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| Project | **IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>** |
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| Re: | In response to Call for Initial Proposals for the 802.16.3 sub-11 BWA PHY layer from Sep 15, 2000. |
| Abstract | A Physical Layer based on OFDM modulation with parameters similar to 802.11a and HIPERLAN/2 is presented. The channel spacing is rescaled to address the 802.16.3 scenarios. The PHY covers data rates of 1.33 to 19 Mbit/s with 3.5 MHz channel spacing. The OFDM based PHY exhibits, in addition to good link budget, excellent multipath robustness. Aligning the 802.16.3 PHY with a contemporary packet data oriented PHY standards 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 BWA PHY layer. |
| Notice |  |
| Release |  |
| Patent Policy and Procedures |  |

# Proposal for an OFDM-based 802.16.3 BWA Air Interface Physical Layer

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# 1 General

## *1.1 Background*

The PHY proposal for 802.16.3 brought below is based on OFDM modulation. It draws on the 802.11a Physical Layer and on the PHY of the HIPERLAN/2 project, while featuring several enhancements, such as a fast polling mechanism, and an FFT switchover mechanism. These features results in increased performance while maintaining co-existence with the existing protocols.

The 802.16.3 calls for an extremely robust PHY. This requirement stems from the deployment scenarios targeted towards residential customers - obstructions by buildings, less directional antennas for self installation and even indoor stations communicating with nondirectional antennas through the building's walls. This scenarios call for a Physical Layer which is highly tolerant both to multipath and to signal level variations. The PHY proposed in this proposal addresses these issues at several layers:

- OFDM based PHY addresses the anticipated multipath problems
- An adaptive modulation enables providing each user with a data rate according to his link quality. In particular, station experiencing a fade will reduce its data rate but will avoid the need to send an installer to deal with connection loss.
- An optional Frequency Hopping sublayer deals with wideband (low delay spread) frequency selective fading situations.

The OFDM modulation enables a fast polling capability based on subcarrier allocation. The orthogonality of the subcarriers is utilized to gather polling requests from multiple stations in parallel, even in heavy multipath environment. This capability is unique to OFDM and enables fast and efficient resource allocation in packet oriented environment.

The parameters of the OFDM modulation in this proposal follow closely the parameters of 802.11a and HIPERLAN/2 standards. This is done for several reasons:

- The 802.11a and HIPERLAN/2 standards are drawing many chip vendors to develop applicable ASICs. By keeping the main parameters aligned with those standards we envision availability of low cost solutions drawing on the economy-of-scale of the WLAN and consumer markets
- The parameters of those standards (number of subcarriers, preamble structures) are optimized towards packet data in terms of burst operation, packet size granularity, overhead and operation is uncertain propagation environment.

- The 802.11a and H/2 standards are capable of transmitting broadcast data, however they are optimized towards a situation typical in data networks in which each station communicates it's own individual data.
- The packet operation with a per-packet preamble facilitates a switched-antenna receive diversity
- Drawing on 802.11a and HIPERLAN/2 characteristics and format will enable inherent co-existence and optional inter-operability.

The proposed OFDM based PHY integrates naturally with the 802.16. MAC, and in particular with the packet oriented TDD and SFDD modes of operation.

The 802.11a and HIPERLAN/2 calls standards specify a 20MHz channel spacing. Due to regulatory restriction or due to the limited bandwidth available to the operator, it may be advantageous to scale the bandwidth down by some factor. This can be easily accomplished within the framework of the proposed OFDM physical layer. Some examples of BW scaling are discussed below:

1. Use of 802.11a/HIPERLAN2 channel spacing of 20MHz. This may be used when high bandwidth is required and interoperability is important.
2. 10MHz channel spacing.
3. 5 MHz channel spacing.
4. 3.5MHz channel spacing.

In this paper we focus on the 3.5MHz channel spacing case, mostly to maintain alignment with the WirelessHUMAN$^{TM}$ proposal. The expansion to higher bandwidths, is straightforward.

At the end, we would like to discuss the negative sides of OFDM. The main one is the Peak-to-Average Ratio (PAR) disadvantage. On the average, OFDM requires about 2 dB higher backoff in power amplifiers than a single carrier QAM signal (worst-case PAR is much higher but it is an extremely rare event). Another disadvantage attributed to of OFDM is its sensitivity to phase noise. This issue was studied in the 802.11a committee and in the case of 52 subcarriers the OFDM system compared favorably with the single carrier systems.

## 1.2 Introduction

The purpose of this paper is to propose a Physical Layer for the 802.16.3 FWA Task Group, based on Orthogonal Frequency Division Modulation (OFDM). The proposed PHY supports two modes of operation:
A basic mode, similar in parameters to 802.11a and HIPERLAN/2 standards for Wireless LANs in the 5 GHz band. The basic mode utilizes OFDM with 52 subcarriers and a 64-point FFT. Some of the parameters are scaled to support the smaller bandwidth allocations available in the in the sub-11 licensed frequency bands.
An enhanced mode, in which the number of subcarriers is increased to 216 and the FFT size is increased to 256. This mode allows higher spectral efficiency and better multipath immunity at the expanse of a slight increase in implementation complexity.

The proposed PHY layer can be scaled to meet different bandwidth requirements. In this paper we focus on the 3.5MHz case in order to maintain alignment with the parallel OFDM proposal to 802.16.3. The parameters of the proposed OFDM PHY are then, for 3.5 MHz channel case:

- Channel spacing of 3.5 MHz, signal bandwidth of approximately 3.2 MHz.
- Data rates ranging from 1.33 Mbit/s to 12 Mbit/s
- 52 subcarriers with 4 MHz / 64 = 62.5 KHz spacing in the 64 point FFT mode, 216 subcarriers with 4 MHz / 256 = 15.625 KHz spacing in the 256 point FFT mode
- 48 data carrying subcarriers and 4 pilot subcarriers for carrier phase reference in the 64 point FFT mode, 208 subcarriers and 8 pilot subcarriers for carrier phase reference in the 256 point FFT mode. Note that the number of data subcarriers per time domain sample increases from 0.75 to 0.8125, adding 8.3% to the data rate.
- BPSK, QPSK, 16-QAM or 64QAM modulation on each subcarrier with Gray-coded constellation mapping
- Binary convolutional coding with bit interleaving
- K=7, R=1/2 industry standard convolutional code with puncturing to rates of R=3/4 and R=2/3.
- Optional Block-Turbo-Coded mode.
- Block interleaver with block size equal to a single OFDM symbol.

- OFDM symbol duration of 18 microseconds, composed of 16 microsecond Fourier period and 2 microsecond Guard Interval (GI) in the 64 point FFT mode. Note the proposed GI overhead is smaller than in the 802.11a (1/8 instead of 1/4 of the Fourier period). Furthermore, in the 256 FFT mode the OFDM symbol duration is 66 microseconds, composed of 64 microsecond Fourier period and 2 microsecond Guard Interval (GI), reducing the GI overhead and adding another 9.1% to the data rate bringing the overall advantage of the 256 point FFT mode to 18%.

In terms of integrating the PHY layer with the MAC we propose an approach which incorporates elements of both 802.11a and of HIPERLAN/2.

- The data payload granularity is a single byte as in 802.11a, rather than 54 bytes as in HIPERLAN/2
- The coarse/fine acquisition sections of the 802.11a preamble are used.
- The concept of several preamble and mid-amble types which are used according to the amount of prior knowledge on the receiving side is similar to HIPERLAN/2
- An entirely new component which draws on OFDM technology but is not part of 802.11a or HIPERLAN/2 is the concept of subcarrier-based polling. In the extreme, it enables to poll 52 stations in each 18 microsecond (64-pt OFDM symbol) interval.

