WiMax Overview

Sanida Omerovic,
Faculty of Electrical Engineering,
University of Ljubljana, Slovenia

1. Introduction

1.1. IEEE 802.16

The IEEE 802.16 Working Group is the IEEE group for wireless metropolitan area network. The IEEE 802.16 standard defines the Wireless MAN (metropolitan area network) air interface specification (officially known as the IEEE WirelessMAN* standard). This wireless broadband access standard could supply the missing link for the “last mile” connection in wireless metropolitan area networks.
Wireless broadband access is set up like cellular systems, using base stations that service a radius of several miles/kilometers. Base stations do not necessarily have to reside on a tower. More often than not, the base station antenna will be located on a rooftop of a tall building or other elevated structure such as a grain silo or water tower. A customer premise unit, similar to a satellite TV setup, is all it takes to connect the base station to a customer. The signal is then routed via standard Ethernet cable either directly to a single computer, or to an 802.11 hot spot or a wired Ethernet LAN.

The IEEE 802.16 designed to operate in the 10-66 GHz spectrum and it specifies the physical layer (PHY) and medium access control layer (MAC) of the air interface BWA systems. At 10-66 GHz range, transmission requires Line-of-Sight (LOS).
IEEE 802.16 is working group number 16 of IEEE 802, specializing in point-to-multipoint broadband wireless access.

The IEEE 802.16 standard provides the foundation for a wireless MAN industry. However, the physical layer is not suitable for lower frequency applications where non-line-of-sight (NLOS) operation is required. For this reason, the IEEE published 802.16a standard to accommodate NLOS requirement in April 2003. The standard operates in licensed and unlicensed frequencies between 2 GHz and 11 GHz, and it is an extension of the IEEE 802.16 standard.

The IEEE 802.16 Working Group created a new standard, commonly known as WiMax, for broadband wireless access at high speed and low cost, which is easy to deploy, and which provides a scalable solution for extension of a fiber-optic backbone. WiMax base stations can offer greater wireless coverage of about 5 miles, with LOS (line of sight) transmission within bandwidth of up to 70 Mbps.

WiMax is supported by the industry itself, including Intel, Dell, Motorola, Fujitsu, AT&T, British Telecom, France Telecom, Reliance Infocomm, Siemens, Sify, PriceWatehouseCoopers and Tata Teleservices – forming an alliance called WiMax Forum. It represents the next generation of wireless networking. WiMAX original release the 802.16 standard addressed applications in licensed bands in the 10 to 66 GHz frequency range. Subsequent amendments have extended the 802.16 air interface standard to cover non-line of sight (NLOS) applications in licensed and unlicensed bands in the sub 11 GHz frequency range. Filling the gap between Wireless LANs and wide area networks, WiMAX-compliant systems will provide a cost-effective fixed wireless alternative to conventional wire-line DSL and cable in areas where those technologies are readily available. And more importantly the WiMAX technology can provide a cost-effective broadband access solution in areas beyond the reach of DSL and cable. The ongoing evolution of IEEE 802.16 will expand the standard to address mobile applications thus enabling broadband access directly to WiMAX-enabled portable devices ranging from smartphones and PDAs to notebook and laptop computers. Figure 1.1. below from the WiMAX Forum summarizes the 802.16 standards.

Completion Date	**802.16** Dec 2001	**802.16a/ 802.16REVd** 802.16a: Jan 2003 802.16Revd: Q3 2004	**802.16e** 2005
Spectrum	10 to 66 GHz	< 11 GHz	< 6 GHz
Channel Conditions	Line-of-Sight only	Non-Line-of-Sight	Non-Line-of-Sight
Bit Rate	32 to134 Mbps	75 Mbps max 20-MHz channelization	15 Mbps max 5-MHz channelization
Modulation	QPSK 16QAM 64QAM	OFDM 256 subcarrier QPSK 16QAM 64QAM	Same as 802.16a
Mobility	Fixed	Fixed	Pedestrian mobility Regional roaming
Channel Bandwidths	20, 25 and 28 MHz	Selectable between 1.25 and 20 MHz	Same as 802.16a with uplink subchannels
Typical Cell Radius	1 to 3 miles	3 to 5 miles (30 miles max based on tower height, antenna gain, and power transmit)	1 to 3 miles

Figure 1.1. Summary of 802.16 Standards

1.2. IEEE 802.16a

The IEEE 802.16a standard allows users to get broadband connectivity without needing direct line of sight with the base station. The IEEE 802.16a specifies three air interface specifications and these options provide vendors with the opportunity to customize their product for different types of deployments. The three physical layer specifications in 802.16a are:

- Wireless MAN-SC which uses a single carrier modulation format.
- Wireless MAN-OFDM which uses orthogonal frequency division multiplexing (OFDM) with 256 point Fast Fourier Transform (FFT). This modulation is mandatory for license exempt bands.
- Wireless MAN-OFDMA which uses orthogonal frequency division multiple access (OFDMA) with a 2048 point FFT. Multiple access is provided by addressing a subset of the multiple carriers to individual receivers.

In 1998, the IEEE (The Institute of Electrical and Electronics Engineers) began a standards project to specify a point-to-multipoint broadband wireless access system suitable for the delivery of data, voice, and video services to fixed customer sites. The initial standard, designated IEEE 802.16, was developed for the higher microwave bands (> 10 GHz) where line-of-sight between system antennas is required for reliable service. Despite the availability of licensed spectrum for potential deployments, completion of the standard in 2001 failed to have a significant impact; most vendors abandoned their proprietary equipment and did not attempt to implement high-frequency multipoint systems based on the 802.16 standard.

Factors beyond equipment cost (e.g., installation, roof rights, backhaul, spectrum costs) were significant contributors to the poor economics of the high-frequency multipoint systems.

In early 2000, work on a low-frequency (<11 GHz) revision of the 802.16 standard was begun by the IEEE working group. This revision (designated 802.16a) incorporated new radio link system options more suitable for low-frequency service while maintaining most of the access control system specifications of the original standard. Completed in January 2000, the 802.16a standard included features supporting:
- Non-line-of-sight service capability
- Multiple radio modulation options (single carrier, OFDM)
- Licensed and unlicensed band implementations
- Versatile access control and QoS features, including TDM and packet services,
advanced security A corrected and modified version of 802.16a (designated 802.16-REVd) was completed in June 2004. Initial WiMAX profiles are a subset of the 802.16-REVd standard. A mobile extension to the low-frequency 802.16 standard is now being developed by the IEEE 802.16e working group. This extension will support delivery of broadband data to a moving wireless terminal, such as a laptop computer with an integrated WiMAX modem being used by a passenger on a commuter train. The WiMAX Forum expects to endorse a mobile profile following completion of the 802.16e standard.

1.3. WiMax vs. WLAN

Unlike WLAN, WiMAX provides a media access control (MAC) layer that uses a grant-request mechanism to authorize the exchange of data. This feature allows better exploitation of the radio resources, in particular with smart antennas, and independent management of the traffic of every user.

This simplifies the support of real-time and voice applications.
One of the inhibitors to widespread deployment of WLAN was the poor security feature of the first releases. WiMAX proposes the full range of security features to ensure secured data exchange:
- Terminal authentication by exchanging certificates to prevent rogue devices,
- User authentication using the Extensible Authentication Protocol (EAP),
- Data encryption using the Data Encryption Standard (DES) or Advanced Encryption Standard (AES), both much more robust than the Wireless Equivalent Privacy (WEP) initially used by WLAN. Furthermore, each service is encrypted with its own security association and private keys.

1.4.WiMax VS. WiFi

WiMAX operates on the same general principles as WiFi -- it sends data from one computer to another via radio signals. A computer (either a desktop or a laptop) equipped with WiMAX would receive data from the WiMAX transmitting station, probably using encrypted data keys to prevent unauthorized users from stealing access.

The fastest WiFi connection can transmit up to 54 megabits per second under optimal conditions. WiMAX should be able to handle up to 70 megabits per second. Even once that

70 megabits is split up between several dozen businesses or a few hundred home users, it will provide at least the equivalent of cable-modem transfer rates to each user.

The biggest difference isn't speed; it's distance. WiMAX outdistances WiFi by miles. WiFi's range is about 100 feet (30 m). WiMAX will blanket a radius of 30 miles (50 km) with wireless access. The increased range is due to the frequencies used and the power of the transmitter. Of course, at that distance, terrain, weather and large buildings will act to reduce the maximum range in some circumstances, but the potential is there to cover huge tracts of land.

WiMax is not designed to clash with WiFi, but to coexist with it. WiMax coverage is measured in square kilometers, while that of WiFi is measured in square meters. The original WiMax standard (IEEE 802.16) proposes the usage of 10-66 GHz frequency spectrum for the WiMax transmission, which is well above the WiFi range (up to 5GHz maximum). But 802.16a added support for 2-11 GHz frequency also. One WiMax base station can be accessed by more than 60 users. WiMax can also provide broadcasting services also.

WiMax specifications also provides much better facilities than WiFi, providing higher bandwidth and high data security by the use of enhanced encryption schemes. WiMax can also provide service in both Line Of Sight (LOS) and Non-Line Of Sight (NLOS) locations, but the range will vary accordingly. WiMax will allow the interpenetration for broadband service provision of VoIP, video, and internet access – simultaneously. WiMax can also work with existing mobile networks. WiMax antennas can "share" a cell tower without compromising the function of cellular arrays already in place.

1.5. HIPERMAN

The ETSI has created wireless MAN standard for frequency band between 2 GHz and 11 GHz. The ETSI HIPERMAN standard was issued in Nov 2003. The ETSI works closely with the IEEE 802.16 group and the HIPERMAN standard has essentially followed 802.16's lead. The HIPERMAN standard provides a wireless network communication in the 2 – 11 GHz bands across Europe. The HIPERMAN working group utilizes the 256 point FFT OFDM modulation scheme. It is one of the modulation schemes defined in the IEEE 802.16a standard.

1.6. WiMax

Worldwide Interoperability for Microwave Access (WiMAX) is currently one of the hottest technologies in wireless. The Institute of Electrical and Electronics Engineers (IEEE) 802 committee, which sets networking standards such as Ethernet (802.3) and WiFi (802.11), has published a set of standards that define WiMAX. IEEE 802.16-2004 (also known as Revision D) was published in 2004 for fixed applications; 802.16 Revision E (which adds mobility) is publicated in July 2005. The WiMAX Forum is an industry body formed to promote the IEEE 802.16 standard and perform interoperability testing. The WiMAX Forum has adopted certain profiles based on the 802.16 standards for interoperability testing and “WiMAX certification”. These operate in the 2.5GHz, 3.5GHz and 5.8GHz frequency bands, whic typically are licensed by various government authorities. WiMAX, is based on an RF technology called Orthogonal Frequency Division Multiplexing (OFDM), which is a very effective means of transferring data when carriers of width of 5MHz or greater can be used. Below 5MHz carrier width, current CDMA based 3G systems are comparable to OFDM in terms of performance.

WiMAX is a standard-based wireless technology that provides high throughput broadband connections over long distance. WiMAX can be used for a number of applications, including "last mile" broadband connections, hotspots and high-speed connectivity for business customers. It provides wireless metropolitan area network (MAN) connectivity at speeds up to 70 Mbps and the WiMAX base station on the average can cover between 5 to 10 km.
Figure 1.6. below gives WiMAX Overview.

