Project	**IEEE 802.16 Broadband Wireless Access Working Group**
Title	**Proposed Amendments to 802.16.1mc-00/01 for MAC Layer to Include a Bandwidth-On-Demand MAC/PHY Sublayer**
Date Submitted	**1999-12-24**
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Re:	A proposed friendly amendment to 802.16.1-00/01 Media Access Control Protocol Based on DOCSIS 1.1, dated 1999-12-22.
Abstract	This document proposes a Bandwidth-On-Demand MAC Sublayer that provides a universal connectivity interface to 802 MAC and other higher-layer protocols. The approach provides simple methods of lowering system delay while minimizing delay variation and jitter. The proposed approach is to apply the techniques described first to other 802.16 proposed MAC layer protocols plus direct support for SDH/PDH and ATM applications through a single, standardized interface to convergence layers for these protocols.
Purpose	The purpose of this contribution is to propose additions to other 802.16 proposals that can provide enhanced capabilities for an 802.16 Broadband Wireless Access system.
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802.16 MAC Contribution: Proposed Amendments to Include a Bandwidth-On-Demand MAC/PHY Sublayer Option

1 Scope and Purpose

The scope of this contribution is to define a Bandwidth-On-Demand MAC Sublayer as a part of the IEEE 802.16.1 Air Interface protocol. This approach results in a better match to 802.16 requirements than can be result from using only packet-type PDU multiplexing protocols. It results in lower delay, delay variation, and jitter and is particularly important for low-speed compressed voice traffic, a rapidly growing part of communication network market. At this time, the proposal is submitted as a desirable option and not a mandatory addition.

The purpose of the proposed amendments is to produce Broadband Wireless Access systems that can support any MAC or higher-level protocol. The amendments result in performance that cannot be matched using either variable-length or large fixed-length PDUs as the basis of multiplexing information flows from a diverse set of information sources. Areas of greatest improvement include supporting information flows that result in:

- low transport delay,
- low delay variation,
- small, mathematically bounded, jitter,
- improved Quality of Service (QoS) attributes,
- error control that is tailored to specific service classes, and
- very efficient use of available system bandwidth.

1.1 Scope

1.1.1 Scope including a Bandwidth-On-Demand MAC Sublayer

The scope of this amendment is to define a Bandwidth-On-Demand MAC Sublayer with characteristics that enhance the competitiveness of Broadband Wireless Access systems. The major objective of the Sublayer is to dynamically allocate bandwidth to information flows that pass between the Base Station and the Subscriber Stations in a way that minimizes transport delay and jitter and, at the same time, use available RF bandwidth efficiently. Because of the simplicity of implementation of the sublayer, it is possible to produce a first generation 802.16 Air Interface which includes dividing Broadband Wireless Access system bandwidth into partitions, one to support variable length PDU-based MAC layer that is focused on IP and other packet-based services, and separate partitions for SDH/PDH and ATM traffic. These partitions are further divided into any number of data traffic channels each of which can be any integer multiple of some incremental bandwidth (such as 1 Kbps).

In addition to managing bandwidth partitioning, the Bandwidth-On-Demand MAC Sublayer controls messaging between the Base Station and Subscriber Stations related to not only bandwidth management, but also system operation. These messages are meant to complement and not replace protocol-specific messages that are a part of MAC and higher-level protocols connected to the top of the Bandwidth-On-Demand MAC Sublayer.

Included in this amendment is a draft Sublayer message structure with a few examples.

The items covered in the amendment relate to Bandwidth-On-Demand MAC Sublayer operation only. The section numbers conforms to the outline for 802.16, although some of the section titles have been changed slightly to improve naming consistency. Only those section numbers that pertain specifically to Bandwidth-On-Demand MAC Sublayer operation are included in this Amendment.

All sections of the 802.16 outline that do not occur in this document are assumed to conform to the specification of reference [1].

1.2 Requirements

The requirements satisfied by this Amendment include the following:

- Specify an Air Interface that supports a Bandwidth-On-Demand MAC Sublayer that, in turn, can support any digital network protocol.
- Specify a Bandwidth-On-Demand MAC Sublayer that requires minimum modification, if any, of proposed 802.16 MAC protocols, but is not limited to supporting other protocols.
- Specify a MAC Layer that can be controlled by messages sent from the Base Station to Subscriber Stations over a Common Signaling Channel.

1.3 Background

1.3.1 Service Goals

The primary service goals of this Amendment are to produce a Broadband Wireless Access Air Interface specification that:

- enables early implementation of interoperable Broadband Wireless Access systems,
- is based on an architecture that assures non-obsolescence of installed systems,
- outperforms existing wireline systems in terms of service quality and cost, and
- is simple to operate and maintain.

1.4 Definitions, Symbols and Abbreviations

Bandwidth-On-Demand circuit - The equivalent to a physical clocked connection over a communication link that is defined by a set of cell slots within a Time Division Multiplex frame dedicated to the connection. Unlike Time Division Multiplexing within conventional SDH/PDH networks, the number of cell slots allocated to the circuit can be changed in milliseconds or less to provide dynamic bandwidth-on-demand connectivity for the circuit.

Bandwidth-On-Demand Mode - A means for transmitting information over a clocked communication link where information related to a single connection is apportioned among cell slots of a Time Division Multiplex frame. Cell slots assigned to a single connection are spread approximately uniformly throughout the frame. The location of each cell slot within the frame is determined by a transformation algorithm that allows a traffic channel's bandwidth to be assigned in one logical domain (the Element Address domain) where the assigned cell slots for a connection are contiguous with one another. This logical representation is transformed into a second domain (the Ordinal Position Number domain) that denotes the physical location in time of each cell slot within a transmitted Time Division Multiplex frame.

Cell Slot – A primitive data element composed of a fixed number of bits into which a Time Division Multiplex frame is divided. Cell slots in one direction of transmission always contain the same number of bits and each cell slot contains data from a single logical information source.

Element Address - For a Time Division Multiplex frame containing ***F*** cell slots, an Element Address is a number between **0** and ***F* – 1** associated with each cell slot that can be used to assign cell slots to a Bandwidth-On-Demand circuit. Element Addresses are implemented so that a single Bandwidth-On-Demand circuit can be defined as a contiguous range of Element Addresses.

Ordinal Position Number - Within a Time Division Multiplex frame containing ***F*** cell slots, an Ordinal Position Number is a number between **0** and ***F* – 1** that denotes the physical (time) position of a single cell slot within a frame. For a Bandwidth-On-Demand circuit consisting of ***n*** cell slots, the Ordinal Position Numbers for the circuit are determined by an algorithm that transforms ***n*** contiguous Element Addresses into ***n*** nearly-uniformly-distributed Ordinal Position Numbers. Each Ordinal Position Number designates the physical cell slot location in time within a frame that belongs to the Bandwidth-On-Demand circuit.

2 Functional Assumptions

The Bandwidth-On-Demand MAC Sublayer interfaces with a Time Division Multiplex PHY layer stream of *cell slots*. Data from an information source is transmitted over a *Bandwidth-On-Demand circuit* which is defined by an assignment of cell slots designated by *Element Addresses* that are automatically translated into physical cell slot locations (*Ordinal Position Numbers*) within the Bandwidth-On-Demand MAC Sublayer / PHY Layer. Bandwidth-On-Demand circuits are connections that enable universal connectivity to any digital network protocol at the upper boundary of the Bandwidth-On-Demand MAC Sublayer.

3 Communication Protocols

3.2 The Bandwidth-On-Demand MAC Sublayer Forwarder

Figure 3-1 shows the location of the proposed Bandwidth-On-Demand MAC Sublayer and PHY Layer protocols. The interface to the Bandwidth-On-Demand MAC Sublayer to the next higher (adjoining) layers is standardized and includes only send and receive data, send and receive clock (passed through from the physical layer), and a common API that forwards messages over a Common Signaling Channel. In many cases, one or more additional framing signals from the PHY Layer can simplify packet and cell transfer, and can save bandwidth.

A standardized Bandwidth-On-Demand MAC Sublayer interface supports an 802.16 MAC convergence layer [1] and similar convergence layers for STM (SDH/PDH) and ATM protocols (among others). The MAC Sublayer is divided into partitions that support the various network protocols. Such protocols can include not only STM and ATM, but also packet-based services such as IP, Frame Relay and IPX directly although this capability is not being proposed as a part of the standard at this time. Those protocols shown in color (shaded) in Figure 3-1 are the principal consideration of this Amendment and its referenced companion documents.