## *1.3 Abbreviations and Acronyms*

| | |
|---|---|
| OFDM | Orthogonal Frequency Division Multiplex |
| BPSK | Binary Phase Shift Keying |
| QPSK | Quaternary Phase Shift Keying |
| M-QAM | Quadrature Amplitude Modulation with **M** constellation points |
| BER | Bit Error Rate |
| PER | Packet Error Rate |

# 2 Reference documents

*[Ref1] P802.11aD7.0. - Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications: High Speed Physical Layer in the 5 GHz Band.*

*[Ref2] ETSI Broadband Radio Access Networks (BRAN); HIPERLAN Type 2 Technical Specification; Physical (PHY) layer*

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[8] J. Hagenhauer and E. Offer ,"Iterative Decoding of Binary Block and Convolutional Codes,"
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# 3 Main parameters of the proposed OFDM Physical Layer

## *3.1 Number of Subcarriers*

The proposed OFDM PHY supports two modes of operation – the basic 64 point FFT mode and the extended 256 point FFT mode.

The number of subcarriers is a compromise of several factors. Increasing the number of subcarriers improves the multipath robustness and reduces the "guard interval" overhead. On the other hand, it increases the phase noise sensitivity and makes the granularity of the packet size/duration coarse. Moreover, increasing the number of subcarriers increases the length of the training sequence needed.

Our proposal merges the advantages of both modes by having a "FFT size switchover" structure, which starts in the 64 point FFT mode and later, optionally, switches to the 256 point FFT mode. This feature enables to mix lower end stations, supporting 64 point mode only, with higher end stations having the 256 point FFT capability.

### 3.1.1 The basic 64 point FFT mode

In the 64 point FFT mode, the OFDM PHY is based on using 52 subcarriers, of which 4 are designated as pilots. The use of pilot subcarriers facilitates the use of  coherent modulations on the data subcarriers. In addition, it facilitates the use of advanced coding techniques, because the carrier tracking loop does not rely on unreliable tentative decisions.

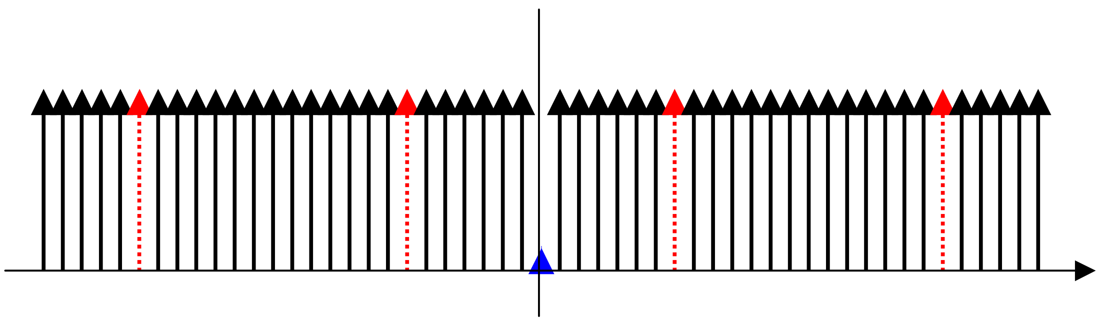


**Figure 1 Frequency plan of the data and pilot subcarriers**

The use of 62.5 KHz (4 MHz/64) carrier spacing implies a 64 point FFT in the implementation. Using 52 out of 64 subcarriers leaves guard bands on the edges, which facilitate anti-aliasing filtering.

The center subcarrier is not utilized. This small sacrifice in bandwidth is paid for an important implementation consideration. The quadrature modulators used to impose the I/Q information onto the carrier frequency exhibit some carrier leakage, which degrades the subcarrier located at the center.
The pilots are spread  across the frequency band to provide frequency diversity to the carrier tracking loop.  The pilots are modulated by a pseudo random sequence, to avoid   the appearance of spectral peaks.

### 3.1.2 The enhanced 256 point FFT mode

In the enhanced 256 point FFT mode, the number of active subacrriers is increased from 52 to 216, of which 208 are used to convey data while 8 are used as pilots. The subcarriers spacing in this case is 15.625KHz. The use of 256 points FFT  results in reduce overheads, increased spectral efficiency and improved spectral roll off.

### 3.1.3 Switchover from 64 to 256 point FFT mode

We propose to have the 64 point mode mandatory and the 256 point mode as an optional one. This is done for several reasons:

- the preambles in the 64 point mode are shorter,
- the packet size granularity is smaller,
- the phase noise tolerance is better
- we would like to have a unified preamble structure,
- we would like to take advantage of the 802.11a PHY components soon-to-appear.

- For Wireless HUMAN, this will facilitate coexistence with 802.11a equipment in the UNII band.

The solution fulfilling these objectives is to switch from 64 to 256 point FFT mode on the fly. The preamble structure is common to both 64 and 256 points FFT modes. In particular, the preamble section and the first few symbols are modulated with 52 subcarriers using a 64 point FFT. In the 256 points FFT mode operation, a switchover to 216 subcarriers is performed after the first few symbols. The figure below illustrates graphically this concept.

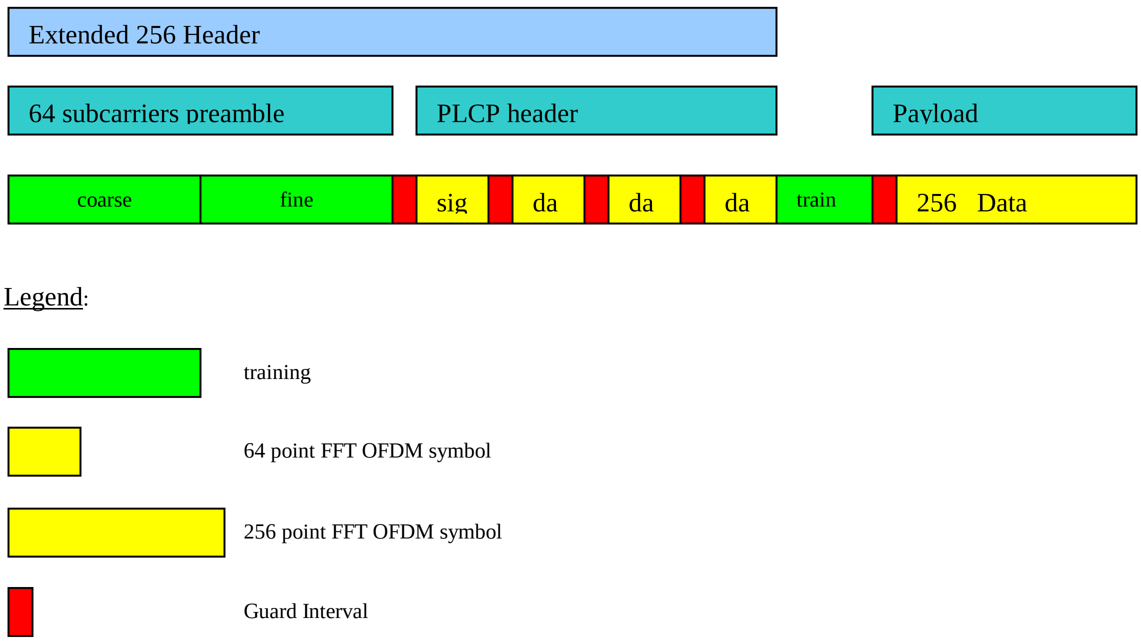



**Figure 2 The FFT size switchover concept illustration**

During the reception of the 64 points FFT symbols, the frequency tracking loops lock into the exact frequency offset. This enables the processing the coming 256 point FFT symbols which requires accurate frequency estimation. If additional frequency estimation is required, then the training sequence inserted before the frequency estimation is required.

The frequency/time diagram of the switchover is shown in the figure below:


**Figure 3 Frequency/Time map of the switchover**

## 3.2 Guard Interval

The data is imposed onto the subcarriers, which are subsequently transformed into time domain by an inverse Fourier transform (IFFT). The resulting waveform is periodic with 16 microsecond periodicity (for the 64 point FFT), or 64 microsecond periodicity (for the 256 point FFT) . One period of the waveform is sufficient for conveying the data imposed on that group of subcarriers. However it is common practice to extend the transmitted waveform by the so-called Guard Interval (GI). The Guard interval prevents the adjacent symbol echoes from leaking into the symbol being currently demodulated, as illustrated in Figure 4.

