Project	**IEEE 802.16 Broadband Wireless Access Working Group**
Title	PHY layer proposal for BWA
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Re:	This contribution is submitted in response to call for contributions from the IEEE 802.16 chair on Sept.29nd, 1999 for submission of PHY proposals for BWA
Abstract	The following PHY proposal is submitted for consideration of the group developing a PHY standard for BWA systems
Purpose	This proposal should be used as a baseline for a PHY standard for BWA
Notice	
Release	
IEEE Patent Policy	

PHY Layer Proposal for 802.16 BWA Systems

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1 Introduction

The following contribution proposes a basis for a *wireless* PHY layer standard enabling *broadband* services to users in a *Point to Multi-Point* (PMP) topology, typically using high frequency bands as *millimeter waves*. Spectrum resources are used efficiently with consideration of implementation costs. The proposal addresses spectrum allocations suitable either for FDD or TDD (dual mode) permitting deployments world wide using a single technology.

2 Frequency Bands & Channel Bandwidths

IEEE 802.16 is considering millimeter wave frequencies as the target operational frequency band, specifically those above 10 GHz. Line of Sight (LOS) communications is mandatory at these frequencies. Typical cell radius in a PMP deployment is limited to a few kilometers due to radio technology (i.e., power amplifiers) and susceptibility to rain attenuation. One outcome of these conditions is the fact that channel bandwidth could be large, hence enabling high bit rates with low to moderate modulation schemes.

The vast amount of available spectrum options worldwide points out additional requirements:

- There are frequency bands that historically follow ETSI recommendations. Recommended relevant channel bandwidths are 14 MHz, 28 MHz and 56 MHz.
- Other frequency bands and new worldwide spectrum allocations favor channel bandwidths of either 20 MHz and 40 MHz or 25 MHz and 50 MHz.
- Both FDD and TDD should be supported.

Smaller channels are not considered due to the fact that it would require complex modulation schemes to enable very high bit rates. Complex modulation schemes are much more susceptible to co-channel interference which is a major problem in PMP deployments.

The following table recommends modem baud rates and channel sizes. The proposed pulse shape is Nyquist Root-Raised Cosine with a roll-off factor of 0.25.

Baud Rate (MBaud)	Channel Bandwidth (US) (MHz)	Channel Bandwidth (ETSI) (MHz)
40	50	56
32	40	-
20	25	28
16	20	-
10	12.5	14

3 Modulation & Subscriber Level Adaptive Modulation (SLAM)

Single carrier QAM is used both for upstream and downstream. The following QAM levels are included:

- QPSK (QAM-4)
- QAM-16
- QAM-64

Subscriber Level Adaptive Modulation (SLAM) is used for compromising efficiently between coverage and capacity. In traditional Carrier Level Adaptive Modulation (CLAM) the modulation level of the RF carrier is set to one of the available modulation choices offered by the system. The main problem of this approach is the inefficiency involved while dealing with the dynamic nature of bandwidth requirements of different users. For example, if a carrier were set to QAM-64, then only users that have excellent link conditions would be capable of using it even if the carrier is not fully utilized (i.e., only a few QAM-64 users require bandwidth), other users with different link conditions are prohibited of using it, hence bandwidth is wasted. SLAM solves this problem by allowing the use of different modulation levels chosen according to the link condition of each subscriber using the same RF carrier. Details of the proposed scheme are presented in the following sections.

The channel bandwidth is set according to targeted spectrum. Both channel bandwidth and channel baud rate is fixed for a specific deployment. The following table summarizes peak bit rates for different channel sizes:

Channel Baud Rate (MBaud)	Peak Bit Rate (QPSK) (Mbps)	Peak Bit Rate (QAM-16) (Mbps)	Peak Bit Rate (QAM-64) (Mbps)
40	80	160	240
32	64	128	192
20(*)	40	80	120
16	32	64	96
10	20	40	60

(*) Recommended for LMDS Block A

4 Multiplexing, Multiple Access and Duplex Scheme

Multiplexing and multiple access management is done in the time domain:

- Time Division Multiplex (TDM) for downstream
- Time Division Multiple Access (TDMA) for upstream

The TDM stream contains all user downstream data and downstream control information multiplexed in time. For the upstream, TDMA allows each user to access the system on a scheduled basis according to its bandwidth needs. Contention based access is limited to scheduled time periods as well (i.e., registration).

