Project	**IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>**
Title	**Proposal for an OFDM-based 802.16.3 Air Interface Physical Layer**
Date Submitted	**2000-10-30**
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Re:	In response to Call for Contributions for the IEEE 802.16.3 Task Group on Initial PHY layer Proposals from September 15th, 2000.
Abstract	A Physical Layer based on OFDM multiplexing with parameters similar to HIPERLAN/2 and IEEE 802.11a is presented. The PHY covers data rates of 1 to 19 Mbit/s with channel spacing ranging from 1.75 to 7 MHz. The OFDM based PHY exhibits, in addition to good link budget, excellent multipath robustness. Aligning the 802.16.3 PHY with a contemporary high-speed wireless LAN PHY standard will result in widely available, cost effective and high-performance solution.
Purpose	To present a proposal which will serve as a baseline of the 802.16.3 PHY layer.
Notice	
Release	
Patent Policy and Procedures	

Proposal for an OFDM-based 802.16.3 Air Interface Physical Layer

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1 Scope

This document describes a Physical Layer proposal based on ETSI BRAN HIPERLAN/2 and IEEE 802.11a, that intends to meet the functional requirements of the IEEE 802.16.3 Task Group FRD.

Electrical and signal processing specifications will be presented that enable the production of interoperable equipment.

The purpose of this paper is to propose a Physical Layer for the 802.16.3 BWA based on Orthogonal Frequency Division Multiplexing (OFDM). The parameters of the proposed Physical Layer are close to those of the ETSI HIPERLAN/2 and very similar to those of IEEE 802.11a.

The main OFDM parameters of the proposed PHY are:

- Channel spacing of 1.75, 3, 3.5, 5, 6, 7 and scalable up to 25 MHz (conforming to channellization described in IEEE 802.3 F.R.D). Other channel spacings are feasible.
- Data rates ranging from 1 Mbit/s to 19 Mbit/s of user payload
- 52 subcarriers with variable spacing
- 48 data carrying subcarriers and 4 pilot subcarriers for carrier phase reference.
- QPSK, 16-QAM or 64QAM modulation on each subcarrier with Gray-coded constellation mapping
- Block interleaver with block size equal to a single OFDM symbol.
- K=7, R=1/2 industry standard convolutional code with puncturing to rates of R= 9/16 and 3/4.
- Variable OFDM symbol duration according to channel width.

The rest of the paper will discuss the details of the proposed PHY. At the end we will address the 802.16.3 comparison criteria.

2 References

[1] ETSI TS 101 475 V1.1.1 (2000-04), “Broadband Radio Access Networks (BRAN); HIPERLAN Type 2; Physical (PHY) layer”.
[2] IEEE 802.11a, “Supplement to STANDARD FOR Telecommunications and Information Exchange Between Systems - LAN/MAN Specific Requirements - Part 11: Wireless Medium Access Control (MAC) and physical layer (PHY) specifications: High Speed Physical Layer in the 5 GHz band”.
[3] ETSI EN 300 421 V1.1.2 (1997-08), "Digital Video Broadcasting (DVB); Framing structure, channel coding and modulation for 11/112 GHz satellite services."
[4] ETSI EN 301 210 V1.1.1 (1999-03), "Digital Video Broadcasting (DVB); Framing structure, channel coding and modulation for Digital Satellite News Gathering (DSNG) and other contribution applications by satellite."

3 Physical Layer Overview

3.1 Introduction

The following physical layer specification was designed to meet the functional requirements that have been defined for Broadband Wireless Access (BWA) systems below 11 GHz. It incorporates many aspects of existing standards [1]-[4] in order to leverage existing technology for reduced equipment cost and demonstrated robustness of implementation, with modifications to ensure reliable operation in the targeted 3-11 GHz frequency band. In addition, this physical layer was designed with a high degree of flexibility in order to allow service providers the ability to optimize system deployments with respect to cell planning, cost considerations, radio capabilities, offered services, and capacity requirements. The mode of operation defined for the downstream channel, is targeted to support a burst transmission stream.

3.2 Reference Configuration

Below is a simple reference model that is used to show the interface between the physical layer and the MAC layer. The convergence layer between the MAC and higher layers is beyond the scope of this specification. The convergence layer between the MAC and PHY ensures interoperation between the two entities and adapts the needs of the MAC services to the PMD sublayer. This PMD sublayer is the main subjet that this proposal addresses.

