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# The WiMAX PHY Layer

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## 1. Introduction

This chapter will explore The PHY layers defined in IEEE 802.16d&e (2004/5 standards updates), OFDM/OFDMA and SOFDMA in the frequency domain, Symbol mapping and channel encoding, Link Adaptation - Channel coding and modulation schemes, Control mechanisms and antenna diversity and spatial multiplexing.

The discussions thereof shall thus be based on IEEE 802.16d, herewith referred to as *fixed WiMAX* and IEEE 802.16e herein referred to as *mobile WiMAX.* The specific PHY technical descriptions are given in the WiMAX Forum-T21/3 documentations or the original IEEE 802.16d suite of standards [2, 3, 4].

The PHYsical Layer in Fig. 1 provides the air interface between the Base Station (BS) and the Subscriber Stations (SS/MS) in different frequency bands for the entire range of IEEE 802.16* standards for single and multi-carrier bands with OFDM/OFDMA and SOFDM/SOFDMA. PHY) layer thus takes MAC PDUs at the PHY SAP and arranges them for transport over the air interface [4, 5].
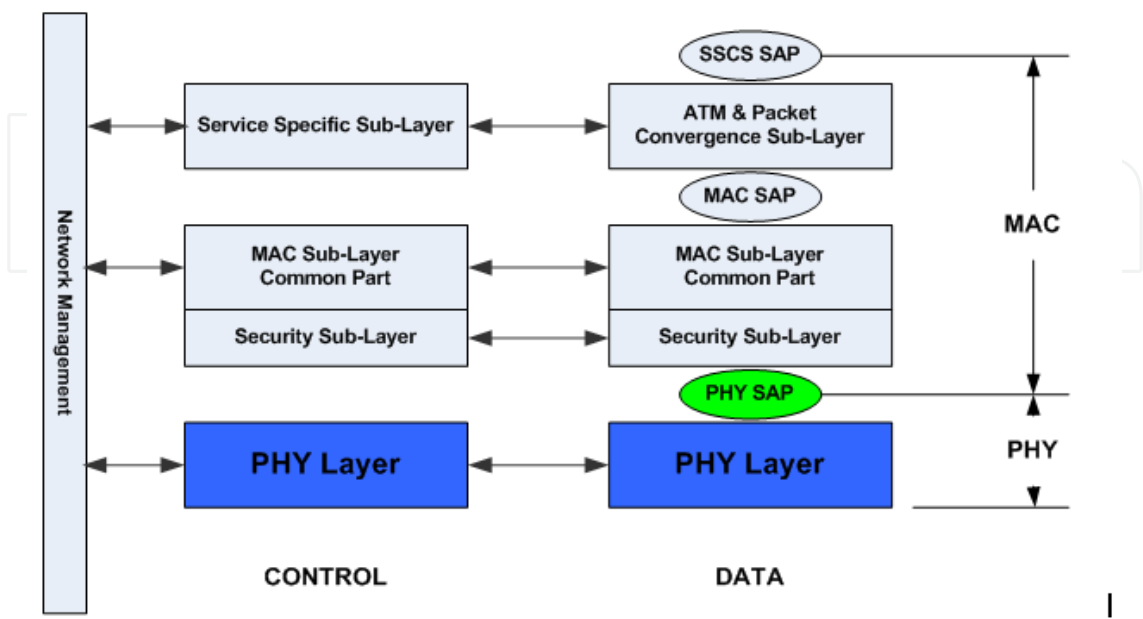


Fig. 1. WirelessMAN Protocol Layers

IEEE 802.16 (2001) specified PHY in 10-66 GHz range. This was further updated in 2004 and 2005 to 802.16d and 802.16e to define the 2-11 GHz range with enhancements such as Scalable Orthogonal Frequency-Division Multiple Access (SOFDMA) to the original multiplexing technique for fixed WiMAX, Orthogonal Frequency-Division Multiplexing (OFDM). Further updates have since been done in 2009 and 2011 to define Fixed and Mobile Broadband, and Mobile WiMAX respectively. In between these updates are several mergers, superseded and withdrawn projects. This chapter will NOT give further discussions on 2009 and 2011 updates to the 802.16 standard which have introduced multi-hop relay features (2009) and enhanced mobility and data rate features (2011).

The IEEE802.16 suite of standards defines four PHY layers in the Licensed Band namely WirelessMAN SC, WirelessMAN SCa, WirelessMAN OFDM (IEEE 802.16-2004) and WirelessMAN OFDMA (IEEE 802.16-2004), with further modifications to a Scalable OFDMA with a further one in the Unlicensed Band, WirelessHUMAN as summarized in Table 1 [2, 3].

| PHY | Propagation | Operation | Freq Band | Carrier | Duplexing |
|---|---|---|---|---|---|
| WirelessMAN SC | LOS | P2P | 10-66 GHz | Single | T/FDD |
| WirelessMAN SCa | LOS | P2P | 2-11 GHz | Single | T/FDD |
| WirelessMAN 16d (OFDM/A) | NLOS | PMP | 2-11 GHz | 256 | T/FDD |
| WirelessMAN 16e (S/OFDMA) | NLOS | PMP | 2-11 GHz | 2048 | T/FDD |
| WirelessHUMAN* | NLOS | PMP | 2-11 GHz* | 1/256/2048 | TDD, Dynamic Frequency Selection |

\* is for the High-speed Unlicensed band using license except frequencies in the 2-11 GHz band.
P2P is Point to Point
PMP is Point to Multi-Point

Table 1. Brief of IEEE 802.16 PHY

A functional WiMAX PHY Layer is represented by Fig. 2 both in time-frequency domains and digital-analog domains. The figure is shown from the transmitter end which is by default what's defined and the receiver is mostly left to vendor discretion. The first stage has to deal with Forward Error Check (FEC), channel encoding, puncturing or repeating, interleaving, and symbol mapping.

