equipment, such as the QoS management tool box, among others.

In the following sections it is explained how the Network Management System is expected to work for monitoring and controlling the data exchange between this

subsystems and components in order to keep up the level of QoS delivered to the users of the network.

IV. Network Management Objectives

The IHNMSA¹ is responsible for providing operational stability to the INSTINCT network topology and to the QoS Control Architecture. Its main objectives are:

A. Update the Traffic Engineering Database

One of the most important objectives of the management infrastructure is to maintain the network traffic information updated. In each INSTINCT domain (Fig. 2) there will be an Integrated Management Subsystem (IMS) responsible for monitoring and controlling the network equipments inside its respective domain. Hence, all network conditions (equipments configuration, processors capacity, link states, among others) will be known by the IMS. The IMS obtain the information through SNMP communication with the agents installed in the equipments. There is another component within this infrastructure, called Network Management Probe (NMP), which feeds the IMS of the Delivery Domain with network management information. These special probes are management appliances for the DVB and Radio telecommunication equipments, and were designed to be used in networks or parts of networks that do not have SNMP agents.

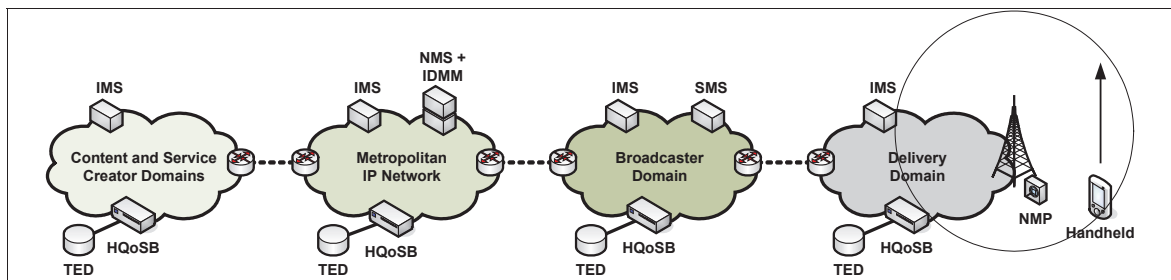


Figure 2. Simplified View of the INSTINCT's Domains and Components

However, there are networks that already use a SNMP network management solution, but which might not be in compliance with the integrated heterogeneous network view of INSTINCT. In these cases, a special module called INSTINCT Domain Management Module (IDMM) can be installed in order to make the proprietary Network Management Systems (NMS) interoperate with INSTINCT's integrated heterogeneous network. Hence, the IDMM will behave as the IMS in an INSTINCT network.

Once the appropriate mechanisms to manage and control the network are set, the network QoS and traffic information should be stored in a special TED within an Heterogeneous QoS Broker (HQoSB) (MAIA et al., 2005) for the calculation of QoS routes across the topology using the link status and bandwidth information acquired from the network by the IMS.

In order to have the QoS route tables generated, the QoS and network traffic information should be pre-processed by the IMS (or IDMM, if the network has a NMS).

¹ Although this work does not address the return path issues for enabling the end-user terminal interaction with the broadcaster domain, the integrated heterogeneous architecture proposed in this work was elaborated foreseeing this functionality in the future.

That is due the fact that the IMS collects management data from all managed links and equipments within its domain. Therefore, it is necessary to filter this information before storing it into the TEDs. The TED is the result of a consolidation distributed operation of the IMSs and IDMM working together.

TEDs should be constantly updated by the network management mechanism, i.e. the IMS, otherwise it will not be possible to control the QoS levels required by applications.

B. Enable Service Level Management

SLM is done through the SMS by contrasting the network traffic information (acquired from IMS) and QoS information with the SLAs of the services requested by the CCS or the SCS. Thus, in order to understand the interaction between these two subsystems, it is necessary to understand what should be the data that the SMS should request and provide to the IMS.

The SMS has two fundamental components directly related with the SLA: the User Management Component and the Contract & Monitoring Manager Component (ALLAMANDRI, 2004). The User Management Component has data concerning user contract, user profile, terminal profile, service subscription, list of personalized services, i.e. contains data about what the end-user expects to receive in his terminal according to the services he contracted; the Contract & Monitoring Manager Component has data concerning service usage measuring, service performance and availability (from the user point of view at the application layer), SLA needs and SLA monitoring status, i.e. contains information related to the provisioning of the service over the infrastructure.