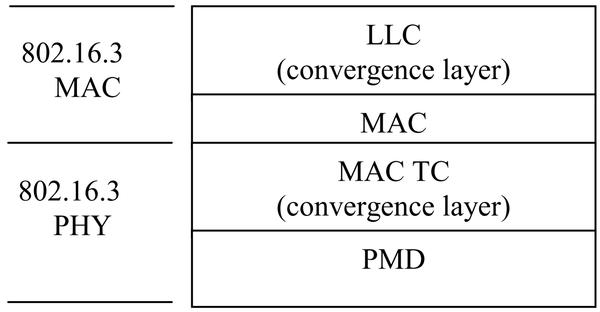

Figure 1: Protocol Stack Reference Model.

3.3 Multiplexing and Multiple Access Technique

The Multiple Access Technique is TDMA bursts/packets based. OFDM is chosen as multiplexing method: a number of orthogonal subcarriers are multiplexed in frequency to form the OFDM signal. Previously, each individual subcarrier is modulated by a low symbol rate.

3.4 Duplexing Technique

Two duplexing techniques are supported with this physical layer. The burst mode of operation supports FDD or TDD. The burst mode supports the capability to have different modulation formats transmitted on the same RF channel so that modulation level can be chosen on a subscriber level basis.

3.5 Mode of Operation - Philosophy

The downstream physical layer defined in this proposal has been designed to support a burst transmission format. This burst format allows systems to implement an adaptive modulation scheme for an FDD system as well as supporting TDD configurations.

This approach to standardization allows for service providers the ability to pick the format which best allows them to meet their system requirements. Standards compliant subscriber stations are required to support at least one of the modes of operation as defined here.

3.5.1 Downstream Coding, Interleaving, Scrambling & Modulation.

The downstream physical layer first encapsulates MAC packets into a convergence layer frame as will be defined by the transmission convergence sublayer. Then, the data is randomized and passed through a convolutional encoder of code rate 1/2. For lower code rates,the output is then punctured to obtain the final code rate of 3/4, or 9/16 as indicated in the following sections.

The data is then interleaved by a block interleaver, the block size equal to the number of bits in a OFDM symbol.

Code bits are then mapped to a QPSK, 16-QAM, or 64-QAM (optional) signal constellations with symbol mapping as described below.

Finally, symbols are processed to obtain the OFDM modulated signal, adding a Cyclic Prefix and windowing (roll-off filter in the time domain).

3.5.2 Upstream Coding, Interleaving, Scrambling & Modulation

Since many of the specific upstream channel parameters can be programmed by MAC layer messaging coming from the base station, several parameters can be left unspecified and configured by the base station in order to optimize performance for a particular deployment scenario. In this mode, the bursts are designed to carry MAC messages of variable lengths.

The baseband processing chain is the same of the Downstream. Each burst also contains a variable length preamble. Nyquist pulse shaping is also employed, using a temporal window.

3.5.3 Framing.

Even though the IEEE 802.16.3 FRD requires only packet mode operation, this PHY proposal is able to work with both burst/packet and scheduled frames.

4 Physical Layer Details

4.1 Introduction

The Baseband Process functions for the physical layer are summarized in the following block diagram.