The next functional stage is the construction of the OFDM symbol in the frequency domain by mapping data onto the appropriate sub-channels/subcarriers and inserting pilot symbols into pilot subcarriers to enable the receiver to estimate and track the channel state information (CSI). Space/time encoding for transmit diversity is also implemented in this stage. The final stage involves the conversion of the OFDM symbol from the frequency domain to the time domain and eventually to an analog signal for transmission over the air interface [9, 4].
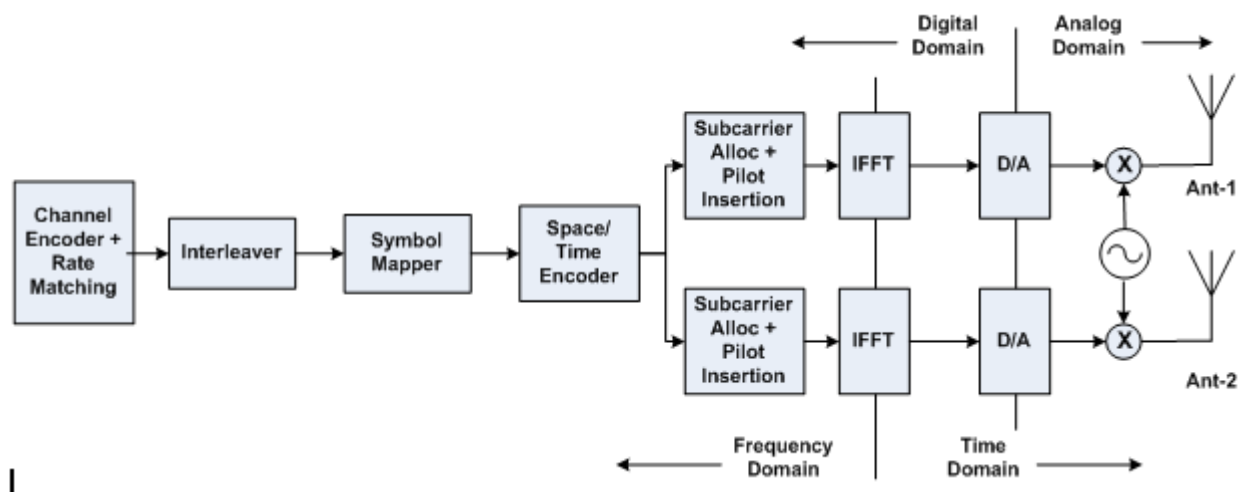
Fig. 2. WiMAX PHY Functional Diagram in Time-Frequency & Digital-Analog Domains

## 2. OFDM

Orthogonal Frequency-Division Multiplexing is multicarrier modulation technique with dedicated carrier spacing in the frequency domain. The orthogonality aims to address the Inter-Symbol Interference (ISI) while bringing better data rates with increased numbers of sub-carriers. If the modulated carrier is represented by a $sin\,x$ function, then the sub-channels peak at the zero crossings where modulation/demodulation occurs.

OFDM systems provide amongst other advantages robustness to multi-path and frequency selective fading, simple equalization and a better spectral efficiency due to enhanced modulation techniques, optimized capacity due to flexibility in time and frequency domains, an expanded coverage provided by sub-channelization and a scalable design to support extra demand giving preserved radio performance.

### 2.1 Sub-carriers

To achieve an OFDM system two conditions must apply:

i.    In an FFT interval every subcarrier has a certain number of integer cycles.
ii.   The difference between adjacent carriers is one cycle long.

This condition is satisfied by the equation 1.1 with the property expressed as a complex conjugate function.

$$\int_{t_s}^{t_s+T_s} e^{-j2\pi\frac{k}{T_s}(t-t_s)} \cdot \sum_{n=0}^{N-1} d_n e^{j2\pi\frac{n}{T_s}(t-t_s)}\, dt = \sum_{n=0}^{N-1} d_n \int_{t_s}^{t_s+T_s} e^{j2\pi\frac{n-k}{T_s}(t-t_s)}\, dt = \delta_{nk}\,|-T_g \le t \le T_s \qquad (1.1)$$

*where N is the number of subcarriers, $T_s$ is symbol time, $\delta$ is the Kronecker delta function*

The adjacent sub-carrier separation shown in Fig. 3 is given by $1/T_s$ and the peak values are found at $n\left[1/T_s\right]$ where $n = 1,2,3 \dots L$ is an integer with a maximum $L$ value equivalent to the maximum possible number of sub-carriers.
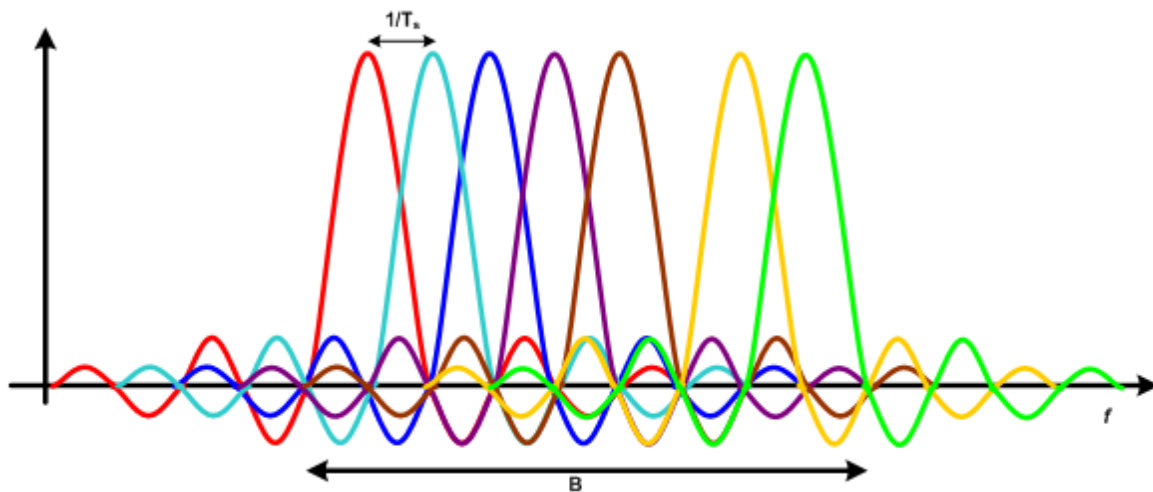
Fig. 3. OFDM Spectra of Sub-Carriers

