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A Quality of Service Support Module (QASM) for a Wireless Multi-Segment Integrated 3G Network

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Abstract Deployment of IP multimedia services with guaranteed Quality of Service (QoS) is a primary requirement for Beyond 3G (B3G) systems. In this paper we propose a new architecture to support Internet QoS-sensitive services (e.g., video-conferencing, voice over IP, interactive gaming), thus providing users with end-to-end QoS guarantees. In particular, the paper discloses a new hybrid Intserv/Diffserv scheme for handling IP packets and an interworking procedure with the RSVP protocol which allows to support QoS over an integrated, multi-segment network. Such scheme is implemented by means of a suitable Quality of service Support Module (QASM). Advantages and drawbacks of QASM are discussed and the impact on both system architecture and Multi-Mode Mobile Terminal is investigated. Performance evaluations, carried out via computer simulations, confirm the effectiveness of the proposed solution.

Keywords Quality of Service · Heterogeneous networks · Radio resource management · Virtual home environment

Abbreviations

AN	Access Network
BE	Best Effort
CAC	Connection Admission Control
CCM	Congestion Control Module
CLS	Controlled Load Service
DIFFSERV	Differentiated Services

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DLB	Dual Leaky Bucket
E2E	End to End
EDF	Earliest Deadline First
ESW	Euro Sky Way
FES	Fixed Earth Station
GPRS	General Packet Radio Service
GMBS	Global Mobile Broadband System
GGSN	Gateway GPRS Support Node
GS	Guaranteed Services
INTSERV	Integrated Services
IP	Internet Protocol
MT	Mobile Terminal
PDP	Packet Data Protocol
QASM	Quality of Service Support Module
QoS	Quality of Service
QSD	QASM Signalling Datagram
RSVP	Resource Reservation Protocol
SCTP	Stream Control Protocol
SIP	Session Initiation Protocol
TCP	Transport Control Protocol
TE	Terminal Equipment
T-IWU	Terminal InterWorking Unit
VHE	Virtual Home Environment
WLAN	Wireless Local Area Network

1 Introduction

The new frontier of the Internet world is commonly recognized to be the design of a system able to offer multimedia services with global coverage and QoS guarantees. A possible solution to achieve this goal is represented by the integration of the different access technologies grown during the last decade in a unique system. This implies the development of new procedures and modules to allow the convergence of several access technologies and multiple protocols [1].

A key issue is definitely represented by the architecture for QoS support in this heterogeneous environment [2]. QoS procedures shall be able to harmonize the different QoS offered by the several access networks of the system in order to present services to the user in a seamless fashion. In this context is inserted the SUITED (multi-segment System for broadband Ubiquitous access to InTErnet sevices and Demonstrator) project sponsored by the European Union in the framework of the Information Society and Technology (IST) programme. This project has studied, designed and implemented key functionalities of an integrated satellite-terrestrial Multi-Segment network with global coverage aiming at an efficient provision of IP multimedia services with guaranteed end-to-end QoS to mobile users. Such Global Mobile Broadband System (GMBS) includes four different mobile Access Networks (hereafter, for the sake of brevity, often referred to as *segments*), namely General Packet Radio Service (GPRS), Universal Mobile Telecommunication System (UMTS), Euro Sky Way satellite system (ESW) and Wireless Local Area Network, IEEE 802.11 standard (W-LAN), all linked to an IP Core Network. This paper includes some of the main results achieved in the framework of this research project.

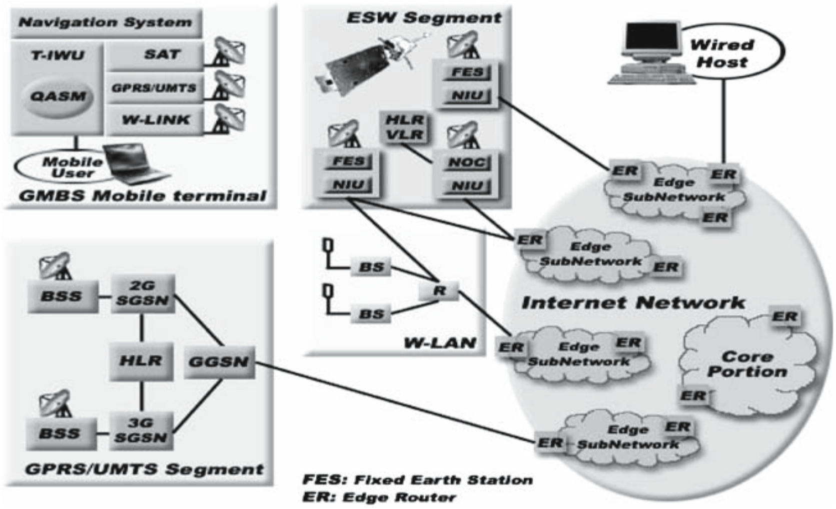

Fig. 1 Reference scenario for the GMBS architecture. The GMBS Mobile Terminal, Access Networks and the Internet Core Network are detailed in the figure

The reference scenario is shown in Fig. 1 and detailed in [3]. This figure highlights that the GMBS Mobile Terminal (GMBS MT) consists of four access-specific terminals (the GPRS and the UMTS terminals are shown as a single one to stress the fact that, in the SUITED project, synergies between the GPRS and the UMTS equipment have been achieved), a Navigation System (including a GPS receiver), a mobile user Terminal Equipment (TE) and a so-called Terminal Inter-Working Unit (T-IWU). This last is the key equipment conceived in the SUITED project; its roles are the interfacing among the mobile user TE, the Navigation System and the access-specific terminals, the selection, on a connection by connection basis, of the most appropriate Access Network to support the connection (which can even vary during connection lifetime resulting in possible inter-segment handovers) and the provision of functionalities to uniform the QoS provided in the GMBS. This paper just focus on these last key functionalities.

Each Access Network has its own specific mechanisms to manage user QoS requirements: the main challenge of GMBS interworking is to harmonize these different ways of operating so that the whole system can be seen, from a user perspective, as a single network providing global coverage and QoS guaranteed multimedia services. This concept is often referred to as Virtual Home Environment (VHE) [4].

In the present research on the VHE issue, various proposals are being presented which basically differ for the layer at which the functionalities necessary for the interworking and harmonization are placed. In this respect, some proposals place these functionalities at application layer [5,6]. This approach has the advantage of requiring a relatively low complexity, but has the drawback of not achieving a real network integration and no seamless services for mobile users. Moreover the interworking at such high level provides unsatisfactory performance for QoS sensitive services.

Other proposals work at transport layer. For example, in [7] the authors aim at providing a comprehensive transport layer solution for a multi-homed mobile host when it moves across heterogeneous wireless networks. They propose a new protocol, called pTCP, that is able to achieve transparent mobility. The protocol is designed for TCP-based services only and no QoS harmonization feature is envisaged in the proposed protocol.