The downstream and upstream duplex scheme could be done either in the time domain (TDD) or in the frequency domain (FDD). In both cases it is assumed that the channel bandwidth required for downstream communications is identical to the bandwidth required by upstream communications as it will be benefitial to allow the end user to peak to high bit rates. If the allocation is prefixed to some asymmetrical ratio then it will be impractical to balance link asymmetry by modulation level settings only.

In the case of FDD, the following proposal supports a low cost user terminal that is not capable of transmitting and receiving at the same instant (a.k.a Half-duplex FDD or H-FDD). The proposal allows mixture of both low cost H-FDD terminals and FDD terminals.

5 Physical Slots (PS) & Frames

The following description applies both for downstream and upstream. A Physical Slot (PS) is consists of 25 symbols. This number is fixed and independent of modulation scheme or channel baud rate. The number of bits in a PS depends on modulation level:

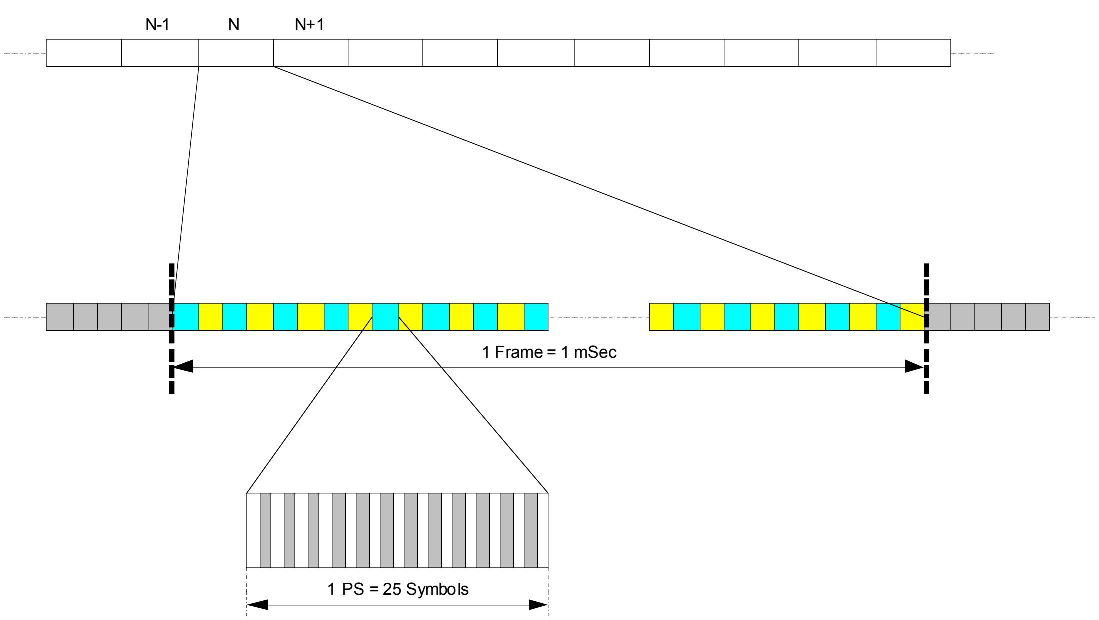
Modulation	Bits in PS
QPSK	50
QAM-16	100
QAM-64	150

A Frame has a duration of $T_F = 1$ mSec which is fixed and independent of modulation scheme, channel baud rate or duplex scheme. The number of PSs in a single frame, depends on channel baud rate:

Channel Baud Rate (Mbaud)	No. of PSs
40	1600
32	1280
20(*)	800
16	640
10	400

(*) Recommeded for LMDS block A

A PS defines the granularity level the PHY frame. A single PS allocated every frame has the equivalent gross rate of 25 Kbaud. Depending on modulation level this would translate to 50 Kbps, 100 Kbps and 150 Kbps for QPSK, QAM-16 and QAM-64 respectively. The MAC layer controls frame construction using a PS as its basic building block as example, bandwidth allocated on the upstream is done on PS boundaries.



