Project	**IEEE 802.16 Broadband Wireless Access Working Group**
Title	**Proposed Amendments to 802.16.1pc-00/02 for a PHY 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 802.16.1pc00/02: Physical Layer Proposal for the 802.16 Air Interface Specification dated 1999-12-23.
Abstract	This document proposes a PHY layer that contains minimal changes to the referenced document so that the PHY can support a Bandwidth-On-Demand MAC Sublayer as a part of the 802.16 standard.
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 PHY Contribution: Proposed Amendments to Include a Bandwidth-On-Demand MAC/PHY Sublayer Option

1 Scope and Purpose

The scope of this contribution is to propose small modifications to IEEE 802.16 PHY protocol proposals that will allow inclusion of a Bandwidth-On-Demand MAC/PHY Sublayer within the 802.16.1 Broadband Wireless Access Air Interface standard. At this time, the proposal is submitted as a desirable option and not a mandatory addition.

The purpose of the proposed amendments is to result in Broadband Wireless Access systems that can support any MAC or higher-level protocol. The amendments provide performance that cannot be achieved using variable-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 of Proposed PHY Changes

Most of the areas of existing 802.16 PHY proposals can be used with the changes proposed by this amendment without modification. Areas of proposed modifications include the following:

1. Define Time Division Multiplex frames, both downstream and upstream, into which all information between the Base Station and Subscriber Stations is transmitted.
2. Define robust frame synchronization methods that result in rapid frame synchronization acquisition and tracking.
3. Coupled with the Bandwidth-On-Demand MAC Sublayer, apply error control to individual flows (or aggregates of flows within the same service class) rather than to all transmissions.

Because of the simplicity of implementation of the proposed PHY and its companion Bandwidth-On-Demand MAC Sublayer, it is possible to produce a first generation 802.16 Air Interface that includes dividing Broadband Wireless Access system bandwidth into partitions, one for IEEE 802-based, MPEG-based or other PDU-type protocol standards and separate partitions for SDH/PDH and ATM traffic. The SDH/PDH and ATM partitions are further divided into any number of data channels each of which can be any integer multiple of some incremental bandwidth (such as 1 Kbps).

The items covered in this document relate to PHY layer operation with a Bandwidth-On-Demand MAC Sublayer only. The section numbers conforms to the outline for the 802.16 Air Interface standard, although some of the section titles have been changed slightly to improve naming consistency. Only those section numbers that pertain specifically to the PHY modifications are included.

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 PHY layer that is a minimum modification of current practice but is not limited to such embodiments.
- Specify a PHY 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

The Bandwidth-On-Demand MAC Sublayer Forwarder supports any digital network and user protocols. The Sublayer divides the total available bandwidth into partitions that support both the protocols defined by IEEE 802 standards and other network protocols as well. Such additional protocols include, among others, ATM, Frame Relay and both isochronous and plesiochronous STM. This capability is illustrated in Figure 3-1. The operation of the Bandwidth-On-Demand MAC Sublayer is described in more detail in Section 5.2 of a companion 802.16 MAC contribution [2].

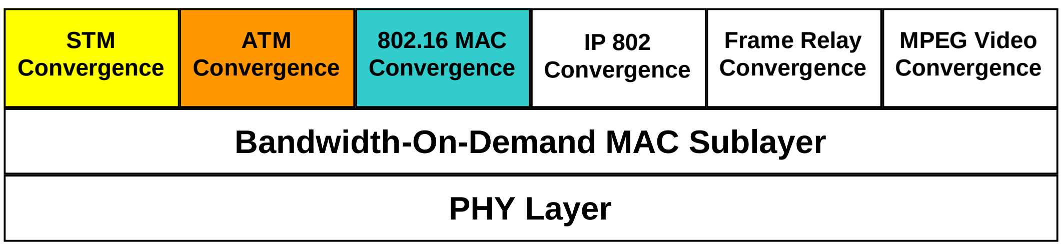

FIGURE 3-1 SOME PROTOCOLS THAT CAN BE SUPPORTED BY A BANDWIDTH-ON-DEMAND MAC SUBLAYER

3.5 Physical Layer

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 is to send 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 and there is no need for allocating frame synchronization cell slots upstream. On the other hand, 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.