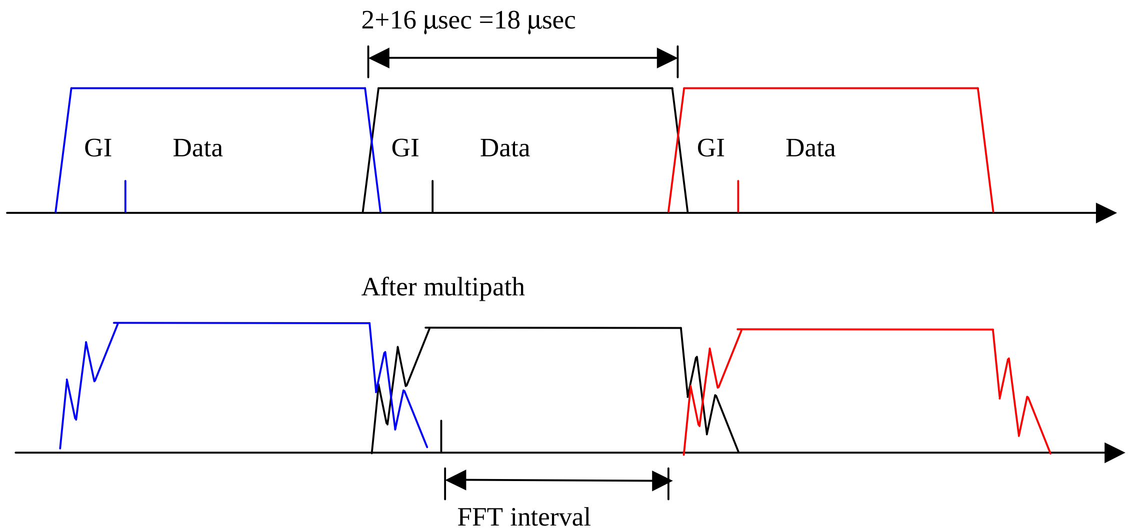



**Figure 4 The robustness of OFDM to multipath due to Guard Interval**

The length of the Guard Interval is directly related to the duration of the anticipated multipath. Our recommendation for the 802.16.3 sub-11 GHz BWA project is to use GI of 2 microseconds (for the case of 3.5 MHz channels). The induced overhead of the GI is 12.5% for the 64 point FFT case and 3.1% for the 256 points FFT.

While the GI duration is the same for both modes, the 256 point FFT mode enjoys higher immunity to multipath, due to its longer symbol duration. This way, the energy of the residual multipath components extending beyond the guard interval, is smaller relative to the energy of the FFT interval.

## 3.3 Frame Types and Formats

The proposed PHY supports several frame types, each type optimized to a specific MAC layer functions. The frame types differ in structure, format and synchronization method.

Most frame types are composed of a synchronization section (preamble and midamble) and optional SIGNAL field and a data section. An exception is the polling frame which is described in section 3.4.

In the following sections, an overview of the frame components is given. An illustration of several frame types is given in section 3.3.4.

### 3.3.1 Synchronization Sections

The synchronization section is composed of preambles and mid-ambles.

The preamble section is used for initial gain timing, frequency and channel response estimation. The preamble is also used to resolve antenna diversity, where applicable. The preamble is composed of an optional coarse estimation section and a fine estimation section. The use of the coarse estimation section is dictated by several factors:

- The time since previous transmission of same station. If the previous transmission occurred too long ago, then receiver settings will be mismatched to the incoming signal. This applies especially to gain and antenna settings. In this case a coarse estimation section should be used to allow the receiver to adjust the gain and antenna settings.
- If no a-priori information is available on timing frequency and gain settings then a coarse estimation section should be used. An example of such situation is the transmission of registration requests.

A synchronization section which contains only the fine estimation section is termed a *short preamble*, while a synchronization section which contains both a coarse and a fine synchronization sections is termed a *long preamble*.

The midamble is used to allow a station to regain synchronization when reception was interrupted. This may be required in the case of SFDD operation, when a station may stop listening to the media while transmitting up-stream information, or a multibeam system in which previous section was sent to a different beam.

The synchronization sections are described in detail in section 3.3.5.

### 3.3.2 Data Section

The data section contains the up-stream and down-stream information. The data section is OFDM modulated as described in section 3.1. The data section conveys information either to a single station, or to several stations. In the latter case, which is applicable in the down-stream channel, the data section is composed of several data fragments. Each data fragment is a completely terminated data unit, which can be decoded independently of other data fragments. To assist independent decoding, mid-ambles may be inserted between adjacent fragments. Data fragments may have different data rates, thereby optimizing throughput for far and near stations.

### 3.3.3 Signal field

The signal field is used to convey information on the rate and length of the subsequent data fragment. The signal field is a fully terminated data fragment, always transmitted at the lowest most reliable rate.

### 3.3.4 Illustration of frame types.

In this section the structure of some frame types is illustrated. The polling request frame is discussed in section 3.4. In the following, all timing and rate related information pertains to the 3.5MHz example.

#### 3.3.4.1 Long preamble + signal field + data

An example of a frame composed of long preamble a Signal field and a data section is shown in figure 5. This frame type is used whenever the transmitting has been inactive for a prolonged period of time, e.g. in registration requests. The inclusion of a signal field enables the use of any data rate and length.

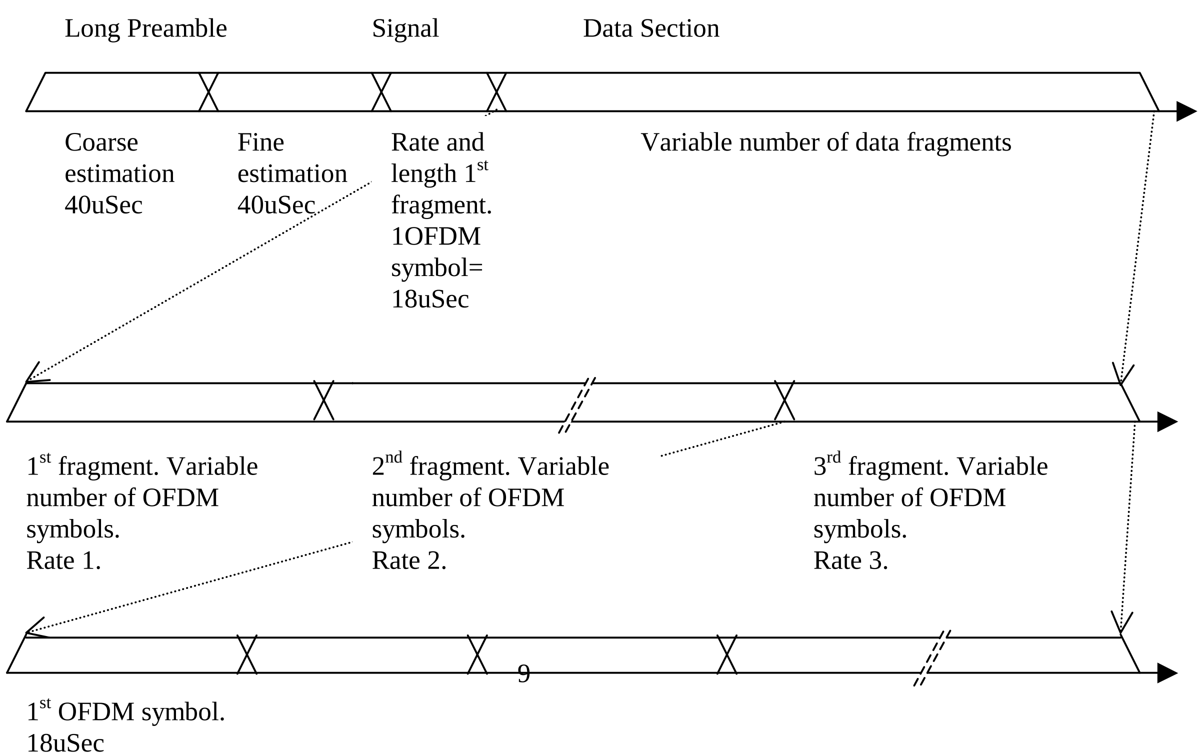
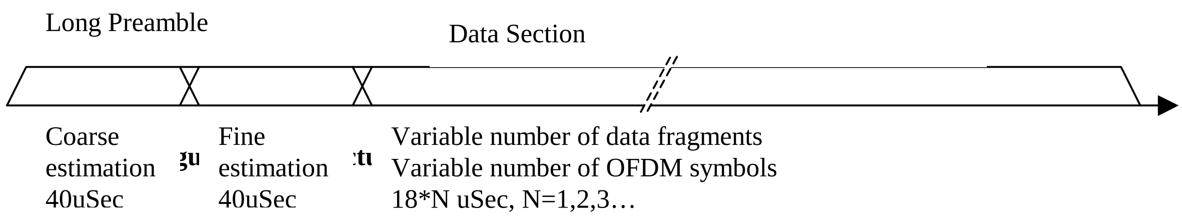


**Figure 5 Structure of a packet with a long preamble, SIGNAL field and multiple data fragments with mid-ambles**

### 3.3.4.2 Long preamble + data

A frame with a long preamble and a data section is shown in figure 6.