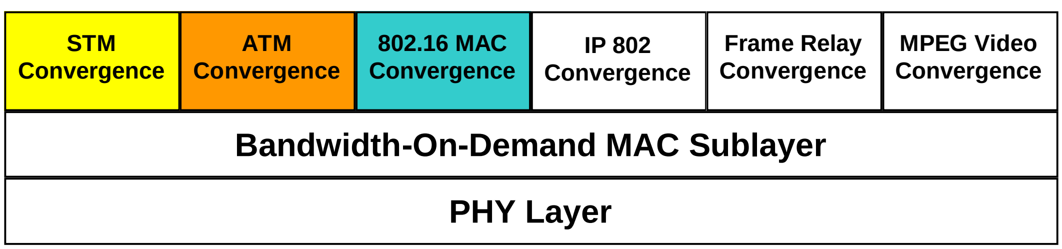

Figure 3-1 Some protocols that can be supported by a Bandwidth-On-Demand MAC Sublayer

3.3 Network Layer

There are two different ways to support network layer protocols. One is through a variable PDU-based multiplexing protocol such as DVB and DOCSIS; the other is to interface these protocols directly on top of a Bandwidth-On-Demand MAC Sublayer. Early market entry for 802.16-based systems is assured by supporting IP and certain other protocols using a PDU-based protocol. However, longer term, direct connection of all higher-level protocols to the Bandwidth-On-Demand MAC Sublayer results in the following benefits:

- More robust class-of-service support for information flows: class of service support is improved since bandwidth is easily allocated dynamically to information flows and aggregates of flows. Also, specified levels of error control can be assigned to each class of service.
- Greater potential for product differentiation among Broadband Wireless Access system vendors: product differentiation comes about from vendor-specific innovative higher-level protocol for Bandwidth-On-Demand MAC Sublayer convergence layers.
- More efficient use of available bandwidth: message sizes are reduced and there is almost no need to include stuff bytes in PDUs devoted to Broadband Wireless Access system operation. In addition, specifying only that amount of error control required for each class of service saves bandwidth since it is not necessary to control the entire system bandwidth to a single highest error control level required by any service.

The performance advantages are particularly significant for support of delay-critical and jitter-critical real-time applications such as voice, video and interactive multimedia. Design of convergence layers for most of these protocols are simple. Design for some packet-based protocols is somewhat more complex, but the performance improvement can be dramatic compared to current practice.

Although not a part of near-term 802.16 considerations, implementing interconnection of 802.16 Base Stations into a Metropolitan Area Network is particularly simple using the proposed Bandwidth-On-Demand MAC Sublayer.

3.5 Physical Layer

The operation of the Bandwidth-On-Demand MAC Sublayer is described in more detail in Section 4 of a companion 802.16 PHY contribution [2].

3.5.1 Downstream Transmission Convergence Sublayer

The downstream transmission convergence sublayer between the Bandwidth-On-Demand MAC Sublayer and the PHY Layer is used to map cell slots coming from the higher layers into a Time Division Multiplex frame structure that sends information imbedded in cell slots over the air in nearly uniformly-spaced time increments.

The PHY Layer for *downstream* transmission consists of a set of cell slots each of which contains a fixed number of bits. These cell slots are configured into Time Division Multiplex frames that are partitioned into three parts. These are:

- synchronization cell slots to establish the Time Division Multiplex frame boundaries,
- cell slots devoted to a Common Signaling Channel that passes messages from the Base Station to all Subscriber Stations, and
- all remaining cell slots, which are devoted to passing traffic from the Base Station to the Subscriber Stations.

The Base Station dynamically assigns cell slots to the Subscriber Stations for upstream transmissions; there is no need for allocating frame synchronization cell slots upstream. There can be a Common Signaling Channel for upstream Subscriber Station transmissions. In this case, the Base Station grants a Subscriber Station a defined amount of transmission capacity on an as-needed case-by-case basis. In addition, there is a need for allowing inactive Subscriber Stations to request bandwidth allocations from the Base Station. This is achieved using a combination of poll bits and a contention mechanism described in the 802.16.1 Air Interface PHY specification [1].

3.6 Above the Network Layer

3.6.1 Effects of Bandwidth-On-Demand MAC Sublayer on Layers above the Network Layer

Subscribers are able to use the capability of a basic 802.16 packet-based protocol (such as that based on DOCSIS and DVB protocols) as a bearer for higher-layer services. In addition, the Bandwidth-On-Demand MAC Sublayer allows optional high-performance bandwidth-on-demand transparent connectivity as a bearer for higher-layer services.

5 Media Access Control Layer with Bandwidth-On-Demand Sublayer

5.1 Bandwidth-On-Demand MAC Sublayer Reference Model

The proposed MAC/PHY Sublayer protocol is based on the ability to assign bandwidth assignments in two domains — one logical (at the MAC Sublayer) and one at the (physical) time domain (PHY) layer. A simple transform translates logical domain assignments into time domain assignments with the PHY Layer Time Division Multiplex frame.

Figure 5-1 shows a suggested first approach for the 802.16 Broadband Wireless Access Air Interface standard. It shows the logical (Element Address) domain bandwidth assignments at the Bandwidth-On-Demand MAC Sublayer. In this approach, the MAC Sublayer supports not only a PDU-based 802.16 protocol such as [1], but also any combination of SDH/PDH, Voice and ATM protocols. In addition to Framing and Common Signaling Channel partitions of the MAC Sublayer frame (that are always present downstream in any Bandwidth-On-Demand MAC Sublayer implementation), only two dynamically assigned information partitions are mechanized — one for the 802.16 MAC [1] and one for STM and ATM traffic. The 802.16 MAC partition is implemented as a single Element Address partition, while the STM partition is divided into subpartitions and channel ranges supporting clocked traffic channels. The amount of bandwidth assigned to framing and the Common Signaling Channel is of the order of two or three percent of the total bandwidth. This approach provides excellent quality (low delay and minimal bounded jitter) for STM and ATM traffic and good bandwidth efficiency.

FIGURE 5-1 EXAMPLE OF ELEMENT ADDRESS ASSIGNMENTS FOR SUPPORTING DOCSIS, CBR, VOICE AND ATM CHANNELS

The approach relieves designers from dealing with the complexity of supporting isochronous and plesiochronous traffic over an asynchronous multiplexing mechanism. It can form the basis of adding services such as those shown in Figure 3-1 and future protocols from the IETF, ITU, ISO and IEEE yet to be developed. Convergence layers for higher level protocols are simple to design since the standard Bandwidth-On-Demand MAC Sublayer interface consists of only three items: serial send and receive data channels, serial send and receive clocking channels, and a standardized API.

Most network traffic consists of information flows. Detecting and managing flows at the MAC layer within a Broadband Wireless Access Bandwidth-On-Demand MAC Sublayer environment is vendor specific and represents a rich area for product differentiation.

5.2 Bandwidth-On-Demand MAC Sublayer Concept

The relationship between the convergence layers of Figure 3-1 and the Bandwidth-On-Demand MAC Sublayer is illustrated schematically in Figure 5-2. Requests for bandwidth assignments are passed from a convergence layer to the Base Station and Subscriber Station Controllers. The function of the Base Station Controller is to send memory map information over the Common Signaling Channel to Subscriber Stations and synchronize their map changes with those at the Base Station. A Subscriber Station Controller responds to Base Station messages and implements map changes locally. The stations also format system operational messages including station acquisition and ranging, synchronization, signal monitoring, network management and other support functions independent of convergence layers. The Base Station Controller alone is responsible for all bandwidth allocations, both downstream and upstream including all data transfer and system operational messages. It is responsible for arbitrating competing quality demands (requests for bandwidth) among requests from various services according to service rules established by the network operator.