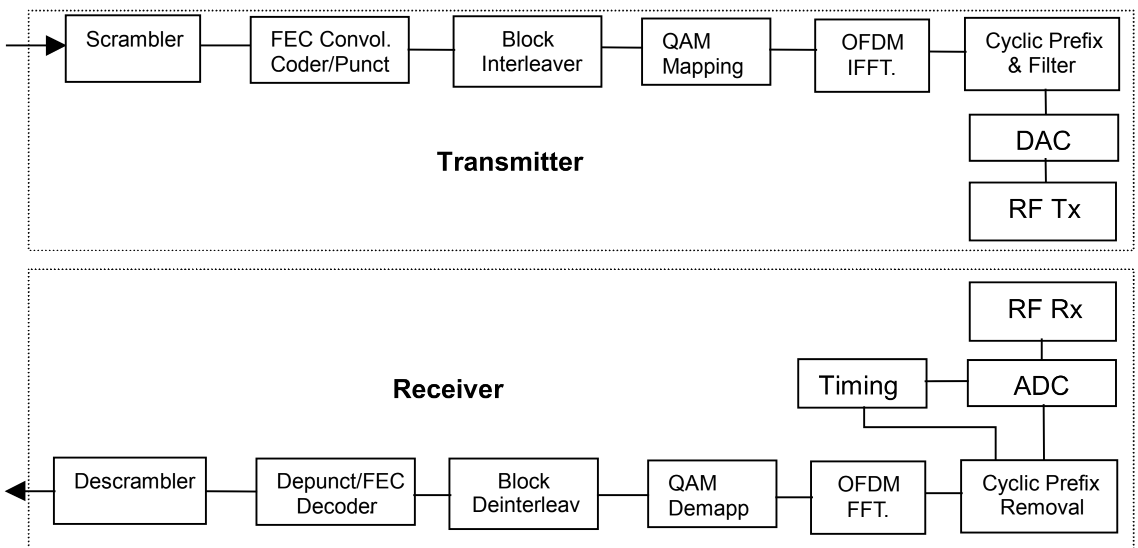

Figure 2: Conceptual Block diagram of the Physical Layer

4.2 Randomization

This unit shall adapt the data structure coming from the transmission convergence sublayer, and randomize the data stream for spectrum shaping purposes. Randomization shall be employed to minimize the possibility of transmission of an unmodulated carrier and to ensure adequate numbers of bit transitions to support clock recovery.

The stream of uncoded downstream packets, shall be randomized by modulo-2 addition of the data with the output of a pseudo random binary stream (PBRS) generator.

The generator polynomial S(x) is given by:

$$S(x)= X^7+X^4+1$$

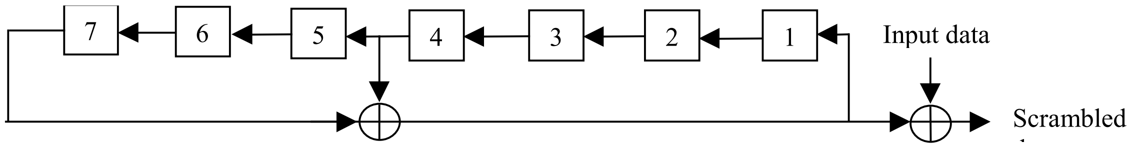

Figure 3: Randomizer logic diagram

The same randomizer shall be used to scramble transmit data and to descramble receive data. PBRS shall be initialized to a pseudorandom non-zero state, determined by some frame counters.

4.3 FEC Coder.

The randomized train shall be encoded by a channel encoder unit. The proposed encoder is described in this clause and depicted in Figure 4. It consists of four consecutive operational blocks:

code termination,

encoding,

code rate independent puncturing (P1) and

code rate dependent puncturing (P2).

It should be noted that this sequence of operation indicates a logical operation of the encoding process, but not a specific implementation.

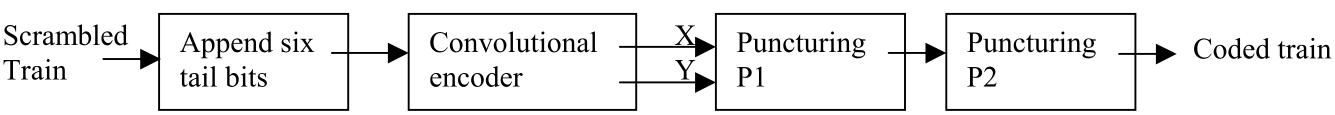

Figure 4: Functional blocks of the FEC coder

The code termination, consists in the addition of six bits to the PDU, to return the convolutional encoder to zero state.

The resulted (N+6) bits shall be coded with a convolutional encoder of code rate 1/2 with 64 states. The generator polynomials of the mother code are G 1 =133 OCT for X output and G 2 = 171 OCT [ITU reference for G 1 and G 2] for Y output (see Figure 5). The encoder shall be set to "zero state" before the encoding process.

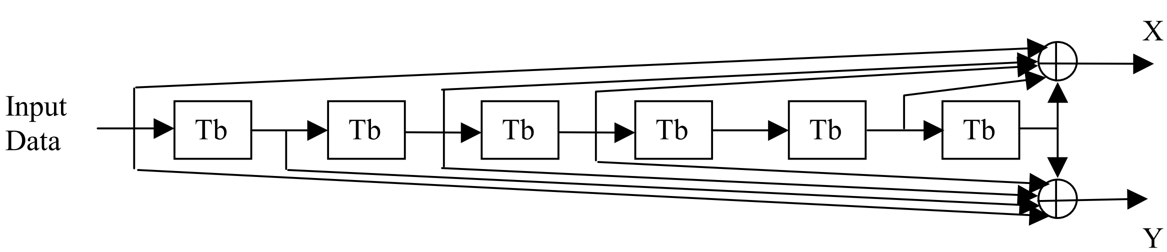

Figure 5: The convolutional coder of rate 1/2, K=7.

The first puncturing scheme P1 will be applied independently from the code rate. The puncturing shall be applied always to the first PDU of the last DLC Connection of the PDU train to be transmitted over the air interface.

The first 156 bits of the PDU, which the P1 puncturing is applied to, are punctured differently from the rest of the encoded bit stream. The puncturing patterns are given in Table 1. In this table X and Y refer to the two outputs of the convolutional encoder (see Figure 5) where X 1 is sent first.

