

A Review of Physical Layer of Mobile WiMAX System and OFDM

Jayshree Sisodiya¹, Deepti Rai²

¹PG Student , ECE Deptt. , Alpine Institute of Technology, Ujjain

²HOD , ECE Deptt. , Alpine Institute of Technology, Ujjain

Abstract: *The WiMAX technology, based on the IEEE 802.16-2004 Air Interface Standard is rapidly proving itself as a technology that will play a key role in fixed broadband wireless metropolitan area networks. The first certification lab, established at Cetecom Labs in Malaga, Spain is fully operational and more than 150 WiMAX trials are underway in Europe, Asia, Africa and North and South America. Unquestionably, Fixed WiMAX, based on the IEEE 802.16-2004 [1] Air Interface Standard, has proven to be a cost-effective fixed wireless alternative to cable and DSL services. In December, 2005 the IEEE ratified the 802.16e amendment [2] to the 802.16 standard. This amendment adds the features and attributes to the standard necessary to support mobility. The WiMAX Forum is now defining system performance and certification profiles based on the IEEE 802.16e Mobile Amendment and, going beyond the air interface, the WiMAX Forum is defining the network architecture necessary for implementing an end-to-end Mobile WiMAX2 network. Release-1 system profiles will be completed in early 2006. This particular paper focusses on giving an overview of the mobile WiMAX technology and LDPC coding typically used to enhance the performance of OFDM systems.*

Keywords: OFDM, WiMAX, Physical Layer, QoS, Circular prefix.

1. Introduction to Mobile WiMAX

Mobile WiMAX is a broadband wireless solution that enables convergence of mobile and fixed broadband networks through a common wide area broadband radio access technology and flexible network architecture. The Mobile WiMAX Air Interface adopts Orthogonal Frequency Division Multiple Access (OFDMA) for improved multipath performance in non-line-of-sight environments. Scalable OFDMA (SOFDMA) [3] is introduced in the IEEE 802.16e Amendment to support scalable channel bandwidths from 1.25 to 20 MHz. The Mobile Technical Group (MTG) in the WiMAX Forum is developing the Mobile WiMAX system profiles that will define the mandatory and optional features of the IEEE standard that are necessary to build a Mobile WiMAX-compliant air interface that can be certified by the WiMAX Forum. The Mobile WiMAX System Profile enables mobile systems to be configured based on a common base feature set thus ensuring baseline functionality

for terminals and base stations that are fully interoperable. Some elements of the base station profiles are specified as optional to provide additional flexibility for deployment based on specific deployment scenarios that may require different configurations that are either capacity-optimized or coverage-optimized. Release-1 Mobile WiMAX profiles will cover 5, 7, 8.75, and 10 MHz channel bandwidths for licensed worldwide spectrum allocations in the 2.3 GHz, 2.5 GHz, 3.3 GHz and 3.5 GHz frequency bands. The WiMAX Forum Network Working Group (NWG) is developing the higher-level networking specifications [4] for Mobile WiMAX systems beyond what is defined in the IEEE 802.16 standard that simply addresses the air interface specifications. The combined effort of IEEE 802.16 and the WiMAX Forum help define the end-to-end system solution for a Mobile WiMAX network. Mobile WiMAX systems offer scalability in both radio access technology and network architecture, thus providing a great deal of flexibility in network deployment options and service offerings.

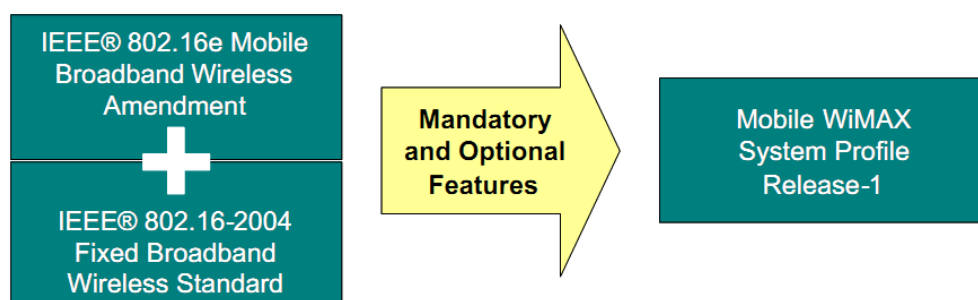


Figure 1: Mobile WiMAX system Profile

2. Salient Features Supported by Mobile WiMAX

Some of the salient features supported by Mobile WiMAX are:

- **High Data Rates:** The inclusion of MIMO antenna techniques along with flexible sub-channelization

schemes, Advanced Coding and Modulation all enable the Mobile WiMAX technology to support peak DL data rates up to 63 Mbps per sector and peak UL data rates up to 28 Mbps per sector in a 10 MHz channel.

- **Quality of Service (QoS):** The fundamental premise of the IEEE 802.16 MAC architecture is QoS. It defines Service Flows which can map to Diff Serv code points or MPLS flow labels that enable end-to-end IP based QoS.

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Additionally, sub-channelization and MAP-based signaling schemes provide a flexible mechanism for optimal scheduling of space, frequency and time resources over the air interface on a frame-by-frame basis.

- **Scalability:** Despite an increasingly globalized economy, spectrum resources for wireless broadband worldwide are still quite disparate in its allocations. Mobile WiMAX technology therefore, is designed to be able to scale to work in different channelizations from 1.25 to 20 MHz to comply with varied worldwide requirements as efforts proceed to achieve spectrum harmonization in the longer term. This also allows diverse economies to realize the multi-faceted benefits of the Mobile WiMAX technology for their specific geographic needs such as providing affordable internet access in rural settings versus enhancing the capacity of mobile broadband access in metro and suburban areas.
- **Security:** The features provided for Mobile WiMAX security aspects are best in class with EAP-based authentication, AES-CCM-based authenticated encryption, and CMAC and HMAC based control message protection schemes. Support for a diverse set of user credentials exists including; SIM/USIM cards, Smart Cards, Digital Certificates, and Username/Password schemes based on the relevant EAP methods for the credential type.
- **Mobility:** Mobile WiMAX supports optimized handover schemes with latencies less than 50 milliseconds to ensure real-time applications such as VoIP perform without service degradation. Flexible key management schemes assure that security is maintained during handover. While the Mobile WiMAX standards activity has been progressing, equipment suppliers have been aggressively developing equipment that will be WiMAX/802.16e-2005 compliant. With commercial availability of Mobile WiMAX-compliant equipment anticipated in the very near future and the launch of

WiBro services this year in Korea, it begs the question as to how the Mobile WiMAX technology relates to and impacts concurrent advances in 3G cellular technology. To address this question it is necessary to gain an understanding of the underlying technology for Mobile WiMAX as well as the planned 3G enhancements.

3. OFDMA basics for Mobile WiMAX

Orthogonal Frequency Division Multiplexing (OFDM) [6,7] is a multiplexing technique that subdivides the bandwidth into multiple frequency sub-carriers as shown in Figure 2. In an OFDM system, the input data stream is divided into several parallel sub-streams of reduced data rate (thus increased symbol duration) and each sub-stream is modulated and transmitted on a separate orthogonal sub-carrier. The increased symbol duration improves the robustness of OFDM to delay spread. Furthermore, the introduction of the cyclic prefix (CP) can completely eliminate Inter-Symbol Interference (ISI) as long as the CP duration is longer than the channel delay spread. The CP is typically a repetition of the last samples of data portion of the block that is appended to the beginning of the data payload as shown in Figure 3. The CP prevents inter-block interference and makes the channel appear circular and permits low-complexity frequency domain equalization.

A perceived drawback of CP is that it introduces overhead, which effectively reduces bandwidth efficiency. While the CP does reduce bandwidth efficiency somewhat, the impact of the CP is similar to the “roll-off factor” in raised-cosine filtered single-carrier systems. Since OFDM has a very sharp, almost “brick-wall” spectrum, a large fraction of the allocated channel bandwidth can be utilized for data transmission, which helps to moderate the loss in efficiency due to the cyclic prefix.

