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Evolution of satellite communications: Integration of ETSI BSM and DVB-RCS for future satellite terminals

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SUMMARY

The main added value of the European Telecommunications Standards Institute broadband satellite multimedia (ETSI BSM) architecture is the definition of the Satellite Independent-Service Access Point (SI-SAP) protocol interface, which formally separates Satellite Dependent (SD) from SI layers, thus enabling the implementation of powerful vertical QoS mapping strategies. On the other hand, DVB-S2/RCS satellite standard is considered the driving technology to integrate satellite with terrestrial infrastructure and provide up-to-date services. This paper focuses on the integration of ETSI BSM architecture and DVB-RCS technology, by analysing the adaptations needed on real DVB-RCS terminals to be interoperable with the SI-SAP interface. To this end, the detailed design of an underlying architecture taking into account required adaptations and new functionalities is proposed. The possible further evolutions of the BSM specification are also highlighted, showing the potential for the development of future devices integrating both DVB-RCS and ETSI BSM architectures also in view of the recent upgrade to the DVB-RCS2 standard. The paper also validates the SI-SAP QoS functionalities and proves the performance benefits in terms of QoS and quality of experience of Web-browsing by means of a satellite emulator developed fors this aim. Copyright © 2015 John Wiley & Sons, Ltd.

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1. INTRODUCTION

The penetration of satellite communication into everyday life is continuously increasing, thus broadening the range of services that were traditionally limited to TV broadcasting [1, 2]. Actually, current satellite services also encompass lottery networks, banking and financial applications, GSM backhauling, governance and defence, and mobility applications. Furthermore, media distribution is performed in terms of IPTV, and, in general, internet protocol (IP)-based applications are the baseline for present and future services. In spite of this increasing number of services that are either already available through satellite or promoted for future use, the satellite market is still suffering from technology fragmentation because of the lack of a reference standard. Actually, different manufacturers implement their own proprietary technology with little probability of interoperability with other technologies, thus creating barriers for a unified standardisation framework for satellite communications. From a standardisation point of view, the advent of DVB-S and DVB-S2 [3] for the air interface on the forward link has been recognised as a suitable candidate for more efficient satellite communications,

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also thanks to the deployment of Adaptive Coding and Modulation available in the second version of the standard. DVB-S and DVB-S2 standards were initially conceived to support video broadcast over satellite, but actually, they can support more general broadcast and broadband transport so as to meet the current service users' demands.

As far as the return channel air interface is concerned, the second version of the DVB-RCS standard, defined as DVB-RCS2 [4], has recently appeared. It must be noticed that DVB-RCS(2), unlike DVB-S2, has been designed for data rates lower than those offered on the forward link, because traditionally, return links have been conceived to transport a limited amount of traffic (e.g. satellite signalling) rather than broadband traffic. The new release (DVB-RCS2) actually extends the features already available in the DVB-RCS standard and also provides the specification of the higher layers of the protocol stack. The market penetration of DVB-RCS [5] is, however, still controversial, as terminals still implement proprietary solutions, thus possibly lacking interoperability. The introduction of DVB-RCS2 technology is expected to cope with this market fragmentation, owing to the definition of a standardised protocol interface (Return Link Encapsulation[6]) between network layer (e.g. IP) and DVB-RCS2 layer. Nevertheless, the overall DVB-RCS2 protocol stack still lacks modularity, whereby the upgrade of functions (e.g. cross-layer QoS management) involving IP and DVB-RCS2 layers cannot be easily implemented without significant changes in the protocol interfaces. A straightforward solution to these yet unsolved issues is to actually provide a hardware abstraction layer working on top of the satellite technology, hence, acting like a "glue" among layers, and enable more efficient cross-layer functions and improve interoperability between multi-vendor implementations.

This concept is actually the foundation of the ETSI BSM architecture [7], built on the Satellite Independent-Service Access Point (SI-SAP) interface, responsible for logically separating the functionalities of higher layers (application, transport and network) from lower layers (data link and physical), defined as Satellite Independent (SD) and Dependent (SD) layers, respectively. In more detail, this interface allows the interaction between SI and SD layers by means of specific primitives aimed at providing the tools for achieving a cross-layer architecture [8], in terms of QoS and multicast management. This paper focuses on the integration of DVB-S2/RCS2 technologies with the ETSI BSM architecture by identifying the modifications requested to support SI-SAP interface functions with respect to address resolution, multicast, QoS management and data transfer. The results of this analysis are in turn used to address the implementation of the proposed integrated architecture in real satellite terminals in order to understand the limits and the implementation challenges.

The remainder of the paper is structured as follows. Section 2 illustrates the essential of SI-SAP interfaces and proposes an integrated architecture implementing both ETSI BSM and DVB-RCS2 protocol stacks. Section 3 focuses on the details of translating such design in real terminal implementations. Section 4 presents an emulation system of the SI-SAP, while performance assessment is given in Sections 5 and 6, where web-browsing, and audio and video streaming applications are analysed. Section 7 describes the possible evolutions of the SI-SAP interface specification. Finally, Section 8 draws the conclusions about the conducted study.

2. SI-SAP INTERFACE: PRINCIPLES AND DVB INTERWORKING

2.1. SI-SAP functionalities

SI-SAP [9] defines an abstract interface between SI and SD layers. It is responsible for separating the implementation of the protocol functions provided at SI and SD layers; for example, it is in charge of separating the IPv4 at SI (or IPv6) protocol layer from DVB-RCS2/S2 (or other satellite technology standard) at SD protocol layer. Hence, the implementation of different SI and SD services is independent from one another, and the related mapping functionalities are provided by the SI-SAP interface, composed of suitable primitives, which enable the following:

- Address resolution to map SI to SD addresses.
- Resource reservation and QoS mapping, implemented through the creation, modification and closing of queues at SD layer.
- Multicast management to activate and configure multicast as SD layer.
- Data transfer through the exchange of control information between the adjacent layers.

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The overall list of standardised [9] SI-SAP primitives is summarised in Table I, where the different actions between User (U-), Control (C-) and Management (M-) planes are detailed. The primitives' names are structured according to the usual OSI nomenclature.

No primitives for the management plane are standardised, because the management of SI and SD layers is performed by the functionalities already implemented in these layers with no need to exchange management information through the SI-SAP interface. The primitives are generated by the Satellite Independent Adaptation Function (SIAF) and Satellite Dependent Adaptation Function (SDAF), implemented in the SI and SD layers, respectively. SIAF is responsible for adapting all the functionalities implemented at the network layer (i.e. resource reservation, multicast and addressing) so that they can be mapped into the underlying layers. SDAF implements adaptation functions on resource reservation, address resolution and group multicast membership requests generated at the SD layer and mapped onto specific SI-SAP primitives by SIAF. More precisely, SDAF translates SI-SAP primitives into SD specific primitives in order to assign the requested physical resources to the IP traffic (unicast or multicast) coming from the SI layer. The overall ETSI BSM architecture is depicted in Figure 1.

Two concepts are fundamental to map functionalities between SI and SD layers through the SI-SAP primitives: BSM identifier (BSM_ID) [9] and Queue identifier (QID) [9], described shortly in the following.

BSM_ID. It is the SI-SAP address used for exchanging primitives between SI and SD layers. It actually identifies a subnetwork point of attachment, whereby its format is compliant to the IEEE 802 specification for LAN MAC addresses (48 bits). BSM_ID is used for both unicast and multicast services. In the second case, BSM_ID is usually renamed as BSM_GID (BSM Group ID), in order to have an efficient management of multicast group addresses. The aim of the BSM_ID is to avoid a direct mapping between SI and SD addresses, which would require a close interaction between the technologies implemented at SI and SD, with the consequent implementation of interface adaptations in case of upgrades. On the contrary, a two-fold mapping is performed to make the implementation of addressing schemes at SI and SD layers perfectly transparent with one with another: SI addresses are mapped into BSMIDs and BSMIDs into SD addresses.

Table I. U-plane, C-plane and M-plane services and corresponding SI-SAP primitives [9].

	U-plane services	
Service	Description	Primitives
Data transfer	Submission of data from SI to the SD layer for transmission to peer destination; Receipt of data from the SD layers by that peer; Service used for both unicast and multicast data transfer.	SI-U-UNITDATA-req, SI-U-UNITDATA-ind
	C-plane services	
Service	Description	Primitives
Resource reservation	To open, modify and close SD layer queues; To confirm (reject) the received request used by the SD layer.	SI-C-QUEUE_OPEN-req, -cfm, SI-C-QUEUE_MODIFY-req, -cfm, SI-C-QUEUE_CLOSE-req, -cfm, SI-C-QUEUE_MODIFY-ind, -res, SI-C-QUEUE_CLOSE-ind, -res, SI-C-QUEUE_STATUS-ind, -res
Group receive	To activate and configure the SD layer to receive a requested multicast service	SI-C-RGROUP_OPEN-req, -cfm, SI-C-RGROUP_CLOSE-req, -cfm
Address resolution	To perform the mapping between SI and SD addresses	SI-C-AR_QUERY-req, -cfm, SI-C-AR_INFO-ind, -res
	M-plane services	
Service	Description	Primitives
None	No M-plane services are defined	None