4 *Physical Layer*

4.1 Scope

This specification defines only those electrical characteristics and protocols that are unique to a Broadband Wireless Access system using a Bandwidth-On-Demand MAC Sublayer above the PHY layer. All properties of the PHY layer not defined herein are those defined in the 802.16.1 PHY Layer Air Interface standard. It is the intent of this specification to define an interoperable Subscriber Station and Base Station such that any implementation of a Subscriber Station can work with any Base Station. It is not the intent of this specification to define any specific implementation.

4.3 PHY Overview

4.3.1 Introduction

In Frequency Division Duplex (FDD) operation, the downstream Bandwidth-On-Demand PHY Layer contains a Physical Medium Dependent (PMD) sublayer that is a continuous stream of cell slots. In Time Division Duplex (TDD) operation, the downstream transmissions are (long) bursts of contiguous cell slots interrupted by a period that allows bursts of upstream cell slots to transmit on the same Radio Frequency without interference.

In the upstream direction, each of the cell slots is distinct and not concatenated with another cell slot from the same Subscriber Station (except in unusual chance circumstances). In FDD operation, the cell slots for a given information flow from a single Subscriber Station are spread nearly uniformly throughout a Time Division Multiplex frame. In TDD operation, the upstream cell slots for a flow are spread nearly uniformly through the periods when the Base Station is not transmitting.

4.3.3.1 Duplexing

Duplexing can be Frequency Division Duplex (FDD), Half-Duplex Frequency Division (H-FDD), or Time Division Duplex (TDD). Frame structures are the same for FDD and H-FDD but are different for TDD.

4.3.3.2 Frames, Multiframes & Hyperframes

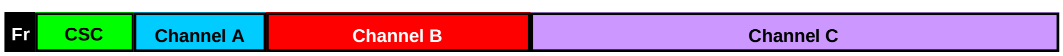

FIGURE 4-1 A SIMPLE TIME DIVISION MULTIPLEX STRUCTURE IN THE ELEMENT ADDRESS DOMAIN (DOWNSTREAM)

Figure 4-1 shows an example of a simple Bandwidth-On-Demand MAC Sublayer frame structure. The example shows three traffic channels plus a Common Signaling Channel (labeled CSC) and a Framing channel (labeled Fr) where the framing cell slots either can be made contiguous at the beginning of the Time Division Multiplex frame or can be distributed uniformly throughout the frame.

The frame structure exists both in a logical domain, called the Element Address domain (shown in Figure 4-1) and in a physical (time) domain, called the Ordinal Position Number domain shown in Figure 4-2.

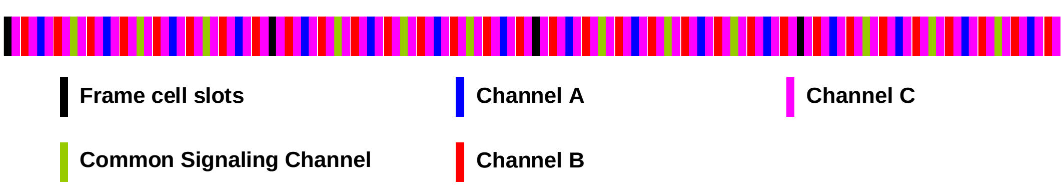

FIGURE 4-2 EXAMPLE OF FIGURE 4-1 SHOWN IN THE PHYSICAL (ORDINAL POSITION NUMBER) DOMAIN

In the Element Address domain of Figure 4-1, the number of cell slots per frame assigned to a data channel determines the channel's bandwidth. A data channel is defined in the Element Address domain as a contiguous set of cell slots. (The total number of cell slots in the Element Address domain is ***F***, the length of the Time Division Multiplex frame.)

Figure 4-2 shows the distribution of cell slots in the Ordinal Position Number domain, which is the physical Time Division Multiplex domain. There are also ***F*** cell slots in this domain as well in the Element Address domain. In this example, the cell slots happen to be exactly uniformly spaced for traffic channels A, B and C and for the Frame channel cell slots. They are approximately uniformly spaced for the Common Signaling Channel. In most instances, it is rare for the cell slots for a given traffic channel to be exactly uniformly spaced, but, in all cases, they are nearly uniformly spaced and the non-uniformity results in a small amount of jitter that is mathematically bounded.

The example of Figure 4-1 and Figure 4-2 pertains to downstream transmissions for FDD operation. A Transmission Convergence Sublayer includes the Framing and a Common Signaling Channels. (For TDD operation, each downstream frame would be separated by a silence period where upstream Subscriber Station channels transmit.)