Other ideas are based on SIP ([8]), SCTP ([9]) or Mobile IP ([10]). These protocols are utilised to achieve seamless mobility and vertical handoff control, but no QoS management is foreseen in the solutions presented in these papers.

The main novelty of this paper lies in the proposal to place these functionalities at an ad hoc layer just beyond the IP layer, as detailed in the following. As a matter of fact, by so doing, on the one hand, a real integration of the different Access Networks is achieved and, on the other hand, by following the concepts described in this paper, complexity is kept feasible.

The approach followed in the present paper has been also considering and studying by IEEE 802.21 group in the recent past [11] for defining media independent handover. The IEEE 802.21 framework is intended to provide methods and procedures that facilitate handover between heterogeneous access networks. These handover procedures can make use of information gathered from both the mobile terminal and network infrastructure to satisfy user requirements. The 802.21 framework facilitates the network discovery and selection process by exchanging network information that helps mobile devices determine which networks are in their current neighbourhoods [12,13]. Anyway the standard aims at defining trigger events and messages for seamless inter-system handoff and does not specify algorithms or methods for QoS management and harmonization over the heterogeneous scenario.

In order to provide users with the same QoS regardless of the Access Network supporting the communication, a special module, the so-called *Quality of Service Support Module* (*QASM*), filtering all traffic coming in the GMBS, has been designed. This module is placed, on terminal side, in the T-IWU and, on network side, in the GPRS Gateway Support Nodes (GGSNs) for the GPRS/UMTS network, and in the Fixed Earth Stations (FESs), for the ESW network (see Fig. 1).

From a layering point of view, the QASM layer is placed over the Access Network specific layers (i.e., the radio-technology dependent layers specific of the various Access Networks, in the following also referred to as *Underlying Network Layers*) and below the IP layer. A key issue of the QASM layer is its *transparency* with respect to both IP and the Access Network specific layers, i.e., all QASM functionalities do not have any impact on the way of working of either the IP layer, or the Access Network specific layers. This means that no QASM-specific header is added to the IP datagrams crossing the QASM, i.e., no overhead is added to the system by the insertion of this new special layer. This feature keeps low the T-IWU computational time since no specific header processing is needed.

The rest of the paper is organized as follows: in Sect. 2 the QASM architecture is outlined. Sects. 3 and 4 describe the two major sub-blocks included in the QASM. Section 5 deals with QASM performance evaluation, carried out via software simulations. Finally, some conclusions are drawn in Sect. 6.

2 Quality of Service Support Module (QASM) Architecture

The QASM goal is to perform functionalities (such as classification, scheduling, traffic shaping and policing) aiming at helping the respect of the QoS requirements and at enhancing the efficiency of bandwidth exploitation. Each QASM functionality could be either enabled or disabled depending on the involved Access Network; for instance, a functionality x could be enabled for all IP flows directed to the UMTS network and disabled for all IP flows directed to the GPRS network. The criterion for enabling/disabling the various functionalities is as follows: a given functionality x is enabled for IP flows directed to the Access Network y if and only if the functionality x in the Access Network y is either absent, or less efficiently working than the corresponding functionality in the QASM. This means that the QASM module uniforms the QoS offered to the various Access Networks, thus allowing the actual realization of the VHE concept; in other words, an user roaming through different Access Networks always experiences the same QoS as its home Access Network.

In this paper, following the literature [14], an *IntServ* approach [15] has been adopted in the Access Networks. Such an approach allows a tighter tracking of connection QoS requirements. In particular, the Resource reSerVation Protocol (RSVP) signalling protocol has been considered [16]. In this respect, the QASM module intercepts the RSVP signalling in a reading-only way, i.e., the QASM only reads the RSVP information, but, according to the above-mentioned transparency paradigm, does not perform any modification of this information; the QASM just reads and forwards the RSVP information without modifying it. The reading of the RSVP information allows the QASM to be aware of the QoS connection parameters and hence to take proper QoS support actions, as explained in the following. In light of the above, it should be evident that the QASM must be inserted within RSVP-aware network entities; in this respect, GMBS Mobile Terminal, GGSNs and FESs are appropriate to host the QASM.

The QASMs placed in different network entities communicate through a specific QASM signalling. In this respect, each QASM is able to generate the so-called QASM Signalling Datagrams (QSDs) which are forwarded to the underlying networks as they were standard IP datagrams (i.e., from the underlying network point of view the QSDs look like standard IP datagrams). The QSDs generated by the originating QASM are intercepted by the destination QASM and are not forwarded to the upper layers.

In addition to RSVP signalling, basic QASM inputs are the measurements performed at the underlying network specific layers. For instance, the present status of Access Network specific resources (e.g., bandwidth) is a key information for many QASM procedures.

2.1 The QASM Functional Architecture

The QASM includes the following QoS functionalities:

- *Interfacing the wireless access networks with the overall GMBS network from the QoS point of view.* In this respect, the QASM is able to communicate with the RSVP Intermediate Entity (RSVPIE)[1], in order to catch the RSVP parameters.
- *Performing a set of QoS related support functions such as traffic shaping, congestion control, scheduling, Connection Admission Control, etc.* These actions aim at improving the QoS in the Access Network which has been selected as most appropriate for handling the connection.
- *Monitoring the Access Network status.* In this respect, the QASM collects the measurements performed at the underlying network specific layers and elaborates these measurements for achieving proper parameters which are used for helping the QoS related support functions mentioned in the previous issue.

The QASM functional architecture is described in Fig. 2. In this figure, the signalling information exchanged among QASM functional entities is indicated by means of continuous lines, whereas the dashed lines are related to the IP datagram flow.

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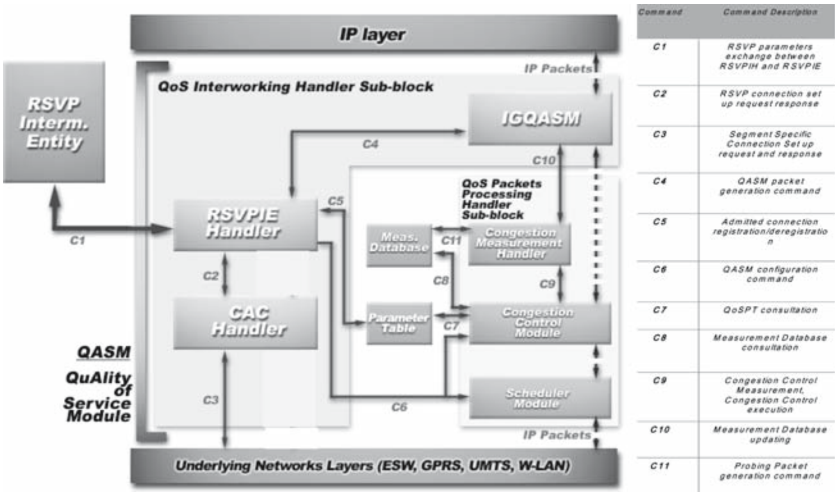
[1] This is the RSVP entity in charge of intercepting and reconstructing the RSVP messages in order to extract RSVP parameters.