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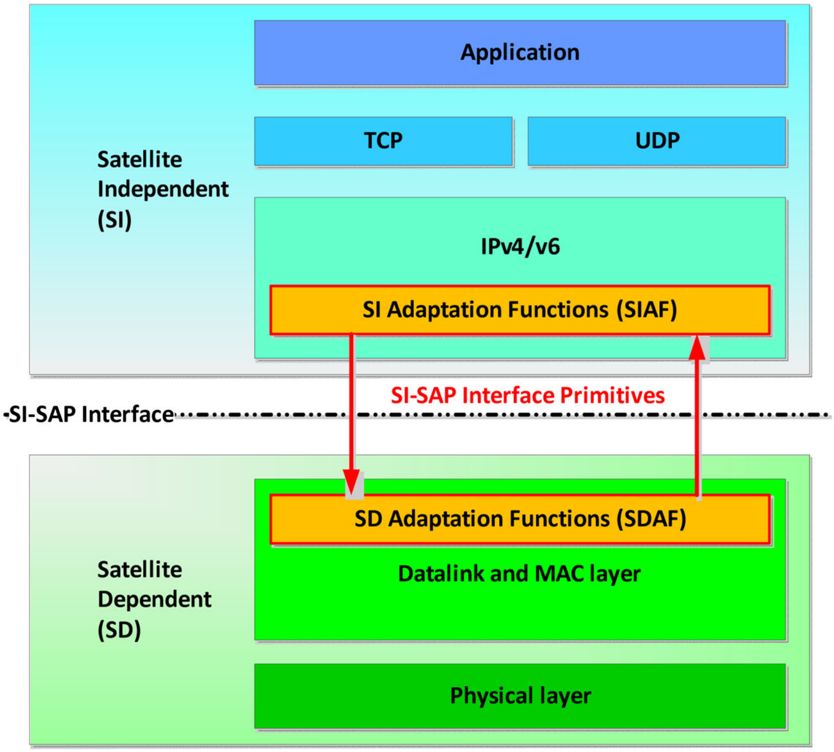

Figure 1. ETSI BSM architecture implementing the SI-SAP interface.

QID. The QID identifies the queues implemented at the SD layers, thus implicitly linking lower layer resources' reservation to IP layer QoS requests. QID is composed of 24 bits and must be included in all U-plane primitives (i.e. in every SI-U-UNITDATA-req), in order for the SD protocol layer to correctly forward each data traffic to the proper SD queues. QID can be assigned either statically or dynamically by using the SI-SAP reservation requests (summarised in Table 1). Such assignment is performed according to the QoS guarantees that each data traffic (e.g. IP DiffServ aggregate) demands. From this point of view, taking IP DiffServ as QoS reference model, the QID can be regarded as a mapping function between DiffServ Per-Hop Behaviours and SD queues.

2.2. *Essentials of DVB-S2/RCS systems*

DVB-S2/RCS [10, 11] is the ETSI standard for satellite communications. The defined system is composed of satellite terminals (STs) and a gateway (GW), which can exchange data over the forward and return links, which implement DVB-S2 and DVB-RCS standards, respectively. The forward link operates according to a TDM strategy and enables broadband/broadcast services, whereas the return link implements MF-TDMA and offers lower data rates.

Usually, the network is defined with a star topology, where the gateway plays the role of a central node (Hub). Besides, a Network Control Centre and a Network Management Centre are also key elements in the overall satellite network. The former performs most of the control functions, whereas the latter is mostly responsible for the overall management of the system elements and manages the Service Level Agreement (SLA) assigned to each satellite terminal. Usually, DVB-S2/RCS systems implement a multi-beam star-transparent satellite network, although regenerative satellites can be also adopted. Throughout the rest of the paper, we will focus on the star-transparent configuration, which is actually the most consolidated in real satellite system implementations.

The main functionalities of DVB-S2/RCS systems include: (1) login; (2) resource management; and (3) and data transfer. At start-up, each satellite terminal must log in the satellite system in order for the gateway to assign the available satellite capacity. The login phase is accomplished by means of messages' exchange (request from a ST and confirmation from the GW), which completes with the satellite terminal acquiring the forward link and receiving all signalling tables necessary for data communication operations (e.g. unicast/multicast management and resource allocation). Resource allocation involves both satellite terminals and gateway: the former issues satellite capacity according to five classes: rate-based dynamic capacity (RBDC), volume-based (VBDC), absolute volume-based (AVBDC), constant rate assignment and free-capacity assignment. These requests are in turn processed by the gateway to compute the portion of satellite capacity to be possibly allocated. This information is hence conveyed in the Terminal Burst Time Plan (TBTP), periodically forwarded from the gateway to the satellite terminals, which contains indications about the assigned number of slots and the transmission plan.

Finally, IP-services data are forwarded to DVB-layers on top of MPEG Transport Stream (TS) packets through the Generic Stream Encapsulation and Multi-Protocol Encapsulation (MPE) ‡ protocols for DVB-S2 and DVB-RCS technologies. TS packets are composed of a header and payload, for a fixed number of 188 bytes in total. Concerning the header, a special note has to be dedicated to the packet identifier (PID), which actually differentiates the various TS data streams and the signalling therein transported (e.g. program association table (PAT), program map table (MPT), etc.).

2.3. *DVB-RCS2*

The evolution of the DVB-RCS standard into the second generation (DVB-RCS2)[12] specified in a more structured way the overall protocol stack of satellite terminals and gateway, addressing user, control and management plane. To this end, the specification of the lower layers, including physical and datalink, as well as higher layers is provided. In this respect, particular attention can be dedicated to some of the novel functions that are introduced in there: random access to the return link, security [13], Adaptive Coding and Modulation and DRA [14], the concept of Satellite Virtual Network (SVN), the specification of the Return Link Encapsulation[6] as well as the refinement of the QoS management to perform flow identification at the lower layers [15].

In spite of these new features, the applicability of the SI-SAP interface on top of the DVB-RCS2 technology is, however, not affected, because the overall resource allocation and address resolution concept of DVB-RCS does not change in DVB-RCS2. In more detail, the resource allocation strategy defined for DVB-RCS in the previous section does not change significantly in DVB-RCS2. As a result, the QoS management functions offered by the SI-SAP interface can be straightforwardly applied also to the use of DVB-RCS2. On the other hand, similar considerations also hold for address resolution functions, because the BSM_ID can be anyway associated to the hardware address (unicast or multicast) of the satellite terminal. Finally, the use of Return Link Encapsulation [6] as novel protocol encapsulation of IP datagrams into DVB-RCS2 frames as a replacement of AAL5 or MPE cannot represent an obstacle to SI-SAP functions, because SI/SD adaptation functions are already implemented in the corresponding SIAF and SDAF modules.

Hence, the design of the integrated architecture composed of the ETSI BSM architecture on the upper part and the DVB-S2/RCS in the bottom is actually not affected by the introduction of the DVB-RCS2 technology. As such, though referring to the DVB-RCS standard for the sake of simplicity, the architectural considerations drawn in the next sections can be easily extended to the case of DVB-RCS2 without loss of generality.

2.4. *Application of SI-SAP concepts to DVB-RCS systems*

The implementation of the SI-SAP interface in a DVB-S2/RCS system implies some re-engineering of the interface actually provided between IP and DVB-RCS layers in order to efficiently incorporate SIAF and SDAF modules and properly interwork with the SI-SAP primitives. For a better

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[‡] DVB-RCS standard recommendation actually defines the transport unit in terms of ATM cells, whereby interface between IP and DVB-RCS has to be implemented according to AAL5. The current practice, however, is to transport MPEG TS streams on both forward and return link, thus making the use of ATM cell actually obsolete.

understanding of the integrated architecture design, it is worthwhile to go through the different phases (address resolution, multicast group membership and QoS management) of data communications from a satellite terminal to a gateway, once the logon procedure is accomplished.

2.4.1. Address resolution (AR). The process to acquire a unicast address is distributed between satellite terminals (requesting the address) and gateway (providing the address) as follows:

- Satellite Terminal (ST): the SI-C-AR-QUERY-REQ primitive is used to find out the BSM_ID of the Gateway. This is actually derived by the SDAF of the satellite terminal, mapping the gateway MAC address available upon successful logon completion, into a corresponding BSM_ID. As a result, the SI-C-AR-QUERY-CFM containing the requested BSM_ID is generated by the SDAF and returned back to the SIAF of the ST.
- Gateway. A procedure specular to that performed on the satellite terminal is carried out. The MAC address of the satellite terminal is available from the logon request received from the ST; the BSM_ID is generated accordingly and henceforth used for all forthcoming address resolution operations (e.g. data delivery from gateway to satellite terminals).

From a functional point of view, additional modules have to be implemented in the IP and DVB-RCS layers, in order to store MAC addresses and related mapping into IP addresses and BSM-IDs. These can be summarised as follows:

- Two ‘unicast AR caches’ (U-AR addresses cache), implemented at IP and DVB-RCS levels. They contain the mapping between BSM_ID and IP addresses of destination as look-up tables, as soon as the resolution address is completed successfully. These caches are accessed through SI and SD proprietary functions as soon as address resolution functions (IP-to-BSM and BSM-to-DVB) are invoked.
- Logon database (Logon db). It contains the MAC addresses of the gateway (and satellite terminals) and the mapping into the corresponding BSM_ID. The gateway MAC address is retrieved from the logon confirmation received by the satellite terminal; the satellite one is instead inferred by the gateway upon logon request reception.