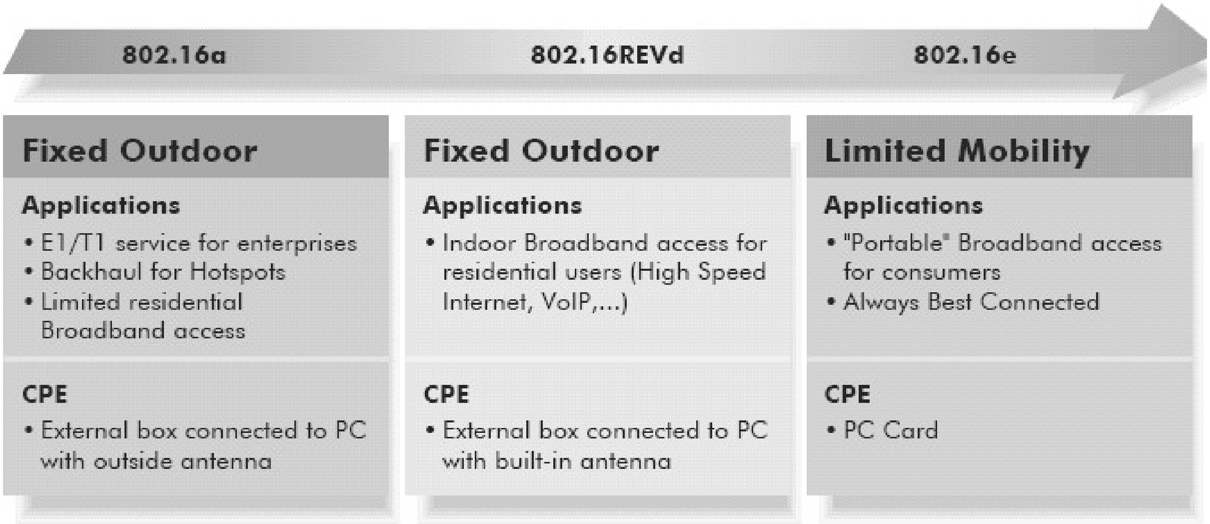

Figure 1.6. WiMAX Overview

1.6.1. WiMax Forum

WiMAX Forum is a non-profit corporation that was formed in April 2001 by equipment and component suppliers to help to promote and certify the compatibility and interoperability of Broadband Wireless Access (BWA) equipment. As of May 2004, there are over 100 members of WiMAX Forum. WiMAX's members, which include Airspan, Alcatel, Alvarion, Fujitsu, Intel, OFDM Forum, Proxim, Siemens, account for over 75 percent of sales in the 2 to 11 GHz BWA market.

The WiMAX Forum (the Forum) is a coalition of wireless and computer industry companies that has endorsed and is aggressively marketing the WiMAX standard. A principal purpose of the organization is to promote and certify compatibility and interoperability of devices based on the various 802.16 specifications and to develop such devices for the global marketplace.
The Forum believes that the adoption of industry standards will be a key factor in any successful deployment of WiMAX technology. For example, one of the most significant problems with WiFi initial deployment, was the lack of any early industry standards. In the early days of WiFi deployment, the marketplace was saturated with equipment well before industry standards were adopted. As a result, equipment often lacked interoperability and was expensive.

One of the purposes of the WiMAX Forum is to create a single interoperable standard from the IEEE and ETSI BWA standards.
In order to create a single interoperable standard, WiMAX has decided to focus on the 256 FFT OFDM which is common between 802.16a and HIPERMAN. WiMAX has developed system profiles covering the popular licence-exempted bands in 2.4 GHz and 5 GHz and other licensed bands in 2.3 GHz, 2.5 GHz and 3.5 GHz. At the moment, WiMAX will focus its conformance and interoperability test procedures on equipment that operates in 2.5 GHz and 3.5 GHz licensed bands and 5.8 GHz unlicensed band using 256 FFT OFDM modulation scheme. The flexible channel plan from 1.5 MHz to 20 MHz per channel will be adopted by WiMAX.

The Figure 1.6.1.1. table below summarizes differences between the two systems.

	802.16REVd/WiMAX	802.11/WiFi	Technical Difference
Range	Up to 30 miles – Typical cell size of 4-6 miles	Sub ~300 feet (add accesspoints for greater coverage)	802.16 tolerates greater multi-path, delay spread via implementation of 256 FFT vs. 64 FFT for 802.11.
Coverage	Outdoor NLOS – performance standard support for advanced antenna techniques	Optimized for indoor performance, short range	802.16 systems have an overall higher system gain, delivering greater penetration through obstacles at longer distances.
Scalability	Designed to support hundreds of CPEs, with unlimited subscribers behind each CPE	Intended for LAN applications, users scale from one to tens with one subscriber for each CPE device	802.16 can use all available frequencies, multiple channels support cellular deployment. 802.11 is limited to license exempt spectrum.
Bit Rate	5 bps/Hz peak up to 100 Mbps in 20 MHz channel	2.7 bps/Hz peak up to 54 Mbps in 20 MHz channel	Higher modulations coupled with flexible error correction results in more efficient use of spectrum.
QoS	QoS built into MAC – voice/video service levels	No QoS support	802.11 is contention based MAC (CSMA/CA) basically wireless Ethernet. 802.16: Dynamic TDMA-based MAC with on-demand bandwidth allocation.

Figure 1.6.1. 1. WiMax Forum WiMax vs. WiFi

The WiMAX Forum strategy has been formed in an attempt to promote high-volume, worldwide adoption of WiMAX equipment. Components of the WiMAX Forum strategy include:
- Select a workable subset of the many allowed system profiles and variations in the 802.16 standard
- Develop a testing and certification process to validate that equipment submitted by vendors conforms to “WiMAX” certification requirements of standard compliance and multi-vendor interoperability
- Continue to support IEEE 802.16 standard updates and corrections, including the current mobile enhancement project (802.16e)

The availability of a standard eliminates the need for the large investment by equipment vendors required to develop and verify basic radio and access control systems from scratch. With volume, equipment costs are further lowered as component makers and system integrators achieve manufacturing efficiencies. Service providers (and ultimately consumers) benefit from the interoperability requirement, as multiple vendors compete for business during initial system build-out, expansion, and evolutionary upgrades.
The WiMAX Forum timeline (past and projected) for standard development, certification testing, and availability of initial “WiMAX” equipment is shown below at Figure 1.6.1.2.

January 2003	April 2003	4Q03	3Q04	4Q04/1Q05
IEEE 802.16 Standard Released	Initial System Profiles selected OFDM at 2.5 (MMDS/ITFS), 3.5 (non-USA) and 5.8 (unlicensed) GHz	Select Certification Lab Complete Suites Test developed	Initial Vendor tests planned to begin	WiMAX Certified Solutions targeted for the market

Figure 1.6.1.2. WiMAX Schedule

The WiMAX Forum has estimated CPE (customer premises equipment) availability and cost by type:
- **First Generation.** Fixed outdoor antenna/radio (similar to DBS), 2005, ~$350
- **Second Generation.** Indoor directional antenna/radio, late 2005/2006, ~$250
- **Third Generation.** Integrated system in laptops, 2006/2007, ~$100

Figure 1.6.1.3. contains details for WiMAX standards.

	802.16	802.16a	802.16-2004	802.16e
Date Completed	Dec. '01	Jan '03	June 2004	2Q 2005
Spectrum	10 to 66 GHz	< 11 GHz	< 11 GHz	< 6 GHz
Operation	LOS	Non-LOS	Non-LOS	Non-LOS /Mobile
Bit Rate	32-134 Mb/s	Up to 75 Mb/s	Up to 75 Mb/s	Up to 15 Mb/s[f]
Cell Radius	1 to 3 miles	3-5 miles.	3-5 miles.	1 to 3 miles

Figure 1.6.1.3. WiMAX Standards

Despite the fact that "WiMAX" is often mentioned in articles discussing broadband access alternatives, it is important to note that no "WiMAX" equipment will exist until the formal WiMAX certification is completed by the initial candidates. Vague terms such as "802.16 compatible," "pre-WiMAX," or "WiMAX compliant" are not endorsed by the WiMAX Forum. Some vendors using the "pre-WiMAX" terminology have stated that hardware and software modifications will allow these products to be upgraded to the equivalent of future "WiMAX certified" versions. Figure 1.6.1.4. shows progress of WiMAX technology till 2009.

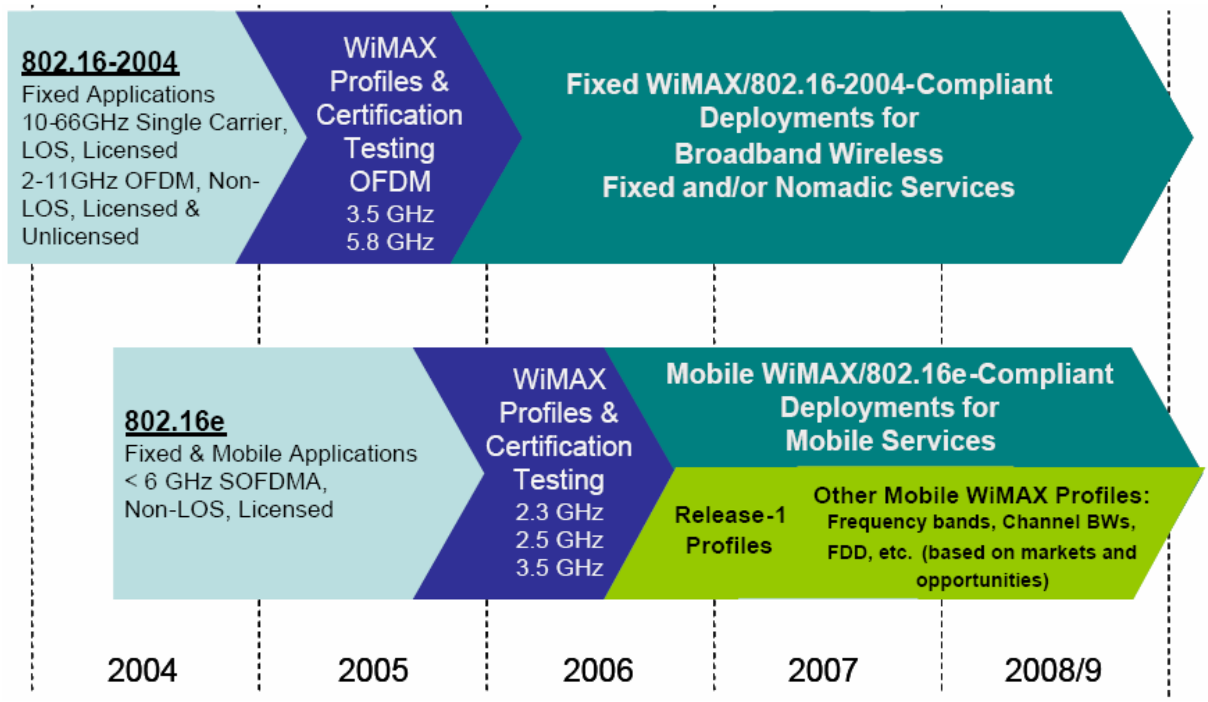

Figure 1.6.1.4. Roadmap for WiMax technology

As part of its deployment plan, the WiMAX Forum anticipates rollout of its technology in three phases.