Table 1: Puncturing pattern P1 and transmitted sequence after parallel-to-serial conversion

PDU-wise bit numbering	Puncturing pattern	Transmitted sequence (after parallel-to-serial conversion)
0-155	X:1 1 1 1 1 1 0 1 1 1 1 1 1 Y:1 1 1 1 1 1 1 1 1 1 1 1 0	X 1 Y 1 X 2 Y 2 X 3 Y 3 X 4 Y 4 X 5 Y 5 X 6 Y 6 X 8 Y 7 X 9 Y 8 X 10 Y 9 X 11 Y 10 X 12 Y 11 X 13 Y 12
>156	X: 1 Y: 1	X 1 Y 1

The code rate dependent puncturing P2 is to provide code rates of 9/16 and 3/4 and it is applied to bits from puncturing P1. It shall be performed equally to all the PDU train types. The input is de-multiplexed into 2 sub-streams. The de-multiplexing is defined as a mapping of the input bits xi onto the output bits Beo (see Figure 6), where i is the input bit number, o is the output bit number in each sub-stream

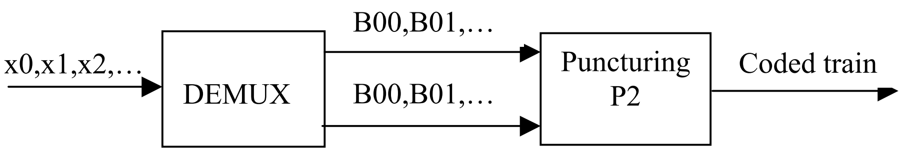

Figure 6: Code rate dependent puncturing P2

Puncturing P2 is applied to the two bit sub-streams B0o and B1o as given in Table 2. The result is parallel-to-serial converted into a coded and punctured bit stream from which B00 is sent first.

Table 2: Puncturing pattern P2 and coded train transmitted sequence for the possible code rates

Code Rates r	Puncturing pattern	Transmitted sequence (after parallel-to-serial conversion)
1 / 2	B0o :1 B1o :1	B00 B10
9/16	B0o :1 1 1 1 1 1 1 1 0 B1o :1 1 1 1 0 1 1 1 1	B00 B10 B01 B11 B02 B12 B03 B13 B04 B05 B15 B06 B16 B07 B17 B18
3 / 4	B0o :1 1 0 B1o :1 0 1	B00 B10 B01 B12

NOTE: 1 = transmitted bit

0 = non transmitted bit

4.4 Convolutional interleaving

All encoded data bits shall be interleaved by a block interleaver with a block size corresponding to the number of bits in a single OFDM symbol, N=48*m. The interleaver is defined by a two step permutation. The first ensures that adjacent coded bits are mapped onto nonadjacent sub-carriers. The second permutation ensures that adjacent coded bits are mapped alternately onto less and more significant bits of the constellation, and by this long runs of low reliability bits are avoided.

We shall denote by k the index of the coded bit before the first permutation; i shall be the index after the first and before the second permutation and j shall be the index after the second permutation, just prior to modulation mapping.

The first permutation, is defined by the rule:

$i = (N/16)(k \bmod 16) + \text{floor}(k/16),\ k = 0, 1, \ldots, N-1$

The function floor(.) denotes the largest integer not exceeding the parameter, and mod is the integer modulo operator.

The second permutation is defined by the rule:

$j = s \times \text{floor}(i/s) + (i + N - \text{floor}(16 \times i/N)) \bmod s,\ i = 0, 1, \ldots N-1$

The value of s is determined by the number of coded bits per sub-carrier, m , according to:

$s = \max(m/2, 1)$

4.5 Signal constellations and mapping.

The proposed PHY layer uses Orthogonal Frequency Division Multiplex (OFDM) transmission. The OFDM sub-carriers shall be modulated by using QPSK, 16QAM or 64QAM modulation depending on the PHY mode selected for data transmission. The interleaved binary serial input data is divided into groups of (2, 4 or 6) bits and converted into complex numbers representing QPSK, 16QAM or 64QAM constellation points. The conversion shall be performed according to Gray coded constellation mappings, illustrated in Figure 7, with the input bit b1 being the earliest in the stream. Additionally, Table 4 illustrates encoding from input bits to the I and Q values for all the modulations.

