Enhanced IP-based satellite architecture compatible with many satellite platforms

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ABSTRACT

In this document we describe the architecture of BRAHMS (Broadband Access for High speed Multimedia via Satellite), project sponsored by EU in the framework of IST research programme. BRAHMS aims at specifying an IP-based architecture for broadband satellite access independently of the particular GEO or LEO satellite technology adopted in the satellite link. Broadband Multimedia Satellite System (BMSS) is intended as a generic solution for provision of multimedia services via satellite access networks within a future worldwide IP-based terrestrial public network. This scenario is defined to promote integration and harmonization of many access networks services and functions (e.g. QoS, multicast, roaming, security) whilst allowing flexibility for optimized or proprietary air interfaces (i.e. frequency, access type, orbit, space segment architecture, etc.).

Key words: IP-based architecture, QoS, multicast, IntServ, DiffServ.

I. INTRODUCTION

Driven by the growth of the World Wide Web and the Internet, most of the satellite revenues in the next years are expected to come from the transport and delivery of IP-based applications and services, either to seamlessly complement the available terrestrial broadband services, or to propose, in some niche markets, added-value services as compared to terrestrial ones. The challenge for the Next Generation satellite systems is therefore finding an efficient integration in IP-centric Next Generation Telecommunication Networks. Currently studied GEO (Geostationary Earth Orbit) satellite system technologies, which aim at providing a transparent integration in Internet networks, rely on ATM (Asynchronous Transfer Mode), ATM-like or DVB (MPEG/DVB) technologies. They share their mission of supporting multimedia, in variable proportion from one system to another, between broadcast or multicast (point-to-multi-point), point-to-point, multi-point-to-point bi-directional traffic pattern (symmetrical or asymmetrical), and cover a more or less wide range of service provisioning. They are associated with transparent or regenerative satellites. Research has delivered a number of proprietary solutions, which in the satellite field are hardly open to the public. This number is likely to increase in the next few years and in the long term. At this stage the role of the standardization process assumes particular prominence. Compatibility issues have to be evaluated carefully and in this context IP is seen as the common denominator which will drive future applications into a platform-independent transport scheme. Optimization of IP (Internet Protocol) transport over a generic satellite technology then becomes a goal of primary importance.

This document proposes a general model for an IP-oriented satellite architecture in which a range of existing and future satellite technologies can be accommodated and exploited at the most by IP-based applications.

The Broadband Multimedia Satellite System (BMSS) is intended as a generic solution for provision of multimedia services via satellite access networks within a future worldwide IP-based terrestrial public network. This overall scenario (Fig.1) is defined to promote integration and harmonization of many access networks services and functions (e.g. QoS, multicast, roaming, security) whilst allowing flexibility for optimized or proprietary air interfaces (i.e. frequency, access type, orbit, space segment architecture, etc.). The BMSS is therefore intended to support a choice of several (RTD - Radio Technology Dependent) radio access technologies through a common set of RTI (Radio Technology Independent) protocols, which present common interfaces at the periphery of the BMSS. Furthermore, the RTI protocols are designed to support the widest possible range of end-to-end teleservices based on IP transport, in conjunction with present and future (QoS enabled) IP-based services provided via terrestrial networks.
In this document we describe the architecture of BRAHMS (Broadband Access for High speed Multimedia via Satellite), project sponsored by EU in the framework of IST research programme. BRAHMS project aims at specifying an IP-based architecture for broadband satellite access independently of the particular GEO or LEO satellite technology adopted in the satellite link.

This BMSS approach is seen as a vehicle for convergence between fixed and mobile multimedia networks towards the Global Multimedia Mobility (GMM) architecture, by merging service functions derived from the UMTS/IMT segments, as can be seen in Fig.2.

The Internet access-oriented architecture includes four segments, as can be seen in Fig.2.