Phase I (2004 - 2005): ***Fixed Location, Private Line Services, Hot Spot Back-Haul.***
Using the initial 802.16 standard as its cornerstone, Phase I of WiMAX deployment has already begun with the provision of traditional dedicated-line services to carriers and enterprises. Companies such as Towerstream Wireless are offering wireless Internet access to more than 600 customers in six major markets, including New York, Boston and Chicago.14 Phase I also will include such operations as aggregating public Wi-Fi hot spots to a central, high-capacity internet connection.

Phase II (2005 - 2006): ***Broadband Wireless Access/Wireless DSL.***
Phase II of the rollout will entail the first mass-market application of WiMAX technology. With the backing of computer industry heavyweights such as Intel Corporation and Dell, this phase will involve the delivery of low-cost, user installable premises equipment that will not have to be pointed at a base station. In conjunction with the equipment rollout, the Forum anticipates that the number of wireless internet service providers (WISPs) utilizing WiMAX compatible technology will increase exponentially.

Phase III (2007): ***Mobile/Nomadic Users.***
Phase III of the rollout will focus on the development of a mobile-broadband market. In this final phase, laptops and other mobile computing devices will be fully integrated with WiMAX chips and antennas, allowing mobile workers to send and receive high-bandwidth files such as schematics, videos, and multimedia presentations in real time over a wireless broadband connection. The WiMAX Forum anticipates that the technology will be deployed for the offering of other products and services, as well.
Figure 1.6.1.5. presents partial list of members WiMAX forum.

Agilent Technologies, Inc.
AT&T
Cisco Systems
Dell Computers
Euskaltel S.A.
France Telecom
Lucent Technologies, Inc.
Motorola
Nortel Networks Limited
SES Americom

Figure 1.6.1.5. Partial List of WiMAX Forum Members

1.6.2. WiMAX Spectrum — Licensed and Unlicensed

As with any other spectrum based technology, successful WiMAX deployment will depend largely upon the availability and suitability of spectrum resources. For entities providing wireless communications services, two sources of spectrum are available:
- Licensed spectrum and
- Unlicensed spectrum.

Licensed spectrum requires an authorization/license from the Commission, which offers that individual user — or “Licensee”— the exclusive rights to operate on a specific frequency (or frequencies) at a particular location or within a defined geographic area.
In contrast, unlicensed spectrum permits any user to access specific frequencies within any geographic area inside the United States without prior Commission authorization. While users of this spectrum do not have to apply for individual licenses or pay to use the spectrum, they are still subject to certain rules. First, unlicensed users must not cause interference to licensed users and must accept any interference they receive. Second, any equipment that will be utilized on unlicensed spectrum must be approved in advance by the Commission. Because of its broad operating range, licensed and unlicensed spectrum options for WiMAX technology are extensive.

To take best advantage of the benefits provided by WiMAX systems, large block spectrum assignments are most desirable. This enables systems to be deployed in TDD mode with large channel bandwidths, flexible frequency re-use and with minimal spectral inefficiencies for guard-bands to facilitate coexistence with adjacent operators. Another key activity for the WiMAX Forum is collaborating with standards and regulatory bodies worldwide to promote the allocation of spectrum in the lower frequency bands (< 6 GHz) that is both application and technology neutral. Additionally, there is a major push for greater harmonization in spectrum allocations so as to minimize the number equipment variants required to cover worldwide markets.

The initial system performance profiles that will be developed by the WiMAX Forum for the recently approved 802.16-2005 air interface standard are expected to be in the licensed 2.3 GHz, 2.5 GHz and 3.5 GHz frequency bands. The 2.3 GHz band has been allocated in South Korea for WiBro services based on the Mobile WiMAX technology.
With a 27 MHz block of spectrum assignment to each operator, this band will support a TDD deployment with 3 channels per base station and a nominal channel bandwidth of 8.75 MHz. The 2.5 to 2.7 GHz band is already available for mobile and fixed wireless services in the United States. This band is also currently underutilized and potentially available in many countries throughout South America and Europe as well as some countries in the Asia-Pacific

region. The 3.5 GHz band is already allocated for fixed wireless services in many countries worldwide and is also well-suited to WiMAX solutions for both fixed and mobile services.

2. Mesh Networks

The IEEE 802.16 WiMax standard provides amechanism for creating multi-hop mesh, which can be deployed as a high speed wide-area wireless network.

Beyond just providing a single last hop access to a broadband ISP, WiMax technology can be used for creating wide-area wireless *backhaul* network. When a backhaul-based WiMax is deployed in *Mesh* mode, it does not only increase the wireless coverage, but it also provides features such as lower backhaul deployment cost, rapid deployment, and reconfigurability. Various deployment scenarios include citywide wireless coverage, backhaul for connecting 3G RNC (Radio Network Controller) with base stations, and others. In addition to the single-hop IEEE 802.16 PMP (point-tomultipoint) operation, IEEE 802.16a standard defined the basic signaling flows and message formats to establish a mesh network connection. Subsequently, the Mesh mode specifications were integrated into the IEEE 802.16-2004 revision. Although single hop WiMax provides high flexibility to attain Quality of Service in terms of data throughput, achieving the same in multi-hop WiMax mesh is challenging. One of the major problem is dealing with the interference from transmission of the neighboring WiMax nodes. Cross-layer design and optimization is known to improve the performance of wireless communication and mobile networks. Interference in wireless systems is one of the most significant factors that limit the network capacity and scalability of wireless mesh networks. Consideration of interference conditions during radio resource allocation and route formation processes impacts the design of concurrent transmission schemes with better spectral utilization while limiting the mutual interference.

A newly formed group within 802.16, the Mesh Ad Hoc committee, is investigating ways to improve the coverage of base stations even more. Mesh networking allows data to hop from point to point, circumventing obstacles such as hills. Only a small amount of meshing is required to see a large improvement in the coverage of a single base station. If this group's proposal is accepted, they will become Task Force F and develop an 802.16f standard.

In comparison to IEEE 802.11a/b/g based mesh network, the 802.16-based WiMax mesh provides various advantages apart from increased range and higher bandwidth. The TDMA based scheduling of channel access in WiMax-based multi-hop relay system provides fine granularity radio resource control.ThisTDMA based scheduling mechanism allows centralized slot allocation, which provides overall efficient resource utilization suitable for fixed wireless backhaul network. (The WiMax based mesh backhaul application differs from the 802.11a/b/gbased mesh, which targets mobile ad hoc networks.) However, the interference remains a major issue in multi hop WiMax mesh networks. To provide high spectral usage, an efficient algorithm for slot allocation is needed, so as to maximize the concurrent transmissions of data in the mesh. The level of interference depends upon how the data is routed in the WiMax network.

In IEEE 802.16 Mesh mode, a Mesh base station (BS) provides backhaul connectivity of the mesh network and controls one or more subscriber stations (SS). When centralized scheduling scheme is used, the Mesh BS is responsible for collecting bandwidth request from subscriber stations and for managing resource allocation. First will be introduced the 802.16 Mesh

network entry process (i.e., a process by which a new node joins the mesh), and then we describe the network resource allocation request/granting procedure.
In IEEE 802.16 Mesh mode, Mesh Network Configuration *(MSH-NCFG)* and Mesh Network Entry (MSH-NENT) messages are used for advertisement of the mesh network and for helping new nodes to synchronize and to joining the mesh network. Active nodes within the mesh periodically advertise MSH-NCFG messages with Network Descriptor, which outlines the basic network configuration information such as BS ID number and the base channel currently used. A new node that plans to join an active mesh network scans for active networks and listens to MSH-NCFG message. The new node establishes coarse synchronization and starts the network entry process based on the information given by MSH-NCFG. Among all possible neighbors that advertise MSH-NCFG, the joining node (which is called Candidate Node in the 802.16 Mesh mode terminology) selects a potential Sponsoring Node to connect to. A Mesh Network Entry message (MSH-NENT) with NetEntryRequest information is then sent by the Candidate Node to join the mesh.

The IEEE 802.16 Mesh mode MAC supports both centralized scheduling and distributed scheduling.
Centralized mesh scheme is used to establish high-speed broadband mesh connections, where the Mesh BS coordinates the radio resource allocation within the mesh network. In the centralized scheme, every Mesh SS estimates and sends its resource request to the Mesh BS, and the Mesh BS determined the amount of granted resources for each link and communicates. The request and grant process uses the Mesh Centralized Scheduling (MSH-CSCH) message type. A Subscriber Stations capacity requests are sent using the MSHCSCH:
Request message to the Subscriber Station's parent node. After the Mesh BS determines the resource allocation results, the MSH-CSCH:Grant is propagated along the route from Mesh BS. To disseminate the link, node, and scheduling tree configuration information to all participants within the mesh network, the Mesh Centralized Scheduling Configuration (MSH-CSCF) message is broadcasted by the Mesh BS and then re-broadcasted by intermediate nodes.

3. Inter-operability and QoS

WiMAX is a layer 1 (PHY or Physical layer) and layer 2 (MAC or Media Access Control layer) technology that does not define connectivity at the network layer, or layer 3. IEEE leaves 3rd parties to innovate and standardize at the higher layers. The result is that WiMAX is positioned to connect to a wide array of legacy systems, either the IP cores of wireline carriers, or the IP cores of wireless operators. In particular, IP Multimedia Subsystem, or IMS based cores based on 3GPP standards offer a clear opportunity to provide internetwork roaming, compatibility with 3G cellular, IPbased Quality of Service and common application while leveraging investments made in existing core networks. Connectivity at the IP layer also makes WiMAX a natural extension of other networks using Seamless Mobility.

4. Wireless Services

What this points out is that WiMAX actually can provide two forms of wireless service:

- There is the non-line-of-sight, WiFi sort of service, where a small antenna on subscriber computer connects to the tower. In this mode, WiMAX uses a lower frequency range -- 2 GHz to 11 GHz (similar to WiFi). Lower-wavelength transmissions are not as easily disrupted by physical obstructions -- they are better able to diffract, or bend, around obstacles.

- There is line-of-sight service, where a fixed dish antenna points straight at the WiMAX tower from a rooftop or pole. The line-of-sight connection is stronger and more stable, so it's able to send a lot of data with fewer errors. Line-of-sight transmissions use higher frequencies, with ranges reaching a possible 66 GHz. At higher frequencies, there is less interference and lots more bandwidth.

WiFi-style access will be limited to a 4-to-6 mile radius (perhaps 25 square miles or 65 square km of coverage, which is similar in range to a cell-phone zone). Through the stronger line-of-sight antennas, the WiMAX transmitting station would send data to WiMAX-enabled computers or routers set up within the transmitter's 30-mile radius (2,800 square miles or 9,300 square km of coverage). This is what allows WiMAX to achieve its maximum range. Below, at figure Figure 4., we can see how WiMAX works.