The output values d are formed by multiplying the resulting (I+jQ) value by a normalization factor K_{MOD} :

$d = (I+jQ) \cdot K_{MOD}$

The normalization factor K MOD depends on the modulation as prescribed in Table 3. Note that the modulation type can vary inside a PDU train from one PDU to another while inside one PDU only one modulation type is used. The purpose of the normalization factor is to achieve the same average power for all mappings. The normalization factor K MOD should indicate this fact and no implementation rule. In practical implementations an approximate value of the normalization factor may be used, as long as the device conforms to the general transmitter and receiver performance requirements specified in the present document.

Table 3: Modulation dependent normalization factor K_{MOD}

Modulation	**K_{MOD}**
QPSK	1
16QAM	1/sqr5
64QAM	1/sqr21

Table 4: Encoding tables for QPSK, 16QAM and 64QAM

QPSK			
Input bit b1	**I-out**	**Input bit b 2**	**Q-out**
0	-1	0	-1
1	1	1	1

16QAM			
Input bit b1b2	**I-out**	**Input bit b3b4**	**Q-out**
00	-3	00	-3
01	-1	01	-1
11	1	11	1
10	3	10	3

64QAM			
Input bit b1b2b3	**I-out**	**Input bit b4b5b6**	**Q-out**
000	-7	000	-7
001	-5	001	-5
011	-3	011	-3
010	-1	010	-1
110	1	110	1
111	3	111	3
101	5	101	5
100	7	100	7

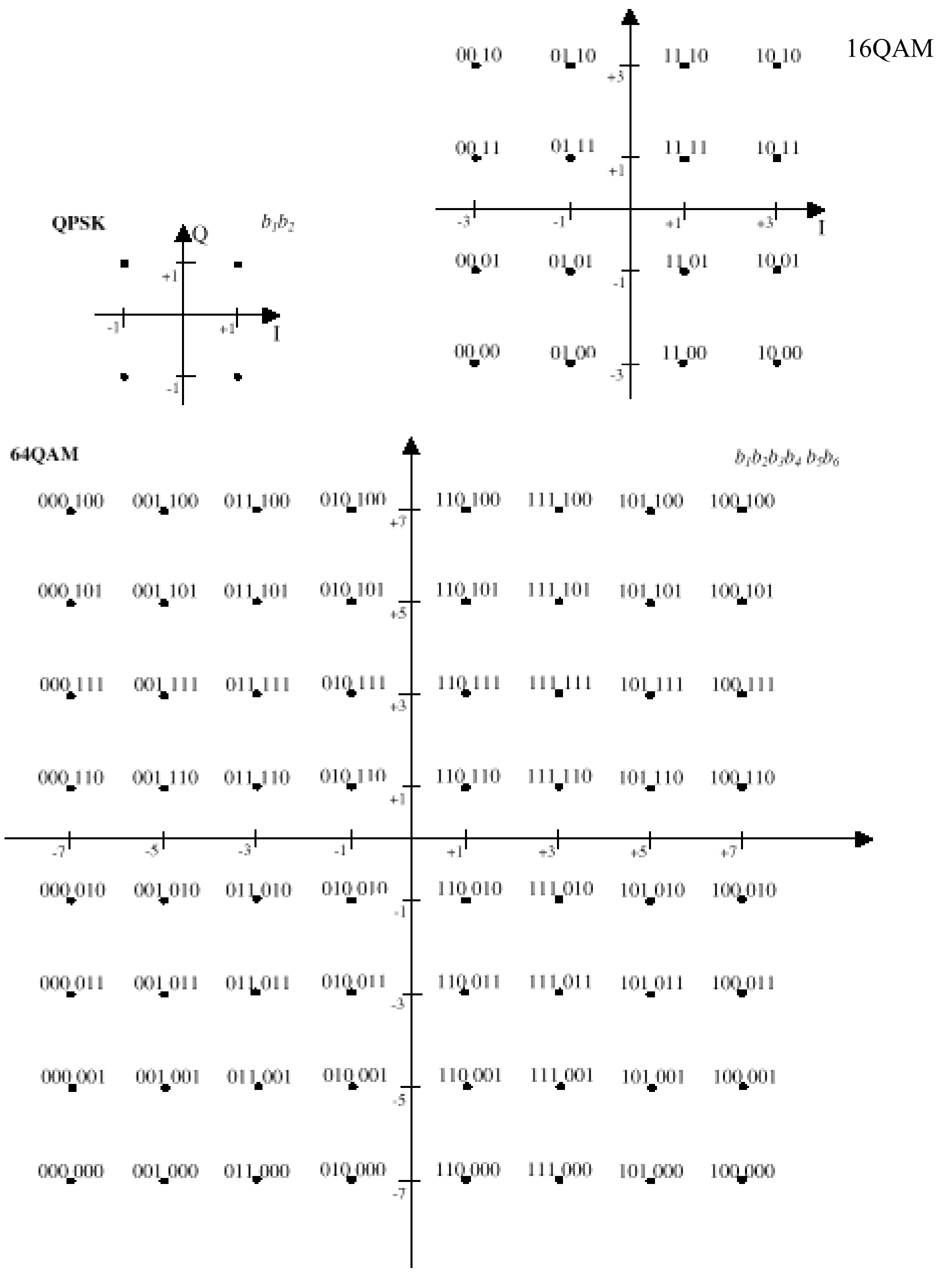

Figure 7: QPSK, 16QAM and 64QAM constellations.