Ideally, in a high data rate system the channel delay spread $\tau$ is much smaller than the symbol time $T_s$ to avoid ISI. In wideband communications we require a much smaller symbol time. It's therefore, crucial to modulate the available spectrum into $L$ sub-carriers, several discrete narrowband channels, to reduce ISI to ensure $\tau \ll T_s$ or $T_s/_L \gg \tau$. The $L$ concurrent sub-channels are then used to send the total desired data rate ISI free, see Fig 3 [9]. Usually Inter-Carrier Interference (ICI) is easily eliminated by transmitter-receiver synchronization

## 2.2 Cyclic prefix

Also known as the guard interval, the Cyclic Prefix (CP) is the overhead in the time domain of an OFDM system that utilizes the delay spread due to multipath. When available spectrum is spread into several narrow-band subcarriers the symbol time increases and the opportunity to improve spectral efficiency and robustness by introducing overhead in Time Domain is possible.

By a careful estimation of the delay spread and hence a reasonable cyclic prefix $T_g$ the ISI can be eliminated or reduced to negligible levels. The net effect of the guard interval is that all multipath effects only affects the guard interval and not the actual data symbol while the $T_g$ remains small enough to be ignored in useful symbol time $T_s$ [7]. The symbol duration, $T$ is thus composed of the useful symbol time $T_s$ and the guard interval $T_g$. as illustrated in Fig 4.

In attempting to create an ISI free channel the channel must appear to provide a cyclic convolution, a major property of I/FFT as we shall see in the next section. The idea of a cyclic prefix is thus integral to interference free multi-carrier wideband technology.

Consider a maximum channel delay spread, $\tau = u + 1$, if you add $T_g = u$ then we can then consider the entire bit-stream as a single OFDM symbol with $L$ vector-lengths.
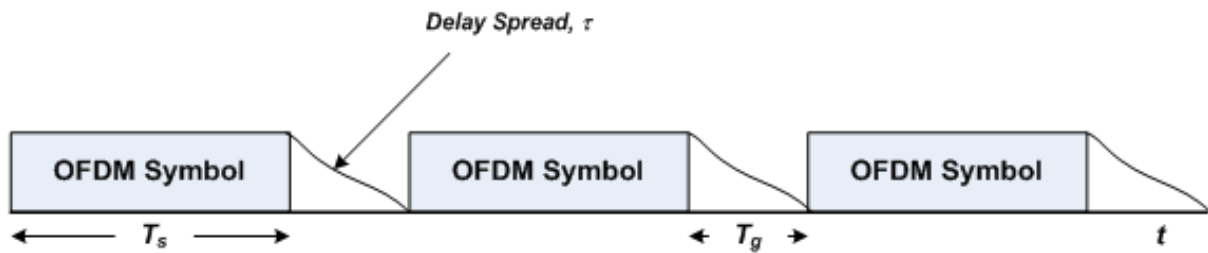
Fig. 4. OFDM Symbol

$$X = [x_1 x_2 x_3 \ldots x_L]$$ (1.2)

$$X_{cp} = [x_{L-u} x_{L-u+1} x_{L-u+2} \ldots x_{L-1} x_0 x_1 \ldots x_{L-1}] = x_{cp} x_d$$ (1.3)

$$where \ x_{cp} \ is \ the \ cyclic \ prefix \ and \ x_d \ is \ the \ original \ data$$

The channel output is given by, $Y_{cp} = h \circledast X_{cp}$, where h is a length $u + 1$ vector describing the impulse response of the channel during the OFDM symbol and the length of $Y_{cp}$ is $L + 2u$ samples with one $u$ from the previous symbol discarded and the other $u$ discarded at the next symbol leaving only the L symbols as, originally intended, output. The idea thus to represent the signal as a circular convolution system with CP that is at least as long as the channel delay spread results in a desired channel output $Y$ to be decomposed into a simple product of the channel frequency response H = FFT{h} and the channel frequency domain input, X = FFT{x} [9].

## 2.3 I/FFT

OFDM employs an efficient computational technique known as the Fast Fourier Transform (FFT) and its inverse, the Inverse First Fourier Transform (IFFT). An FFT transforms or decomposes into its frequency components while the IFFT will reverse the signal to the special domain. The FFT is a faster algorithm of the Discrete Fourier Transform (DFT) with time savings of up to a factor of $[N/logN]$.

If we consider a data sequence $X = (X_0, X_1, \ldots X_n, \ldots X_{N-2}, X_{N-1})$ and $X_k = A_k + jB_k$ then a DFT/IDFT representation of an OFDM signal can be expressed thus, 1.4 below

$$x_n \frac{1}{N} \sum_{k=0}^{N-1} X_k e^{j2\pi \frac{kn}{N}} = \frac{1}{N} \sum_{k=0}^{N-1} X_k e^{j2\pi f_k t_n}, \ n = 0,1,2..N-1$$ (1.4)

Where $f_k = {k}/{N\Delta t}, t_n = n\Delta t$ and $\Delta t$ is an arbitrary symbol duration of the = sequence $x_n$

If we take the real part as $S_n = Re(x_n)$

$$= \frac{1}{N} \sum_{k=0}^{N-1} (A_k cos 2\pi f_k t_n - B_k cos 2\pi f_k t_n, \quad n = 0,1,2..N-1$$ (1.5)

Applied to a low-pass filter we $t_n = t \ intervals, 0 \leq t \leq N\Delta t \ in \ equation \ 1.5 \ above.$

The time and frequency domain representations can be given as in Eq 1.6.

$$\int_{-\infty}^{\infty} x_i(t)x_j^*(t)dt = \begin{cases} 1, & i = j \\ 0, & i \neq j \end{cases} \text{ and } \int_{-\infty}^{\infty} X_i(f)X_j^*(f)df = \begin{cases} 1, & i = j \\ 0, & i \neq j \end{cases} \qquad (1.6)$$

The time-domain spreading is achieved by repeating the same information in an OFDM symbol on two different sub-bands giving frequency diversity while the frequency-domain spreading is achieved by choosing conjugate symmetric inputs to the IFFT. This also exploits frequency diversity and minimizes the transmitter complexity and improves power control.