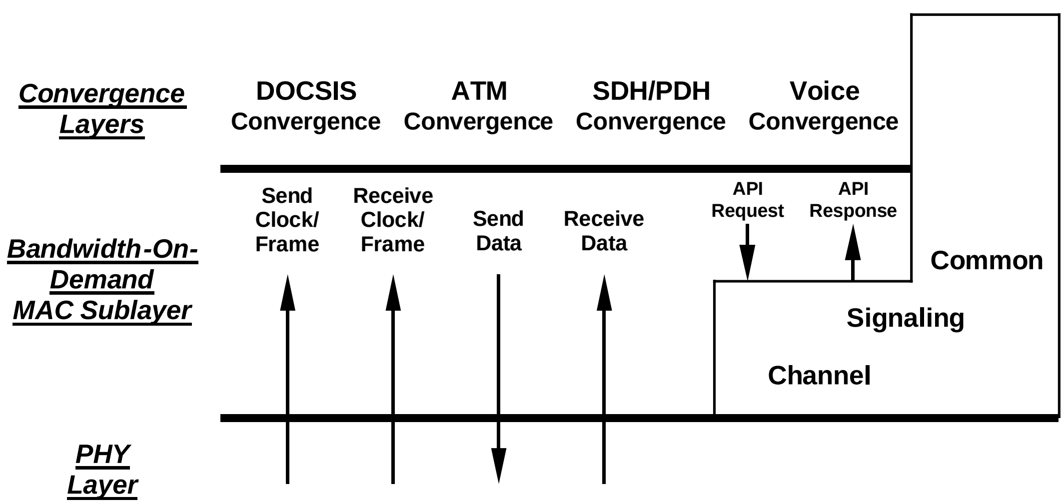

FIGURE 5-2 SCHEMATIC DIAGRAM OF THE BANDWIDTH-ON-DEMAND MAC LAYER AND PHY LAYER

A Subscriber Station Controller is responsible for formatting messages that are to be passed to the Base Station for the Base Station's action. The Subscriber Station must send these messages only when directed to do so by the Base Station using upstream bandwidth that the Base Station has allocated for the purpose. These messages are either requests for services, status information or operational support messages.

In response to Base Station messages, PHY Layers in both the Base Station and the Subscriber Stations set up bandwidth for signals to be passed across the Bandwidth-On-Demand MAC Sublayer / PHY Layer interface. Data flows are clocked by signals generated within the PHY Layer. Both send and receive primitive data elements (bytes, except under unusual circumstances) are made available by either:

1) the MAC Sublayer (for Send Data) or by
2) the PHY Layer (for Receive Data).

Framing information is often embedded within the clocking signals to denote the start of PDUs (packets or cells) for packet- and cell-based traffic. Using this method saves bandwidth compared to conventional asynchronous PDU framing approaches.

5.2.1 Relationship Between Higher Layers and Bandwidth-On-Demand MAC Sublayer Protocol

All convergence layers pass bandwidth control information across a standardized API interface. Most, if not all, of the protocol primitives for this API already exist within current network protocols. Perhaps those based on a small subset of Asynchronous Transfer Mode (ATM) methods are particularly relevant, although specific elements of both IP-based networks and those based on SS7 signaling are important.

5.2.2 Relationship Between Physical Layer and Bandwidth-On-Demand MAC Sublayer Protocol

The Bandwidth-On-Demand MAC Sublayer controls many of the PHY layer characteristics. The Base Station dynamically controls the upstream burst timing; transmit power and pre-equalization filter coefficients (if needed) via downstream Common Signaling Channel messages. This allows the Base Station to adjust each Subscriber Station's bursts to achieve precise burst arrival timing and signal amplitude at the Base Station, to minimize interference from neighboring cells, to minimize multipath effects, and to optimize demodulation efficiency.

The proposed downstream message stream consists of messages that are multiples of four bytes in length, aligned with the Time Division Multiplex frames. In other words, a four-byte message segment always begins with the start of a Time Division Multiplex frame and each subsequent four-byte segment follows contiguously. The Common Signaling Channel is set up so that it always contains an integer number of four-byte segments per Time Division Multiplex frame. The message format, sent over the Common Signaling Channel, is shown in Section 5.3.3.1.

5.2.2.1 Downstream transmission

For Frequency Division Duplex (FDD) operation where the Base Station transmits continuously, the requirements for the physical layer are particularly simple. For Time Division Duplex (TDD) operation, the situation is only slightly more complex. In TDD operation, frame synchronization must be re-acquired by each Subscriber Station for each downstream transmission, whereas in FDD operation, frame synchronization need only be acquired once and synchronization tracking is all that is required thereafter. Another minor system complication exists in TDD operation within convergence layers above the Bandwidth-On-Demand MAC Sublayer. The effects of jitter caused by the discontinuous transmissions (both upstream as well as downstream) must be managed by buffers within these convergence layers both at the Base Station and at Subscriber Stations.

A Time Division Multiplex frame whose size is system-configuration dependent is defined to support all data rates to be supplied to upper layer protocols. It is not necessary to specify specific data rates. Rather, all that is required is to specify the increment of bandwidth (defined as the *Base Incremental Bandwidth*) that is the largest integer sub-multiple (Greatest Common Divisor) of every data rate to be supported.

In many cases, the configuration need be defined only at system installation. However, a first system configuration, as an option, can be changed under software control after a system has been installed and operational. (Details for this method of operation are to be defined.) In other words, frame size parameters need only be changed when a new Base Incremental Bandwidth must be implemented that is not an integer multiple of the extant configuration.

Definition of frame sizes required and other relevant matters are discussed in Sections 4.3.3 and 4.4.2.2 of [2].

5.2.2.2 Cell Slots

All Time Division Multiplex frames are divided into cell slots. Small cell slot sizes are preferred as there is a direct linear relationship between cell slot size and system latency. The larger the cell size, the greater is the latency.

In Time Division Multiplex frames, a single data channel is assigned cell slots that are nearly uniformly spaced throughout a Time Division Multiplex frame. For a given channel data rate, the number of cell slots required within a frame is inversely proportional to the size of the cell slot. As a result, the larger the cell slot, the fewer number of cell slots required to support a particular data rate. The fewer the number of cell slots spaced throughout a frame, the greater the period between each successive cell slot; hence, the greater the latency for that channel. This effect is illustrated in Figure 5-3.

In distribution networks such as Broadband Wireless Access systems, latency must be kept to a minimum, i.e., of the order of one millisecond[1].

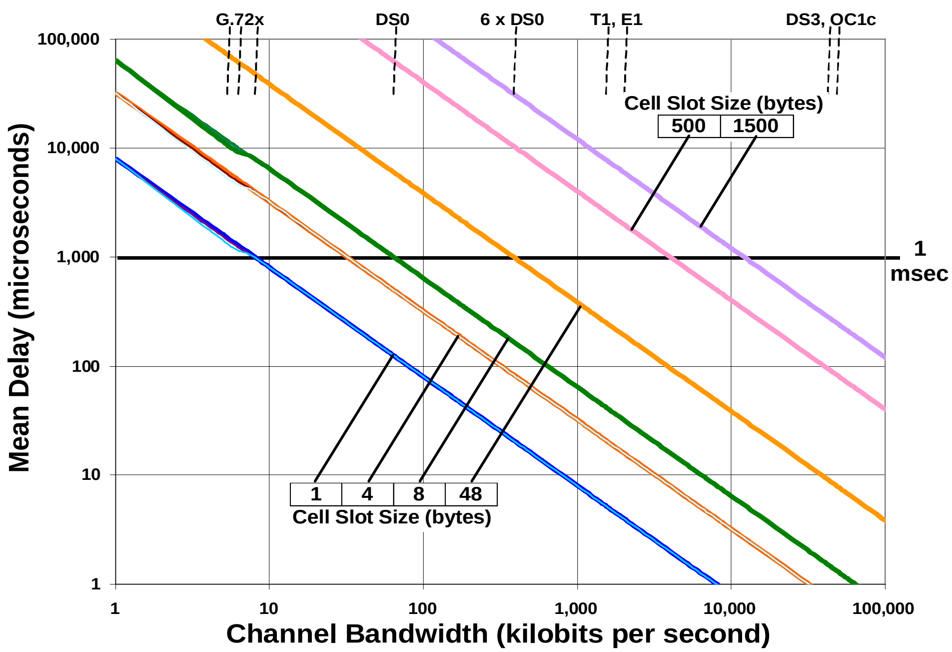

FIGURE 5-3 MEAN DELAY (MICROSECONDS)
VERSUS DATA CHANNEL BANDWIDTH (KILOBITS PER SECOND)
FOR VARIOUS CELL SLOT SIZES (BYTES)

For Broadband Wireless Access applications limited to distributing high bandwidth data channels (for example, 384,000 bps and higher), ATM size cells are adequate. This is one reason that ATM-based systems have found favor early in the Broadband Wireless Access market since most customers have focused on distribution of Constant Bit Rate channels at high speeds. As the Broadband Wireless Access market matures, this situation is changing. Particularly this is true when attempting to penetrate the residential market. Because of the explosive growth in the

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[1] A one-millisecond mean delay obtains from an 8,000 bps channel using a one-byte cell slot size. From this single example, one can easily calculate the latency for various channel data rates and cell slot sizes. For example, the mean delay for an ATM cell slot size (48 bytes) and an 8,000 bps channel is 48 milliseconds. The minimum channel speed to achieve one millisecond delay or less using an ATM cell slot size is 384,000 bps.

cellular telephone market, it is very likely that very low speed channels defined by ITU Recommendation G.723, G.729, and others will become a requirement. It will be difficult to support this market efficiently with high quality service without implementing small cell slot sizes uniformly distributed in time.

