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Re:	802.16 Medium Access Control Task Group Call for Contributions – Session #4
Abstract	The proposed MAC protocol is based on DOCSIS 1.1 with modifications to make it more suitable to wireless environment. The MAC protocol is designed to support the transport of multiple protocols both in point-to-point and point-to-multipoint system configurations.
Purpose	The authors desire that the proposed MAC protocol be accepted in whole or partially as the MAC protocol standard for IEEE 802.16.
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MAC Protocol Proposal for Fixed BWA Networks Based on DOCSIS

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1. Introduction

This document presents an overview of a MAC layer protocol recommended for adoption by the 802.16 Work Group for BWA networks. This MAC protocol is designed to support the transport of multiple protocols, such as IP and ATM, in both point-to-point and point-to-multipoint system configurations. The MAC protocol proposed is based on DOCSIS 1.1 [1] with modifications to make it more suitable to wireless environment.

1.1. Overview

This section highlights features of the proposed MAC protocol, which include:

- Bandwidth allocation controlled by BWA BTS.
- A stream of mini-slots in the upstream.
- Dynamic mix of contention- and reservation-based upstream transmit opportunities.
- Bandwidth efficiency through customized support of fixed-size and variable-size PDU as well as bandwidth-efficient MAC messaging.
- Support for transport of multiple protocols.
- Support for QoS, including:
  - Support for bandwidth, latency and bit-error-rate guarantees.
  - Dynamic Service Establishment.
- Optimized for point-to-multipoint as well as point-to-point BWA systems.
- Optional security at the data link layer.
- Support for a wide range of data rates.

1.2. Acronyms

ATM	Asynchronous Transfer Mode
BWA	Broadband Wireless Access
BTS	Base Station
DOCSIS	Data-Over-Cable Service Interface Specifications
EH	Extended Header
FEC	Forward Error Correction
IE	Information Element
IP	Internet Protocol
MAC	Media Access Control
PDU	Protocol Data Unit

PHY Physical (Layer)

PMD Physical Medium Dependent

QoS Quality-of-Service

SFID Service Flow Identifier

SID Service Identifier

SNMP Simple Network Management Protocol

STS Stations

SYNC Synchronization

1.3. Definitions

MAC Layer Domain

A MAC layer domain is a collection of upstream and downstream channels for which a single MAC allocation and management protocol operates. Its attachments include one BWA BTS and one or more BWA STS. The BWA BTS services all of the upstream and downstream channels. Each BWA STS may access one or more upstream and downstream channels.

Service Flow

The concept of service flows is central to the operation of the MAC protocol. Service flows provide a mechanism for upstream and downstream QoS management. In particular, they are integral to bandwidth allocation.

A SFID defines a particular unidirectional mapping between a BWA STS and the BWA BTS. Active SFIDs also have associated SIDs. Upstream bandwidth is allocated to SIDs, and hence to BWA STS, by the BWA BTS. SIDs provide the mechanism by which upstream Quality-of-Service is implemented.

The BWA BTS may assign one or more SFIDs to each BWA STS, corresponding to the service flows required by the BWA STS. This mapping can be negotiated between the BWA BTS and the BWA STS during registration or via dynamic service establishment.

It is necessary to be able to send certain upstream packets needed for MAC management, SNMP management, key management, etc. For the network to function properly, all BWA BTSs must support at least one upstream and one downstream service flow. These service flows are referred to as the upstream and downstream primary service flows. The SID assigned to the upstream primary service flow is referred to as the primary SID.

The primary SID must always be assigned to the first provisioned upstream service flow during the registration process. The primary service flow must be immediately activated at registration time. The primary SID must always be used for station maintenance after registration. The primary service flows may be used for traffic.

All SFIDs are unique within a single MAC layer domain. The length of the SFID is 32 bits. The length of the SID is 16 bits.

A service flow is differentiated by, among other things, the type of protocol data unit being transported (e.g., IP, ATM).

Upstream Intervals and Mini-Slots

The upstream transmission time-line is divided into intervals by the upstream bandwidth allocation mechanism. Each interval is an integral number of mini-slots. A mini-slot is the unit of granularity for upstream transmission opportunities. There is no implication that any PDU can actually be transmitted in a single mini-slot. Each interval is labeled with a usage code, which defines both the type of traffic that can be transmitted during that interval and the physical-layer modulation encoding.