**The User Segment** includes all entities which require access to a network, through standard IP devices; this covers:
- Residential users, equipped with standard PCs or home servers and subscribed to an ISP (Internet Service Provider) or to some specific content delivery network;
- SOHO users, equipped with workstations, PCs or small capacity routers/servers and subscribed to an ISP or other private networks;
- Corporate LANs (e.g. part of an international corporate network)

The **Access Network** (e.g. BMSS), adopts various terrestrial technologies (usually circuit switched), e.g. PSTN, ISDN, wireless access networks, ADSL etc. The Satellite Access Network includes the following components, hereinafter subsystems, whose protocol stack is depicted in Fig.3:
- the user-side access terminal equipment, hereinafter referred to as **BMSS Satellite Access Terminal (BSAT)**, interfacing with a Customer Premises Equipment (CPE) including Customer Premise Networks (CPNs) of UIEs (User IP Equipments), through standard protocols, for example PPPoE (PPP over Ethernet), PPP/USB, and IP/Ethernet; one BSAT can interface with several UIE
- the network-side access equipment, hereinafter referred to as **BMSS Hub Station (BHS)**, interfacing with routers (or IAP/ISP access servers for individual access) with transport protocols such as ATM over SDH, or ATM over ADSL, or Ethernet on the core network side.
- the **satellite payload**, which can be transparent, providing layer 1 connectivity (at frequency channel or carrier or time-slot level), or it can be regenerative and provide layer 2 packet connectivity; the connectivity can be more or less dynamic, most probably quasi-static in the case of a transparent satellite and more dynamic in the case of a layer 2 packet switching.

The **Network Control Center (NCC)**, which manages the operation of the satellite network including the satellite as well as the ground stations; this is assumed to be entirely dependent on the satellite technology. It is in charge of the control and management of the satellite access network including BSATs, BHSs, satellite communications functions and as well as communications resources (radio resources and addressing resources). The satellite Mission Control Center (MCC) which may be associated with the NCC, supervises the basic satellite facilities through the TM/TC.

The **Core Network** includes all the “Internet networks”, themselves connected to the Internet Backbone and composed of routers, servers and gateways towards the Internet Backbone. These networks are ISP networks,
corporate networks or other types of networks (e.g. content delivery networks).

III. BSAT FUNCTIONAL CHARACTERISTICS

BSAT (BMSS Satellite Access Terminal) is the network equipment allowing devices on the User Segment to access the satellite segment

A BSAT interfaces with costumer premise devices via standard IP to support interworking of the satellite segment with a wide range of terrestrial link-layer technologies. The requirements on bandwidth, throughput, etc for business communications could be stronger than those for home terminals. As a consequence, resource allocation policy, not supported by traditional IP, is needed. Dynamic resource allocation procedures can be arranged depending on the type of terminals in the User Segment adopting a DiffServ ([3],[4]) or an IntServ ([1],[2]) QoS approach through RSVP messages exchange.

BSAT functionalities can be divided into two distinct areas, namely the Radio Technology Dependent (RTD) and Radio Technology Independent (RTI) parts. The RTI design shall be oriented so as to allow convergence with a variety of radio access technologies. Control and User plane functions will be separately considered for both RTI and RTD components.

IV. RTI-RTD: BMSS NETWORK LAYER (BNL)

The BNL interfaces with the IP layer and the satellite platform on the satellite link side. It performs IP-flow classification, IP performance enhancing functions and adaptation of IP over satellite platforms.

A BNL entity in the BSAT is in communication with its peer entity in a BHS and is responsible for transmitting and receiving control information and data across the Satellite segment.

BNL functionalities are distributed in the control and user plane:

Control plane – handling RTI signaling to control the RTD resource management policy.

User plane – processing IP datagram and adapting IP QoS techniques (IntServ and DiffServ) to the specific RTD traffic management mechanisms, by means of configurable traffic control architecture.

As depicted in Fig.4, the BNL is divided into two sub-layers, the BNL-Common Part and the BNL-Specific Part. The BNL-Common Part performs all those functions that are common to the BMSS. It is thought to provide a common basis for the BNL-SP parts which, instead, are configured to provide adaptation to a particular satellite technology. The BNL-CP contains functionalities that can be activated in order to enhance performances of IP streams to transport over a satellite link. These can include IP header compression ([8]), TCP PEPs (Proxy Enhancing Performances) ([5]), signaling overhead reduction.