4.6 Multiplexing technique (OFDM)

The stream of complex valued sub-carrier modulation symbols at the output of mapper, shall be divided into groups of 48 complex numbers.

Each group shall be transmitted in an OFDM symbol. All data OFDM symbols contain data in data carriers and reference information in pilot carriers. For data there are 48 carriers and for pilots 4 carriers in each symbol. Thus, each symbol is constituted by a set of 52 carriers and transmitted with a duration Ts .Two parts compose this OFDM symbol interval: a first part called the FFT section, with duration Tc, and a second part, called the cyclic prefix, with duration Tp. The cyclic prefix is a copy of the last 16 samples of the FFT section, and are placed in front of the FFT section. Some samples at the begining of the cyclic prefix, can include a temporal window for baseband pulse shaping.

The length of the useful symbol part (FFT section) is equal to 64 samples. The length of the cyclic prefix is 16 samples. Thus, the total length of the OFDM symbol is 80 samples.

As an example, numerical values for the OFDM parameters are given in Table 5, in correspondance with some of the channelization values listed in F.R.D (IEEE 802.16.3-00/02r4).

By scaling, other channelings are easily achievable.

Table 5: Example of numerical values for the OFDM parameters

RF Channel (MHz)	B	7	6	5	3,5	3	1,75
Sampling rate 1/T (MHz)	B	7	6	5	3,5	3	1,75
FFT size N	64	64	64	64	64	64	64
Subcarrier spacing fc (KHz)	B/64	109,375	93,75	78,125	54,688	46,875	27,344
FFT time Tc (µs)	64 x T	9,143	10,667	12,800	18,286	21,333	36,571
Cyclic prefix time Tp (µs)	16 x T	2,286	2,667	3,200	4,571	5,333	9,143
Symbol duration Ts (µs)	80 x T	11,429	13,333	16,000	22,857	26,667	45,714
Symbol rate fs (Ksym/s)	1 / Ts	87,500	75,000	62,500	43,750	37,500	21,875
Number of data subcarriers	48	48	48	48	48	48	48
Number of pilot subcarriers	4	4	4	4	4	4	4
Total number of subcarriers	52	52	52	52	52	52	52
Occupied BW (KHz)	53 x fc	5797	4969	4141	2898	2484	1449

4.7 Preamble Structure

A preamble is transmitted in front of the OFDM data symbols to form the physical burst.

This preamble helps the receiver to set AGC, estimate frequency offset, recover symbol timing and to perform a channel estimation.

Is composed of (see Figure 8):

A sequence of 10 short symbols (Tc/4), during 2Ts and modulating only 12 subcarriers.

A long symbol (2Ts), modulating the 52 subcarriers.

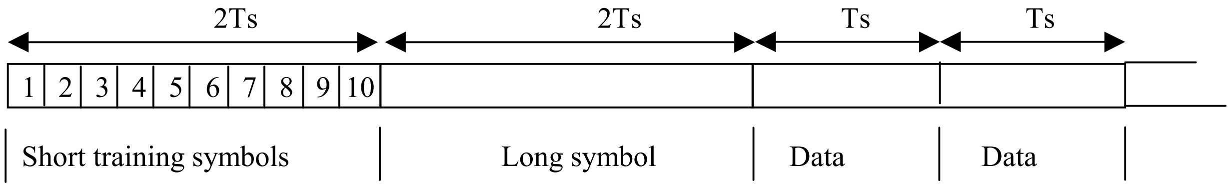

Figure 8: Burst and Preamble structure.

It is clear that this particular preamble has a length of 4 Ts. There could be other types of preambles, depending on traffic type, radio conditions, receiver implementations, or other considerations.