The case of multicast communication is an extension of the unicast approach, with an increase of implementation complexity, as outlined in the following. Multicast is usually managed only at the IP layer, whereas DVB-RCS simply associates a specific PID (Packet or Program Identifier) to the whole multicast traffic, thereby implementing a broadcast service. In order to avoid the satellite capacity saturation because of an excessive number of broadcast packet transmissions, it is more efficient and scalable to allocate a number of multicast PIDs to each satellite terminal to manage multicast transmission also at the DVB-RCS layer. A PID is composed of 13 bits, of which three are used for signalling purposes; therefore, the remaining 10 bits can be used to accommodate different unicast and multicast channels. It is immediate to see that, however, it is not possible to map all possible IP multicast group addresses (28 bits) to PIDs. No standardised recommendation about such mapping exists; actually, multicast PIDs are usually assigned statically and managed by the network operator. Selected PIDs are in turn signalled from the gateway to the satellite terminals as part of the Multicast Mapping Tables, broadcasted regularly over the satellite network. The multicast group membership operation is completed at the IP layer, which triggers the protocol to subscribe a given host (IP unicast address) to the desired multicast group (IP multicast address). As a result, the design of the multicast address resolution in integrated ETSI BSM-DVB [§] systems has to be carried out according to the following operations:

- the participation of hosts to multicast groups: it is regulated by the IP layer by means of the IGMP protocol that is used by hosts to communicate the participation to the desired multicast groups to the adjacent router (the satellite terminal, in this case);

[§] The integrated ETSI BSM and DVB-RCS architecture will be hereafter denoted as ETSI BSM-DVB throughout the rest of the paper for the simplicity of notation.

- composition of BSM_GID: it can be carried out by using the recommendations contained in [16] to construct a multicast MAC address from an IP group multicast address.

In summary, from an architectural point of view, multicast address resolution requires the implementation of M-AR address caches to store the association between multicast IP addresses and PIDs. Such mapping is mediated by BSM_GID, obtained through the same SI-SAP primitives (SI-C-AR-QUERY-req and -cfm) invoked for the unicast address resolution. Differently from unicast address resolution where MAC address of gateway and satellite terminal are known at logon, multicast address resolution requires a tighter interaction between IGMP functions and PID management, as activation (de-activation) of multicast services is very dynamic.

2.4.2. Multicast management. As outlined in the previous section, multicast address resolution is performed once multicast group membership is requested through IGMP messages. As soon as this phase is completed, the multicast transmission from the GW to a ST is performed as follows:

- Transmission of multicast packets from the GW to a ST: the BSM_GID of the destination is locally computed, and the data transfer goes through IP and DVB-S2 layers, by means of the SI-U-UNITDATA-req, where a dedicated flag signals the transport of a multicast data session. Mapping between IP addresses and DVB PIDs is carried out through the BSM_GID.
- Reception of multicast packets at a ST: the ST receives the multicast session, composed of packets carrying multicast PIDs. The BSMGIDs corresponding to PIDs is used to filter out the multicast groups to which the receiving satellite terminal does not belong. In case of successful membership validation, a SD-U-UNITDATA-ind containing the multicast stream is forwarded to the IP layer.

In addition to these steps, it is worth noting that the coordination between the gateway and each satellite terminal in terms of multicast group leave and join calls is implemented by means of multicast routing or group membership protocols. In the first case, satellite terminals and gateways have to be configured as multicast routers, and the use of PIM-SM protocol is recommended in [17], by taking into account the adaptions of PIM-SM for satellite scenarios. Under this configuration, it is immediate to see that the creation of multicast spanning tree is rather trivial, because the star topology implies that the gateway also acts as a rendezvous point. In the second case, IGMP protocol can be also used over the satellite link, thus requiring terminals and gateways to be configured as IGMP-proxies. In this respect, adaptation of IGMP for satellite environment shall be also taken into account, namely S-IGMP [18].

2.4.3. QoS management. DiffServ implementation in ETSI BSM [19] is mainly connected to the mapping between IP queues and DVB-RCS queues, achieved through the concept of QID. Each QID can offer a defined type of service for the transfer of IP packets to the DVB-RCS layer in the integrated ETSI BSM-DVB architecture. In more detail, a given QID is univocally associated to DVB-RCS queues and used for all data flows aggregated in that queue. Hence, the QID works as a label logically appended to IP streams, whose transport is signalled by means of SI-U-UNITADA-req primitives. QIDs are locally handled by the Satellite Terminal QID Resource Manager (STQRM), implemented in the SDAF module. The STQRM receives QID allocation requests from the IP resource manager (BSM QoS Manager) implemented in the SIAF and starts the resource reservation request by interacting with the resource request manager implemented in the DVB-RCS layer. In more words, the overall QoS management is performed according to the following steps [19]:

- The BSM QoS manager requests the creation of a new QID to the STQRM using the SI C QUEUE_OPEN req primitive.
- The STQRM adapts the resource reservation and forwards them to the DVB-RCS resource request manager, which in turn will request new capacity allocations to the gateway.
- Once the new resource allocation contained in TBTP (sent by the gateway over DVB-S2) messages is received, the STQRM finally responds to the request using the SI C QUEUE-OPEN cfm primitive.

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Table II. IP to DVB-RCS resource allocation mapping with SI-SAP implementation (QID use).

Service class	**PHB**	**DSCP**	**QID**	**MAC aggregate**	**Allocation scheme**
Network control	CS6	0x30	0x0003	Real Time	CRA, FCA
Telephony	EF	0x2E	0x0003	Real Time	CRA, FCA
Signalling	CS5	0x28	0x0003	Real Time	CRA, FCA
Multimedia conferencing	AF41, 42, 43	0x22, 0x24, 0x26	0x0002	Real Time	CRA, RBDC
Real-time interactive	CS4	0x20	0x0002	Real Time	CRA, RBDC
Multimedia streaming	AF31, 32, 33	0x1A, 0x1C, 0x1E	0x0002	Data Critical	RBDC, VBDC
Video broadcast	CS3	0x18	0x0002	Data Critical	RBDC, VBDC
Low-latency data	AF21, 22, 23	0x12, 0x14, 0x16	0x0001	Data Critical	VBDC, AVBDC
OAM	CS2	0x10	0x0001	Data Critical	VBDC, AVBDC
High-throughput data	AF11, 12, 13	0x0A, 0x0C, 0x0E	0x0001	Data Critical	VBDC, AVBDC
Standard	DF (CS0)	0x00	0x0000	Best Effort	AVBDC
Low priority data	CS1	0x01	0x0000	Best Effort	AVBDC

IP, internet protocol; SI-SAP, Satellite Independent-Service Access Point; QID, Queue identifier.

- The fulfilled request triggers the creation of a new QID, with its relative associations to IP queues and DVB-RCS queues. If the QID cannot be created because of unavailability of satellite capacity, the STQRM rejects the request by setting an appropriate flag in the SI-SAP primitive and notifies the SIAF module.
- In case a modification or a cancellation of a QoS profile is requested, SI-C-QUEUE_MODIFY and SI-C-QUEUE_CLOSE primitives are exchanged between SIAF and SDAF modules. It can be noticed that the generation of such requests may result from updated TBTP messages communicating the variation of satellite capacity resources' availability or from specific IP-QoS signalling protocols (e.g. SIP, H.323), reporting about change of QoS class profile (e.g. service delay or rate requirements). In this respect, it is worth noting that in the first case (TBTP), the action is triggered from the DVB-S2 layer requiring actions taken from IP layer, whereas in the second case (IP-QoS signalling), the requests are generated at the IP layer with effect on the underlying layers.

Another important aspect is how QoS requests contained in the SI-SAP primitives are translated into resource allocations actions at the DVB-RCS layer. In the case of the proposed ETSI BSM-DVB integrated architecture, this task corresponds to mapping QID onto corresponding MAC aggregates, based on the QoS guarantees specified during the creation of a new QID (SI-C-QUEUE-OPEN-req). On the other hand, the IP manager is responsible for associating DSCPs to specific QID, through different mapping strategies. From a theoretic point of view, it is possible to associate IP queues to SD queues by means of a one-to-one mapping. In practice, DVB-RCS typically implements few queues (typically three), implying that a number of DSCPs shall be associated to the same QID. Alternatively, it is also possible to implement a one-to-one mapping once the IP manager marks (and shapes) different traffic flows with the same DSCP, thus performing traffic aggregation at the IP layer. The overall resource allocation mapping is shown in Table II, according to [20] and [21].[¶]

2.4.4. Data transfer. Transport of data messages over the SI-SAP interfaces is carried out by the SI-U-UNITDATA primitives, which allow SIAF and SDAF modules to exchange IP datagrams. Hence, the adaptation of the frame format from IP to DVB-RCS is directly performed at the SD layer.

[¶] The following notes should be outlined for some items of Table II. Multimedia Conferencing: RBDC may be used alone and also in combination with VBDC and AVBDC, the latter is recommended; Multimedia Streaming: VBDC is recommended used in combination with RBDC for general purpose networks and used alone only for special applications; Low-latency data: AVBDC always follows VBDC.

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In particular, DVB-RCS standard mandates the use of ATM cells, although most recent implementations support the use of MPEG cells [22], resulting in the implementation of the MPE protocol as encapsulation format. Further to this, the user plane primitives bring also information about the destination address (BSM_ID, or BSM_GID in the case of unicast and multicast, respectively) and the specific agreed QoS treatment (QID), resulting from the use of the control-plane primitives, previously described.

2.4.5. Summary. Previous sections detailed the building blocks necessary for the integration of the SI-SAP interface into DVB-RCS systems, consisting in the implementation of SIAF and SDAF modules within the IP and data link layer part of DVB-RCS, respectively. The need for clearly separating SIAF and SDAF functions from the rest of the protocol layers' services stems from the definition of SI-SAP interface primitives that are actually exchanged between these two modules. It is, however, important to note that most of these functions are already available in SI and SD layers, so that the definition of SIAF and SDAF modules can be regarded only as a logical separation. Nevertheless, it is worth also highlighting that new functions have instead to be considered for the implementation within SIAF and SDAF modules, especially for what regards address resolution and multicast management.