Command	Command Description
C1	RSVP parameters exchange between RSVPIH and RSVPIE
C2	RSVP connection set up request response
C3	Segment Specific Connection Set up request and response
C4	QASM packet generation command
C5	Admitted connection registration/deregistration
C6	QASM configuration command
C7	QoSPT consultation
C8	Measurement Database consultation
C9	Congestion Control Measurement, Congestion Control execution
C10	Measurement Database updating
C11	Probing Packet generation command

Fig. 2 QASM functional model and internal signalling

As shown in Fig. 2, QASM basically consists of two major sub-blocks: the *QoS Packets Processing Handler* sub-block and the *QoS Inter-working Handler* sub-block.

The functional entities belonging to the QoS Packets Processing Handler sub-block processes all datagrams crossing the QASM from IP to the Underlying Network layers. These functional entities are:

- the *Congestion Control Module* which is in charge of shaping, policing and queuing IP traffic;
- the *Scheduler module* which is in charge of assigning the right priority to the IP datagrams;
- the (CCM) *Congestion Measurement Handler* which is in charge of setting the Congestion Control Module (CCM) parameters according to the information stored in the so-called *Measurement Database* (see below).

The QoS Inter-working Handler does not process the IP datagrams crossing the QASM. As a matter of fact, it deals with the handling of RSVP signalling, underlying network information and QASM specific signalling. The QoS Inter-working Handler consists of the following functional entities:

- the *Interceptor & Generator of QASM specific signalling* (IGQASM) which is in charge of intercepting and generating the QASM specific Signalling Datagrams (QSDs);
- the *RSVP Intermediate Handler* (RSVPIE) Handler which, during each RSVP connection set-up phase, is in charge of interfacing the RSVPIE, in order to make the QASM aware about the RSVP parameters agreed for the new connection;
- the *CAC Handler* which is in charge of triggering the CAC procedures of the Underlying Networks.

The QASM functional model also includes two databases, namely the *QoS Parameter Table* and the *Measurement Database*. The former stores the QASM QoS parameters of the in-progress connections agreed at connection set-up (static information), as detailed in Sect. 4.1; the latter stores the underlying network status in term of bandwidth availability and congestion (dynamic information). Both kind of information is used for performing the QASM QoS related support functions.

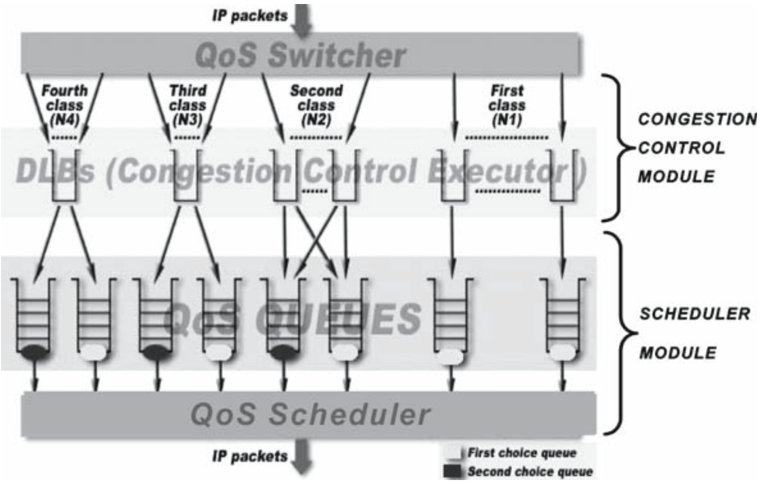


Fig. 3 Congestion Control Module (consisting in QoS Switcher and Congestion Control Executor) and Scheduler Module (consisting in QoS Queues and QoS Scheduler) internal structure

In the following two sections, the two main QASM sub-blocks are described in detail.

3 QoS Packet Processing Handler Sub-block

In order to manage QoS, the various connections are grouped in QoS classes. A given *QoS class* includes all in progress connections characterized by the same QoS requirements (e.g., in terms of minimum bandwidth, maximum tolerated transfer delay, maximum tolerated jitter). These QoS requirements are established at connection set-up through the RSVP signalling and, thanks to the fact that such signalling is intercepted (in a reading-only fashion) by the QASM, are stored in the QASM QoS Parameter Table.

Every class is processed by the QoS Packet Processing Handler using different approaches tailored on the specific QoS class requirements. The selected number of QoS Classes and their rationale will be detailed in Sect. 3.3.

When a new connection is set-up a new data flow (both at terminal side and at network side) crosses the QASM; then, the *Congestion Control Module* (*CCM*), together with the *Scheduler Module*, are in charge of providing the right QoS support (i.e., to match the requirements of the various QoS classes), while aiming at maximizing bandwith exploitation. Figure 3 shows the internal structure of these modules, which will be detailed in Sects. 3.1 and 3.2, respectively.

3.1 Congestion Control Module

The IP datagrams entering the CCM are processed by the QoS Switcher, which is in charge of sorting the IP datagrams according to the QoS Class they belong to. The sorted IP datagrams are sent to a battery of Dual Leaky Buckets (DLBs) [17] which is in charge of performing traffic shaping and traffic policing. The IP datagrams going out of the DLBs are sent to a battery of QoS Queues. The IP datagrams stored in a certain QoS Queue are all relevant to connections belonging to a same QoS class; this means that each QoS Queue is univocally associated a QoS Class. Vice versa, more than one QoS Queue can be associated a same QoS Class.

In any case, the IP datagrams are retrieved from the QoS Queues following the decision of a QoS Scheduler.

The DLBs parameters are configured by taking into account the static information (RSVP T_{spec} parameters) stored in the QoS Parameters Table (this mapping procedure will be described in Sect. 4.1). Let the *compliant traffic* denote the traffic which complies the DLB parameters and hence is accepted by the DLBs, while let the *non compliant traffic* denote the traffic exceeding the DLB parameters and hence overflowing from the DLBs. As for compliant/non-compliant traffic handling, following extensive research and simulations [18] aiming at finding a solution which minimizes the amount of discarded traffic (thus maximizing bandwidth exploitation), while satisfying the connection QoS requirements, we have selected the following approach: the compliant traffic is forwarded towards *first choice* QoS Queues, while the non complaint traffic is forwarded towards *second choice* QoS Queues (i.e., is not necessarily discarded, as it happens in several DLB arrangements).

As detailed in the next section, the QoS Scheduler takes decision about IP datagram retrieval from the QoS Queues basing on the category of the QoS Queue (either first choice, or second choice) and on a priority assigned to each datagram.