Frame

A frame is a unit of data exchanged between two or more entities at the Data Link layer. A MAC frame consists of a MAC header and a variable-size PDU.

1.4. References

1. Data-Over-Cable Service Interface Specifications, Radio Frequency Interface Specification, SP-RFIv1.1-I01-990311.

2. Media Access Control Specifications

2.1. MAC Reference Model

The proposed MAC layer lies between the optional Security layer and the PHY layer as seen in Figure 1. The MAC layer functionality is invisible to higher layers.

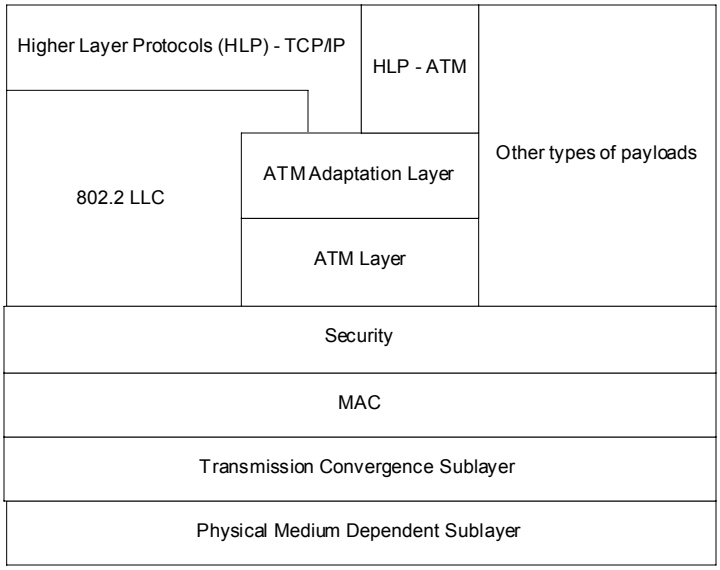

Figure 1. MAC Reference Model

2.2. MAC Frame Format

2.2.1. Generic MAC Frame Format

A MAC frame is the basic unit of transfer between the MAC layer at the BWA STS and the BWA BTS. The same basic structure is used in both the upstream and downstream directions. MAC frames are variable in length.

Generic format of MAC frames is shown in Figure 2. The MAC header uniquely identifies the contents of the MAC frame. The size of the MAC header can be 1 or 4 bytes, depending on whether the header is a base header or an extended header.

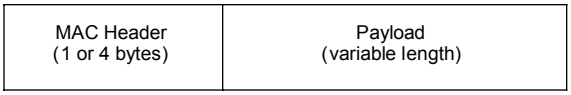

Figure 2. Generic MAC Frame

2.2.2. Base MAC Header

The base MAC header is 1 byte long, and is used to indicate that the MAC frame contains a fixed-size PDU (e.g., an ATM cell). The format of the base MAC header is shown in Figure 3.

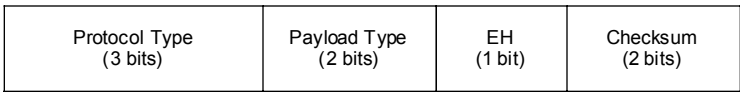

Figure 3. Base MAC Header Format

The 3-bit Protocol Type field indicates the type of PDUs carried within the MAC frame. The encoding of the Protocol Type field is shown in Table 1.

Protocol Type Encoding	Protocol Data Unit
000	IP
001	ATM
010 - 111	Reserved

Table 1. Protocol Type Field Encoding

The 2-bit Payload Type field indicates the content of the payload section of the MAC frame. The encoding of the Payload Type field is shown in Table 2.

Payload Type Encoding	Payload Content
00	Higher-Layer Data
01	MAC Management and Control Data
10	MAC Management and Control Data, and Higher-Layer Data
11	Request

Table 2. Payload Type Field Encoding

The 1-bit EH field indicates whether the length of the MAC header is 1 byte (base header, EH = 0) or 4 bytes (extended header, EH = 1).

Finally, the 2-bit Checksum field is used to protect the MAC header.

2.2.3. Extended MAC Header

The extended MAC header is used to indicate that the MAC frame contains a variable size PDU (e.g., MAC management / control messages, IP packets, ATM cells, etc.). The format of the extended MAC header is shown in Figure 4.