The overall summary of the key building blocks subdivided per functions is listed as follows:

- **Address resolution**. Address resolution functions are jointly performed by IP and DVB-RCS protocol layers, whereby mapping functions are performed by SIAF and SDAF modules to properly process BSM_ID addresses. Further to this, both modules also implement dedicated memory caches to store unicast and multicast addresses defined as IP addresses (IP layer), and PID and MAC addresses (DVB-RCS) for the correct address translation in (from) BSM_IDs.
- **Multicast management**. It exploits the multicast address resolution functions summarised earlier and also provides filtering functions implemented in both SIAF and SDAF modules. Further to this, the SIAF also interacts with the multicast routing protocol in order to dynamically update the status of multicast group membership.
- **QoS management**. The implementation of the QID concept is almost transparent to DVB-RCS implementation because resource manager functions are already available. To allow cross-layer QoS management, the QoS class classification and DVB-RCS resource manager have to interwork with the STQRM, responsible for mapping classes of services into dedicated QIDs.
- **Data transfer**. Data transfer and forwarding from IP to DVB-RCS layer is essentially carried out by protocol encapsulation procedures implemented in the SDAF module. This functionality is obviously already available in native DVB-RCS systems, so that no new functions actually need to be implemented.

Finally, the overall ETSI BSM-DVB architecture is depicted in Figure 2, where interfaces and related functions are also shown. In particular, it can be noticed that SI and SD layers are still clearly separated, and the introduction of the SI-SAP interface implies exchange of messages between SIAF (dotted blue polygon in the SI layer) and SDAF (dotted red polygon in the SD layer) modules.

In particular, new interfaces are required to allow the interaction between the SDAF modules pertaining to address resolution and multicast management with the corresponding functions natively carried out by the DVB-RCS layer. On the other hand, the overall DVB-RCS physical layer keeps untouched its native interface, because information packets and resource allocation signalling is fetched directly from the DVB-RCS queue scheduler and resource request manager, respectively, which are already present in the native DVB-RCS implementation.

Similarly to DVB-RCS link layer part, native IP layer functions are complemented by new ones in order to enable address resolution and multicast management, to be performed by the SIAF module.To this end, interaction with multicast routing protocol is carried out through the multicast group management functional block indicated in Figure 2.

From this sketch, it is therefore immediate to see that introduction of SI-SAP interface requires some minor modification to SI and SD layer interfaces but allows a more dynamic and efficient management of resources and multicast services.

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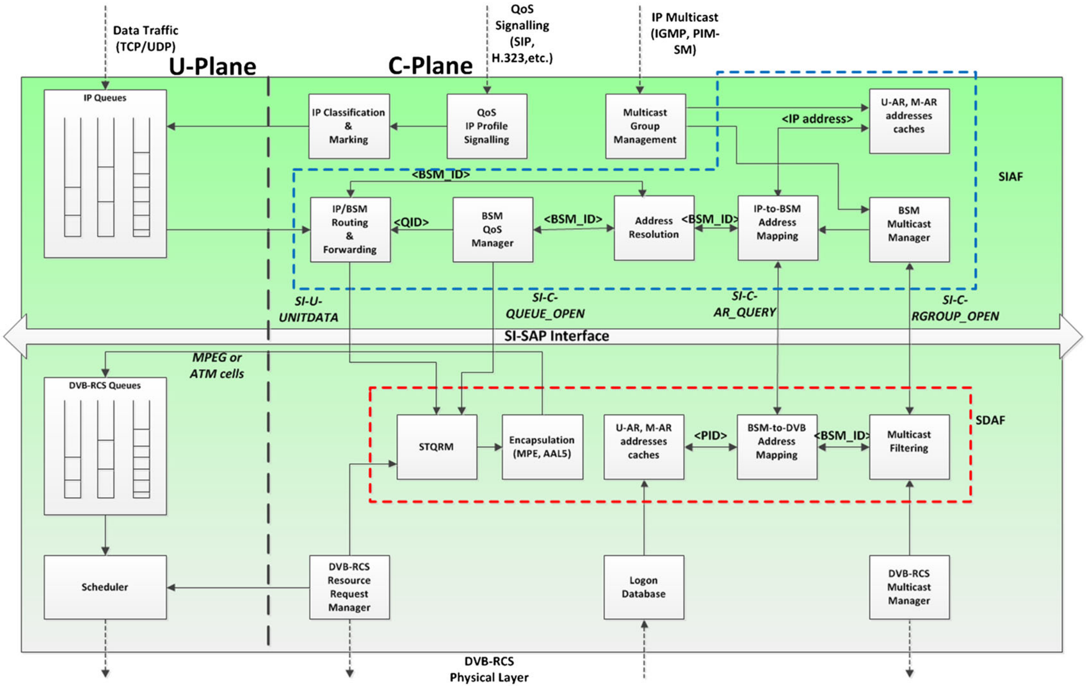

Figure 2. Overall ETSI BSM-DVB architecture for a satellite terminal.

3. SI-SAP INTEGRATION AND ARCHITECTURE DEFINITION OVER REAL SATELLITE TERMINALS

3.1. *Real satellite terminal architecture*

The architecture of a real satellite terminal is composed of two main parts: software (SW) and hardware (HW). The former is implemented in real-time operating system, where an abstraction layer is used to define the fundamental processing functions. All datalink and higher layer functions are implemented as SW modules, so that interaction between layers is achieved by SW system calls. The interconnection between DVB-RCS and IP is essentially carried out through the DVB Air IF (DAI) module that also terminates the DVB-RCS protocol. On the other hand, as far as the HW part is concerned, the TDM link (forward) is typically terminated by a COTS DVB receiver inside the in-door unit. The TDMA link (return) is implemented in firmware at both transmitter and receiver over HW components like FPGAs, DSPs and CPUs. At the user interface side, the Ethernet interface is implemented by a standard device. The overall architecture of the ST is depicted in Figure 3.

3.2. *Integration of the SI-SAP interface*

As described in section II-B, the integration of the SI-SAP interface into DVB-RCS satellite terminals requires the implementation of the SIAF module at the IP layer and the SDAF module at the DVB-RCS layer. The SIAF module incorporates the BSM QoS manager, and the SDAF module incorporates the STQRM, which, in turn, interacts with the DVB-RCS resource request manager. From the implementation perspective, it is convenient to look at the interface between the IP module and the DVB Air IF module as it were split in three sub-interfaces:

- SAP(1) interface between IP module and SIAF.
- SAP(3) interface between SDAF and DVB Air IF module.
- SAP(2) interface: the exchange of SI-SAP primitives is regulated by the SIAF and SDAF modules, thus formally composing the SW architecture of the SI-SAP interface.

The overall integrated architecture is depicted in Figure 4.

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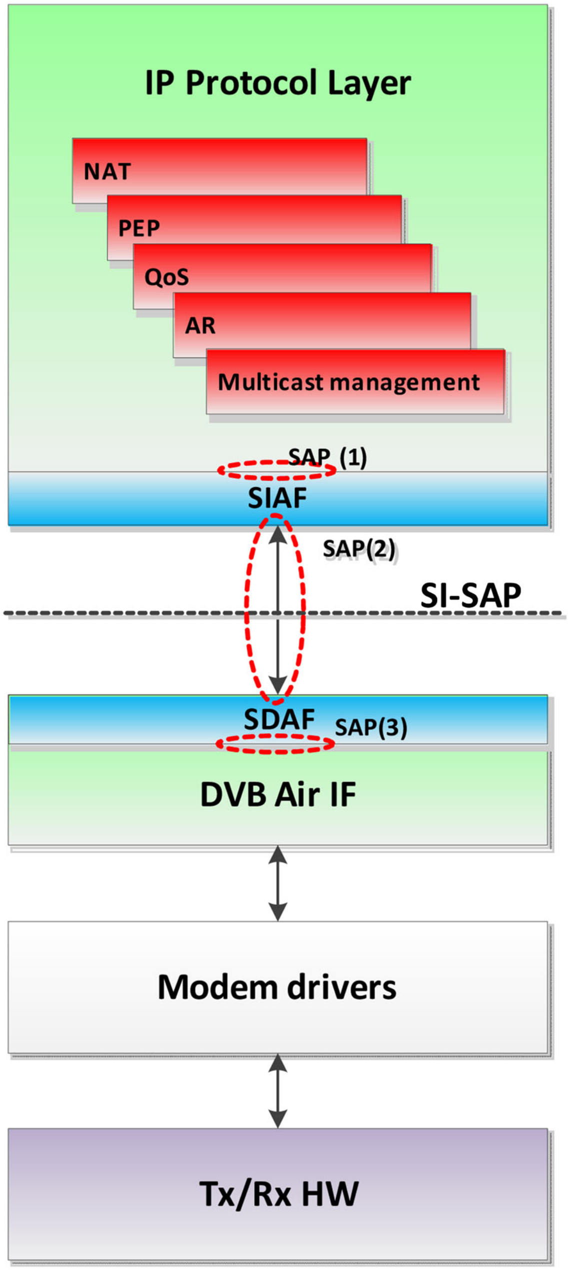

Figure 3. Example of satellite terminal implementation architecture.