Fortunately, for downstream transmissions using a cell slot size of one byte is easily implemented so that the mean delay for any channel is small even for very low bandwidths as shown in Figure 5-3. For upstream transmissions, cell slot sizes of the order of 4 to 8 bytes are viable even for compresses voice channels.

5.2.2.3 Upstream Transmission

The approach proposed is to define each upstream burst as a cell slot that is assigned by the Base Station to a single data channel. An attractive alternative that is available for Subscriber Stations that carry a large amount of traffic is to aggregate multiple data channels into a single “pipe”, the logical equivalent of an ATM Path. In this case, the mean delay can be much smaller, particularly for low speed channels, since inter-cell-slot periods (that determine latency) are spaced much more closely together than would be the case where each data channel is assigned its own cell slot set.

5.3 Medium Access Control Specification

5.3.1 Introduction

This Amendment focuses on partitioning available bandwidth of a Broadband Wireless Access system that can support DOCSIS 1.1 capability as it is defined for an all-DOCSIS approach, as it has been modified for the 802.16 Air Interface standard [1], and concomitantly supporting services described in Section 5.1 that are difficult to support using DOCSIS alone.

This section describes details of the Bandwidth-On-Demand MAC Sublayer.

5.3.1.1 Overview

In this Amendment, the Bandwidth-On-Demand MAC Sublayer enables rapid setup and clearing of data channels. Initial implementations are proposed to focus on assigning bandwidth to clocked network protocols although asynchronous protocols can be supported as well. The bandwidth management capability is implemented by Common Signaling Channel Controller over the Broadband Wireless Access downstream Common Signaling Channel. Descriptions of message protocols appear in Section 5.3.4.

In this Amendment, it is assumed that the total Broadband Wireless Access bandwidth is partitioned into two major parts, one solely focused on DOCSIS forwarding and one on all other protocols can allow early implementation of higher performance Broadband Wireless Access systems than can result from an all-DOCSIS approach.

5.3.1.2.3 Service Flows

The concept of Service Flows is central to the operation of the Bandwidth-On-Demand MAC Sublayer protocol. Service Flows provide a mechanism for upstream and downstream Quality of Service management. In particular, they are integral to bandwidth allocation.

As in the DOCSIS specification, a *Service Flow ID* (SFID) defines a particular unidirectional mapping between a Subscriber Station and the Base Station. Each active Upstream Service Flow ID also has an associated *Service ID* (SID). Upstream bandwidth is allocated to Service IDs, and hence to Subscriber Stations, by the Base Station. Service IDs provide the mechanism by which upstream Quality of Service and associated bandwidth allocation is implemented.

The Base Station MAY assign one or more Service Flow IDs to each Subscriber Station, corresponding to the Service Flows required by the Subscriber Station. This mapping can be negotiated between the Base Station and the Subscriber Station during Subscriber Station registration or via dynamic service establishment.

In a basic Subscriber Station implementation, two Service Flows (one upstream, one downstream) can be used.

Even in complex Subscriber Stations, it is necessary to be able to send upstream packets needed for MAC Layer management, SNMP management, key management, etc. For the network to function properly, all Subscriber Stations must support at least one upstream Service Flow. One Service Flow, (called the upstream Primary Service

Flow in DOCSIS), is provisioned for each station. Primary Service Flows is always provisioned to allow the Subscriber Station to request and to send a defined amount of information (refer to Section 5.3.3.2).

The Primary SID is always assigned to the first provisioned upstream Service Flow during the registration process (which may or may not be the same temporary SID used for the registration process). The Primary Service Flow is immediately activated at registration time and is always used for station maintenance after registration. All Service Flow IDs are unique within a single Bandwidth-On-Demand MAC-sublayer domain. The length of the Service Flow ID is 32 bits. The length of the Service ID is 14 bits.

5.3.1.2.4 Cell Slots and System Time

A cell slot is the unit of granularity for upstream transmission opportunities. A single cell slot's duration in time is determined by the modem design. The minimum cell slot size is 16 symbols and alternative cell slot sizes of 32, 64, 128, and 256 symbols can be supported (to be reviewed). These sizes using QPSK modulation are equivalent to 4, 8, 16, 32 and 64 bytes. These cell slot sizes represent "raw" transmitted bits; that is, they do not include error correction bits.

5.3.1.2.5 Time Division Multiplex Frames

Time Division Multiplex Frames are configured as described in 4.4.2.2 of [2]. A set of standard configurations may be defined to enable simple setup methods.

5.3.1.3 Future Use

Certain fields within Bandwidth-On-Demand MAC Sublayer messages may be reserved for future use. (TBD)

5.3.3 Bandwidth-On-Demand MAC Sublayer Message Formats

This section contains draft material that is subject to review and change. The purpose of the section is to suggest some of the possibilities available and not propose a definitive approach.

5.3.3.1 Generic Bandwidth-On-Demand MAC Sublayer Message Format[2]

Bandwidth-On-Demand MAC Sublayer message packets are used for only one purpose — to transfer both downstream and upstream messages. The proposed basic format for a message fragment is shown in Figure 5-4. Compared to conventional packet-based messaging systems, there are two major differences. These are:

1. message packet sizes are short, and
2. packet boundaries can coincide with subframes within a larger Time Division Multiplex system frame.

A message fragment can be 4, 8, 16, 24, or 32 data bytes (TBD). Each fragment begins with an extra framing (FC) bit that designates whether the bits that follow in the fragment are the beginning of a message, or a continuation of a message delineated by previous fragment(s).

FC	**4, 8, 16, 24 or 32 bits (TBD)**

FIGURE 5-4 POSSIBLE BANDWIDTH-ON-DEMAND MAC SUBLAYER MESSAGE FRAGMENTS

A 4-byte (32 bit) message format has been chosen as a recommended first choice as it seems to result in efficient use of bandwidth compared with the larger alternatives. The overhead consumed by extra framing bit (33^{rd} bit) is about 3% plus possible pad bytes at the end of a string of fragments. The advantage of a 4-byte fragment size is that the number of pad bytes required, even for large messages is small (which, for random-sized messages would be 1.5 bytes).

The FC bit shown in the figure is a message-framing bit. It is set to **0** if the fragment is the start of a message and set to a **1** if the fragment is a continuation of a message. To find message start times, it is only necessary look at the

[2] The approach described in the section assumes that a very robust Forward Error Control mechanism is implemented for the Common Signaling Channel Element Address partition (of the order of 10^{-11} BER or better). A recovery mechanism will exist when this error rate has not been met and will be described at a later time.

fixed possible FC bit locations (which start as the first bit in the Common Signaling Channel frame and continue every 33rd bit).

Note: In the case of 32-plus-1-bit fragments, a Time Division Multiplex frame that is 284 bits long (33 bytes) contains exactly 8 33-bit fragments. In other words, a 264-bit frame supports 8 4-byte Common Signaling Channel message fragments. As long as a Common Signaling Channel frame contains an integer multiple of 264 bits (33 bytes), fragments will always exactly fill the allocated bandwidth.

This analysis does not include the requirement for Error Correction overhead. It is assumed (for the time being) that a Forward Error Correction coding method is applied to all downstream and upstream Common Signaling Channel transmissions that result in error rates of 10^{-11} or less and that the probability of an undetected error occurring within a 1 msec (or, some other period to be determined) by a station is 10^{-12}. This latter constraint represents an error occurring per station once every 31.7 years, or, for a 1,000 Subscriber Station system, one error occurring within the system once every 11.6 days.