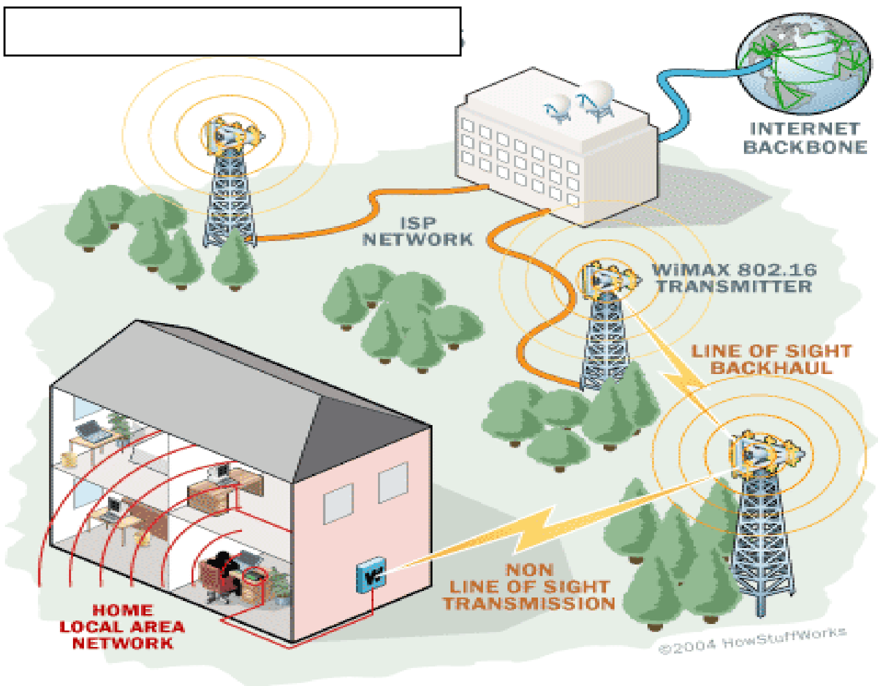

Figure 4. How WiMAX works

5. WiMAX Infrastructure

Typically, a WiMAX system consists of two parts:

- A WiMAX Base Station**:** Base station consists of indoor electronics and a WiMAX tower. Typically, a base station can cover up to 10 km radius (Theoretically, a base station can cover up to 50 kilo meter radius or 30 miles, however practical considerations limit it to about 10 km or 6 miles). Any wireless node within the coverage area would be able to access the Internet.

- A WiMAX receiver - The receiver and antenna could be a stand-alone box or a PC card that sits in your laptop or computer. Access to WiMAX base station is similar to accessing a Wireless Access Point in a WiFi network, but the coverage is more.

Several base stations can be connected with one another by use of high-speed backhaul microwave links. This would allow for roaming by a WiMAX subscriber from one base station to another base station area, similar to roaming enabled by Cellular phone companies.

Several topology and backhauling options are to be supported on the WiMAX base stations: wireline backhauling (typically over Ethernet), microwave Point-to-Point connection, as well as WiMAX backhaul. With the latter option, the base station has the capability to backhaul itself. This can be achieved by reserving part of the bandwidth normally used for the end-user traffic and using it for backhauling purposes. At Figure 5. we can see topologies of urban and rural areas in WIMAX deployment.

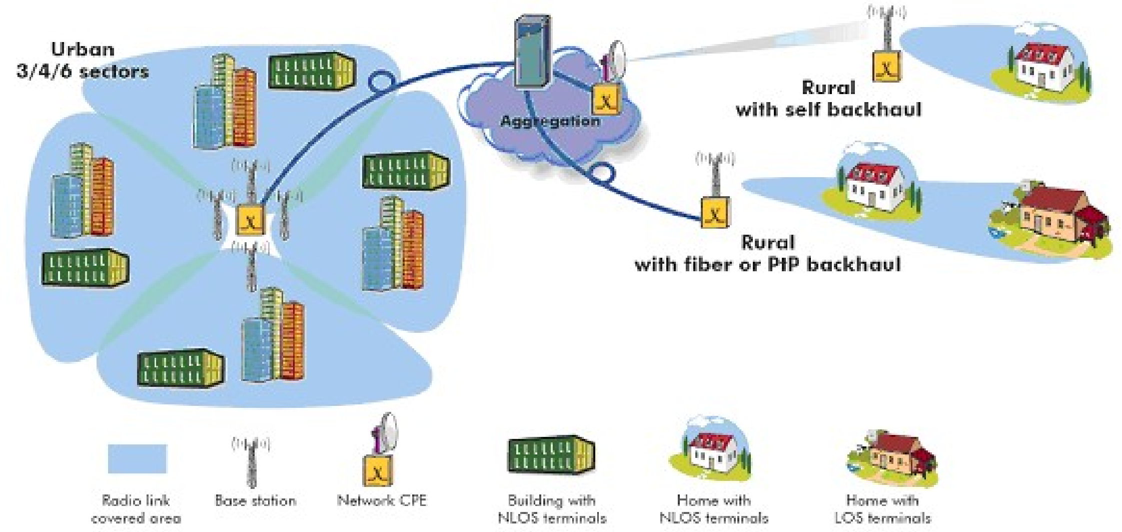

Figure 5. Topologies in urban and rural areas

6. WiMAX Network IP-Based Architecture

The network specifications for WiMAX-based systems are based on several basic network architecture tenets, including those listed below. Some general tenets have guided the development of Mobile WiMAX Network
Architecture and include the following:
- Provision of logical separation between such procedures and IP addressing, routing and connectivity management procedures and protocols to enable use of the access architecture primitives in standalone and interworking deployment scenarios,

- Support for sharing of ASN(s) (Access Service Networks) of a Network Access Provider (NAP) among multiple NSPs, - Support of a single NSP (Network Service Provider) providing service over multiple ASN(s) – managed by one or more NAPs,
- Support for the discovery and selection of accessible NSPs by an MS or SS,
- Support of NAPs that employ one or more ASN topologies,
- Support of access to incumbent operator services through internetworking functions as needed,
- Specification of open and well-defined reference points between various groups of network functional entities (within an ASN, between ASNs, between an ASN and a CSN (Connectivity Service Network) , and between CSNs), and in particular between an MS, ASN and CSN to enable multi-vendor interoperability,
- Support for evolution paths between the various usage models subject to reasonable technical assumptions and constraints,
- Enabling different vendor implementations based on different combinations of functional entities on physical network entities, as long as these implementations comply with the normative protocols and procedures across applicable reference points, as defined in the network specifications and
- Support for the most trivial scenario of a single operator deploying an ASN together with a limited set of CSN functions, so that the operator can offer basic Internet access service without consideration for roaming or interworking.
The WIMAX architecture also allows both IP and Ethernet services, in a standard mobile IP compliant network. The flexibility and interoperability supported by the WiMAX network provides operators with a multi-vendor low cost implementation of a WiMAX network even with a mixed deployment of distributed and centralized ASN's in the network.

The WiMAX network has the following major features:

- Security. The end-to-end WiMAX Network Architecture is based on a security framework that is agnostic to the operator type and ASN topology and applies consistently across Greenfield and internetworking deployment models and usage scenarios. In particular there is support for:
1. Strong mutual device authentication between an MS and the WiMAX network, based on the IEEE 802.16 security framework,
2. All commonly deployed authentication mechanisms and authentication in home and visited operator network scenarios based on a consistent and extensible authentication framework,
3. Data integrity, replay protection, confidentiality and non-repudiation using applicable key lengths,
4. Use of MS initiated/terminated security mechanisms such as Virtual Private Networks (VPNs),
5. Standard secure IP address management mechanisms between the MS/SS and its home or visited NSP.

- Mobility and Handovers. The end-to-end WiMAX Network Architecture has extensive capability to support mobility and handovers. It will:
1. Include vertical or inter-technology handovers— e.g., to Wi-Fi, 3GPP (The Third Generation Partnership Project) , 3GPP2, DSL, or MSO (Multiple Service Operators) – when such capability is enabled in multi-mode MS,
2. Support IPv4 (IP Version 4) or IPv6 based mobility management. Within this framework, and as applicable, the architecture shall accommodate MS with multiple IP addresses and simultaneous IPv4 and IPv6 connections,

3. Support roaming between NSPs,
4. Utilize mechanisms to support seamless handovers at up to vehicular speeds— satisfying welldefined (within WiMAX Forum) bounds of service disruption.
Some of the additional capabilities in support of mobility include the support of: i) Dynamic and static home address configurations, ii) Dynamic assignment of the Home Agent in the service provider network as a form of route optimization, as well as in the home IP network as a form of load balancing and iii) Dynamic assignment of the Home Agent based on policies.

- Scalability, Extensibility, Coverage and Operator Selection. The end-to-end WiMAX Network Architecture has extensive support for scalable, extensible operation and flexibility in operator selection. In particular, it will:
1. Enable a user to manually or automatically select from available NAPs and NSPs,
2. Enable ASN and CSN system designs that easily scale upward and downward – in terms of coverage, range or capacity,
3. Accommodate a variety of ASN topologies – including hub-and-spoke, hierarchical, and/or multi-hop interconnects,
4. Accommodate a variety of backhaul links, both wireline and wireless with different latency and throughput characteristics,
5. Support incremental infrastructure deployment,
6. Support phased introduction of IP services that in turn scale with increasing number of active users and concurrent IP services per user,
7. Support the integration of base stations of varying coverage and capacity - for example, pico, micro, and macro base stations and
8. Support flexible decomposition and integration of ASN functions in ASN network deployments in order to enable use of load balancing schemes for efficient use of radio spectrum and network resources.
Additional features pertaining to manageability and performance of WiMAX Network Architecture include:
- Support a variety of online and offline client provisioning, enrollment, and management schemes based on open, broadly deployable, IP-based, industry standards,
- Accommodation of Over-The-Air (OTA) services for MS terminal provisioning and software upgrades, and
- Accommodation of use of header compression/suppression and/or payload compression for efficient use of the WiMAX radio resources.

- Quality of Service. The WiMAX Network Architecuture has provisions for support of QoS mechanisms. In particular, it enables flexible support of simultaneous use of a diverse set of IP services. The architecture supports:
1. Differentiated levels of QoS - coarse-grained (per user/terminal) and/or fine-grained (per service flow per user/terminal),
2. Admission control, and
3. Bandwidth management
Extensive use is made of standard IETF mechanisms for managing policy definition and policy enforcement between operators.

7. End-to-End WiMAX Architecture

The IEEE only defined the Physical (PHY) and Media Access Control (MAC) layers in 802.16. This approach has worked well for technologies such as Ethernet and WiFi, which rely on other bodies such as the IETF (Internet Engineering Task Force) to set the standards for higher layer protocols such as TCP/IP, SIP, VoIP and IPSec. In the mobile wireless world, standards bodies such as 3GPP and 3GPP2 set standards over a wide range of interfaces and protocols because they require not only airlink interoperability, but also inter-vendor inter-network interoperability for roaming, multi-vendor access networks, and inter-company billing. Vendors and operators have recognized this issue, and have formed additional working groups to develop standard network reference models for open inter-network interfaces. Two of these are the WiMAX Forum's Network Working Group, which is focused on creating higher-level networking specifications for fixed, nomadic, portable and mobile WiMAX systems beyond what is defined in the IEEE 802.16 standard, and Service Provider Working Group which helps write requirements and prioritizes them to help drive the work of Network WG. The Mobile WiMAX End-to-End Network Architecture is based an All-IP platform, all packet technology with no legacy circuit telephony. It offers the advantage of reduced total cost of ownership during the lifecycle of a WiMAX network deployment. The use of All-IP means that a common network core can be used, without the need to maintain both packet and circuit core networks, with all the overhead that goes with it. A further benefit of All-IP is that it places the network on the performance growth curve of general processing advances occur much faster than advances in telecommunications equipment because general purpose hardware is not limited to telecommunications equipment cycles, which tend to be long and cumbersome. The end result is a network that continually performs at ever higher capital and operational efficiency, and takes advantage of 3rd party developments from the Internet community. This results in lower cost, high scalability, and rapid deployment since the networking functionality is all primarily software-based services. In order to deploy successful and operational commercial systems, there is need for support beyond 802.16 (PHY/MAC) air interface specifications. Chief among them is the need to support a core set of networking functions as part of the overall End-to-End WiMAX system architecture. Before delving into some of the details of the architecture, we can note a few basic tenets that have guided the WiMAX architecture development:

- The architecture is based on a packet-switched framework, including native procedures based on the IEEE 802.16 standard and its amendments, appropriate IETF RFCs and Ethernet standards.
- The architecture permits decoupling of access architecture (and supported topologies) from connectivity IP service. Network elements of the connectivity system are agnostic to the IEEE 802.16 radio specifics.
- The architecture allows modularity and flexibility to accommodate a broad range of deployment options such as:
  1. Small-scale to large-scale (sparse to dense radio coverage and capacity) WiMAX networks.
  2. Urban, suburban, and rural radio propagation environments
  3. Licensed and/or licensed-exempt frequency bands
  4. Hierarchical, flat, or mesh topologies, and their variants
  5. Co-existence of fixed, nomadic, portable and mobile usage models

Support for Services and Applications. The end-to-end architecture includes the support for:

- Voice, multimedia services and other mandated regulatory services such as emergency services and lawful interception,
- Access to a variety of independent Application Service Provider (ASP) networks in an agnostic manner,
- Mobile telephony communications using VoIP,

- Support interfacing with various interworking and media gateways permitting delivery of incumbent/legacy services translated over IP (for example, SMS over IP, MMS, WAP) to WiMAX access networks and
- Support delivery of IP Broadcast and Multicast services over WiMAX access networks.