Special attention has to be dedicated to the implementation of signalling and data forward along the path from IP layer to DAI. Current satellite terminal implementations use proprietary interfaces to allow the exchange of data/control messages between modules. In particular, DAI exploits the concept of device virtualisation, thus providing different sub-interfaces to which data messages can be forwarded. To this end, DAI implements queuing functionalities for each DVB-Air-IF sub-interface and defines virtual link for each implemented sub-interface, logically connecting the IP layer to the physical interface. This mapping can be actually regarded as a QID, where the queue identifier denotes here the virtual channel from IP layer to virtual DAI sub-interfaces assigned to specific data traffic matching given QoS requirements. In view of the aforementioned architecture of satellite terminals, SAP(3) can be considered as a virtual interface resulting in the implementation of SDAF directly within

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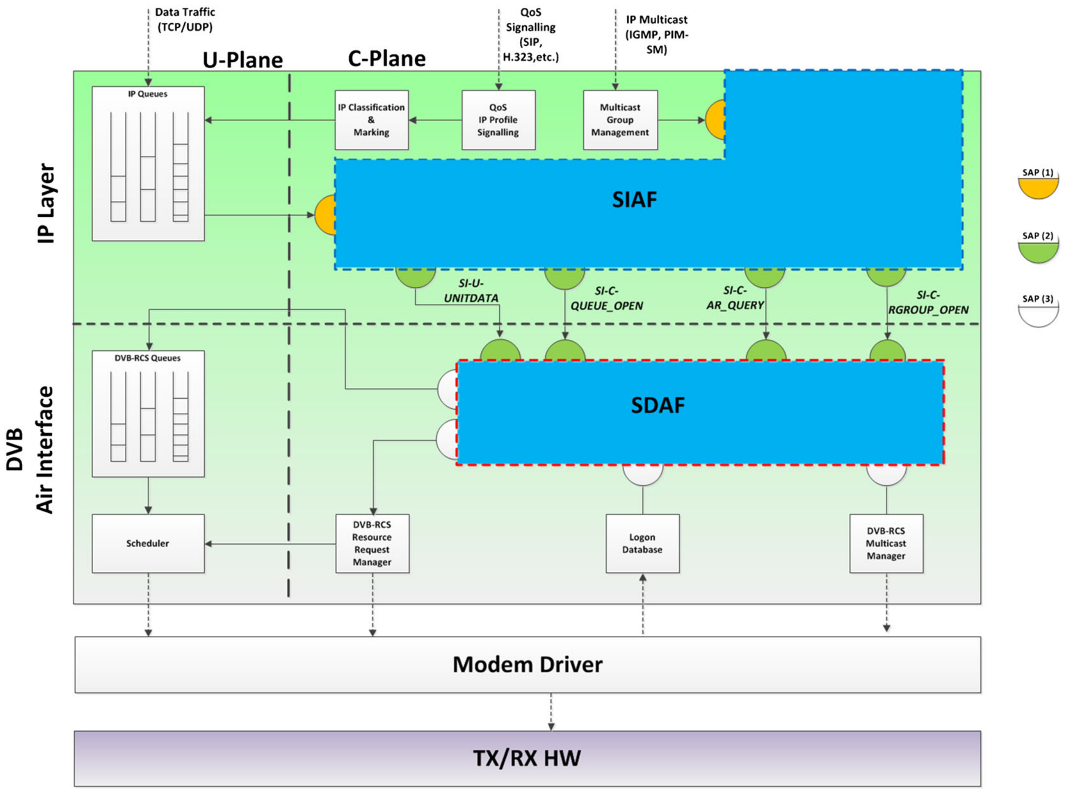

Figure 4. Functional ETSI BSM-DVB architecture for a RST.

the DVB Air IF module to more efficiently access memory storing information pertaining to the DVB Air IF module (e.g. the Logon database). As such, DAI can already locally provide all the necessary SAP(3) features and the inherent APIs, without the need for the real implementation of a dedicated SAP(3), which should be provided as simple access point to each of the virtual sub-interfaces of DAI. The implementation of the remaining SAP(1) and SAP(2) interfaces has to be carried out to optimally exploit the benefit of the SI-SAP interface functionalities. Hence, SAP(1) and SAP(2) interfaces shall be implemented at the IP layer, to properly interact with the SIAF module. As a result, SI-SAP and SAP(1) should be easily implemented as generic APIs in run-time SW in light of the large computation capability already available in current satellite terminals. The implementation of SAP(2) can be carried out by simply mapping the SI-SAP primitives to the existing function calls provided by DAI to interwork with the IP layer. This operation actually consists in software functions overriding,[‖] allowing to keep the implementation of DVB-RCS almost untouched and independent of the implementation of the other interfaces.

3.3. *Design of SI-SAP -enabled real satellite terminals*

QoS management. A real satellite terminal implements a multi-field classifier at the IP layer to classify and mark the incoming IP datagrams and to possibly shape the corresponding flows. According to the SLAs and SLSes provided by the Network Management Centre, the classes of service assigned to a specific flow (or to an aggregation of flows) are defined and marking of DSCP fields is performed in the IP datagrams. In turn, the DSCP along with the class of service

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[‖] SW overriding is a common language feature that allows a new function to provide a specific implementation of a method that is already provided by an existing function. The new implementation overrides (replaces) the old one by providing a method that has same name, same parameters and same return type as the old one.

specification is used by the SI-SAP primitives to request the creation of a new QID, which triggers the DVB-RCS layer to issue a new resource request towards the gateway. Eventually, the capacity allocation is signalled back by the gateway through TBTPs transmitted over the DVB-S2 forward link. As observed in the previous section, the ST QID resource manager (STQRM) is part of the SDAF module, implemented in the interface between the DAI and IP layer. As a result, the QoS SI-SAP primitives are exchanged between the SIAF and SDAF modules, by simply overriding the already existing DVB-Air-IF APIs. The exchange of QoS information between the STQRM and the DVB-RCS resource manager is implemented by overriding again the protocol interface defined between DAI and IP layer. Indeed, the protocol interface is modified in a way as follows:

- IP datagrams and signalling messages are transported in SI-SAP primitives and processed by the SDAF module in the DAI.
- The STQRM and the DVB-RCS resource manager exchange signalling information for resource request generation through the same interface originally used by the IP layer to signal resource requests with a proprietary format.

Address resolution and multicast management. The implementation of address resolution and multicast management strictly follows the guidelines presented in Section 2.3 and the design of real satellite terminal drawn in Section 3.2. In particular, the logon database is already part of the DVB-RCS implementation and its access will be achieved by overriding the primitives offered by the interface SAP(3). The exchange of primitives between SIAF and SDAF will be implemented over SAP(3), by overriding the existing APIs implemented between IP layer and DVB-RCS in the same way as the SI-SAP primitives for QoS management will be implemented. Concerning the multicast management part, some attention has to be dedicated to the construction of BSM_GID and the implementation of the related filtering operations. BSM_GID is derived from the MAC address, known from the logon message exchange. Similarly, filtering options on the incoming multicast streams will be implemented in the SDAF module, by processing the BSM_GID identifier. The multicast management at IP layer is performed by means of IGMP protocol (for the group management) and PIM-SM (for the multicast routing). The group membership information in terms of mapping between BSM_GID and IP group multicast addresses is performed by the BSM Multicast Manager and stored in the M-AR tables implemented in the SIAF. Further to this, ‘leave’ and ‘join’ actions notified by IGMP or PIM-SM messages will translate into specific SI-SAP multicast primitives, which will be implemented over the SAP(2) interface, in the same way as described for QoS management and address resolution primitives.

Data transfer. Data messages are transported by IP datagrams, which are exchanged by SIAF and SDAF modules through SI-U-UNITDATA primitives, which are implemented over the SAP(2) interface. Encapsulation (decapsulation) of IP datagram into DVB-RCS frame format (MPEG TS packets) is implemented in the SDAF module, by overriding the APIs provided by the original interface SAP(3). The overall architecture of a real satellite terminal, derived from Figure 2 and extended according to Figure 4, is sketched in Figure 5.

4. SI-SAP EMULATOR

4.1. Aim

Figure 6 summarises the structure of the emulation system, developed in the framework of the ‘Emulator for an ETSI BSM Compliant SI-SAP Interface’ project, funded by the European Space Agency (ESA). The complete structure of two nodes of the BSM architecture is considered: the ST and the GW. More than one ST can be linked to the GW. The reference system is a star network. The aim is to implement the SI-SAP mapping and those services as well by means of a prototype that manages different kinds of traffic in real time and emulates in real time both the SIAF and SDAF modules of the SI-SAP interface, as standardised by the ETSI SES/BSM working group. SDAF modules are integrated into an appropriate real-time simulation tool implementing the DVB-RCS/S2