Note: An alternative to the format of Figure 5-4 is to make the entire fragment an integer number of bytes including the FC bit. The FC bit would then be the first bit of the first byte within the fragment. This becomes an implementation issue and is open for discussion. The advantage of the method shown is that the message part of the fragment can make use of existing signaling formats currently used in other network protocols (DOCSIS, ATM, IP and SS7).

5.3.3.1.4 Bandwidth-On-Demand MAC Sublayer Message Format

Bandwidth-On-Demand MAC Sublayer Messages are based largely on DOCSIS message protocols for clarity. Station operation messages currently proposed as a part of a DOCSIS-only based 802.16 standard [1] are routed over the Bandwidth-On-Demand MAC Sublayer Common Signaling Channel instead of being sent directly to Subscriber Stations. All other DOCSIS messages relating to traffic management in the proposed 802.16 standard [1] are contained in messages sent over the bandwidth partition dedicated to the DOCSIS-based traffic.

A suggested basic Bandwidth-On-Demand MAC Sublayer Message Header Format is shown in Figure 5-5

FC	**Byte 1**	**Byte 2**	**Byte 4*n***	FC

FIGURE 5-5 GENERIC BASIC BANDWIDTH-ON-DEMAND MAC SUBLAYER MESSAGE

Bandwidth-On-Demand MAC Sublayer Message Frames are delimited by two FC bits. Using the suggested fragment size, a Bandwidth-On-Demand MAC Sublayer Message Frame is 4***n*** bytes long, where ***n*** is the number of fragments in a frame. Using the FC bits in this way saves one bit within a message itself that would be devoted to denoting whether a the message has an extended header format that requires more than a single fragment.

There are number of message formats required for Bandwidth-On-Demand MAC Sublayer operation. These include the following:

There is at least one Bandwidth-On-Demand MAC Sublayer message that makes use of a single 4-byte fragment. This is Data Channel Allocation message shown in Figure 5-6.

2 bits	**14 bits**	**8 bits**	**8 bits**
Type	**SSID**	**Bandwidth**	**Start**

FIGURE 5-6 BANDWIDTH ALLOCATION BANDWIDTH-ON-DEMAND MESSAGE

The Type field is 2 bits long. Bit pattern **00** designates a downstream bandwidth allocation message. A bit pattern **01** designates an upstream flow. The Bandwidth-On-Demand MAC Sublayer Service ID (SSID) field is 14 bits long. It is used to identify both upstream and downstream flows. (Note: The SSID field is not the same as the DOCSIS SID. DOCSIS SIDs can be defined independent of Bandwidth-On-Demand MAC Sublayer SSIDs.)

As in DOCSIS, each SSID is defined by a Type/Length/Value (TLV) packet. The SSID value may or may not be the same in the upstream and downstream directions. Associated with each SSID is a service type designation. Service types include a number of service parameters including the Base Incremental Bandwidth for the service. For example, the Base Incremental Bandwidth for SDH/PDH services may be a DS0 isochronous data channel where the Base Incremental Bandwidth is stated in terms of number of cell slots per frame. The Base Incremental Bandwidth for a full ATM cell flow would be 53 bytes per frame in most cases, although it could be an integer number times this amount for very high speed services. The Base Incremental Bandwidth for a headerless ATM cell slow would be 48 bytes per frame.

For the DOCSIS partition, the Base Incremental Bandwidth could be some integer multiple of a DS0 rate.

Also associated with each SSID is a Service Partition Identifier of the Element Address in which service flows are assigned.

The reason for this approach is that it enables, in most cases, using the short Bandwidth Message Allocation format shown in Figure 5-6. There can be cases where the range of bandwidths and number of Element Address start locations to be supported are greater than 255. In these cases, an extended header format is required. Type designations **10** and **11** are reserved for downstream and upstream message formats respectively.

An extended Bandwidth Message Allocation format would consist of two message fragments and the Bandwidth and Start would be doubled in size as shown in Figure 5-7.

2	14	16	16	16
Tp	SSID	(reserved)	Bandwidth	Start

FIGURE 5-7 EXTENDED FORMAT BANDWIDTH ALLOCATION BANDWIDTH-ON-DEMAND MAC SUBLAYER MESSAGE

The 16 reserved bits may be used to modify the meaning of the Bandwidth and Start Element Address fields. For example, they may become total number of cell slots allocated per frame rather than number of Base Incremental Bandwidth.

5.3.3.2.1 Variable-Length Packets

Variable length packets in the initial version of the 802.16 option are supported over the DOCSIS partition [1].

5.3.3.2.2 ATM Cell and Fixed Length Packet Support

One important aspect of the Bandwidth-On-Demand MAC Sublayer approach is the fact that fixed-length multiple-byte PDUs can be lined up with Time Division Multiplex frames and subframes. A good example of this is supporting ATM. Depending on the applications; ATM may be supported as 48, 49, 52 or 53 byte PDUs. In the 48-byte case, no header information need be supplied as all cells conform to a header that need be sent once in a Bandwidth-On-Demand MAC Sublayer message at the time that a flow is established. 49-byte PDUs carry a minimal amount of ATM header information needed in some cases while 52-byte PDUs carry all ATM header information with the exception of the Header Error Control (HEC) byte. The 53-byte PDU is, of course, the full ATM cell.

Element Address partitions can be set up for each of these classes. Each partition contains an integer number of cell slots tied to the fixed length of the PDUs to be supported. For example, in the downstream case, suppose that the Time Division Multiplex frame period is 8 milliseconds and that it is desired to support 49-byte ATM cells. In this case, an Element Address partition would set up that would be an integer multiple of 49 cell slots long. Since, in the downstream case, the cell slot size is 1 byte, each Element Address range within the partition would be 49 bytes long. The Base Incremental Bandwidth would be 49,000 bps ($8 \times 49 \times 1{,}000/8$). If the ATM signal source is not synchronized with the ATM source and only the Base Incremental Bandwidth is assigned to the channel, the mean delay to start transmitting the ATM cell would be 4 msec (8/2) and the time to transmit the entire cell is 8 msec [3]. If, for example 10 Base Incremental Bandwidth units are assigned to the channel, the time to transmit an entire cell is 800 µsec. A Bandwidth-On-Demand MAC Sublayer Message designates the first cell slot boundary within a frame that lines up with an ATM cell so that it is not necessary to wait for an entire Time Division Multiplex frame to occur before traffic is sent. In this case, the average wait time would be 400 µsec unless the ATM traffic source is synchronized with the Time Division Multiplex framing structure, in which case the wait time would be zero.

A similar approach can be used for fixed length packets or fixed-length fragments thereof. For example, suppose it is desired to support 1,518-byte packets over the same frame size. One way to do this is to assume that each packet

[3] The mean inter-cell-slot time is 163 µsec which relates to the transport delay for the ATM cell. ATM cells are not stored within the Bandwidth-On-Demand MAC Sublayer.

is padded out to a length of 1,520 bytes. Since 1,520 = 16×95, each packet fragment could be 95 bytes long. The beginning of a packet could be aligned with a Time Division Multiplex frame or any fragment start time that is designated in a Bandwidth-On-Demand MAC Sublayer Message. This approach eliminates the need for packet or fragment framing bytes. For the 8 msec Time Division Multiplex frame period, the Base Incremental Bandwidth is 95,000 bps. If this incremental bandwidth is assigned to carry the packet, the mean transport delay for the entire packet is (not counting buffering or waiting for a frame time to arrive) 128 msec.

8-byte extended message formats can be used for designating the relevant start times for both the ATM fixed cell size and the packet fixed length cases.

In the upstream direction, the same mechanism is used. Since cell slots sizes are larger (e.g., 8 bytes), frame times are usually set to be longer than is the case in the downstream direction. For example, for 8-byte cell slots, a frame time of 64 msec maintains the 1,000 bps Base Incremental Bandwidth. The grant structure for assigning bandwidth remains the same (since bandwidth grants all originate at the Base Station). However, upstream messages denoting fixed length packet and cell start times become even more important than in the downstream case if delay is to be minimized. These messages are passed as conventional packets with appropriate error control procedures. These will be defined later.