Interworking and Roaming. Another key strength of the End-to-End Network Architecture with support for a number of deployment scenarios. In particular, there will be support of
- Loosely-coupled interworking with existing wireless networks such as 3GPP and 3GPP2 or existing wireline networks such as DSL, with the interworking interface(s) based on a standard IETF suite of protocols,
- Global roaming across WiMAX operator networks, including support for credential reuse, consistent use of AAA for accounting and billing, and consolidated/common billing and settlement,
- A variety of user authentication credential formats such as username/password, digital certificates, Subscriber Identify Module (SIM), Universal SIM (USIM), and Removable User Identify Module (RUIM).
WiMAX Forum industry participants have identified a WiMAX Network Reference Model (NRM) that is a logical representation of the network architecture. The NRM identifies functional entities and reference points over which interoperability is achieved between functional entities. The architecture has been developed with the objective of providing unified support of functionality needed in a range of network deployment models and usage scenarios (ranging from fixed – nomadic – portable – simple mobility –to fully mobile subscribers).

8. WiMax Protocol

An 802.16 wireless service provides a communications path between a subscriber site and a core network such as the public telephone network and the Internet. This wireless broadband access standard provides the missing link for the "last mile" connection in metropolitan area networks where DSL, Cable and other broadband access methods are not available or too expensive. The Wireless MAN technology is also branded as WiMAX. At Figure 8.1. we can see different parameters for technologies such as WiMAX, WLAN, and Bluetooth.

Parameters	**802.16 (WiMAX)**	**802.11 (WLAN)**	**802.15 (Bluetooth)**
Frequency Band:	2-11GHz	2.4GHz	Varies
Range	~31 miles	~100 meters	~10meters
Data transfer rate:	70 Mbps	11 Mbps – 55 Mbps	20Kbps – 55 Mbps
Number of users:	Thousands	Dozens	Dozens

Figure 8.1. WiMAX, WLAN, and Bluetooth parameters

IEEE 802.16 Protocol Architecture has 4 layers: Convergence, MAC, Trnamission and physical, which can be map to two OSI lowest layers: phusical and data link, as shown at Figure 8.2.

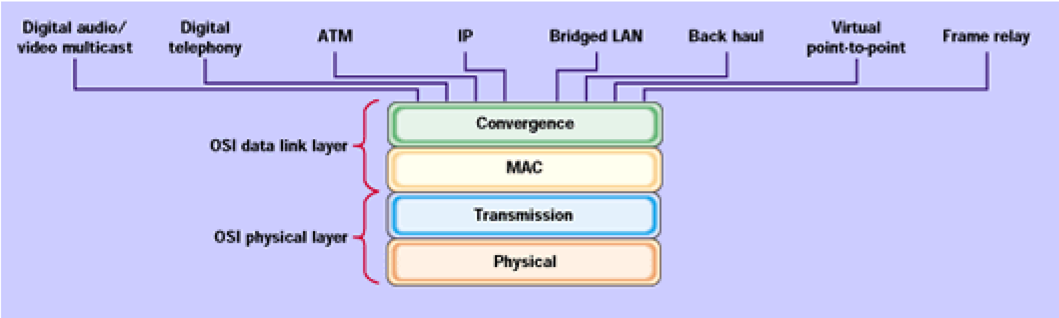

Figure 8.2. IEEE 802.16 Protocol Architecture

9. Mobile WiMax

9.1 Introduction

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 Air Interface Standard, has proven to be a costeffective fixed wireless alternative to cable and DSL services. In December, 2005 the IEEE ratified the 802.16e amendment to the 802.16 standard. This amendment adds the features and attributes to the standard that are 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 was completed in early 2006.
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 multi-path performance in non-line-of-sight environments. Scalable OFDMA (SOFDMA) 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, and 3.5 GHz frequency bands.

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. Some of the salient features supported by Mobile WiMAX are:

- **High Data Rates.** The inclusion of MIMO (Multiple Input Multiple Output) 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 DiffServ code points that enable end-to-end IP based QoS. Additionally, subchannelization 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.** Support for a diverse set of user credentials exists including; SIM/USIM cards, Smart Cards, Digital Certificates, and Username/Password schemes.
- **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.

9.2. Physical Layer Description

WiMAX must be able to provide a reliable service over long distances to customers using indoor terminals or PC cards (like today's WLAN cards). These requirements, with limited transmit power to comply with health requirements, will limit the link budget. Subchannelling in uplink and smart antennas at the base station has to overcome these constraints. The WiMAX system relies on a new radio physical (PHY) layer and appropriate MAC (Media Acess Controller) layer to support all demands driven by the target applications.

The PHY layer modulation is based on OFDMA, in combination with a centralized MAC layer for optimized resource allocation and support of QoS for different types of services (VoIP, real-time and non real-time services, best effort). The OFDMA PHY layer is well adapted to the NLOS propagation environment in the 2 - 11 GHz frequency range. It is inherently robust when it comes to handling the significant delay spread caused by the typical NLOS reflections. Together with adaptive modulation, which is applied to each subscriber individually according to the radio channel capability, OFDMA can provide a high spectral efficiency of about 3 - 4 bit/s/Hz. However, in contrast to single carrier modulation, the OFDMA signal has an increased peak: average ratio and increased frequency accuracy requirements. Therefore, selection of appropriate power amplifiers and frequency recovery concepts are crucial. WiMAX provides flexibility in terms of channelization, carrier frequency, and duplex mode (TDD and FDD) to meet a variety of requirements for available spectrum resources and targeted services.

9.3. OFDMA Basics

Orthogonal Frequency Division Multiplexing (OFDM) is a multiplexing technique that subdivides the bandwidth into multiple frequency sub-carriers as shown in Figure 9.3.1. 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 9.3.2. 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.

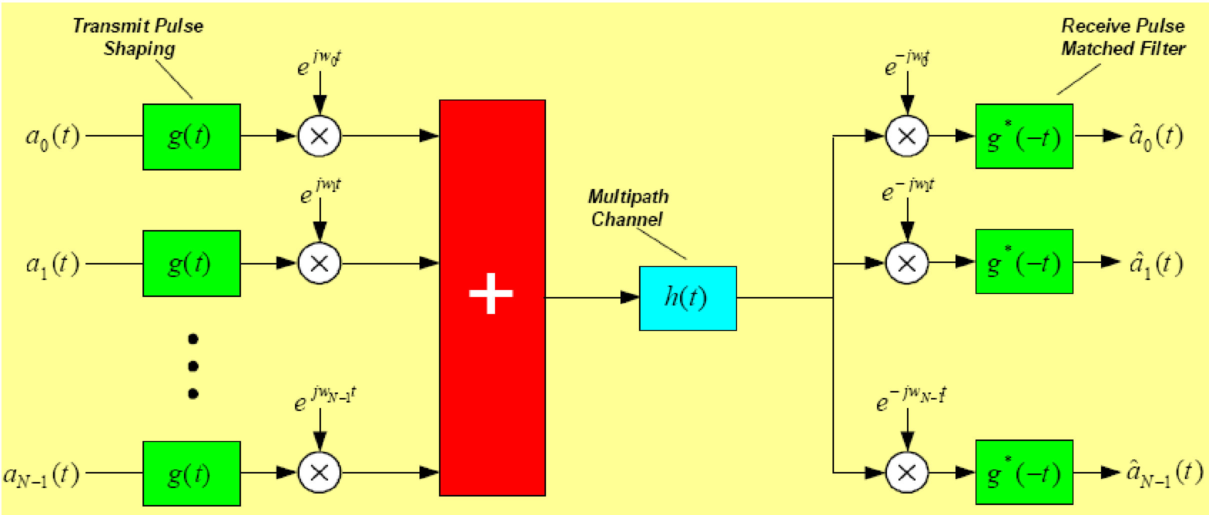

Figure 9.3.1. Basic Architecture of an OFDM System

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.

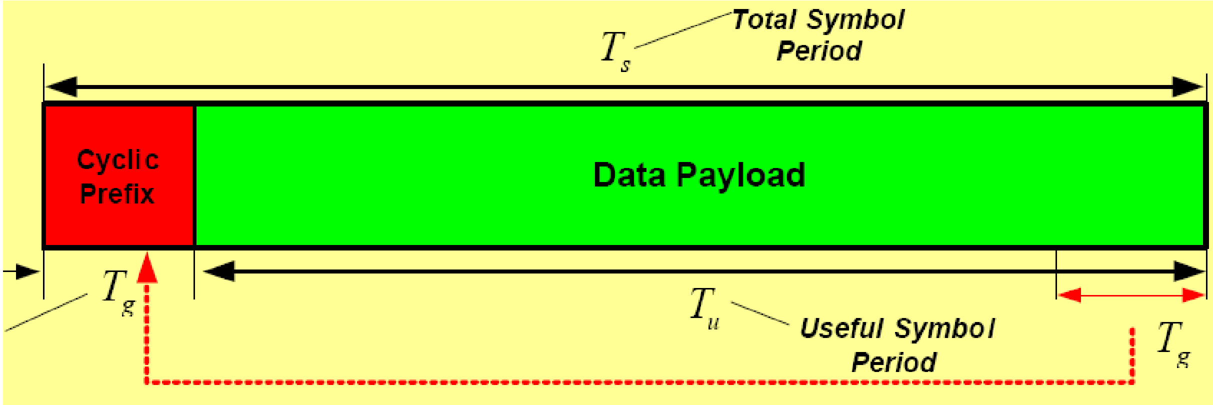

Figure 9.3.2. Insertion of Cyclic Prefix (CP)

9.4. TDD Frame Structure

The 802.16e PHY supports TDD, FDD, and Half-Duplex FDD operation; however the initial release of Mobile WiMAX certification profiles will only include TDD. With ongoing releases, FDD profiles will be considered by the WiMAX Forum to address specific market opportunities where local spectrum regulatory requirements either prohibit TDD or are more suitable for FDD deployments. To counter interference issues, TDD does require system-wide synchronization; nevertheless, TDD is the preferred duplexing mode for the following reasons:
- TDD enables adjustment of the downlink/uplink ratio to efficiently support asymmetric downlink/uplink traffic, while with FDD, downlink and uplink always have fixed and generally, equal DL and UL bandwidths.
- TDD assures channel reciprocity for better support of link adaptation, MIMO and other closed loop advanced antenna technologies.
- Unlike FDD, which requires a pair of channels, TDD only requires a single channel for both downlink and uplink providing greater flexibility for adaptation to varied global spectrum allocations.
- Transceiver designs for TDD implementations are less complex and therefore less expensive.