3.2 Scheduler Module

Following extensive research and simulations, the selected approach for the QoS Scheduler has been the Earliest Deadline First (EDF) [19]. Each QoS Queue is associated the maximum transfer delay tolerated by the IP datagrams belonging to the connections of the QoS Class associated to the QoS Queue in question. Then, each IP datagram stored in a QoS Queue x is associated a *Time-to-Live* equal to the difference between the maximum tolerated delay associated to the QoS Queue (parameter stored in the QASM QoS Parameter Table) and the time already spent by the IP datagram in the QoS Queue.

Then the QoS Scheduler works as it follows. Whenever it is possible to forward an IP datagram towards the underlying layers the QoS Scheduler considers the first choice queues. Within all the IP datagrams stored in these last queues, the IP datagram selected for transmission is always the one with the lowest Time-to-Live. In case no IP datagram is present in any first-choice queue, then the QoS Scheduler considers the second choice queues. As it happens for the first choice queues, within all the IP datagrams stored in the second-choice queues, the IP datagram selected for transmission is always the one with the lowest Time-to-Live. Nevertheless, if the Time-to-Live of the selected IP datagram is negative (i.e., the IP datagram has waited more than the maximum tolerated delay), then such IP datagram is discarded (i.e., is not forwarded towards the underlying layers) and an other IP datagram is selected. Note that, in general, IP datagram discarding can happen only in second choice queues (i.e., the ones storing non-compliant traffic) and not in first-choice queues (i.e., the ones storing compliant traffic); as a matter of fact, the CAC Handler, basing on the present network status, accepts a new connection only if its QoS requirements can be satisfied for the compliant traffic.

It should be evident that the proposed approach aims, on the one hand, at meeting the delay QoS requirement for the compliant traffic and, on the other hand, at maximizing bandwidth exploitation since, if possible, even the most urgent non compliant traffic is transmitted.

3.3 QASM QoS Class Management

In order to group connections into classes, a key factor is the connection delay sensitivity (e.g., video conferencing applications are extremely delay sensitive, whilst e-mail applications are

Table 1 QASM QoS Classes and Relevant QoS Constraints

QASM QoS classes	Typical applications	QoS Constraints
1st Class	Voice over IP, video conference	Very low transfer delay, delay jitter
2nd Class	Audio-video on demand (MPEGs)	Low transfer delay, delay jitter
3rd Class	Web browsing, telnet	Packet Loss, round-trip delay
4th Class	SMS, E-Mail, FTP	Packet loss

delay insensitive). Moreover, a suitable correspondence between the QASM QoS classes and the underlying network QoS classes (e.g., UMTS, GPRS, ESW QoS classes) has been sought.

It should be clear that the trade-off behind the selection of the number of QoS classes is that to increase the number of classes allows a better fitting between the connections and their QoS requirements, but also increases the complexity of the QoS Packet Processing Handler. As a result of this trade-off, we have selected four QoS classes, as summarized in Table 1.

In order to manage the four QASM QoS classes, we have adopted a hybrid IntServ/DiffServ approach which makes use of either the IntServ paradigm and/or the DiffServ one, as detailed in the following sub-sections.

3.3.1 First QASM QoS Class

Connections belonging to this class have very stringent delay jitter and transfer delay requirements; conversely, a certain datagram loss can be accepted. Then, this class requires fast packet processing. This is obtained by processing the IP datagrams belonging to this class in a completely IntServ way, which means that each connection has its own DLB and QoS Queue (see Fig. 3).

The one-to-one correspondence between QoS Queues and flows ensures a very low delay jitter. Queue length is dimensioned considering the maximum transfer delay tolerated by the IP datagrams relevant to the connection.

In this QoS class, the non-compliant traffic is discarded, because of the very stringent transfer delay requirements.

3.3.2 Second QASM QoS Class

All connections belonging to this class have more relaxed requirements on transfer delay than the first QoS class connections, but stringent delay jitter requirements.

An hybrid IntServ/DiffServ treatment is then assumed for the compliant traffic: each flow has its own DLB, but only one QoS Queue is foreseen for each flow belonging to the second QASM QoS class in order to reduce complexity (see Fig. 3). By so doing, most likely, the IP datagrams are subject to delays which, anyhow, can be tolerated by this QoS Class.

The second-class QoS Queue is dimensioned by considering the maximum delay jitter allowed by the application. The worst case (i.e., maximum delay jitter) occurs when the j-th IP datagram belonging to a certain connection enters the second-class QoS Queue and finds the buffer empty; then the $(j + 1)$-th IP datagram, belonging to the same connection, enters the second-class QoS Queue when the buffer is full. In this case, the relative delay between the two IP datagrams is proportional to the buffer length.

Furthermore, in consideration of the more relaxed transfer delay requirements, a second-choice QoS Queue is adopted for storing the non-compliant traffic.

3.3.3 Third and Fourth QASM QoS Classes

The third and the fourth QASM QoS Classes are less delay sensitive than the first and the second QoS Classes, but have stringent loss requirements.

Third and fourth classes are managed according to a DiffServ approach: for each of these two QoS Classes only one DLB, one first-choice QoS Queue and one second-choice QoS Queue are present (see Fig. 3); as usual, for both these QoS Classes the non compliant traffic overflows towards the second choice QoS queue.

The only difference between these two QoS Classes concerns the way in which they are handled by the QoS Scheduler: the third QoS Class has higher priority than the fourth QoS Class.

4 QoS Inter-Working Handler Sub-block

In order to describe the QoS Inter-working Handler, the case of a GMBS mobile user originated call is considered. Assume that the T-IWU has selected a certain Access Network to handle the call, which, in the following, will be referred to as *active* Access Network.

When a mobile user triggers the connection set-up procedure, the GMBS Mobile Terminal (GMBS MT) generates the RSVP Path massage and forwards the corresponding IP datagram towards the active Access Network. This IP datagram reaches the GGSN (or the FES if satellite is the active Access Network), which are RSVP-aware nodes. Then, the GGSN (or the FES) is in charge of the standard RSVP Path message processing and of forwarding this message towards the IP backbone Core Network.

Following a consolidated paradigm [20], the Core Network does not support RSVP, but adopts a DiffServ QoS approach; hence, suitable inter-working equipment shall manage the interface between the IntServ Access Network and the DiffServ Core Network [21].

Then, according to the standard RSVP procedure, the GGSN (or the FES) receives from the Core Network an RSVP Resv message containing the information about the resources to be reserved for the connection which is going to be set-up. Then, the RSVP Intermediate Entity (RSVPIE) in the GGSN (or in the FES) is in charge of intercepting the RSVP Resv message and of extracting the T_{spec}, R_{spec} and $Flow_{spec}$ values (see [16]), i.e., the so-called *RSVP QoS profile*. This information is passed to the RSVP Intermediate Entity Handler (RSVPIEH) which checks, through the Call Admission Control Handler (CACH), the actual resource availability in the active Access Network.