By contrasting the SLA provided by the CCS, or SCS - with data related to the network traffic, QoS levels (Peak Bitrate, Burst Size, Packet Delay, Packet Delay Jitter, Packet Loss, Average Bit Rate, Bit Rate Jitter) (ALLAMANDRI, 2004), service usage, service performance and service availability - with network status requested from IMS, the SMS has enough information for SLM application, i.e. for the generation of countermeasures that will make the infrastructure tend to a stable QoS provisioning (the countermeasures will occur when a certain monitored QoS parameter of the network reaches a pre-determined warning level, such as minimum bandwidth, minimum QoS limits, among others).

C. Provide Feedback to the QoS Control System

The System Management Architecture assures QoS control through the exchange of QoS Information, QoS Alarms and Service Implementation Reports with the HQoSB. It is from the result of the interaction between the SMS, IMS (or IDMM) that the HQoSB implement its functionalities.

D. Provide Network Management Information to the Key Players of the System

The last, but not least important mechanism of the INSTINCT IHNMSA is the provisioning of network management information to and among the key players of the system (Content Creators, Service Creators and Broadcasters) for the maintenance of the business rules that might have been agreed for the provision of services. Each player has

total control of its network infrastructure management information within its domain. However some management information can be used to verify if the agreed SLAs are in accordance with the signed contractual terms. In general, the network management information that will be shared between the key players is related to specific functions, like for example, billing management. For this, SMS will integrate the necessary information, receiving them from the IMSs and IDMMs. The whole set of IMSs and IDMMs is called IHNMS.

V. Network Management System Overview

For the description of the system, three possible scenarios for the creation of content and service provisioning were considered (Fig. 3):

- The Content Creator and the Service Creator domains have contractual agreements that implies in a dedicate link between them (represented in the figure by number 1);
- The Content Creator Subsystem and the Service Creator Subsystem are in the same domain (represented in the figure by number 2);
- The Content Creator Subsystem and the Service Creator Subsystem have independent domains that are interconnected through a Metropolitan IP backbone (represented in the figure by number 3).

The scenario models two broadcasters that operates each one at two regions, each one with your own local operator. This kind of scenario is possible in the DVB technology. These domain and broadcaster configurations are based on business reasons, and the INSTINCT IHNMSA supports all possibilities mentioned.

Fig. 3 depicts the use of the management architecture previously described in the scenario:

- The IMSs are located at all domains that do not have a management solution. It is the main part of the management network architecture because it provides network information to the other subsystems within the architecture by acquiring information from the Management Information Base (MIB) of the equipments (THOMPSON, 1998).

- All domains that already have network management solutions receive an IDMM. This module has the exact same functionalities of an IMS, however it is used in NMSs that want to be in compliance with INSTINCT Integrated Heterogeneous Network and System Management Architecture. Therefore the sum of NMS and IDMM functionalities should provide similar results that an IMS.
- NMPs are located, mainly, in the radio segments of the network. It is responsible for acquiring management information from the transmission equipments (radio or DVB) located at the Delivery Domain.
- TEDs are located in all the domains and used by the HQoSB for storing traffic engineering information. Its tables are fed by the IMSs (or IDMMs) and contain the network statistical status and information.