In section 2.2 we introduced cyclic prefix and the crucial role of circular convolution applied to a linear-time invariant FIR. We shall illustrate this further to help understand the I/FFT processing in an OFDM system.

Suppose we were to compute the output y[n] of a system as a circular convolution of its impulse response h[n] and the channel input x[n] [9].

$$y[n] = h[n] \circledast x[n] = x[n] \circledast h[n] \qquad (1.7)$$

where $h[n] \circledast x[n] = x[n] \circledast h[n] \triangleq \sum_{k=0}^{L-1} h[k]x[n-k]_L$ with the circular function $x[n]_L = x[n \bmod L]$ is periodic with period L.

We can thus define the output as a DFT{ y[n]} in time and frequency as given in Eq. 1.8

$$DFT\{y[n]\} = DFT\{h[n] \circledast x[n]\} \text{ and } Y[m] = H[m]X[m] \qquad (1.8)$$

The L point DFT is then defined by

$$DFT\{x[n]\} = X[m] \triangleq \frac{1}{\sqrt{L}} \sum_{n=0}^{L-1} x[n]e^{-j\frac{2\pi nm}{L}} \qquad (1.9)$$

with the inverse, IDFT defined by

$$IDFT\{X[m]\} = x[n] \triangleq \frac{1}{\sqrt{L}} \sum_{n=0}^{L-1} X[m]e^{j\frac{2\pi nm}{L}} \qquad (2.0)$$

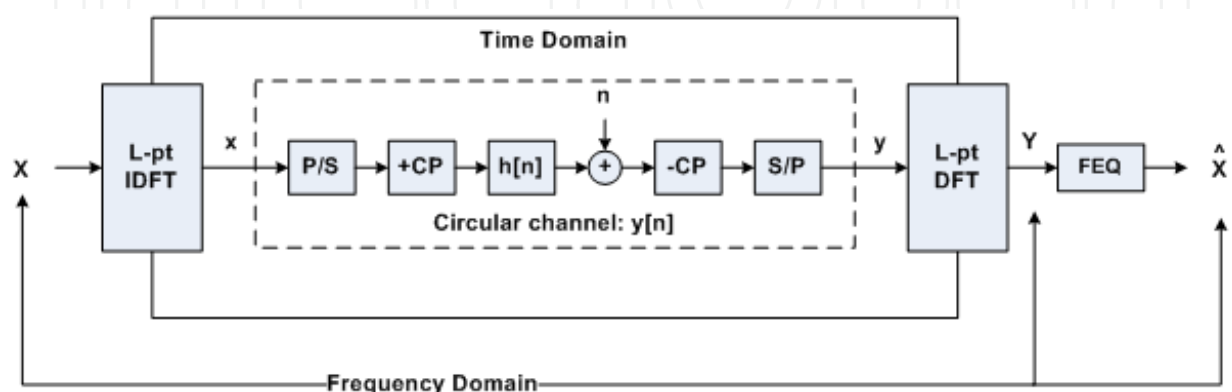In summary an OFDM system may be viewed as a functional block diagram shown in Fig. 5.



Fig. 5. OFDM Functional Block Diagram

From Fig. 5 the estimated data symbols, $\hat{X}[m] = \frac{Y[m]}{H[m]}$ while X and Y represent the L transmitted and received symbols.

i.   Decompose the wideband signal of bandwidth B into L narrowband, flat-fading signals, vector x.
ii.  Modulate the L subcarriers into a single wideband Radio using an IFFT operation.
iii. Attach a CP after the IFFT operation to achieve orthogonality and send serially through the wideband channel.
iv.  At the receiver, discard CP, and demodulate using an FFT operation, which results in L data symbols.
v.   Equalize each subcarrier using FEQ by dividing by the complex channel gain H[i] for that subcarrier [6, 7, 9].

## 3. OFDMA and SOFDMA

To enhance the performance of OFDM flexible extensions have been developed. These include Orthogonal Frequency Division Multiple Access (OFDMA) and Scalable OFDMA (SOFDMA). The OFDMA feature schedules a varying number of subcarriers to each subscriber depending on needs, channel conditions or both. This gives rise to the concept of flexible sub-channelization of the bandwidth. The access domain is further enhanced by multiple access technologies of FDMA and TDMA. SOFDMA on the other hand is used on the transmission end to 'scale' the channel bandwidth. By enabling the adjustment of the FFT size hence the number of carriers to the transmission channel bandwidth, SOFDMA brings scalability to OFDM. OFDMA thus incorporates features of the Code Division Multiple Access (CDMA) by combining OFDMA and allowing low-data-rate users to transmit continuously at lower power with shorter and constant delay. A similar concept applies in the frequency domain and TDMA where the resources are partitioned in the time-frequency space, and slots are assigned along the OFDM symbol subcarrier indices [8].

Certain frequency selective impacts can be minimized by spreading subcarriers of a user over the entire channel spectrum in addition S/OFDMA can be configured for Adaptive Antenna Systems (AAS) enhancing payload and coverage. OFDMA also comes with better high-performance coding techniques such as Turbo Coding and Low-Density Parity Check (LDPC), enhancing security and NLOS performance increase system gain by use of denser sub-channelization, thereby improving indoor penetration [7]. The sum effect of sub-channelization is that the link budget is greatly enhanced by allocating each subscriber one or several portions of the overall bandwidth and NOT the entire channel bandwidth. The immediate benefit of this technique is not hard to discern since the UL-DL budgets can then be easily balanced. With a good scheduling technique a fair throughput trade-off can be optimized at cell edge and overall UL data rate.