As a matter of fact, at first, the RSVPIEH maps the RSVP QoS profile into an Access Network (AN) specific QoS profile (the so-called *AN QoS profile*), according to the so-called "RSVP-to-AN QoS mapping procedure" which will be detailed in Sect. 4.1 Afterwards, the AN QoS profile is passed to the CACH which interacts with the Access Network specific Connection Admission Control (CAC) procedure, in order to check the availability of the resources necessary for satisfying the AN QoS profile of the incoming connection, thus eventually meeting even the connection RSVP QoS profile. As detailed below, the AN QoS profile is also used to initialise the functional entities of the QoS Packets Processing Handler in the GGSN (or FES) QASM.

If the active Access Network avails of the requested resources, then the RSVP Resv message is forwarded downstream till it reaches the GMBS Mobile Terminal (GMBS MT) which generated the RSVP Path message (i.e., which triggered the connection set-up). At the GMBS MT, this last message is intercepted by the RSVPIE which extracts the Resv QoS profile and forwards it to the RSVPIE Handler in the GMBS MT QASM. This latter performs the RSVP-to-AN QoS mapping procedure and forwards the AN QoS profile to the CACH in the GMBS MT QASM. This latter, by interacting with the active Access Network reserves the resources necessary to meet the AN QoS profile.

Note that the procedure taking place in the GGSN (or in the FES), just checked the availability of the resources necessary to satisfy the connection AN QoS profile, while the procedure taking place in the GMBS MT provides for actually reserving them.

As a meaningful example, Sect. 4.2 details the above-mentioned procedure in the case in which the active Access Network is the UMTS.

4.1 RSVP-to-AN QoS Mapping Procedure

The first basic issue of the RSVP-to-AN QoS mapping procedure concerns the mapping of the RSVP QoS Classes, namely Guaranteed Service (GS), Controlled Load Service (CLS) and Best Effort (BE) [5] into the four QASM QoS Classes defined in Sect. 3.

The CLS service class is considered for adaptive real-time applications with relaxed delay requirements. The QoS offered by a CLS is similar to that achievable by a BE service in an unloaded network. In other words, the CLS does not make use of specific target values for control parameters, such as delay or loss. Consequently, applications that require a CLS specify only the T_{spec} parameters, the R_{spec} parameters are not required.

Instead GS is considered for “ real-time applications” with tight delay requirements. QoS provision to a GS implies: (i) assured level of bandwidth (Guaranteed throughput), (ii) mathematically bounded end-to-end delay (Guaranteed maximum delay) and (iii) no queuing losses for conforming packets. The applications that require a GS specify both the traffic characteristics (T_{spec}) and reservation characteristics (R_{spec}). When a GS class is selected by the Receiver application, each network element involved in the end-to-end data path, (from the Sender to the Receiver), in order to support the requested service, has to perform an admission control test to evaluate if it has sufficient resources to reserve the requested Rate (R). Thus, the most appropriate mapping is the one shown in Table 2.

The second basic issue of the RSVP-to-AN QoS mapping procedure is the mapping of the RSVP parameters into the QASM QoS parameters, i.e., basically, the parameters of the DLBs present in the Congestion Control Module and the maximum delay tolerated by the connection in progress.

As for the DLB parameters, they are selected by “translating” the RSVP T_{spec} parameters, as follows:

- [T_{spec}] Sustainable rate = [DLB] Tocken Bucket Rate;
- [T_{spec}] Peak Data rate = [DLB] Peak Data Rate;
- [T_{spec}] Tocken Bucket Depth = [DLB] Tocken Bucket Size.

As for the maximum delay tolerated by a connection, it is deduced, at connection set-up, by the RSVPIEH basing on the R_{spec} parameters received from the RSVPIE.

4.2 An Example Case: RSVP–QASM–UMTS Interaction

In order to detail the inter-working between RSVP and QASM, this section considers the meaningful case in which the UMTS Access Network is active. Both user-originated and network-originated connection set-ups are dealt with.

Table 2 RSVP-QASM QoS Class mapping

RSVP classes	QASM classes
GS	1°class
	2°class
CLS	3°class
BE	4°class

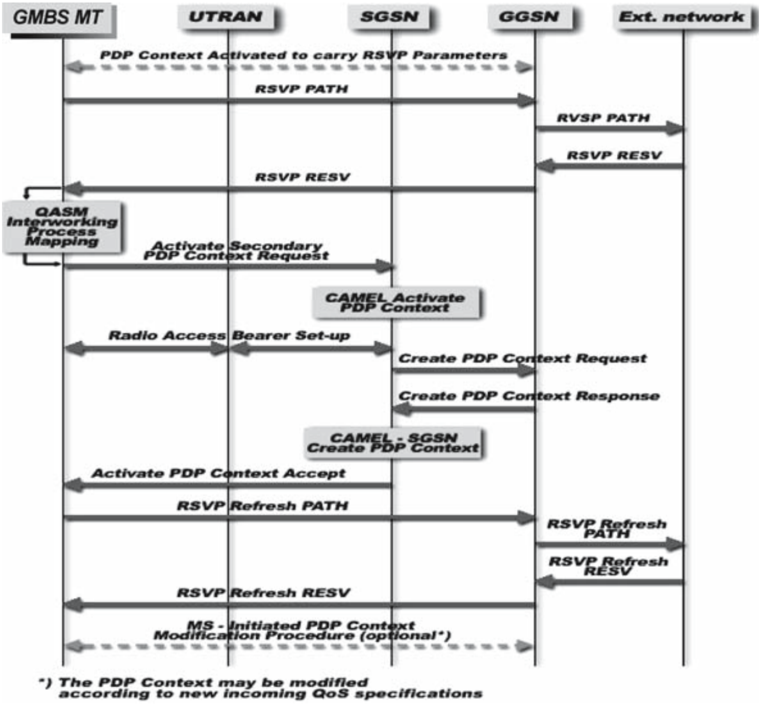
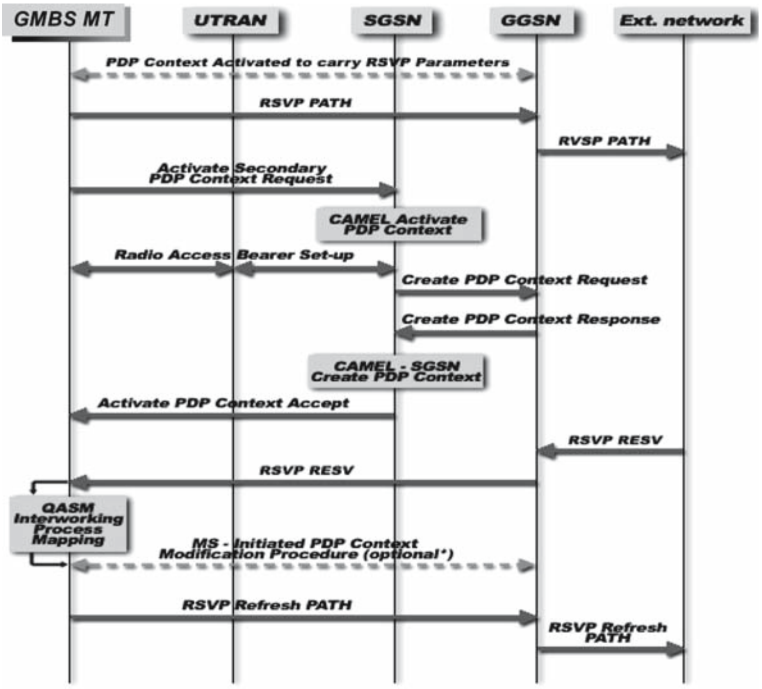


