

# Two-way Broadband Satellite Access for Interactive Multimedia Services\*

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## Abstract

*In this paper, we investigate the feasibility of providing two-way broadband access for residential interactive multimedia services over multi-beam satellite systems. We propose air-interface protocols and terminal structures for broadband access with special emphasis on the MAC (Medium Access Control) sub-layer. We have used SDL-based formal techniques to describe and validate the behavior of the proposed protocols.*

## 1. INTRODUCTION

Access systems are mainly used in providing residential services. The term access involves a subscriber access to some other network such as the Internet, a private network, a telephony network or any other core network. A typical access system is constituted of:

- A subscriber network: It does not necessary constitute of a single user. An interface from some network on the subscriber side (LAN or PBX) more likely represents the standard configuration.
- An access network: It is connected to a core network. Alone, it does not represent a complete end-to-end communication system.
- A backbone network: Internet, PSTN (Public Switched Telephone Network), etc.

Various broadband access system technologies (such as cable, copper, fiber, wireless, etc.) are currently under development [1]. This development is driven by and coincides with increasing demands for transparent transmissions of data traffic, especially multimedia between subscribers and core networks in support of envisioned services. Envisioned multimedia services may include asymmetric services, such as Internet access, VoD (Video on Demand) and Digital Audio/Video Multicast or symmetric services, such as digital telephony and video conferencing. In deploying such services, efficient transport of data, voice and video in terms of bandwidth, reliability and delay is required. A key element in satisfying such a requirement is the development of an efficient MAC protocol/technique, especially over shared media.

In this paper, we consider the provision of two-way interactive residential broadband services with satellite as an access network. We introduce the system configuration and describe its constituents. Based on that, we will propose flexible protocol stacks, which can support IPv6 or ATM as

well as differentiated services. We emphasize our study on the development of a MAC layer that addresses the challenges facing construction of an efficient satellite access system. Inside the proposed MAC, we introduce new terminal structures that rely on distributed and co-operative control through two levels of scheduling and dynamic capacity allocation based on an enhanced Combined Free Demand Assignment Multiple Access (CFDAMA) [2] technique in support of QoS. We implemented the proposed MAC structure using the formal Specifications and Description Language (SDL) [3]. We confirmed the system correctness through formal verification using the ObjectGEODE [4] tools .

## 2. BROADBAND SATELLITE ACCESS (BSA) SYSTEM

BSA is an access system with a satellite segment representing its access network. It addresses same markets and services as the other access technologies. Services deployed over current conventional satellite systems are only one-way, as they rely on a phone line for the return path (upstream). Any failures in the public network will directly terminate any communication. In BSA, two-way interactive multimedia services are supported over shared bandwidth. In this section, we present the configuration structure and constituents of a BSA system. We will also show proposed protocol stacks and discuss relevant protocol layers.

### A. BSA Configuration

Figure 1 shows the general block configuration for one access domain of a BSA system. An access domain defines a group of subscribers accessing services at a certain service provider. The BSA system constitutes of three main elements. The Base Transceiver Station (BTS) represents the gateway to the backbone network. It contains subscribers' information and registration files to be downloaded during STS initialization. The Subscriber Transceiver Station (STS) interfaces the customer premises equipment to the satellite network. The Master Control Station (MCS) supervised by the satellite provider is necessary in order to regulate medium access among subscribers within the same domain as well as across different domains.

One of the main differences that distinguish satellite access from other technologies is that service providers and the network provider (satellite) are usually separate in contrast to other technologies. This requires proper coordination and signaling between both providers to guarantee a successful access. Efficient MCS allocation schemes

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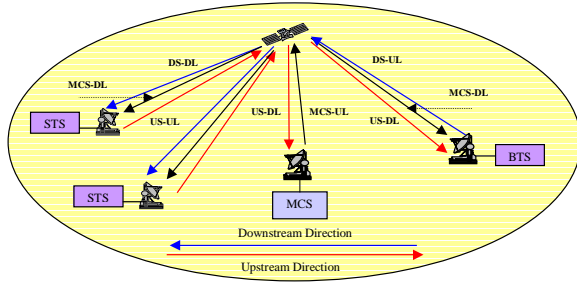


Fig. 1. BSA Single Domain Block Model

should be devised in order to fairly distribute bandwidth among subscribers according to their corresponding contracts, yet dynamically to attain a maximum utilization. The upstream (US) direction involves data transmissions from STS to the BTS. The downstream (DS) direction involves data transmissions from the BTS to STS. The satellite can have non-regenerative transponders and acts as a bend pipe where up-link (UL) transmitted signals are amplified, retransmitted and switched at RF onto the corresponding down-link (DL) beams.