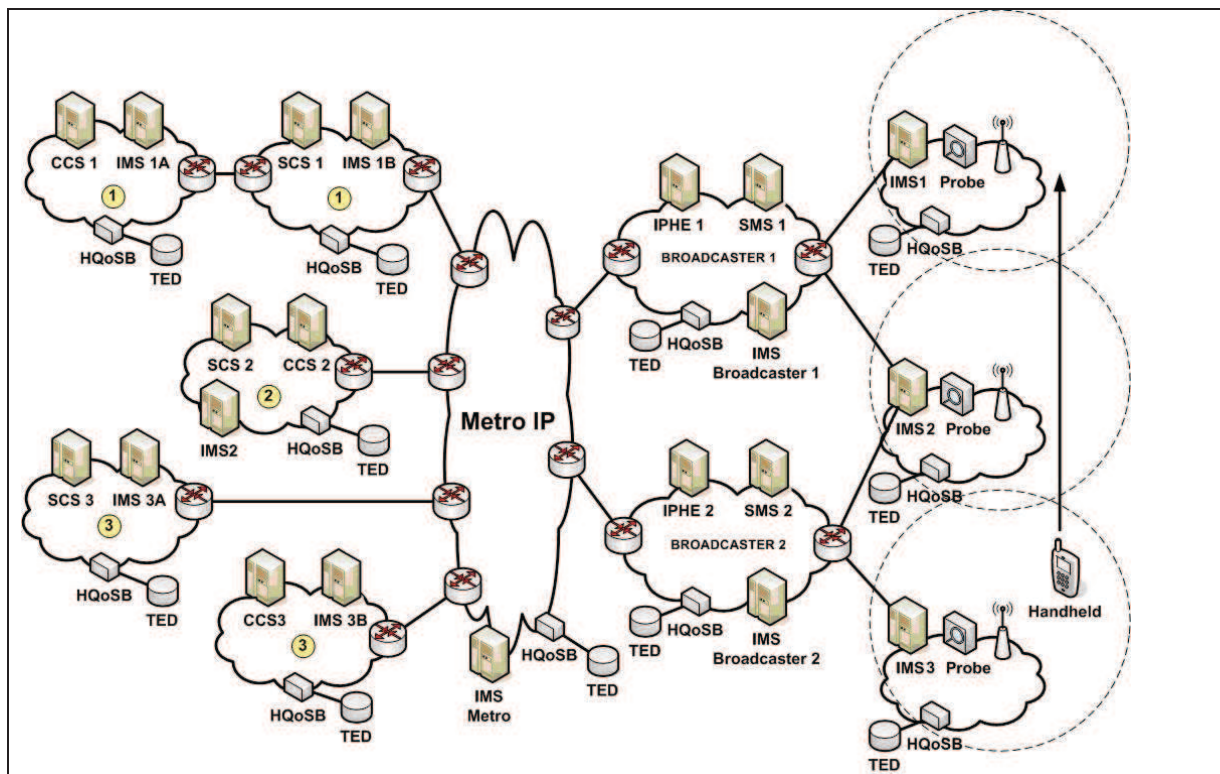


Figure 3. INSTINCT's Integrated Heterogeneous Network Management System Architecture

- Network Equipments: Traditional equipments used in network topologies such as, routers, switches, among others. They usually receive commands from the HQoSB for changing their configuration in order to adequate the traffic to the QoS conditions needed by the components.

Basically, each INSTINCT Domain should have an IMS, although the Delivery Subsystem contains NMPs.

A. Components Descriptions and Functionalities

With the aim of making clear the understanding of the INSTINCT IHNMSA shown in Fig. 3, the descriptions, functionalities and interactions of each components of the architecture is explained as follows:

Integrated Management Subsystem (IMS)

The IMS is the main component of the IHNMSA and has as its main objective the management of the Network Equipments within a domain. This subsystem has functionalities that are similar to those encountered in corporative network management systems.

As shown in Fig. 4, the IMS receives Service Implementation Reports from the SMS, containing several SLA parameters (which are specified in the Electronic Service Guides (ESG) (ALLAMANDRI et al, 2004) and in the end-user contracts) that must be monitored. These parameters together with the network QoS levels, network link status and equipment status are pre-processed inside the IMS and sent to the HQoSB which by its turn updates its TED for improving its statistical QoS models of the network.

Once this preliminary information is exchanged, IMS keeps monitoring the network by collecting QoS levels information, network link status and equipment status stored in the MIBs of each Network Equipment (server, router, bridges, switches, among others) within its domain. If any QoS fluctuation, or another link constraint, reaches a warning level the IMS sends a QoS Request to the HQoSB for network QoS adjustments. From this point, the QoS Control mechanism from the QoS Control Architecture gets in action by sending QoS recovery commands to the Network Equipments in order to assure the QoS level of a determined service of the ESG.

It is important to notice that, as seen in Fig. 3, there is an IMS (or IDMM) for each domain, but the SMS is located only in the broadcaster domain. Once the best QoS route was set by the HQoSB of each domain, the IMSs start to communicate with themselves in a distributed way for reporting the network conditions to the SMS responsible for a determinate application that has demanded some specific QoS levels (usually described in the ESG).