The BNL-Specific Part constitutes the Radio Technology Dependent part of the BNL; it performs the same functions for any satellite platform but configured so as to achieve adaptation to the RTD parts. In particular, adaptation is needed to render the transfer modes that is provided by the RTD part transparent to the upper layer, i.e. if the underlying technology is connection-oriented or connection-less. The BNL-SP is then provided with functionalities capable of receiving connectionless streams from the upper interface and requesting bearer setup to the lower interface for connection-oriented transport over the satellite link, when connectionless transport is not supported.

Another form of adaptation is needed to configure multiplexing and demultiplexing of IP flows onto satellite bearers, which could vary in the number and in the degree of QoS provision. The design of the BNL-SP is made sufficiently parametrical so as to operate over any satellite technologies. The BNL-SP is configured on the particular platform to guarantee compatibility and to exploit it as much efficiently as possible.

User Plane functionalities

As concerns to the user plane, the BNL is mainly concerned with the Traffic control mechanisms, TCP PEP (e.g. TCP spoofing), Data Unit compression/decompression and Data encryption/decryption.

As to the traffic control mechanisms, they are located in the BNL-Specific Part. The rationale for this choice is that BNL design has the purpose of enriching RTD

Fig.3. BMSS protocol stack

Fig.4. BSAT protocol stack
functionalities, avoiding duplication of functions where possible. Therefore, if the underlying RTD platform has got sophisticated traffic control mechanisms, like in the case of an ATM-based system, the set of functionalities to implement in the BNL-SP traffic control should to be reduced to the minimum. In addition, the multiplexing/demultiplexing strategy of IP flows onto and from satellite bearers is dependent on satellite technology. Examples of blocks constituting the traffic control entity are:

**Policing blocks.** Its task is to regulate IP traffic before this is offered to the underlying RTD parts adopted by an advanced agreed profile or dynamically negotiated through signaling exchange. BNL policing can operate a finer control of network resources utilization by IP flows, before these are multiplexed onto satellite bearers. If policing is performed only in the RTD part, discarding non-conformant RTD cells could mean discarding also conformant flows at IP level.

**Classifier.** On the grounds of the information contained in the packet header, it classifies packets coming from the I_USER into flows with an associated QoS policy

**Shaper.** It gives incoming traffic a more regular profile, by smoothing peaks through dropping and buffering.

**Scheduler.** It performs packet reordering on multiplexing IP flows on a same satellite bearer, on the basis of the class of service which traffic flows belong to.

**Control Plane functionalities**

The complexity of the functions performed by this plane depends basically on the transfer mode adopted by the RTD platform. When the latter has no switched connection capabilities, i.e. is connectionless, no connection establishment operations are required; therefore, the BNL, and its Specific Part in particular, will not be able to control the RTD resource management policy. In case RTD provides switched connection capabilities, BNL-SP has to perform the following set of operations:

**Interworking** with the RTD signaling protocol entities in order to hide the channel establishment/tear-down peculiarities to the BNL-CP mechanisms.

**Translating the BNL QoS parameters** into RTD specific QoS parameters, which are required for connection establishment in the RTD part.

In the BNL Common Part sub-layer, a set of functionalities dealing with the adaptation of RSVP protocol to the satellite environment has been put. Even if RSVP module lies on top of the BNL, some added functionalities in the control plane are necessary underneath to make the use of RSVP convenient for the BMSS.

**V. RTD**

Due to the number of satellite platforms that can be supported by the BMSS, it is not possible to make a general characterization of the RTD part. However, a first distinction is between systems which are connection-oriented from those which do not require connection establishment. As for the first systems, these provide satellite terminal with switched transfer capabilities and resources can be assigned dynamically. Conversely, the second systems have a simpler architecture as resources cannot be requested but are statically assigned to each terminal. In the following the considered RTD part is connection-oriented so as to examine a richer and more complex set of functionalities.