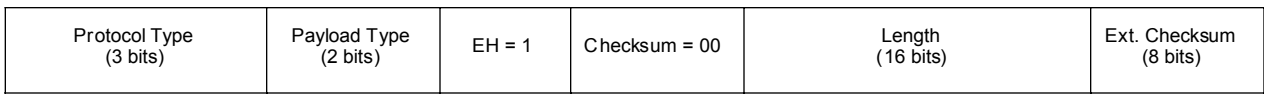

Figure 4. Extended MAC Header Format

The 16-bit Length field indicates the length of the MAC frame (in bytes), whereas the 8-bit Extended Checksum field is used to protect the overall MAC header. Note that the 2-bit Checksum field is set to '00' for an extended MAC header.

2.2.4. MAC Management and Control Frame

MAC Management and Control Frames are used to exchange MAC management and control data between the BWA BTS and BWA STSs. The format of the MAC Management and Control Frame is shown in Figure 5.

Protocol Type (3 bits)	Payload Type = 01	EH = 1	Checksum = 00	Length (16 bits)	Ext. Checksum (8 bits)	MAC Management and Control Data (variable length)

Figure 5. MAC Management and Control Frame

Upstream and downstream MAC management and control messages are composed of one or more IEs. The general format of information elements is shown in Figure 6.

IE Type (8 bits)	IE Length (8 or 24 bits)	Payload (variable length)

Figure 6. Information Element General Format

The IE Type field specifies the purpose of the information element.

The IE Length field specifies the length of IE data (in bytes). All information elements are an integral number of octets in length. When the payload field is less than 255 octets long, the IE Length field shall be an 8-bit unsigned integer. When the payload field is 255 octets long or larger, the IE Length field shall be a 24 bits long; in this case, the first byte of the IE Length field shall be set to 255 and the remaining two bytes shall be taken as a 16-bit unsigned integer. Both the BWA STS and the BWA BTS shall be able to correctly receive both the 8-bit and 24-bit codings of the IE Length field.

2.2.5. MAC Management / Control and Higher-Layer PDU Frame

MAC Management / Control and Higher-Layer PDU Frames are used to transport both MAC management / control messages and higher-layer PDUs between the BWA BTS and the BWA STS. For example, MAC Management / Control and Higher-Layer PDU Frames can used to piggyback request for bandwidth in the data PDU or to transport concatenated / fragmented data PDUs. The format of the MAC Management / Control and Higher-Layer PDU Frame is shown in Figure 7.

Protocol Type (3 bits)	Payload Type = 10	EH = 1	Checksum = 00	Length (16 bits)	Ext. Checksum (8 bits)	MAC Management / Control IEs and Higher-Layer PDU (variable length)

Figure 7. MAC Management / Control and Higher-Layer PDU Frame

2.2.6. Request MAC Frame

Note in Table 2 that a specific Frame Type encoding (Frame Type = 11) is used to indicate that that the content of the payload is a request. Request MAC frames are used to transport bandwidth requests for SIDs to the BWA

BTS during unicast or contention request opportunities. The format of the Request MAC frame is shown in Figure 8.

Protocol Type (3 bits)	Payload Type = 11	EH = 1	Checksum = 00	SID (16 bits)	Request (16 bits)	Ext. Checksum (8 bits)

Figure 8. Request MAC Frame

The 16-bit SID field indicates the SID for which bandwidth is requested. The 16-bit Request field indicates the amount of bandwidth requested for the SID (in mini-slots). The 8-bit Extended Checksum field is used to protect the Request MAC frame.

2.3. Upstream Bandwidth Allocation

The upstream channel is modeled as a stream of mini-slots. The BWA BTS must generate the time reference for identifying these slots. It must also control access to these slots by the BWA STSs. For example, it may grant some number of contiguous slots to a BWA STS for it to transmit a PDU. The BWA STS must time its transmission so that the BWA BTS receives it in the time reference specified.

The basic mechanism for assigning bandwidth management is the allocation map. The allocation map is a variable-length MAC management message transmitted by the BWA BTS on the downstream channel, which describes, for some interval, the uses to which the upstream mini-slots must be put. A given map may describe some slots as grants for particular stations to transmit data in, other slots as available for contention transmission, and other slots as an opportunity for new stations to join the link.

Many different scheduling algorithms may be implemented in the BWA BTS by different vendors. This specification does not mandate a particular algorithm.