### 3.3.4.3 Short preamble + data

A frame with a short preamble and a data section is shown in figure 7.

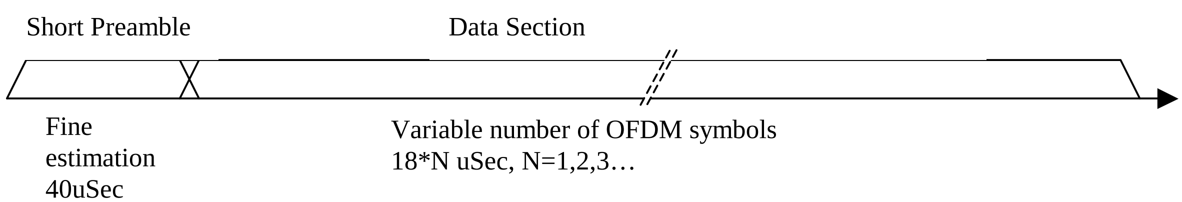



**Figure 7 Structure of a packet with a short preamble and data**

### 3.3.4.4 Long preamble + signal field data +mid-ambles

The use of mid-ambles to separate data fragments is shown in figure 8.

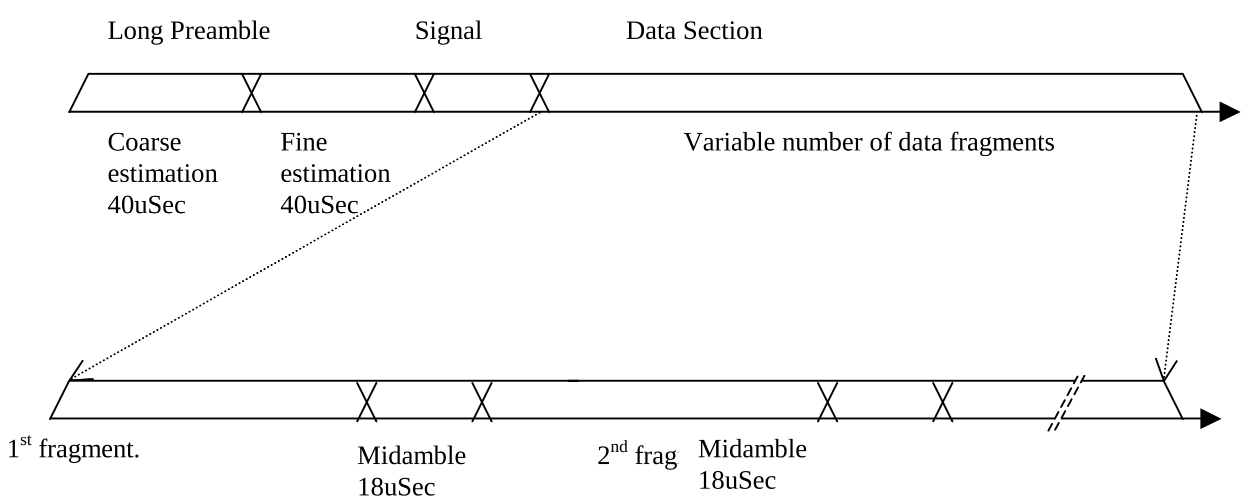


**Figure 8 Structure of a packet with a long preamble and multiple data fragments with mid-ambles**

### 3.3.5 Preamble and midamble Sections

Receiving an OFDM packet requires acquisitions of several parameters, among them are:

- Exact time of packet start.
- Frequency offset.
- Channel response.

In addition both the analog gain setting and the antenna diversity needs to be resolved prior to decoding the data sections.

The preamble section was designed to estimate the above parameters. The preamble section is divided into two subsections, the coarse estimation section and the fine estimation section.

The coarse estimation section allows coarse parameters estimation without any prior knowledge of timing and frequency offset. The analog gain setting and antenna diversity can be resolved using this section.

The fine estimation section is used for accurate parameter estimation, while relying on some a-priori knowledge.

The midamble section is used to aid the re-synchronization of the receiver when continuous reception was not possible, such as in the cases of full-duplex operation or in the case very long frames.

A short preamble is composed only of the fine estimation section.

A long preamble is composed of coarse estimation section followed by a fine estimation section.

#### 3.3.5.1 Coarse estimation Section

The coarse estimation is composed of 10 repetitions of a short sequence pattern. Each sequence is 1/4 of the length of an OFDM symbol (prior to cyclic extension). The time domain is depicted in figure 9 for the case of the 3.5MHz bandwidth.

The coarse estimation section is generated by taking the inverse Fourier transform of the frequency domain sequence shown in table 1 and cyclically extending to the required length. The sequence is normalized so that the RMS power is equal to that of data section.

Note that only subcarriers the index of which is multiple of 4 are utilized. This agrees with the periodicity of the sequence, which is ¼ of the OFDM symbol.

The relative phases of the active subcarriers are chosen such the overall peak to average power ratio is extremely low. Thus the estimation section is not distorted by power amplifier non-linearities.

The relatively short periodicity of the coarse estimation section enables low-ambiguity frequency estimation. Also antenna diversity and analog gain setting are supported.

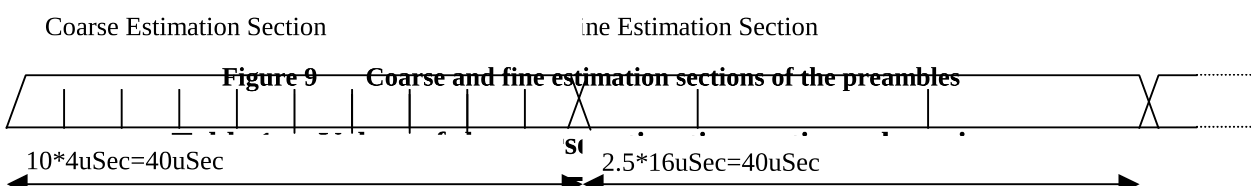



**Figure 9 Coarse and fine estimation sections of the preambles**

| Subcarrier location | Subcarrier value | Subcarrier location | Subcarrier value |
|---|---|---|---|
| -24 | 1+j | 4 | -1-j |
| -20 | -1-j | 8 | -1-j |
| -16 | 1+j | 12 | 1+j |
| -12 | -1-j | 16 | 1+j |

| | | | |
|---|---|---|---|
| -8 | -1-j | 20 | 1+j |
| -4 | 1+j | 24 | 1+j |

### 3.3.5.2 Fine estimation Section

The fine estimation section is composed of 2.5 repetitions of a basic sequence. each sequence is of the length of 1 OFDM symbol (prior to cyclic extension). The time domain presentation is depicted in figure 9. The fine estimation section can be generated by taking the inverse Fourier transform of the frequency domain sequence shown in table 2 and cyclically extending to the required length.

The structure of the fine estimation section allows:

Fine frequency estimation, by comparing the phases of the two repetitions.

- Channel estimation.
- Fine timing estimation.

As with the coarse estimation section, the relative phases of the active subcarriers are chosen such the overall peak to average power ratio is minimized.