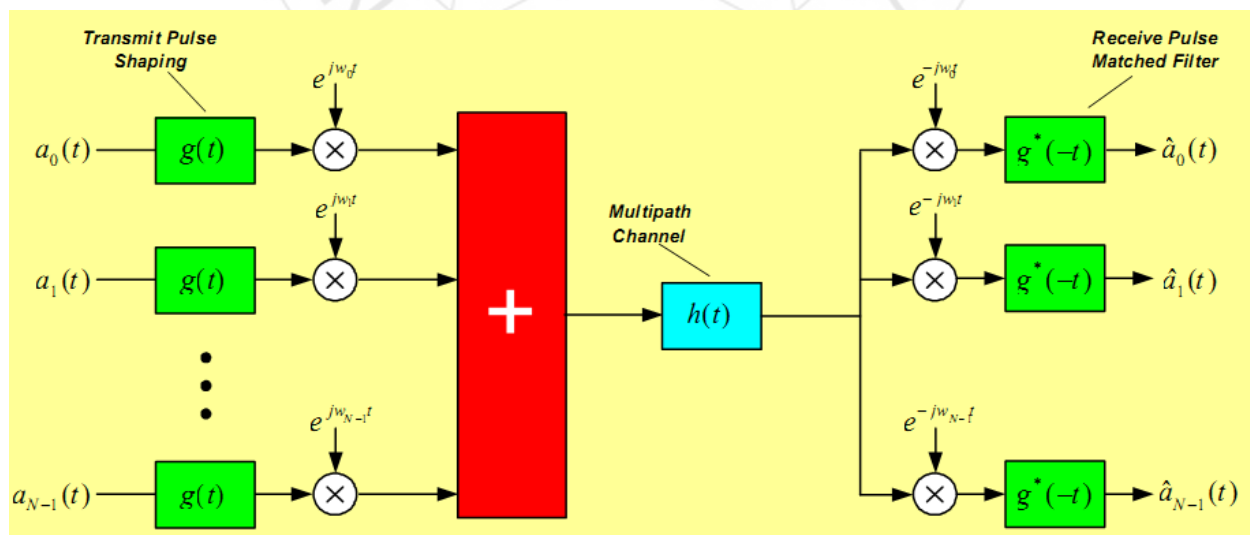


Figure 2: Basic Architecture of an OFDM System

OFDM exploits the frequency diversity of the multipath channel by coding and interleaving the information across the sub-carriers prior to transmissions. OFDM modulation can be realized with efficient Inverse Fast Fourier Transform (IFFT), which enables a large number of sub-carriers (up to

2048) with low complexity. In an OFDM system, resources are available in the time domain by means of OFDM symbols and in the frequency domain by means of sub-carriers. The time and frequency resources can be organized into sub-channels for allocation to individual users.

Orthogonal Frequency Division Multiple Access (OFDMA) is a multiple-access/multiplexing scheme that provides multiplexing operation of data streams from multiple users

onto the downlink sub-channels and uplink multiple access by means of uplink sub-channels.

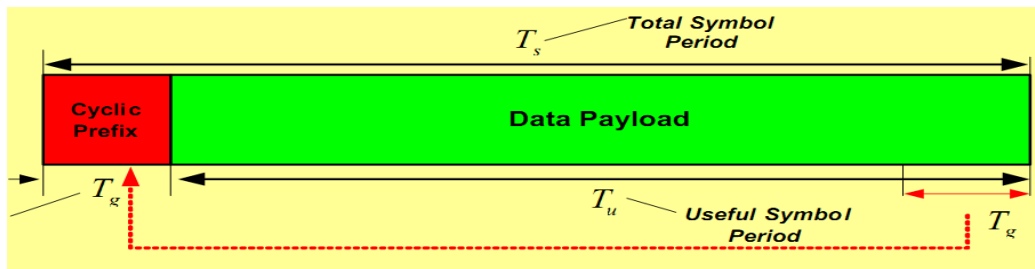


Figure 3: Insertion of Cyclic Prefix

4. OFDMA Symbol Structure and Sub Channellization

The OFDMA symbol structure consists of three types of sub-carriers as shown in Figure 4:

- Data sub-carriers for data transmission

- Pilot sub-carriers for estimation and synchronization purposes
- Null sub-carriers for no transmission; used for guard bands and DC carriers

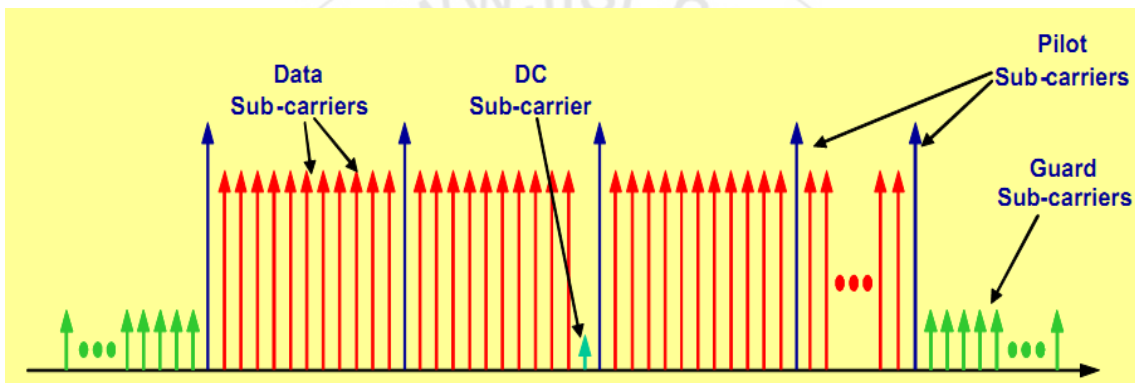


Figure 4: OFDMA Sub-Carrier Structure

Active (data and pilot) sub-carriers are grouped into subsets of sub-carriers called sub-channels. The WiMAX OFDMA PHY [3] supports sub-channelization in both DL and UL. The minimum frequency-time resource unit of sub-channelization is one slot, which is equal to 48 data tones (sub-carriers). There are two types of sub-carrier permutations for sub-channelization; diversity and contiguous. The diversity permutation draws sub-carriers pseudo-randomly to form a sub-channel. It provides

frequency diversity and inter-cell interference averaging. The diversity permutations include DL FUSC (Fully Used Sub-Carrier), DL PUSC (Partially Used Sub-Carrier) and UL PUSC and additional optional permutations. With DL PUSC, for each pair of OFDM symbols, the available or usable sub-carriers are grouped into clusters containing 14 contiguous sub-carriers per symbol period, with pilot and data allocations in each cluster in the even and odd symbols as shown in Figure 5.



Figure 5: DL Frequency Diverse Sub-Channel

A re-arranging scheme is used to form groups of clusters such that each group is made up of clusters that are distributed throughout the sub-carrier space. A sub-channel in a group contains two (2) clusters and is made up of 48 data

sub-carriers and eight (8) pilot sub-carriers. The data sub-carriers in each group are further permuted to generate sub-channels within the group. Therefore, only the pilot positions in the cluster are shown in Figure 5. The data sub-

carriers in the cluster are distributed to multiple sub-channels. Analogous to the cluster structure for DL, a tile structure is defined for the UL PUSC whose format is shown in Figure 6

