Project	**IEEE 802.16 Broadband Wireless Access Working Group**
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Source	Farid Elwailly Stanford Wireless Broadband, Inc. 1221 Crossman Ave. Sunnyvale, CA 94088 Voice: (408)745-3938 Fax: (408)745-2506 E-mail: farid.elwailly@stelhq.com
Re:	This contribution is a response to the Call for Contributions from the 802.16 Medium Access Control Task Group, dated 29 October, 1999, for a proposed MAC layer protocol for Broadband Wireless Access (BWA) systems.
Abstract	A general description of a proposed MAC layer for the 802.16 Air Interface Specification is presented. The proposed MAC layer is based on ATM transport and is simple and robust. It supports the quality of service classes that are defined for ATM and it has been implemented and successfully installed in the field in a number of field trials worldwide.
Purpose	To provide a general description of a proposed MAC layer specification that is applicable to BWA systems.
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ATM Based MAC Layer Proposal for the 802.16 Air Interface Specification

Farid Elwailly
Stanford Wireless Broadband, Inc.

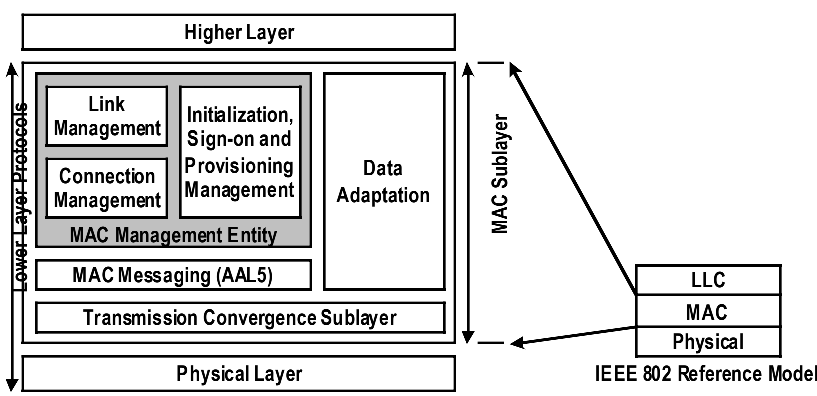
Overview

This contribution gives a general description of a proposed MAC layer specification for the Broadband Wireless Access system being considered by the 802.16 MAC Task Group.

In order to leverage existing technology for demonstrated robustness of implementation as well as for reduced cost, this proposal is based on ideas, such as the ATM encapsulation of MAC messages, from the ETSI based Digital Video Broadcasting (DVB) standards for the interaction channel for local multi-point distribution systems (LMDS). In addition, this proposal contains many aspects of the DAVIC standard for lower layer protocols and physical interfaces. The following sections provide a general description of several aspects of the proposed MAC layer.

MAC Reference Model

The scope of this proposal is limited to the definition and specification of the MAC layer protocol. The detailed operations within the MAC layer are hidden from the above layers. This specification focuses on the required message flow between the Base Transceiver Station (BTS) and the Subscriber Transceiver Station (STS) for media access control. These messages can be divided into three categories: Initialization, provisioning and sign-on management, Connection management, and Link management.



MAC Reference Model

MAC Concept and ATM Transport

The goal of the MAC protocol is to provide tools for higher layer protocols in order to transmit and receive data transparently and independently of the physical layer. Higher services are provided by the BTS to the STS. The BTS is thus responsible for indicating the transmission requirements to the MAC layer for each type of service. However, bandwidth in the physical layer does not need to be assigned immediately by the BTS for a given connection. This can be deferred until either the BTS or STS determines the need for bandwidth.

The physical layer is assumed to support one or more downstream channels and one or more upstream channels between the BTSs and the STSs. Each downstream channel is associated with only one BTS and each upstream channel is associated with a number of STSs. This is a star network. Hence each STS is associated with one BTS and must be associated with a downstream channel when first activated. The MAC allows the BTS to optionally move an STS to another downstream channel and to indicate the upstream channel to be used by that STS. Only one downstream frequency channel may be received by the STS at any instance and only one upstream frequency channel may be transmitted in by the STS at any instance. A task of the MAC layer is the maintenance of time, frequency, and power synchronization between the BTS and the STSs to allow multiple STSs to use the same upstream frequency. A second task is the initial synchronization of STSs that are performing network entry.