Fig. 4 User-originated connection set-up: standard approach

It is worth reminding that, at each connection set-up attempt occurring in the UMTS network, a PDP (Packet Data Protocol) Context Activation procedure is triggered [22,23]. This procedure aims at checking the possibility to accept the incoming connection and at making the UMTS entities aware about the requested QoS profile. In this respect, note that it is possible to modify the QoS profile for an already in progress connection through the PDP Context Modification Procedure [22,23]. In addition, a PDP Secondary Context Activation Procedure is used to open many PDP Contexts having the same PDP address, but with different QoS profiles. A PDP Context Deactivation procedure is used to release an already active Context.



*) The Secondary PDP Context has been set up with an extimated QoS profile whose specifications are taken from the previously sent PATH message. It may be modified according to the new incoming QoS specifications.

Fig. 5 User-originated connection set-up: alternative approach

In the following, the inter-working between RSVP and PDP Context Activation/Modification Procedures through the QASM will be detailed.

4.2.1 User-originated Connection Set-up

Figure 4 shows the whole signalling procedure involving RSVP, QASM and PDP Context. In this case, the GMBS MT triggers a PDP Context Activation as soon as it receives the RSVP Resv message.

Figure 5 shows an alternative, original approach in which the GMBS MT triggers a PDP Context Activation as soon as it sends the RSVP Path message. The basic idea behind this last approach is that for CLS and BE classes it is often possible to select the QoS parameters for the PDP Context Activation Procedure just looking at the information included in the RSVP Path message (i.e., static source description), without waiting for the RSVP Resv message; nevertheless, this approach is not applicable for the GS class which needs the parameter R = "Requested Rate", contained in Resv message, to establish the PDP QoS profile. This approach has the evident advantage of saving signalling time since both the RSVP and the PDP procedures can evolve in parallel.

In light of the above, the most appropriate approach is to use the standard approach for the GS class and the alternative approach for the CLS and BE classes.

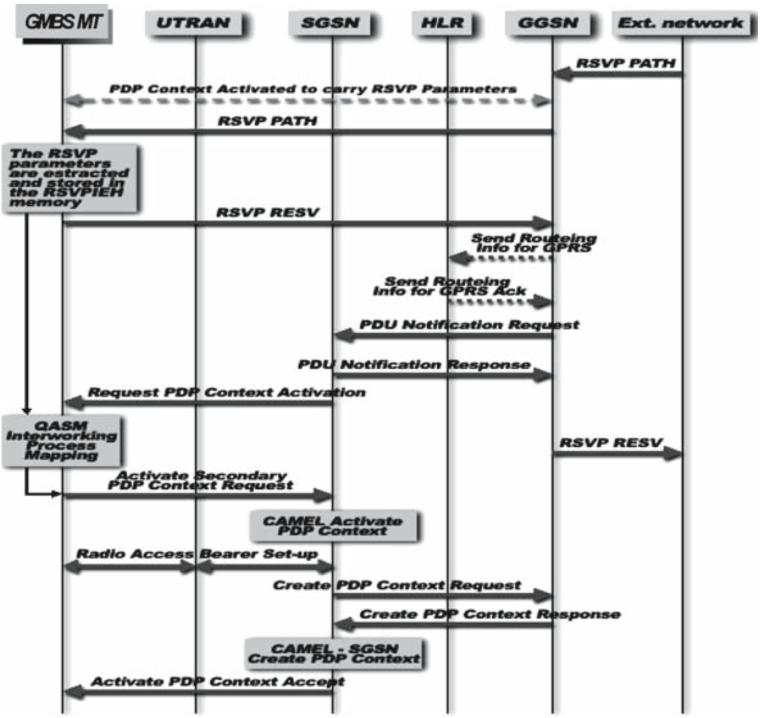


Fig. 6 Network-originated connection set-up: standard approach

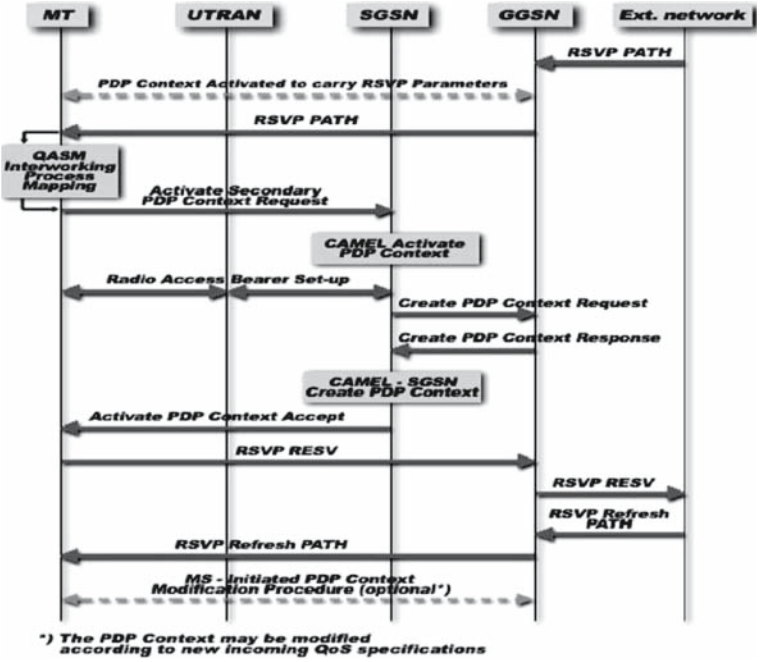


Fig. 7 Network-originated connection set-up: alternative approach

4.2.2 Network-originated Connection Set-up

Figure 6 shows the whole signalling procedure involving RSVP, QASM and PDP Context. Even in this case, as it happens for the user-originated case, the PDP Context Activation procedure can be triggered by the MT even before the arrival of the RSVP Resv message, as shown in Fig. 7.

The same considerations, as the user-originated connection set-up case, concerning the use of the two approaches in conjunction with the GS, CLS and BE classes, apply.