The communication between IMSs from different domains is needed for granting the business agreements between each key player (SCS, CCS, Broadcasters, among others) and is only through the acquired management information of the network that it is possible to assure the contractual purposes. Therefore, this network management information can be requested from the local IMSs by the network manager of a domain in order to analyses if the provided services are being offered with the correct QoS levels through different domains.

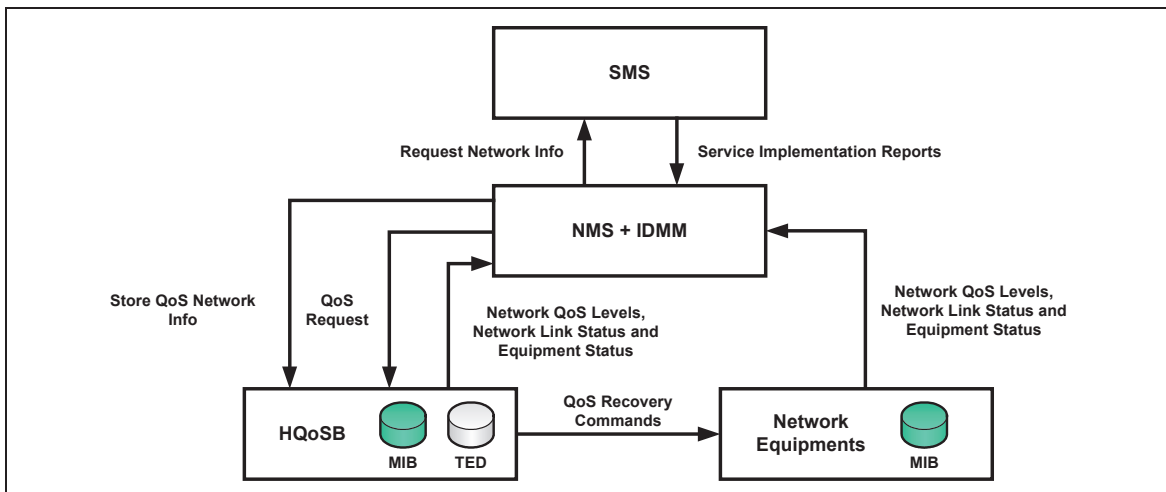


Figure 4. IHNMSA Core with IDMM

A unified view of the communication between different IMSs of different domains is called IHNMS, which is the sum of all IMS efforts for managing this integrated heterogeneous network infrastructure.

INSTINCT Domain Monitoring Module (IDMM)

Many networks have proprietary NMSs for monitoring network QoS levels, network link status and equipment status of its network. Even in the case of using standardized SNMP solutions, the NMSs do not have the IMS functionalities. Therefore, to make this proprietary network management solutions exchange information with the IHNMSA it is necessary to use the IDMM, which are capable of monitoring and collecting information of the network and equipments, pre-process it and to deliver it to the TED that are located inside the HQoSB of its domain and to interact with the SMS.

As it can be seen, the IDMM capabilities in conjunction with the legacy NMSs should execute equivalent IMS's equivalent tasks (Fig. 5).

Network Management Probes (NMP)

The NMP is a specific network management appliance that is used together with the DVB and Radio transmission systems. This appliance is located right before the antenna in order to monitor the DVB-T/H transport streams. It is expected that the Probe informs to the IMS of the Delivery Domain the network QoS levels, network link status and equipment status within this domain.