5.3.3.5 Extended MAC Headers

Described in Section 5.3.3.1

5.3.3.5.3.1 Payload Header Suppression Header

Follow DOCSIS practice

5.3.3.5.3.2 Unsolicited Grant Synchronization Header

Combined with flow mechanism

5.3.3.6 Fragmented MAC Frames

Described in 5.3.3.2.2

5.3.6 Quality of Service and Fragmentation

5.3.6.1 Theory of Operation

Bandwidth for each data channel or aggregation of channels of the same type is made in the logical Element Address domain. These Element Addresses are then translated into physical cell slot Ordinal Position Numbers that denote a cell slot's exact position within a Time Division Multiplex frame. There are a number of simple ways to implement the transformation between the logical and physical domains. The key point of the approach is to be able to assign data channels in an Element Address domain in contiguous cell slot order and transform these assignments into physical cell slot that are nearly uniformly spaced, thereby minimizing channel latency and jitter.

FIGURE 5-8 ELEMENT ADDRESS DOMAIN BANDWIDTH-ON-DEMAND MAC SUBLAYER CHANNEL ASSIGNMENTS EXAMPLE (DOWNSTREAM)

Although there are several different ways to aggregate traffic in the Element Address domain, the one shown in Figure 5-8 has advantages. All Bandwidth-On-Demand MAC Sublayer data channels are grouped according to their anticipated flow persistence. Those channels with the longest persistence are placed toward the beginning and toward the end of the Element Address domain frame. The leftmost Element Address in the figure market "Fr" designates framing cell slots that are infinitely persistent. In other words, the framing Element Address range is configured before a system is put into operation. In like manner, a Common Signaling Channel (CSC) is predefined as a part of a specific system configuration. This is a fixed amount of bandwidth that is assigned for the purpose of sending messages from the Base Station to each Subscriber Station. Both Framing and a persistent Common

Signaling Channel exist in the downstream direction only. Upstream frame synchronization is accommodated by ranging each Subscriber Station during its registration and turn-on process. An upstream Common Signaling Channel is shared among Subscriber Stations under control of the Base Station.

Shown in the figure are Constant Bit Rate (CBR) channels, voice channels and Variable Bit Rate (VBR) channels all of which have relatively long persistence. Available Bit Rate (ABR) and Undefined Bit Rate (UBR) channels have relatively short persistence so that bandwidth changes occur relatively frequently.

There are two classes of ABR channels shown in the figure. This can be the case where two different QoS classes need be defined for asynchronous traffic, a capability of increasing importance to Internet applications.

Conclusions

This contribution has outlined an approach to providing a Bandwidth-On-Demand MAC Sublayer that enhances the value of Broadband Wireless Access systems. It is proposed that this capability be included within the 802.16 Air Interface specification. To make it complete, it is proposed that the capability be added to another 802.16 such as that provided in reference [1].

The benefits of the approach include minimizing transport delay, delay variation and jitter for all 802.16 traffic. This is most important for time-sensitive applications that are an increasingly large proportion of modern communication system requirements. Video and interactive multi-media are replacing delay-insensitive data applications of the past. Compressed voice transmissions are becoming a larger and larger proportion of voice traffic emphasizing the importance of low transport delay for low-speed applications.

The proposed approach is agnostic to high-level user and network protocols, thereby assuring that systems built on a standard that includes the Bandwidth-On-Demand MAC Sublayer will not become obsolete.

References

[1] 802.16.1mc-00/01: Media Access Control Protocol Based on DOCSIS 1.1, dated 1999-12-23.

[2] 802.16.1mc-00/xx: Proposed Amendments to 802.16.1pc-00/02 for a PHY Layer to Include a Bandwidth-On-Demand MAC/PHY Sublayer Option, dated 1999-12-24.

[3] 802.16s-99/00r1: 802.16 Functional Requirements, Rev. 1, dated 1999-12-17.

[4] 802.16mc-99/01 and 802.16mp-99/01: System Requirements Assuring That Point-to-Multipoint Broadband Wireless Access Networks Are Agnostic to User and Network Protocols, dated 1999-06-30 and 1999-11-11.

[5] 802.16mc-99/11 and 802.16mp-99/11: A Proposed Approach to Defining an Interoperable MAC/PHY Layer Scheduler for 802.16, dated 1999-10-29 and 1999-11-11.

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Evaluation Table - Session #5

(This table includes only those areas where there are substantial changes or additions to the table in Appendix J MAC Evaluation Table included in 802.16.1mc00/01)

#	Criterion	Discussion
1	Meets system requirements	*How well does the proposed MAC protocol meet the requirements described in the current version of the 802.16.1 Functional Requirements? (See Document IEEE 802.16s-99/00).* See 802.16mc00/01. In addition, the Bandwidth-On-Demand MAC Sublayer allows meeting the functional requirements with better delay and jitter characteristics than can be achieved with a PDU-based scheduling system alone.
2	Mean access delay and variance	*How effective are the mechanisms presented in controlling the delay and variance?* See 802.16mc00/01. Using the Bandwidth-On-Demand MAC Sublayer significantly reduces access delay and delay variance compared to other known MAC approaches *Does it seem possible for an operator to offer a bounded delay for a prescribed offered load?* Absolutely! This is a major attribute that is a characteristic of including the Bandwidth-On-Demand MAC Sublayer
3	Payload and bandwidth efficiency	*1. How well does the overhead due to the proposed MAC PDU headers allow for efficient user data transfer over the air interface?* All DOCSIS services included in 802.16mc00/01 are available. A number of these are efficiently handles using the Common Signaling Channel provisioned as a part of the Bandwidth-On-Demand MAC Sublayer. It provides a bandwidth-efficient means of supporting messaging between the Base Station and Subscriber Stations. *2. Is the proposed MAC protocol designed such that the MAC signaling is efficient in terms of not requiring excessive overhead?* Yes. Particularly with the addition of the Common Signaling Channel. *3. How well does the proposed MAC protocol provide the mechanisms for fair allocation and sharing of the bandwidth among users? (Please include payload example.)* In addition to DOCSIS supported services, the Bandwidth-On-Demand MAC Sublayer allocates bandwidth with small granularity and low delay to any provisioned service. Fragmentation in the downstream direction spreads bytes nearly uniformly throughout a Time Division Multiplex frame. (In the upstream direction small fixed-size transmission bursts are nearly uniformly distributed.) A specific example is included in the Section 4.4.2.2 of a companion PHY contribution (Reference [2]) submitted on 1999-12-24.
4	Simplicity of implementation/low complexity	*How well does the proposed MAC protocol allow for an implementation that is simple and generic enough that it is likely to be accepted by industry?* Providing the Bandwidth-On-Demand MAC Sublayer involves only simple-to-implement algorithms that are expected to be readily accepted by the industry.
5	Scalability	*Does the MAC protocol support a broad range of operational bandwidths and number of connections across all services?* The Bandwidth-On-Demand MAC Sublayer can support ***any*** operational bandwidth. All that is required is sizing a supporting Time Division Multiplex frame so that the frame rate is the Greatest Common Divisor (GCD) of all desired data rates (taking into account the chosen cell slot size). Frames can be made very long without compromising either system reliability or delay characteristics.
6	Service Support Flexibility	*1. How completely does the MAC protocol support the services mentioned in the 802.16.1 Functional Requirements?* Many services can be supported through the proposed DOCSIS bandwidth partition. In addition ***any*** user or network protocol can be supported through a convergence that, for STM and ATM services (among others) are simple to implement. *2. How well does the MAC protocol support additional services?* The Bandwidth-On-Demand MAC Sublayer is non-obsolescent since it is agnostic to any user of network protocol.
7	Robustness	*1. Is the MAC protocol able to recover from events such as unexpected shut down or loss of link?* The mechanisms of 802.16mc-00/01 are available through either the DOCSIS bandwidth partition or over the Common Signaling Channel, a more logical choice for managing the system. *2. How well does the MAC Layer react in the face of errors arising from the Physical Layer?*

		DOCSIS-based methods are available. In addition, messages sent over the Common Signaling Channel are protected by a combination of very robust Forward Error Control and error detection means.
8	Security	*How well does the MAC protocol provide security mechanisms to meet the 802.16.1 Functional Requirements?* See 802.16mc-00/01
9	Maturity	*Does the proposed MAC protocol have data to demonstrate its ability to operate in an actual system that is representative of the BWA networks targeted for 802.16.1?* DOCSIS is currently in use in a large number of cable-modem environments. Also, some fixed wireless access providers have operational systems based on the DOCSIS standard. Although the proposed Bandwidth-On-Demand MAC Sublayer has not yet been implemented in a Broadband Wireless Access environment, it is based on similar technology that has been field-proven in large network environments for several decades.
10	Sign-on process	*1. How well does the MAC protocol resolve initial two way ranging?* See 802.16mc-00/01. Ranging methods used in DOCSIS are proposed as first embodiments. *2. How automatic is the sign-on process?* See 802.16mc-00/01.
11	Adequacy of management functions	*How well does the MAC protocol provide link management functions for subscribers' timing, power, and frequency?* See 802.16mc-00/01. In addition, the Common Signaling Channel enhances the efficiency of managing Broadband Wireless Access systems.
12	Convergence with existing protocols	*How simple is it to adapt the proposed MAC protocol to well-known LAN and WAN protocols?* See 802.16mc-00/01. In addition, direct support for any network protocol is available over the Bandwidth-On-Demand MAC Sublayer
13	Ability to work with physical layer variations, e.g.,duplexing, constellation, etc.	*How independent is the proposed MAC protocol of the PHY protocol?* See 802.16mc-00/01. The Bandwidth-On-Demand MAC Sublayer is capable of operating efficiently in any mode (FDD, TDD and H-FDD). To maximize the utility of the Sublayer, the PHY should be able to efficiently send bursts to the Base Station that are short. The Bandwidth-On-Demand MAC Sublayer can work equally well using any modulation method including OFDM and CDMA.