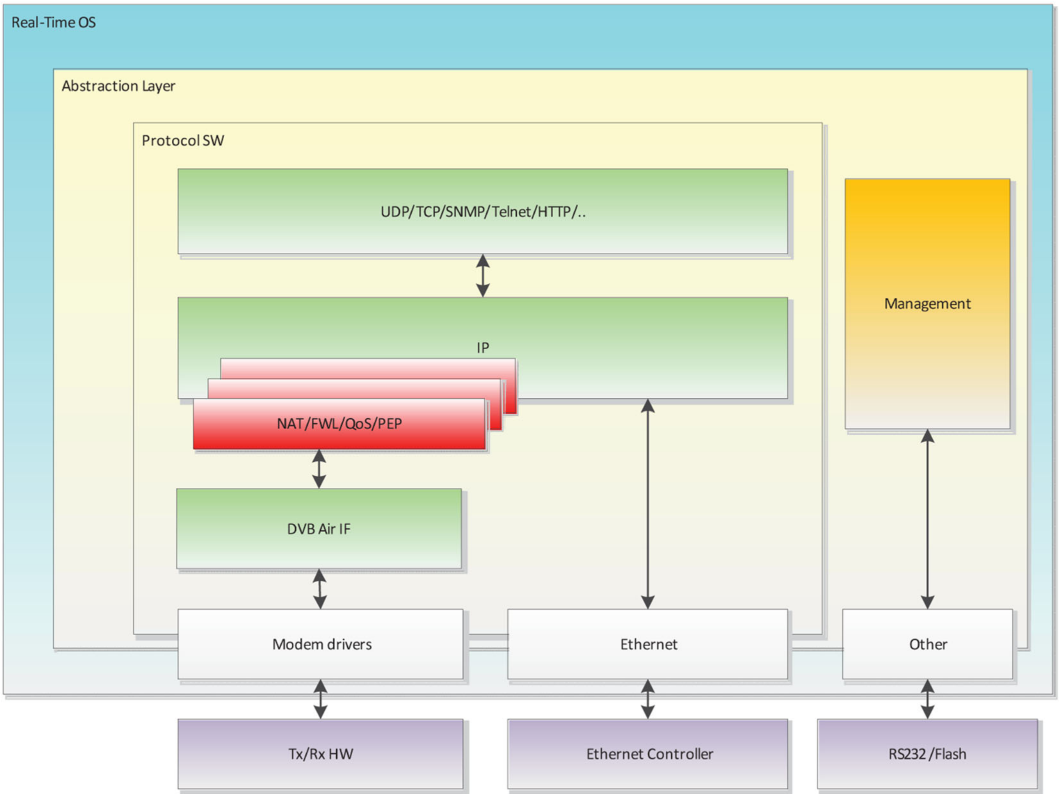

Figure 5. ETSI BSM-DVB architecture for RSTs with SAP(1), SAP(2), SAP(3) interfaces and SI-SAP primitives implementation.

stack. In the ETSI BSM specifications, the SI-SAP interface conceptually appears between the SIAF and the SDAF internal modules and not as an external interface. Emulation of the SI-SAP interface is thus necessary to provide a level of visibility that may not be required in a real product. This brings clarity about the usefulness of the SI-SAP concept and gives the opportunity to check the level of SI-SAP conformance of real devices, as well as the possibility to test the interface with real applications.

4.2. *Technical details*

The emulator is composed of regular Linux PCs. Linux are widely used for the emulation of communication chains and devices, including the satellite context [23]. SIAF and SDAF parts are implemented independently. The ‘SIAF_SI’ sw modules are responsible for the SIAF primitives (Figure 1) and are located in different machines, which also make use of Kernel functionalities for the processing, addressing and routing of IP datagrams. Because SIAF and SDAF are implemented separately, the system actually implements the concept of ‘external’ SI-SAP, whereby the related SI-SAP primitives cannot be simply realised as function-calls but have to be transported in specific messages actually exchanged by SIAF and SDAF modules. To this end, additional headers to specify SIAF primitives are added by the SIAF_SI modules before sending information (original IP data plus SIAF primitives) to the ‘DVB simulator’ machine. This machine is in turn responsible for implementing the main functionalities of a DVB-S2/RCS system, in terms of resource allocation, ModCod assignment and data encapsulation together with the management of SDAF primitives. The ‘SIAF_SAP’ SW modules build an interface to read SIAF primitives and write appropriate responses in terms of SDAF primitives. Those modules act before sending/receiving IP datagrams to/from the DVB layer. The communication between SIAF_SI and SIAF_SAP modules is obtained by regular TCP/IP sockets and can be deployed over a LAN (as depicted in Figure 6) or over the Internet, thus enabling a distributed implementation

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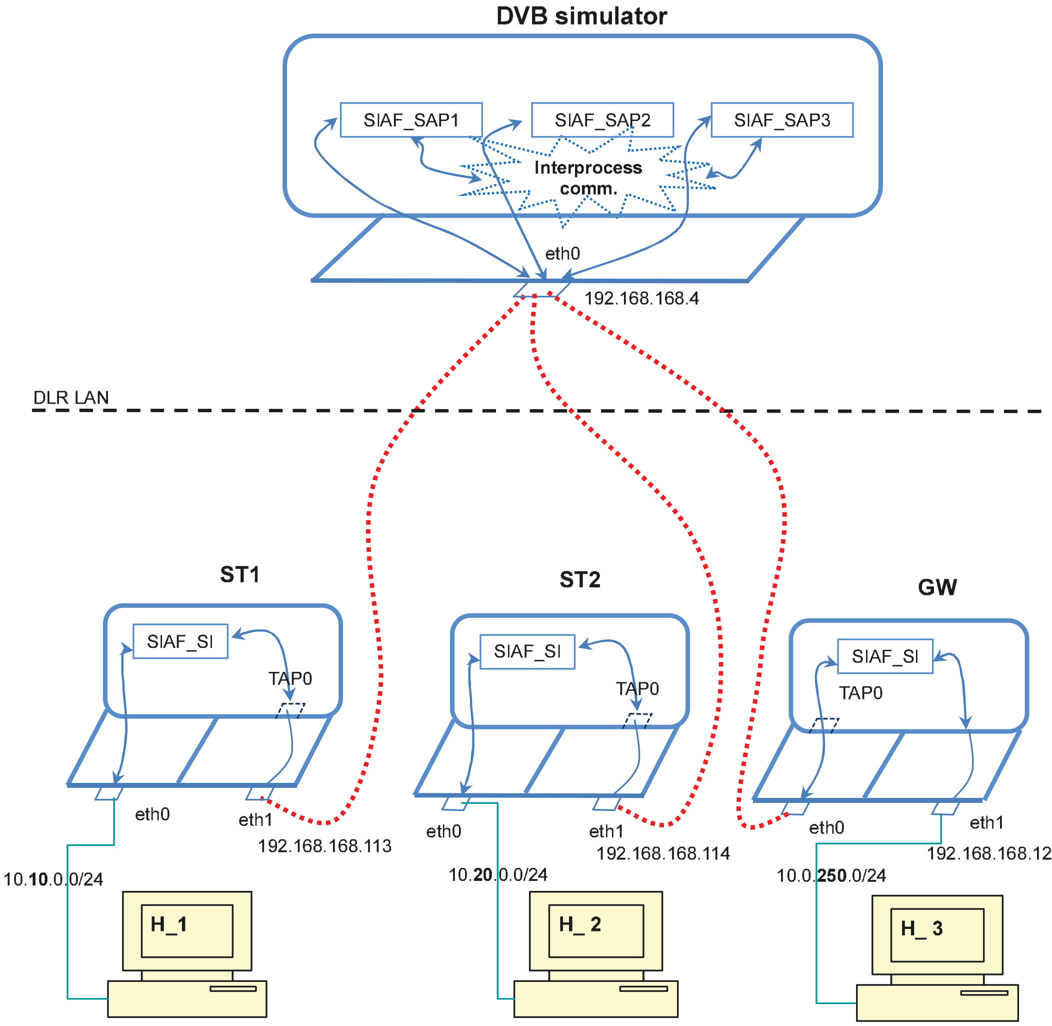

Figure 6. ETSI BSM-DVB architecture for RSTs with SAP(1), SAP(2), SAP(3) interfaces and SI-SAP primitives implementation.

of the emulator. To this aim, the sockets are routed over a virtual network of TAPs, whose internal communication is depicted in red in Figure 6, which is in turn made transparent to the 'real' SI-SAP system. The emulation system of Figure 6 implements two STs and one GW to which three hosts are attached.

4.3. Reasons for the distributed implementation

The distributed structure of the emulator has an obvious advantage: the distribution of the emulation tool allows extending its future employment with different devices. The SI protocols, based on IP QoS solutions (e.g. Differentiated Services), will interact with DVB-S2/RCS SD protocols, but the design and implementation in separate ways allow, on one hand, changing the SD or the SI layers, on the other hand, locating the emulator parts in different places. This solution will be representative of a modular tool that can be employed by different research institutes that need to test QoS-based solutions over satellite terminals applied in different scenarios. It strictly follows the SI-SAP philosophy: to keep separate the SI and SD layers functionalities. The described advantage of the split SI-SAP Emulator may have a significant counterpart that should be compensated: the operative design and implementation of the distributed tool maintain all the functional characteristics of the alternative stand-alone solution which represent a real system.

4.4. *Validation campaigns*

The following results outline the performance of web-browsing and media streaming, experiencing different conditions under the presented emulator. The conditions involve different bandwidth allocations, and performance includes both quantitative and qualitative metrics.

- **Bandwidth allocation**. Each application is firstly evaluated in Best Effort (BE) modality, which means the satellite channel may not be able to provide the required target rate of the application. Then, a bandwidth allocation is provided, denoted by 'rate[...] + x_i%' (i=ssh, web, audio, video and videoconf), which means a given bandwidth is allocated in order to support QoS.
- **Round trip time and bit error rate**. The satellite delay is coherent with a GEO environment, thus leading to Round Trip Times in the order of 500 ms. The Bit Error Rate at the satellite physical layer follows time-series traces obtained from real data.
- **Mean opinion score** (MOS). The MOS is obtained by registering the opinions of 15 persons and 13 persons in the web-browsing and media streaming cases, respectively. The largest part of the opinions have been taken by unanimity. The score can be as follows: '2 (bad)', '3 (acceptable)', '4 (good)' or '5 (very good)'. Detailed descriptions are anyway provided when specific comments are worth to be noted.