5 Simulation Results

Several computer simulations, using OPNET Modeler tool, have been carried out in order to evaluate QASM performance. The main goal of the simulations has been the verification that, by inserting the QASM into the GMBS Mobile Terminal (GMBS MT) does (i) enhance the exploitation of the lower layer resources and (ii) harmonise the offered QoS by the different Access Networks of the GMBS.

The simulation scenario basically consists in:

- a GMBS MT, whose protocol stack includes the QASM layer, which can transmit/receive IP datagrams to/from both satellite (ESW) and terrestrial (GPRS) link;
- several GPRS terminals (in order to simulate a congested cell), with their protocol stack;
- a wired host connected to the IP Core Network;
- a GPRS Access Network (i.e., a base station and a GGSN connected to the IP Core Network);
- ESW Access Network (i.e., a satellite link and a FES directly connected to the wired host);

During the simulation time interval (600 s), data traffic characterising typical IP services is generated, both on terminal and on network side; in particular, voice over IP (codec G.729), video streaming (codec H.261), web browsing and file transfer protocol sources have been taken into account and simulated, as examples of the four QASM QoS classes.

The available capacity of the considered GPRS link is up to about 200 kbps [24].

In order to highlight the above-mentioned issue (i), only GPRS Access Network is considered “active”.[2] Two different kinds scenarios have been simulated: the former considers the GMBS MT only availing of the GPRS QoS management (i.e., *without the QASM*), the latter considers the GMBS MT also availing of the QASM QoS management (i.e., *with the QASM*). A comparison between the main QoS parameters of these scenarios has been carried out.

Figure 8 and Table 3 show that QASM insertion does improve the QoS performance with respect to the one offered by the underlying network layers. In particular, it is possible to notice that QASM allows IP traffic differentiation thus satisfying the heterogeneous QoS requirements of the different traffic categories. Jitter is drastically reduced for the real-time classes (i.e., the first and the second). The design of the play-out buffer to handle real-time traffic in the receiver will be easier thanks to the insertion of QASM in GPRS protocol stack. Jitter reduction in the first class coincides with an end-to-end (e2e) delay reduction due to the higher priority assigned to this type of traffic. On the contrary, jitter reduction in the second class is at the expenses of an increase in e2e delay, due to a lower priority assigned to that

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[2] An access network is considered active when IP traffic is passing through it.

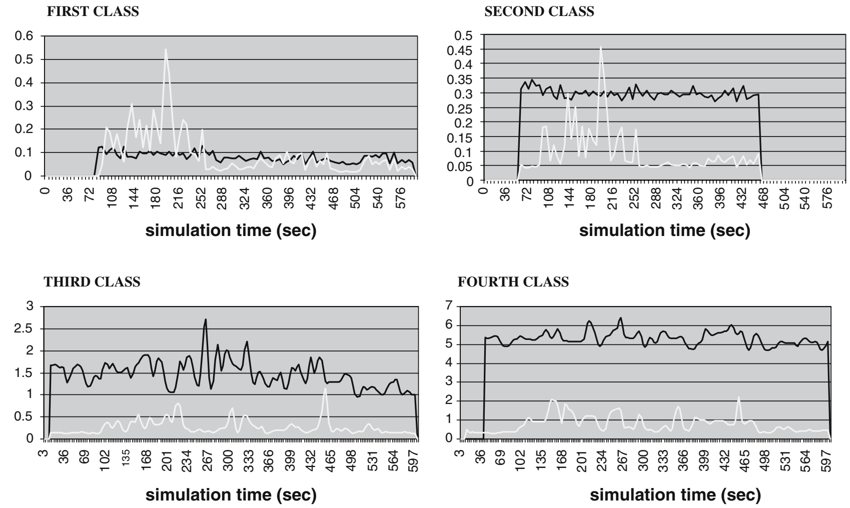


Fig. 8 End-to-end delay (expressed in seconds) for the four QASM QoS classes, during the considered simulation time interval (600 s), when the GPRS Access Network is active White lines and black lines represent the cases *without* and *with* the QASM, respectively

Fig. 9 Total radio interface throughput (expressed in bps) for the four QASM QoS Classes, during the considered simulation time interval (600 s), when the GPRS Access Network is active. White lines and black lines represent the cases *without* and *with* the QASM, respectively

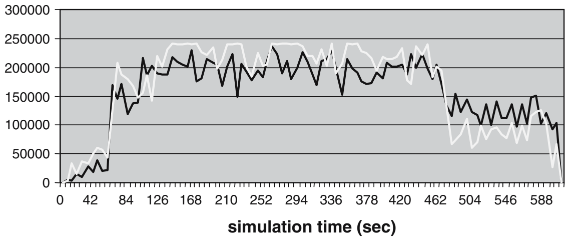


Table 3 Numerical results of the first set of simulations: Enhancing lower layer resource exploitation

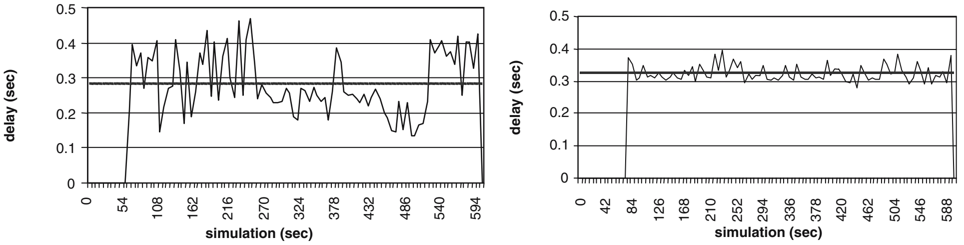
QASM Classes	Average E2E delay GPRS (s)	Average E2E delay QASM + GPRS (s)	Maximum jitter GPRS (s)	Maximum jitter QASM + GPRS (s)
First (voice)	0.21	0.11	0.39	0.03
Second (video)	0.12	0.29	0.37	0.09
Third (http)	0.4	1.5	–	–
Fourth (ftp)	0.09	5.1	–	–

category where delay requirements are less stringent. Nevertheless the obtained value is still compliant with 3GPP specifications [25]. Third and fourth class also suffer an increase in e2e delay due to the lower priority assigned to them by QASM QoS management. Anyway packet starvation is avoided thanks to the EDF scheduler.

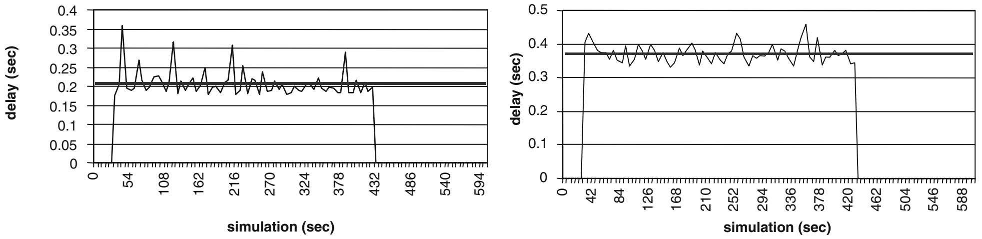
Likewise, Fig. 9 shows that the presence of the QASM in the system , and in particular its battery of DLBs, enables traffic smoothing procedures thus permitting a better bandwidth exploitation (Table 3).