System Requirements
Mandatory Requirements

(This table includes only those areas where there are substantial changes or additions to Table K-1 Mandatory Requirements included in Appendix K of 802.16.1mc00/01)

#	Section	Requirement	How this MAC With Proposed Sublayer Complies
M1	1	The forthcoming air interface standard MUST comply with the system requirements.	See 802.16.1mc00/01
M2	1.1	The 802.16.1 air interface interoperability standard SHALL be part of a family of standards for local and metropolitan area networks.	The proposed Bandwidth-On-Demand MAC Sublayer can become a part of a family of standards for local and metropolitan area networks by attaching a simple convergence layer between existing and future MACs and the proposed Sublayer.
M3	2	802.16.1 systems SHALL be multiple-cell frequency reuse systems.	See 802.16.1mc00/01
M4	2.1	The air interface MUST NOT preclude repeaters or reflectors to bypass obstructions and extend cell coverage.	See 802.16.1mc00/01
M5	2.1	The standard (e.g., MAC/PHY protocols) SHALL describe common access protocol(s) and common modulation technique(s).	See 802.16.1mc00/01. Common access protocols include interfacing to a Common Signaling Channel over which control messages are passed between the Base Station and Subscriber Stations.
M6	2.2	All data traffic in a single cell of an 802.16.1 network MUST go through the base station.	Conforms.
M7	2.2	The base station SHALL serve as a radio resource supervisor.	Conforms.
M8	2.2	802.16.1 protocols MUST provide the means to multiplex traffic from multiple subscriber stations in the downstream direction, and provide for a means to resolve contention and allocate bandwidth in the upstream direction.	Conforms with more robust data interleaving and better QoS performance than can obtain by using only variable-length or large PDUs.
M9	3.1.2	802.16.1 systems and protocols MUSTsupport the QoS requirements of the services: · Narrowband/Voice Frequency Telephony - POTS (supporting FAX services), Centrex, ISDN BRI 35 · NxDSO Trunking - Fractional DS1/E1 to PBXs and/or data equipment, ISDN PRI 36 · Full DS1/E1 - transparent mapping including all framing information · Voice Over IP, Voice Over Frame Relay, Voice and Telephony over ATM (VToA), and similar services	All services are supported without relying on circuit emulation over asynchronous multiplexing protocols. The Bandwidth-On-Demand MAC Sublayer produces the equivalent of clocked isochronous and plesiochronous circuits with transport delays that are inversely proportional to the required circuit bandwidth. The result is much smaller delay, delay variation and jitter than is possible using PDU-based multiplexing approaches. The result is also more bandwidth-efficient. Even single compressed voice connections from the Base Station to a single Subscriber Station are practical, a capability that is difficult to achieve with other approaches.
M10	3.1.2.1	The amount of delay between a user speaking and another user hearing the speech MUST be kept below a certain level to support two-way conversation.	Delay characteristics using the Bandwidth-On-Demand MAC Sublayer approach are superior to other known methods.
M11	3.1.2.1	BWA protocols MUST support efficient transport of encoded voice data in terms of bandwidth, reliability and delay.	Not only are delay characteristics excellent, but the bandwidth efficiency with which encoded voice is superior to other known methods. Reliability is assured by using well-understood virtual circuit techniques.
M12	3.1.2.2	MUST meet the transport requirements of telephony signaling, whether TDM-or message-oriented.	Telephony signaling can be based on any existing telephony messaging protocol including SS7, ATM Adaptation Layer or H.323. For the circuit-based approach to supporting voice, signaling messages are sent efficiently over the Common Signaling Channel that is a standard part of the Bandwidth-On-Demand MAC Sublayer. Although it is possible to support asynchronous flows over the MAC Sublayer channels, it is proposed that such flows be supported using the referenced DOCSIS-based protocol of 802.16.1mc0001. For example, Ethernet support of compressed voice channels (Voice Over IP, for example) would make use of this capabitlity.

M13	3.1.4	802.16 MUST directly transport variable length IP datagrams efficiently.	See 802.16.1mc00/01
M14	3.1.4	Both IP version 4 and 6 MUST be supported.	See 802.16.1mc00/01
M15	3.1.4	The 802.16.1 IP service MUST provide support for real-time and non-real-time services.	See 802.16.1mc00/01. In the future, support for asynchronously multiplexed services (such as IP) will be supported over the Bandwidth-On-Demand MAC Sublayer with improved performance
M16	4	The MAC protocol MUST define interfaces and procedures to provide guaranteed service to the upper layers.	See 802.16.1mc00/01. In addition to the capability defined therein, guaranteed service is provided directly without using a PDU-based MAC layer for STM and ATM services.
M17	4	The MAC protocol MUST efficiently resolve contention and bandwidth allocation.	Efficient, low-transport-delay scheduling of bandwidth is a major attribute of the Bandwidth-On-Demand MAC Sublayer. Scheduling can be based on flows that make use of cell slots that are assigned for the duration of a flow. In other words, the Base Station need only “grant” bandwidth once for a flow reducing the mapping overhead required. Contention by Subscriber Station for additional services need occur only when a Subscriber Station goes from an inactive to an active state. Otherwise, requests for changes in service are embedded within (piggyback on) Subscriber Station to Base Station transmissions.
M18	4	Further details, and finalization of the protocol reference model, SHALL be worked out by the 802.16.1 MAC and PHY task groups while developing the air interface interoperability standard.	It SHALL be done!
M19	5.2	802.16.1 protocols SHALL be optimized to provide the peak capacity from 2 to 155 Mbps to a subscriber station sufficiently close to the base station.	See 802.16.1mc00/01
M20	5.2	802.16.1 protocols SHALL NOT preclude the ability of an 802.16.1 system to deliver less than 2 Mbps peak per-user capacity.	The Bandwidth-On-Demand MAC Sublayer can operate at *any* PHY peak bandwidth capacity without compromising efficiency. System overhead for framing and control is directly proportional to aggregate system bandwidth
M21	5.4	The 802.16.1 specifications SHALL NOT preclude the ability of the radio link to be engineered for different link availabilities, based on the preference of the system operator.	PHY issue except that PHY parameters can be set over the Common Signaling Channel in most cases.
M22	5.4	802.16.1 MAC and PHY protocols MUST accommodate atmospheric conditions, perhaps consuming more radio bandwidth and/or requiring smaller radio propagation distance (radius) to meet the availability requirements.	See 802.16.1mc00/01. System messages are sent efficiently over the Common Signaling Channel by the Base Station to one or more Subscriber Stations.
M23	5.4	Since statistical atmospheric conditions vary widely in geography, the 802.16.1 protocols MUST be flexible in consumed radio bandwidth (spectral efficiency), cell radius, and transmit power to accommodate a rain allowance that varies with geography.	PHY issue.
M24	5.5	The error rate, after application of the appropriate error correction mechanism (e.g., FEC), delivered by the PHY layer to the MAC layer SHALL meet IEEE 802 functional requirements: The bit error rate (BER) is 10E-9.	PHY issue. Using the Bandwidth-On-Demand MAC Sublayer approach, this requirement can be met and expanded upon to allow different error rates to apply to different classes of service.
M25	5.5	Each block of data delivered by the PHY to the MAC layer MUST allow for detection of errors by the MAC (e.g., by CRC) with 1, 2 or 3 errored bits (a Hamming Distance of 4).	PHY issue. See 802.16.1mc00/01. Additional error checking capability can be invoked for any class of service. The Common Signaling Channel always includes periodic error checking (in addition to error control) that assures synchronization of Subscriber Stations maps with the Base Station.