MAC flow is bi-directional supported by modems at the BTS and STS. Messages may be sent downstream from the BTS to the STS or upstream from the STS to the BTS. Both the downstream and upstream channels are divided into time slots that encapsulate exactly one ATM cell each. These ATM cells carry all traffic including higher level services as well as MAC traffic. MAC traffic uses ATM AAL5 encapsulation for all messages. Other traffic may use native ATM, AAL5, or other adaptation types for transport over the air. Another task of the MAC layer becomes the efficient allocation of these ATM slots in the downstream and upstream to meet the needs of the higher layer services.

Frames and Time Slot Types

On the downstream channels the MAC layer provisions bandwidth using a priority scheme associated with the ATM VPI/VCI. On the upstream channels the MAC layer provisions bandwidth by assigning time slots suitable for one ATM cell each to STS sessions. Sessions are assigned slots based on the class of service they represents, hence a guaranteed bandwidth service may have a number of slots periodically assigned on a permanent basis, whereas a best effort service gets assigned slots only when available.

The MAC manages time slots by grouping them into frames and designating a small fraction of the slots in each frame as special types for bandwidth management. The frames are an integral number of time-slots in length. Downstream and upstream frames may differ in the number of slots they contain but they must be exactly the same duration in time. In fact there is a one to one correspondence between each downstream and upstream frames. Also, there is a fixed delay between the start of downstream frame and start of upstream frame referenced at the BTS. This imposes a relationship between the downstream and upstream data rates in the PHY layer.

The downstream scheme is time division multiplex and the time slot types are divided into frame start slots and random access slots. The upstream scheme is time division multiple access and the time slot types are divided into polling response slots, contention slots, and reserved time slots.

Downstream Time Slots

Downstream timeslots are either Frame Start Time Slots or Random Access Time Slots. The first slot of the downstream frame is always a frame start slot in order that the STS may determine the beginning of the downstream frame and synchronize its upstream frame to it. This time slot always encapsulates the first cell of a single or multi-cell AAL5 Service Data Unit (SDU). The whole AAL5 SDU is referenced as frame start and therefore more than one slot at the start of the frame may be marked as frame start. The unique VPI/VCI of the ATM cells in those slots is used as the marker and flags the frame start. ATM cells with this VPI/VCI will not appear anywhere else in the frame. The SDU contains the frame number and optional polls to one or more STS. Poll MAC messages must occur in the frame-start SDU. Following the poll messages the SDU can contain other MAC messages destined for any STS.

The random access slots are all the remaining time slots in the downstream frame after the frame start. The BTS may transmit on any of these time slots whenever it has any cells that need to be sent to an STS. The cells may be OAM cells or part of an adaptation layer SDU such as AAL5. The random access slots can be referenced as virtual channel slots because they are utilized in a true ATM sense rather than being synchronous or semi-synchronous due to physical layer constraints.

Upstream Time Slots

The number of upstream slots per frame depends on the upstream baud rate. There needs to be a maximum limit on this number to keep the processing of slot allocation maps efficient (in the range of 100 to 200 for example.)

Slots on the upstream are Poll Response Time Slots, Contention Time Slots, or Reservation Time Slots.

The poll response time slots are allocated to one STS each per frame. They are utilized to send a poll response after the STS receives a poll request from the BTS. The poll response time slot will only encapsulate a single-cell AAL5 SDU whose payload is a MAC message. The VPI/VCI utilized is special and used to identify the STS.

The contention time slots are open to all STSs. Utilizing the contention time slot may cause a collision with another STS utilizing the same contention time slot. If a collision occurs, then contention must be resolved via a contention resolution algorithm. Although not necessary, the MAC layer may make use of information from the PHY layer indicating a collision occurred in a contention cell. Contention time slots encapsulate a single-cell AAL5 SDU containing MAC messages, a single-cell AAL5 SDU consisting of higher layer data, or the first cell of a multi-cell AAL5 SDU consisting of higher layer data. The STS shall always use the special VPI/VCI for transmission of a MAC message or the VPI/VCI of the higher layer session for transmission of higher layer data in contention time slots.

