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QoS Provisioning for Multimedia Services on all-IP Based Hybrid Networks

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The objective of this paper is to identify a dynamic QoS architecture for multimedia services applicable to all types of QoS scenarios in integrated IP-based terrestrial/satellite networks. The main contribution of this work focuses on the capability of the dynamic QoS architecture to provide QoS also to QoS unaware applications and to easily interconnect DiffServ and IntServ based terrestrial networks with DVB-RCS satellite networks implementing DiffServ features. The proposed dynamic QoS architecture presents two cross-layer mechanisms: the first one between application and network layers in order to provide guaranteed QoS for multimedia applications and a second one between IP and MAC layers in order to maximise the efficiency of satellite resources utilization. Two different configurations have been proposed for the dynamic QoS architecture. The first option implements both cross-layer mechanisms allowing dynamic resource reservation at Layer 2 and 3. The second option presents only the first interface and performs dynamic QoS at IP layer. Both options are compared from a functional point of view and comparative assessment of their performance and complexity is provided. We have implemented and tested at ESA laboratory the second option of the dynamic QoS architecture in order to validate the presented architecture.

I. Introduction

NEXT generation satellite and hybrid networks based on an Internet Protocol (IP) platform play a decisive role in providing seamlessly support to multimedia applications. Satellite communications and, in particular, geostationary satellites are becoming more and more popular due to global coverage, scalability, broadcast and multicast capability, Bandwidth on Demand (BoD) flexibility and reliability. Digital Video Broadcasting-Return Channel via Satellite (DVB-RCS) [1] based satellite networks have several powerful BoD mechanisms that can be used for providing multimedia applications such as Voice over IP (VoIP) with adequate Quality of Service (QoS), but the interaction between the IP layer, where QoS is set, and the lower layers, where the traffic is finally prioritized for transmission, is not covered by the specification. In support of QoS provisioning over DVB-RCS, SatLabs, a not-for-profit organization initiated by European Space Agency (ESA), has defined QoS architecture and mapping mechanisms of IP layer into DVB-RCS layer [2]-[4]. For QoS provisioning in IP networks, the Internet Engineering Task Force (IETF) has proposed two different QoS models: the Integrated Services (IntServ) [5] and the Differentiated Services (DiffServ) [6] architectures. The main characteristics of these approaches have not been deeply investigated in hybrid networks, where terrestrial and satellite networks are connected, in particular the interaction between the resource management at IP level and the allocation strategy of the satellite resources based on Demand Assigned Multiple Access (DAMA) scheme.

The aim of this work is to elaborate a dynamic QoS architecture able to provide QoS guarantees and dynamic resource allocation to IP multimedia services in an integrated terrestrial/satellite network introducing cross-layer techniques to optimize the overall satellite resources. The paper is organized as follows. Section II investigates all possible QoS scenarios that are able to provide guaranteed services to multimedia applications. Section III presents

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the overall dynamic QoS architecture that fulfils the QoS scenarios described in the previous section. In Section IV two possible configurations, one presenting a cross-layer interface between IP and Medium Access Control (MAC) layers and one characterized by no interaction between these two layers, are described and compared in detail. In Section V the complete test bed of the second configuration developed at ESA laboratory is described. Finally, conclusions are drawn in Section VI.

II. QoS scenarios definition

The reference scenario for the dynamic QoS architecture is based on a satellite domain implementing a DiffServ IP QoS framework, while the user and applications terrestrial domains are free to be based on IntServ or DiffServ models (Fig.1).

The Multimedia Client (MC) in the user domain gets external connectivity through the DVB-RCS Satellite Terminal (RCST). The Multimedia Server (MS) in the application domain may be either collocated in the satellite Gateway (GW) or connected through the Internet. RCST and GW represent the Edge Routers (ERs) of the satellite DiffServ domain. The QoS Manager acts as a Bandwidth Broker (BB) for the satellite DiffServ domain, collecting QoS information on traffic flows from MCs or MSs and configuring accordingly IP layer in the satellite domain.

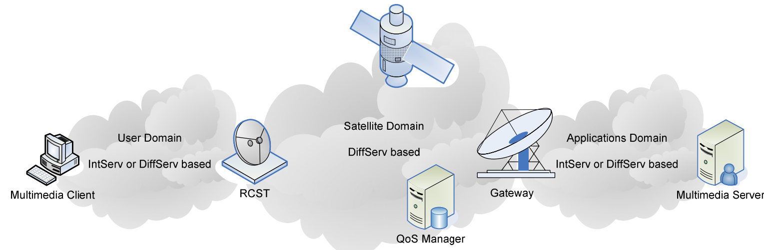

Figure 1. Reference network scenario.