6 Preamble

A preamble occupies a single PS and consists of 25 symbols. A downstream frame has a preamble occupying its first PS. Each upstream transmission must start with a preamble as well. Preambles are different for downstream and upstream. There are different preambles for the different modulation levels. Preambles are used for frame synchronization and equalization training if necessary.

7 Guard Time

A Guard time is needed for either upstream TDMA transmissions (transmitter turn on/off) or TDD transmit-receive transitions. The recommended guard time is an integer number of PSs with the recommendation of using a single PS. The guard time duration depends on the channel baud rate (assuming one PS per guard time):

Channel Baud Rate (Mbaud)	Guard Time Duration (μSec)
40	0.625
32	0.781
20(*)	1.250
16	1.562
10	2.500

(*) Recommended for LMDS block A

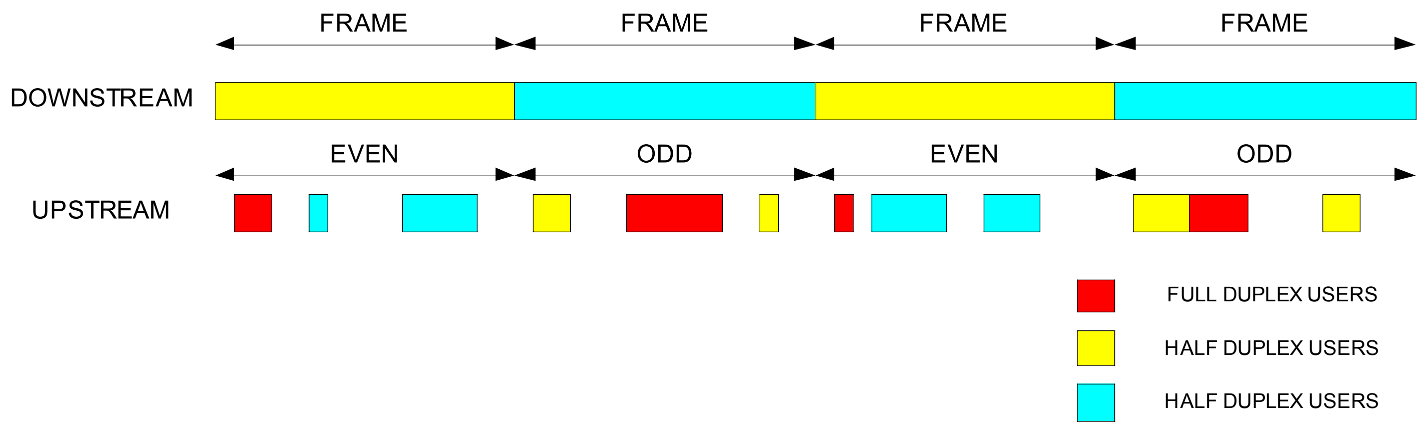
TC/MAC layer can schedule an overlapping guard times for turn off of one burst and a turn on of the burst after. This would allow increased link efficiency as less time is wasted.

8 FDD and H-FDD Operation

In this mode of operation the downstream and upstream are using 2 different carrier frequencies. Both carriers are equal in channel bandwidth *and* instantaneous baud rate. The frequency separation between carriers is set either according to the target spectrum regulations or to some value sufficient for complying with radio channel transmit/receive isolation and desensitization requirements. In the time domain both upstream and downstream are frame *synchronized*.

A subscriber capable of full duplex FDD operation, meaning it is capable of transmitting and receiving at the same instant, imposes no restriction on the hub (or base station) controller regarding its upstream bandwidth allocation management. On the other hand, a subscriber that is limited to half duplex FDD operation imposes a restriction on such a controller not to allocate upstream bandwidth for the subscriber, which may force it to instantaneously transmit and receive. It is mandatory that both types of subscribers could co-exist in a FDD deployment, meaning that radio channels could address both type of subscribers instantaneously.