**Control plane functionalities**

As far as the control plane is concerned, the main task that the RTD part has to carry out is to manage allocation of resources and establishment/release of channels. In a connectionless transport scheme this part of the system is remarkably simpler, since no channel establishment is needed.

Regardless of the nature of the RTD system, several data channels have to be offered to the BNL layer, which are identified by the following information:

- **Channel Identifier (Channel_ID).** The Channel_ID which is used for routing in the satellite link.
- **Service Access Point Identifier (SAPI).** It indicates the service type to be offered for the frame transport.

The resource allocation policy could vary from a simple static allocation of resources to a more complex strategy governed by a congestion control algorithm. This exploits statistical multiplexing of packet-switching transfer to optimize satellite resource utilization. An efficient allocation of resources could assign a minimum share of bandwidth to specific satellite bearers plus an additional and variable portion to contend among competing bearers. The congestion control algorithm should monitor the state of load of the satellite link and take actions so as to control delay introduced by statistical multiplexing and prevent buffer overflows. Resources to be monitored carefully are especially those belonging to the satellite payload, which is provided with limited resources and located at the center of a star topology and, hence, likely to be considerably loaded by surrounding BHSs and BSATs.

**User Plane functionalities**

A BSAT is designed to provide transport of IP datagrams, which have variable-length format. As radio capacity is often shared on time-multiplexed channels having fixed time-slots, IP datagrams should be fragmented in fixed-size cell to be transmitted. Therefore, an assumption that will be made in the document is the presence of segmentation and reassembly functions in the RTD part. This, however, is not a requirement to be necessarily satisfied by the RTD part.

Segmentation and Reassembly is only one of the possible framing operations performed by the RTD part, which is likely to add some control information to the fragmented
IP datagrams, often comprising L2 addresses or Channel_ID, priorities, frame numbers, authentication fields. On transmission into the radio channel, packets are likely to be scheduled according to their L2 address or Channel_ID and their priorities.

Management plane functionalities
Due to the broadcast nature of satellite systems, the radio interface has to support at least the following security features:

Confidentiality of subscriber and user identities. It ensures that the identities are not available or disclosed to unauthorized parties.

Subscriber and user authentication. It provides support for the verification of subscriber and user identities.

Confidentiality. It ensures that the conveyed traffic (signaling, ordinary calls, data) is not made available or disclosed to unauthorized parties.

VI. BSAT ARCHITECTURE
In this section a more detailed description of the BSAT functional entities and their relations are given. It is worth pointing out that each BHS is endowed with the same entities described for the BSAT subsystems; for this reason and for readers’ convenience their description will be left out.

In Fig.5 horizontal dotted lines represent interfaces between layers, while vertical lines separate the three functional planes: User Plane (UP), Control Plane (CP) and Management Plane (MP).

Rounded boxes (e.g. “ARP”) represent entities, whereas square boxes with a bent corner (e.g. “Routing Table”) represent databases which are read or written by entities. Dotted black arrows represent signaling exchanges between two entities, while plain black arrows indicate the flow of packets from an entity to another one.

VII. IP LAYER ENTITIES

User Plane principal entities are listed below:

Type of protocol (ToP) Classifier, which divides arriving packets at the IP layer, according to the protocol transported (TCP, UDP, RSVP, ICMP, IGMP, etc.).

Control Plane principal entities are listed below:

RSVP Daemon, whose role is to process RSVP signaling ([2]) and request reservation of resources for data flows that ask a differentiated QoS treatment;

IGMP, performing Multicast related functions ([7]);

Routing Entity, whose task is to updated the routing table;
ARP, which is called by the Forwarding Module when an IP address needs to be resolved into the corresponding L2 address specific of the satellite link. ARP entity behavior depends on the ARP technique that is adopted. In this regard, there are various alternatives for ARP operation in a satellite environment. For instance, the BMSS could adopt a centralized ARP entity whereby all the correspondences are stored in a proxy address server or a distributed ARP (in the fashion of Ethernet) where all BSATs or BHSs can reply to an address resolution query.

