Project	**IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>**
Title	**MAC Layer Support for the Two PHY Proposal**
Date Submitted	**2000-05-03**
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Re:	IEEE 802.16-00/11, Call for Evaluations, Improvements, and Mergers (MAC-specific), IEEE 802161pc-00_29.pdf, Physical Layer Proposal for the 802.16.1 Air Interface Standard, and IEEE 802.16.1mc-00/14, Media Access Control Layer Proposal for the 802.1 Air Interface Standard.
Abstract	This document describes the modifications that can be made to the proposed MAC layer as defined in 802.16.1mc-00/14 (D+MAC) to support the proposed combination of the two PHY layer submittals (802161pc-00_29.pdf).
Purpose	To illustrate the capability of the MAC as described in 802.16.1mc-00/14 to support the dual PHY layer approach with minor modifications, allowing that MAC to be used as a baseline for the BWA standard.
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MAC Layer Support for the Two PHY Proposal

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1 Issues

Document 802.16.1pc-00/27 proposes combining the D+ (Mode A) and E+ (Mode B) PHY layer proposals into a single proposed PHY layer document for use the baseline standard. Mode A is taken from the Mode A of the D+ proposal. Mode B is taken from the E+ proposal. Modifications from the original proposed MAC, 802.16.1mc-00/14(D+MAC), can be made in order to support this "merged" PHY proposal. The goal is to minimize these changes to the greatest extent possible. The following items discuss some of the issues that supporting the Mode B PHY layer from the E+ proposal has on the MAC layer:

- Network entry of a CPE must take into account the possibility that the CPE may be able to see either mode of the PHY layer implemented on a RF channel. The CPE must have a method for searching the channel(s) in an appropriate manner to gain access to the network in a fast and reliable manner. The process of acquiring the downstream channel is primarily a receiver implementation issue, but can be simplified by having a predefined set of possible PHY layer configurations, which can be addressed in the PHY group.
- Mode B of the proposal uses a downstream MAP message that conveys slot position (within a frame) information to the CPE. This information is used by the CPE in conjunction with a preamble to aid the acquisition of a downstream burst. Mode A does not rely upon this type of information since no gating mechanism is required for the continuous downstream transmissions.
- Mode B of the proposal uses an explicit framing structure with associated numbering for the frames. The Upstream and Downstream frames are linked together through this mechanism. Mode A uses an implicit framing that is controlled via MAP message timing. The linkage between the upstream and downstream is not explicit, other than controlling the Upstream timing with the use of synchronization messages.
- Bandwidth allocations from request messages and the corresponding grant differ between the two modes. Mode A manages requests and grants in units of mini-slots while Mode B uses Physical Slots (PS).

- The Network Entry Contention interval for ModeA is left up to the implementation at the base station and its scheduling algorithm. The Mode B intervals requiresthe BS to schedule the interval at the start of a downstream frame. Both use different burst profiles.
- The Request Contention interval for Mode A is left up to the implementation at the base station and its scheduling algorithm. Mode B intervals require the BS to schedule the interval following the Network Entry Contention interval. Both use different burst profiles.
- Mode B couples the frame numbering system to the user-data encryption process using a Counter Mode. The Mode A PHY is de-coupled from the security sub-layer. One, consistent security mechanism should be used.
- It is likely that some vendors will build CPEs that are capable of operating in both PHY modes. The mechanisms by which the CPEs inter-operate within available channels must be defined.
- Adaptive Modulation management messages are required to support the MODE B operation. These messages allow the CPE to request changes in the downstream modulation based upon measurement of the RF channel (C/I+N, etc.).
- Mode A uses a SYNC message to support timing control of the upstream channels in a given MAC domain. Mode B links the upstream and downstream timing together using its framing structure.

- MAC messages that are used to perform spectrum management and load balancing of the CPEs need to include additional information upon a Dynamic Channel Change to support movement between different operational Modes if the CPE has this capability.
- Error detection is performed at PHY level in Mode B. The operation of Mode A requires the MAC to handle error detection. One consistent method should support any error detection technique.