### B. BSA Protocol Structures

Figure 2 shows a 3-D model for the BTS and STS acting as forwarders at the network layer. The stack is divided into two planes. In the data plane the following layers may be defined:

- Upper layers: The proposed MAC may independently support Internet protocol or ATM services. We assume that real-time traffic over these layers bypasses the LLC and directly accesses the MAC. In this way, supported services may accept slightly erroneous packets rather than afford delays resulting from retransmissions.
- Convergence Layer: It encapsulates upper layers PDU into the native BSA MAC PDU and translates upper layer QoS parameters into BSA MAC constructs.
- MAC Layer: It guarantees efficient data transmission over the satellite medium.

Note that in the BTS only, digital audio/video may bypass the MAC protocol layer and directly access the physical layer in the downstream as it usually conveys broadcast traffic and does not need the MAC access functionality used with upstream transmissions. In the control plane, we can identify the following layers:

- RSVP (Reservation Protocol): It is the control protocol used for resources reservation in IPv6. In RSVP, data is forwarded to the destination across the path determined during the resources reservation phase.
- Interface layer: It translates RSVP commands into local messages that will be used for the resource reservation over the satellite link.
- MAC Management layer: It is responsible for overall management of the MAC layer. Typical functions include synchronization, ranging and registration.

- LLC packaging: MAC Management messages carry critical information. Protection to these messages is achieved by LLC packaging in un-numbered information frames.

### 3. MEDIUM ACCESS CONTROL (MAC) ARCHITECTURE

A key element to the successful deployment of a BSA system is the development of a suitable MAC protocol/technique to efficiently manage and share the satellite resources. The proposed MAC should address the following challenges:

1. Satellite medium long delay and its resources constraint.
2. Expected bursty Internet and multimedia traffic of envisioned services.
3. QoS requirements for real-time and non-real-time data expected to be conveyed by the BSA system.

In this section, we present aspects of the devised MAC and describe the proposed MAC layer. We also introduce bandwidth allocation and scheduling mechanisms and their block structures.

#### A. Media Control Aspects

Capacity of the downstream connections is assumed to be fixed, as the aggregate broadcast transmission is considered to have high load and is rather smooth (i.e., the peak-to-average ratio is close to unity). Transmission over the upstream and MCS links is bursty with high peak-to-average ratio and necessitates an efficient MAC. We assume the widely used Multiple Frequency Time Division Multiple Access (MF-TDMA) format as shown in Figure 3 [2]. A channel in MF-TDMA is defined by a time-frequency slot in a two-dimensional frame. All subscriber transceiver stations may access these time-frequency slots in a shared manner.

For Dynamic Capacity Allocation (DCA), we propose to use a CFDMA-based MAC access technique. CFDMA [2] is a hybrid access technique where un-requested bandwidth is freely allocated to users according to a predetermined algorithm. Performance evaluation in [5] shows that the CFDMA provides a superior delay-throughput performance over satellite systems for multimedia traffic. Furthermore, we consider a prediction scheme to enhance its performance as follows; at each STS, requests to the MCS will not reflect instantaneous needs. Rather, anticipated bandwidth after two round trip delays will be demanded. A complementary prediction function may also be performed at the MCS. Free bandwidth will be assigned to terminals based on a prediction of their future bandwidth needs.

MCS are obliged to control a large number of connections over a huge population. In order to reduce the MCS complexity, we have structured two levels of scheduling in our system; a macro level at the MCS responsible for handling the aggregate requests of each STS terminal and a micro level within the STS themselves, where each terminal distributes granted requests over local connections.