An OFDMA transmission is shown in Fig. 6 in the frequency domain, with the Pilot Subcarriers used for channel estimations, the DC subcarrier is the centre frequency, unused, the SS1/2 Data Subcarriers are the user data subcarriers scaled for subscribers 1&2 and the Guard band is to limit ISI and channel decay.
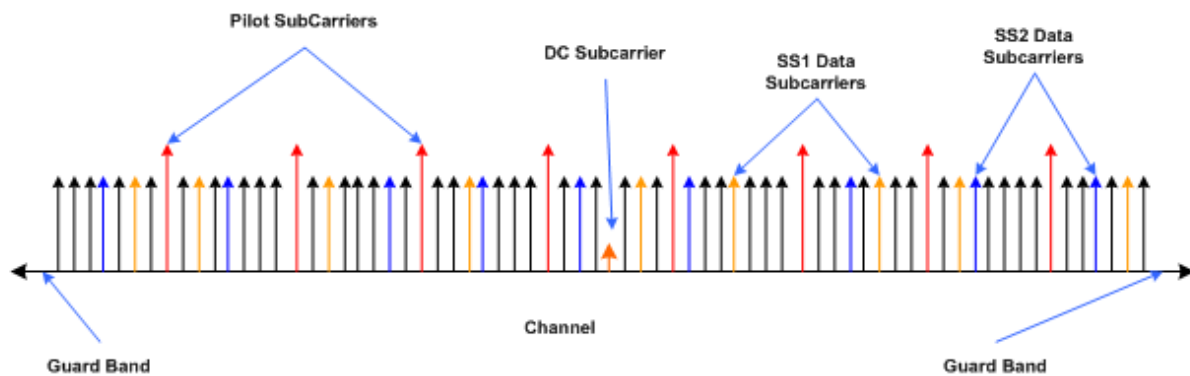
Fig. 6. OFDM Subcarriers

## 4. Subcarrier permutations

To create an OFDM symbol in the frequency domain, the mapping of the physical resources (subcarriers) to the logical channels (sub-channels) has to be done. This is not only aimed at assigning the right modulated signals with the right transmission blocks but also meant at reducing sub-channel sensitivity with regards to spectral fading. Permutation scheme is used to carry out this mapping. This ensures a sub-channel can use its assigned subcarrier only for a finite number of symbols and then permutated to another subcarrier. In general 802.16* suite of standards define a number permutation schemes for varied requirements ideally to introduce a robustness that minimizes interference. These schemes could be [2, 3]:

- Full or Partial sub-channel permutations.
- Distributed or Adjacent permutations.
- Uplink and Downlink permutations.

Distributed permutations use the full spectral diversity of the subcarriers for the permutation of a sub-channel while adjacent permutations assign adjacent sub carriers to a sub-channel. The distributed mode is ideal for optimizing a network towards a more robust spectral sensitivity. On the other hand the adjacent sub carriers allow faster system feedback and permutation processing thus better suited for fixed/portable devices with increased throughput [7].

### 4.1 Segmentation and sub-channelization

A sub-channel is a logical transmission resource of a collection of physical subcarriers. A permutation scheme defines the number and pattern for mapping the subcarriers to the sub-channels. A sub-channel is constant in time over a transmission block and maybe allocated to different connections over time. However, subcarriers of a sub-channel do not have to be adjacent. Certain factors such as size of data block to be transmitted, the modulation scheme and the coding rate may determine the amount of sub-channels allocated to a specified data block. It's important to note that a particular data region of users always uses the same burst profile. A burst profile is defined by a chosen modulation scheme, coding rate and FEC type while a data region of users refers to the contiguous set of sub-channels assigned to a user(s) in frequency and time [8,9].

An optional alternative to sub-channelization is segmentation shown in Fig. 7 that aims to divide a transmission channel into groups of sub-channels with the following properties:

- A segment consists 1 of a number of sub-channels.
- The segments share the bandwidth of the transmission channel.
- No reuse of Sub-channels of one segment and consequently the subcarriers cannot be reused either.
- Segmentation is done by interleaving the subcarriers in the Frequency Domain.
- Every segment has its own MAC instance complete with a preamble, UL MAP, DL MAP (a whole separate transmission frame).
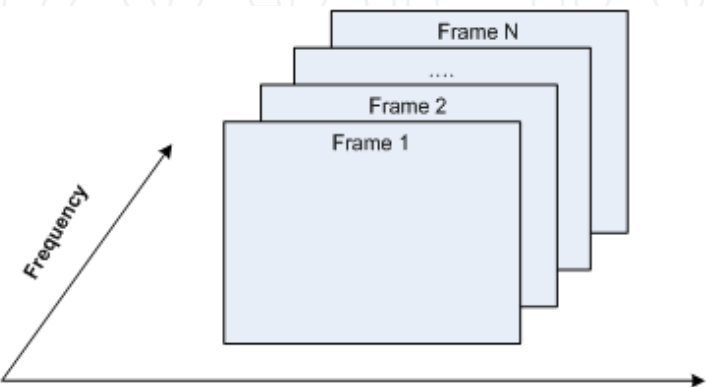- One subcarrier can be used only in one segment at a given time.