5. WEB-BROWSING TESTS

5.1. *Web-browsing HTML application*

An HTTP server is installed on the host connected to the GW, and a client software is installed on the host connected to the ST. The client software tests the network and server performance by sending HTTP requests. The performance metric under investigation is the time to complete each single page download. The inherent service level agreement is reported in Table III.

5.2. *Browsing*

An Apache HTTP server was installed on the GW side. Three web pages were prepared: /low.html, only text, 10 Kbytes, /medium.html, with low resolution images, 305 Kbytes and /high.html, with high resolution images, 1.4 Mbytes. MOS is evaluated by using the Firefox web browser, which implements http compression and pipelining of TCP. Apache JMeter was installed on the hosts. JMeter allows performance monitoring of download operations of web pages; it highlights the web page downloading time (the 'One-way delay' SLA metric of interest, reported subsequently). The next table describes the tests in more details. The 'X.html navigation' notation means that tests were carried

Table III. Service level agreement according to ITU-T G.1010 (End-user multimedia QoS categories): Web-browsing.

Application	**Degree of symmetry**	**Typical data rates**	**Key performance parameters and target values**		
			One-way delay	**Delay variation (jitter)**	**Information loss**
Web browsing HTML	Primarily one-way	N/A	**<2 s/page (*,**)**	**N/A**	**0**

* For these applications 'One-way delay' means the time to complete the download of a specific web page (Web-browsing HTML application) or the time to complete a SSH command (Remote Login SSH).

**It is important to highlight that performance targets for Web-browsing HTML were proposed in 2001 and they can be considered now overestimated for cable networks but reasonable for satellite environments.

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out with an HTML web page (/'X'.html) whose size corresponds to the mentioned low/medium/high cases. 'Mixed navigation' means web browsing is performed on a sequence of low/medium/high pages. More specifically, the mixed navigation is obtained using the low-size, medium-size and high- size pages, by setting (on JMeter) three different users accessing the pages in parallel; the allocations are as in the high case. It consists of navigating on all the pages earlier by changing from one page to another one, also when one (the high in particular) has not finished the downloading of the images.

5.3. *Best effort and bandwidth allocation*

The BE rate is set according to the throughput generated by the web server as follows. The web throughput was firstly measured (with Wireshark) for low-size , medium-size and high-size web pages: (1) in the presence of background traffic: 36.4 kbps on low, 310 kbps on medium, 656 kbps on high (in forward link, FL, direction); (2) without background traffic (reduced by a factor of 100): 42 kbps on low, 330 kbps on medium, 718 kbps on high. Those values may have fluctuations due to internal statistics of the simulator mainly related to the background traffic and fading events on the channel. Then, the BE rate was set to the measured throughput (without background traffic), divided by a factor of two (and then allocated to the FL) because the server is at the GW). The bandwidth allocation is, on the other hand, the exact measured throughput (without background traffic). Concerning the return link (RL), the FL rate is divi ded by a factor of two and allocated to the RL. The overall test configuration is shown in Table IV.

5.4. *Accuracy of the delay measures*

Using JMeter, each test is sampled over 10 repetitions (whose overall average and deviation are reported); JMeter does not use parallelization of TCP connections inside a web page. JMeter also does not make use of any http compression like other web browsers (e.g. Firefox uses gzip on text). For those reasons, the performance delay measured by JMeter is higher than the one of other browsers. Each repetition of the transmission with JMeter contains the handshakes to open and close the connection (the regular TCP three-way handshake when establishing the connection).

5.5. *Ideal delay*

The ideal delay, whose values are reported with the '(ideal)' notation in the table, is the size of the page divided by the allocated rate, the actual delay may be lower than the ideal when more slots are actually allocated on the channel by the DVB resource manager (it happens when few resources are requested , first case only) or it is typically higher than the ideal due to TCP congestion control.

5.6. *Discussion*

The results of the conducted testing campaign are summarised in Table V.

Overall, the perceived quality of web browsing is acceptable in BE conditions and almost good in case of bandwidth allocation, also with respect to the high-size page.

Table IV. Summary of tests on web-browsing.

#	Characteristics	Bandwidth allocation
1	low.html	BestEffort
2	low.html	rateWebBrowsing + x%
3	medium.html	BestEffort
4	medium.html	rateWebBrowsing + x%
5	high.html	BestEffort
6	high.html	rateWebBrowsing + x%
7	mixed	BestEffort
8	mixed	rateWebBrowsing + x%

Table V. Web browsing results.

Test	**Description**	**One way delay/(ideal)[ms]**	**Mean opinion score (MOS)**
1	low.html navigation (Best Effort, BE rate=21 kbps)	Avg: 3264, Dev: 639 / (3809)	**5** (fast web access, very good)
2	low.html navigation (with bw allocation 42 kbps)	Avg: 2117, Dev: 94 / (1904)	**5** (fast, very good)
3	medium.html navigation (BE rate=155 kbps)	Avg: 21695, Dev: 135 / (15690)	**4** (no so fast, but good)
4	medium.html navigation (with bw allocation 330 kbps)	Avg: 15935, Dev: 59 / (7369)	**4** (no so fast, but good) (a little improvement over the previous case)
5	high.html navigation (BE rate=359 kbps)	Avg: 41320, Dev: 178 / (30529)	**2** (slow, annoying)
6	high.html navigation (with bw allocation 718 kbps)	Avg: 27721, Dev: 563 / (15264)	**3** (almost good)
7	mixed navigation (BE rate=359 kbps)	Avg_medium: 30059, Dev_medium: 3939 Avg_low: 4637, Dev_low: 2744 Avg_high: 47552, Dev_high: 3662	**3** (navigation is not so fast, sometimes slow with high page, but acceptable) **3** (acceptable, also with the high page)
8	mixed navigation (with bw allocation 718 kbps)	Avg_low: 2750, Dev_low: 661 Avg_medium: 17869, Dev_medium: 1058 Avg_high: 29686, Dev_high: 1344	

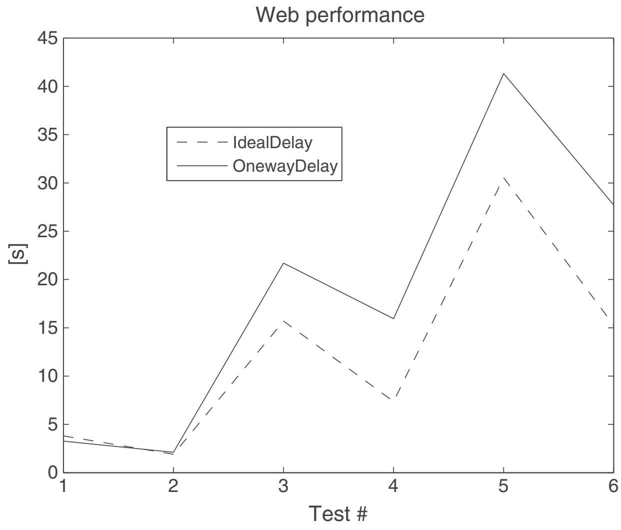

Figure 7. Web performance.

The bandwidth allocation strictly depends on the measured throughput during web-browsing, the inherent values are evidenced in bold in the table (in the mixed case, the bandwidth allocation is the same as in the high case). Such a throughput depends on the size of the page. For this reason, in general conditions, some overprovisioning for bandwidth allocation should be carried out, for example with respect to the measured throughput of the largest web-page among the ones really used. In the test #2, for instance, there is no improvement with the bandwidth allocation due to the low size of the webpage being transferred. Figure 7 highlights the registered delays. It is interesting to note that only the maximum delay experienced on test # 5 is related to a bad MOS. This leads to fixing the maximum acceptable delay approximately to 30 s. This is also corroborated by the delay and MOS values achieved in the mix navigation cases (tests # 7 and 8).

6. STREAMING TESTS

The SLA of streaming applications and the inherent working conditions are summarised in Tables VI and VII. The VLC MediaPlayer software was installed on a GW-side host. Two audio files (AudioFlow 1 and AudioFlow 2) and two video files (VideoFlow 1 and VideoFlow 2) were used to test streaming application. VLC on GW host was the sender of the stream, while hosts at STs-side were the receivers. The following audio files are used: AudioFlow 1: music, codec MPEG-2 Audio Layer III (MP3) and CBR, target rate 64 kbit/s; AudioFlow 2: music codec MPEG-2 Audio Layer III (MP3) and CBR, target rate 256 kbit/s. The audio source is the song of Kraftwerk 'the robot' (CBR mp3, converted through the Free Lossless Audio Codec tool). The following video files are used: VideoFlow 1: film clip, codec MPEG-2 and VBR, average (target) rate 700 kbit/s; VideoFlow 2: film clip, codec MPEG-2 and VBR, average (target) rate 256 kbit/s. The video source is a NASA launch video taken from the NASA website.

For streaming applications, One-way delay means the maximum delay accepted between the sending of the stream from source to destination buffer. This delay is not related to interactivity because, in general, the audio/video streaming is not interactive. For this reason, the target delay is about 10 s. The jitter is not specified by the standard, but we measure and report it anyway.

Table VIII shows the results for audio streaming; Figure 8 outlines the corresponding delay and jitter values. The performance metrics were measured through Wireshark traces of real time control protocol packets (about 20 samples). The RTT was measured on the GW host, jitter and loss on the ST host. BE conditions mean the satellite channel reserves the 75% of the target rate to the streaming application; the bandwidth allocation is the target rate+10% of the target rate, except for the last two tests as detailed in the following. The round trip time is used as defined in [24] in order to take into

Table VI. Summary of tests on media streaming.