Shown in Figure 4-3 is a diagram for an upstream physical Time Division Multiplex domain without as much detail as the preceding two figures. The total framing period is divided into two sections. A short period that can be used for contention access by Subscriber Stations followed by an Ordinal Position Number domain of cell slots sent where bandwidth is assigned to the Subscriber Stations for upstream transmissions.

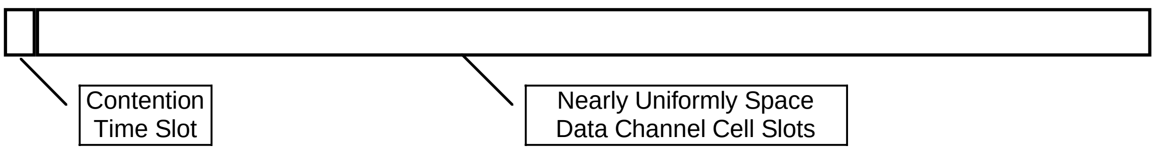

FIGURE 4-3 PHYSICAL (ORDINAL POSITION NUMBER) CELL SLOT DOMAIN (UPSTREAM)

The contention interval must have sufficient capacity to serve inactive Subscriber Stations when they become active. The amount of time reserved for this contention-based access is based on the well-defined principles as a part of 802.16 PHY proposals.

4.3.3.3 Time Slots & bursts

The PMD sublayer format includes a Time Division Multiplex frame made up of fixed-length cell slots (time slots). The size of the cell slots is usually different in the upstream and downstream directions of transmission as can be the number of cell slots per frame. Each cell slot MAY support a flexible modulation, symbol rate, preamble, randomization of payload, and programmable Forward Error Correction (FEC) encoding that is coupled with information flows based on class of service objectives.

All upstream transmission parameters associated with burst transmission outputs from the Subscriber Station are configurable by the Base Station via MAC messaging sent over the downstream Common Signaling Channel.

4.3.3.4 Logical Channels

Logical channels are defined using the methods within the Bandwidth-On-Demand MAC Sublayer described in Section 5 of [2].

4.3.5 Modulation

In the downstream direction, a frame is made up of modulated symbols that carry a continuous stream of cell slots. Since cell slots are defined with byte boundaries, the number of bits transmitted in a symbol may or may not be an integer submultiple of the cell slot size. For example, for 64QAM modulation, each symbol carries 6 bits of information. For a one-byte cell slot size (the nominal size in the downstream direction), cell slot boundaries occur at the beginning of a symbol only every four symbols (24 bits corresponding to 3 bytes). However, this is not a limitation to the proposed PHY standard. There is no requirement to confine cell slot boundaries to symbol boundaries since downstream transmissions are continuous.

In the upstream direction, the situation is different. In the 64QAM case, in order to not waste bandwidth, a 16-symbol burst would be the smallest possible burst size representing a 12-byte burst.

To enable the best delay and jitter performance for upstream transmissions using of a Bandwidth-On-Demand MAC Sublayer, it is desirable to implement the shortest transmission burst size possible. Achieving small upstream cell slot sizes is difficult using existing modem technology. The smallest practical modem is likely to be of the order of 16 symbols, (4 bytes using QPSK modulation) without requiring excessively large guard times and burst preambles.

4.4 Multiple Access & Traffic Channel Multiplexing

4.4.2.2 Framing & Formatting

The size of the Time Division Multiplex frame is chosen to support any combination of information rates for a given set of services. The size and other aspects of a frame are field programmable. All Time Division Multiplex frames MUST contain a number of cell slots such that the frame period is an integer multiple of 125 µsec, the basic international digital networking timing standard. In other words, the frame rates are integer sub-multiples of 8,000 frames per second.

The downstream and upstream frame formats are similar. Downstream frames contains synchronization information that is detected by Subscriber Stations to assure both Subscriber Station send and receive frames are locked to the Base Station's reference clock. The upstream frames do not require including framing information on a continuing basis after initial registration (or re-registration) and ranging of a Subscriber Station with the Base Station, matters that are covered in other 802.16 PHY contributions.

(The downstream Bandwidth-On-Demand frame includes a default Common Signaling Channel that is configured during initial system setup. An upstream signaling channel can be set up to transmit Subscriber Station to Base Station control messages and response. These messages are sent using grants from the Base Station.)