M26	5.6	The budget for the 802.16.1 system transit delay and access delay MUST be derived. The MAC layer may have different requirements for each direction, upstream and downstream.	Using the Bandwidth-On-Demand MAC Sublayer results in very low downstream delay since cell slot size is nominally one byte long and is equal to the mean (nearly uniform) interval between cell slots assigned to a given flow. A downstream interleaver need not be used since cell slots are already spread in time for each flow or aggregation thereof. In the upstream direction, the situation is similar, except that delay is directly proportional to cell slot size that is limited by modem technology.
M27	5.6	In the upstream direction, time MUST be budgeted for requesting bandwidth and contending among nodes.	Except for contention by an inactive Subscriber Station that needs to request service (and initial Subscriber Station registration), all service requests are transmitted over the Common Signaling Channel that consumes only a small percentage of the aggregate system bandwidth.
M28	5.7	In a given 802.16.1 system instance, capacity MUST be carefully planned to ensure that subscribers' quality of service guarantees and maximum error rates are met.	See 802.16.1mc00/01.
M29	5.7	The MAC and PHY protocols MUST accommodate channel capacity issues and changes in channel capacity to meet contracted service levels with customers.	The Bandwidth-On-Demand MAC Sublayer can manage dynamically (in milliseconds) to meet changing channel capacity issues.
M30	5.7	As subscribers are added to 802.16.1 systems, the protocols MUST accommodate them in an automated fashion.	See 802.16.1mc00/01. The methods defined therein are used sending required messages over the Common Signaling Channel.
M32	6	802.16.1 protocols MUST support classes of service (CoS) with various quality of service (QoS) guarantees to support the bearer services that an 802.16.1 system MUST transport.	See 802.16.1mc00/01. Service guarantees are provided for both DOCSIS-based services and for STM and ATM services that are directly to the Bandwidth-On-Demand MAC Sublayer. Control messages are passed over the Common Signaling Channel
M32	6	802.16.1 protocol standards MUST define interfaces and procedures that accommodate the needs of the bearer services with respect to allocation of prioritization of bandwidth.	Using the Bandwidth-On-Demand MAC Sublayer significantly enhances the ability of 802.16 systems to accommodate allocation and prioritization of bandwidth.
M33	6	802.16.1 protocols MUST provide the means to enforce QoS contracts and Service Level Agreements.	Since bandwidth management with small granularity is a key aspect of enforcing QoS contracts and Service Level Agreements, adding the Bandwidth-On-Demand MAC Sublayer significantly improves 802.16 ability to meet system operator and user needs.
M34	6	The 802.16.1 protocols MUST be capable of dedicating constant-rate, provisioned, bandwidth for bearer services such as SDH/PDH.	This is one of the major benefits of employing the Bandwidth-On-Demand MAC Sublayer within 802.16. Smaller delay, delay variation and jitter obtain than can be achieved by embedding ATM cells within PDU protocols either by supporting SDH/PDH by the Sublayer directly or by supporting ATM through a simple convergence layer on top of the Bandwidth-On-Demand MAC Sublayer.
M35	6	For QoS-based, connectionless, but not circuit-based, bearer services, the 802.16.1 protocols MUST support bandwidth negotiation "on-demand.	See 802.16.1mc00/01. In addition, vendors may implement convergence layers for these services that connect directly to the Bandwidth-On-Demand MAC Sublayer resulting in excellent performance.
M36	6	Table 1 provides a summary of the QoS requirements that the PHY and MAC SHALL provide.	See 802.16.1mc00/01. Including the Bandwidth-On-Demand MAC Sublayer enhances QoS performance.
M37	6.2	802.16.1 protocols SHALL define a set of parameters that preserve the intent of QoS parameters for both ATM- and IP-based services.	See 802.16.1mc00/01. Including the Bandwidth-On-Demand MAC Sublayer enhances QoS performance.
M39	6.3	A network node that serves as an inter-working function (IWF) between a QoS-capable LAN or WAN and an 802.16.1 system MUST participate in signaling protocols to set up QoS parameters for connection-oriented services.	See 802.16.1mc00/01. Message structures can be sent efficiently over the Common Signaling Channel for DOCSIS-supported traffic and for traffic that is supported directly over the Bandwidth-On-Demand MAC Sublayer.
M40	6.3	The IWF MUST participate in the ATM signaling protocol that sets up the circuit.	See 802.16.1mc00/01. Signaling messages may be sent efficiently over the Common Signaling Channel, a benefit in many cases.

M41	6.3	The IWF also MUST utilize 802.16.1 interface primitives (e.g., MAC layer user interface primitives) to request QoS.	See 802.16.1mc00/01. Signaling messages may be sent efficiently over the Common Signaling Channel, a benefit in many cases.
M42	6.3	If 802.16.1 is to be a "link" in the IP network, an IWF MUST interface with 802.16.1 to negotiate resource allocation.	See 802.16.1mc00/01. “Resource allocation” usually includes primarily bandwidth allocation that is a major attribute of the Bandwidth-On-Demand MAC Sublayer
M43	6.3	The QoS parameters for 802.16.1 MUST be chosen and interface primitives defined that allow for bearer services’ IWFs to negotiate QoS "through" an 802.16.1 system.	See 802.16.1mc00/01. Signaling messages may be sent efficiently over the Common Signaling Channel, a benefit in many cases.
M44	7.1	The 802.16.1 protocol MUST permit operators to enforce service level agreements (SLAs) with subscribers by restricting access to the air link, discarding data, dynamically controlling bandwidth available to a user or other appropriate means.	See 802.16.1mc00/01. Since the Bandwidth-On-Demand MAC Sublayer can allocate a specific amount of bandwidth to any user service, there is never any possibility that a user can violate a service level agreement by delivering a higher data rate to the system than his contract provides. There is never any need to discard data, an attribute that guarantees high quality service for a user.
M45	7.1	The 802.16.1 protocols MUST permit subscribers to monitor performance service levels of the 802.16.1 services being provided at the delivery point.	See 802.16.1mc00/01. This capability may be provisioned outside DOCSIS for maximum flexibility.
M46	7.2	The operator MUST have means to shut down a subscriber station if necessary, remote from the subscriber station, in the face of a malfunction.	See 802.16.1mc00/01. This capability may be provisioned outside DOCSIS for maximum flexibility.
M47	7.2	The operator MUST have the means to shut down a Base Station remotely.	See 802.16.1mc00/01.
M48	7.3	The 802.16.1 system management framework, architecture, protocols and managed objects MUST allow for operators to effectively administer accounting and auditing.	See 802.16.1mc00/01.
M49	7.3	An operator MUST be able to account for time- and bandwidth-utilization and the various QoS parameters for each subscriber.	See 802.16.1mc00/01.
M50	8	The 802.16.1 system SHALL enforce security procedures described in section 8.	See 802.16.1mc00/01.
M51	8	The security system chosen by 802.16.1 SHALL be added to the protocol stack (Figure 4-1) and reference points (Figure 2-3) to include security protocols, and "database" servers for authentication, authorization, key management, etc.	See 802.16.1mc00/01.
M52	8.1	This initial authentication MUST be very strong in order to prevent an "enemy" subscriber station from entering the network or an "enemy" base station from emulating a real base station.	See 802.16.1mc00/01.
M53	8.1	1 Initial authentication MUST be supported by the 802.16.1 MAC layer.	See 802.16.1mc00/01.
M54	8.1	The authentication mechanisms MUST be secure so that an "enemy" subscriber station is not able to gain access to an 802.16.1 system, or to the core network beyond.	See 802.16.1mc00/01.
M55	8.1	Passwords and secrets MUST NOT be passed "in the clear" through the air interface.	See 802.16.1mc00/01.
M56	8.2	The 802.16.1 standard SHALL identify a standard set of credentials and allow for vendors to extend the defined credentials with non-standard credentials.	See 802.16.1mc00/01.
M57	8.2	Subscriber authorization requests and responses MUST be transacted securely.	See 802.16.1mc00/01.

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