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3C5

Trinity Term 2009

WiMAX – an overview

purpose of last few lectures

- we have looked at different aspects of communication systems
- it is useful now to look at one complete communication system – for **wireless broadband**
- though you will not understand all parts of the system … you will have a good idea of the main concepts involved

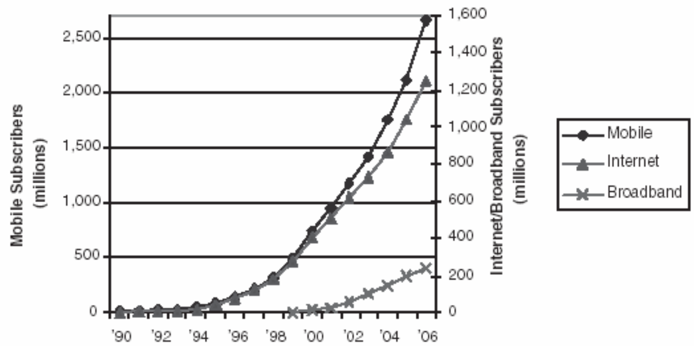
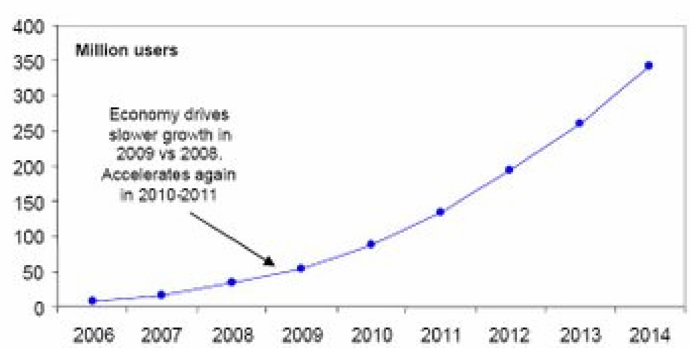


Figure 1.1 Worldwide subscriber growth 1990–2006 for mobile telephony, Internet usage, and broadband access [1, 2, 3]

Figure: Worldwide mobile broadband computing active user base



Note: includes users with notebooks, netbooks, UMPCs, MIDs. Excludes smartphones

Source: Disruptive Analysis, December 2008

Rank	Country	Combined Score 2008	Rank	Country	Percentage change in number of subscribers 2005-2008
1	Japan	6.6	1	Russia	27,829%
2	Sweden	5.3	**2**	**EU-10**	**10,707%**
3	S. Korea	4.2	3	Ireland	6,088%
4	France	3.4	4	Japan	3,254%
5	Germany	3.3	5	India	2,618%
6	Canada	3.0	6	Poland	2,285%
7	**U.S.**	**3.0**	7	Mexico	1,863%
8	**EU-15**	**2.8**	8	China	1,835%
9	UK	2.8	9	Australia	1,682%
10	Singapore	2.6	10	Singapore	1,064%
11	EU-25	2.5	11	UK	1,016%
12	Australia	2.5	12	France	815%
13	NAFTA	2.1	13	Brazil	775%
14	Spain	2.0	14	EU-25	630%
15	Ireland	1.4	**15**	**EU-15**	**598%**
16	**EU-10**	**0.9**	16	Spain	513%
17	Russia	0.6	17	Germany	511%
18	Poland	0.3	18	Canada	506%
19	Brazil	-0.6	19	NAFTA	287%
20	Mexico	-0.7	20	S. Korea	270%
21	China	-0.8	21	Sweden	267%
22	India	-1.9	**22**	**U.S.**	**252%**
	Average	**0.0**		**Average**	**2,778%**

Source: International Telecommunications Union and Said Business School, 2008 data.

broadband

- most of the broadband access we use is over the fixed network
- some of it is wireless however
- wireless is especially important in terms of accessing places that are otherwise difficult to access
- this can mean rural areas or indeed urban areas in which it may not be possible to dig up the roads to lay new cables

wireless broadband access

1. The first type attempts to provide a set of services similar to that of the traditional fixed-line broadband but using wireless as the medium of transmission. This type, called ***fixed wireless broadband***, can be thought of as a competitive alternative to DSL or cable modem.

2. The second type of broadband wireless, called ***mobile broadband***, offers the additional functionality of portability, nomadicity and mobility.

National Broadband Scheme

- The National Broadband Scheme aims to bring broadband to rural and low populated areas deemed commercially unviable by most telecom operators.

  3 has been appointed as the preferred tenderer

  All residential and business premises within the National Broadband Scheme coverage area will have broadband connectivity by September 2010.

what are we looking at?

We are going to focus on **wireless broadband** that is provided using a standard known as **IEEE 802.16.** Both fixed wireless access standards as well as ones that support mobility have been devised.

We often currently mix the terms WiMAX and 802.16 as **WiMAX** is the more commercially known name.

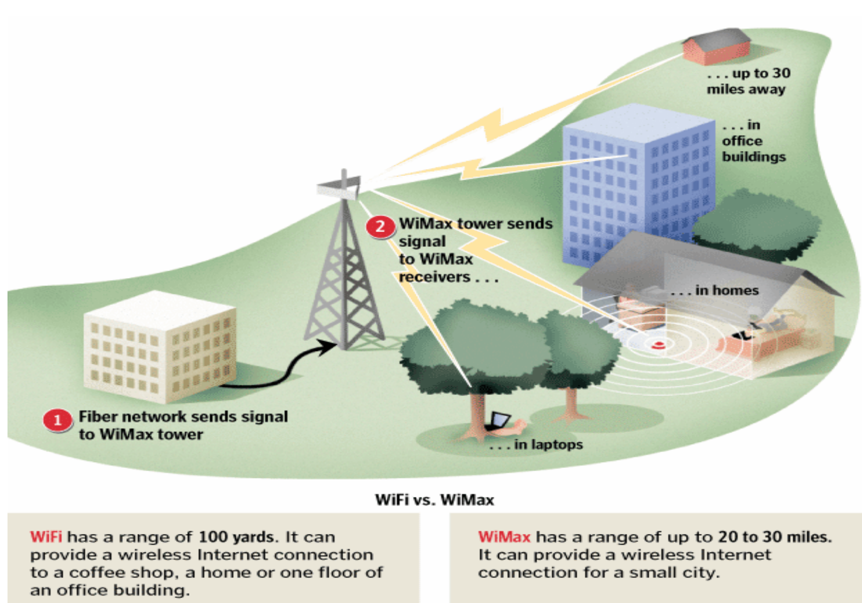
IEEE 802.16

- In 1998, the Institute of Electrical and Electronics Engineers (IEEE) formed a gr[illegible]lled 802.16 to develop a standard for what [illegible]lled a *wireless metropolitan area network* [illegible]reless MAN.
- Originally, this group fo[illegible]n developing solutions in the 10GH[illegible]Hz band, with the primary application [illegible]delivering high-speed connections to bu[illegible]es that could not obtain fiber. This wa[illegible] service.
- After c[illegible]ng this standard, the group started work [illegible]ending and modifying it to work in both li[illegible] and license-exempt frequencies in the [illegible]o 11GHz range, which would enable NLOS [illegible]loyments.

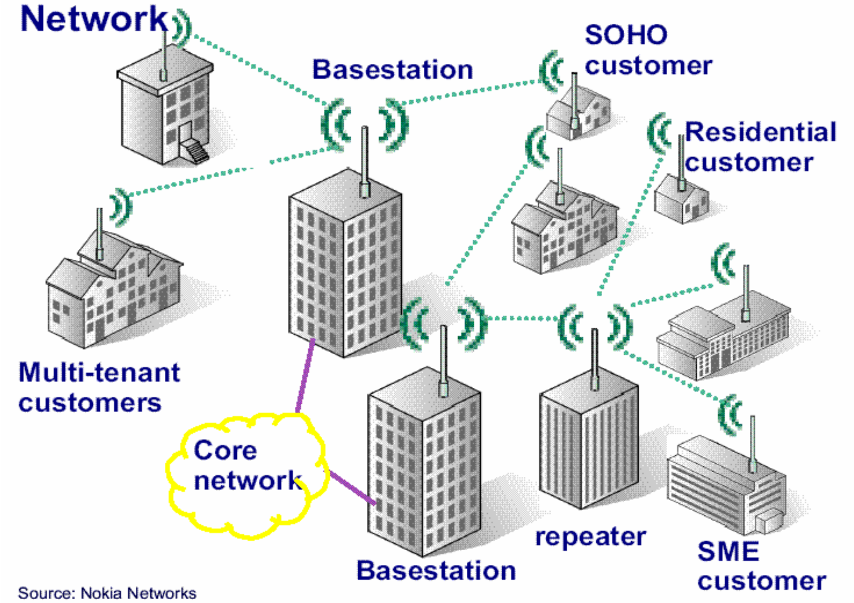
let's look at each of these terms

metropolitan area network

- Sometimes wireless networks are named according to the distances they cover. We have BANs – body area networks, PANs - personal area networks, LANs – local area networks and MANs
- The wireless system you use in college is a LAN
- Metropolitan area networks link base stations in metropolitan areas, up to a range of 20 km at present.



WirelessMAN: Wireless Metropolitan Area Network



Source: Nokia Networks

Licensed and Licensed Exempt

Some systems need licenses to operate in. For example Vodafone and O2 etc need a license to use the spectrum they use. No one else can use their spectrum – it is private

License-exempt spectrum can be used by anyone who wants (provided some simple rules are followed)

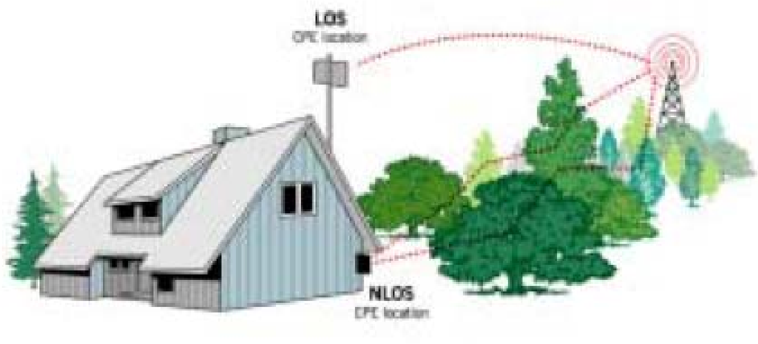
802.16 has been considered for both scenarios

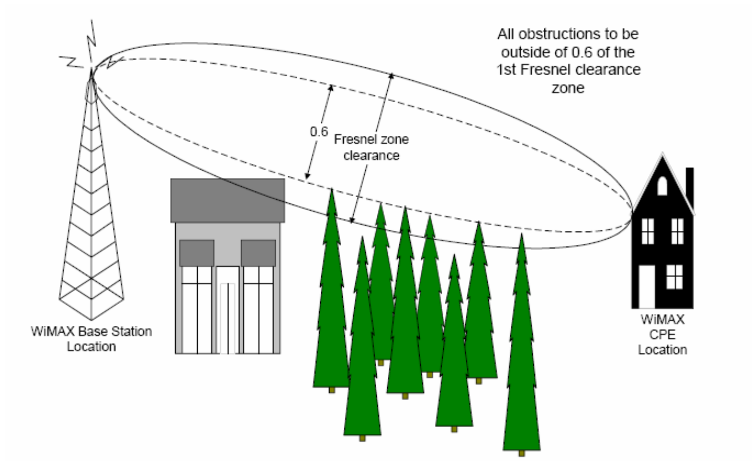
what are the advantages and disadvantages of either options?

FREQUENCY	USES
2-11 GHZ	What the IEEE 802.16-2004 specifies as the operating range for point to multi-point operations
1.7 and 2.1 GHz	Advanced Wireless Services in US; potentially a spectrum of choice for AWS spectrum holders (legacy service providers)
2.3 GHz	Wireless Communications Services in US; expect incumbent service providers who already hold this spectrum to use it for WiMAX services
2.4 – 2.483 GHz	ISM and FCC Part 15, largely unlicensed, used for Wi-Fi; to be avoided by WiMAX operators on concerns of interference from Wi-Fi
2.5 GHz	BRS/EBS in US; - Projected as being a popular licensed WiMAX spectrum choice in US and for those who could not get 3.5 GHz in other nations, probably the second most popular spectrum vendors will build product for
3.5 GHz	Unlicensed in many nations outside the US. Many nations have allocated it as the WiMAX spectrum. Almost all vendors offer WiMAX product for this frequency. Not useable commercially in the US, as it is spectrum held by the military.
3.65 GHz	FCC issued an announcement in 2004 promoting opening spectrum here for quasi-unlicensed use. Has yet to be finalized. Many products made for 3.5 GHz may work well in 3.65 GHz US application
4.9 GHz	aka "Public Safety", in the US, intended for use by First Responders (police, fire, ambulance and other emergency services)
5.4 and 5.8 GHz	US unlicensed; many vendors will offer this as their US unlicensed spectrum offering

LOS and NLOS

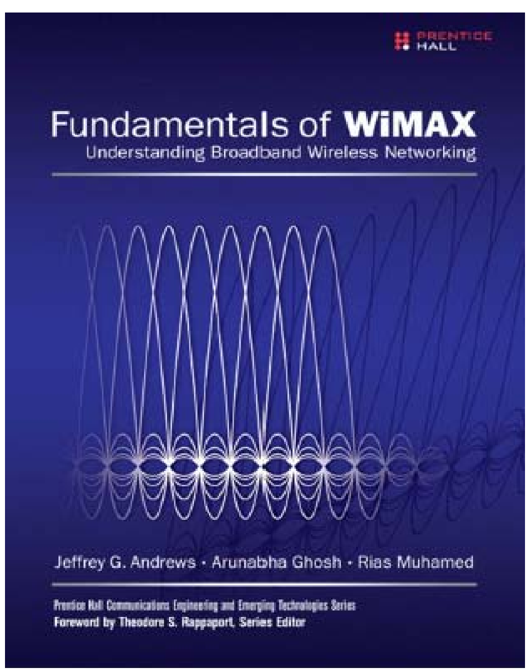
- Line-of-sight as the name would suggest means that the two transceivers in communication with each other must 'see' each other to function. At the 10-66 GHz range the signals would experience too much attenuation to operate under any conditions other than line-of-sight.
- Non-line-of-sight means that this is not necessary. In the lower frequency range there are options for non-line-of-sight operation.


LOS
CPE location
NLOS
CPE location


All obstructions to be outside of 0.6 of the 1st Fresnel clearance zone
0.6
Fresnel zone clearance
WiMAX Base Station Location
WiMAX CPE Location

So

- The 802.16 tells us how to deliver large bandwidth wireless access over long distances.
- 802.16 is a PHY and MAC layer specification
- There are many different flavours of 802.16, some suited to FWA and others for mobility etc. We will look at these later.



salient features of an 802.16 system

1. OFDM-based physical layer
2. High data rates
3. Scalable bandwidth and data rate support
4. Adaptive modulation and coding (AMC)
5. Link-layer retransmissions
6. Support for TDD and FDD
7. Orthogonal frequency division multiple access (OFDMA)
8. Flexible and dynamic per user resource allocation
9. Support for advanced antenna techniques
10. Robust security
11. Support for mobility
12. IP-based architecture

some things you will know a little about already … whether you realise it or not!

1. **OFDM-based** physical layer
2. High data rates
3. Scalable bandwidth and data rate support
4. **Adaptive modulation and coding (AMC)**
5. **Link-layer retransmissions**
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9. **Support for advanced antenna techniques**
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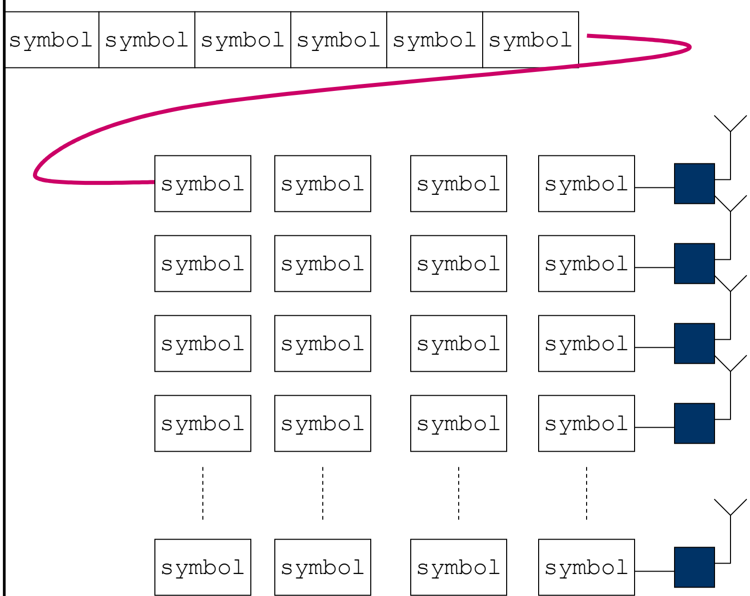
1. OFDM physical layer

- The WiMAX physical layer (PHY) is based on orthogonal frequency division multiplexing, a scheme that offers good resistance to multipath, and hence allows WiMAX to operate in NLOS conditions.
- OFDM is now widely recognized as the method of choice for mitigating multipath for broadband wireless.

OFDM belongs to a family of transmission schemes called *multicarrier modulation*, which is based on the idea of dividing a given high-bit-rate data stream into several parallel lower bit-rate streams and modulating each stream on separate carriers—often called subcarriers, or tones.

WHY ARE MULTICARRIER SYSTEMS OF INTEREST IN GENERAL? LET'S LOOK AT SOME GENERAL MULTICARRIER PRINCIPLES BEFORE RETURNING TO OFDM SPECIFICALLY



Understanding ISI

- we came across this briefly already
- intersymbol interference
- like anything in the communications world we can use two different views of understanding what is happening when ISI occurs
- we can use a frequency or time domain view

time

frequency

- This is the more intuitive view.
- If I send successive symbols too fast they will crash in to each other at the receiver causing distortion
- The channel has what is known as a delay spread and I must make sure the time between sending successive symbols is bigger than this

time

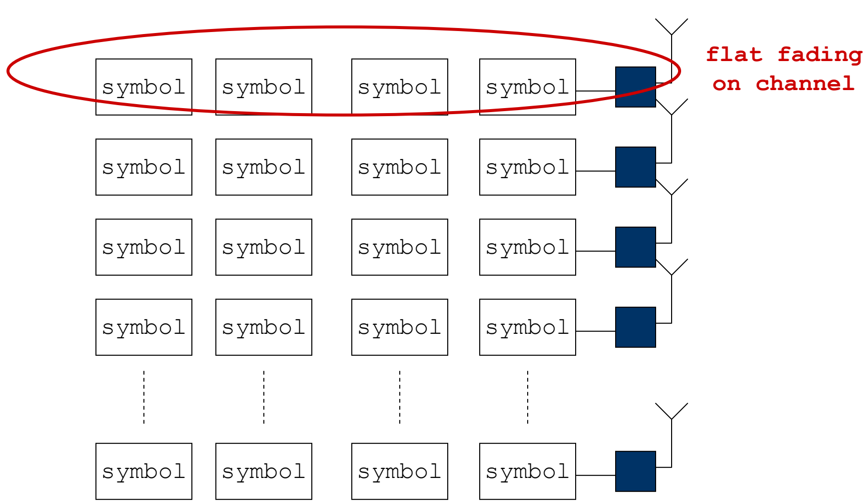
- This is intuitive when you think multipath (which causes ISI)
- What is happening on the frequency front is that constructive and destructive interference is happening – frequency selective fading
- The opposite of this is flat fading – so flat fading insures no ISI

frequency

ISI

- In order to have a channel that does not have ISI, the symbol time, T_s, has to be larger—often significantly larger—than the channel delay spread which is donated τ.
- Digital communication systems simply cannot function if ISI is present
- For wideband channels that provide the high data rates needed by today's applications, the desired symbol time is usually much smaller than the delay spread, so intersymbol interference is severe => very long T_s needed to overcome
- But with MULTICARRIER SYSTEMS you can meet the T_s demands on individual STREAMS, i.e. the transmit at a low rate but overall your rate is LT_s due to having L STREAMS IN TOTAL

the symbol rate on individual STREAMS can be low while overall through-put is high



- **In the time domain, the symbol duration on each subcarrier has increased to $T = LT_s$ so letting L grow larger ensures that the symbol duration exceeds the channel-delay spread, τ , which is a requirement for ISI-free communication.**

- **In the frequency domain, the subcarriers have bandwidth $B/L <= B_c$, which ensures flat fading, the frequency-domain equivalent to ISI-free communication.**

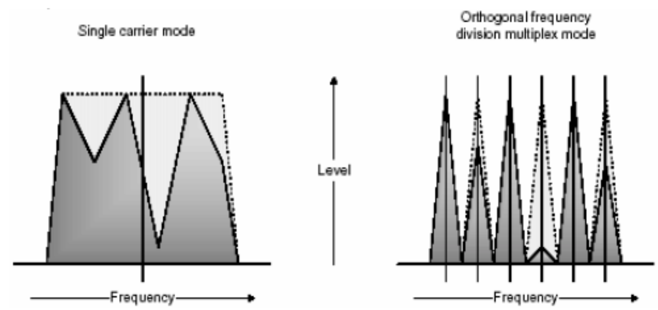
Example 4.1 A certain wideband wireless channel has a delay spread of 1μ sec. We assume that in order to overcome ISI, $T_s \geq 10\tau$.

1. What is the maximum bandwidth allowable in this system?
2. If multicarrier modulation is used and we desire a 5MHz bandwidth, what is the required number of subcarriers?

For question 1, if it is assumed that $T_s = 10\tau$ in order to satisfy the ISI-free condition, the maximum bandwidth would be $1/T_s = .1/\tau = 100$ KHz, far below the intended bandwidths for WiMAX systems.

In question 2, if multicarrier modulation is used, the symbol time goes to $T = LT_s$. The delay-spread criterion mandates that the new symbol time is still bounded to 10 percent of the delay spread: $(LT_s)^{-1}$ = 100 Khz. But the 5MHz bandwidth requirement gives $(T_s)^{-1}$= 5 MHz Hence, L $\geq$50 allows the full 5MHz bandwidth to be used with negligible ISI.

good for frequency selective fading



BIG PROBLEM

L transmitters
L receivers

NOT FEASIBLE

OFDM

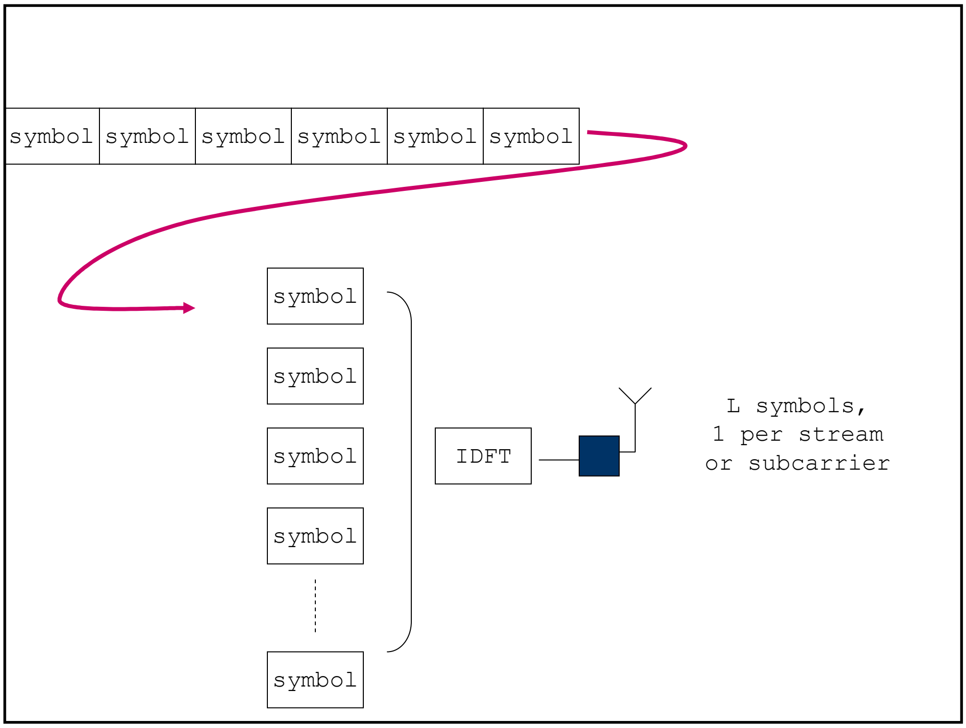
OFDM is indeed a multicarrier system but it is one version that has gotten over the problem of using L receivers and L transmitters by making use of the inverse Fourier transform and the Fourier Transform

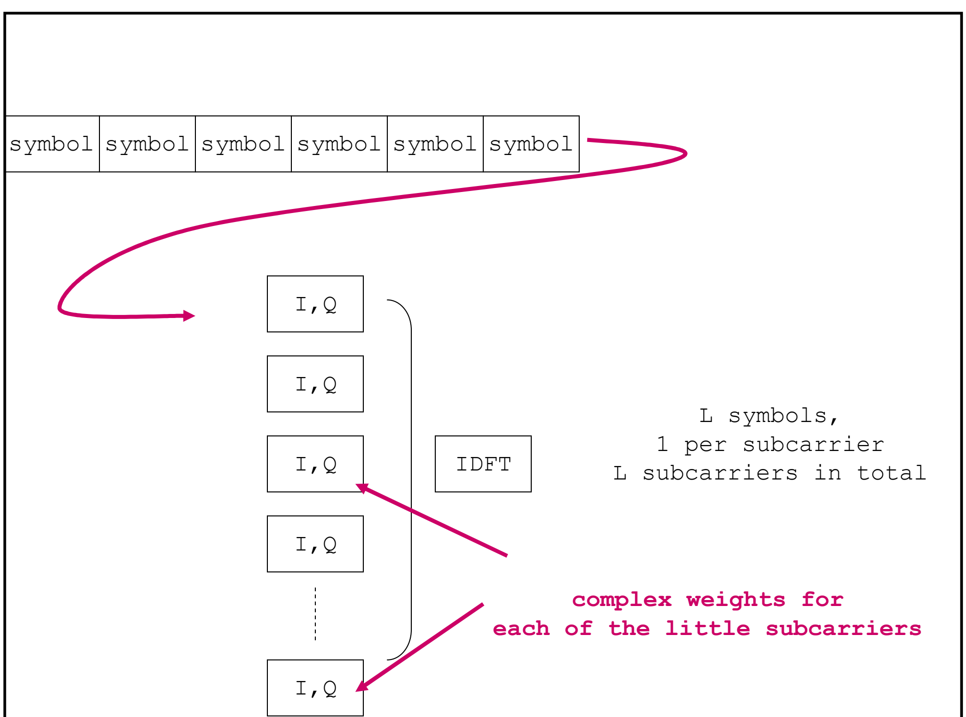
- I have provided a handout of OFDM basics which is very good
- We will work through some of that now

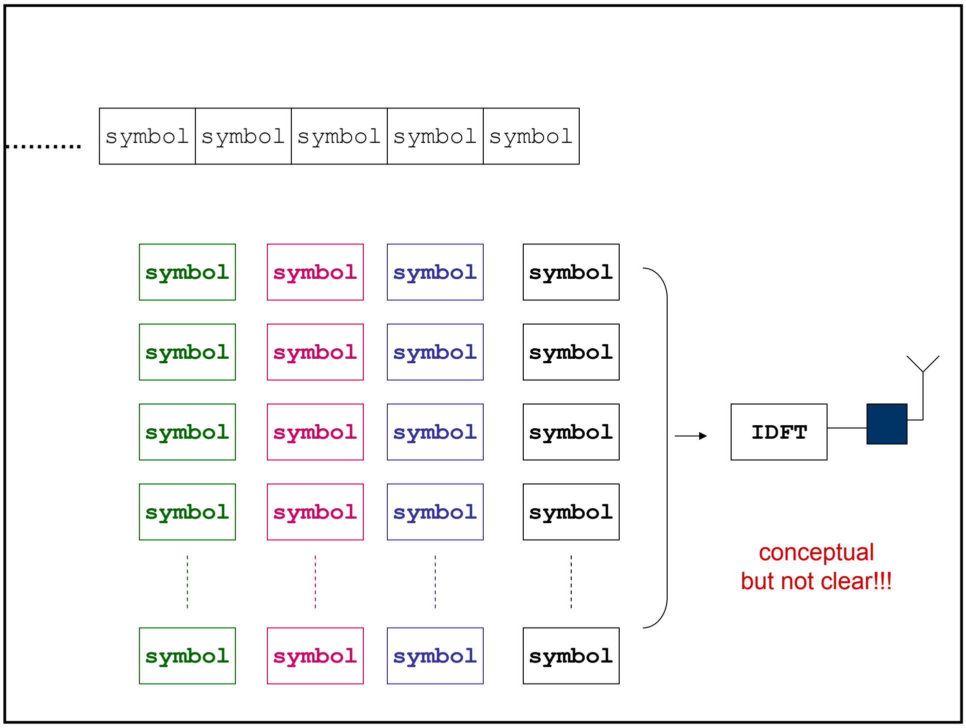
The principles of OFDM

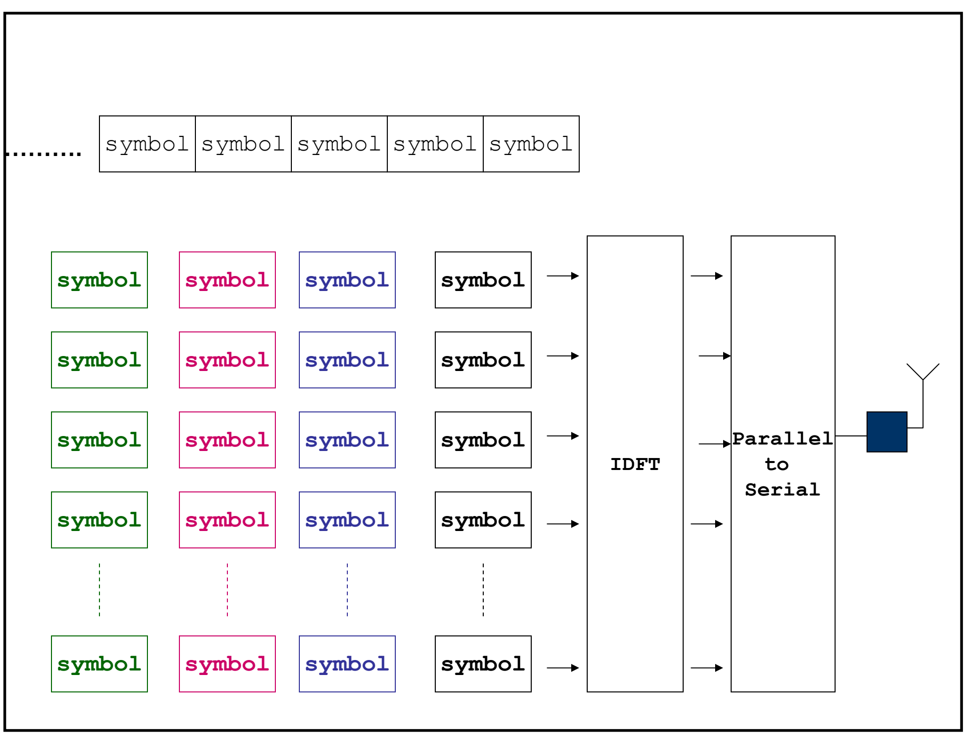
Multicarrier modulation techniques are rapidly moving from the textbook to the real world of modern communication systems

By Louis Litwin and Michael Pugel


symbol symbol symbol symbol symbol symbol
symbol
symbol
symbol
symbol
symbol
IDFT
L symbols,
1 per stream
or subcarrier

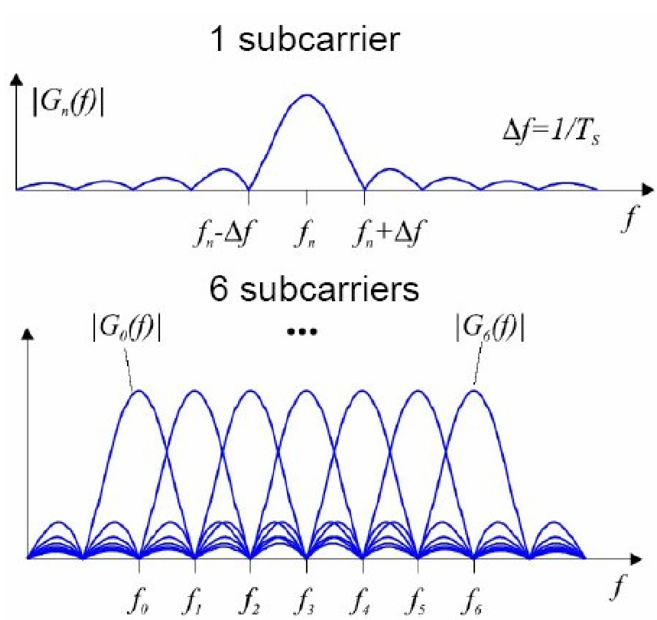

symbol symbol symbol symbol symbol symbol
I,Q
I,Q
I,Q
I,Q
I,Q
IDFT
L symbols,
1 per subcarrier
L subcarriers in total
complex weights for
each of the little subcarriers

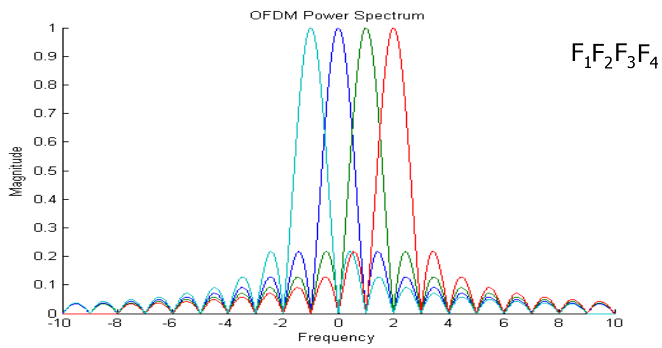

....
symbol symbol symbol symbol symbol
symbol symbol symbol symbol
symbol symbol symbol symbol
symbol symbol symbol symbol
symbol symbol symbol symbol
symbol symbol symbol symbol
IDFT
conceptual
but not clear!!!


....
symbol symbol symbol symbol symbol
symbol symbol symbol symbol
symbol symbol symbol symbol
symbol symbol symbol symbol
symbol symbol symbol symbol
symbol symbol symbol symbol
IDFT
Parallel
to
Serial

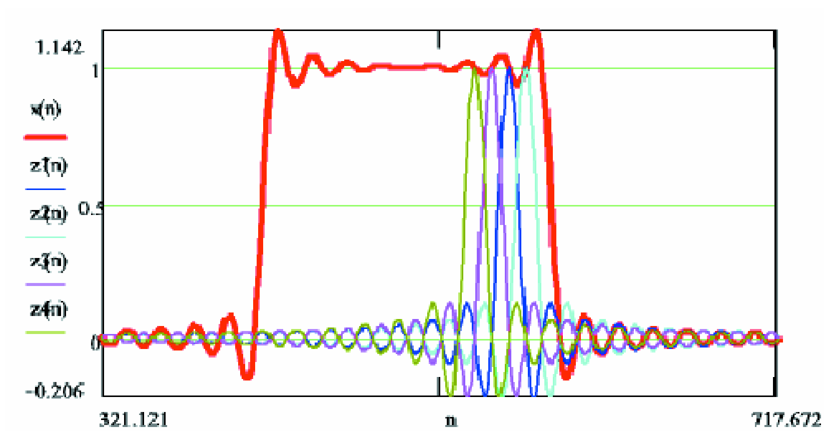
On the receive side

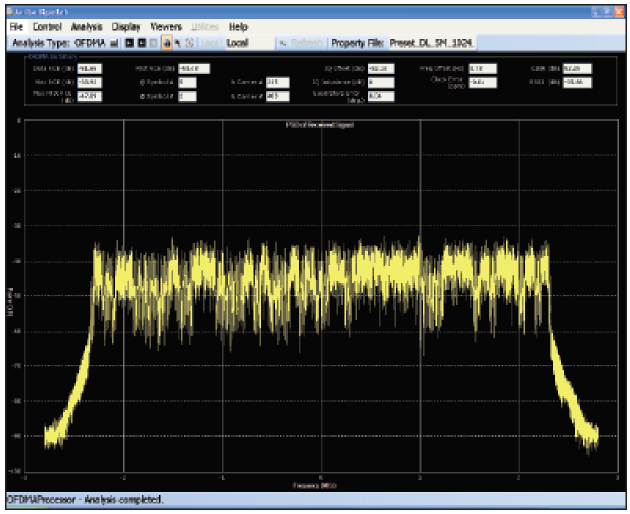
- The time varying signal is received and then with the use of the FFT converted to the frequency domain for processing
- The I and Q values associated with each carrier can be retreived





the carriers are orthogonal => tightly packed.



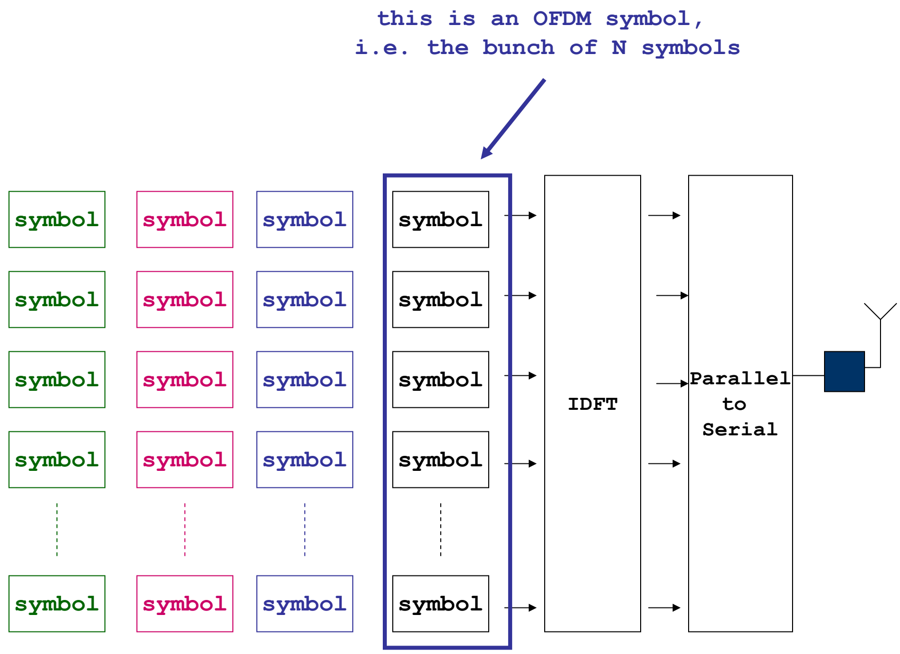


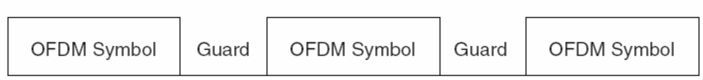
so what happens to ISI in the ODFM case?

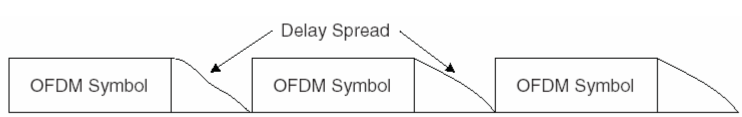
Need to think on two levels

1. Between OFDM symbols
2. Within OFDM symbols

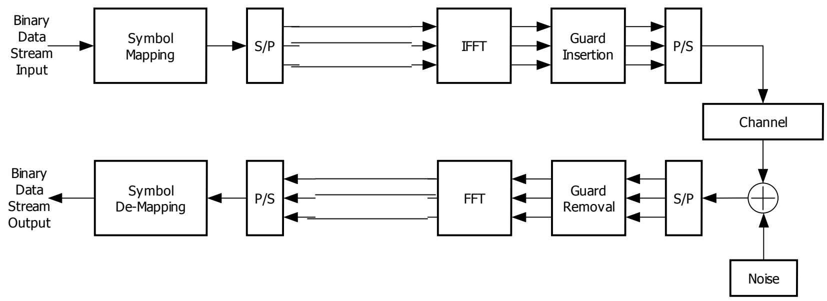
BUT what is an OFDM symbol?





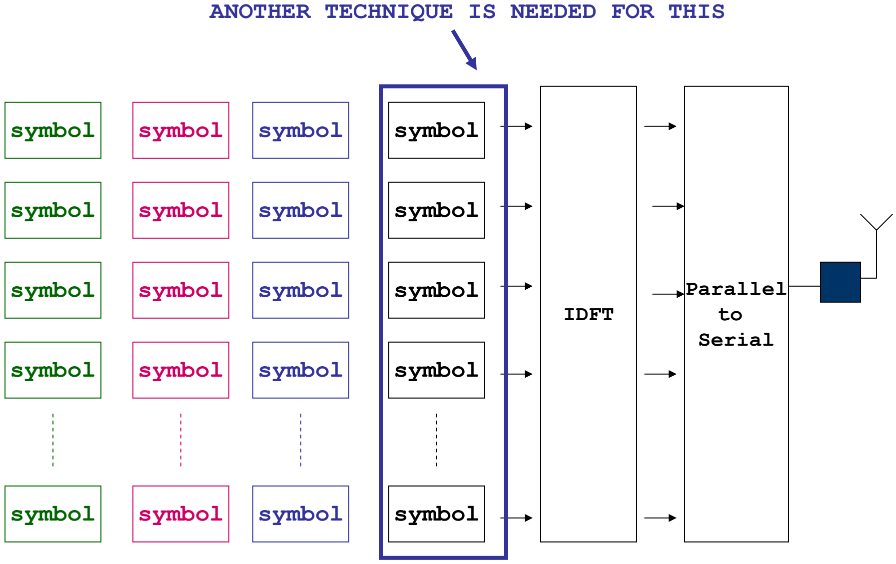


But by including a sufficiently large guard band, it is possible to guarantee that there is no interference *between* subsequent OFDM symbols.



ofdm transceiver

BUT WE HAVE ISI BETWEEN THE SYMBOLS IN THE OFDM SYMBOL.
ANOTHER TECHNIQUE IS NEEDED FOR THIS



BASIC IDEA

- Unlike between OFDM symbols we do not have the luxury of spacing the transmission time of the individual consecutive symbols within the OFDM symbol.
- It is the effect of the channel these symbols that causes the ISI - If we can undo the effect of the channel then all is ok
- That is precisely what happens – we use channel estimation (estimate what happens and reverse it)to undo the effect
- Key idea - Cyclic Prefixes are used in OFDM in order to combat multipath by making channel estimation easy.

- When the transmitted signal frequency response is X(n) and the channel response is H(n) it is always desirable to get received signal frequency response as,

$$Y(n)=H(n)*X(n)$$

- This is because you can then you can recover X(n) simply as

$$X(n)=Y(n)/H(n)$$

This is only true if the transmitted signal is infinite or periodic

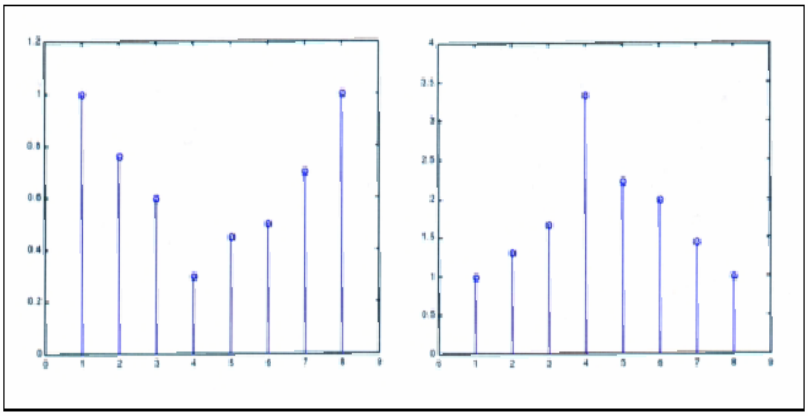
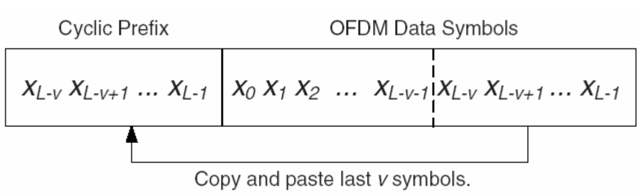
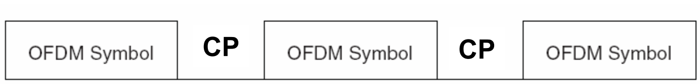


Figure 7. Left plot shows the frequency response of a channel, and the right plot shows the corresponding frequency-domain equalizer response. Note that the equalizer response is large when the channel response is small in order to counteract the effect of a channel null.

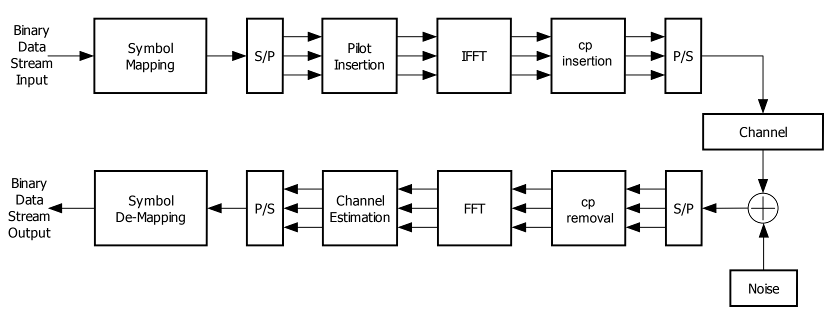


Addition of a CP makes the OFDM symbol appear periodic

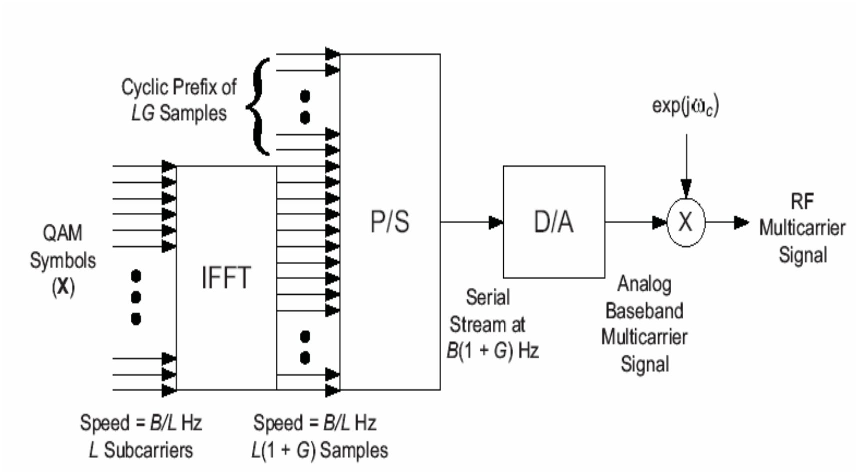


summary of ideas

- a cyclic prefix is added to make OFDM symbol appear periodic
- this allows for equalisation to be performed easily in the frequency domain – multiplication essentially
- the CP is then used instead of a guard interval
- the CP is created by simply repeating some of the symbols that are already in the OFDM symbol



ofdm transceiver



2. Very High Peak Data Rates

- WiMAX is capable of supporting very high peak data rates. In fact, the peak PHY data rate can be as high as 74Mbps when operating using a 20MHz wide spectrum.
- More typically, using a 10MHz spectrum operating using TDD scheme with a 3:1 downlink-to-uplink ratio, the peak PHY data rate is about 25Mbps and 6.7Mbps for the downlink and the uplink, respectively.
- These peak PHY data rates are achieved when using 64 QAM modulation with rate 5/6 error-correction coding.
- Under very good signal conditions, even higher peak rates may be achieved using multiple antennas

3. Scalable bandwidth and data rate support

- WiMAX has a scalable physical-layer architecture that allows for the data rate to scale easily with available channel bandwidth.

- The FFT (fast fourier transform) size may be scaled based on the available channel bandwidth. For example, a WiMAX system may use 128-, 512-, or 1,048-bit FFTs based on whether the channel bandwidth is 1.25MHz, 5MHz, or 10MHz, respectively.

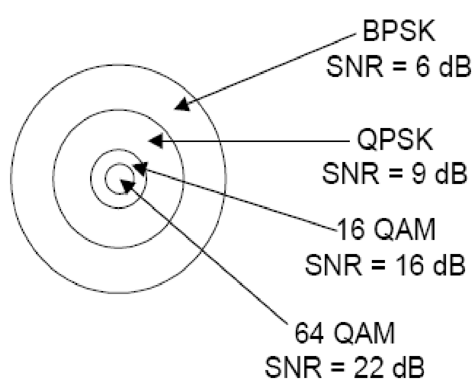
4. Adaptive modulation and coding

- WiMAX supports a number of modulation and forward error correction (FEC) coding schemes and allows the scheme to be changed on a per user and per frame basis, based on channel conditions.

- AMC is an effective mechanism to maximize throughput in a time-varying channel. The adaptation algorithm typically calls for the use of the highest modulation and coding scheme that can be supported by the signal-to-noise and interference ratio at the receiver such that each user is provided with the highest possible data rate that can be supported in their respective links.

Parameter	802.16	802.16-2004	802.16e	WiBRO
Bandwidth range	1.25 to 28.0 MHz	1.25 to 28.0 MHz	1.25 to 28.0 MHz	8.75 MHz
Modulation type	BPSK QPSK 16-QAM 64-QAM	QPSK 16-QAM 64-QAM	QPSK 16-QAM 64-QAM	QPSK 16-QAM 64-QAM
FFT size	–	256	128, 256, 512, 1024, 2048	1024
Duplex type	TDD/FDD	TDD/FDD	TDD/FDD	TDD
Guard period	1/4, 18, 1/16, 1/32	1/4, 1/8, 1/16, 1/32	1/4, 1/8, 1/16, 1/32	1/8
MIMO	Yes	Yes	Yes	Yes

Table 5. WiMAX-related standards at a glance



Relative cell radii for adaptive modulation

Modulation/Code Rate	QPSK 1/2	QPSK ¾	16 QAM 1/2	16 QAM 3/4	64 QAM 2/3	64 QAM 3/4
7MHz	4.1MBit/s	8.7MBit/s	11.6MBit/s	17.5MBit/s	23.8MBit/s	26.2MBit/s

note

- note even though we worked in Eb/No for the BER curves of the various modulation techniques, the adaptive modulation schemes are dealt with in terms of SNR

How to calculate SNR

- To do this we need to be able to determine the strength of the signal at the receiver and the noise at the receiver
- We need some kind of model to calculate the power of the signal at the receiver
- Like we have been learning before we can use all sorts of models to evaluate what happens to the signal on its journey.
- Some other simple models are given here.

Free Space Path Loss Model

$$P_r = P_t \frac{\lambda^2 G_r G_t}{(4\pi d)^2}$$

P_r is the received power, P_t is the transmitted power. G_r and G_t and the gains of the transmitting and receiving antennas and d is the distance from the transmitter.

Two Ray Approximation Model

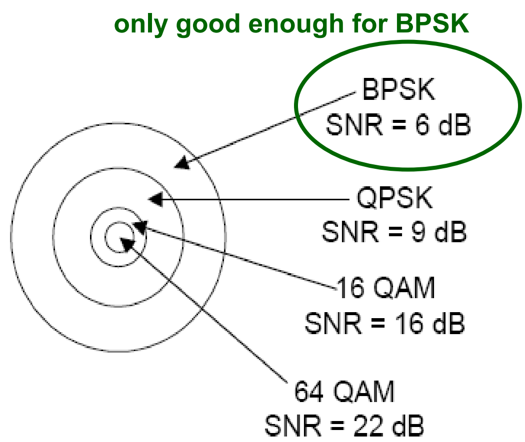
$$P_r = P_t \frac{G_r G_t {h_t}^2 {h_r}^2}{(d)^4}$$

h_r and h_t are the
heights of the transmitting and receiving antennas and d is the distance from the transmitter.

Estimator for Noise

- A simple way of estimating the noise in dB at the receiver is
- noise = N_o + N_f + 10log B
- where N_0 = -173 dBm/Hz, N_f is the noise figure and B is bandwidth

- example 10 MHz bandwidth N_f = 5dB gives a noise value of -98dBm
- suppose signal = - 90dBm
- SNR = -90+98 = 8dBm



Relative cell radii for adaptive modulation

In Reality

The 802.16 system can measure its SNR at the receiver and make decisions as to how to react

5.Link-layer retransmissions

- For connections that require enhanced reliability, WiMAX supports automatic retransmission requests (ARQ) at the link layer.
- ARQ-enabled connections require each transmitted packet to be acknowledged by the receiver; unacknowledged packetsare assumed to be lost and are retransmitted.
- WiMAX also optionally supports hybrid-ARQ, which is an effective hybrid between FEC and ARQ.

ARQ approaches

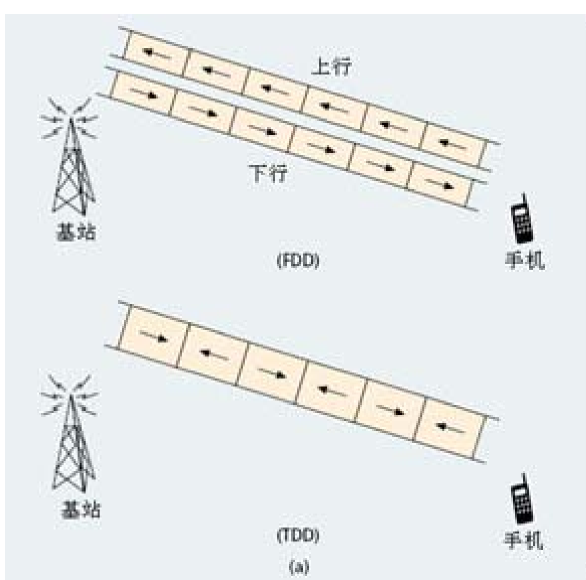
- the main idea is that the receiver asks the transmitter to repeat the transmission

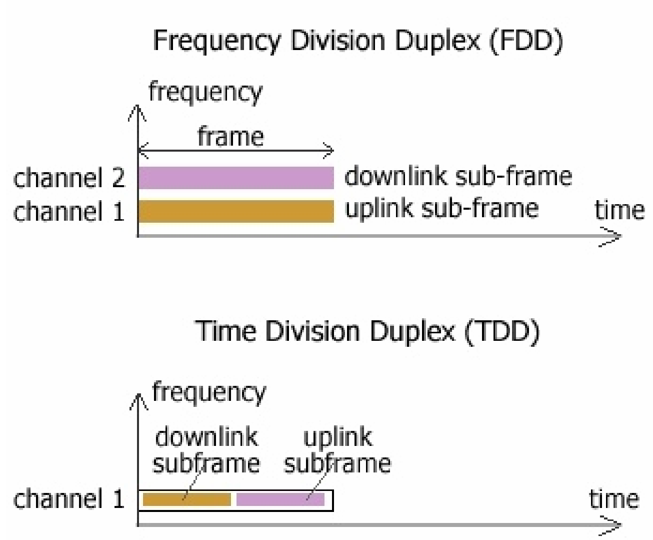
6. Support for FDD and TDD

- Both time division duplexing and frequency division duplexing, as well as a half-duplex FDD, which allows for a low-cost system implementation are supported.

- TDD is favored by a majority of implementations because of its advantages: (1) flexibility in choosing uplink-to-downlink data rate ratios, (2) ability to exploit channel reciprocity, (3) ability to implement in non-paired spectrum, and (4) less complex transceiver design.

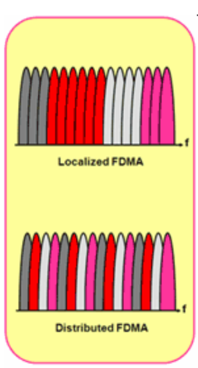
- All the initial WiMAX profiles are based on TDD.





7. Orthogonal frequency division multiple access

WiMAX **uses OFDM as a multiple-access technique, whereby different users can be allocated different subsets of the OFDM tones.**



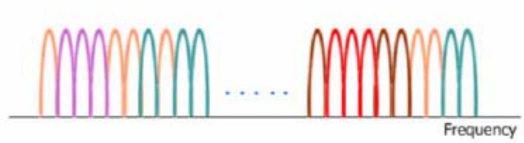
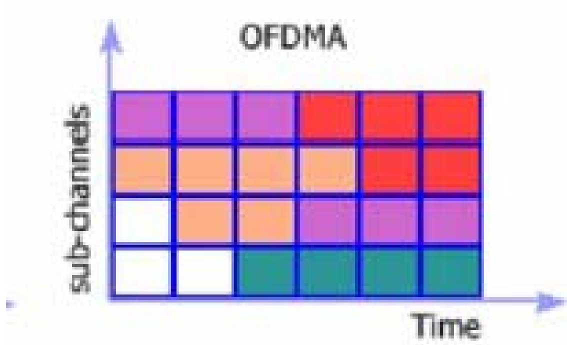


Figure. Orthogonal Frequency Division Multiple Access
Sub-carriers with the same color represent a sub-channel.

7. Flexible and dynamic per user resource allocation

- Both uplink and downlink resource allocation are controlled by a scheduler in the base station.
- Capacity is shared among multiple users on a demand basis.
- When using the OFDMA-PHY mode, multiplexing is additionally done in the frequency dimension, by allocating different subsets of OFDM subcarriers to different users.
- Resources may be allocated in the spatial domain as well when using the optional advanced antenna systems (AAS).
- The standard allows for bandwidth resources to be allocated in time, frequency, and space and has a flexible mechanism to convey the resource allocation information on a frame-by-frame basis.



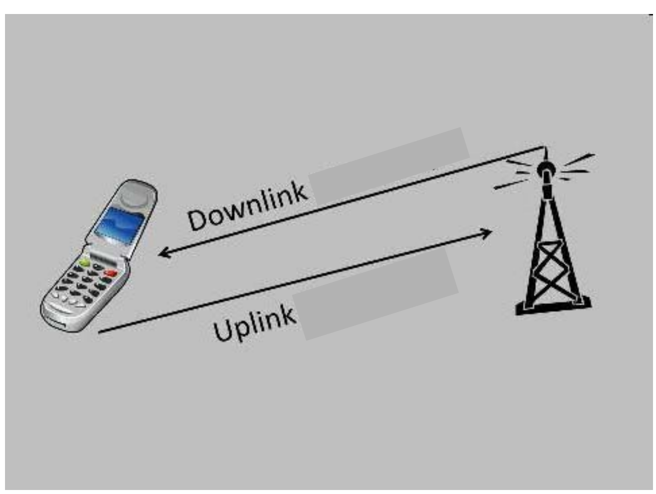
sub-channelisation

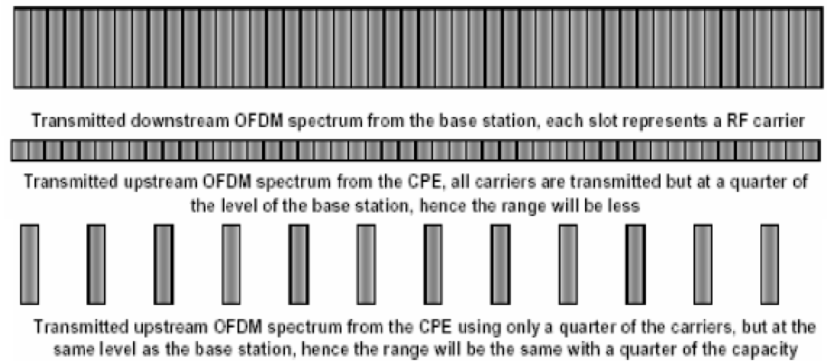
- **This is a further example of how different subcarriers can be combined and used differently**

- **In general, the CPE/MS is power constrained in any wireless network.**

- **This makes the link budget asymmetrical and the coverage area of a BS is uplink limited.**

- **Sub channelisation can balance the link budget in the uplink and downlink and extends the coverage area in a WiMAX system.**

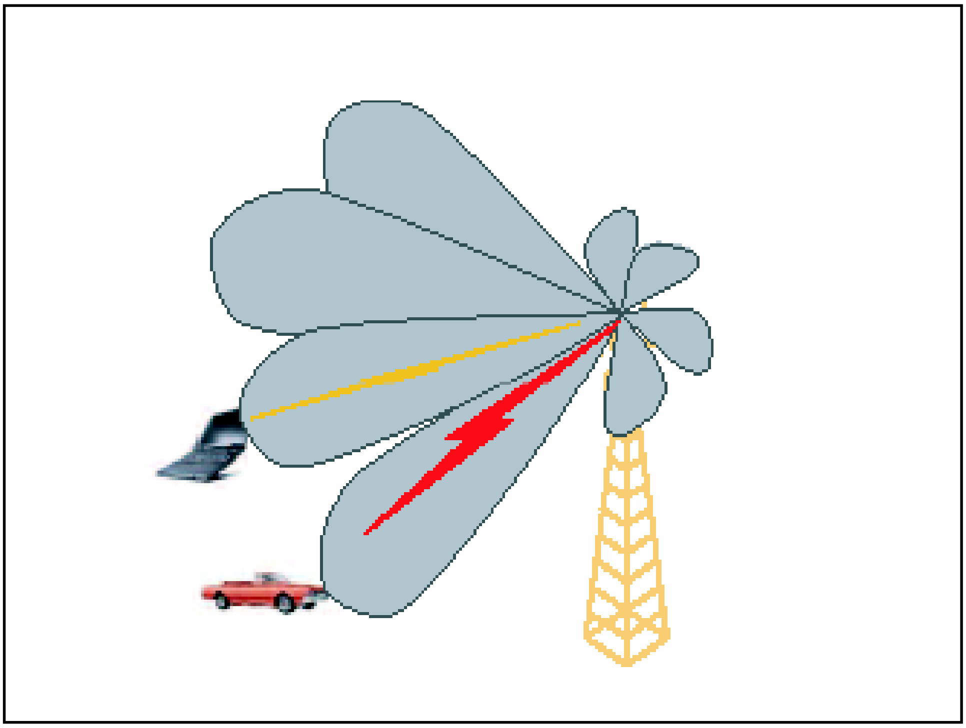


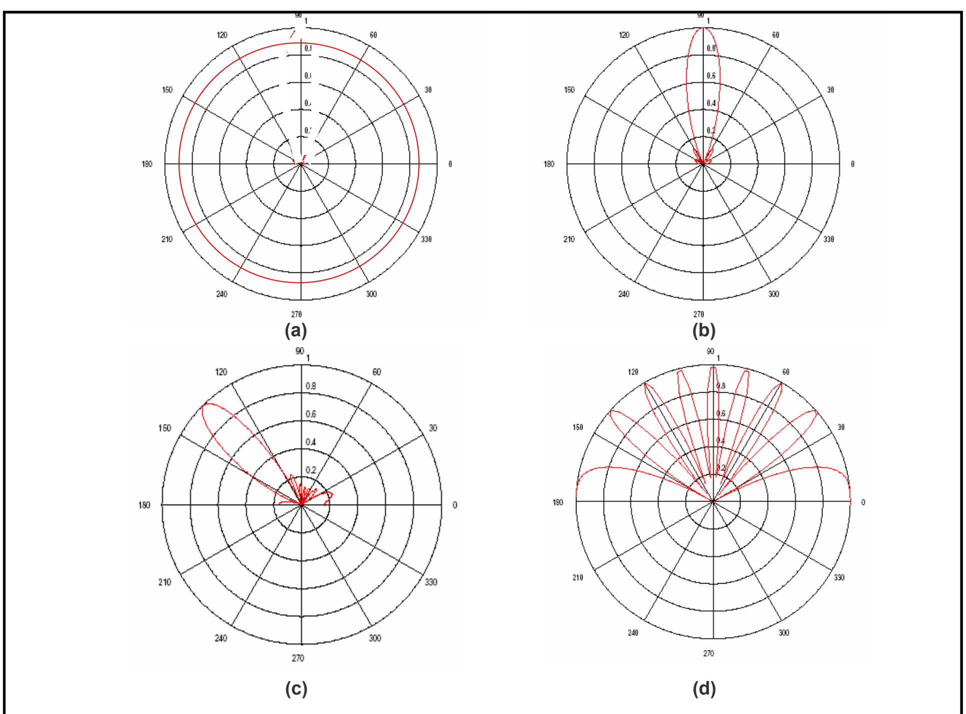


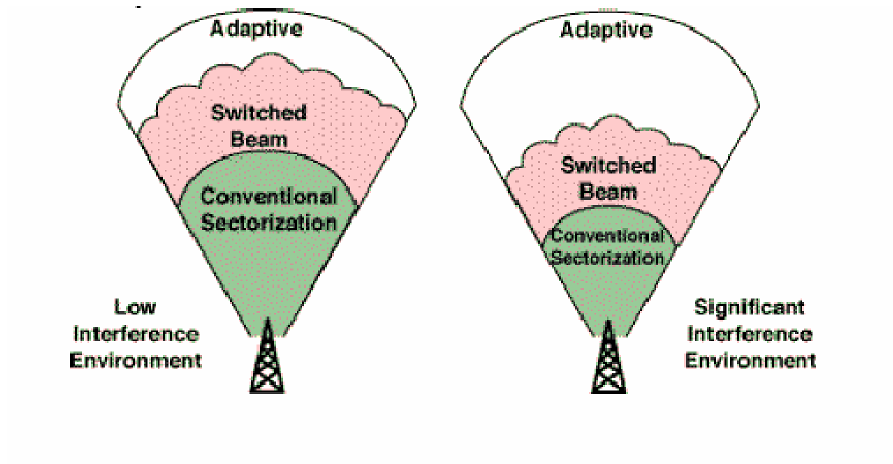
9. Support for advanced antenna techniques

- **The WiMAX solution has a number of hooks built into the physical-layer design, which allows for the use of multiple-antenna techniques, such as beamforming, space-time coding, and spatial multiplexing.**

- **These schemes can be used to improve the overall system capacity and spectral efficiency by deploying multiple antennas at the transmitter and/or the receiver.**




(a)
(b)
(c)
(d)



space-time coding

- Space-time coding (STC) deals with the design of good codes for multiple antenna wireless systems.

- They take advantage of diversity that can be achieved - A method for dealing with fading, is to introduce diversity, or multiple independent paths across which the signal is transmitted. Space-time systems exploit specifically designed signals for transmission over multiple transmit and receive antennae to generate and capture different copies of signal and improve performance.

maybe you can make some sense of this!

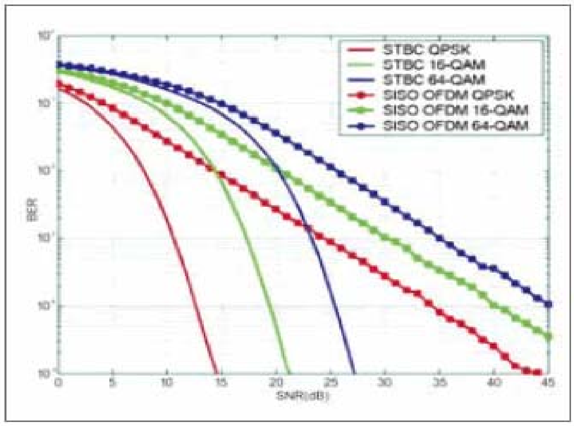


Figure 2 MIMO-STC effectively reduces BER

spatial multiplexing

- WiMAX also supports spatial multiplexing, where multiple independent streams are transmitted across multiple antennas.
- If the receiver also has multiple antennas, the streams can be separated out using space-time processing.
- Instead of increasing diversity, multiple antennas in this case are used to increase the data rate or capacity of the system.

9. Quality-of-service support

- The **WiMAX MAC layer** has a connection-oriented architecture that is designed to support a variety of applications, including voice and multimedia services.
- The system offers support for constant bit rate, variable bit rate, real-time, and non-real-time traffic flows, in addition to best-effort data traffic.
- WiMAX MAC is designed to support a large number of users, with multiple connections per terminal, each with its own QoS requirement.

QoS defined ….

- QoS is a broad and loose term that refers to the “collective effect of service,” as perceived by the user.
- For the purposes of this discussion, QoS more narrowly refers to meeting certain requirements — typically, throughput, packet error rate, delay, and jitter—associated with a given application.
- Broadband wireless networks must support a variety of applications, such as voice, data, video, and multimedia, and each of these has different traffic patterns and QoS requirements.

Table 1.4 Sample Traffic Parameters for Broadband Wireless Applications

Parameter	Interactive Gaming	Voice	Streaming Media	Data	Video
Data rate	50Kbps–85Kbps	4Kbps–64Kbps	5Kbps–384Kbps	0.01Mbps–100Mbps	> 1Mbps
Example applications	Interactive gaming	VoIP	Music, speech, video clips	Web browsing, e-mail, instant messaging (IM), telnet, file downloads	IPTV, movie download, peer-to-peer video sharing
Traffic flow	Real time	Real-time continuous	Continuous, bursty	Non–real time, bursty	Continuous
Packet loss	Zero	< 1%	< 1% for audio; < 2% for video	Zero	$< 10^{-8}$
Delay variation	Not applicable	< 20 ms	< 2 sec	Not applicable	< 2 sec
Delay	< 50 ms–150 ms	< 100 ms	< 250 ms	Flexible	< 100 ms

10. Robust Security

- **WiMAX supports strong encryption, using Advanced Encryption Standard (AES), and has a robust privacy and key-management protocol.**
- **The system also offers a very flexible authentication architecture based on Extensible Authentication Protocol (EAP), which allows for a variety of user credentials, including username/password, digital certificates, and smart cards.**

What is authentication?

- All communication systems need to be made secure to operate. Typically any users of a system have to be authenticate themselves on the network.
- Authentication is the process of determining whether someone or something is, in fact, who or what it is declared to be.
- Some authentication processes may involve the simple use of a password but others are more complex.
- The use of digital certificates, issued and verified by a what is known as a Certificate Authority (CA) as part of a public key infrastructure is an example of a more stringent process.

Key Infrastructure

- In cryptography, a public key infrastructure (PKI) is an arrangement that binds public keys with respective user identities by means of a certificate authority (CA).
- The user identity must be unique for each CA. The binding is established through the registration and issuance process, which, depending on the level of assurance the binding has, may be carried out by software at a CA, or under human supervision.
- The primary function of a PKI is to allow the distribution and use of public keys and certificates with security and integrity.
- The specific security functions in which a PKI can provide foundation are confidentiality, integrity, non-repudiation, and authentication.

11. Support for mobility

- The mobile WiMAX variant of the system has mechanisms to support secure seamless handovers for delay-tolerant full-mobility applications, such as VoIP.
- The system also has built-in support for power-saving mechanisms that extend the battery life of
- handheld subscriber devices.
- Physical-layer enhancements, such as more frequent channel estimation, uplink subchannelization, and power control, are also specified in support of mobile

1. **Nomadic**. The user is allowed to take a fixed subscriber station and reconnect from a different point of attachment.
2. **Portable**. Nomadic access is provided to a portable device, such as a PC card, with expectation of a best-effort handover.
3. **Simple mobility**. The subscriber may move at speeds up to 60 kmph with brief interruptions (less than 1 sec) during handoff.
4. **Full mobility**: Up to 120 kmph mobility and seamless handoff (less than 50 ms latency and <1% packet loss) is supported.

handoff

- To meet the second challenge of mobility, the system should provide a method for seamlessly handing over an ongoing session from one base station to another as the user moves across them.
- A handoff process typically involves detecting and deciding when to do a handoff, allocating radio resources for it, and executing it. It is required that all handoffs be performed successfully and that they happen as infrequently and imperceptibly as possible.
- The challenge for handoff-decision algorithms is the need to carefully balance the dropping probability and handoff rate. Being too cautious in making handoff decisions can lead to dropped sessions; excessive handoff can lead to an unnecessary signaling load.

12. IP based architecture

- **The WiMAX Forum has defined a reference network architecture that is based on an all-IP platform.**
- **All end-to-end services are delivered over an IP architecture relying on IP-based protocols for end-to-end transport, QoS, session management, security, and mobility.**
- **Reliance on IP allows WiMAX to ride the declining costcurves of IP processing, facilitate easy convergence with other networks, and exploit the rich ecosystem for application development that exists for IP.**

Reference Architecture

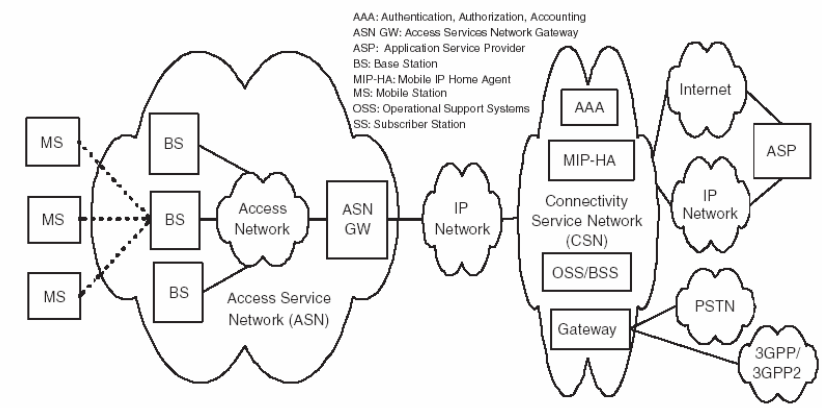


Figure 2.3 IP-Based WiMAX Network Architecture

aside:slot and frame structure

different flavours of WiMAX

Standard	Defined in	Frequencies covered
IEEE 802.16	2002	10 to 66 GHz
IEEE 802.16a	2003	2 to 11 GHz
IEEE 802.16b	2003	5 to 6 GHz
IEEE 802.16c	2003	10 to 66 GHz
IEEE 802.16d	2003	2 to 11 GHz
IEEE 802.16-2004	2004	2 to 66 GHz
IEEE 802.16e	2005	2 to 66 GHz

Table 2. Tracing the evolution of IEEE 802.16 standards

Band Index	Frequency Band	Channel Bandwidth	OFDM FFT Size	Duplexing
		Fixed WiMAX Profiles		
1	3.5 GHz	3.5MHz	256	FDD
		3.5MHz	256	TDD
		7MHz	256	FDD
		7MHz	256	TDD
2	5.8GHz	10MHz	256	TDD
		Mobile WiMAX Profiles		
1	2.3GHz–2.4GHz	5MHz	512	TDD
		10MHz	1,024	TDD
		8.75MHz	1,024	TDD
2	2.305GHz–2.320GHz, 2.345GHz–2.360GHz	3.5MHz	512	TDD
		5MHz	512	TDD
		10MHz	1,024	TDD
3	2.496GHz–2.69GHz	5MHz	512	TDD
		10MHz	1,024	TDD
4	3.3GHz–3.4GHz	5MHz	512	TDD
		7MHz	1,024	TDD
		10MHz	1,024	TDD
5	3.4GHz–3.8GHz, 3.4GHz–3.6GHz, 3.6GHz–3.8GHz	5MHz	512	TDD
		7MHz	1,024	TDD
		10MHz	1,024	TDD

Table 2.1 Basic Data on IEEE 802.16 Standards

	802.16	802.16-2004	802.16e-2005
Status	Completed December 2001	Completed June 2004	Completed December 2005
Frequency band	10GHz–66GHz	2GHz–11GHz	2GHz–11GHz for fixed; 2GHz–6GHz for mobile applications
Application	Fixed LOS	Fixed NLOS	Fixed and mobile NLOS
MAC architecture	Point-to-multipoint, mesh	Point-to-multipoint, mesh	Point-to-multipoint, mesh
Transmission scheme	Single carrier only	Single carrier, 256 OFDM or 2,048 OFDM	Single carrier, 256 OFDM or scalable OFDM with 128, 512, 1,024, or 2,048 subcarriers
Modulation	QPSK, 16 QAM, 64 QAM	QPSK, 16 QAM, 64 QAM	QPSK, 16 QAM, 64 QAM
Gross data rate	32Mbps–134.4Mbps	1Mbps–75Mbps	1Mbps–75Mbps
Multiplexing	Burst TDM/TDMA	Burst TDM/TDMA/ OFDMA	Burst TDM/TDMA/ OFDMA
Duplexing	TDD and FDD	TDD and FDD	TDD and FDD
Channel bandwidths	20MHz, 25MHz, 28MHz	1.75MHz, 3.5MHz, 7MHz, 14MHz, 1.25MHz, 5MHz, 10MHz, 15MHz, 8.75MHz	1.75MHz, 3.5MHz, 7MHz, 14MHz, 1.25MHz, 5MHz, 10MHz, 15MHz, 8.75MHz

Table 2.3 OFDM Parameters Used in WiMAX

Parameter	Fixed WiMAX OFDM-PHY	Mobile WiMAX Scalable OFDMA-PHY[a]				
FFT size	256	128	**512**	1,024	2,048	
Number of used data subcarriers[b]	192	72	**360**	720	1,440	
Number of pilot subcarriers	8	12	**60**	120	240	
Number of null/guardband subcarriers	56	44	**92**	184	368	
Cyclic prefix or guard time (Tg/Tb)	1/32, 1/16, **1/8**, 1/4					
Oversampling rate (Fs/BW)	Depends on bandwidth: 7/6 for 256 OFDM, 8/7 for multiples of 1.75MHz, and 28/25 for multiples of 1.25MHz, 1.5MHz, 2MHz, or 2.75MHz.					
Channel bandwidth (MHz)	3.5	1.25	**5**	10	20	
Subcarrier frequency spacing (kHz)	15.625	**10.94**				
Useful symbol time (μs)	64	**91.4**				
Guard time assuming 12.5% (μs)	8	**11.4**				
OFDM symbol duration (μs)	72	**102.9**				
Number of OFDM symbols in 5 ms frame	69	**48.0**				

a. Boldfaced values correspond to those of the initial mobile WiMAX system profiles.