According to the capabilities of MC and MS to support QoS mechanisms and QoS call signaling, it is possible to define four different QoS scenarios [7] summarized as follows:

1) Service provider-oriented model: the MC does not support QoS signalling mechanisms, it only requests an application specific service to the MS by sending a “Service Request”. The MS is able to determine the QoS needs for that well-know application and to start the QoS request to the QoS Manager that can authorize the request and configure properly RCST and GW (Fig. 2a).
2) User-oriented model: the MC is capable of sending QoS Request over Layer 3 QoS signaling for its own QoS needs to the QoS Manager. It is assumed that the terminal guesses its QoS needs, but has no precise information of actual needs. It is more estimation on the aggregate QoS needs rather than per service ones. Authorization for the IP QoS request is obtained “on the fly” at the time the QoS request is actually signaled and does not require prior authorization. Resource Reservation can be performed by the QoS Manager on RCST and GW (Fig.2b).
3) Application-signaling-based models:
    a. User-requested QoS: the MC requests an application-specific service by sending a “Service Request” to the MS. It is in charge of determining the QoS needs of the requested service and to inform the MC about them. The MC then uses network signalling (e.g. RSVP, NSIS) to request resource reservation to the QoS Manager that authorizes the request and configures properly RCST and GW (Fig. 2c).
    b. User-originated application layer QoS signaling: the MC requests a service from the MS via application layer signaling, and the QoS requirements are included in the signaling (SIP message with SDP). The MS extracts the QoS requirements, interprets them and passes the QoS request to the QoS Manager that performs Resource Reservation on RCST and GW (Fig. 2d).

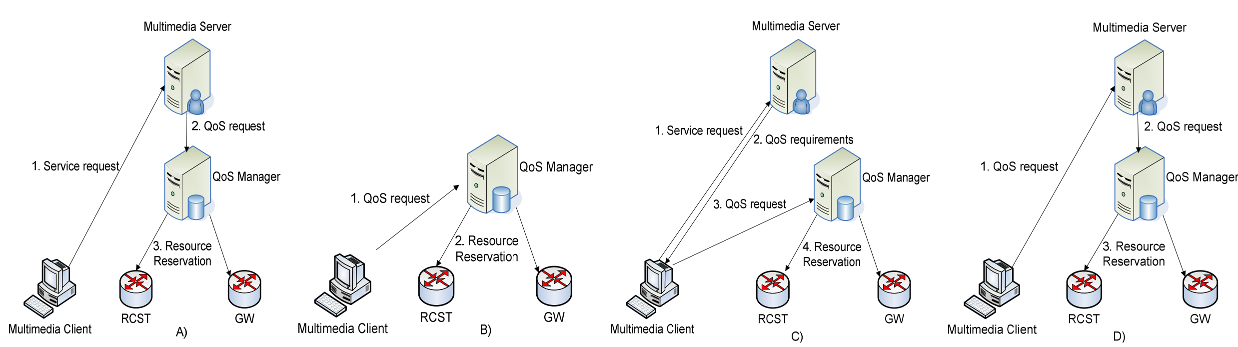

Figure 2. QoS scenarios

It is possible to group the four cases in two main groups:

- the first group is composed by scenarios 1 and 3b. In both of them the MC sends a service request to the MS and the MS is in charge of sending the QoS request to the QoS Manager;
- the second group is composed by scenarios 2 and 3a. Indeed, scenario 3a is an extension of scenario 2b where the MS provides the QoS parameters to the MC after the Service Request.

In summary, the four cases can be divided according to two different criteria (Table 1):

- QoS parameters specified by the MS or by the MC.
- QoS request invocated by the MS or by the MC.