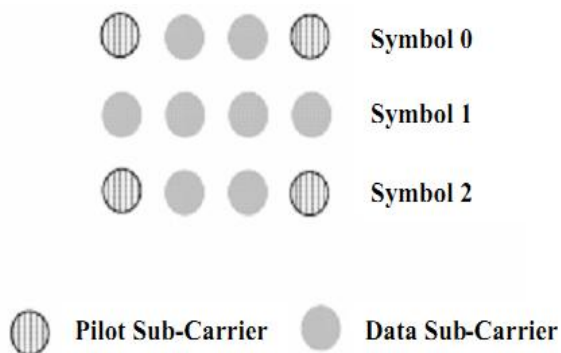


Figure 6: Tile Structure for UL PUSC

The available sub-carrier space is split into tiles and six (6) tiles, chosen from across the entire spectrum by means of a re-arranging/permutation scheme, are grouped together to form a slot. The slot comprises 48 data sub-carriers and 24 pilot sub-carriers in 3 OFDM symbols. The contiguous permutation groups a block of contiguous sub-carriers to form a sub-channel. The contiguous permutations include DL AMC and UL AMC, and have the same structure. A bin consists of 9 contiguous sub-carriers in a symbol, with 8 assigned for data and one assigned for a pilot. A slot in AMC is defined as a collection of bins of the type $(N \times M = 6)$, where N is the number of contiguous bins and M is the

number of contiguous symbols. Thus the allowed combinations are [(6 bins, 1 symbol), (3 bins, 2 symbols), (2 bins, 3 symbols), (1 bin, 6 symbols)]. AMC permutation enables multi-user diversity by choosing the sub-channel with the best frequency response. In general, diversity sub-carrier permutations perform well in mobile applications while contiguous sub-carrier permutations are well suited for fixed, portable, or low mobility environments. These options enable the system designer to trade-off mobility for throughput.

5. Other Advanced Phy Layer Features

Adaptive modulation and coding (AMC), Hybrid Automatic Repeat Request (HARQ) and Fast Channel Feedback (CQICH) were introduced with Mobile WiMAX to enhance coverage and capacity for WiMAX in mobile applications. Support for QPSK, 16QAM and 64QAM are mandatory in the DL with Mobile WiMAX. In the UL, 64QAM is optional. Both Convolutional Code (CC) and Convolutional Turbo Code (CTC) with variable code rate and repetition coding are supported. Block Turbo Code and Low Density Parity Check Code (LDPC) are supported as optional features. Table 1 summarizes the coding and modulation schemes supported in the Mobile WiMAX profile. The optional UL codes and modulation are shown in italics.

Table 1: Supported Code and Modulations

		DL	UL
Modulation		QPSK, 16QAM, 64QAM	QPSK, 16QAM, <i>64QAM</i>
Code Rate	CC	1/2, 2/3, 3/4, 5/6	1/2, 2/3, 5/6
	CTC	1/2, 2/3, 3/4, 5/6	1/2, 2/3, 5/6
	Repetition	x2, x4, x6	x2, x4, x6

The frame duration is 5 milliseconds. Each frame has 48 OFDM symbols, with 44 OFDM symbols available for data transmission. The highlighted values indicate data rates for optional 64QAM in the UL. The base station scheduler determines the appropriate data rate (or burst profile) for each burst allocation based on the buffer size, channel propagation conditions at the receiver, etc.

A Channel Quality Indicator (CQI) channel is utilized to provide channel-state information from the user terminals to the base station scheduler. Relevant channel-state information can be fed back by the CQICH including: Physical CINR, effective CINR, MIMO mode selection and frequency selective sub-channel selection. With TDD implementations, link adaptation can also take advantage of channel reciprocity to provide a more accurate measure of the channel condition (such as sounding). Hybrid Auto Repeat Request (HARQ) is supported by Mobile WiMAX. HARQ is enabled using N channel "Stop and Wait" protocol which provides fast response to packet errors and improves cell edge coverage. Chase Combining and optionally, Incremental Redundancy are supported to further

improve the reliability of the retransmission. A dedicated ACK channel is also provided in the uplink for HARQ ACK/NACK signaling.

Multi-channel HARQ operation is supported. Multi-channel stop-and-wait ARQ with a small number of channels is an efficient, simple protocol that minimizes the memory required for HARQ and stalling [8]. WiMAX provides signaling to allow fully asynchronous operation. The asynchronous operation allows variable delay between retransmissions which gives more flexibility to the scheduler at the cost of additional overhead for each retransmission allocation. HARQ combined together with CQICH and AMC provides robust link adaptation in mobile environments at vehicular speeds in excess of 120 km/hr.

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