The reserved time slots are allocated to STSs as required by the BTS. An STS may transmit on any slots it has reserved whenever it has any cells that need to be transmitted to the BTS or to a higher level interface via the BTS. CBR traffic is assigned reserved time slots that are dedicated until deallocated. VBR/UBR traffic is assigned slots on an ongoing basis as needed. Multiplexing of data traffic into timeslots can be based on ATM QoS to ensure QoS guarantees.

Network Entry and Calibration

The BTS polls every STS in its group. When an STS attempts to enter the network, it acquires a downstream frequency channel and listens for polls directed to it. All STSs will be polled on a downstream frequency channel within a fixed time period. If the STS waits that long, but does not receive its poll, it will acquire the next downstream frequency and again listen for its poll. This process repeats until the STS finds a downstream frequency channel on which it is being polled.

Once the STS responds to the poll and goes through network entry, the STS will only be polled on this one downstream frequency channel.

A poll response from the STS to the BTS generates a calibration message from the BTS to the STS telling it its time, frequency, and power errors. The physical layer must support the measurement of these errors in the poll response slots. Once it receives these errors the STS corrects its time, frequency, and power and tries again. When satisfied, the BTS tells the STS it is considered calibrated.

Since STSs that have not yet gone through network entry are not as well synchronized with the BTS, guard time slots will need to follow the STS poll response time slot reserved for net entry.

Once the STS is calibrated, contention slots can be used, reserved time slots may be allocated, and MAC control sessions may be assigned and utilized. The BTS will continue to poll the STS periodically to maintain upstream calibration even if there is a lack of user activity.

MAC Session Connections

MAC session connections are ATM connections between the STS and BTS that transport communication between two control entities. The control entities may or may not reside in the STS and BTS. It may be necessary that the connection assigned by a mac_session_connection message be switched to other virtual connections one or more times to reach the final control entity.

In order to establish a session connection, it is not necessary that the STS request a connection. The BTS may simply establish the connection by sending a mac_session_connection message to the STS. The first MAC session connection is set up by default with a unique VPI/VCI (called a MAC VC) for each STS. This session is the MAC connection for transporting MAC messages in the downstream random access time slots and in the upstream reserved time slots.

Due to the shared wireless physical media, assigning a different MAC VC for each STS alleviates the need for every STS to process every MAC message cell to identify which cell payloads contain its STS_id.

When the STS detects a need for bandwidth in a session (for example it may use the level of the queues holding traffic waiting to go out as an indicator), it sends a reservation request to the BTS. If the BTS agrees, it reserves some reservation slots for use by that STS and sends it a slot allocation message to let the STS know which slots it may use.

MAC Messaging

The MAC messages all utilize the same basic structure. Every message consists of the fields: STS_id, msg_length, poll_slot_id, msg_type, num_msg_items, and a list of the msg_items. If in the message header the number of message items is greater than one, the message will contain more than one instance of the message item. A reserved STS_id is used to indicate all STSs, i.e. it is the “broadcast” ID.

The following message type table lists the types of MAC messages used in the specification. Other message types can be added to this table in the future and will be added at the end of the enumeration list identifying the message types.

Message Class	*Messages in these Classes*
Messages to handle bandwidth allocation	*STS to request bandwidth and BTS to allocate it. BTS to de-allocate slots. BTS to define the poll and contention slots*
Messages to handle net entry and maintain synchronization	*BTS polls STSs not yet in the network. BTS polls STSs in the network. STSs respond to poll. BTS lets STSs know the accuracy of their time, frequency, and power settings. BTS can ask for status as well and the STSs respond.*
Messages to handle setup and tear-down of Sessions	*STS asks for a session. BTS sets up a session. STS drops a session. BTS drops a session. Ack's for all these messages will be required.* *BTS moves STS to other downlink channel.* *BTS gives feedback on contention slot collisions.*

802.16 MAC Task Group Criterion

We feel that the MAC protocol proposed in this write-up does well when measured against many of the criterion being used by the MAC Task Group to evaluate the submittals. In some of the areas addressed by the criterion, we are looking into modification of the proposed message set to improve performance. More specifically:

1. The proposed MAC layer meets the system requirements.

2. The proposed MAC layer has well defined delays that can be calculated from knowledge of the ALOHA variant algorithm being used to utilize the contention slots. We are looking at improving efficiency and lowering delay by going to mini-slots in the contention slots. We are also looking at a simple change to piggy-back bandwidth requests on data cells that would allow guaranteed delays for real time VBR service classes.