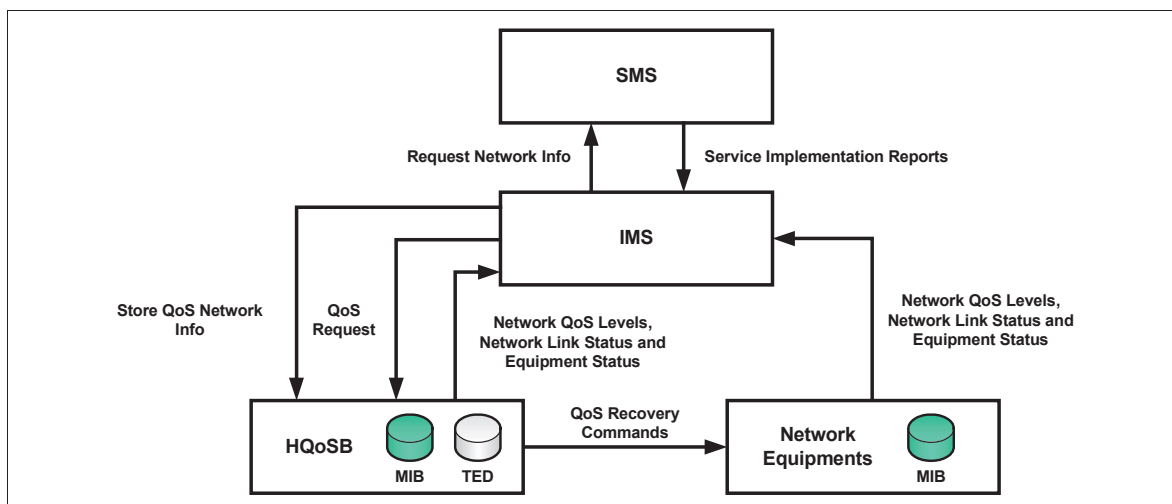


Figure 5. IHNMSA Core with IMS

Traffic Engineering Database (TED)

The TED receives pre-processed and consolidated QoS and Network Information from the IMS (or IDMM) with the objective of providing to the HQoSB enough data for the elaboration of network statistical models that will later result in the generation of route tables that will indicate the best paths across the network for a stable QoS delivery, according to the service running. Fig. 4 and Fig. 5 show how the HQoSB might change the topology configuration based on the data stored in the TED by sending QoS Recovery Commands to the Network Equipments of its domain.

VI. Network Management System Operation Process

Once the network objectives and functionalities were explained together with the details about the components of the architecture, it is necessary to understand how the IHNMSA will work in a continuous operation and in conjunction with the QoS Control Architecture.

A. Continuous Operation

The continuous operation can be understood as the way the network components collect information of the network uninterruptedly without QoS Control influence. As mentioned in item V, although it is possible to have different network configurations (topologies with different rearranges of SCSs, CCSs, among others) the network management architecture supports all possibilities mentioned. Therefore, in order to illustrate the continuous operation mechanism it was chosen topology number one (Fig. 3) to illustrate how the IHNMSA would behave in a continuous operation.

The independence of topology is a result of the fact that the IMSs (or IDMM) of each domain exchange management information between themselves no matter their location in the network, hence the transparency of IMSs location is assured.

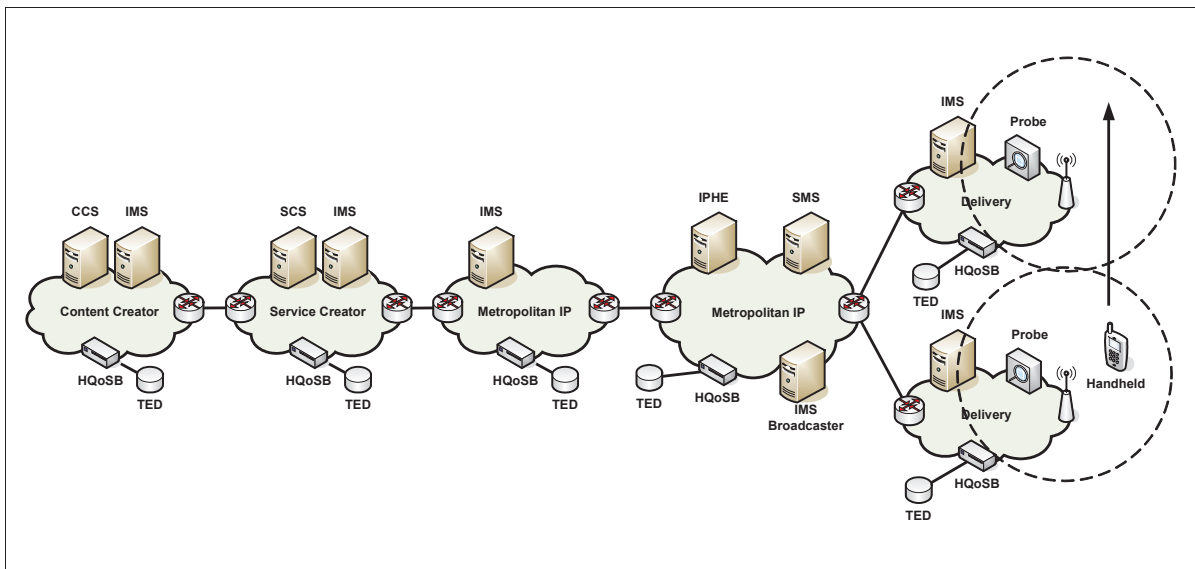


Figure 6. Continuous Operation Scenario

Once the transparency of the domain locations is assured, the IMS (or IDMM) of each domain collects QoS and network information from the MIBs of the Network Equipments and NMPs, including the HQoSB status, status of communication links, failure traps, among others. This information is pre-processed by the IMSs and stored, thus being available to the SMS.