The following modifications to the MAC defined in IEEE 802.16.1mc-00/14 (D+) are suggested as a means to support the dual PHY approach. Each section defines the mechanisms in the MAC that resolve the "combined" PHY issues as outlined in the previous section.

1.1 Network Entry

The CPE must be able to search the downstream channels to which it has access. This is a standard function of any CPE. A CPE must always begin its search during network entry using parameters that are saved in non-volatile memory. This includes, at a minimum, the RF channel that it previously used and the type of channel (Mode A or B). This allows the CPE to quickly acquire a RF channel after the initial acquisition during CPE installation. These parameters may also be programmed into the CPE during the installation process.

When searching, a CPE that is capable of operating in only one of the two modes would only detect a channel that matches its capabilities. This is due to the synchronization technique used by Mode A, which requires a series of synchronization patterns to be found within the Transmission Convergence (TC) layer before declaring synchronization. A Mode A CPE would never find this synchronization on a Mode B channel. For a Mode B CPE searching for a Mode B channel, it requires a specific preamble to be found that delineates the start of a frame. The same "multiple preamble/sync" detection algorithm that is used for Mode A can be used for Mode B to aid in preventing false detects of a Mode B CPE on a Mode A channel.

During this process, the CPE must communicate the capability to operate within the PHY modes and sub-options to the BS via the MAC. The BS must authorize the use of capabilities. A model for this capability is currently defined in the D+ MAC. The only changes required are for the CPE to identify its capabilities (Mode A, Mode B, or both) during the registration process. This is done by adding a new (Type/Length/Value) TLV to the set of configuration settings in the "Modem Capabilities Set":

PHY Mode Support

This field indicates the different PHY modes the CPE is able to support.

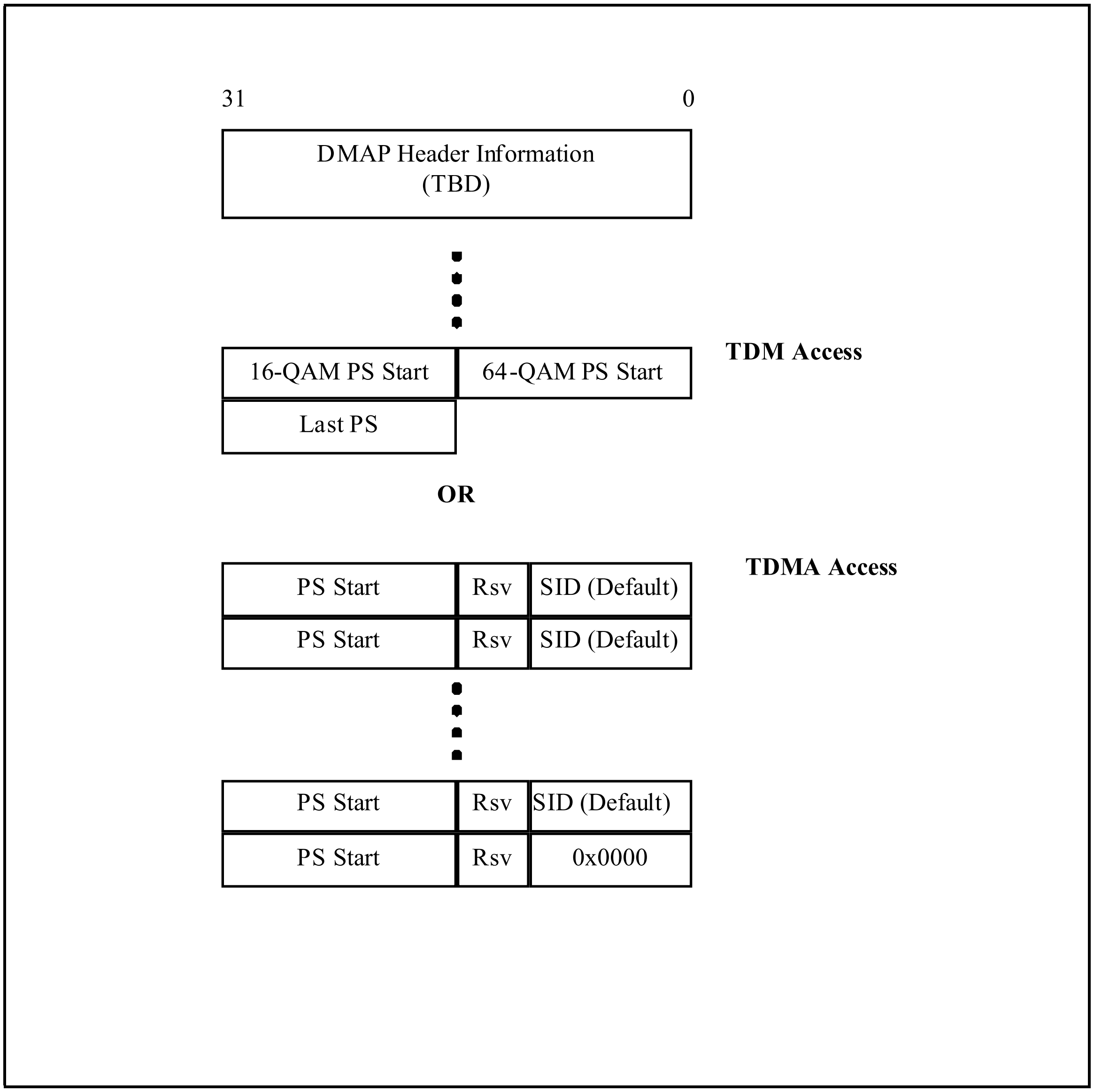
Type	Length	Value
5.15	1	Bit #0: Mode A Bit #1: Mode B Bits 2-7: Reserved