Table 1. QoS scenarios classifications

QoS parameters / QoS request	Server-defined	Client-defined
Server-initiated	1	3b
Client-initiated	3a	2

III. Dynamic QoS architecture

A generic dynamic QoS architecture [8]-[9] that fulfills the QoS scenarios defined in Section II is shown in Fig. 3. The architecture is organized in four functional components and two layers:

1) The User Equipment (UE) includes the MC;
2) The RCST includes the Multimedia Proxy Server (MPS) in the service layer, IntServ [10] and DiffServ [11] functionalities in the network layer in order to be able to interface with both models, and DVB-RCS architecture components in the MAC layer.
3) The Network Control Center (NCC) consists of the QoS Manager and SRM.
4) The GW includes MS in the service layer, IntServ and DiffServ functionalities in the network layer and DVB-RCS features in the MAC layer.

For sake of simplicity, MPS, MS and QoS Manager are included in the functional components, but they can be surely considered as independent physical devices.

In order to illustrate better the applicability of the QoS architecture to all possible configurations, it is useful to make the following differentiation:

- If the MS is located in the satellite domain, for example in the GW, the MC, QoS aware or unaware located in the user domain, can interact with the MS to request the service and then the QoS request can be sent from the MS to the QoS Manager.
- If the MS is located outside the satellite domain, the simplest solution for QoS provisioning in the satellite domain consists in the utilization of the MPS in the user domain. All the MCs need to go through it to connect to external MSs and to benefit of QoS management in the same time. It is MPS's duty to send the QoS request to the QoS Manager.
- If the MS is not used, the MC can contact the QoS Manager through the QoS Agent in the RCST (QoS aware application). The QoS Agent can allow and authenticate the MC to select the QoS of a given application and send the associated QoS to the QoS Manager.

In the following, the most important functional blocks are explained in detail.

A. Multimedia Server

The MS contains:

- a database that defines, for each well-known service and for all kind of codecs used in the multimedia session, IP QoS parameters as delay, packet loss and delay jitter;
- a Session Initiation Protocol (SIP) Proxy Server representing RCST in the satellite domain over the Internet. Thanks to Session Description Protocol (SDP) parameters in the SIP message, it is aware of IP flow parameters and data rate.

Thus, for each multimedia flow and for each type of application, the MS is able to define the IP flow mask specified in Table 2 and to send it to the QoS Manager.

For QoS provisioning in IP networks, many different protocols can be used for dynamic QoS negotiation. In this architecture the Common Open Police Service (COPS) protocol has been chosen as the negotiation protocol between the MS and the QoS Manager.

Table 2. IP flow mask

IP FLOW PARAMETERS	IP QOS PARAMETERS
SrcAddress	Data rate
SrcPort	Delay
DestAddress	Packet loss
DestPort	Delay Jitter
Transport Protocol ID	
DSCP	

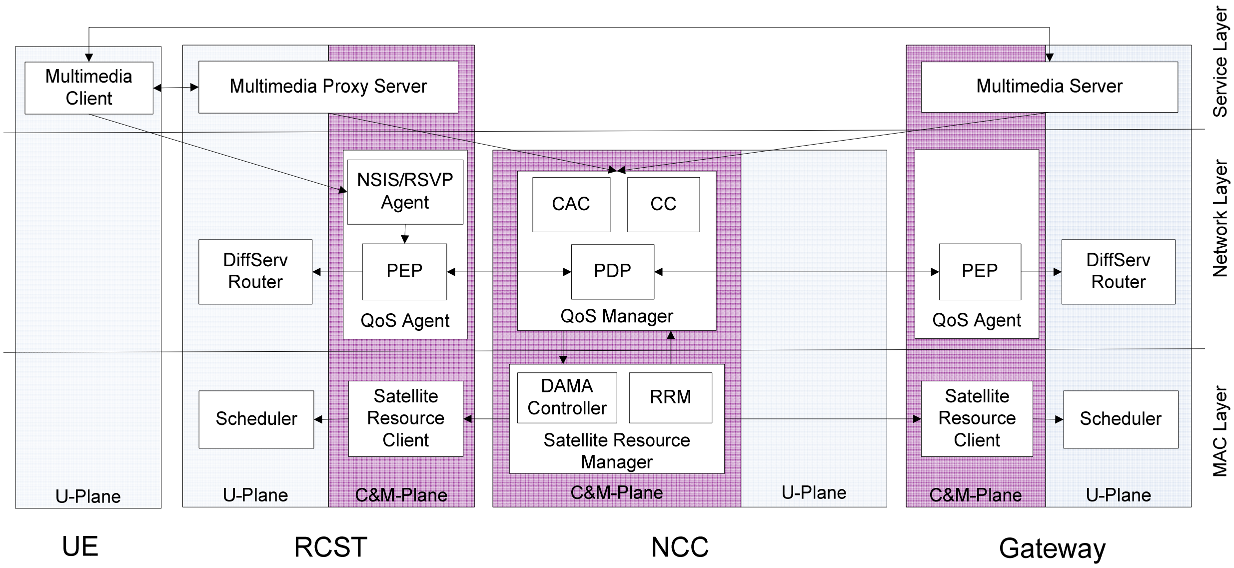

Figure 3. Dynamic QoS architecture

B. QoS Manager

The QoS Manager contains two important blocks:

- The CAC is a network process that receives as an input, a connection request that specifies the traffic descriptor and QoS requirements of the connection and returns a response granting or denying the admission request. The objective of the CAC is to ensure that the network meets its end-to-end QoS guarantees to connections that are admitted into the network. The CAC process is responsible for deciding whether a new connection request can be accepted, and if so, how much resources should be allocated to it.
- The CC ensures that the network traffic intensity never reaches the level to cause unacceptable congestion. In case of congestion, it renegotiates or drops existing connections following predefined policies.

i. *Connection Admission Control*

The CAC should have:

- a view on available network resources over the satellite domain;
- a view on the use of network resources over the satellite domain;
- a view on available network resources in every ST;
- a view on the use of network resources in every ST;
- admission control of new IP flow based on network resources availability.

An example of a simple admission control scheme for flow-level dynamic QoS provisioning under the centralized QoS architecture model is illustrated hereafter. When a new flow reservation set-up request arrives at the CAC requesting a certain amount of bandwidth, it applies an admissibility test to determine whether the new flow can be admitted. In particular, the CAC examines the following databases:

- Return Link (RL) QoS state information base: it contains information regarding current residual bandwidth on RL.
- Forward Link (FL) QoS state information base: it contains information regarding current residual bandwidth on FL.
- ST QoS state information base: it contains information regarding residual resources for each ST.

The CAC determines whether there are sufficient resources available in the system and in the RCST physical link to accommodate the new flow. If the flow can be admitted, the CAC updates all the databases to reflect the new bandwidth reservation in the satellite domain. If the admissibility test fails, the new flow reservation set-up request will be rejected, and no QoS databases will be updated. In either case, the CAC will signal the MS of its decision. For a flow reservation tear-down request, the CAC will simply update the corresponding link state databases and the involved ST database to reflect the departure of the flow.

ii. <u>*Congestion Control*</u>

The CC is in charge of controlling traffic entry into the satellite network, so as to avoid congestive collapse. Through the utilization of Path QoS state information base, the congestion controller is aware of flows traversing the satellite domain and their QoS parameters. In this way, if a flow is not compliant to its QoS negotiated parameters, it may be dropped or negotiated.

C. Satellite Resource Manager

The Satellite Resource Manager contains the following blocks:

- The RRM is in charge of power control, channel estimation, frequency allocation and mode selection, it maintains radio link quality, minimises and controls the power used in radio interface, the interferences that can affect the satellite link, the real utilization of the radio resources affected by weather conditions.
- The DAMA Controller performs dynamic satellite resource control in the return link assigning slots to terminals based on their requests and limit values negotiated/set during connection establishment. It implements DAMA protocol, which is in charge of the BoD mechanism.

IV. Configurations for the dynamic QoS architecture

Two different configurations are presented in this paper as the most suitable to solve the problem of efficient management of satellite network resources. In the first configuration, a cross-layer interface between IP and MAC layers is used to configure resources at those layers, while the second configuration, with no interaction between IP and MAC layers, implements resource reservation only at IP layer. We have considered as reference for both configurations the user-originated application layer QoS signalling (scenario 3b).

A. Option 1: QoS interaction between IP and MAC layers

The first configuration, shown in Fig. 4, is based on assumption that the QoS Manager and the SRM have the full control over the satellite network and they are able to configure QoS settings and reserve satellite resources in the network layer and MAC layer respectively. In this way a cross-layer interface is created between the QoS Manager and the SRM for QoS signaling. It makes this option more reactive to QoS needs because of the dynamic management of MAC and physical layers resources.