In order to be able to assign channels without resorting to pad bits (or bytes) within cell slots (an approach that complicates a multiplexing protocol and wastes bandwidth), it is necessary that all channel rates to be supported are integer multiples of an incremental bandwidth. Starting with a set of desired channel rates, the largest possible incremental bandwidth for the set is the greatest common divisor (GCD) of the rates.

For example, suppose it is desired to support isochronous channel rates of 56,000, 64,000, 65,333.33 (196,000/3), 69,333.33 (208,000/3), 384,000, and 1,536,000 bps. [Note: 65,333.33 bps and 69,333.33 bps are required rates for supporting 49- and 52-byte compressed ATM cell data channels carrying a single DS0 channel without wasting bandwidth.] The GCD of these rates is 1,333.33 (4,000/3) bps, which can be taken as the desired incremental bandwidth. The required frame period to support these rates is 6 msec. For the specified data rates, 42, 48, 49, 52, 288 and 1,152 cell slots per frame, respectively, are assigned. Integer multiples of these cell slots per frame result in integer multiples of the data rates. The mean transport delay for these channels is approximately 143, 125, 122, 115, 21, and 5.2 µsec respectively.

Similar results can be obtained for upstream transmissions. Suppose that, instead a one-byte cell size, the cell size is now 8 bytes (the minimum size mini-slot in the DOCSIS standard). In this case, the data rates of the example of the last paragraph would require a 48 msec frame to result in no wasted bandwidth. The mean transport delays would now be eight times those of the one-byte cell slot case —still small compared to many PDU-based multiplexing approaches. It should be noted that long Time Division Multiplex frame periods do *not* result in large transport delays.

There is great flexibility in achieving bandwidth-efficient support for any number of data rates. Transport delays are small even for low speed channels.

4.4.3 Logical Channels

4.4.3.1 Hierarchy

The Time Division Multiplex frame is partitioned (in the Element Address domain) into the following hierarchy:

- *Partition*: A partition is a major grouping of cell slot addresses in accordance with a logical grouping such as traffic type and/or Quality of Service. At least three partitions always exist in downstream transmission: Framing and Common Signaling Channel are always present. At least one other partition exists to transfer data between the Base Station and Subscriber Stations.
- *Sub-Partition*: A sub-partition is a grouping of cell slots within a partition that further describes the traffic type of data carried within the Sub-Partition.
- *Traffic Channel*: A traffic channel is a range of cell slot addresses (in the Element Address domain) that support traffic for a specific system unicast of multicast connection.

4.4.3.2 Traffic Channels (TCHs)

At the PHY layer, all traffic channels are determined by Element Address ranges within the Element Address domain. They are transparent to packet/cell layer protocols. However, in many cases, the Bandwidth-On-Demand Time Division Multiplex structure can generate periodic timing signals based on the periodic nature of PHY Time Division Multiplex frames. In many cases, these frames obviate the necessity of including asynchronous framing bytes within a traffic channel thereby improving bandwidth efficiency.

4.4.3.3 Control Channels (CCHs)

From the PHY perspective, a Control Channel is indistinguishable from a traffic channel. Since signaling messages are usually very short, the use of PHY periodic framing greatly improve the bandwidth efficiency of control channel messaging.

4.4.5 Mapping of Logical Channels into Physical Channels

Mapping of logical channels into physical channels is described in detail in Section 5 of [2].

4.4.6 PHY-MAC Interaction

The downstream Time Division Multiplex data stream is encoded with both a frame synchronization header and a Common Signaling Channel that matches any clocked Physical Layer interface. The data stream is divided into contiguously transmitted cell slots in conformance with the Bandwidth-On-Demand PHY Layer format. The upstream Time Division Multiplex data stream also conforms to the same format. However, in this case, upstream transmission takes the form of short fixed-length bursts where the burst size is usually a compromise between short burst size (to support lower speed traffic channels with small latency) and long burst size (to provide for guard band and preambles being a small proportion of total upstream bandwidth)[1].

4.5 Traffic Channel Coding

There are a number of options for implementing error control. In the downstream case, applying the basic coding technique of the 802.16.1 PHY or one of its optional alternatives is a good approach. However, it is not necessary to restrict the size of the encoding to the size of a fixed-size packet. For example, Reed-Solomon coding might be employed over GF(256) for the entire continuous downstream transmission but using a code word size that optimally meets 802.16 requirements.

In both the downstream and upstream cases, error control is easily applied to either individual flows or aggregates of flows that must meet given QoS objectives. One advantage of the proposed PHY is that cell slot spreading is an inherent part of the system so that further interleaving is not required.