#	Characteristics	Bandwidth allocation
9	AudioFlow 1	BestEffort
10	AudioFlow 1	rateAudio + 10%
11	AudioFlow 2	BestEffort
12	AudioFlow 2	rateAudio + 10%
13	VideoFlow 1	BestEffort
14	VideoFlow 1	rateVideo + 10%
15	VideoFlow 2	BestEffort
16	VideoFlow 2	rateVideo + 10%
17	VideoFlow 1	rateVideo + 25%
18	VideoFlow 2	rateVideo + 25%

Table VII. Service level agreement according to ITU-T G.1010 (End-user multimedia QoS categories): media streaming.

			Key performance parameters and target values		
Application	**Degree of symmetry**	**Typical data rates**	**One-way delay**	**Delay variation (jitter)**	**Information loss**
Audio	Primarily one-way	64-256kbs	$\leqslant$ 10 s	$\lll$ 1 ms	$\leqslant$ 1% (Packet loss probability)
Video	Primarily one-way	256-700kbs	$\leqslant$ 10 s	N/A	$\leqslant$ 1% (Packet loss probability)

Table VIII. Media streaming results: **audio**.

Test	Description	Round-trip time [s]	Delay variation (jitter) [ms]	Loss [%]	Mean opinion score (MOS)
9	AudioFlow 1 BE	Avg. 13.59, Dev. 9.9	Max 67.30, Avg. 54.18	0	**3** (perceivable)
10	AudioFlow 1 bw allocation	Avg. 0.6034, Dev. 0.0513	Max 24.19, Avg. 10.40	0	**4** (very good)
11	AudioFlow 2 BE	Avg. 14.53, Dev. 9.63	Max 44.13, Avg. 36.20	0	**3** perceivable
12	AudioFlow 2 bw allocation	Avg. 0.60, Dev. 0.038	Max 31.20, Avg. 26.11	0	**5** (CD-like) quality

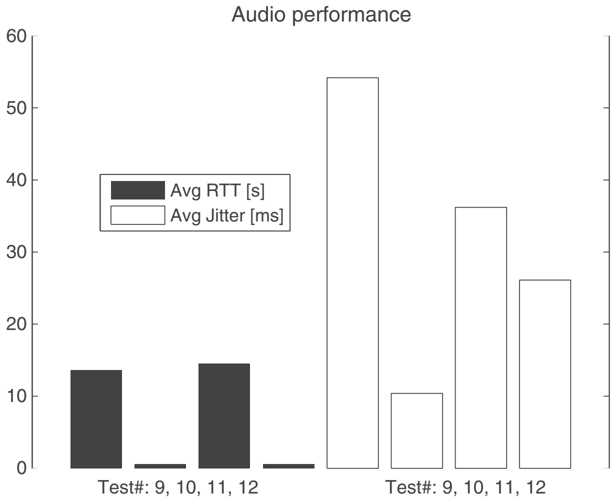

Figure 8. Audio performance.

account possible asynchronism of sender and receiver clocks (see, in particular, the example presented in Figure 2 of [24]). The perceivable indication for MOS in Table VIII is associated to the highest peaks of delay and jitter of Figure 8. It refers more specifically to the fact that the song is still audible but with bad quality due to many sound losses. The losses are inherent to some disordering accumulation of packets at the buffer of the application layer, because no loss is registered at layer 3. Such a disordering accumulation is due to the high experienced jitter. The audio streaming service is of very good quality in the presence of bandwidth allocation. In this case, the provisioning is simple, because the files are in CBR format. This is not the case for the video streaming as shown subsequently.

Table IX and Figure 9 show the results for video streaming. The perceived quality is not so good as in the audio case, mainly in virtue of the bursty behaviour of the application. Actually, the bandwidth allocation following the target rate is only an average indication of the generated traffic. The delay and jitter values in Figure 9 corresponding to the first four video tests (#13-16) map to either bad or almost acceptable quality. For this reasons, the last two video tests (#17-18) include an increased rate allocation of 25% over the target rate for both video 1 and 2. The corresponding decrease of the QoS metrics (delay, jitter and loss) is significant, and this leads to an improved perceived quality as well.

7. EVOLUTIONS OF THE SI-SAP INTERFACE SPECIFICATION

The use of ETSI BSM architecture for future terminal development is not limited to the current DVB-RCS implementation, but it can be considered for integration with other satellite standards, as already

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Table IX. Media streaming results: **video**.

Test	Description	Round-trip time [s]	Delay variation [ms]	Loss [%]	Mean opinion score (MOS)
13	VideoFlow 1 BE	Avg. 6.30, Dev. 4.55	Max 40.37, Avg. 30.56	0	**2** (bad)
14	VideoFlow 1 bw allocation	Avg. 4.97, Dev. 2.53	Max 38.02, Avg. 24.99	0	**3** (almost acceptable)
15	VideoFlow 2 BE	Avg. 3.51, Dev. 2.88	Max 26.32, Avg. 16.49	11.2	**2** (bad)
16	VideoFlow 2 bw allocation	Avg. 6.33, Dev. 0.80	Max 25.21, Avg. 13.45	6.5	**3** (almost acceptable)
17	VideoFlow 1 increased bw allocation	Avg. 1.28, Dev. 1.01	Max 8.18, Avg. 8.18	0	**4** (good)
18	VideoFlow 2 increased bw allocation	Avg. 2.03, Dev. 0.12	Max 9.11, Avg. 5.23	1.24	**4** (good)

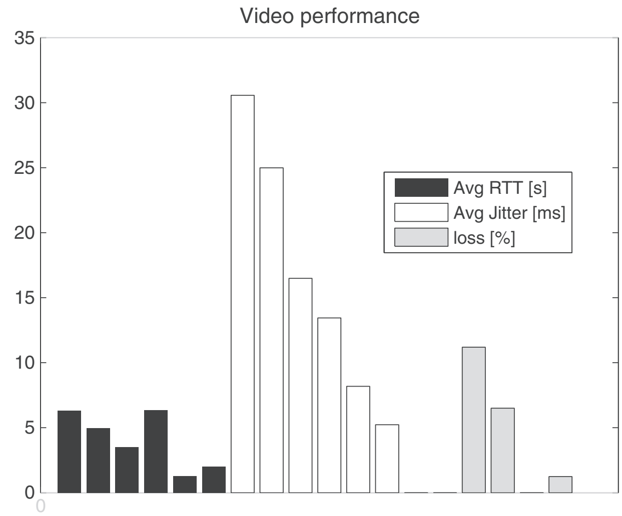

Figure 9. Video performance.

anticipated from a design perspective in the ETSI BSM documents, with respect to DOCSIS [25] and IPoS [26] systems. Further to this, the application of SI-SAP interface functionalities seems particularly appealing for next-generation satellite systems, building on the concept of smart gateway diversity to target terabit/s capacity systems [27]. From this perspective, an extension of SI-SAP primitives would be helpful to better address the problem of resource allocation in case of gateway handover, in order to achieve a better load distribution among the gateways available in the satellite network. Further to this, the use of the SI-SAP primitives would be particularly beneficial to signal the state of the satellite link in terms of layer 2 queue occupation when more robust ModCods are being used, thus reducing the information rate offered at the network layer. These functions, as already highlighted in the introduction, are partly already implemented in the satellite terminals as proprietary solutions, thus limiting the possibility of satellite capacity optimisation which is instead a feature offered by integrating the ETSI BSM architecture.

8. FINAL REMARKS, CONCLUSIONS AND FUTURE WORK

This paper focused on the integration of ETSI BSM and DVB-RCS/S2 architecture in future satellite terminals. The reason for this integration stems from the necessity of separating upper layer (SI) from lower layers (SD), thus enabling the implementation of cross-layer concepts, thanks to the functions offered by the SI-SAP interface. To this regard, a specific architecture design has been carried out to implement addressing, QoS and multicast management functions, by highlighting the limitations imposed by the DVB-RCS standard and the consequent modifications to be made on real satellite terminals. It was also pointed out that the integration of the proposed architecture with the new version DVB-RCS2 can be easily carried out, thus making the potentials of the SI-SAP interface even more attractive from a market point of view. Finally, it was shown that a simple overriding of the software implementation of DVB interface towards a higher layer allows the integration of ETSI BSM architecture, with a limited cost of realisation. Further to this, it is observed that the SI-SAP interface works as a hardware abstraction layer, hiding the functions performed by the DVB-RCS implementation to the upper layer, thus also allowing its application over other satellite standards. In particular, the integration of SI-SAP interface with the recently standardised DVB-RCS2 turns out to be also feasible and therefore results as promising technology candidate for the evolution of satellite communications. The conducted analysis through an emulator environment was around the performance benefits that a web-browsing application can receive, when dynamic QoS management, enabled by the SI-SAP primitives, is implemented.

Future work concerns the extension of the presented study so as to include a larger range of applications, in order to better characterise the application data usually transiting over satellite networks, such as UHDTV video streaming, 3DTV and http 2.0 browsing. Further to this, investigation on the benefits offered by the SI-SAP interface in the case of M2M/SCADA services when DVB-RCS2 is used with Random Access slots will be carried out.

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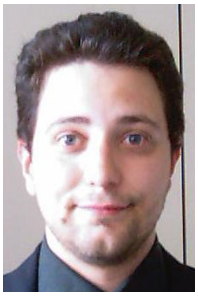

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