Then, the SMS makes the SLM by requesting the network status to the IMS and contrasting this information with the SLAs contained in the ESGs. Fig. 6 illustrates the continuous operation scenario.

B. QoS Control

After the SCS has sent the EPGs to the SMS, the SMS generates the ESGs (Electronic Service Guides) containing all QoS constraints related to the service (SLA). The SMS receives the ESG (containing QoS parameters), requests network information from the IMS and by contrasting this information implements SLM functionalities.

If no fluctuation has occurred or threshold limits were reached, the IMS continues monitoring the network and sending information to the SMS when requested (usually from time to time). Otherwise, if any fluctuations or threshold limits were detected, the SMS will send a QoS request to the HQoSB, which by its turn will take the appropriate countermeasures to stabilize the QoS provisioning.

VII. Integrated Heterogeneous Network Management System Architecture

The architecture shown in Fig. 3 shows the heterogeneity of management solutions that might be used in the INSTINCT. It was detected that the network backbone, as well as the access networks, can use WBEM (Web Based Enterprise Management) (THOMPSON, 1998), (FESTOR et al, 1999), SNMP (STALLINGS, 1998) and TMN (Telecommunications Management Network) (DITTRICH; HOFT, 1996) management solutions. The encoders, decoders and RF Transmitters (used to create and transmit the transport streams) use different management protocols where some of them are proprietary

solutions. Table 1 shows the most often used management solutions that might be used for each kind of entity at INSTINCT network.

The main challenge to manage the entire system is the heterogeneity of management solutions. The backbone routers, for IP or ATM networks, usually use SNMP to provide management information; some equipment has WBEM solutions and only a few use proprietary solutions. Recent MPEG encoders and decoders measure bit rates, modularization and error rates using a Web interface or SNMP messages to provide management information to the system administrator. DVB and RF Transmitters have a wide use of distinct management solutions, these equipments usually measure the RF signals looking for errors caused by noise and attenuation in through-air transmission. The Probe proposed in INSTINCT gather the transport stream RTP packets to measure delay, jitter and packet loss and send this information through SNMP or Web interface. Although the return channel is not considered in this work, the GSM return channel should basically use TMN and proprietary solutions for network management.

The solution can be found in an additional layer that hides the heterogeneity of the platforms and improve the distribution transparency: the middleware (Fig. 7). This concept is commonly used in distributed systems where entities get interconnected through the network. These entities communicate and coordinate its actions through the exchange of messages.

In order to reach an adequate QoS, it is necessary to properly manage the network architecture that provides video and data applications. This complex architecture aggregates middleware and network operating systems that should interoperate even being different.