The QoS Manager receives the IP flow mask (Table 2) from the MS through COPS Request message and performs CAC and CC functionalities. After a positive result, it sends a configuration message with the IP flow mask to the SRM. The SRM calculates the allocation plan in function of RCST physical layer information, updates the RCSTs Service Level Agreement (SLA) accordingly and sends back to the QoS Manager a confirmation message. As soon the QoS Manager receives the positive feedback, it updates its databases and responds to the MS sending a positive COPS Decision messages.

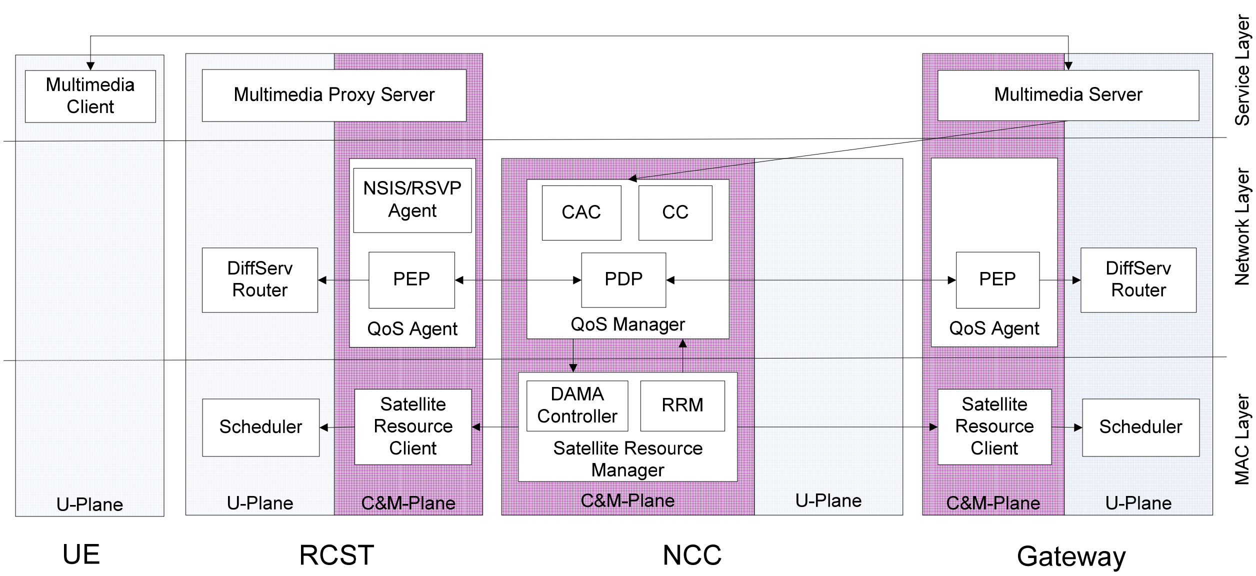

Figure 4. QoS interaction between IP and MAC layers

i. IP layer configuration

The QoS Manager configures DiffServ edge routers at RCST and GW sending a COPS configuration message with the IP flow mask through Policy Decision Point (PDP) and Policy Enforcement Point (PEP) interfaces.

The RCST and GW shall support at least three Per Hop Behavior (PHB) queues:

- Expedited Forwarding (EF);
- Assured Forwarding (AF) with at least two drop precedences;
- Best Effort (BE).

DiffServ routers classify incoming IP packets into one of the traffic categories according to the IP flow parameters provided by the QoS Manager. They perform policing, shaping and dropping of IP packets according to the traffic category (PHB) they belong to. The QoS Manager may update the traffic shaping parameters on a given PHB if needed. According to SatLabs recommendation [3], as a DiffServ node, the RCST is capable of mapping packets to the different PHBs supported by the DVB-RCS network. The classifier used to this end should map a packet to the PHB of choice based at least on the Differentiated Service Code Point (DSCP) value in the packet header.

ii. MAC layer configuration

The SRM is in charge of configuring QoS at MAC layer in RCST and GW. It communicates the MAC configuration to the SRC, so the Scheduler is able to store incoming packets in the corresponding MAC queues, to drop and to schedule them according to the MAC configuration.

In [3] the capacity categories for real-time traffic are:

- CRA_RT, the Constant Rate Assignment (CRA) for the Real Time (RT) Request Class (RC), allocated as a static rate and in fully every superframe, whether the RCST has traffic to transmit or not;
- RBDC_RT, the Rate Based Dynamic Capacity (RBDC) for the RT RC, allocated as a dynamic rate based on requests, but limited to a fixed maximum value called $RBDC\_RT_{max}$ for every ST.