4.8 Summary of Physical Layer Parameters

Table 6: Physical parameters summary

Randomization	1 + X^4 + X^7
Convolutional coding	Selectable: rate 1/2, 9/16, 3/4.
Modulation	QPSK, 16-QAM, or 64-QAM.
Spectral shaping	Done in the time domain.
Interleaving block size:	One OFDM symbol.
OFDM FFT size	64
Number of subcarriers	48 data + 4 pilots
Preamble length:	Variable, up to 4Ts

4.9 Baud Rates and Channel Bandwidths

Due to the scarse availability of RF resources in the bands below 11 GHz for point-to-multipoint operation, and the different regulatory requirements in various countries around the world, the baud rates and RF channel bandwidths should be left very flexible in order to allow service providers the ability to maximize capacity for a given spectrum allocation.

The OFDM multiplexing parameters have been proposed for 7, 6, 5, 3.5, 3, and 1.75 MHz. (As given in the mentioned F.R.D.). However, other channel widths are easily achievable.

As a reference, the following table shows the available bit rates for a 7 MHz RF channel, considering different modulation formats, and code rates:

Table 7: Available bit rates for a 7 MHz RF channel

Modulation	**Symbol rate (Mbaud/s)**	**Coded bit rate (Mbit/s)**	**Code rate**	**Payload bit rate (Mbit/s)**
QPSK	4.2	8.4	1 / 2	4.2
QPSK	4.2	8.4	3 / 4	6.3
16QAM	4.2	16.8	9 / 16	9.45
16QAM	4.2	16.8	3 / 4	12.6
64QAM	4.2	25.2	3 / 4	18.9

5 Addressing the Evaluation Criteria

5.1 Meets system requirements

How well does the proposed PHY protocol meet the requirements described in the current version of the 802.16.3 Functional Requirements Document (FRD)?

The proposed OFDM-based PHY was already chosen by projects of similar scope, both by IEEE 802.11a, which is connectionless by nature, and by HIPERLAN/2 which is tightly managed and is ATM-oriented. We are confident that by coupling the proposed PHY with an appropriate MAC and by exploiting the flexibilities inherent in it (data rates, preamble overheads etc.) the proposed PHY meets the 802.16.3 system requirements.

5.2 Channel Spectrum efficiency

Defined in terms of single channel capacity (TDD or FDD) assuming all available spectrum is being utilized (in terms of bits/sec/Hz). Supply details of PHY overhead.

The specific proposal covers data rates of 1 Mbit/s up to 19 Mbit/s of available user payload with channel spacings ranging from 1.75 to 7 MHz (other widths are easily achievable), and modulation levels from QPSK to 64 QAM. This translates to a channel spectrum efficiency of 0.57 bit/sec/Hz up to 2.71 bits/sec/Hz of user information at the PHY-to-MAC interface.

5.3 Simplicity of implementation

How well does the proposed PHY allow for simple implementation or how does it leverage on existing technologies?

The proposed PHY draws on recently adopted standards – 802.11a and HIPERLAN/2 PHY. Thes committees decided that the technology described here is implementable with a reasonable effort. OFDM based standards of even more ambitious scale, such as DVB-T and dTTb, are destined for consumer use. We believe that aligning the 802.16.3 Physical Layer with 802.11a and HIPERLAN/2 technology will facilitate availability of competitively priced chip-sets supporting this technology.

5.4 SS cost optimization

How does the proposed PHY affect Subscriber Station cost?

It is estimated that the Physical Layer proposed here can be implemented in the Subscriber Station in less than 40 mm2 of silicon. We believe that aligning the 802.16.3 Physical Layer with 802.11a and HIPERLAN/2 technologies will facilitate availability of competitively priced chip-sets.

5.5 BS cost optimization

How does the proposed PHY affect Base Station cost?

It is estimated that the Physical Layer proposed here can be implemented in the Base Station in less than 40 mm2 of silicon. Aligning the 802.16.3 Physical Layer with HIPERLAN/2 technologies will facilitate the availability of competitively priced chip-sets supporting this technology.

5.6 Spectrum resource flexibility

Flexibility in the use of the frequency band (i.e., channelization, modularity, band pairing, and Upstream/Downstream data asymmetry)

The current proposal conforms to the requirements put forward in the FRD, supporting channel widths of 1.75, 3, 3.5, 6, and 7 MHz, with other channel widths easily achievable, and associated with modulation levels from QPSK to 64 QAM. In addition, it can operate in TDD or FDD duplexing, offering the customer control in many types of band allocations, and at the same time presents many possibilities of upstream/downstream capacity and data assymetry.

5.7 System service flexibility

How flexible is the proposed PHY to support FRD optional services and potential future services?

With an appropriate MAC layer, the PHY is capable of supporting both isochronous and asynchronous services. Future services can be accomodated by defining appropriate Convergence Layers in the MAC. Increasing data rates in the future can be accomplished, for example, by creating wider channels and increasing the number of subcarriers, while maintaining the OFDM symbol duration. The basic ideas presented contain flexibilities which can support multiple enhancements in the future. Other services that for instance require QoS-based delivery of the MAC services can be easily added without placing any additional requirements on the PHY layer.