**Table 2 Values of the fine estimation section subcarriers**

| Subcarrier location | Subcarrier value | Subcarrier location | Subcarrier value |
|---|---|---|---|
| -26 | 1 | 1 | 1 |
| -25 | 1 | 2 | -1 |
| -24 | -1 | 3 | -1 |
| -23 | -1 | 4 | 1 |
| -22 | 1 | 5 | 1 |
| -21 | 1 | 6 | -1 |
| -20 | -1 | 7 | 1 |
| -19 | 1 | 8 | -1 |
| -18 | -1 | 9 | 1 |
| -17 | 1 | 10 | -1 |
| -16 | 1 | 11 | -1 |
| -15 | 1 | 12 | -1 |
| -14 | 1 | 13 | -1 |
| -13 | 1 | 14 | -1 |
| -12 | 1 | 15 | 1 |
| -11 | -1 | 16 | -1 |
| -10 | -1 | 17 | 1 |
| -9 | 1 | 18 | -1 |
| -8 | 1 | 19 | 1 |
| -7 | -1 | 20 | -1 |
| -6 | 1 | 21 | 1 |
| -5 | -1 | 22 | -1 |
| -4 | 1 | 23 | 1 |
| -3 | 1 | 24 | 1 |
| -2 | 1 | 25 | 1 |
| -1 | 1 | 26 | 1 |

### 3.3.5.3 Midamble

The midamble is composed of a cyclic extension of the basic sequence of the fine estimation section. The sequence is extended to the length of a single OFDM symbol.

### 3.4 Subcarrier based polling

The polling packets allows for a very efficient polling process. This is achieved by assigning each SU a combination of subcarrier and time slot. Whenever a SU needs to be polled, it transmits a continuous wave signal at the assigned time and frequency slot. Thus a form of sub-carriers based multiple accesses mechanism is established. Using this mechanism, the AU can poll simultaneously a large number of SUs. The polling packet is composed of a predefined number of OFDM symbols which is transmitted once per up-stream period. The subcarrier-time assignment may span several such periods, and ensures that all stations are polled. At each polling period the subcarrier-time allocations to SUs are permuted, so the polling process is immune to selective fading, avoiding the situation in which a station tries repeatedly to transmit on a faded frequency.

Additionally, during the polling packet, each SU transmits only at a single subcarrier, and the transmit power density can be much higher than in regular transmissions.

Figure 10 shows an example of two instances of a polling process. Each polling packet contains 3 OFDM symbols, allowing thus polling of 156 stations. Two sets of sub-carrier assignments are shown. In the first, shown in red the SU transmits the subcarrier 24 in the first symbol of first polling period and the subcarrier –25 in the second symbol of the second polling period.
Another station, marked in gray, transmits subcarrier 26 in the 3rd symbol of first polling period and subcarrier –24 in the 1st symbol of the 2nd polling period.

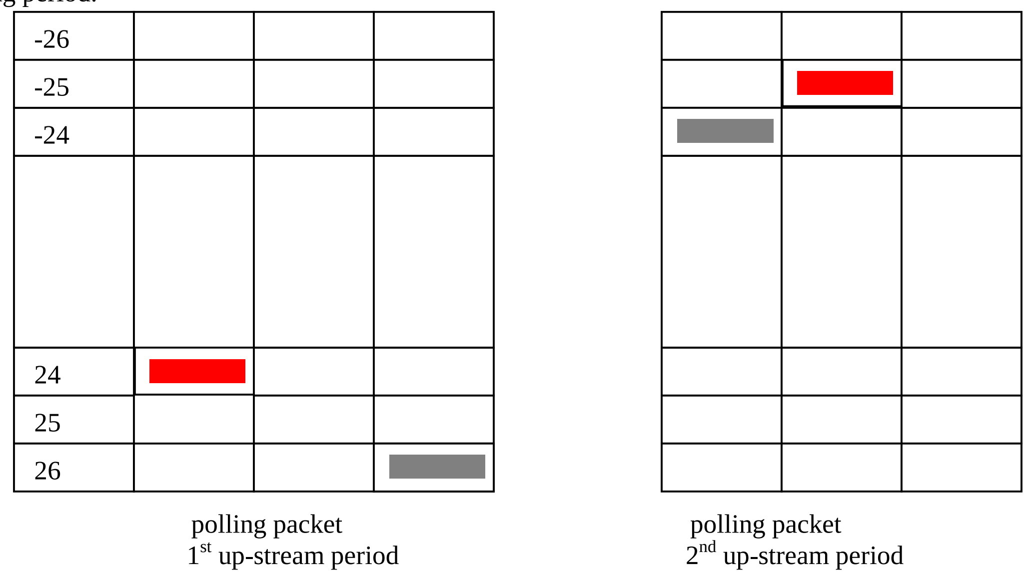



**Figure 10 Illustration of subcarrier based polling**

## 3.5 Error Correction Coding

The error correction coding used in 802.11a and HIPERLAN is based on binary convolutional codes. The industry veteran K=7, R=1/2 convolutional code is used, with R=2/3 and R=3/4 coding rates derived by puncturing (omitting coded bits on the Tx side and inserting "zero metric" on the Rx side).

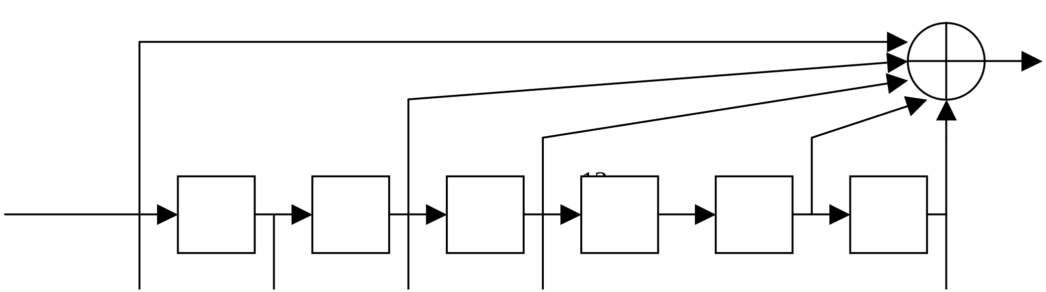


**Figure 11 Convolutional encoder with K=7, R=1/2, $g1=133_8$ , $g2=171_8$**

The encoded bits are interleaved (reordered), divided into groups of 1, 2, 4 or 6 bits, depending on the constellation, mapped onto the constellation values and then OFDM-modulated.

### 3.5.1 Packet termination

The convolutional codes are designed for continuous streams of data. When used for packet data, care is needed in handling the beginning and the end of the packet. The common practice, implemented in 802.11a and in HIPERLAN is to zero the contents of the shift register in the beginning and to feed extra 6 zero-value "tail bits" at the end of the packet until the contents of the shift register is flushed. This process is called "trellis termination" and it assists the Viterbi decoder to decode correctly the last bits of the packet.

In HIPERLAN the data "atoms" are 54 bytes long and they accommodate an integral number of OFDM symbols. In order to avoid loosing this property due to the 6 extra tail bits, an extra "puncturing" process is used, omitting 12 coded bits. In 802.11a the extra puncturing is not used, because anyway the packet sizes are variable with a granularity of a single byte. BWA can choose either to implement this procedure or not, depending on the approach taken to fragmenting the data.

### 3.5.2 Interleaving

The interleaving used in the 802.11a and HIPERLAN/2 serves the purpose of spreading adjacent coded bits among distant subcarriers. In addition, adjacent bits are assigned different significance in the constellation (MSB, LSB) in order to avoid clusters of less reliable bits. Interleaving over longer blocks improves the reliability, but incurs penalty on the encoding and decoding latency and the block size granularity. Both 802.11a and HIPERLAN/2 agreed to perform the interleaving over blocks of bits constituting one OFDM symbol. The number of bits per OFDM symbol depends on the data rate, and is summarized in the following table.

