WiMAX

IEEE and The WiMAX Forum

The IEEE is a standards body and operates in a purely technical capacity. IEEE 802.16e-2005 defines the radio interface between the Mobile Station and the network for BWA. The standard defines only Layer 1 (*PHY*) and Layer 2 (*MAC*). Included in the standard are handoff definitions and descriptions of mandatory and optional features.

The WiMAX Forum is a non-profit industry body dedicated to promoting the adoption of the IEEE 802.16 standard. The WiMAX Forum is responsible for developing the end-to-end, all IP network architecture for WiMAX. The WiMAX Forum is responsible for interoperability certification of vendor equipment and operates test labs throughout the world. The WiMAX Forum defines system profiles that define the feature set to be supported by WiMAX equipment.

The IEEE and WiMAX Forum logos are registered certification marks of their respective organizations.

Evolution of 802.16 Standard

	802.16 (Dec. 2001)	*802.16-2004 (June 2004)*	*802.16e-2005 (Dec. 2005)*
Air Interface	TDMA with TDD and FDD	OFDM and OFDMA with advanced antenna technology with TDD or FDD	
Spectrum	10-66 GHz	< 11 GHz	< 6 GHz
Operation	LOS	NLOS	NLOS and Mobile
Bitrate	134 Mbps in a 28 MHz channel	75 Mbps in a 20 MHz channel	63 Mbps in a 10 MHz channel
Cell Radius	1-3 miles	10-12 miles with a maximum of 30 miles.	3-6 miles

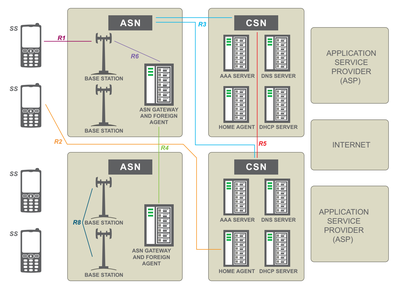
IEEE 802.16 Options

Four physical layers	▪ SC ▪ SCa ▪ OFDM ▪ OFDMA
Multiple options for	▪ Channel bandwidths ▪ Frame lengths ▪ Duplexing modes (TDD, FDD) ▪ Channel coding ▪ Cyclic prefixes
Support for multiple antenna technology	▪ AAS ▪ STC ▪ MIMO
Link adaptation	▪ Adaptive modulation and coding per subscriber ▪ Trade off capacity and robustness in real time

WiMAX Forum Release 1 Mobile System Profiles

CHANNELIZATION (MHz)	*FFT SIZE*	*Frequency Band (GHz)*							
		2.3 - 2.4	*2.305 - 2.32*	*2.345 - 2.36*	*2.496 - 2.69*	*3.3 - 3.4*	*3.4 - 3.6*	*3.4 - 3.6*	*3.6 - 3.8*
3.5	512	----	TDD	TDD	----	----	----	----	----
5.0	512	TDD	TDD	TDD	TDD	TDD	TDD	TDD	TDD
7.0	1024	----	----	----	----	TDD	TDD	TDD	TDD
8.75	1024	TDD	----	----	----	----	----	----	----
10	1024	TDD	TDD	TDD	TDD	TDD	TDD	TDD	TDD

WiMAX Network Architecture developed by the WiMAX Forum



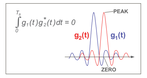
All IP network	▪ Existing IP standards used to avoid creating new network entities ▪ WiMAX Forum defines procedures that permit WiMAX to 3GPP and WiMAX to 3GPP2
Access Service Network (ASN)	▪ Provides the radio interface that connects the SS with the network ▪ Handles the radio interface and contains the base stations ▪ Contains the ASN Gateway which has a one-to-many relationship with base stations ▪ ASN Gateway handles mobility between base stations ▪ Foreign Agent function acts as proxy for authentication and mobile IP
Connectivity Service Network (CSN)	▪ Provides connectivity between the ASN and the Internet or Application Services ▪ Home Agent and AAA provide Authentication ▪ Home Agent and DHCP provide IP Address Management ▪ AAA provides billing records ▪ Home Agent supports mobility
Logical Interfaces	▪ 802.16 Interfaces *- R1 interface – SS to BS connection, radio link* ▪ WiMAX Forum Interfaces *- R2 interface – SS to HA, supports roaming* *- R3 interface – ASN to CSN, supports authentication, billing, an d MIP messages* *- R4 interface – ASN to ASN, defines mobility procedures when a SS crosses from one ASN to another* *- R5 interface – CSN to CSN, supports roaming* *- R6 interface – BS to ASN Gateway; supports mobility messages* *- R7 interface – Internal to the ASN Gateway, not shown* *- R8 interface – BS to BS; supports handoff*

OFDM Basic Principle

- OFDM is a multi-carrier modulation scheme that transmits data over a number of orthogonal sub-carriers. Conventional transmission uses only a single carrier.
- OFDM breaks the data to be sent in to multiple data streams. Each data stream is passed to a sub-carrier for modulation. The data streams are sent in parallel on the orthogonal sub-carriers.
- OFDM Advantages
  - *NLOS performance while maintaining a high level of spectral efficiency and maximizing the available spectrum.*
  - *Simple equalizer design.*
  - *Supports operation in multi-path propagation environments*
  - *Uses a cyclic prefix to provide multi-path immunity and tolerance for time synchronization errors.*
  - *Scalable bandwidths provide flexibility and potentially reduces capital expense.*

Two signals $g_1(t)$ and $g_2(t)$ are said to be orthogonal over the period T_s if:

$$\int_0^{T_s} g_1(t)\,g_2^*(t)\,dt = 0$$

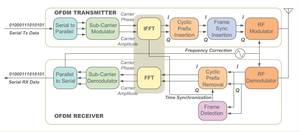


For Example:

$$\int_0^{T_s} e^{(2\pi f_c t}\, e^{)(2\pi k f_c t}\, dt = 0$$

For p ≠ q, where fk = k/T

OFDM Transceiver



IFFTs and FFTs in OFDM

The Transmitter contains an IFFT block and the receiver contains an FFT block. FFT and IFFT are a linear transform pair, defined by the following equations.

$$IFFT:\ X(n) = \frac{1}{N}\sum_{k=0}^{N-1} x(k)\sin\left(\frac{2\pi kn}{N}\right) + j\sum_{k=0}^{N-1} x(k)\cos\left(\frac{2\pi kn}{N}\right)$$

$$FFT:\ x(k) = \frac{1}{N}\sum_{n=0}^{N-1} x(n)\sin\left(\frac{2\pi kn}{N}\right) + j\sum_{n=0}^{N-1} x(n)\cos\left(\frac{2\pi kn}{N}\right)$$

OFDM Spectral Overlap

Conventional Frequency Division Multiplex (FDM) Multi-Carrier Modulation Technique

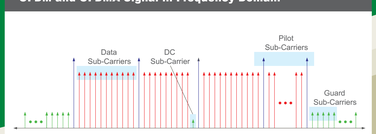
In conventional FDM, each carrier frequency is separated by a guard band to prevent interference. The frequencies in the guard band area cannot be used to carry information.

Orthogonal Frequency Division Multiplex (OFDM) Multi-Carrier Modulation Technique

OFDM sub-carriers have a sinc (sin(x)/x) frequency response resulting in overlapin the frequency domain. This overlap does not cause interference due to the orthogonality of the sub-carriers.

- The OFDM receiver uses a time and frequency synchronized FFT to convert the OFDM time waveform back into the frequency domain. In this process the FFT picks up discrete frequency samples, corresponding to the peaks of the carriers. At these frequencies, all other carriers pass through zero eliminating interference between the sub-carriers.
- The FFT requires strict adherence to:
  - *An integer number of cycles during a symbol period*
  - *An integer number of cycles separating the sub-carriers*
  - *No phase or amplitude changes during symbol period*

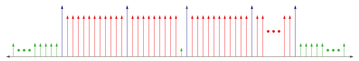
OFDM and OFDMA Signal in Frequency Domain



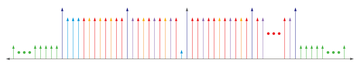
The sub-carriers are divided into several types

- Data Sub-carriers
  - *Use QPSK, 16-QAM, 64-QAM modulation to transport data bits*
- Pilot Sub-carriers
  - *Data-free symbols used to maintain optimal operation of the receiver*
- Guard Sub-carriers
  - *Off, no power is generated at these frequencies*
- DC Sub-carrier
  - *Off to support direct-conversion receivers*

Sub-carrier Spacing (1/T) is the reciprocal of the modulation symbol time (T)



OFDM - All sub-carriers belong to a single user for some period of time. Multiple users are accommodated at different times.



OFDMA - Users share the sub-carriers with a bandwidth dependent on the data service in use. Each color represents a different user.

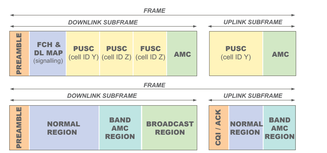
OFDMA Sub-Channels and Permutation Zones

The sub-carriers are divided into groups known as sub-channels

- Sub-carriers may be adjacent or distributed in a sub-channel
- Sub-carriers are assigned to sub-channels to ensure frequency diversity and interference diversity.

Sub-channel Usage Schemes

- PUSC – Partial Usage of Sub-Channels
  - *Mandatory mode for sending preambles and allocation messages and all the uplink messages*
  - *Sub-carriers are divided between cells (N=3) and then grouped into sub-channels*
  - *Goal: Reduce RF interference*
- FUSC - Full Usage of Sub-Channels
  - *Optional and used in the downlink only.*
  - *All sub-carriers are available in every cell (N=1)*
  - *Goal: Maximize throughput*
- AMC – Adaptive Modulation and Coding
  - *Adjacent sub-carriers are grouped into sub-channels.*
  - *Mobile devices provide feedback on channel conditions so the BS can adjust coding and modulation to match channel conditions.*

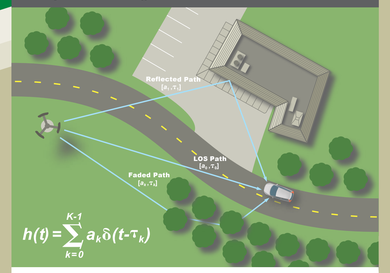


In Mobile WiMAX, flexible sub-channel reuse is facilitated by sub-channel segmentation and permutation zones. A Permutation Zone is a number of contiguous OFDMA symbols in the downlink or uplink that use the same permutation or mapping sequence between the sub-channels and the sub-carriers. A downlink frame may contain more than one permutation zone.

Zone Partitioning makes use of sub-carrier characteristics

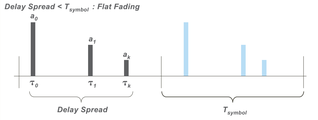
- Normal region contains frequency diverse sub-channels. Time scheduling is used to support voice service.
- Band AMC region makes use of adjacent sub-channels and both time and frequency scheduling is available.
- Broadcast region uses frequency-diverse sub-channels in a simulcast mode. This concept is borrowed from DVB/DAB system.
- Preamble is a data-free symbol at the beginning of the frame for rough frequency synchronization in the receiver.

Multipath and Fading



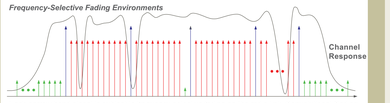
$$h(t) = \sum_{k=0}^{K-1} a_k \delta(t-\tau_k)$$

Delay Spread < T_{symbol} : Flat Fading



Delay Spread > T_{symbol} : Frequency-Selective Fading

Frequency-Selective Fading Environments

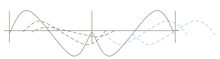


Each narrow band signal is subject to frequency-selective fading on the radio link. Convolutional Coding (CC) or Convolutional Turbo Coding (CTC) is used to protect the data.

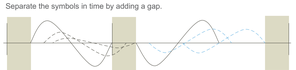
Cyclic Prefix (CP)

Cyclic prefix (CP) mitigates multipath fading and inter-symbol interference (ISI) at the price of increasing bandwidth.

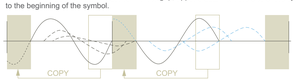
Delay spread exceeds symbol time. ISI is the result.



Separate the symbols in time by adding a gap.

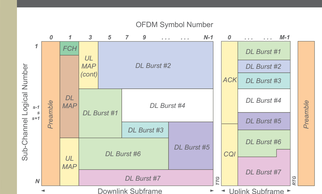


Transmission must be continuous. To "fill" the gap, append data from the end of the symbol to the beginning of the symbol.



CP allows the system to ignore the initial part of each symbol thus avoiding the area that would be most likely impacted by multipath delay. Data in the CP region of the signal is discarded. CP is set to 4-6 times the delay spread. WiMAX Forum profiles use a CP of 1/8, meaning that a section of data equal to 1/8 of the original symbol is used.

OFDMA



TDD Frame Structure

OFDMA is two-dimensional with users sharing in both the time and frequency domains. This allows scheduling and optimum use of finite spectrum.

Each user is assigned a burst area that has dimensions of sub-channels and symbols.

Key Elements

- Preamble is broadcast for one symbol period and allows the user devices to acquire the system and synchronize. A known PN code is transmitted.
- FCH reports the length of the DL-Map.
- DL-Map contains bandwidth allocation for users and location of the UL-Map.
- UL-Map contains bandwidth allocation of the UL for the next frame.
- Both maps contain burst data regions, modulation, and coding type for the user.
- Allocated regions in UL are available for random access, CQI, and ACKs.
- Transmit Recieve Transition Gap (TTG) and Receiver Transmit Transition Gap (RTG) are guard times between the transmit and receiver portions of the frame.

Index of Terms

AAA	Authentication, Authorization and Accounting
AAS	Adaptive Antenna System also Advanced Antenna System
ACK	Acknowledgement
AMC	Adaptive Modulation and Coding
ASN	Access Service network
ASP	Application Service Provider
BS	Base Station
BWA	Broadband Wireless Access
CC	Convolutional Coding
CP	Cyclic Prefix
CQI	Channel Quality Information
CSN	Connectivity Service Node
CTC	Convolutional Turbo Coding
DHCP	Dynamic Host Configuration Protocol, typically used to assign IP addresses
DL	Down Link
DVB/DAB	Digital Video Broadcast/ Digital Audio Broadcast
FA	Foreign Agent (MIP)
FCH	Frame Control Header
FDD	Frequency Division Duplex
FFT	Fast Fourier Transform
FUSC	Full Use of Sub-Channels
GW	Gateway
HA	Home Agent (MIP)
HARQ	Hybrid Automatic Repeat reQuest
HHO	Hard Hand-Off
IEEE	Institute of Electrical and Electronics Engineers
IFFT	Inverse Fast Fourier Transform
ISI	Inter-Symbol Interference
LOS	Line of Sight
MAC	Media Access Control
MIMO	Multiple Input Multiple Output
MIP	Mobile IP (RFC 3344)
MS	Mobile Station
NLOS	Non Line-of-Sight
OFDM	Orthogonal Frequency Division Multiplex
OFDMA	Orthogonal Frequency Division Multiple Access
PHY	Physical Layer, Layer 1
PUSC	Partial Usage of Sub-Channels
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
RTG	Receive/transmit Transition Gap
S-OFDMA	Scalable Orthogonal Frequency Division Multiple Access
SS	Subscriber Station
STC	Space Time Coding
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
TTG	Transmit/receive Transition Gap
UL	Up Link
WiMAX	Worldwide Interoperability for Microwave Access

MS2690A *Signal Analyzer*

MG3700A *Vector Signal Generator*

MS2717B/18B/19B *Economy Spectrum Analyzers*

MT8222A BTS Master *Handheld Base Station Analyzer*

MS2721B/23B/24B Spectrum Masters *Handheld Spectrum Analyzers*

Anritsu

UNITED STATES	+1-800-ANRITSU	(+1-972-644-1777)
CANADA	+1-800-ANRITSU	(+1-613-591-2003)
SOUTH AMERICA	+55-11-3283-2511	
JAPAN	+81-46 223-1111	
ASIA-PACIFIC	+852-2301-4980	
EUROPE	+44-1582-433433	

www.us.anritsu.com

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