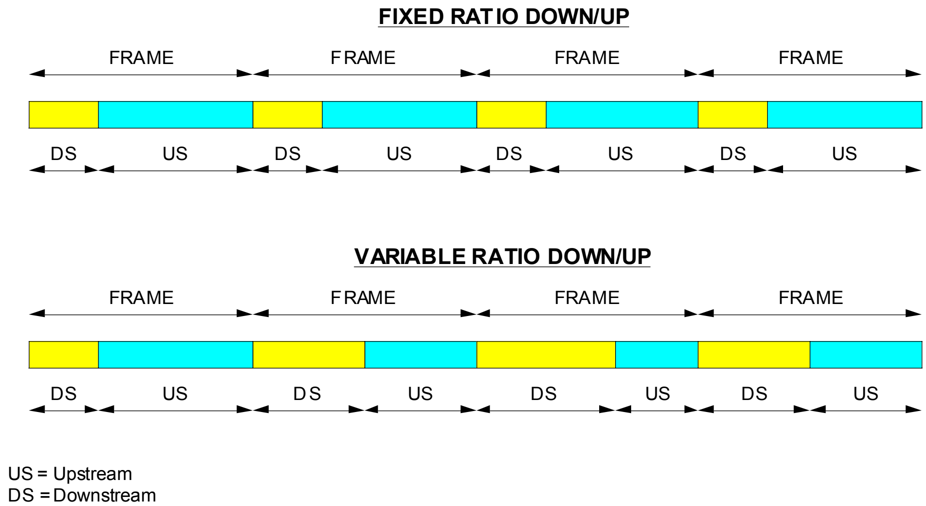
The following figure describes the basics of the FDD and H-FDD based operation. Frames are either even numbered or odd numbered. A subscriber limited to H-FDD operation is designated at registration to operate either on even frames or odd frames. Those that are receiving downstream on even frames are using odd frames for upstream and vice versa. A user that is capable of full duplex FDD ignores the even/odd structure and may utilize the system on both even and odd frames.



9 TDD Operation

In this mode of operation the downstream and upstream are time-sharing a single carrier frequency. In either case they both occupy the same channel bandwidth and maintain the same instantaneous baud rate.

Downstream communications occurs on every frame start and ends on a PS boundary within the frame. Upstream communications occurs immediately afterwards and ends on frame end. The point of transition between downstream and upstream may occur almost on any PS boundary. The transition point information is part of some PHY related control information supplied on each frame start and could be either fixed or variable from frame to frame according to current link asymmetry requirements.