**Table 3 Number of bits per OFDM symbol 64point FFT mode**

| Modulation | Coding rate | Data Rate | Number of coded bits per symbol | Number of data bits per symbol |
|---|---|---|---|---|
| BPSK | R=1/2 | 1.33 Mbit/s | 48 | 24 |
| BPSK | R=3/4 | 2 Mbit/s | 48 | 36 |
| QPSK | R=1/2 | 2.66 Mbit/s | 96 | 48 |
| QPSK | R=3/4 | 4 Mbit/s | 96 | 72 |
| 16QAM | R=1/2 | 5.33 Mbit/s | 192 | 96 |
| 16QAM | R=3/4 | 8 Mbit/s | 192 | 144 |
| 64QAM | R=2/3 | 10.67 Mbit/s | 288 | 192 |
| 64QAM | R=3/4 | 12 Mbit/s | 288 | 216 |
| 256QAM | R=2/3 | 14.22 Mbit/s | 384 | 256 |
| 256QAM | R=3/4 | 16.0 Mbit/s | 384 | 288 |

**Table 4 Number of bits per OFDM symbol 256 point FFT mode**

| Modulation | Coding rate | Data Rate | Number of coded bits per symbol | Number of data bits per symbol |
|---|---|---|---|---|
| BPSK | R=1/2 | 1.62 Mbit/s | 208 | 104 |
| BPSK | R=3/4 | 2.44 Mbit/s | 208 | 156 |
| QPSK | R=1/2 | 3.25 Mbit/s | 416 | 208 |

| | | | | |
|---|---|---|---|---|
| QPSK | R=3/4 | 4.87 Mbit/s | 416 | 312 |
| 16QAM | R=1/2 | 6.5 Mbit/s | 832 | 416 |
| 16QAM | R=3/4 | 9.75 Mbit/s | 832 | 624 |
| 64QAM | R=2/3 | 13.0 Mbit/s | 1248 | 832 |
| 64QAM | R=3/4 | 14.62 Mbit/s | 1248 | 936 |
| 256QAM | R=2/3 | 17.33 Mbit/s | 1664 | 1109 |
| 256QAM | R=3/4 | 19.5 Mbit/s | 1664 | 1248 |

### 3.5.3 Turbo Coding Option

The performance of an OFDM modulation system may gain significantly from proper usage of stronger error correction codes, such as turbo codes. In particular turbo product codes as defined in IEEE802.16.1 [1] are recommended for the following system modes to enhance the system performance in both LOS and NLOS operating conditions. The Turbo coding option can be applied both to payloads sent at 64 and at 256 point FFT mode. The implementation of the BTC is optional.

In downlink packets the first PPDU containing the downlink map shall always be sent with the convolutional code, so that all the station will comprehend this part. Later, the PPDUs addressed to the stations supporting the BTC option may use this ECC format.

In the rest of this Section we describe the proposed turbo coding scheme and how it integrates with the two sub-carrier modes.

#### 3.5.3.1 Turbo Code Description

Turbo product code (TPC) is a turbo decoded product code. The general idea of TPC is to use simple component block codes (e.g., binary extended Hamming codes or single parity check codes) for constructing large block codes that can be easily decoded by an iterative Soft-In \ Soft-out decoder. In this proposal two or three dimensional component codes are taken to construct a product-code [1]. The codes recommended for the IEEE802.16.3 standard follow the principles of the codes specified in IEEE802.16.1 MODE B [2].

The matrix form of the two-dimensional code is depicted in Figure 1. The $k_1$ information bits in the rows are encoded into $n_1$ bits, by using a binary block $(n_1,k_1)$ code. The binary block codes employed are extended Hamming Codes or parity check codes. As product codes belong to a class of linear codes, the order of the encoding is not essential. In this proposal it is assumed that the encoding process is completed row-by-row, starting from the first row.
The redundancy of the code is $r_1 = n_1 - k_1$ and $d_1$ is the Hamming distance. After encoding the rows, the columns are encoded using another block code $(n_2,k_2)$, where the check bits of the first code are also encoded, producing checks on checks bits. The overall block size of such a product code is $n = n_1 \times n_2$, the total number of information bits $k = k_1 \times k_2$ and the code rate is $R = R_1 \times R_2$, where $R_i = k_i/n_i$, i=1, 2. The Hamming distance of the product code is $d = d_1 \times d_2$.

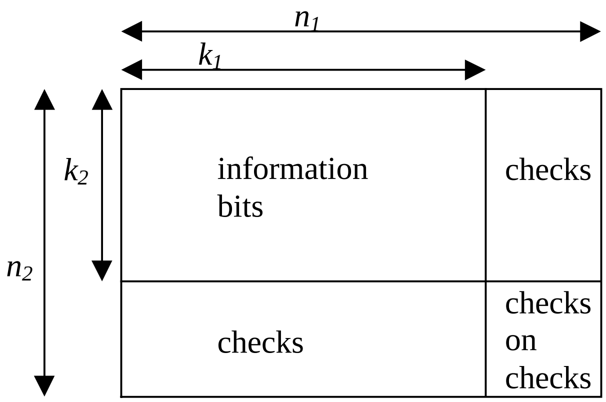



**Figure 12 Figure 1 - Two-dimensional product code matrix**

#### 3.5.3.2 Encoding

The encoder for a TPCs has near zero latency, and is constructed of linear feedback shift registers (LFSRs), storage elements, and control logic. Encoding of a product code requires that each bit be encoded by 2 or 3 codes. The constituent codes of TPCs are extended Hamming codes or parity check codes. Table 5 gives the generator polynomials of the Hamming codes used in TPCs. For extended Hamming codes an overall parity check bit is added at the end of each codeword.

| N | K | Generator Polynomial |
|---|---|---|
| 15 | 11 | $x^4 + x + 1$ |
| 31 | 26 | $x^5 + x^2 + 1$ |
| 63 | 57 | $x^6 + x + 1$ |

**Table 5 Example Generator Polynomials Component Hamming Codes**

In order to encode the product code, each data bit is input both into a row encoder and a column encoder. Note that only one row encoder is necessary for the entire block, since data is input in row order. However, each column of the array must be encoded with separate encoders. Each column encoder is clocked for only one bit of the row, so a more efficient method of column encoding is to store the column encoder states in a $k_1 \times (n_2\text{-}k_2)$ storage memory. A single encoder can then be used for all columns of the array. With each bit input, the appropriate column encoder state is read from the memory, clocked, and written back to the memory.
The encoding process will be demonstrated with an example. Assume a two-dimensional $(8,4) \times (8,4)$ extended Hamming Product code is to be encoded. This block has 16 data bits, and 64 total encoded bits.
shows the original 16 data bits denoted by $D_{yx}$.

$$\begin{matrix} D_{11} & D_{21} & D_{31} & D_{41} \\ D_{12} & D_{22} & D_{32} & D_{42} \\ D_{13} & D_{23} & D_{33} & D_{43} \\ D_{14} & D_{24} & D_{34} & D_{44} \end{matrix}$$

**Figure 13 Original Data for Encoding**

The first four bits of the array are input to the row encoder in the order $D_{11}$, $D_{21}$, $D_{31}$, $D_{41}$. Each bit is also input to a unique column encoder. Again, a single column encoder may be used, with the state of each column stored in a memory. After the fourth bit is input, the first row encoder error correction coding (ECC) bits are shifted out.
This process continues for all four rows of data. At this point, 32 bits have been output from the encoder, and the four column encoders are ready to shift out the column ECC bits. This data is shifted out at the end of the row. This continues from the remaining 3 rows of the array. **Error! Reference source not found.** shows the final encoded block with the 48 generated ECC bits denoted by $E_{yx}$.

$$\begin{matrix} D_{11} & D_{21} & D_{31} & D_{41} & E_{51} & E_{61} & E_{71} & E_{81} \\ D_{12} & D_{22} & D_{32} & D_{42} & E_{52} & E_{62} & E_{72} & E_{82} \\ D_{13} & D_{23} & D_{33} & D_{43} & E_{53} & E_{63} & E_{73} & E_{83} \\ D_{14} & D_{24} & D_{34} & D_{44} & E_{54} & E_{64} & E_{74} & E_{84} \\ E_{15} & E_{25} & E_{35} & E_{45} & E_{55} & E_{65} & E_{75} & E_{85} \\ E_{16} & E_{26} & E_{36} & E_{46} & E_{56} & E_{66} & E_{76} & E_{86} \\ E_{17} & E_{27} & E_{37} & E_{47} & E_{57} & E_{67} & E_{77} & E_{87} \\ E_{18} & E_{28} & E_{38} & E_{48} & E_{58} & E_{68} & E_{78} & E_{88} \end{matrix}$$

**Figure 14 Encoded Block**

Transmission of the block over the channel occurs in an interleaved fashion. This improves the performance of the code in a multipath channel. To reduce the latency to a minimum it is proposed to operate with an interleaver operating on each individual OFDM symbol. In this case the output of the block from the encoder to the symbol interleaver occurs in a linear fashion, with all bits of the first row transmitted left to right followed by the second row, etc. This allows for the construction of a near zero latency encoder, since the data bits can be sent immediately over the channel, with only the delay of the OFDM symbol interleaver, with the ECC bits inserted as necessary. For the $(8,4)\times(8,4)$ example, the output order for the 64 encoded bits would be $D_{11}$, $D_{21}$, $D_{31}$, $D_{41}$, $E_{51}$, $E_{61}$, $E_{71}$, $E_{81}$, $D_{12}$, $D_{22}$, … $E_{88}$.
A simple bit interleaver over 1 TPC block is a possible alternative which may slightly improve performance in a Rayleigh Channel environment. This case would allow the construction of an encoder with only 1 TPC block latency.