The definitions that were added to the Modem Capabilities Set for Session #7 already support the other required parameters that are associated with Mode B. This includes duplexing support, modulation support, etc.

1.2 Downstream MAP message

A new MAP message for downstream operation is required to support the Mode B operation of the PHY. This message format is given in the following diagram.

Figure 1 – Downstream MAP Message Format

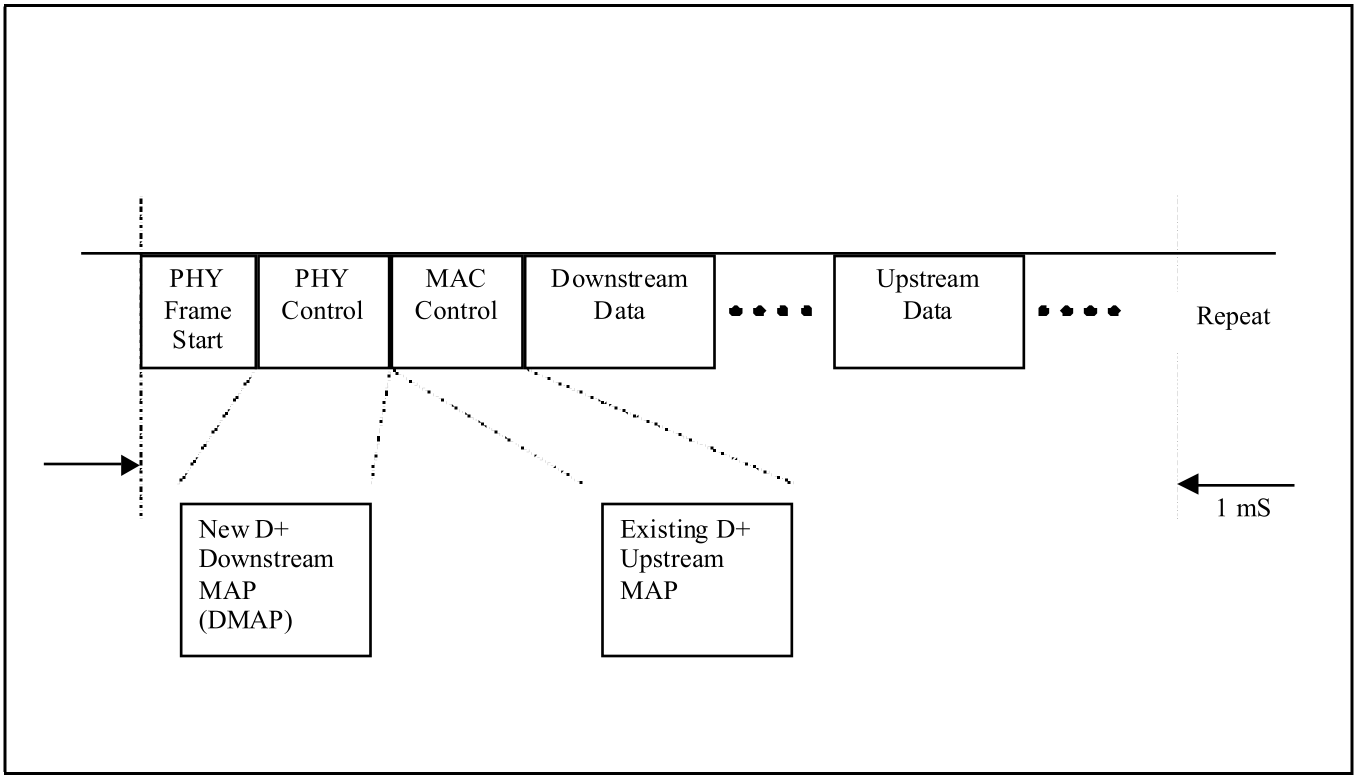


This message is only used for the Mode B operation. It is never used for the Mode A operation. The downstream MAP has two different formats, depending upon its use for TDM access to the downstream or TDMA access to the downstream. For the TDM case, it identifies the transition point between the QPSK and 16-QAM modulations. It also identifies the transition point between the 16-QAM and 64-QAM modulations and the end of the frame. The points are defined in terms of the Physical Slot (PS) on the downstream. The QPSK modulation region is implied within the MAP. For any modulation regions that are not used, the entry is set to 0x0000.

The second format of the MAP message is for use in supporting a network that has H-FDD terminals. This TDMA access MAP defines the starting PS for each of the CPE using the CPE's default Service Identifier (SID). The PS is defined as a 16-bit offset. The SID is a 13-bit quantity, leaving three reserved bits.

The downstream MAP message immediately precedes the upstream MAP for each one mS frame in the Mode B PHY. The following diagram illustrates the use of the downstream MAP message (DMAP) in conjunction with the upstream MAP message. Note that each frame begins with PHY-specific information that defines the start of a one mS frame independently from the MAC operation.

Figure 2 – MAP Message Ordering



1.3 Framing

Mode B uses a one mS (preferred) framing structure for both the upstream and downstream. The framing is explicit due to the use of a frame numbering scheme and the requirement that certain message types (PHY and MAC control) occur on specific boundaries at the start of every frame. Further, the upstream and downstream are linked such that the upstream and downstream PS are synchronized in time. The start of a 1 mS frame in a FDD system occurs at the same time for both the upstream and downstream, each contains an equivalent number of PS, and the first PS in each direction occur at the same time.

The D+ MAC provides the capability to support this framing structure since it allows a flexible use of the MAP messages. In general, the D+ MAC can schedule information at any time based upon the algorithm in the BS. This allows the BS to use the MAC on a framed PHY such as in Mode B's operation.

For example, assume a 20 Msps rate for a FDD (or H-FDD) Mode B network. Each frame consists of 5000 PS in each direction. The upstream uses a multiplier of two PS per mini-slot. For QPSK modulation, this gives a mini-slot size of 2 bytes for a total of 2500 mini-slots in a frame. The upstream and downstream are time synchronized such that the start of each upstream mini-slot corresponds to the start of every other downstream PS.

The start of a frame is always demarcated by Preamble that is independent of the MAC layer. This is followed by the PHY control and MAC control messages. The PHY control message (Downstream MAP or DMAP) has a concise format that allows for quick hardware parsing by the CPE. This format is given in Figure 1. For TDD, the entire frame is mapped by the DMAP and MAP messages. The DMAP always defines the current frame's downstream access and the MAP always defines the following frame's upstream access.

1.4 Bandwidth Allocation and the Upstream Map Message (MAP)

Mode A requires the upstream bandwidth allocations to be performed in units of mini-slots, whose size are defined in the UCD message. Mode B requires the upstream bandwidth allocations to be performed in units of Physical Slots (PS). A mini-slot is typically 4 to 8 bytes in length. The size of a PS (in bytes) is a function of the modulation type. For QPSK, the PS size is 1 byte, for 16-QAM it is 2 bytes, and for 64-QAM it is 3 bytes[1]. Allocations in the MAP message are also done in equivalent units.

The REQ message format provides an 8-bit field to support requesting up to 256 mini-slots. When requesting PS using MODE B, the PS can be defined in units of mini-slots, with mini-slots mapping to one or more PS (as defined in the UCD message). This definition allows a consistent mapping of the size of the request to the two PHY modes. The MAP message responds with the equivalent allocation of mini-slots for every Interval Usage Code (IUC). Again, the same mapping of PS to mini-slots can be used. The allocation field in the MAP message is a 13-bit offset, allowing for the larger allocations that are used when aggregating upstream bandwidth requests for Mode B.

The definition of the mini-slot size field would be done using the same equations already defined with the additional multiplier of the PS size.

Mode A has FDD duplexing scheme that is optimized for continuous operation. This requires the allocation of upstream bandwidth to be performed relative to the MAP message, as opposed to a PHY framing mechanism. The MAP message specifies the starting mini-slot relative to the upstream time stamp clock. For Mode B operation, the *Alloc Start Time* parameter is always set to the first PS in the frame of the first upstream burst. This forces the MAP offsets to be relative to the start of the 1 mS frame.

1.5 Upstream Burst Profiles and Adaptive Modulation

The MAP message defines three pairs of data intervals that can be used to support adaptive modulation in the upstream direction. Each pair of IUCs (short and long data grant) allows for a different upstream burst profile. Each burst profile can be of a different modulation type, as well as other PHY characteristics. This includes FEC values (T and k), guard size, etc. A BS can be provisioned to support both modes of PHY operation using different profiles.

For example, the first burst profile pair would be defined to support QPSK bursts. The second pair would define 16-QAM bursts and the third pair would define 64-QAM bursts.

1.6 Adaptive Modulation Management Messages

Management of Adaptive Modulation is handled in two different manners depending upon the direction in the RF channel that it is applied. Adaptive modulation in the upstream has been supported by the D+ MAC since the first proposal. Support is given by a combination of the UCD definitions of upstream burst profiles and the assignment of those profiles on a per SID (or CPE) basis.

For the downstream, a full set of management message have been added to the D+ MAC and are defined in the current proposal. These messages allow a CPE to request a specific modulation type based upon a RF channel metric that is measured by an algorithm in the CPE. The CPE can request downstream modulation changes when operating with a Mode B PHY. Since these messages are an extension of the ranging messages, all new values are encoded as TLVs. This allows the ranging messages to work with both PHY modes of operations without structural change to the ranging messages. In other words, the TLV approach allows the same basic message set for ranging to support both PHY modes.

The following set of TLVs were added to the RNG-RSP message (BS to CPE):

16-QAM Threshold An optional parameter. The threshold for transition between QPSK and 16-QAM on a downstream channel is specified by the BS for use by the CPE.

64-QAM Threshold An optional parameter. The threshold for transition between 16-QAM and 64-QAM on a downstream channel is specified by the BS for use by the CPE.

[1] The sizing is modified when a parity bit is included

Threshold Delta An optional parameter. The delta about which a hysteresis is defined for transition of the SS between modulation types. Used by the CPE in conjunction with the 16-QAM and 64-QAM thresholds to determine when to request a modulation change for the downstream channel.

Modulation Type An optional parameter. The maximum allowed set of Modulation types allowed for the SS for downstream traffic. This parameter is sent in response to the RNG-REQ Modulation Type from the CPE. The BS responds with the maximum allowed set of modulation types based upon the combination of the requested modulation type and the maximum allowable modulation type determined at registration or from a dynamic service operation.

The following set of TLVs were added to the RNG-REQ message (CPE to BS):

Modulation Type An optional parameter. The Modulation type requested by the CPE for downstream traffic. The CPE determines the appropriate modulation type to use based upon measurements of the downstream RF channel relative to the Modulation Transition Thresholds defined in the RNG-RSP message.

The BS provides ranging opportunities at intervals best suited to the network operation. The CPE use these opportunities to initiate the ranging process by sending a RNG-REQ message. If the CPE has determined the need for a modulation change (based on the parameters from the previous ranging response), then it adds the new modulation TLV to the RNG-REQ message. The BS acts upon this message according to the provisioned limits for the CPE. More on this process can be found in IEEE 802.16.1mc-00/14, "Media Access Control Layer Proposal for the 802.1 Air Interface Standard".

1.7 Network Entry Contention Interval

The MAP message allows flexible definition of size and placement of the Initial Maintenance interval. The same MAP format and function can be used in both modes of PHY operation without change. The ability to specify a particular upstream burst profile (FEC, etc.) allows either PHY mode to be supported without modification of the MAC protocol.

Mode B specifies a value of T = 2 and K = 14. These values can be easily assigned to the IUC for the Initial Maintenance interval using the standard UCD message. The MAP message would then allocate the required number of PS for the maintenance interval. Note that the length of the contention interval could change from frame to frame and that this is handled via the upstream MAP allocation.

Continuing ranging is also supported in the same manner. A separate set of burst profiles can be defined for the Station Maintenance intervals for either type of PHY mode. Further, these can be tailored to specific operation by a vendors implementation or by provisioning. This allows tailoring of the network access parameters as appropriate for a specific deployment scenario.

1.8 Request Contention Interval

The MAP message allows flexible definition of size and placement of the Station Maintenance interval. The same MAP format and function can be used in both modes of PHY operation without change. The ability to specify a particular upstream burst profile (FEC, etc.) allows either PHY mode to be supported without modification of the MAC protocol.

Mode B specifies a value of T = 3 and K = 5. These values can be easily assigned to the IUC for the request contention interval using the standard UCD message. The MAP message would then allocate the required number of PS for the contention interval. Note that the length of the contention interval could change from frame to frame and that this is handled via the upstream MAP allocation.

1.9 Encryption

The D+ MAC does not require knowledge of the frame numbering scheme since it using the Cipher Block Chaining (CBC) mode of operation. This allows the encryption methods defined in the MAC to support both PHY modes.

1.10 Upstream Synchronization

Mode A requires a mechanism to provide synchronization of the CPEs to ensure upstream burst timing is correct. This is achieved using the SYNC message in conjunction with the MAP message. Both messages are inherent in the D+ MAC. These messages are not needed for Mode B operation

1.11 Load Balancing and Spectrum Management

When a deployment has more than one RF channel available in sector, it is possible to move CPEs among those channels to efficiently balance the load on a given channel. It is possible that the different PHY modes would be operating on accessible channels within the same sector or that dual-mode capable CPEs would be operating in the same sector. In both cases, movement of the CPEs for spectrum management, load balancing, or capacity build-out requires the BS to know the capability of each CPE.

This information is made available to the BS when the CPE enters the network as part of the standard D+ MAC procedure. Specifically, the complete capability set of the CPE is sent to the BS during registration in the REG-REQ message. This information is authenticated by the BS and a response is sent to the CPE with the authorized set of services.

The Dynamic Channel Change (DCC) MAC message is defined to allow a CPE to move between upstream and downstream channels (or a combination of both). This message is slightly modified to support the movement of CPEs between the two different types of PHY modes.

1.12 Error Detection

Error detection is performed at PHY level in Mode B using the TDU structure. The operation of Mode A requires the MAC to handle error detection. The simplest method for resolving this issue is to move error detection out of the TDU and into to the MAC. The ramifications of this change and its relevance to any ARQ strategies needs further investigation.

2 Conclusions

The proposed changes to the MAC as defined in IEEE 802.16.1mc-00/14 (D+) allow an efficient means for supporting both modes of the proposed PHY layer. This is possible due to the flexible design of that MAC layer protocol.