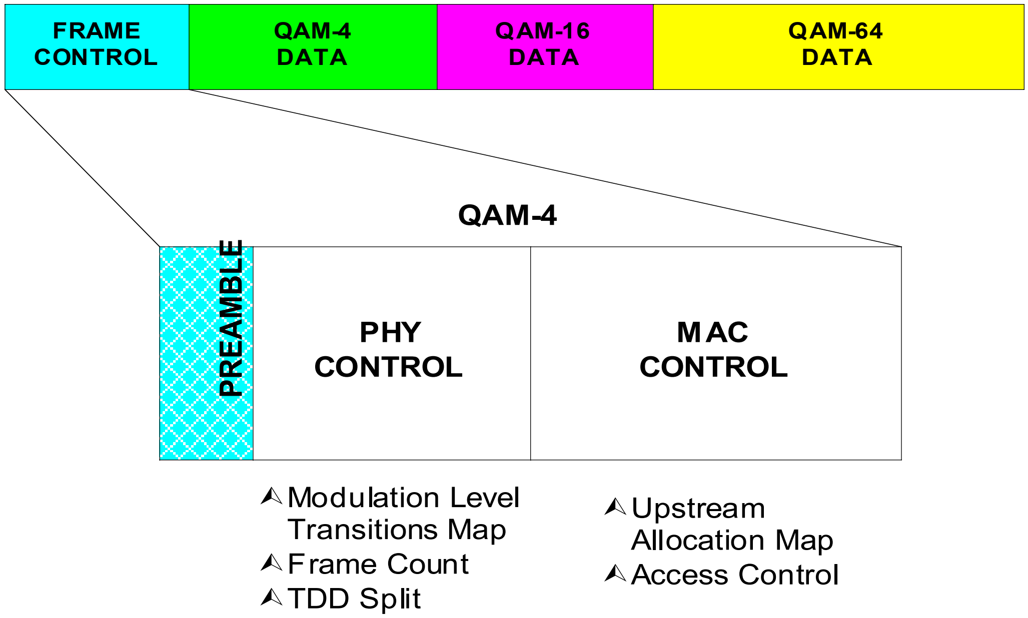


10 PHY Information Elements

The basic information element handled by the PHY (PI – PHY Information Element) is a 300-bit block which includes FEC overhead. The main protection of data is related to the use of a Reed Solomon code with an overhead of about 30%. Data prior to FEC is scrambled. Scrambling synchronization is done on PI basis. The number of PSs required to transport a PI is an integer number depending on the modulation scheme used:

Modulation Used	Number of PSs required for PI
QPSK	6
QAM-16	3
QAM-64	2

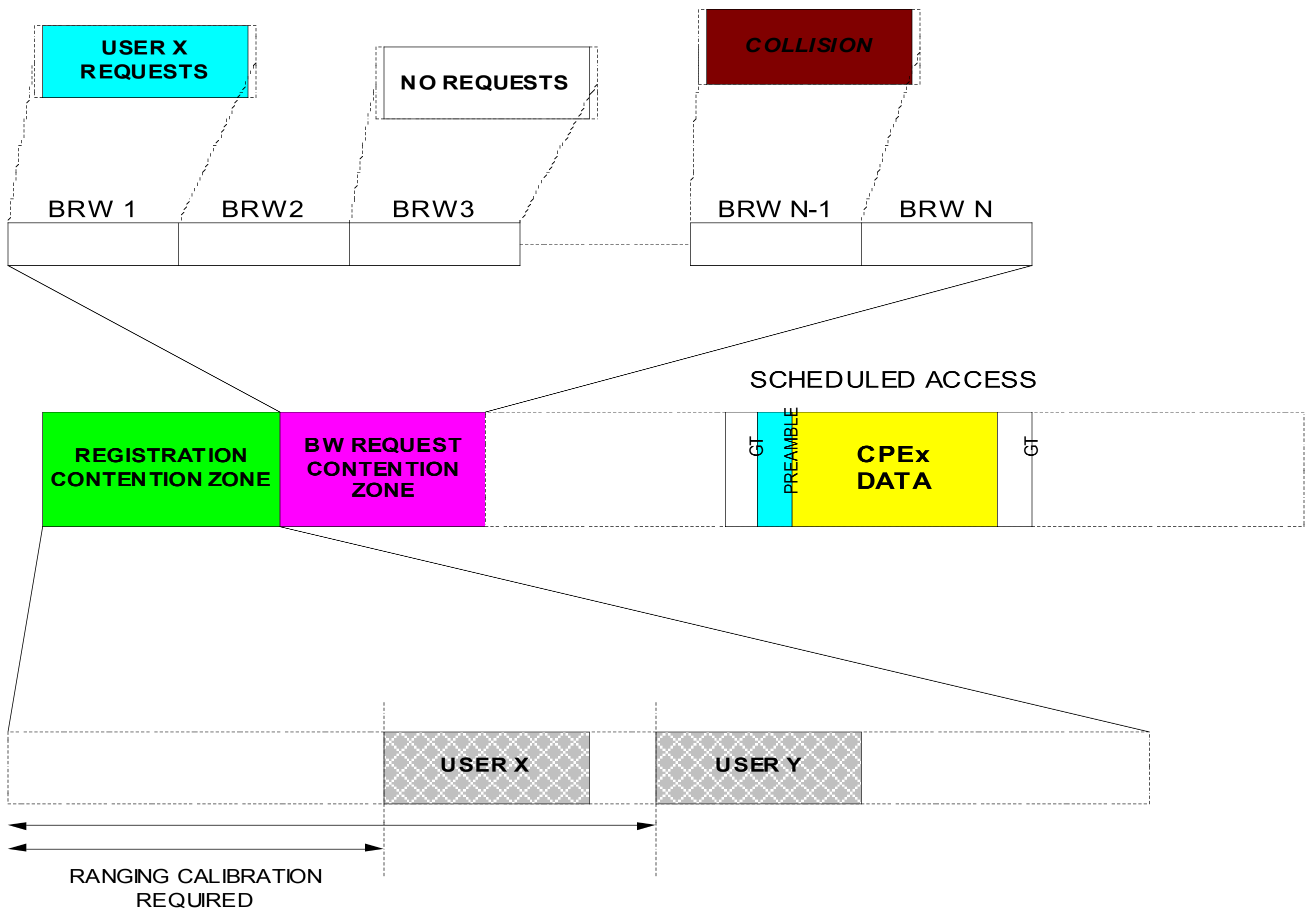
11 Downstream Sub-frame structure



A downstream sub-frame starts with a frame control part that includes a preamble, PHY control information and MAC control information. The frame control part uses QPSK. The PHY control part includes PHY related information such as frame counter, downstream sub-frame length and downstream modulation level transition map. The MAC control part includes MAC related information such as user upstream bandwidth allocation map and access window map.

User data is multiplexed in a time. The multiplexed data is arranged according to modulation complexity, QPSK users transmitted first, QAM-16 users next and QAM-64 last. This permits users with worse link conditions to access their required data elements without losing sync through the downstream sub-frame and in addition minimizes SLAM downstream management operations. The modulation level transmission time windows vary depending on the actual user traffic. For example, there could be no QAM-16 time window if there is no traffic from users using QAM-16 at a specific instant. The time window size and location may be determined using the modulation level transitions map.

12 Upstream sub-frame structure



Upstream sub frame parameters of the current frame are transmitted at the frame control portion of the downstream sub-frame, one frame preceding the current one.

The upstream supports 3 different types of access zones in a sub frame:

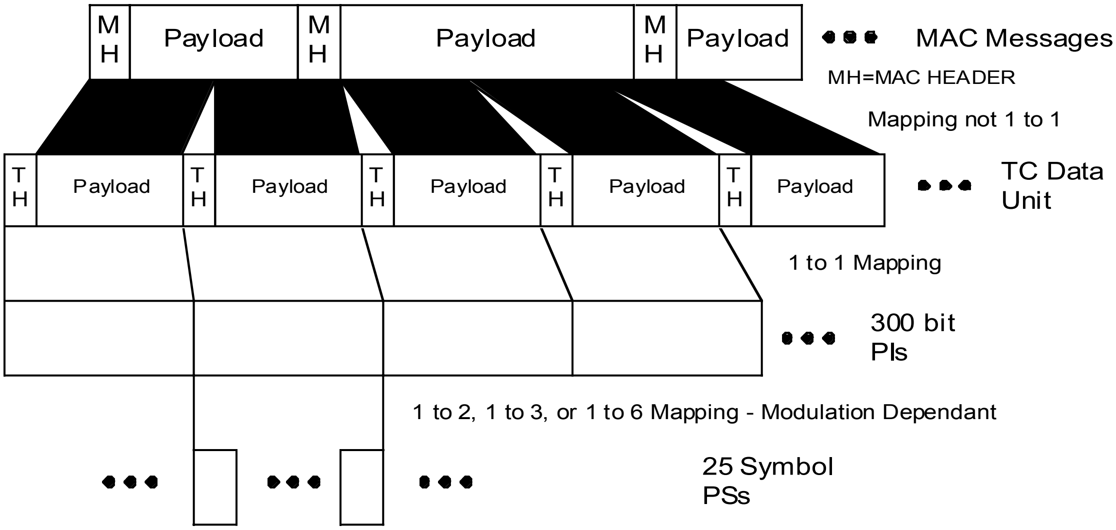
- Registration – Access through this window assumes users are not calibrated in range with the system
- Bandwidth Request – Access for contention based bandwidth allocation requests
- Scheduled – Access for users which are granted bandwidth by the system controller (i.e., MAC)

Registration zone size is directly related to expected cell radius, as it is required to accommodate user propagation delays. This window may not exist as the MAC controller may decide to decline additional system registrations through a specific RF carrier. The Bandwidth Request zone consists of a number of windows allowing the MAC controller to balance users over access opportunities. The number of windows may vary from frame to frame and may be eliminated completely if the MAC controller inhibits contention-based access on a specific RF carrier.

Both Registration and Bandwidth Request zones use QPSK modulation. The Scheduled zone uses any of available modulation schemes according to link conditions. It is recommended that the MAC would group users in time employing identical modulation levels. The base station controls the transmitted power of subscriber station to minimize interference.

13 PHY – TC (Transmission Convergence)

The TC (Transmission Convergence) layer interfaces between the MAC and the PHY. The following figure demonstrates a typical arrangement. The MAC messages, which in the general case are variable in length, contain a header and a payload. For simplicity and efficiency the TC handles fixed size messages. The TC layer messages are expected to have their own headers (kept to minimum size). In general, a TC message could carry parts of several MAC messages. The PHY layer converts TC messages into 300 bits carried over 2 or 3 or 6 PSs depending on modulation.



14 Equalization

Equalization in general is not part of a standard. However the following recommendations follow:

- For upstream transmission, pre-equalization may be implemented at the subscribe terminal.
- Preamble may be used to train an equalizer implemented at the receiver. In multi-path scenarios associated with line of sight, point to multi-point deployments using millimeter wave frequencies, the equalizer does not need to be complex.

15 Modem Performance & System Gain

As expected modem performance depends on modulation scheme used. The following table shows the Es/No required for post coding BER of 10^{-6}:

Modulation Scheme	Es/No [dB]
QPSK	8.7
QAM-16	15.6
QAM-64	21.7

The back-off requirements are approximately 4, 6 and 8 dB for QPSK, QAM-16 and QAM-64 respectively. For a 0 dBW "ideal" transmitter the expected power output is +26 dBm, +24 dBm and +22 dBm for QPSK, QAM-16 and QAM-64 respectively. For the recommended channel bandwidth operation in the LMDS block A band (20 MBaud / 25 MHz) the noise floor is about –100 dBm (assuming an ideal LNA with 0 dB NF). The system gain (normalized, RSG) is therefore:

Modulation Scheme	RSG [dB]
QPSK	117
QAM-16	108
QAM-64	100

16 PHY Criteria List - Summary

1	***Meeting System Requirements***	This proposal is believed to meet system requirements of IEEE 802.16

2	***Spectrum Efficiency***	The use of SLAM (Subscriber Level Adaptive Modulation) balances between range and capacity. The average bps/Hz in a typical deployment (FDD or TDD) would be at least 3 bps/Hz. In TDD mode correct balance between upstream and downstream could be maintained hence increasing spectrum efficiency. This PHY allows efficient implementation of upstream TDMA taking into account dynamic of user traffic.
3	***Implementation Simplicity***	The core functions of this PHY (i.e., QAM modulation, FEC) are well known technologies which do require complex implementations.
4	***CPE Cost Optimization***	The PHY supports either H-FDD or TDD which allow low cost ODU implementation.
5	***Spectrum Resource Flexibility***	The PHY can be used for any worldwide available spectrum. Modem baud rate can be easily modified to support channels between 10 to 40 Mbaud following ETSI-like channel scheme or US-like schemes.
6	***System Diversity Flexibility***	The PHY may be used for various spectrum allocations (as explained in (5)) and is protocol agnostic meaning that it may support various network architectures.
7	***Protocol Interfacing Complexity***	The PHY uses information elements which are small enough to efficiently carry variable length packets such as IP and efficiently carry fixed length packets as ATM or STM.
8	***Implication on Network Interfaces***	As explained in (7) the PHY may be combined with higher layer protocols to transport either ATM, IP or STM. Frame structure is designed for low delay and fast recovery from failure.
9	***RSG***	Actual values are presented in this proposal (section 15). These values allow cell radius of a few miles even when availability is set to a high target. SLAM allows to trade-off almost 20 dB between range and capacity.
10	***Robustness to Interference***	The short packet format supported by the PHY (and by the TC/MAC) offers fast recovery if packet loss occurs. SLAM capability of the modem to back-off to QPSK modulation offers robustness to interference.
11	***Robustness to Channel Impairments***	The short packet format supported by the PHY and the SLAM capability of the modem to back-off to QPSK modulation offers robustness to channel impairments. Equalization procedures are easily implemented at the receiver (or pre-equalization at transmitter) to cope with typical multi-path scenarios in PMP/LOS deployments.