Notation:

- the codes defined for the rows (x-axis) are binary $(n_x,k_x)$ block codes
- the codes defined for the columns (y-axis) are binary $(n_y,k_y)$ block codes
- data bits are noted $D_{y,x}$ and parity bits are noted $E_{y,x}$

### 3.5.3.3 Shortened TPCs

To match packet sizes, a product code can be shortened by removing symbols from the array. In the two-dimensional case rows, columns or parts thereof can be removed until the appropriate size is reached. Unlike one-dimensional codes (such as Reed-Solomon codes), parity bits are removed as part of shortening process, helping to keep the code rate high.
There are two steps in the process of shortening of product codes. The first step is to remove S2 rows or S1 columns from a 2-dimensional code. This is equivalent to shortening the constituent codes that make up the product code, i.e, $(n_1 - S1, k_1 - S1)$ and $(n_2 - S2, k_2 - S2)$. This method enables a coarse granularity on shortening, and at the same time maintaining the highest code rate possible by removing both data and parity symbols. Further shortening could be obtained by removing S3 individual bits from the first row of a 2-dimensional code.

#### *3.5.3.3.1 Example of a Shortened Two-Dimensional BTC*

For example, assume a 456-bit block size is required (53+4 bytes for payload), with code rate of approximately 0.6. The base code chosen before shortening is the (32,26)×(32,26) code which has a data size of 676 bits. Shortening all rows by 2 and all columns by 7 results in a (30,24) × (25,19) code, with a data size of 456 bits and the final code is a (750,456) code, with a code rate of 0.608.
The following shortened codes are given as examples:
Product codes based on shortened binary Hamming code:
$(2^m - S1, 2^m-m-1-S1, 4) \times (2^m - S2, 2^m-m-1-S2, 4)$ where m is the encoder LFSR length and S1 and S2 are configurable shorthening parameters.

m= 5, S1= 2, S2=7 (53+4 bytes for payload)
m= 5, S1= 2, S2=8 (53+1 bytes for payload)
m= 6, S1= 25, S2= 10. (188 bytes for payload)
m= 6, S1= 25, S2=9 (188+4 bytes for payload)

Product codes based on binary parity-check codes:
(2k+1, 2k) × (2k+1, 2k) where k is configurable.

Table 2 illustrates different TPCs with variable block length, code rate and complexity.

| Code | (64,57)×(64,57) S1=S2=16, S3=0 | (64,57)×(32,31) S1=4, S2=15, S3=0 | (32,26)×(64,57) S1=1, S2=23, S3=2 | (64,57)×(64,57)×(16,15) S1=1, S2=S3=0 |
|---|---|---|---|---|
| Component Codes | (48,41)x(48,41) | (60,53)x(17,16) | (31,25)×(41,34)-2 | (63,56)×(64,57)×(16,15) |
| Code Rate | 0.73 | 0.831 | 0.668 | 0.742 |
| Block size (payload bits) | 1681 bits | 848 bits (106 bytes or 2 ATM packets) | 848 bits (106 bytes or 2 ATM packets) | 47880 bits 5985 bytes |

**Table 6 Examples of some TPC**

### 3.5.3.4 Iterative Decoding

Each block code in a product code is decoded independently. First, all the horizontal blocks are decoded then all the vertical received blocks are decoded (or vice versa). The decoding procedure is generally iterated several times to maximize the decoder performance. To achieve optimal performance, the block by block decoding must be done utilizing soft information. This soft decision decoder must also output a soft decision metric corresponding to the likelihood that the decoder output bit is correct. This is required so that the next decoding will have soft input information as well. In this way, each decoding iteration builds on the previous decoding performance. The core of the decoding process is the soft-in\soft-out (SISO) constituent code decoder. High performance iterative decoding requires the constituent code decoders to not only determine a transmitted sequence, but to also yield a soft decision metric which is a measure of the likelihood or confidence of each bit in that sequence. Since most algebraic block decoders don't operate with soft inputs or generate soft outputs, such block decoders have been primarily realized using the Soft-Output Viterbi Algorithm (SOVA) [6] or a soft-output variant of the modified Chase algorithm(s). However, this does not limit the choice of decoding algorithms as other SISO block decoding algorithms can be used [7],[8].

#### 3.5.3.5 Data Formatting

The data is then partitioned into a number of TPC blocks. Stuffing may be added if required. The data stream is then TPC encoded. The encoded datastream is then formatted into OFDM symbols. The formatted data is then symbol interleaved to improve the performance of the system when operating within a Rayleigh channel environment. The encoded and interleaved data is then formatted into OFDM symbols.

## 3.6 Data Rates

The data rates are based on the use of BPSK, QPSK, 16QAM or 64QAM constellations. In conjunction with coding rates of R=1/2, 2/3 or 3/4, the following data rates are obtained:

**Table 7 Data rates versus constellation and coding rate for 64 point FFT mode**

| Coding rate<br>Constellation | R=1/2 | R=2/3 | R=3/4 |
|---|---|---|---|
| BPSK | 1.33 Mbit/s | | 2 Mbit/s |
| QPSK | 2.66 Mbit/s | | 4 Mbit/s |
| 16QAM | 5.33 Mbit/s | | 8 Mbit/s |
| 64QAM | | 10.66 Mbit/s | 12 Mbit/s |
| 256QAM | | 14.22 Mbit/s | 16.0 Mbit/s |

**Table 8 Data rates versus constellation and coding rate for 256 point FFT mode**

| Coding rate<br>Constellation | R=1/2 | R=2/3 | R=3/4 |
|---|---|---|---|
| BPSK | 1.57 Mbit/s | | 2.36 Mbit/s |
| QPSK | 3.15 Mbit/s | | 4.73 Mbit/s |
| 16QAM | 6.3 Mbit/s | | 9.45 Mbit/s |
| 64QAM | | 12.6 Mbit/s | 14.18 Mbit/s |
| 256QAM | | 16.80 Mbit/s | 18.9 Mbit/s |

## 3.7 Support of higher bandwidth

The OFDM proposal can be easily scaled to meet other bandwidth requirements. In this section we discuss the parameters of operation bandwidths other then 3.5MHz.
The change of bandwidth should effect both the complex sampling rate and the Guard Interval duration. The proposed parameters are shown in table 9 and the achieved data rates in table 10.

**Table 9 Parameters for operation at higher Bandwiths**

| Channel Spacing | Complex sampling rate | Symbol duration 64points FFT / 256 points FFT | Guard interval |
|---|---|---|---|
| 3.5 MHz | 4Ms/s | 16/ 64 uSec | 8points = 2 uSec |
| 5MHz | 5Ms/s | 12.8/51.2 uSec | 8points = 1.6 uSec |
| 10MHz | 10Ms/s | 6.4/25.6 uSec | 12points = 1.2 uSec |
| 20MHz | 20Ms/s | 3.2 /12.8 uSec | 16points=0.8 uSec |

**Table 10 Achieved Data rates at higher bandwitdhs**

| Channel Spacing | Achieved Data rates for 64 FFT mode | Achieved Data rates for 256 FFT mode |
|---|---|---|
| 3.5 MHz | 1.33-16 Mbit/s | 1.57-18.9 Mbit/s |
| 5MHz | 1.62-19.45 Mbit/s | 1.95-23.4 Mbit/s |
| 10MHz | 3.16-37.90 Mbit/s | 3.88-46.66 Mbit/s |
| 20MHz | 6-72 Mbit/s | 7.65- 91.77 Mbit/s |

## *3.8 Flexibilities*

The basic ideas presented above can be applied in many ways. For example, multiple payloads, each with its own data rate and with its own code termination and CRC can be concatenated into a single packet. Preambles can be shortened whenever prior information exists. HIPERLAN is a good example of a standard which took advantage of such flexibilities and which can be incorporated into BWA.