Fig. 7. Segmentation

### 4.2 FUSC permutation

In the Fully Used Sub-Channelization permutation shown in Fig. 8, all subcarriers are used in all the sub-channels distributed evenly across the entire frequency band. FUSC is only permutated in the Downlink (DL). The set of Pilot subcarriers, which are assigned first, is divided into two constant and two variables sets. The difference in both sets lies in the indexing of the pilot subscribers. With the variable set the index changes from one OFDM symbol to the next, while the index stays constant with the constant set. The variable sets allows for accurate estimation of channel response at the receiver especially in channels with larger delay spread or small coherence bandwidth. In cases where FUSC is implemented with transmit diversity, say of order n, then each antenna is allocated an nth each of the variable and constant sets of pilot subscribers [4, 9].
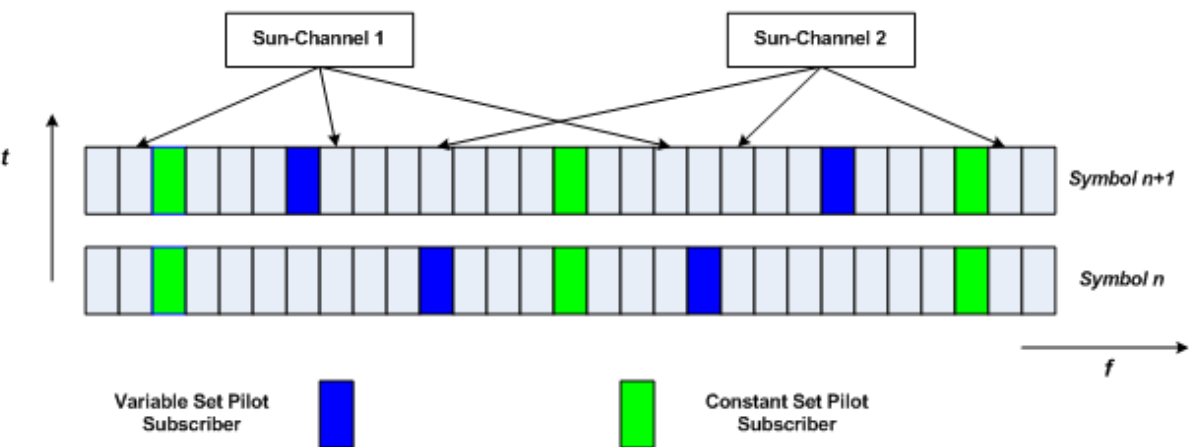


Fig. 8. FUSC Permutation

It's instructive to note that each sub-channel has a max of 48 subcarriers across all FFT sizes as shown in Table 2. The 802.16d does NOT support FUSC/PUSC and thus the 256 FFT size is not ignored in the presentation.

|  | 128 | 512 | 1024 | 2048 |
|---|---|---|---|---|
| Subcarriers per Channel | 48 | 48 | 48 | 48 |
| Sub-channels | 2 | 8 | 16 | 32 |
| Data SCa | 96 | 384 | 768 | 1536 |
| Pilot SCa – Constant Set | 1 | 6 | 11 | 24 |
| Pilot SCa – Variable Set | 9 | 36 | 71 | 142 |
| Left Guard SCa | 11 | 43 | 87 | 173 |
| Right-Guard SCa | 10 | 42 | 86 | 172 |

Table 2. Parameters of FUSC Permutation

## 4.3 PUSC permutation

Partially Used Sub-Channelization is based on the concept of segmentation with subcarriers allocated to a segment first then to the sub-channel belonging to the dedicated segment. PUSC is similar to FUSC but with the extra advantage of permutation both in the UL and DL. The subcarriers are first subdivided into groups of 6 then clustered, save for the null subcarrier. The clusters consist of fourteen adjacent subcarriers spanned over two OFDM symbols. Permutations are thus done within groups independently of the others [12].

In the DL, each cluster's subcarriers are divided into 24 data subcarriers and 4 pilot subcarriers. The clusters are then pseudo-randomly renumbered using a scheme that redistributes the logical identity of the clusters, then divided into six groups, with the first one-sixth of the clusters belonging to group 0, and so on. A sub-channel is created using two clusters from the same group [9]. The segmentation can be done to allocate all or a subset of the six groups to a given transmitter. If this is done over sectors of a BS a better frequency reuse can be achieved.

In the UL, the subcarriers are first divided into various tiles, consisting of 4 subcarriers over three OFDM symbols. The subcarriers within a tile are divided into eight data subcarriers and four pilot subcarriers

|  | 128 | 512 | 1024 | 2048 |
|---|---|---|---|---|
| Subcarriers per Channel | 14 | 14 | 14 | 14 |
| Sub-channels | 3 | 15 | 30 | 60 |
| Data SCa | 72 | 360 | 720 | 1140 |
| Pilot SCa | 12 | 60 | 120 | 240 |
| Left Guard SCa | 22 | 46 | 92 | 184 |
| Right-Guard SCa | 21 | 45 | 91 | 183 |

Table 3. PUSC Permutation - DL

## 4.4 AMC permutation

Advanced Modulation and Coding uses adjacent subcarriers to build a sub-channel. As in the TUSC scheme, it is mainly utilized in the AAS networks. In spite of some loss of

frequency diversity, exploitation of multiuser diversity is easier and robust. Multiuser diversity provides significant improvement in overall system capacity and throughput, since a sub-channel at any given time is allocated to the user with the highest SNR/capacity in that sub-channel [12].

The wireless channel is dynamic and diverse users get allocated on the sub-channel at different instants in time uncorrelated channel conditions. In AMC permutation, nine adjacent subcarriers with eight data subcarriers and one pilot subcarrier are used to form a bin, as shown in Fig. 9. An AMC sub-channel consists of six contiguous bins from within the same band where four adjacent bins in the frequency domain constitute a band. An AMC sub-channel thus consists of one bin over six consecutive symbols, two consecutive bins over three consecutive symbols or three consecutive bins over two consecutive symbols [9, 10].
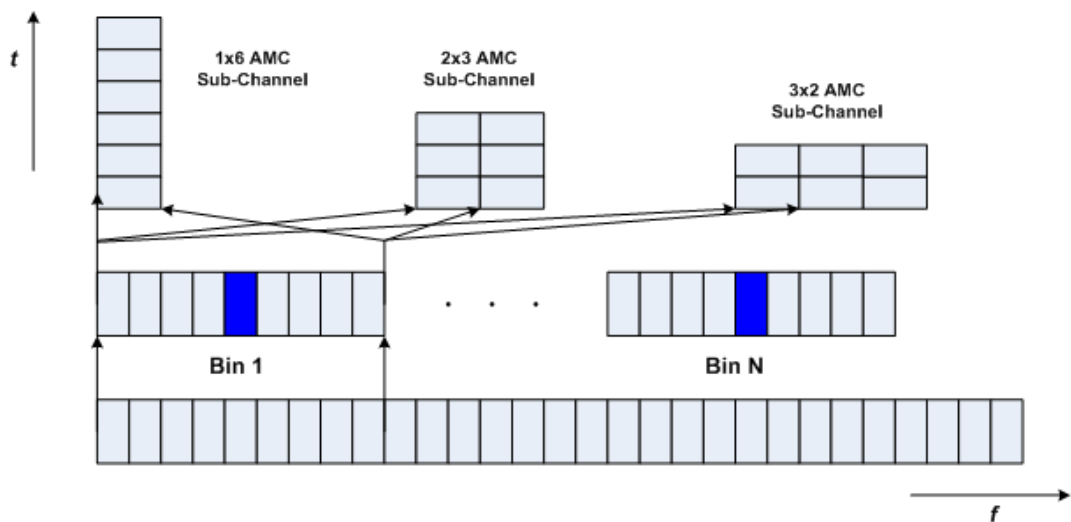