3. ATM overhead applies to any data encapsulated in an adaptation layer in this proposal. We are looking at methods to improve this overhead by transporting ATM sessions more efficiently over the air. Use of ATM transport makes it easy to design bandwidth allocation algorithms that are fair and furthermore enables ATM quality of service to be provided to the users.

4. The proposal is based on ETSI based DVB and existing chip sets allow for very cheap implementations.

5. The proposed MAC layer is scalable. It allows for changing the number of polling and contention slots to handle different service mixes and loads. Frame size and number of slots per frame can also be varied. The proposal does not address the actual bandwidth allocation algorithm. This can have variants to handle different scales.

6. The proposed MAC layer supports the services mentioned in the 802.16 Systems Requirements.

7. FEC and CRC checks are used to protect MAC messages over the air. The proposed MAC protocol recovers from unexpected events through timeout mechanisms that make for a very robust protocol.

8. The proposed MAC layer does have a registration mechanism to control Network Entry by an STS. We are investigating adding security based on a recognized standard.

9. The physical channel is configured through the control of the frame size and number of slots. Bandwidth is allocated through control of the allocation of slots to STSs.

10. The proposed MAC layer has been implemented and successfully fielded in a number of field trials. The downstream, of course, is DVB based and has been used successfully for direct broadcast applications for a number of years.

11. The proposed MAC layer is based on existing standards and technologies (DAVIC and ETSI DVB) and can utilize chip sets developed for those technologies.

Benefits of the Proposed MAC Layer

- **Simplicity**: The protocol is simple and leverages existing technology that has demonstrably worked well. Correct implementations at a reduced cost become achievable.

- **QoS**: The protocol is based on ATM transport and quality of service is well defined and solved for ATM. When coupled with the appropriate bandwidth allocation algorithms in the BTS this MAC layer can provide QoS in a logical and consistent manner. We also cover all IP classes of service using the ATM transport QoS tools.

- **Robustness**: The simple cell structure makes bandwidth allocation algorithms easier to devise and verify. ATM is a proven technology for transport of many classes of service and is the backbone of the MAC layer concept described here.

- **Flexibility**: The MAC layer described is flexible and extensible. New messages may be added to allow for new MAC services. The details of the slot allocation algorithm are not specified allowing for more different styles of algorithms to be used while still utilizing the same basic message set. Frame size, number of channels, and data rates are flexible. The number of poll response slots and contentions slots is selectable and may be varied "on the fly" if so desired by the BTS.

- **Meets the System Requirements**: The current message set coupled with appropriate bandwidth allocation algorithms will meet the requirement set forth in the 802.16 System Requirements.

Drawbacks of the Proposed MAC Layer

- **Contention Slot Size**: Each contention slot is a full ATM cell. This makes designating slots as contention slots easy and simplifies the hardware implementation at the BTS. It is, however, much better to have many more small slots than a few large ones when a large number of users are contending for service. We are investigating the use of mini-slots that fit within a normal slot for contention. Normal traffic would no longer fit in the slots but the request for bandwidth can be very brief and the number of users supported in a fixed number of contention slots would be larger.

- **IP Transport Efficiency**: IP traffic is an important class of service that must be transported over the system. In this MAC layer description IP traffic would be encapsulated using ATM AAL5 with a corresponding cost in overhead. We are looking at encapsulation methods for IP that reduce this overhead, while preserving the inherent flexibility of the ATM segmentation and reassembly function used to support various QoS definitions. Note that premium IP with QoS requires a segmentation method for IP that has overhead approaching the overhead of IP over ATM.

Statement on Intellectual Property Rights

Stanford Telecom and Newbridge Networks have patents, either accepted or pending, which may be relevant to this proposal. Both companies have read the IEEE patent policy and agree to abide by its terms.