4.8 Radio Sub-system Control & Synchronization

4.8.1 Introduction

There are two aspects to Bandwidth-On-Demand MAC/PHY Synchronization. One is Time Division Multiplex frame synchronization as described in Section 4.8.2. The other is synchronization of Subscriber Stations Element Address maps with Base Station allocations.

Frame synchronization is assured by continually sending frame synchronization cell slots within Base Station transmissions. Element Address map synchronization is assured by continually sending error checking and indication messages specifying the location of Element Address partitions for both downstream and upstream transmissions. These messages are followed (periodically) by detailed messages affirming the location of Element Address channel maps within each partition. A system re-start disaster recovery mode is available in the event of catastrophic system failure the occurrence of which can be minimized by properly incorporating redundancy in the Base Station design and shutdown failure modes within Subscriber Stations. Map synchronization errors are highly

[1] Although not proposed as a part of an initial standard, it is possible to use more than one size burst for the upstream transmissions that could improve bandwidth efficiency for conventional modems. It all appears possible to build short burst modems whose efficiency is much better than current practice.

unlikely to occur or persist by assuring that no Common Signaling Channel message is invoked by a Subscriber Station when the Base Station's received signal amplitude falls below a threshold that assures 10^{-11} or better bit error rate probability.

4.8.2 Timing & Synchronization

There are two ways by which frame synchronization by a Subscriber Station to Base Station transmissions can be formatted.

The first method is to set aside a time slot within the physical Time Division Multiplex frame where a frame preamble synchronization pattern is periodically sent by the Base Station. This is the classical method by which Time Division Multiplex systems acquire and maintain synchronization. In this mode, the proposed synchronization pattern is between 32 and 128 bits long. (For a cell slot size of 8 bits, the pattern length corresponds to 4 to 16 cell slots.) The pattern chosen must have good autocorrelation properties (extensive lists of which have been published).

A second method is to assign the first few Element Addresses within the Element Address domain to frame synchronization. By doing so, frame synchronization cell slots are nearly uniformly spaced throughout the frame. This approach is attractive when it is required that Bandwidth-On-Demand MAC/PHY frame sizes be large to accommodate a wide range of traffic channel data rates. This method, contrary to the first method overcomes necessity of waiting until the beginning of a frame to acquire or maintain synchronization. By using comma-free code fragments assigned to the dispersed cell slots, frame synchronization can be quickly acquired or re-acquired by a Subscriber Station.

In order to aid achieving rapid synchronization search using the second method, it is beneficial (as shown in Figure 4-1) to place the frame synchronization cell slots at the beginning of the Element Address domain frame as opposed to the physical Time Division Multiplex frame. This is particularly so if the number of cell slots allocated to frame synchronization is an integer power of two in length and that the total frame length is an integer multiple of this power of two. In this case, the frame synchronization cell slots are exactly uniformly spaced throughout the physical (Ordinal Position Number) frame thereby simplifying mechanization of frame synchronization search alternatives.

Example: Suppose that a frame period of 8 msec is chosen (resulting in an incremental assignable bandwidth of 1,000 bps for an 8-bit cell slot size). Suppose that the total number of cell slots assigned to frame synchronization is increased to 64 cell slots (512 bits) per frame. The total frame size must be 64***n*** cell slots per frame (where ***n*** is any integer). In other words, for an 8 msec frame, the raw transmitted rate (including FEC bits)[2] must be an integer multiple of $64\times1000/8$ = 8,000 cell slots per second or 64,000 bits per second.

The OC1 data rate (51.84 Mbps) is a multiple of 64,000 bps (51,840,000/64,000 =810). The total frame size is $51{,}840{,}000 \times 8 / 1000$ = 414,720 bits or 51,840 cell slots. The number of cell slots between frame synchronization fragments (cell slots) is then 51,840 / 64 = 810 cell slots so that a frame synchronization cell slot (byte) occurs once every 125 µsec. In this example, robust and rapid synchronization is achieved using less than 0.123% of the raw downstream bandwidth.

4.8.2.1 Base Station

The Base Station supplies frequency and time references for the entire Broadband Wireless Access system. Since transmissions from the Base Station are continuous (except for TDD operation where they are long burst continuous), Subscriber Station timing can be accurately derived. By tying a Base Station timing reference to Universal Time (using the Global Positioning Satellite (GPS) or other means) and sending, for example, time marks over the Common Signaling Channel once per second, timing for any period that is an integral multiple or submultiple of the Base Station frame rate is easily derived. This capability can obviate the necessity of including time stamps within services (such as ATM and some DOCSIS services) that normally are asynchronously multiplexed.