Multimedia services are given the highest priority and allowed to maintain that priority within a static value at terminal, so the capacity is guaranteed if not overbooked up to CRA_RT plus $RBDC\_RT_{max}$. Static SLAs lead to a strict policy, meaning that multimedia services cannot exceed the agreed traffic rate, even when spare rate may be available in the network. In satellite networks such a static fragmentation of the return link capacity among a number of terminal groups may lead to poor statistical multiplexing and a quick exhaustion of the available capacity.

A less strict policy is possible through the utilization of dynamic SLA, so that multimedia services are allowed to exceed the guaranteed rate if spare rate is available within the same group or other groups. Thus, multimedia services are allowed to maintain the highest priority within the whole network, meaning that a terminal overloaded with real-time traffic can borrow capacity from other terminals in the network transmitting lower priority data on the spare capacity.

The enhancement proposed in this work is a long-term QoS for multimedia services achieved through a dynamic capacity allocation of the resources based on the instantaneous users demand. To reach this important goal, a more QoS suitable scheme of RC for real-time traffic has been developed in order to obtain maximum capacity utilization and to guarantee QoS for all applications. The proposed long-term QoS regards the CRA_RT and $RBDC\_RT_{max}$ parameters: both of them are dynamically adjusted in order to follow multimedia sessions.

iii. QoS signaling

In [3] SLA parameters are fixed for the duration of the RCST session (log-on to log-off), and they are non-volatile and persistent so that the RCST applies the parameter values used in the previous logon session if new values are not given. The proposed long-term QoS requires dynamic configuration of terminal QoS settings without the need to re-logon into the network. In particular, the QoS Manager needs to communicate the SLA modification to the SRM and it is necessary that the SRM dynamically modifies SLA parameters in the SRC. As a consequence, in order to implement dynamic SLA solution, it is necessary to define two interfaces:

- one interface between the QoS Manager and the SRM;
- one interface between the SRM and the SRC.

For both interfaces two different protocols for QoS signalling can be used:

- Simple Network Management Protocol (SNMP): specific MIBs are defined in order to change CRA_RT and $RBDC\_RT_{max}$ parameters in the SRM without any re-logon procedures;
- Connection Control Protocol (C2P): connections between the RCST and the GW are established during the logon phase but their parameters are dynamically modified using C2P Modify messages.

B. Option 2: no QoS interaction between IP and MAC layers

The second configuration, shown in Fig. 5, is based on the assumption that dynamic QoS is managed only at IP level by the QoS Manager and that the RCST and GW are able to configure DiffServ routers and schedulers properly according to QoS Manager's decision. In this configuration, there is no interaction between the QoS Manager and the SRM for dynamic QoS signaling.