9.5. MAC Layer Description

The 802.16 standard was developed from the outset for the delivery of broadband services including voice, data, and video. The MAC layer is based on the time-proven DOCSIS standard and can support bursty data traffic with high peak rate demand while simultaneously supporting streaming video and latency-sensitive voice traffic over the same channel. The resource allocated to one terminal by the MAC scheduler can vary from a single time slot to the entire frame, thus providing a very large dynamic range of throughput to a specific user terminal at any given time. Furthermore, since the resource allocation information is conveyed in the MAP messages at the beginning of each frame, the scheduler can effectively change the resource allocation on a frame-by-frame basis to adapt to the bursty nature of the traffic.
Every wireless network operates fundamentally in a shared medium and as such that requires a mechanism for controlling access by subscriber units to the medium. The 802.16a standard

uses a slotted TDMA protocol scheduled by the BTS to allocate capacity to subscribers in a point-to-multipoint network topology. While this on the surface sounds like a one line, technical throwaway statement, it has a huge impact on how the system operates and what services it can deploy. By starting with a TDMA approach with intelligent scheduling, WiMAX systems will be able to deliver not only high speed data with SLAs, but latency sensitive services such as voice and video or database access are also supported. The standard delivers QoS beyond mere prioritization, a technique that is very limited in effectiveness as traffic load and the number of subscribers increases. The MAC layer in WiMAX certified systems has also been designed to address the harsh physical layer environment where interference, fast fading and other phenomena are prevalent in outdoor operation. We can see major 802.16a MAC features at Figure 9.5.

Feature	Benefit
TDM/TDMA Scheduled Uplink/Downlink frames.	• Efficient bandwidth usage
Scalable from 1 to hundreds of subscribers	• Allows cost effective deployments by supporting enough subs to deliver a robust business case
Connection-oriented	• Per Connection QoS • Faster packet routing and forwarding
QoS supportContinuous GrantReal Time Variable Bit RateNon Real Time Variable Bit RateBest Effort	• Low latency for delay sensitive services (TDM Voice, VoIP) • Optimal transport for VBR traffic(e.g., video)· Data prioritization
Automatic Retransmission request (ARQ)	• Improves end-to-end performance by hiding RF layer induced errors from upper layer protocols
Support for adaptive modulation	• Enables highest data rates allowed by channel conditions, improving system capacity
Security and encryption (Triple DES)	• Protects user privacy
Automatic Power control	• Enables cellular deployments by minimizing self interference

Figure 9.5. 802.16a MAC Features

9.6. QoS Support

With fast air link, symmetric downlink/uplink capacity, fine resource granularity and a flexible resource allocation mechanism, Mobile WiMAX can meet QoS requirements for a wide range of data services and applications.

In the Mobile WiMAX MAC layer, QoS is provided via service flows as illustrated in Figure 9.6 This is a unidirectional flow of packets that is provided with a particular set of QoS parameters. Before providing a certain type of data service, the base station and user-terminal first establish a unidirectional logical link between the peer MACs called a connection. The outbound MAC then associates packets traversing the MAC interface into a service flow to be delivered over the connection. The QoS parameters associated with the service flow define the transmission ordering and scheduling on the air interface. The connection-oriented QoS therefore, can provide accurate control over the air interface. Since the air interface is usually the bottleneck, the connection-oriented QoS can effectively enable the end-to-end QoS control. The service flow parameters can be dynamically managed through MAC messages to accommodate the dynamic service demand. The service flow based QoS mechanism applies to both DL and UL to provide improved QoS in both directions.

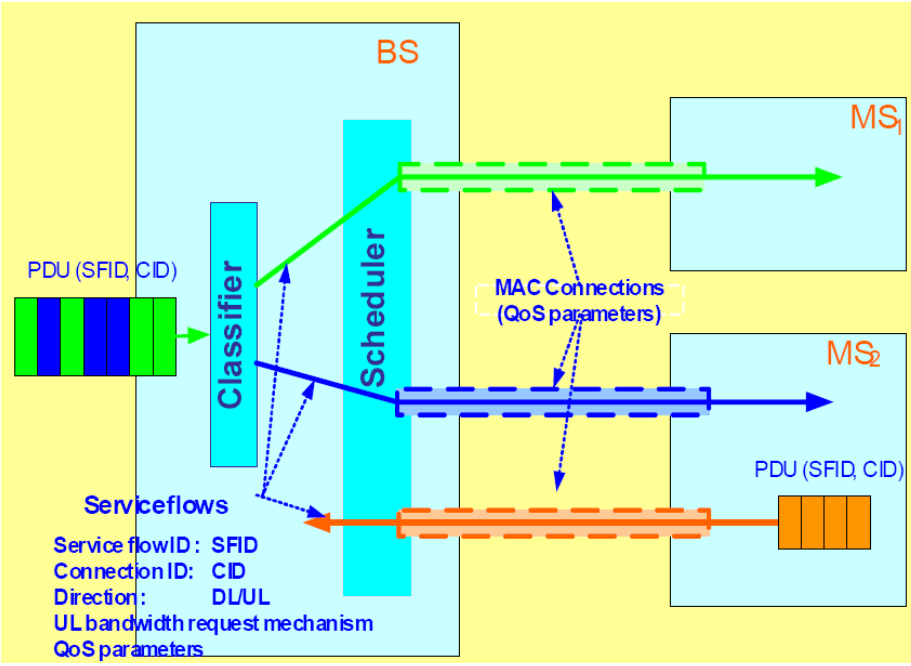

Figure 9.6 Mobile WiMAX QoS Support

9.7. Mobility Management

Battery life and handoff are two critical issues for mobile applications. Mobile WiMAX supports Sleep Mode and Idle Mode to enable power-efficient MS operation. Mobile WiMAX also supports seamless handoff to enable the MS to switch from one base station to another at vehicular speeds without interrupting the connection.

- Power Management. Mobile WiMAX supports two modes for power efficient operation Sleep Mode and Idle Mode. Sleep Mode is a state in which the MS conducts pre-negotiated periods of absence from the Serving Base Station air interface. These periods are characterized by the unavailability of the MS, as observed from the Serving Base Station, to DL or UL traffic.
Sleep Mode is intended to minimize MS power usage and minimize the usage of the Serving Base Station air interface resources. The Sleep Mode also provides flexibility for the MS to scan other base stations to collect information to assist handoff during the Sleep Mode.
Idle Mode provides a mechanism for the MS to become periodically available for DL broadcast traffic messaging without registration at a specific base station as the MS traverses an air link environment populated by multiple base stations. Idle Mode benefits the MS by removing the requirement for handoff and other normal operations and benefits the network and base station by eliminating air interface and network handoff traffic from essentially inactive MSs while still providing a simple and timely method (paging) for alerting the MS about pending DL traffic.

- Handoff. The IEEE 802 Handoff Study Group, is another group chartered with addressing roaming that studies hand-offs between heterogeneous 802 networks. The key here will be enabling the “hand-off” procedures that allow a mobile device to switch the connection from one base station to another, from one 802 network type to another (such as from 802.11b to 802.16), and even from wired to 802.11 or 802.16 connections. The goal is to standardize the hand-off so devices are interoperable as they move from one network type to another.

Today, 802.11 users can move around a building or a hotspot and stay connected, but if they leave, they lose their connection. With 802.16e, users will be able to stay “best connected”—connected by 802.11 when they’re within a hot spot, and then connected to 802.16 when they leave the hot spot but are within a WiMAX service area. Furthermore, having a standard in place opens the door to volume component suppliers that will allow equipment vendors to focus on system design, versus having to develop the whole end-to-end solution. When having either 802.16e capabilities embedded in a PDA or notebook (or added through an 802.16e-enabled card) user remain connected within an entire metropolitan area. For example, a notebook could connect via Ethernet or 802.11 when docked, and stay connected with 802.16 when roaming the city or suburbs.

There are three handoff methods supported within the 802.16e standard – Hard Handoff (HHO), Fast Base Station Switching (FBSS) and Macro Diversity Handover (MDHO). Of these, the HHO is mandatory while FBSS and MDHO are two optional modes. The WiMAX Forum has developed several techniques for optimizing hard handoff within the framework of the 802.16e standard. These improvements have been developed with the goal of keeping Layer 2 handoff delays to less than 50 milliseconds.

9.8. Security

Mobile WiMAX supports best in class security features by adopting the best technologies available today. Support exists for mutual device/user authentication, flexible key management protocol, strong traffic encryption, control and management plane message protection and security protocol optimizations for fast handovers. The usage aspects of the security features are:

- **Key Management Protocol.** Privacy and Key Management Protocol Version 2 (PKMv2) is the basis of Mobile WiMAX security as defined in 802.16e. This protocol manages the MAC security using Traffic Encryption Control, Handover Key Exchange and Multicast/Broadcast security messages all are based on this protocol.
- **Device/User Authentication.** Mobile WiMAX supports Device and User Authentication using IETF EAP (Internet Engineering Task Force Extensible Authentication Protocol) by providing support for credentials that are SIM-based, USIM-based or Digital Certificate or UserName/Password-based.
- **Traffic Encryption.** Cipher used techniques for protecting all the user data over the Mobile WiMAX MAC interface. The keys used for driving the cipher are generated from the EAP authentication. A Traffic Encryption State machine that has a periodic key (TEK) refresh mechanism enables sustained transition of keys to further improve protection.
- **Fast Handover Support:** A 3-way Handshake scheme is supported by Mobile WiMAX to optimize the re-authentication mechanisms for supporting fast handovers. This mechanism is also useful to prevent any man-in-the-middle-attacks.

10. Advanced Features of WiMAX

An important and very challenging function of the WiMAX system is the support of various advanced antenna techniques, which are essential to provide high spectral efficiency, capacity, system performance, and reliability:

- Beam forming using smart antennas provides additional gain to bridge long distances or to increase indoor coverage; it reduces inter-cell interference and improves frequency reuse,
- Transmit diversity and MIMO techniques using multiple antennas take advantage of multipath reflections to improve reliability and capacity.

10.1. Smart Antenna Technologies

Smart antenna technologies typically involve complex vector or matrix operations on signals due to multiple antennas. OFDMA allows smart antenna operations to be performed on vector-flat sub-carriers. Complex equalizers are not required to compensate for frequency selective fading. OFDMA therefore, is very well-suited to support smart antenna technologies. In fact, MIMO-OFDM/OFDMA is envisioned as the corner-stone for next generation broadband communication systems. Mobile WiMAX supports a full range of smart antenna technologies to enhance system performance. The smart antenna technologies supported include:
- **Beamforming.** With beamforming, the system uses multiple-antennas to transmit weighted signals to improve coverage and capacity of the system and reduce outage probability.
- **Space-Time Code (STC).** Transmit diversity such as Alamouti code is supported to provide spatial diversity and reduce fade margin.
- **Spatial Multiplexing (SM).** Spatial multiplexing is supported to take advantage of higher peak rates and increased throughput. With spatial multiplexing, multiple streams are transmitted over multiple antennas. If the receiver also has multiple antennas, it can separate the different streams to achieve higher throughput compared to single antenna systems. With 2x2 MIMO, SM increases the peak data rate two-fold by transmitting two data streams. In UL, each user has only one transmit antenna, two users can transmit collaboratively in the same slot as if two streams are spatially multiplexed from two antennas of the same user. This is called UL collaborative SM.