The choice between the various alternatives depends on several aspects, such as the availability of broadcast transfer capabilities or the resource consumption on the uplink channel brought by these operations. In fact, a distributed ARP, where each subsystem on the satellite link can reply to an ARP request, seems more onerous from the point of view of uplink resource utilization. However, distribution of the ARP database could be needed so as not to load a single proxy ARP server excessively.

VIII. BNL Layer Entities

User Plane principal entities are listed below:

BNL QoS Management Entity, which separates downstream traffic into IntServ flows or DiffServ classes on the basis of some fields in the datagrams’ headers, as described in [3]. In addition, when a BE packet is detected (by means of the Flow DB, which contains no reservation state for it), if no channel towards the packet destination is available, this entity is in charge of triggering a channel establishment in the RTD part. We use the term “channel” and not “connection” to take into account the case of connectionless transfer. In fact, if the satellite technology is connectionless, this means that a channel establishment will simply correspond to an additional flow to multiplex on the available resources (a simple configuration of the Traffic Control entity in the BNL-SP), with no connection establishment and signaling exchange to negotiate resources in the RTD parts. On the other hand, if the satellite platform supports connection-oriented transport only, even BE will have to be transported over a dynamically established satellite connection. It classifies the upstream flow in BNL specific signaling and IP datagrams.

TCP PEP, e.g. TCP spoofing, whose goal is to achieve a throughput enhancement for TCP connections [5],[6].

Traffic Control, whose main elements are one classifier, a set of policers and a set of packet scheduler. Their functions have already been described in a previous section.

Compression/Decompression Entity, which performs header compression ([8]) for small PDUs on downstream flow, and then sends compressed packets along with their channel identifier (CI) to the Encryption/Decryption Entity. On upstream flow it makes the reverse function.

Encryption/Decryption Entity, which encrypts packets in the downstream flow and decrypts them in the upstream one.

Control Plane principal entities are listed below:

Configurable Logical Connection Handler (CLCH), which directly interfaces with the RTD entity (if any) that supervises resource management. It is important remarking that this entity plays a central role in the BMSS as concerns RTI/RTD separability concept. In overview, this entity is placed at the boundary between RTD and RTI entities and talks with RTD Resource Management Entity translating BNL QoS parameters into the RTD specific parameters which are supported. For instance, in case an ATM system is used as RTD platform, the CLCH should be configured so as to interact with Q.2931 signaling procedures on the RTD side and with RSVP on the RTI side. It should be able to translate IntServ parameters into the ATM ones as specified in.

The Flow DB is read and written by the RSVP Daemon, the BNL QoS Management Entity, and the BNL Management Plane Entity. It is also read by the Compression Entity. It stores the following pieces of information:

Filter Spec, which is used by traffic control mechanisms to identify IP flows as specified in [2];

Reservation parameters (Res Par), i.e. a description of the reservation according to a set of parameters as will be specified in a further section.

The Channel_ID (Channel Identifier), which identifies the RTD-channel associated to the considered flow. This can be the result of both static and dynamical assignments, depending on the RTD features.

An L2 address (L2Addr) resulting from the ARP operations.

Management Plane principal entities are listed below:

the BNL Management Plane Entity, which accomplishes all management operations of BMSS complementing those which are carried out by the RTD system. In fact, as this entity directly talks with the RTD part, its tasks depend on the particular RTD system that is supported. An example is the management of semi-permanent channels, i.e. those virtual channels that are established through management operations without control plane entities’ participation.