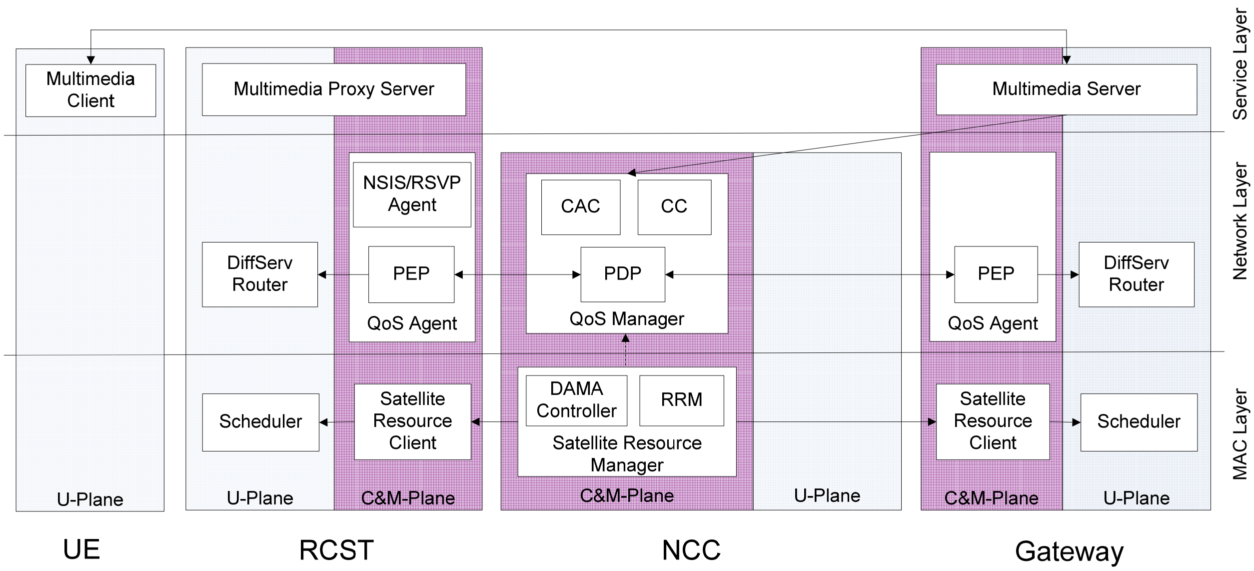

Figure 5. No QoS interaction between IP and MAC layers

The QoS Manager maintains the same functionalities as described before; in particular it has the complete view of resource allocation in the satellite domain and performs CAC and CC functionalities. It is in charge of dynamic resource management at IP layer end to end (from the GW to the RCST).

At MAC layer, the idea is that RCST and GW can allocate resources up to their current terminal channel conditions, so only physical and power limitations affect the satellite resource utilization. Then it is QoS Manager's duty to distribute the resources to the RCSTs and GW according to SLAs and dynamic QoS that each subscriber has been assigned at IP layer. The SRM communicates periodically to the QoS Manager through cross-layer interface terminal characteristics, channel information and MAC congestion in order to keep the QoS Manager's databases updated.

If a new IP flow can be accepted according to the QoS Manager, a COPS Configuration message containing the IP flow mask (Table II) is sent by the PDP implemented in the QoS Manager to the PEPs implemented in the RCST and GW. DiffServ routers use the IP flow mask to schedule the IP flow in the right PHB queue at IP layer. The new IP flow will be mapped to one of the existing MAC layer queues based on its DSCP value. New capacity demand at MAC layer will be derived from the periodic monitoring of the traffic in the queues.

C. Comparative analysis of the two options

i. *<u>Satellite resource utilization efficiency</u>*

The dynamic QoS architecture permits an efficient utilization of satellite resources thanks to dynamic QoS management at IP layer operated by the QoS Manager. It is able to provide the user with QoS guarantees even if a QoS unaware application is used and to allocate satellite resources according to IP multimedia services needs. In the second option with no interaction between IP and MAC layers, MAC layer resources are configured in the RCST and GW in a static way and fixed to their maximum physical transmission capabilities. It allows exploiting satellite resources to their maximum level under the control of the QoS Manager at IP layer. The first option with interaction between IP and MAC layers increases the efficiency of the system thanks to an additional dynamic QoS management at MAC layer. SLA modifications allow the system to rapidly react to QoS needs and consequently to increase the dynamic nature of the QoS architecture, but it requires more signalling overhead over the satellite domain (i.e. dynamic SLA management at MAC layer) that affects directly the satellite link and the satellite resource utilization. Strong impact in the efficiency of the dynamic QoS architecture in the satellite domain has also the frequency of QoS signalling related to the incoming IP flows. If the QoS reservation is performed by the QoS Manager for every new IP flow, the satellite network collapses immediately due to the high number of QoS signalling messages. On the other side, if the QoS Manager does not react rapidly, changing the satellite resource configuration, the dynamic QoS architecture loses its dynamic characteristics and efficiency. In order to maximise the efficiency of the system, a good compromise between the two possibilities consists in managing dynamic QoS with a certain granularity.

ii. *Implementation aspects*

The two QoS options for the dynamic QoS architecture present few technical difficulties as some implementation aspects have to be considered. The first cross-layer interaction is between the service layer and the network layer; for both configurations it is an external cross-layer between the MS and the QoS Manager and the COPS protocol is used for carrying the IP flow mask. The second cross-layer interests only the first option and it operates between IP and MAC layer. The interaction between the QoS Manager and the SRM can be internal or external depending on QoS Manager positioning (internal or external to the NCC). The SNMP protocol or the C2P protocol have been chosen for carrying the IP flow mask on one direction and the SRM's decision on the other direction. Thus, the first option needs to implement, in the SRM and SRC, dynamic SLA or to be C2P enabled implementing C2P Server and Agent respectively. On the other side, the second option with no interaction between IP and MAC layers has less strict constrains. It is based on the assumption that the RCST is IP QoS enabled, so it is needed a RCST performing DiffServ edge router functionalities at IP layer.