10.2. Fractional Frequency Reuse

WiMAX supports frequency reuse of one, i.e. all cells/sectors operate on the same frequency channel to maximize spectral efficiency. However, due to heavy cochannel interference (CCI) in frequency reuse one deployment, users at the cell edge may suffer degradation in connection quality. Users can operate on subchannels, which only occupy a small fraction of the whole channel bandwidth; the cell edge interference problem can be easily addressed by appropriately configuring subchannel usage without resorting to traditional frequency planning.
The flexible sub-channel reuse is facilitated by sub-channel segmentation and permutation zone. A segment is a subdivision of the available OFDMA sub-channels (one segment may include all sub-channels). One segment is used for deploying a single instance of MAC.
Permutation Zone is a number of contiguous OFDMA symbols in DL or UL that use the same permutation. The DL or UL sub-frame may contain more than one permutation zone as shown in the following figure.
In Figure 10.2, F1, F2, and F3 represent different sets of sub-channels in the same frequency channel. With this configuration, the full load frequency reuse one is maintained for center users to maximize spectral efficiency and fractional frequency reuse is implemented for edge users to assure edge-user connection quality and throughput. The sub-channel reuse planning can be dynamically optimized across sectors or cells based on network load and interference

conditions on a frame by frame basis. All the cells and sectors therefore, can operate on the same frequency channel without the need for frequency planning.

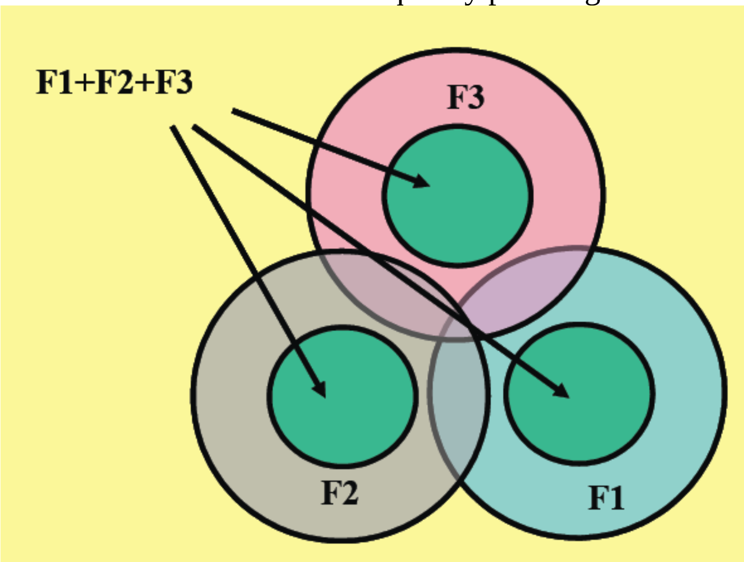

Figure 10.2. Fractional Frequency Reuse

10.3. Multicast and Broadcast Service (MBS)

Multicast and Broadcast Service (MBS) supported by WiMAX satisfies the following requirements:
- High data rate and coverage using a Single Frequency Network (SFN)
- Flexible allocation of radio resources
- Low MS power consumption
- Support of data-casting in addition to audio and video streams
- Low channel switching time

The WiMAX Release-1 profile defines a toolbox for initial MBS service delivery. The MBS service can be supported by either constructing a separate MBS zone in the DL frame along with unicast service (embedded MBS) or the whole frame can be dedicated to MBS (DL only) for standalone broadcast service.

11. Markets for WiMax

Broadband Wireless Access (BWA) has been serving enterprises and operators for years, to the great satisfaction of its users. However, the new IP-based standard developed by the IEEE 802.16 is likely to accelerate adoption of the technology. It will expand the scope of usage thanks to: the possibility of operating in licensed and unlicensed frequency bands, unique performance under Non-Line-of-Sight (NLOS) conditions, Quality of Service (QoS) awareness, extension to nomadicity, and more.

In parallel, the WiMAX forum, backed by industry leaders, will encourage the widespread adoption of broadband wireless access by establishing a brand for the technology and pushing interoperability between products.

A wireless MAN based on the WiMAX air interface standard is configured in much the same way as a traditional cellular network with strategically located base stations using a point-to-multipoint architecture to deliver services over a radius up to several kilometers depending on frequency, transmit power and receiver sensitivity. In areas with high population densities the range will generally be capacity limited rather than range limited due to limitation in the amount of available spectrum. The base stations are typically backhauled to the core network by means of fiber or point-to-point microwave links to available fiber nodes or via leased lines from an incumbent wire-line operator. The range and NLOS capability makes the technology equally attractive and cost-effective in a wide variety of environments. The technology was envisioned from the beginning as a means to provide wireless “last mile” broadband access in the Metropolitan Area Network (MAN) with performance and services comparable to or better than traditional DSL, Cable or T1/E1 leased line services. The market segments, as shown at Figure 11.1. are:

- **Residential and SOHO High Speed Internet Access.** The main contenders for residential and SOHO market are the DSL, and Cable Internet technologies. These technologies have already established a market presence, and have proven track record in meeting the demands of the residential and SOHO customers. WiMAX provides an alternative to existing access methods, where it is not feasible to use DSL or Cable Internet. Typical application will be in remote areas where it is not economically feasible to have a DSL or Cable Internet. WiMAX is also expected to be more reliable due to wireless nature of communication between the customer premises and the base station. This is particularly useful in developing countries where the reliability and quality of land-line communications infrastructure is often poor.

Today, this market segment is primarily dependent on the availability of DSL or cable. In some areas the available services may not meet customer expectations for performance or reliability and/or are too expensive. In many rural areas residential customers are limited to low speed dial-up services. In developing countries there are many regions with no available means for internet access. The analysis will show that the WiMAX technology will enable an operator to economically address this market segment and have a winning business case under a variety of demographic conditions.

- **Small and Medium Business**. The WiMAX BWA is well suited to provide the reliability and speed for meeting the requirements of small and medium size businesses in low density environments. One disadvantage of WiMAX is the spectral limitation, in other words limitation of wireless bandwidth. For use in high density areas, it is possible that the bandwidth may not be sufficient to cater to the needs of a large clientele, driving the costs high.
This market segment is very often underserved in areas other than the highly competitive urban environments. The WiMAX technology can cost-effectively meet the requirements of small and medium size businesses in low density environments and can also provide a cost-effective alternative in urban areas competing with DSL and leased line services.

- **WiFi Hot Spot Backhaul.** Another area where WiMAX connectivity is for WiFi hot spots connectivity. As of now, there have been several WiFi hotspots and a WiMAX backhaul provides full wireless solution to these wireless networks.

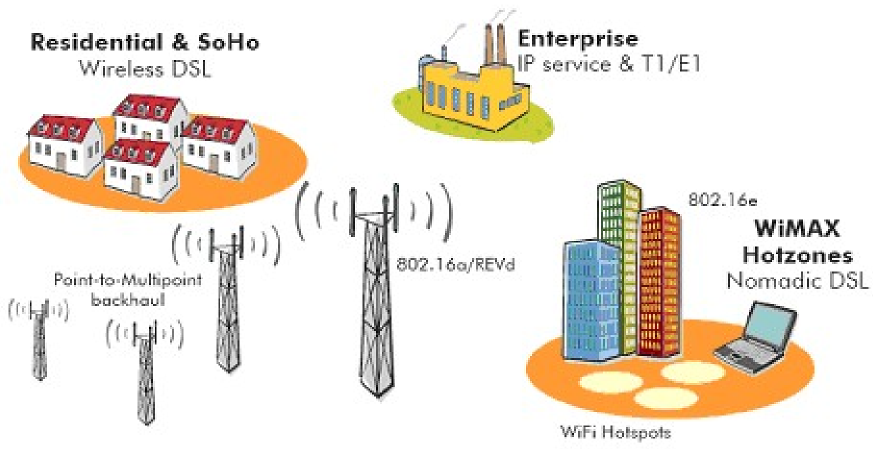

Figure 11.1. Markets for WiMAX

WiFi hot spots are being installed worldwide at a rapid pace. One of the obstacles for continued hot spot growth however, is the availability of high capacity, cost-effective backhaul solutions. This application can also be addressed with the WiMAX technology. And with nomadic capability, WiMAX can also fill in the coverage gaps between WiFi hot spot coverage areas. The WiMAX architecture and applications are illustrated in Figure 11.2.

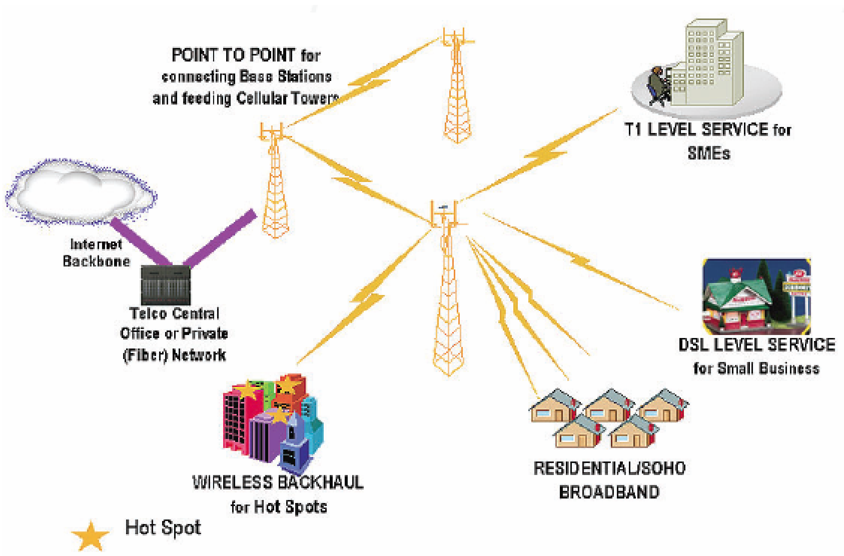

Figure 11.2. The WiMAX Wireless Architecture

12. Current Status of WiMAX

With many technologies, there is a tendency for expectations initially to far exceed the achievable reality. The "Gartner Hype Cycle for Wireless Networking, 2004" (Figure 12.) shows WiMAX technology at the "Peak of Inflated Expectations," with the "Plateau of Productivity" expected in the "two to five years" time frame.