Fig. 9. AMC Permutation

### 4.5 TUSC permutation

The Tile Usage of Sub-channels is a downlink subcarrier permutation mode that is identical to the uplink PUSC. If closed loop advanced antenna systems (AAS) are to be used with the PUSC mode, explicit feedback of the channel state information (CSI) from the MS to the BS would be required even in the case of TDD, since the UL and DL allocations are not symmetric, and channel reciprocity cannot be used. TUSC allows for a DL allocation that is symmetric to the UL PUSC, thus taking advantage of UL and DL allocation symmetry and eliminating the requirement for explicit CSI feedback in the case of closed-loop AAS for TDD systems. Refer to TTD frame structure shown in Fig. 10.

## 5. Slot and frame structure

The MAC layer allocates the time/frequency resources to various users in units of *slots*, the smallest quanta of PHY layer resource that can be allocated to a single user in the time/frequency domain. The size of a slot is dependent on the subcarrier permutation mode as discussed in section 4.

- FUSC: Each slot is 48 subcarriers by one OFDM symbol.
- Downlink PUSC: Each slot is 24 subcarriers by two OFDM symbols.

- Uplink PUSC and TUSC: Each slot is 16 subcarriers by three OFDM symbols.
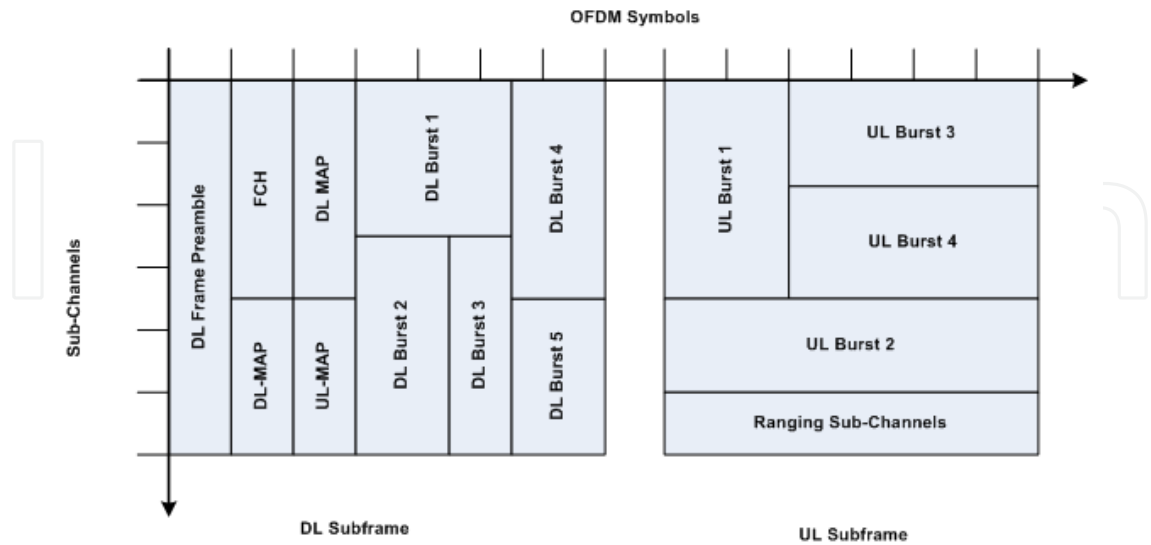- Band AMC: Each slot is 8, 16, or 24 subcarriers by 6, 3, or 2 OFDM symbols.



Fig. 10. TDD Frame Structure

## 6. Channel coding

In the 802.16e definition channel coding constitutes the sum of steps including data randomization, channel coding, rate matching, Hybrid Automatic Repeat reQuest (HARQ), and interleaving. At the beginning of each FEC block is a modulo-2 shift-register of maximum-length whose output is used to randomize the data. This randomization is purely for data integrity by providing PHY encryption and avoiding accidental decode by unintended receivers. In cases where HARQ is used the initial seed of the shift-register is kept the same over the period to allow for joint FEC decoding over several transmissions.

Channel coding is performed on every FEC block, which is n integer long sub-channels and whose maximum depends on channel coding scheme and the modulation constellation. Should the required number of FEC block sub-channels exceed this maximum, then segmentation is done to produce multiple FEC sub-blocks. Encoding and rate matching is done separately for these sub-blocks and then concatenated sequentially [10].

### 6.1 Convolution coding

The default channel coding scheme for WiMAX channels a convolutional encoder; based on binary non-recursive convolutional coding (CC). It uses a constituent encoder with a constraint length 7 and a native code rate $1/2$. The convolutional encoder transforms an m-bit symbol into an n-bit symbol, where m/n is the code rate $\{n \geq m\}$. The transformation is a function of the last k information symbols, where k is the constraint length of the code [5].

The Turbo encoder is used to encode the output of the data randomizer. A padding byte 0x00 at the end of the OFDM mode of each FEC block is used to initialize the encoder to the 0 state. In OFDMA tailbiting is used to initialize the encoder by using 6 bits from the end of the data block appended at the beginning, to be used as flush bits. These appended bits flush out the bits left in the encoder by the previous FEC block. The first 12 parity bits that

are generated by the convolutional encoder which depend on the 6 bits left in the encoder by the previous FEC block are discarded [9].

## 6.2 Turbo coding

Turbo codes are high-performance error correction codes used to achieve maximal information transfer over a bandwidth-limited noise prone communication.

WiMAX uses duo-binary turbo codes with a constituent recursive encoder of constraint length of 4. In duo-binary turbo codes, two consecutive bits from the un-coded bit sequence are sent to the encoder simultaneously. The duo-binary convolution encoder has two generating polynomials, 1+D2+D3 and 1+D3 for two parity bits with four possible state transitions.

## 6.3 Block turbo and LDPC coding

These are some of the optional channel coding schemes for WiMAX. The block turbo codes consist of two binary extended Hamming codes that are applied on natural and interleaved information bit sequences, respectively. The LDPC code, is based on a set of one or more fundamental LDPC codes, each of the fundamental codes is a systematic linear block code that can accommodate various code rates and packet sizes. The LDPC code can flexibly support various block sizes for each code rate through the use of an expansion factor [9, 12].

## 6.4 HARQ

Hybrid Automatic Repeat reQuest can be implemented in type I or II, commonly referred to as chase combining and incremental redundancy respectively. In Chase combining the receiver uses the current and all the previous transmissions of data block for puncturing and hopefully the right information is decoded or the HARQ timer runs out. However, with incremental redundancy the receiver uses different version of the redundancy block leading to lower BER and BLER.

# 7. Symbol mapping and structure

When a symbol is mapped, the sequence of binary bits is converted to a sequence of complex valued symbols. The mandatory constellations are QPSK and 16 QAM, with an optional 64QAM constellation also defined in the IEEE 802.16e standard. Assuming all symbols are equo-probable each modulation constellation is scaled by a factor $\varsigma$ such that the average transmitted power is unity. Where $\varsigma$ is given by $\sqrt{\frac{1}{2}}, \sqrt{\frac{1}{10}}, \sqrt{\frac{1}{42}}$ for QPSK, 16QAm and 64QAM modulations shown in Fig. 11. If convolution coding is applied for PHY encryption then we have an output given by

$$S_k = 2(\frac{1}{2} - w_k)S_k$$

By scaling the preamble and midamble symbols by a factor $2\sqrt{2}$ we we amplify the power by a factor 8 and allow for more accurate synchronization and various parameter estimations, such as channel response and noise variance.

A high-data-rate sequence of symbols can be split into multiple parallel low-data rate-sequences, each of which is used to modulate an orthogonal tone, or subcarrier. The resulting baseband signal, which is an ensemble of the signals in all the subcarriers, can be represented as

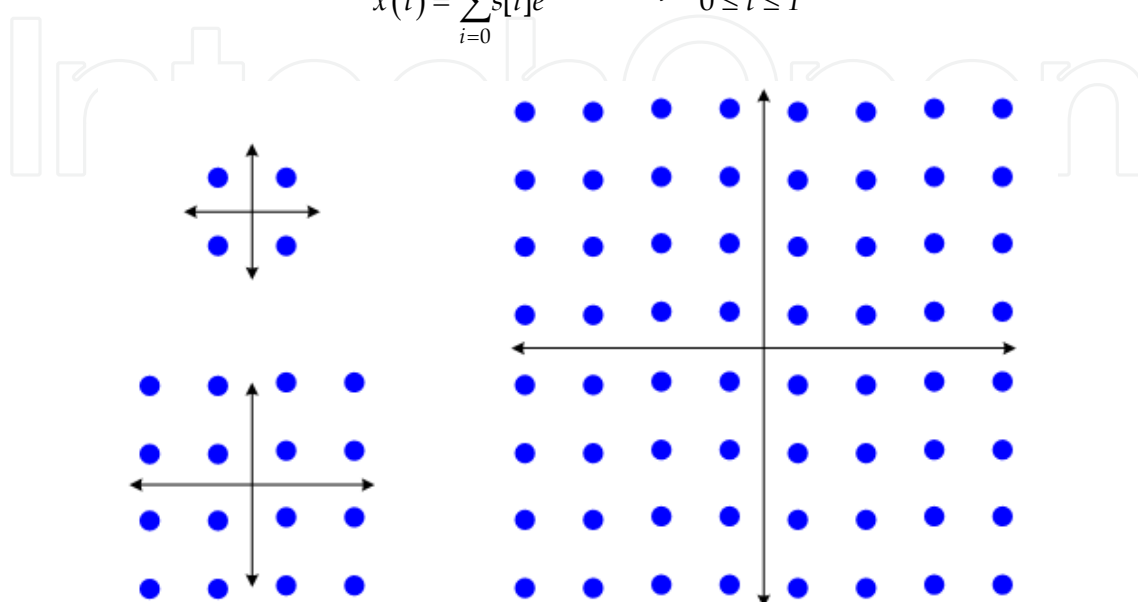$$x(t) = \sum_{i=0}^{L-1} s[i] e^{-j2\pi(\Delta f + iB_\varsigma)t} \quad 0 \leq t \leq T$$

Fig. 11. QPSK, 16QAM and 64QAM Modulation Constellations

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**Digital Communication**

Edited by Prof. C Palanisamy

ISBN 978-953-51-0215-1

Hard cover, 208 pages

**Publisher** InTech

**Published online** 07, March, 2012

**Published in print edition** March, 2012

All marketing is digital and everyone should have a digital strategy. Everything is going mobile. "The world has never been more social" is the recent talk in the community. Digital Communication is the key enabler of that. Digital information tends to be far more resistant to transmit and interpret errors than information symbolized in an analog medium. This accounts for the clarity of digitally-encoded telephone connections, compact audio disks, and much of the enthusiasm in the engineering community for digital communications technology. A contemporary and comprehensive coverage of the field of digital communication, this book explores modern digital communication techniques. The purpose of this book is to extend and update the knowledge of the reader in the dynamically changing field of digital communication.

**How to reference**

In order to correctly reference this scholarly work, feel free to copy and paste the following:

Marcel O. Odhiambo and Amimo P.O. Rayolla (2012). The WiMAX PHY Layer, Digital Communication, Prof. C Palanisamy (Ed.), ISBN: 978-953-51-0215-1, InTech, Available from: http://www.intechopen.com/books/digital-communication/the-wimax-phy-layer

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