Terrestrial link **Satellite link**

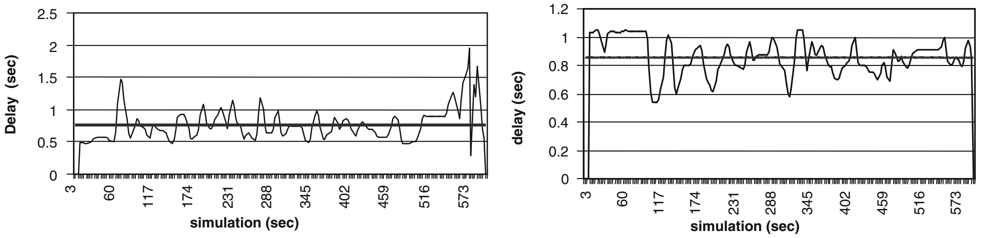
FIRST CLASS (voice source)



SECOND CLASS (video source)



THIRD CLASS (HTTP source)



FOURTH CLASS (ftp source)

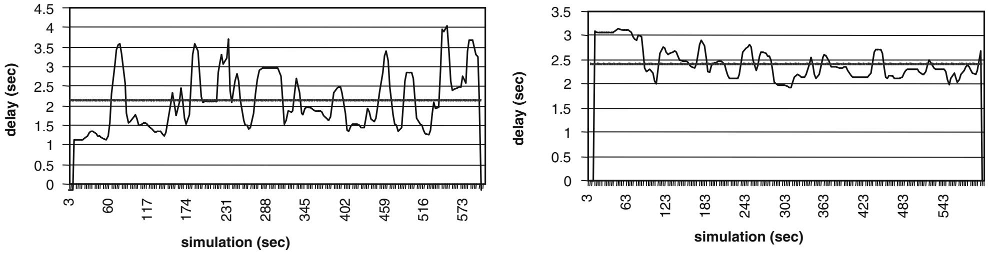


Fig. 10 End-to-end transfer delay for the four QASM class, during the considered simulation time interval (600 s); left and right sides refer to the terrestrial GPRS link end the ESW satellite link, respectively The horizontal line highlights the average end-to-end delay

Table 4 Numerical results of the second set of simulations: Harmonizing the offered QoS in the different access networks

QASM classes	Average E2E delay QASM+GPRS (s)	Average E2E delay ESW (s)	Maximum jitter QASM+GPRS (s)	Maximum jitter ESW (s)
First (voice)	0.28	0.31	0.23	0.12
Second (video)	0.21	0.36	0.15	0.16
Third (http)	0.8	0.9	–	–
Fourth (ftp)	2.1	2.5	–	–

In order to highlight the above-mentioned issue (ii), a set of simulations has been carried out where both the GPRS and the satellite (ESW) Access Networks have been considered. The scenario aims at simulating an inter-system handover between the two segments. QASM congestion control functionalities have been deactivated when ESW segment is "active", since they are already provided by the satellite network itself [26], thus avoiding duplicate operations and preserve computational time within the T-IWU.

Graphs in Fig. 10 and numerical results in Table 4 confirm that the insertion of QASM in the GMBS MT guarantees QoS harmonization among the Access Networks and provides transparent user mobility. End-to-end delay for all the four QASM classes and jitter for the first two have the same order of magnitude regardless of the segment utilized for sending traffic. Therefore the GMBS user is not able to perceive any appreciable QoS change if either the satellite (ESW) or the terrestrial (GPRS) Access Network is used for data transmission (Table 4).

6 Conclusions

In this paper a multi-segment system to access IP services has been studied. In such scenario a special module (called QASM) has been designed in order to provide users with the same QoS regardless of the Access Network, thus realizing a real integration of different access networks and achieving the concept of Virtual Home Environment (VHE).

As confirmed by simulation results, we conclude that the innovative QASM-based architecture meets all the requirements it has been conceived for. On the one hand, it is able of enhancing bandwidth exploitation and satisfying different QoS requirements as well as of harmonising QoS performance among different Access Networks (VHE concept). On the other hand, the QASM is able to efficiently interact with the RSVP signalling in a transparent way, i.e., without causing any modification of the usual procedures of either the IP layer or the Underlying Network layers (Access Network specific); thus, the complexity of its insertion in the GMBS is relatively low.

We consider that the approach proposed in this paper can be used to realize the convergence of several access technologies in an unique IP based system able to provide QoS guarantees and ubiquitous services.

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Paolo Dini received the "laurea" degree (cum laude) in Electronic Engineering and the PhD degree in Telecommunications, both from the Università di Roma "La Sapienza". He worked in the Computer Science and Systems (DIS) and Information and Communication Theory (INFOCOM) departments of the same university as a research assistant and assistant professor. He also worked with the Research Center on Software Technologies (RCOST) as a research assistant. He participated in several research projects funded by EU (SUITED, VIRTUOUS, SAILOR, NATACHA and IMAGES) and by Italian companies. Now he is with the IP Technologies area of the CTTC as a research associate. His research interest areas include wireless networking, protocol analysis, Quality of Service and Resource Management in mobile networks.

Francesco Delli Priscoli was born in Rome in 1962. He graduated in Electronic Engineering "summa cum laude" from the University of Rome "La Sapienza" in 1986. He received the Ph.D. in system engineering from the University of Rome "La Sapienza" in 1991. From 1986 to 1991 he worked in the "Studies and Experimentation" Department of Telespazio (Rome). Since 1991 he is working for the University of Rome "La Sapienza" where, at present, he is "Full Professor" and holds the courses "Automatic Controls", "System Theory" and "Network Control and Management I and II". In the framework of his activity, he researches in the nonlinear control theory and in the area of control-based resource management procedures for the third and forth generation of mobile systems. He is the author of about 150 technical papers on the above topics appeared on major international reviews (about 50) and conferences (about 100). In 2000 he has been scientific consultant for the Italian Council of Ministers in the framework of the auction for the assignment of the Italian Universal Mobile Telecommunication System (UMTS) licensees. He is an associate editor of Control Engineering Practice and a member of the IFAC Technical Committee on "Networked Systems". He is/has been scientific responsible, for the University of Rome "La Sapienza", of 17 projects financed by the European Union (fourth, fifth and sixth framework programmes) or by the European Space Agency (ESA), dealing with resource management for UMTS and broadband terrestrial and satellite wireless systems. He is also a project evaluator for the European Commission.