The bandwidth allocation must include the following basic elements:

- Each BWA STS has one or more short (16-bit) SIDs as well as a 48-bit address.
- Upstream bandwidth is divided into a stream of mini-slots. Each mini-slot is numbered relative to a master reference maintained by the BWA BTS. The clocking information is distributed to the BWA STSs by means of SYNC packets.
- BWA STSs may issue requests to the BWA BTSs for upstream bandwidth.

The BWA BTS must transmit allocation map PDUs on the downstream channel defining the allowed usage of each mini-slot.

2.3.1. Requests

Requests refer to the mechanism that BWA STSs use to indicate to the BWA BTS that it needs upstream bandwidth allocation. A request may come as a stand-alone request frame transmission in a contention or unicast request opportunity, or it may come as a piggyback request in another frame transmission. The request must include:

- The SID making the request.
- The amount of bandwidth requested (in mini-slots).

2.3.2. Request Acknowledgement

Request Acknowledgement IEs acknowledge requests that have been received by the BWA BTS. A Request Acknowledgement IE is preceded by the Acknowledgement Time, which is the latest time (in mini-slots), from BWA BTS initialization, processed in the upstream. Request Acknowledgement IE contains the list of SIDs whose requests have been received by the BWA BTS up to the Acknowledgement Time, and after the Acknowledgement Time of the previous Request Acknowledgement IE.

2.3.3. Data Acknowledgement

Data Acknowledgement IEs acknowledge data PDUs that have been received by the BWA BTS. The BWA STS must have requested this acknowledgement within the data PDU. A Data Acknowledgement IE is preceded by the Acknowledgement Time, which is the latest time (in mini-slots), from BWA BTS initialization, processed in the upstream. Data Acknowledgement IE contains the list of SIDs whose data have been received by the BWA BTS up to the Acknowledgement Time, and after the Acknowledgement Time of the previous Data Acknowledgement IE.

2.3.4. Map Transmission and Timing

The allocation map must be transmitted in time to propagate across the wireless link and be received and handled by the receiving BWA STS. As such, it may be transmitted considerably earlier than its effective time. The components of the delay are:

- Worst-case round-trip propagation delay.
- Queueing delays within the BWA BTS – implementation-specific.
- Processing delays within the BWA STS – must allow a minimum processing time by each BWA STS.
- PMD-layer FEC interleaving.

2.3.5. BWA STS Bandwidth Utilization

The following rules govern the response a BWA STS makes when processing maps.

- A BWA STS must first use any grants assigned to it. Next, the BWA STS must use any unicast request opportunity for it. Finally, the BWA STS must use the next available broadcast/multicast request opportunity for which it is eligible.

2.4. Service Classes

Any service flow may have its QoS parameter set specified in any of three ways:

- By explicitly including all traffic parameters.
- By indirectly referring to a set of traffic parameters by specifying a service class name.
- By specifying a service class name along with modifying parameters.

A service class name is a string, which the BWA BTS associates with a QoS parameter set.

The service class serves the following purposes:

- It allows operators, who so wish, to move the burden of configuring service flows from the provisioning server to the BWA BTS.

- It allows BWA BTS vendors to provide class-based queueing if they choose to, where service flows compete within their class and classes compete with each other for bandwidth.
- It allows higher-layer protocols to create a service flow by its service class name.
- It allows packet classification policies to be defined, which refer to a desired service class, without having to refer to a particular service flow instance of that class.

2.4.1. Quality-of-Service Parameters

QoS parameters supported by this specification are listed in [1], Appendix C. Additional QoS parameters supported by this specification are Maximum Traffic Rate, Upstream Maximum Traffic Rate, Downstream Maximum Traffic Rate, Maximum Bit Error Rate, Upstream Maximum Bit Error Rate and Downstream Maximum Bit Error Rate.

2.5. Benefits and Drawbacks of the Proposed MAC Protocol

Benefits of the proposed MAC protocol are as follows:

- Bandwidth efficiency achieved due to:
  - Small MAC header overhead for fixed-size PDUs, such as ATM cells.
  - Support for variable-size PDUs, such as IP packets.
  - Bandwidth-efficient MAC messages.
- Support for transport of multiple protocols.
- Support for QoS, including bandwidth, latency and bit-error-rate guarantees.

Drawbacks of the proposed MAC protocol are as follows:

- Support for two MAC header size adds to implementation complexity.