[2] The raw transmitted rate includes transmitted FEC bits. FEC algorithms are applied after frame synchronization has been achieved.

4.8.2.2 Subscriber Station (CPE)

There are two main reasons for desiring an accurate timing reference at each Subscriber Station. One is to minimize the need for large guard times between upstream bursts from different Subscriber Stations and to minimize the acquisition range required by the Base Station for Subscriber Station carrier and symbol phase. The other is to be able to mechanize simply the frame timing references referred to in Section 4.8.2.1

References

[1] 802.16.1pc-00/02: Physical Layer Proposal for the 802.16 Air Interface Specification, dated 1999-12-23.

[2] 802.16.1mc-00/xx: Proposed Amendments to 802.16.1mc-00/01 for MAC 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.

Acknowledgment

The author wishes to acknowledge the useful discussions with members of the ad hoc group formed to study modifications required to the DVB and DOCSIS approaches as a basis for the 802.16 Broadband Wireless Access system standard. The individuals include Arun Arunachalam, Farid Elwailly, George Fishel, Jeff Foerster, Phil Guillemette, Leland Langston, Wayne Hunter, Scott Marin, Bill Myers, Moshe Ran, Dr. George Stamatelos, Karl Stambaugh and Jung Yee. There inputs have been most useful in sorting out just where all the elements of this amendment fit together with other IEEE 802.16 PHY proposals.

Evaluation Table - Session #5

(This table includes only those areas where there are substantial changes or additions to the table in Annex Evaluation Table included in 802.16.1pc-00/02)

#	Criterion	Discussion
1	Meets system requirements	*How well does the proposed PHY protocol meet the requirements described in the current version of the 802.16.1 Functional Requirements? (See Document IEEE 802.16s-99/00)* This physical layer meets the Functional Requirements by having a general structure that allows any MAC layer including the Bandwidth-On-Demand MAC Sublayer to reside above it. It has components that allow accurate synchronization of clocks at the subscriber station to support T1/E1 services and accurate determination of burst timing.
2	Spectrum efficiency	*Defined in terms of single sector capacity assuming all available spectrum is being utilized (either in terms of Gbps/Available Spectrum or in terms of Mbps/MHz)* See 802.16.1pc00/02
3	Simplicity of implementation	*How well does the proposed PHY allow for simple implementation or how does it leverage on existing technologies?* See 802.16.1pc00/02. In addition, implementation of a Time Division Multiplex structure is based on well-established networking principles.
4	CPE cost optimization	*How does the proposed PHY affect CPE cost?* See 802.16.1pc00/02
5	Spectrum resource flexibility	*Flexibility in the use of the frequency band (i.e., minimum frequency band required to operate and migration capabilities)* See 802.16.1pc00/02
6	System diversity flexibility	*How flexible is the proposed PHY to any other system variations and future technology improvements or new services?* See 802.16.1pc00/02 The flexibility is enhanced by including the Bandwidth-On-Demand MAC Sublayer.
7	Protocol Interfacing complexity	*Interaction with other layers of the protocol, specifically MAC and NMS* The proposed physical layer is independent of any higher level MAC. It includes simple mapping of Bandwidth-On-Demand MAC Sublayer cell slots cell slots within the physical layer Time Division Multiplex frames. NMS capability is implemented using the Common Signaling Channel.
8	Implication on other network interfaces	*Intrinsic transport efficiency of telecomm and datacomm services* Any network interface can be implemented on top of the Bandwidth-On-Demand MAC Sublayer that attaches to the PHY layer.
9	Reference system gain*	*Sector coverage performance for a typical BWA deployment scenario (supply, reference system gain)* See 802.16.1pc00/02
10	Robustness to interference	*Resistance to intra-system interference (i.e., frequency re-use) and external interference cause by other systems* See 802.16.1pc00/02
11	Robustness to channel impairments	*Rain fading, multipath, atmospheric effects* See 802.16.1pc00/02

System Requirements
Mandatory Requirements

(This table includes only those areas where there are substantial changes or additions to included in Annex A Funcitonal Requirements Table of 802.16.1pc00/02)

#	Section	Requirement	How this MAC With Proposed Sublayer Complies
M1	1	The forthcoming air interface standard MUST comply with the system requirements.	See 802.16.1pc00/02
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.	By including a Time Division Multiplex framing capability with the 802.16.1pc00/02 PHY the capability of supporting local and metropolitan networks is enhance.

M3	2	802.16.1 systems SHALL be multiple-cell frequency reuse systems.	See 802.16.1pc00/02
M4	2.1	The air interface MUST NOT preclude repeaters or reflectors to bypass obstructions and extend cell coverage.	See 802.16.1pc00/02
M5	2.1	The standard (e.g., MAC/PHY protocols) SHALL describe common access protocol(s) and common modulation technique(s).	See 802.16.1pc00/02
M6	2.2	All data traffic in a single cell of an 802.16.1 network MUST go through the base station.	See 802.16.1pc00/02
M7	2.2	The base station SHALL serve as a radio resource supervisor.	See 802.16.1pc00/02
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.	See 802.16.1pc00/02. Interleaving of traffic from multiple sources is enabled by the Bandwidth-On-Demand MAC Sublayer interfacing with the PHY Time Division Multiplex structure.
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. The amount of delay doest not depend on use of interleavers since cell slots are already spread nearly uniformly throughout the PHY Time Division Multiplex frame.
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.	MAC Requirement
M13	3.1.4	802.16 MUST directly transport variable length IP datagrams efficiently.	MAC Requirement
M14	3.1.4	Both IP version 4 and 6 MUST be supported.	MAC Requirement
M15	3.1.4	The 802.16.1 IP service MUST provide support for real-time and non-real-time services.	MAC Requirement that is significantly enhanced by use of the Bandwidth-On-Demand MAC Sublayer.
M16	4	The MAC protocol MUST define interfaces and procedures to provide guaranteed service to the upper layers.	MAC Requirement
M17	4	The MAC protocol MUST efficiently resolve contention and bandwidth allocation.	MAC Requirement
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 802.16.1pc00/02

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.	See 802.16.1pc00/02
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.	See 802.16.1pc00/02
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 802.16.1pc00/02
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.	See 802.16.1pc00/02
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.	See 802.16.1pc00/02. 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).	See 802.16.1pc00/02. 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.	MAC Requirement
M27	5.6	In the upstream direction, time MUST be budgeted for requesting bandwidth and contending among nodes.	MAC Requirement
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 802.16.1pc00/02
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.	See 802.16.1pc00/02. 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 802.16.1pc00/02
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 802.16.1pc00/02
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.	MAC Requirement
M33	6	802.16.1 protocols MUST provide the means to enforce QoS contracts and Service Level Agreements.	MAC Requirement

M34	6	The 802.16.1 protocols MUST be capable of dedicating constant-rate, provisioned, bandwidth for bearer services such as SDH/PDH.	MAC Requirement
M35	6	For QoS-based, connectionless, but not circuit-based, bearer services, the 802.16.1 protocols MUST support bandwidth negotiation "on-demand".	MAC Requirement
M36	6	Table 1 provides a summary of the QoS requirements that the PHY and MAC SHALL provide.	See 802.16.1pc00/02
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.	MAC Requirement
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.	MAC Requirement
M40	6.3	The IWF MUST participate in the ATM signaling protocol that sets up the circuit.	MAC Requirement
M41	6.3	The IWF also MUST utilize 802.16.1 interface primitives (e.g., MAC layer user interface primitives) to request QoS.	MAC Requirement
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.	MAC Requirement
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.	MAC Requirement
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.	MAC Requiremenet
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.	MAC Requirement
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.	MAC Requirement
M47	7.2	The operator MUST have the means to shut down a Base Station remotely.	MAC Requirement
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.	MAC Requirement
M49	7.3	An operator MUST be able to account for time- and bandwidth-utilization and the various QoS parameters for each subscriber.	See 802.16.1pc00/02.
M50	8	The 802.16.1 system SHALL enforce security procedures described in section 8.	MAC Requirement

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.	MAC Requirement
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.	MAC Requirement
M53	8.1	1 Initial authentication MUST be supported by the 802.16.1 MAC layer.	MAC Requirement
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.	MAC Requirement
M55	8.1	Passwords and secrets MUST NOT be passed "in the clear" through the air interface.	MAC Requirement
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.	MAC Requirement
M57	8.2	Subscriber authorization requests and responses MUST be transacted securely.	MAC Requirement