IX. RTD Layer Entities

As concerns RTD part, it should be noted that the descriptions made throughout the documents aim at outlining the functional behavior from the point of view of
the upper interface. In this regard, the main functional entities are:

- the **Data Link Control (DLC)** entity, whose main functions are packet segmentation and reassembly (SAR), multiplexing/demultiplexing and forwarding;
- the **Resource Management Entity (RME)**, which is in charge of supervising switched transfer capabilities in those RTD systems where they are supported. For example, whereas in an ATM system, it can be the Q.2931 entity.
- The **Semi Permanent Channel Handler (SPCH)**, which manages static pre-assigned Semi-Permanent Channels that can be modified only through management actions;
- the **MAC Entity**, whose main functions are controlling access to radio channel;
- the **Registration and Authentication (Reg&Auth)** entity, that performs all those operations needed to register and authenticate a BSAT in the BMSS as soon as it is turned on.

### X. Traffic Control Module

The BMSS traffic control architecture is responsible for assuring QoS in the satellite link, which is an aspect of particular interest in modern telecommunication. The feasibility of supporting most demanding services, namely multimedia, is determined by the presence either of plenty of bandwidth or a powerful traffic control. In the case of satellite, where bandwidth is a particularly precious resource, a traffic control scheme is generally needed.

The BMSS traffic control is implemented in the RTAL, which provides a RTI interface with the specific satellite platform. It is thought to support the five class of services specific of the IntServ ([1]) and Two-Bit DiffServ ([9]) models, whose characteristics are summarized in the table below:

<table>
<thead>
<tr>
<th>Name</th>
<th>QoS MODEL</th>
<th>Quality Degree</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PS Premium Service</td>
<td>2-bit DiffServ</td>
<td>Highest</td>
<td>null queuing delay, peak-rate-based allocation</td>
</tr>
<tr>
<td>GS Guaranteed Service</td>
<td>IntServ</td>
<td>High</td>
<td>controlled queuing delay, guarantees on bandwidth</td>
</tr>
<tr>
<td>CLS Controlled Load Service</td>
<td>IntServ</td>
<td>Good</td>
<td>congestion-free service, moderate queuing delay and packet loss</td>
</tr>
<tr>
<td>AS Assured Service</td>
<td>2-bit DiffServ</td>
<td>Sufficient</td>
<td>packet loss lower than in BES</td>
</tr>
<tr>
<td>BES – Best Effort Service</td>
<td>Both IntServ and 2-bit DiffServ</td>
<td>Scarce</td>
<td>No guarantees or precise commitments</td>
</tr>
</tbody>
</table>

PS and GS are suitable to support anelastic real-time traffic, while CLS and AS can be used to achieve reasonably good performances with elastic traffic.

### Traffic Control Simulation

This section illustrates statistics collected during a simulation of the BMSS traffic control architecture. They show how the five IntServ/DiffServ classes described above can be all supported. Performances of high-quality traffic are particularly good and appear independent of the traffic load pertaining to low-quality classes (good traffic isolation).

Statistics are collected by means of an Opnet simulator of a BHS transmitting traffic into the satellite link under two different load conditions, i.e., injected traffic 100% and 110% of the total link capacity assigned to the node. Statistics were collected over a time window of 10 minutes.

The following pictures show the average queuing delay of packets to be transmitted in the satellite link. Queuing delays of the high-quality traffic, i.e., PS, GS and CLS classes, appear substantially insensitive to low-quality traffic increase and remain limited to acceptable values. PS and GS classes are suitable for supporting real-time traffic as they experience delays of the order of a few units of ms. In addition, the AS class guarantees significantly better performances with respect to simple BES, which experience.

These values were obtained with a packet loss of the order of 1% for high-quality classes while AS class experienced a packet loss of one order of magnitude inferior to BES class.

![Traffic Load: 100% BES: red curve AS: blue curve](image)
XI. Conclusion

The challenge for the Next Generation satellite systems is finding an efficient integration in IP-centric Next Generation Telecommunication Networks. Research has delivered a number of proprietary solutions, which in the satellite field are hardly open to the public. This number is likely to increase in the next few years and in the long term.

This document has proposed a general model for an optimized IP-oriented satellite architecture endowed with new features (such as QoS, support for multicast, security, mobility of terminals) in which a range of existing and future satellite technologies can be accommodated and exploited at the most by IP-based applications.

References