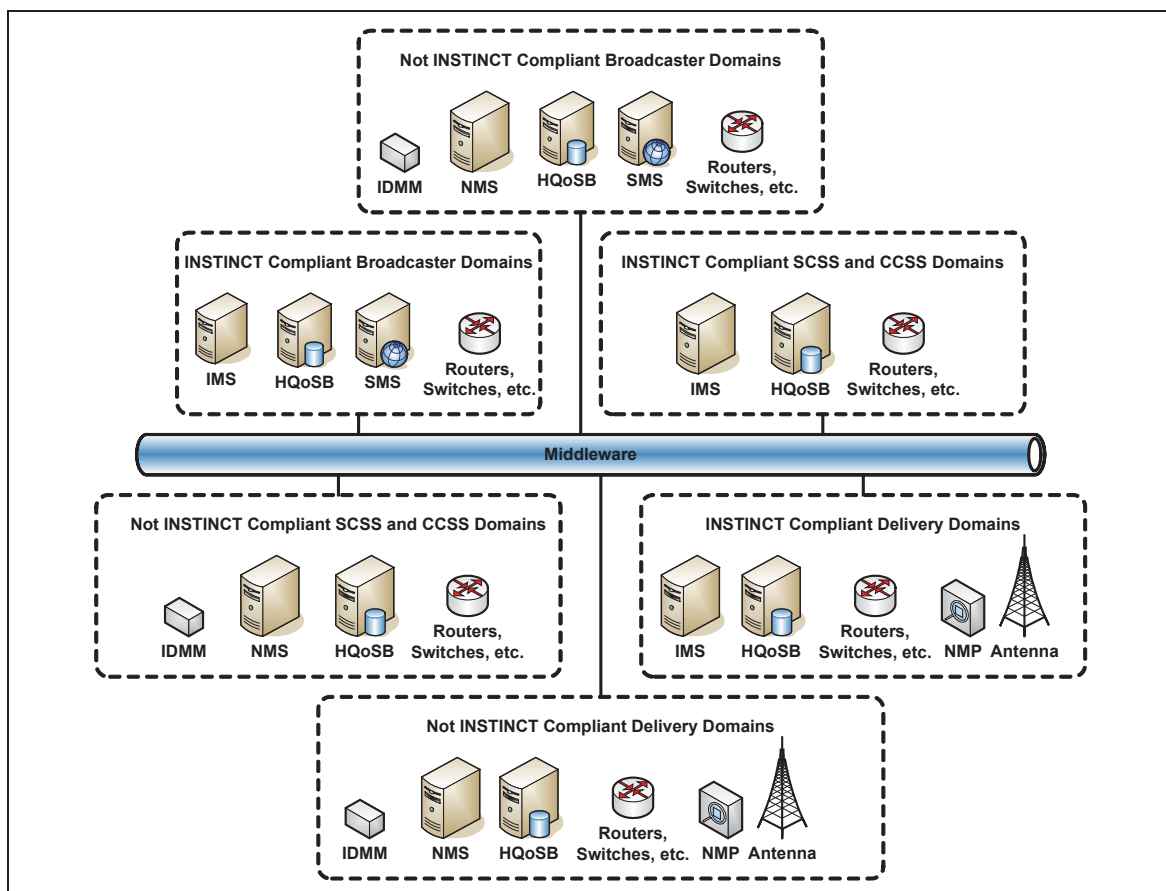


Figure 7. IHNMSA Core

An increasing number of applications have been developed using distributed object computing middleware, offering resources for applications to be executed in a distributed heterogeneous environment. Many of these applications use standardized services and protocols, such as the Common Object Request Broker Architecture (CORBA) (VINOSKI, 1997), (VINOSKI, 1998), which defines a specification to allow the communication of distributed systems in a transparent way, no matter where these objects are placed, whether using an operational system or a specific communication protocol. In addition, CORBA objects offer functionalities to ease the development and implementation of applications for the programmer by defining general interfaces that are generally used in distributed systems.

The specification and use of CORBA as a network management integrator makes possible the use of heterogeneous distributed network management applications, independently of underlying network protocols, abstracting the heterogeneous network details, therefore capable of being used in a variety of environments with the benefit of preserving legacy network management subsystems (HAGGERTY; SEETHARAMAN, 1998).

VIII. Future Work

The next steps include the definition of the TED using XML and the complete specification of the interactions between the modules and subsystems shown in this work. After that, a scenario will be developed for simulate and validate the proposed architecture. Henceforth, it will be necessary to develop software modules to appropriately simulate the digital TV and wireless networks. The use of the NS2 simulator tool (NS2, 2007) is currently being studied for the development of the mentioned software modules, once NS2 does not provide built in software models for the simulation of the intended networks. This tool will provide valuable information concerning the interactions between the modules and subsystems of the QoS control architecture components.

IX. Acknowledgment

This paper describes work undertaken in the context of the INSTINCT Project (IST-1-507014-IP-0e), an IST FP6 Integrated Project that was partly funded by the European Commission.

The EPUSP team would like to thank INSTINCT's colleagues for the valuable contributions during the elaboration of this work and afterwards.

Table 1. Common Management Solutions Available

| | Routers | Encoders/ Decoders | RF Transmitters | Probe | GSM Terminals |
|--------------------|----------------|-------------------------------|----------------------------|--------------|----------------------|
| TMN | | | X | | X |
| SNMP | X | X | X | X | |
| WBEM | X | X | X | X | |
| Proprietary | X | X | X | | X |

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