V. Laboratory testing of option 2

We have implemented and tested the second option of the dynamic QoS architecture at ESA-ESTEC laboratory facilities [12]. The laboratory set-up, shown in Fig. 6, is composed of the following components:

- the MC can be any commercial multimedia SIP client (i.e. Express Talk [13] or Kapanga [14]);
- the edge router represents RCST and GW and it is able to simulate the satellite link delaying the traffic that goes through it. It has been configured in a Linux PC in order to implement DiffServ feature and two PHB queues, high priority class for real-time services and low priority class for best effort traffic;
- the QoS Manager is real time software composed of a COPS Server and a Decision Server, both implemented in C on Linux platform, that interact through a socket-based interface. The Decision Server implements CAC and CC functionality as described in section III, so it can applies admissibility test to allocate resources to new IP flows traversing the satellite domain;
- the MS is represented by the Q-SIP Proxy Server, a real time software developed by the Research Consortium on Telecommunications (CoRiTel) [15] and University of Rome Tor Vergata. It is composed of a SIP Server developed in Java and a COPS Client in C, that are two different Unix processes communicating through a socket interface. This software has been chosen because it is a QoS-enabled SIP Proxy Server and has already COPS interface. We have changed considerably the source code in order to be compliant with SIP protocol and able to communicate with commercial MCs.

We have implemented in the laboratory test bed the QoS scenario 3b presented in section II. SIP messages are interchanged between MC and Q-SIP Proxy Server, while the COPS interface has been used between Q-SIP Proxy Server and QoS Manager to carry the QoS request. Finally, the QoS Manager interfaces with the edge router through remote commands as Secure Shell (SSH) commands for the resource reservation.

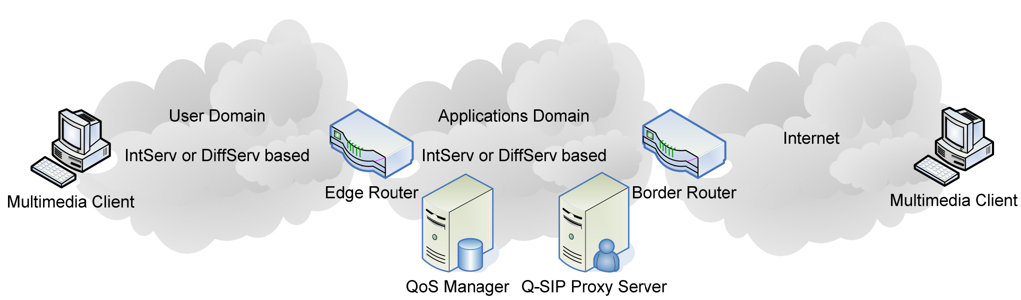

Figure 6. Laboratory test bed of second option

VI. Conclusion

In this paper, a dynamic QoS architecture for multimedia services in hybrid terrestrial-satellite networks has been proposed. This IP-based architecture can be considered as a general architecture for all types of QoS scenarios in multimedia networks. Two configurations have been addressed as the most promising for providing QoS with optimized network resource usage and network configuration.

The first option, in which interaction between IP and MAC layers is present, is based on the latest ETSI and SatLabs recommendations on QoS for DVB-RCS. Dynamic QoS is managed at IP and MAC layers and dynamic SLA is implemented at MAC layer in order to react rapidly to IP multimedia services QoS needs. This option implies a more dynamic management of the satellite resources at MAC layer.

The second option, characterized by no interaction between IP and MAC layers, relies more on existing IP QoS technologies. The main idea is that QoS is managed only at IP level by the QoS Manager and that the RCST and GW configure DiffServ routers and schedulers properly according to QoS Manager's decision. At MAC layer there is no need for dynamic SLA as GW and RCST are configured to their maximum physical transmission capabilities.

Both configurations have been compared in terms of performance and implementation considerations. The first option presents a more responsive satellite interface in particular for the return link, but also increases signalling over the satellite domain. The second option is simpler to implement and fully compliant to current DVB-RCS standard. Special care has to be made in both options in the trade-off signalling overhead versus satellite resources utilization efficiency. Finally, the second option, developed and tested at ESA-ESTEC facilities, has been presented in order to validate the dynamic QoS architecture.

Acknowledgments

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