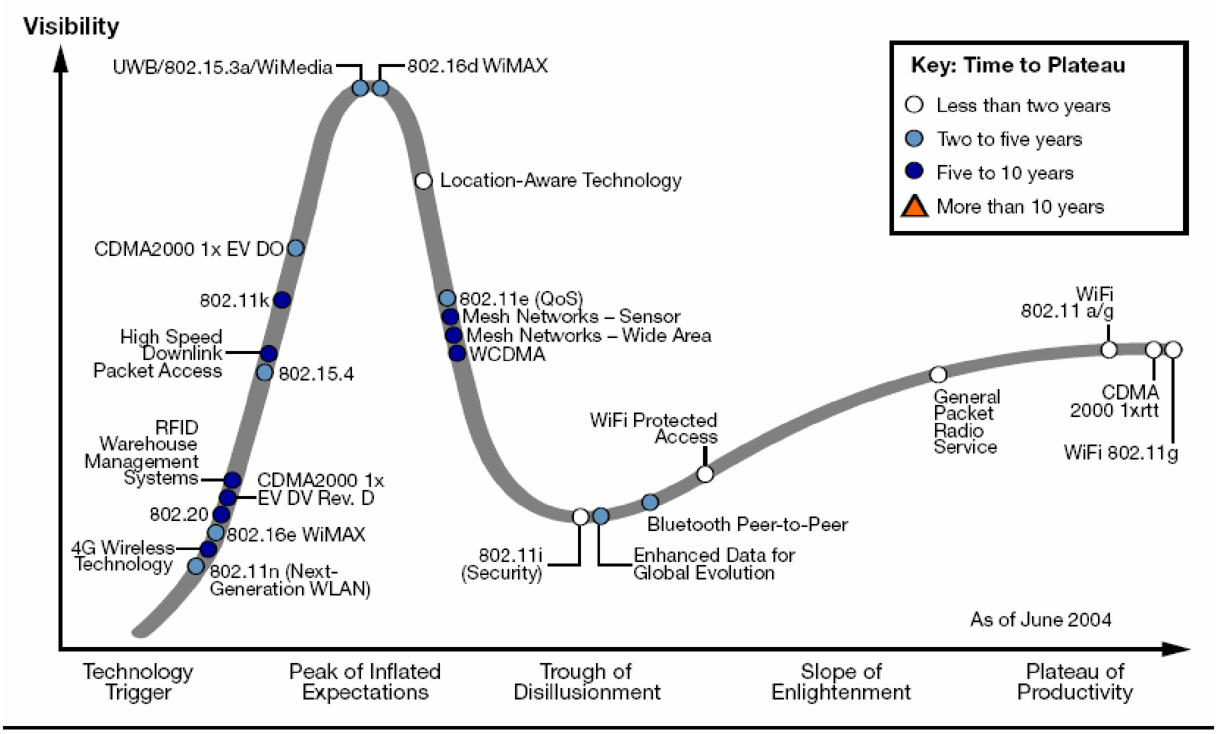

Figure 12. Gartner Hype Cycle for Wireless Networking, 2004

13. The WiMAX Scenario

Here's what would happen if you got WiMAX. An Internet service provider sets up a WiMAX base station 10 miles from your home. You would buy a WiMAX-enabled computer or upgrade your old computer to add WiMAX capability. You would receive a special encryption code that would give you access to the base station. The base station would beam data from the Internet to your computer (at speeds potentially higher than today's cable modems), for which you would pay the provider a monthly fee. The cost for this service could be much lower than current high-speed Internet-subscription fees because the provider never had to run cables.

Network scale. The smallest-scale network is a personal area network (PAN). A PAN allows devices to communicate with each other over short distances. Bluetooth is the best example of a PAN. The next step up is a local area network (LAN). A LAN allows devices to share information, but is limited to a fairly small central area, such as a company's headquarters, a coffee shop or your house. Many LANs use WiFi to connect the network wirelessly. WiMAX is the wireless solution for the next step up in scale, the metropolitan area network (MAN), as shown at Figure 13. A MAN allows areas the size of cities to be connected.

(MAN) Metropolitan Area Network	IEEE 802.16	Connects devices up to an approx. 30-mile radius
(LAN) Local Area Network	IEEE 802.11	Connects devices up to an approx. 300-foot radius
(PAN) Personal Area Network	IEEE 802.15	Connects devices up to an approx. 33-foot radius

Figure 13. WiMAX Network scale

The WiMAX protocol is designed to accommodate several different methods of data transmission, one of which is Voice Over Internet Protocol (VoIP). VoIP allows people to make local, long-distance and even international calls through a broadband Internet connection, bypassing phone companies entirely. If WiMAX-compatible computers become very common, the use of VoIP could increase dramatically. Almost anyone with a laptop could make VoIP calls.

14. Conclusion

WiMAX offers benefits for wireline operators who want to provide last mile access to residences and businesses, either to reduce costs in their own operating areas, or as a way to enter new markets. 802.16e offers cost reductions to mobile operators who wish to offer broadband IP services in addition to 2G or 3G voice service, and allows operators to enter new markets with competitive services, despite owning disadvantaged spectrum. The capital outlay for WiMAX equipment will be less than for traditional 2G and 3G wireless networks, although the supporting infrastructure of cell sites, civil works, towers and so on will still be needed. WiMAX's all-IP architecture lends itself well to high bandwidth multi-media applications, and with QoS will also support mobile voice and messaging services, re-using the mobile networks IP core systems.
The latest developments in the IEEE 802.16 group are driving a broadband wireless access (r)evolution thanks to a standard with unique technical characteristics. In parallel, the WiMAX forum, backed by industry leaders, helps the widespread adoption of broadband wireless access by establishing a brand for the technology. Initially, WiMAX will bridge the digital divide and thanks to competitive equipment prices, the scope of WiMAX deployment will broaden to cover markets with high DSL unbundling costs or poor copper quality wich have acted as a brake on extensive high-speed Internet and voice over broadband. WiMAX will reach its peak by making Portable Internet a reality. When WiMAX chipsets are integrated into laptops and other portable devices, it will provide high-speed data services on the move, extending today's limited coverage of public WLAN to metropolitan areas. Integrated into new generation networks with seamless roaming between various accesses, it will enable endusers to enjoy an "Always Best Connected" experience. The combination of these capabilities makes WiMAX attractive for a wide diversity of people: fixed operators, mobile operators and wireless ISPs (Internet Service Provider), but also for many vertical markets and local authorities. Alcatel, the worldwide broadband market leader with a market share in excess of 37%, is committed to offer complete support across the entire investment and operational cycle required for successful deployment of WiMAX services.

Glossary:

3G (third generation): Radio technology for wireless networks, telephones and other devices. Narrowband digital radio is the second generation of mobile wireless technology.
3GPP: The 3rd Generation Partnership Project. Standardizes evolution from the GSM network standards.
ADSL: Asynchronous DSL
ADSL2+: Ultra high speed ADSL
ARQ: Automatic Repeat Request. In case of errors in a transmitted packet or a nonreceived packet retransmission will occur.
ATM: Asynchronous Transfer Mode
BRAS: Broadband Remote Access Server
BS: Base Station
BWA: Broadband Wireless Access. Enabling high-speed broadband connections over the air instead of over wired (fixed) connections
CDMA: Code Division Multiple Access
Consumers: Private users, subscribers
CPE: Customer Premises Equipment
DHCP: DynamicT THostT TConfigurationT TProtocol
DSL: Digital Subscriber Line
DSLAM: DSL Access Multiplexer
EIRP: EffectiveT TIsotropicT TRadiatedT TPowerT T
ETSI: European Telecommunications Standards Institute
EUL:T TEnhancedT TUpT TLink,T TsameT TasT THSUPA
FDD: Frequency Division Duplex
GPRS: General Packet Radio Service
GSM: Global System for Mobile communication
HSPA: High Speed Packet Access, refers to both downlink (HSDPA) and uplink (EUL/HSUPA)
HSDPA: High Speed Downlink Packet Access
HSUPA: High Speed Uplink Packet Access, same as EUL
IEEE: Institution for Electrical and Electronics Engineers. Standardization body.
IMT-2000: International Mobile Telecommunications-2000 (IMT-2000) is the global standard for third generation (3G) wireless communications, defined by a set of interdependent ITU Recommendations.
IMS: IP Multimedia Subsystem
IP: Internet Protocol
ITU: International Telecommunication Union.
LOS: Line-Of-Sight
MAC: Medium Access Control
MAN: Metropolitan Area Network
MTBF: Mean Time Between Failure
NAT: Network Address Translation. Used to expand the addressing capabilities of IPv4.
NLOS: Non-Line-Of-Sight
OFDM: Orthogonal Frequency Division Multiplexing
PDA: Personal Digital Assistant
PHY: Physical Layer
Prosumers: Professionals and enterprise users/subscribers
PSTN: PublicT TSwitchedT TTelephoneT TNetwork
QoS: Quality of Service

RF: Radio Frequency
SGSN: Serving GPRS Support Node
SIP: Simple Internet Protocol
SME: Small and Medium size Enterprises
SoHo: Small Office Home Office
SS: Subscriber Station
STC: Space-Time Codes
TCO: Total Cost of Ownership
TDD: Time Division Duplex
TDM: TimeT TDivisionT TMultiplexing
TDMA: Time-Division Multiple Access
Users: Consumers, prosumers, end-users and subscribers
VDSL: Very high bitrate DSL
VoIP: Voice over Internet Protocol technology enables users to transmit voice calls via the Internet using packet-linked routes.
WCDMA: Wideband Code Division Multiple Access
WiFi: Wireless Fidelity, or Wireless Local Area Network, WLAN
WiMAX: World-wide interoperability for Microwave Access
WISP: Wireless Internet Service Provider

References:

(1) Interference-Aware IEEE 802.16 WiMax Mesh Networks,
Hung-Yu Wei, Samrat Ganguly, Rauf Izmailov, Zygmunt J. Haas
http://people.ece.cornell.edu/haas/wnl/Publications/vtc05.pdf

(2) The Promise of WiMAX Broadband Access to the Last Mile
http://www.motorola.com/networkoperators/pdfs/Wi4-the-promise-article.pdf

(3) WiMAX, making ubiquitous high-speed data services a reality
http://www.alcatel.com/com/en/appcontent/apl/S0406-WiMAX-EN_tcm172-44791635.pdf

(4) Overview of WiMAX, Telecommunications Standards Advisory Committee
http://www.ofta.gov.hk/en/ad-comm/tsac/ts-paper/ts2004p12.pdf

(5) IEEE 802.16* WirelessMAN* Specification Accelerates Wireless Broadband Access
http://www.intel.com/technology/magazine/standards/st08031.pdf

(6) Technology in Capsules
http://techcapsules.blogspot.com/2005/08/wi-max.html?gclid=CI_Fnr6Z8IQCFSJqEQod8TYzxw

(7) http://computer.howstuffworks.com/wimax.htm/printable

(8) http://www.tutorialsweb.com/wimax/wimax.htm#What%20is%20WiMAX

(9) http://www.wimaxxed.com/wimaxxed_news/wimax_broadba.html

(10) http://computer.howstuffworks.com/wimax1.htm

(11) http://www.wimaxforum.org/news/downloads/WiMAX-The_Business_Case-Rev3.pdf

(12) Business Case Models for Fixed Broadband Wireless Access based on WiMAX Technology and the 802.16 Standard, October 10, 2004

(13) WiMAX: The Next Big Step in Wireless Broadband? A Technical and Regulatory Overview

(14) Mobile WiMAX – Part I: A Technical Overview and Performance Evaluation
Prepared on Behalf of the WiMAX Forum, March, 2006

(15) WiMAX, making ubiquitous high-speed data services a reality, Alcatel

(16) Technology@Intel Magazine, IEEE 802.16* WirelessMAN* Specification Accelerates Wireless, Broadband Access, D.J. Johnston, Intel Corporation

(17) WiMAX Overview, White Paper and MCI Perspective

(18) IEEE 802.16a Standard and WiMAX, Igniting Broadband Wireless Access, White Paper

(19) IEEE, http://grouper.ieee.org/groups/802/16/published.html

(20) INTEL, http://www.intel.com/ebusiness/pdf/wireless/intel/80216_wimax.pdf: