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Re: Call for Contributions: Initial PHY Proposals (IEEE 802.16.3-00/14)

Abstract A PHY is proposed for 802.16.3 in which modulation format and coding rate can be adjusted on a block by block basis to provide optimum channel utilization for the widest range of channel conditions.

Purpose This proposal is offered as a PHY layer for the 802.16.3 Task Group

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# A “Block” Adaptive Modulation and Coding PHY

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## Overview

In contrast to most wire line networks, wireless networks typically involve network paths having widely different propagation characteristics. In particular for the MAN applications envisioned as the target markets in the IEEE 802.16.3 Functional Requirements Document (IEEE 802.16.3-00/02r4) some subscribers may have unobstructed Line of Sight (LOS) links with ranges of only a few kilometers, while others may have ranges of as much as 50 kilometers, still other links may be only a few kilometers in length but suffer substantial blockage of the LOS path. In many of the wireless networks currently in service, the transmission parameters (modulation format, Forward Error Correction, channel bandwidth, etc) are adjusted to provide an acceptable level of performance to the most impaired link. This approach then limits the performance that might be offered to subscribers with less impaired channels. Clearly this traditional method results in sub-optimal utilization of the total channel capacity.

Schemes offering varied modulation and coding for different classes of channel propagation conditions by assigning user classes to different physical channels are a step in the direction of improved channel utilization, but do not completely address the dynamic nature of network traffic and its impact on required link gains. The proposed PHY layer described below optimizes channel utilization by permitting dynamic adaptation of both modulation format and Forward Error Correction (FEC) rate on a subscriber-by-subscriber basis. Further the proposed PHY also enables the ability to adjust the characteristics of an individual subscriber's modulation format and FEC rate. Thus, if the channel characteristics vary over time, say seasonal variations in path loss caused by the presence or absence of foliage, that subscriber’s modulation and coding parameters can be adjusted to compensate for these changes.

For simplicity and lowest-cost implementation, PHY layer is based upon a single-carrier modulation plan utilizing a Decision Feedback Equalizer to compensate for multipath channels. The PHY layer described here offers the capability to adapt the modulation and coding over a wide range to compensate for varying channel conditions. In particular, the modulation format could be BPSK, QPSK, 8PSK, 16QAM, 64QAM or 256QAM in either upstream or downstream. If the FEC was done using Turbo Product coding as in 802.16.1, adjustment of coding rate over a range of 0.2 to .90 is possible. The range of channel parameters is show in Table 1;

| Parameter | Value |
|---|---|
| Downstream modulation | BPSK, QPSK, 8-PSK,16-QAM, 32-QAM, 64-QAM required;<br>128-QAM, 256-QAM optional |
| Downstream symbol rates | 1.4 - 5.36 Msym/s |
| Upstream modulation | BPSK, QPSK, 8-PSK,16-QAM required;<br>32-QAM, 64-QAM optional |
| U | |

Table 1: Channel Parameters

## The “Block-Adaptive” PHY

The “Block-Adaptive“ PHY is based upon a Frequency Division Duplex (FDD) approach employing DOCSIS-like TDM data distribution in the downstream path and Time Division Multiple Access (TDMA) in the upstream direction. Although it is envisioned that many traffic models will require asymmetric data rates in the downstream and upstream directions, the PHY layer proposed here allows for symmetric data rates if so desired. Further, the proposed PHY will support a wide range of channel bandwidths and assignment plans.

### Block Structure

In the “Block-Adaptive” structure the data is partitioned into Blocks delimited by a Block Identifier Word. Each Block represents a unit of data to be sent to an individual subscriber. For convenience in working with DOCSIS-like MAC structures, the discussions that follow will be based upon Blocks being built from an integral number of MPEG-2 frames. However, as will be shown this is not required, the blocks can be of arbitrary length. The number of frames that comprise each block can be varied individually, block by block, or as either a network-wide parameter or on a dynamically adapted basis. The first element of the “Block-Adaptive” PHY transport mechanism is shown in Figure 1, below:

### Block Identifier Word

The Block Identifier Word consists of two fields: A Unique Word and a Code Word. The Block Identifier Word indicates the beginning of one particular modulation/coding format, and, equivalently, the end of another. In other words, a pair of Block Identifier Words 'frame' the duration of a particular modulation format--indicating a particular frame's length. There is only ONE Unique Word, and it is defined by a string of U uncoded symbols transmitted in the lowest order modulation format, *i.e.* BPSK. The Unique Word is designed with good autocorrelation properties, so that its location is easily detected. It is also long enough so that the probability of the same sequence occurring in random data is very, very low.

In contrast, there are SEVERAL 'Code Words'--one for each possible modulation and coding scheme. A 'Code Word' signals what the modulation/code rate should be for the next frame. It is ALWAYS located X symbols after a Unique Word, and is a string of symbols W symbols long. Each Code Word is also taken from an uncoded lowest order modulation alphabet. The structure of the Block Identifier Word is shown in Figure 2.

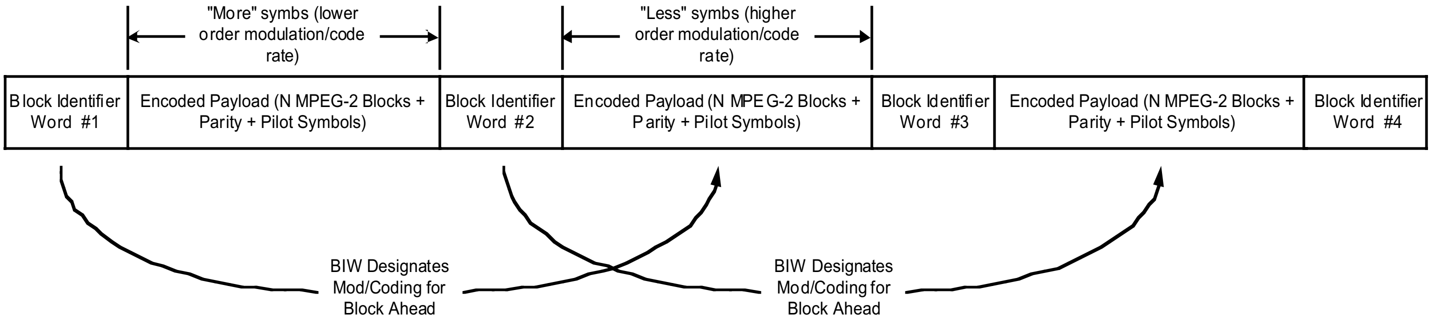


Figure 1: “Block-Adaptive” Transport Mechanism

Since the Unique Word is uncoded, one detector of the Unique Word could be a correlator, run in open aperture mode. Use of a correlator could enable rapid acquisition. Note that either coherent or differential symbol correlation of the Unique Word is possible. Differential correlation would aid rapid acquisition in the presence of frequency and phase offsets--and assist rapid re-acquisition during channel changes. However, differential correlation would also provide lower performance while in tracking lock.

| | | |
|---|---|---|
| Unique Word<br>(U uncoded symbs) | Offset<br>(x symbs) | Code Word<br>(W uncoded symbs) |

Figure 2: Block Identifier Word Structure

Detectors for the Code Word signals could be a bank of correlators, that compare the correlation return for the strongest correlation. Note that since the location of the Code Words is known, the autocorrelation properties of any single Code Word do not have to be strong. However, the cross-correlation properties should be good; in other words, the Code Words should have a large minimum distance between each candidate. Note that a bank of correlator-comparators provides the maximum likelihood decision test statistics for QPSK-based code words.

### Intra-Block Structure

Each Block Identification Word is sent uncoded, in the lowest order modulation format. As shown in Figure 1, the Block Identification Word designates the modulation and coding parameters for the block-after-next in the data stream. Each block contains a payload that is an integer number of encoded N MPEG frames, plus parity data and pilot symbols. The function of the pilot symbols is to facilitate carrier phase tracking within the block. The pilot symbols can be aggregated in bursts to permit averaging of Additive White Gaussian Noise (AWGN) and are regularly spaced within each block to simplify tracking loop implementation. The number and spacing of pilot symbols could either set as a network parameter across all traffic or be included as one of the parameters defined by the Unique Word. Figure 3 illustrates the intrablock structure and the pilot symbols.

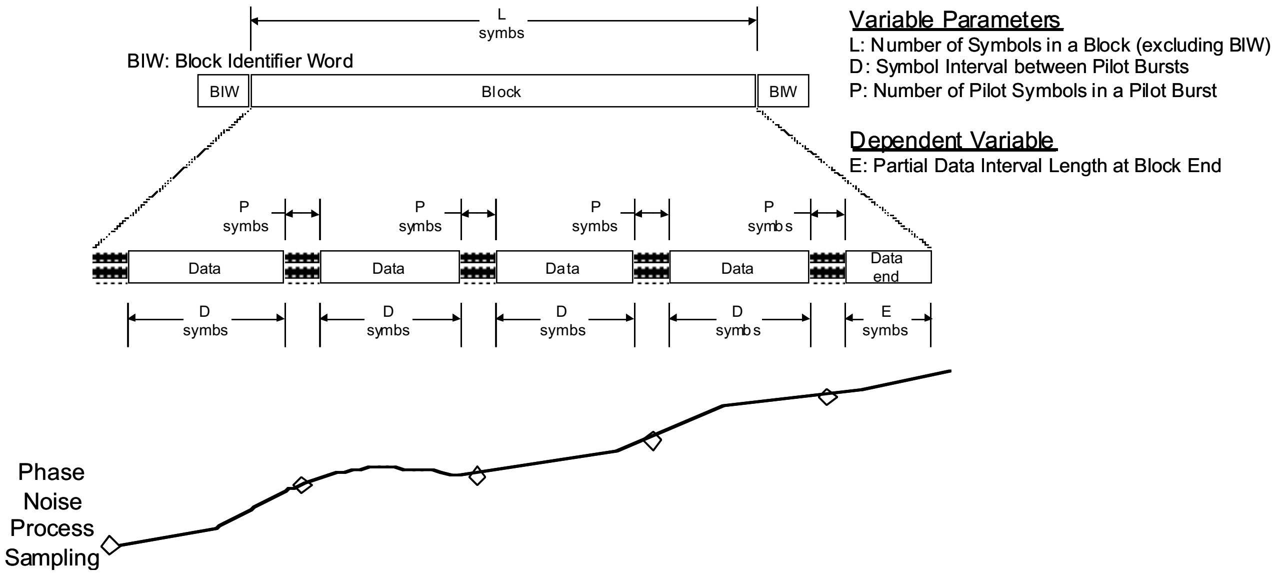


Figure 3: "Block-Adaptive" Pilot Symbols

## Benefits of the "Block-Adaptive" PHY

The most important benefit of the "Block-Adaptive" PHY is the ability to adjust the gain for each link so that each subscriber has just enough link gain to maintain the grade of service required for that link. By doing so, the optimal spectral efficiency is maintained. Note that in the case of the "Block-Adaptive" PHY the usual metric of spectral efficiency, bits/second/Hz, is not totally relevant since a given link might include transmission at several different modulation formats and coding rates depending on mix of traffic and the impairments present in each subscribers channel. Higher layer scheduling protocols offer the mechanism to optimize the mix of traffic to satisfy QoS requirements for each subscriber.

Exploitation of the correlation properties of the Unique Words offers a mechanism for quickly establishing block synchronization, upon either initial channel acquisition or if the subscriber station were reassigned to another downstream channel. Since all the modulation waveforms are coherent to a common carrier frequency, a single carrier acquisition loop in the receiver would be capable of tracking all the modulation waveforms. The Downstream Channel Descriptor (DCD) and the Downstream Link MAP (DL-MAP) messages in the 802.16 MAC will be sent at the lowest order modulation at the most robust FEC on that carrier, ensuring their reception by the most impaired subscribers on that carrier. This information will be used to set the modulation format and FEC rate for that subscriber. In the acquisition process, the subscriber station will return information to the base station indicating the quality of the downstream channel. Once these parameters are set, the subscriber station need only look for Unique Words at rates equal to, or lower than the matching combination of modulation and FEC assigned by the base station.

Table 2 illustrates the range over which the link can be adjusted to match the requirements for the characteristics of an individual channel. In Table 2 the link gain is normalized to the combination of 64QAM modulation. From Table 2 it can be seen that by adjusting modulation format 24 dB of control can be affected in the link gain.

| Modulation Format | Relative Link Gain |
|---|---|
| **BPSK** | 18 dB |
| **QPSK** | 12 dB |
| **16QAM** | 6 dB |
| **64QAM** | 0 dB |
| **256QAM** | -6 dB |

Table 2: Control Range of Link Gain and Channel Capacity

Figure 5 [1] shows the channel bandwidth efficiency in Bps/Hz for the various modulation formats as a function of Eb/No:

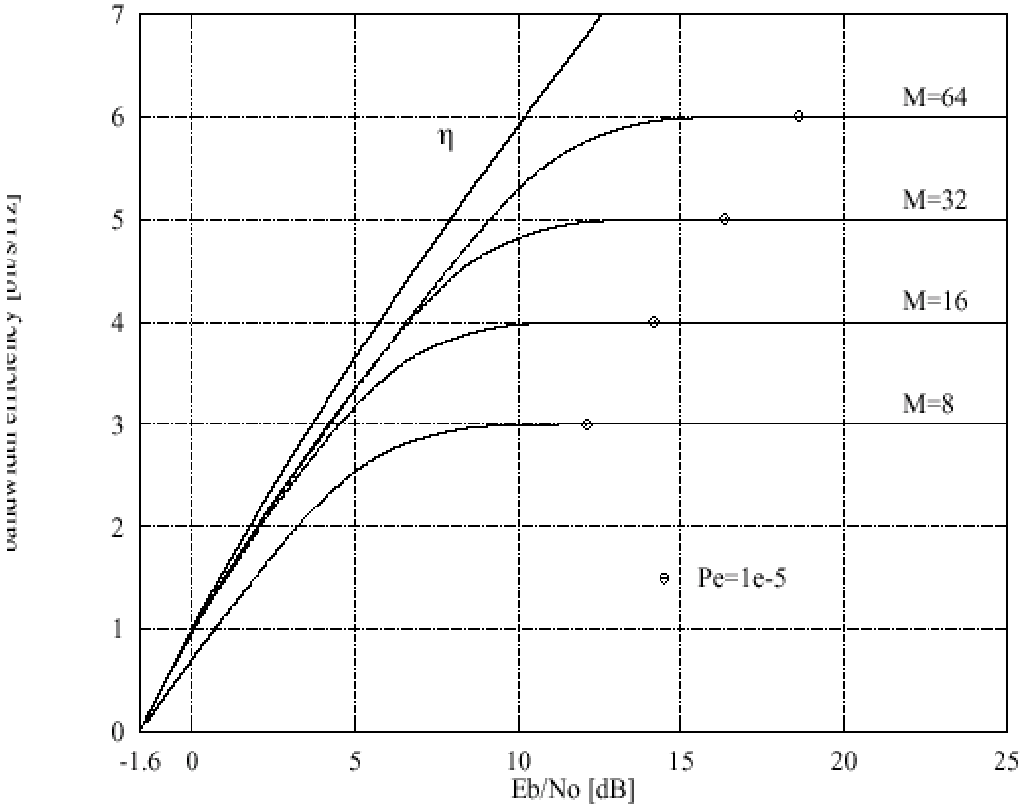
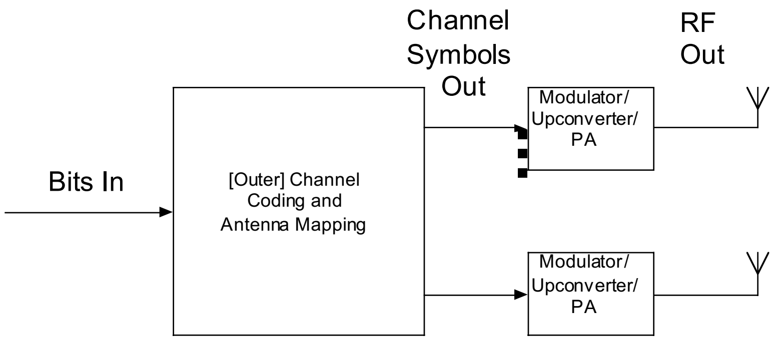


Figure 5: Bandwidth Efficiency for Various Modulation Formats

## Support for Multiple Antenna Spatial Diversity

While the adaptive modulation and coding systems described here offer mechanisms to dynamically allocate network resources to subscribers based on the link requirements, the concepts can be extended to exploit spatial diversity to extend system capacity. The conceptual structure for a dual transmitter spatial diversity implementation is shown in Figure 6. In the system the data stream is encoded by the inner code and interleaved then passed to the outer coder and mapped to the two transmit antennas. On the receiver end of the link the symmetric process takes place and the two streams are combined in a structure analogous to a Decision Feedback Equalizer. The performance gain that might be achieved by a configuration of two transmit antennas and two receive antennas is shown in Figure 7.

Figure 6 Spatial Diversity Conceptual Structure



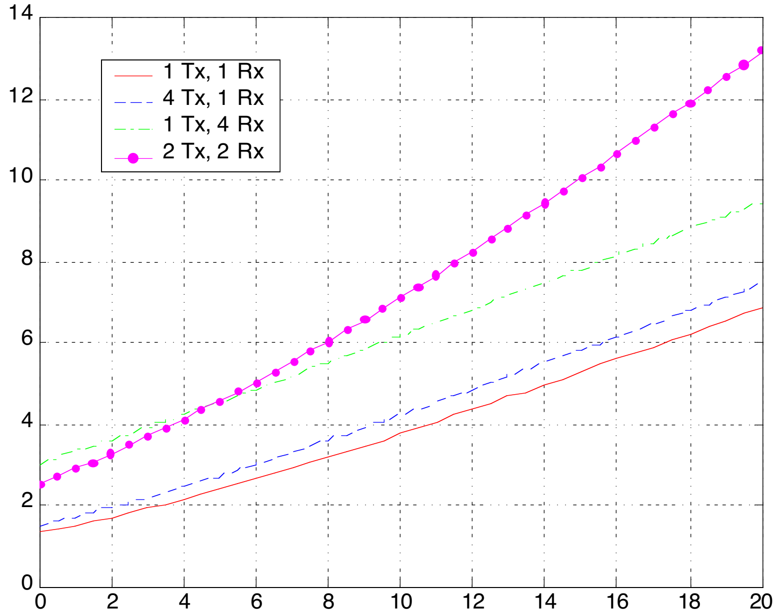


Figure 7:Channel Capacity for 4th Order Spatial Diversity

## Disadvantages of the "Block-Adaptive" PHY

The principal disadvantage of the "Block-Adaptive" PHY is the overhead imposed by the Unique Word when employing short blocks. Under some combinations of poor channel conditions it is advantageous to shorten the length of the transmitted block to minimize bandwidth lost to retransmissions. In other circumstances, the data traffic and its assigned Class of Service may be better served with short packets. Voice traffic is an example of this type of data traffic. Under these conditions, the overhead of the unique word can become an appreciable portion of the total symbol count. The impact of this overhead is mitigated by two mechanisms: The fact that in a given coverage region, only a fraction of the subscribers might need the additional protection offered by a short block; and the potential to concatenate short packets reduces the need for minimal length blocks. Thus the capability of the PHY to adjust link parameters to provide the required level of service to each subscriber works to limit the negative impact of the Unique Word by assuring that only the individual links needing this additional protection get it.

## Relationship to Existing Standards

The "Block-Adaptive" PHY proposed here generally follows the Downstream-Upstream access methods of DOCSIS and 802.16. The MAC sections of the Draft 802.16 Air Interface Standard provide appropriate means of controlling Media Access for the PHY proposed here.

## Scalability

The PHY proposed here does not impose limits on the ability to efficiently transport the several data types described in the 802.16.3 Functional Requirements Document. In particular the adaptive nature of the PHY in concert with higher layer scheduling algorithms offers the ability to extend QoS controls to a wider range of subscribers in a given coverage area.

### References:

1. Philip McIllree; *CHANNEL CAPACITY CALCULATIONS FOR M–ARY N–DIMENSIONAL SIGNAL SETS*; The University Of South Australia School Of Electronic Engineering; February, 1995