5.8 Protocol Interfacing complexity

Interaction with other layers of the protocol, specifically MAC and Network Management. Provide the PHY delay.

The proposed PHY draws on recently adopted standards – HIPERLAN/2 PHY and 802.11a. In particular, the HIPERLAN system is tightly managed and based on resource allocation and therefore is a good baseline for comparison with 802.16.3. We believe that the MAC-PHY integration complexity of 802.16.3 is commensurate with 802.11a and HIPERLAN/2 projects. Given that these projects approved the OFDM based PHY and successfully defined MAC/DLC layers for it indicates that it can be done for 802.16.3 as well.

5.9 Reference system gain

Sector coverage performance for a typical BWA deployment scenario (supply, reference system gain). Provide practical link budget analysis.

The table below summarizes the sensitivities, the transmit power and the system gain (link loss) for a hypothetical system at different data rates. The receive sensitivity assumes 6 dB noise figure, 2 dB implementation degradation and a 3.5 MHz RF channel. The receive sensitivity is derived from simulations Those include the loss due to channel estimation inaccuracy and carrier phase error degradation. The transmit power assumes 0 dBW = 30 dBm saturated transmit power. The backoffs are taken relative to the saturated power. The backoffs at QPSK can be reduced even further, but that comes at expense of adjacent channel interference, and a more conservative value is taken.

Modulation (Coding rate)	Sensitivity NF=6 dB degr.=2 dB	Backoff	Transmit power	System gain (link loss)
QPSK (1/2)	-95	7 dB	23 dBm	118
QPSK (3/4)	-90	7 dB	23 dBm	112
16QAM (3/4)	-80	9 dB	21 dBm	100
64QAM (3/4)	-73	9 dB	21 dBm	94

5.10 Robustness to interference

Resistance to intra-system interference (i.e., frequency re-use) and external interference cause by other systems. Provide co-channel, adjacent channel interference levels and spectral spillage resulting from modulation.

By the nature of the proposed PHY and the strong Error Correction Coding, the system has good interference rejection properties. Adjacent channel rejection for a 7 MHz channel is shown in the following table:

Modulation	Coding rate	Adjacent channel rej. (PER ≤ 10%)	Alternate channel rej. (PER ≤ 10%)
QPSK	1/2	17 dB	36 dB
QPSK	3/4	15 dB	34 dB
16QAM	9/16	11 dB	30 dB
16 QAM	3/4	9 dB	28 dB
64 QAM	3/4	4 dB	23 dB

Blocking levels are in the order of –30 dBm for frequencies close to the operating one, and for a PER (Packet Error Rate) of ≤ 10%.
The transmit mask is such that the output signal should be maintained within the following levels:

Output Power	Frequency offset (relative to channel width)
0 dBc	± 45%
Less than –20 dBc	± 55%
Less than –28 dBc	± 100%
Less than –40 dBc	± 150% and above

5.11 Robustness to channel impairments

Small and large scale fading (Rain fading, multipath,N (non or near) LOS, LOS, Foliage effects, frequency-selective fading, atmospheric effects, etc)

The multipath robustness of OFDM is its main strength. It enables equalizing channels with multiple notches in frequency, and yet maintaining considerable coding gain. The proposed PHY is capable or compensating, for example, up to 2.2 µs of delay spread for a 7 MHz wide channel. Regarding atmospheric effects and rain in particular, those mainly appear as a time-varying attenuation. The proposed PHY contains a support for multiple data rates, so that the system can fall back to lower rates in case of large attenuation. This requires the support of the MAC layer which will detect the link degradation, will negotiate new data rate and will prioritize the traffic according to the new system capacity. All this needs to be done at time scales commensurate with the evolution of the atmospheric phenomena related attenuation.

5.12 Robustness to radio impairments

Specify the degradation due to radio impairments such as phase noise, group delay of filters, amplifier non-linearities, etc.

The propossed PHY requirements for phase noise are –70 dBc/Hz at 10 KHz offset for a 1.75 MHz wide channel (Worst case. For wider channels, the requirement is smaller). Regarding frequency stability, the requirement is around 2 ppm for

a 1.75 MHz wide channel (Worst case. For wider channels, the requirement is smaller). As far as amplifier nonlinerities is concerned, a backoff of between 7 to 9 dB (depending on modulation lever) should be quite enough.
From the above numbers it is clear that the requirements imposed by the PHY are very reasonable as well as easily achievable, resulting in low cost equipment implementation.