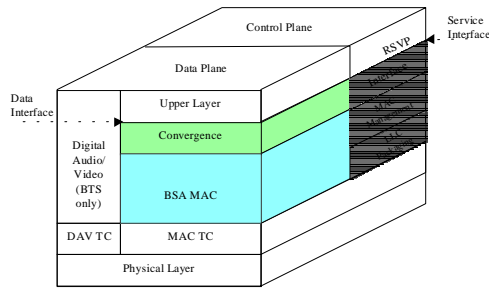


Fig. 2. 3-Dimensional BSA Stack Model

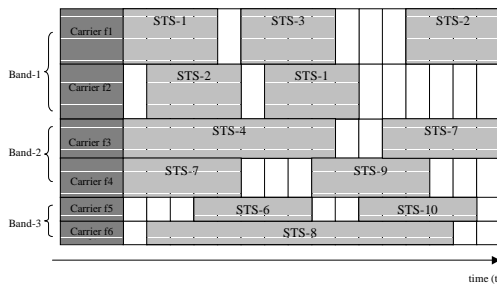


Fig. 3. MF-TDMA Structure in BSA

This renders a distributed scheduling processing duty. Distributed scheduling achieves an MCS with lower complexity and minimum processing delays. However, overall bandwidth control still resides at the MCS in a centralized manner. To further decrease variables processed by the MCS, connections between an STS and the MCS on the upstream up-link may simply be defined by only a limited number of standard service categories (real-time and non-real-time for example). This relieves the MCS from the burden of managing numerous connections per STS with minimum information to be processed.

To support QoS, we also adopt the DOCSIS 1.1 [6] concept of dynamic services. QoS defines parameters as delay, throughput, jitter, etc., that should be sustained during the lifetime of a connection. Dynamic services allow terminals to dynamically add, modify or delete connections based on upper layer requests. Based on upper layer QoS parameters, corresponding connections will be categorized into service categories with equivalent local parameters. Requests with the resulting parameters and consequent negotiations will then be conveyed through dynamic service procedures.

### B. MAC Protocol

A MAC frame defines the unit of information exchanged between MAC entities. MAC frames are either Data Frames (carrying an IP packet or a variable number of ATM cells) or Specific Frames, which may be Request Frames for bandwidth reservation or MAC Management Frames that carry MAC Management messages.

MAC Management is the center of the MAC protocol and controls its MAC main functions. Typical functions include

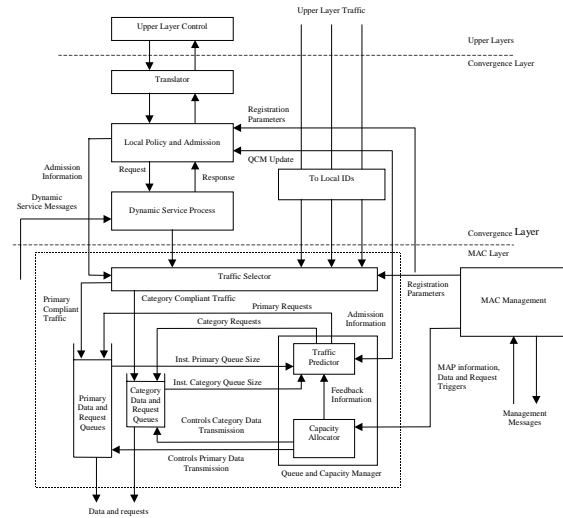


Fig. 4. STS DCA Block Structure

synchronization to achieve global timing reference, channel bands description for defining physical attributes of upstream bands, time frame description for regulating terminals' transmissions, initial and station maintenance (ranging) for timing, power, as well as frequency adjustments and registration to enable STS data transmission over the satellite network. Each function is defined by message exchange scenarios, which coincide with DOCSIS 1.1. Details may be found in [6].

### C. Bandwidth Allocation and Scheduling

Allocations and transmission opportunities over future time frames are defined by the MAP Management message regularly transmitted by the MCS. A MAP message is constituted of a group of consecutive MAP elements. A MAP element is composed of a MAP opportunity, address and allocated slots. Typical MAP opportunities include ranging (Initial and Station) for timing and power adjustments, requests for STS to report their predicted demands, registration for negotiating registration parameters and data grants for bandwidth allocations to various STS.

*Structure of STS DCA.* Figure 4 depicts a block structure that highlights the required components for the proposed DCA and scheduling operation in the STS:

- Upper Layer Control: We assume RSVP. Requests for new connections are initiated there and forwarded towards the dynamic service process.
- Translator: It has the responsibility of translating requested upper layer QoS parameters into local parameters recognized by local admission.
- Local Policy and Admission: It defines the STS policy. It also handles admission of all connection requests from upper layer control. Translated upper layer requests from single connections are categorized according to internal criteria into certain service categories (real-time and non-real-time for example). Local admission might decide itself to

accept/refuse a new connection. Otherwise, it must consult the MCS. In that scenario, connection-related requests accompanied by traffic parameters related to that specific category will be transmitted over the MAC as dynamic service commands.

- **Dynamic Service Process:** The dynamic service process is the means by which the STS conveys its connection requests to the MCS and defines the behavior of mutual negotiations.
- **Traffic Selector:** The traffic selector has the responsibility of forwarding compliant user traffic into data queues of the corresponding category. It also interleaves traffic from different local connections over a time frame before forwarding them into the queues to avoid monopolizing of the queues by a single connection.
- **Data Queues:** Data from all connections of the same category enter the corresponding data queue. Instantaneous queue status updates are reported to help in the prediction process.

- **Queue and Capacity Manager:** It has the responsibility of managing and distributing granted resources from the MCS. Based on queue status and admission information, the QCM will predict and request the required bandwidth and distribute granted allocations. The *Traffic Predictor* utilizes all provided information from admission and data queues in predicting the anticipated number of data requests after two round trips (requests from STS to MCS and back). Fine-tuning is achieved by comparing predicted requests with actual queue size at reception of allocated grants. The *Capacity Allocator* receives description of the grants and manages the queues and their timing. In case of multiple queues, the allocator may decide to borrow allocations of one category to the other (prioritize real-time over non-real-time for example). Excess bandwidth, if any, will also be shuffled based on local algorithms.

**MCS Structure for DCA.** Figure 5 depicts a block structure that highlights the required components for the proposed DCA and scheduling operation at the MCS:

- **Policy and Admission:** It carries policy information acquired during registration. Admission decisions depend on the current network status and regular updates received for the current scheduler status.
- **Scheduler:** It has the responsibility of allocating capacity grants to all requesting STS. The scheduler regularly receives admission information and uses it to monitor complying stations. It is also frequently polled from MAC Management to allocate management opportunities (ranging and registration) to various stations.

#### 4. FORMAL DESCRIPTION AND VALIDATION

##### A. SDL Model

We have chosen SDL as the formal language to model the MAC protocol and system structure. SDL [3] is an ITU standard formal description language that is used to

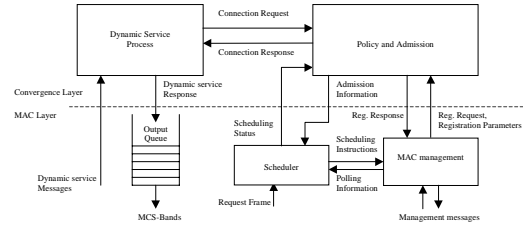


Fig. 5. MCS DCA Block Structure

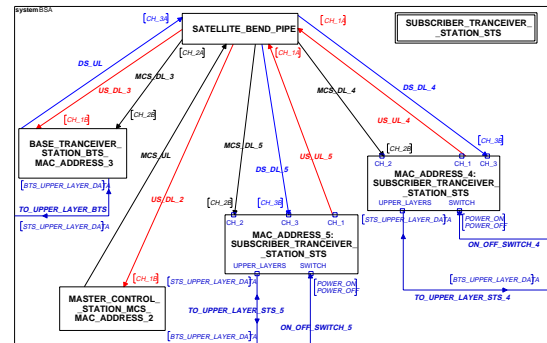


Fig. 6. BSA System Model

describe systems using graphical representations as well as textual representations. In SDL, a system is divided into building blocks that communicate using channels. Blocks are composed of processes. Processes (within a block) are connected using signal routes. Each process is an extended finite state machine, which has its own infinite queue and is assumed to operate independently from all other processes.

Figure 6 shows the devised BSA system model. It is composed of a BTS, an MCS and two STS of an access domain communicating through a satellite bend pipe. The two STS are instances of a common block type. We have modeled an MF-TDMA system over a single band of similar frequency channels to reduce model complexity. Full details on the SDL model may be found in [7]. Figure 6 depicts the following blocks:

**STS Block Type.** Figure 7 depicts the STS block type. Note that its structure coincides with the proposed proto-

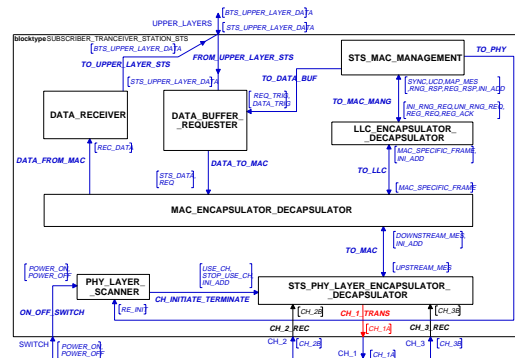


Fig. 7. STS Block Type

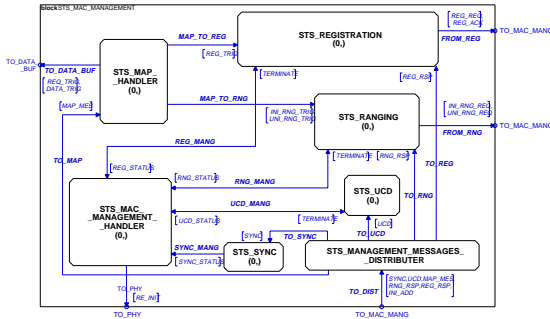


Fig. 8. STS MAC Managementnet

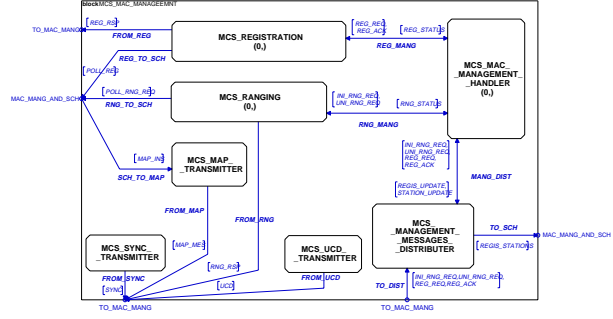


Fig. 10. MCS MAC Management

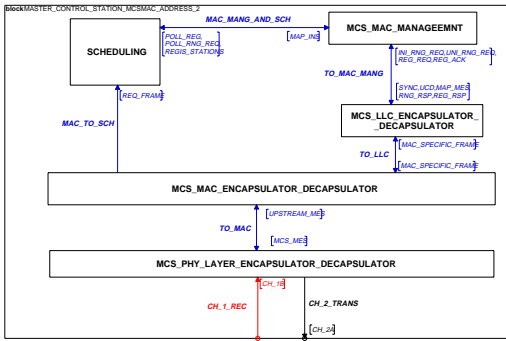


Fig. 9. MCS Block

col layers. The PHY Scanner simulates a channel scanning process. The PHY Encapsulator/Decapsulator models physical layer framing composition and extraction. The MAC Encapsulator/Decapsulator simulates encapsulation and decapsulation of MAC frames. The LLC Encapsulator/Decapsulator converts MAC Management messages to MAC Specific Frames and vice versa. A Data Receiver receives Data Frames and forwards them to upper layers, while the Data Buffer/Requester represents the QCM process and traffic queues. It is made simple assuming a single queue (i.e., one category) to reduce model complexity. STS MAC Management is responsible for managing synchronization, ranging, registration, etc. Figure 8 depicts the STS MAC Management structure. In addition to the processes that manage MAC Management operations (synchronization, ranging, registration, etc.), the MAC Management has a Handler process that controls its overall functionality and a Distributer process that forwards incoming Management messages to the correct processes.

**MCS Block.** Figure 9 depicts the MCS block. For simplicity, the Scheduler in the MCS uses a first come first serve scheduling algorithm. It processes STS request frames as well as management opportunities polls and sends instructions to MAC Management describing contents of future MAP messages. MCS MAC Management structure is shown in Figure 10. The MCS MAC Management instantiates a Handler process for each registered terminal. Each Handler controls MAC Management operations (ranging

and registration) of its corresponding terminal. Management messages input to the MCS are forwarded through the Distributer, then via the corresponding terminal Handler to the correct Management processes.

**BTS Block.** The BTS might elect to monitor the MAP messages to anticipate its subscribers' transmissions. In order to adjust its timing, it periodically receives the broadcasted synchronization (SYNC) messages.

## B. System Validation

We verified the correctness of the protocol's general properties by running the verification process in ObjectGEODE. Results proved the protocol free from deadlocks, unspecified receptions and livelocks. We have also derived the most critical specific properties that should cover the validation of the largest portion of the protocol behavior. Validation against specific properties guarantees proper system operation against the requirements and the informal specification. We have validated the derived specific properties by running the verification process against Message Sequence Chart (MSC) [8] observers in ObjectGEODE [4]. We have found that none of the properties were violated [7]. Hence we concluded correctness of our BSA terminal structure.

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