### 3.8.1 Switching Antenna Diversity

The OFDM is optimized for operation in multipath with long delay spreads. In low delay-spread (nearly flat fading), however, additional measures are needed, since the energy of the signal may nearly vanish. One such measure is switching antenna diversity, taking advantage of the fact that two antennas at sufficient spacing seldom experience deep fades at the same time. In the switching diversity case there's no need to have double RF chains, as needed with combining diversity, while obtaining most of the gain. This requires, however sufficiently long preambles which allow examination of the signal at both antennas and selection of the best. Current proposal incorporates 802.11a-like preambles which were designed with this application in mind.

### 3.8.2 Frequency Hopping option

Another measure designed to cope with low delay-spread (nearly flat fading) situation is Frequency Hopping (FH). The FH exploits higher bandwidth, spread over time, than a single channel and enjoys the frequency domain diversity even at relatively short multipath. We suggest incorporating an optional support of FH within 802.16.3 and 802.16.4. This capability integrates naturally with the SuperFrame-based nature of the 802.16 MAC. The technology of low cost, fast settling time frequency hoppers is readily available, for example in 802.11FH and Bluetooth networks. Not related to 802.16.3, FH is also a valuable addition to WirelessHUMAN networks, which must withstand uncoordinated interference.

### 3.8.3 Smart Antenna support option

Additional means for throughput improvement is the possibility to point several beams to different users simultaneously, improving thus the frequency reuse. Beamforming in presence of multipath poses an extreme challenge for single carrier systems, but fits naturally in the context of OFDM systems. In OFDM systems the beamforming can be performed per subcarrier, hiding thus the "matrix equalization" complexity.

Applying this concept requires monitoring the channel responses from all the antenna elements in the base station to the users. On the uplink side the channel estimation can be done by the base station autonomously. In the downlink direction this calls for issuing appropriate training beacons and gathering the response data from the stations (the channel estimation beacons for multiple antennas can be shared for all the subscribers). An exception is a TDD system, in which due to reciprocity the uplink training can be applied for downlink beamforming. Introduction of smart antenna capability calls for appropriate hooks in the MAC and in the PHY

# 4 Summary

The OFDM based Physical Layer has numerous advantages for BWA systems. In addition to its good link gain performance, it excels in multipath robustness, it's scalable due to its variable rate support, its phase noise requirements are comparable to single carrier systems.

Chip-sets implementing this Physical Layer will become available due to the implementation efforts of 802.11a and HIPERLAN device developers. These chipsets will be available from several vendors and will be competitively priced.

For all those reasons we see in 802.11a/HIPERLAN2-like PHY an excellent candidate for the 802.16 BWA Physical Layer.

# 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 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 the 802.16 MAC and by exploiting the flexibilities inherent in it (data rates, preamble overheads etc.) the proposed PHY can meet the 802.16.3 FRD requirements.

## *5.2 Channel spectrum efficiency*

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.
-Modulation Scheme
-Gross Transmission Bit Rate
-User information bit rate at PHY-to-MAC Interface
-Occupied Bandwidth
The channel spectrum efficiency varies between 0.38 bit/sec/Hz up to 3.42 bits/sec/Hz. In the example of 3.5 MHz channel spacing used throughout the proposal the data rates range between 1.33 Mbit/sec and 12 Mbit/sec. The modulation is OFDM, with variable size QAM constellation and variable coding rate in order to trade data rate for link quality over wide range of channels conditions.

## *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. These 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 WBA Physical Layer with 802.11a and HIPERLAN technologies will facilitate availability of competitively priced chip-sets supporting this technology.

## *5.4 CPE cost optimization*

How does the proposed PHY affect CPE cost?

We believe that aligning the 802.16.3 WBA Physical Layer with 802.11a and HIPERLAN technologies will facilitate availability of competitively priced chip-sets supporting this technology.

## *5.5 BS cost optimization*

How does the proposed PHY affect Base Station cost?

We believe that aligning the 802.16.3 WBA Physical Layer with 802.11a and HIPERLAN technologies will facilitate availability of competitively priced chip-sets supporting this technology. The use of OFDM has some disadvantage with PA backoff, but on the other hand has considerable advantages for future introduction of smart antenna 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 proposal can be scaled to virtually any channel spacing. The inherent packet-based nature of the proposed PHY makes it particularly well suited to TDD with asymmetric Upstream/Downstream allocation.

## *5.7 System service flexibility*

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

The new services are provided with the 802.16 MAC assistance. The proposed PHY supports the MAC's capabilities with providing the flexibilities in many respects: adapting data rates, providing the capability to shorten the preamble overhead by exploiting prior knowledge and by reducing the reservation overhead and latency using the fast polling capability.

## 5.8 Protocol Interfacing complexity

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

The proposed PHY draws on recently adopted standards – 802.11a and HIPERLAN/2 PHY. In particular, HIPERLAN system is tightly managed and based on resource allocation and therefore is a good baseline for comparison with BWA. We believe that the MAC-PHY integration complexity of the WBA is commensurate with HIPERLAN/2 and 802.11a 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 BWA as well.

The PHY delay for the modulation scheme based on OFDM is about one OFDM symbol of demodulation and couple hundred bit delay of ECC decoding. For the example of 3.5 MHz bandwidth and speed of 8 Mbit/s the delay is about 40 microseconds.

A particular strength of the proposed PHY is its capability to efficiently poll multiple stations in parallel, utilizing the inherent parallelism of the subcarrier transmission. In a time equivalent to a single reservation slot tens or hundreds of stations may be polled.

## 5.9 Reference system gain*

Sector coverage performance for a typical BWA deployment scenario (supply reference system gain)

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 0 dB noise figure and 2 dB implementation degradation. The receive sensitivity is derived from simulations conducted in 802.11a and 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 BPSK can be reduced even further, but that comes at expense of adjacent channel interference, and a more conservative value is taken.

**Table 11 Link budget versus data rate**

| Data Rate | Sensitivity NF=0 dB degr.=2 dB | Backoff | Transmit power | System gain (link loss) |
|---|---|---|---|---|
| 1.33 Mbit/s | -102dBm | 7 dB | 23 dBm | 125 dB |
| 2 Mbit/s | -101 dBm | 7 dB | 23 dBm | 124 dB |
| 2.66 Mbit/s | -99 dBm | 7 dB | 23 dBm | 122 dB |
| 4 Mbit/s | -97 dBm | 7 dB | 23 dBm | 120 dB |
| 5.33 Mbit/s | -94 dBm | 7 dB | 23 dBm | 117 dB |
| 8 Mbit/s | -90 dBm | 7 dB | 23 dBm | 113 dB |
| 10.67 Mbit/s | -86 dBm | 9 dB | 21 dBm | 107 dB |
| 12 Mbit/s | -85 dBm | 9 dB | 21 dBm | 106 dB |

The Sensitivity, and correspondingly, the system gain, are expected to improve by about 1 dB for the 256 point FFT mode. Thje inclusion of turbo codes may improve performance by additional 2 dBs.

## 5.10 Robustness to interference

Resistance to intra-system interference (i.e., frequency re-use) and external interference cause by other systems

By the nature of the proposed PHY and the strong Error Correction Coding, the system has good interference rejection properties. Specific C/I data will be brought at later stage.

## 5.11 Robustness to channel impairments

Rain fading, multipath, atmospheric effects

The multipath robustness of OFDM is its main strength. It enables equalizing channels with multiple notches in frequency, and yet maintaining considerable coding gain. 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.