Net Business Community

The Next Wireless Wave: Exploring WiMax Technology

Carl Wu

April 2006

Abstract

Limited bandwidth, distance, and, more importantly, lack of security and QoS capabilities have confined the use of Wi-Fi networking to residences, small businesses, and areas such as airport lounges and Starbucks. WiMAX technology, IEEE 802.16, overcomes the limitations of Wi-Fi; it can transmit up to 75 Mbps and reach a maximum distance of 30 miles. IEEE standards 802.16-2004, for fixed wireless, and 802.16e, for mobile wireless, were ratified in 2004-2005. Interoperable products are now available from many vendors. With superior capabilities and business-critical features including QoS and security, WiMAX technology is expected to complement Wi-Fi as a backhaul application and/or serve as a standalone wireless application.

Table of Contents

List of Figures

1. What is WiMAX?

WiMAX is an emerging standard to provide wireless broadband access for point-to-point and point-to-multipoint applications. WiMAX can transmit data up to 75 Mbps and serve up to 30 miles in radius. Its extended distance and data capacity make the technology an ideal alternative for providing last mile access, interconnection of Wi-Fi hot spots, and wireless connectivity for digital subscriber line (DSL) and cable modem service delivery in rural areas. WiMAX also incorporates added security and QoS capabilities that are imperative to business users and law enforcement agencies. There are two variations of WiMAX standards: IEEE 802.16-2004 and IEEE 802.16e. The 2004 version supports fixed wireless applications, such as connectivity between a base station and residential or office building; the e-version addresses nomadic usage and full mobility (e.g., movement from location to location, travel at 60 mph without connection loss). 802.16-2004 was ratified in July 2004, and 802.16e was ratified in late 2005. The WiMAX Forum, an industry-led, nonprofit corporation formed to promote and certify compatibility and interoperability of broadband wireless products, will begin testing in early 2006 for 802.16-2004 systems and late 2006 (or 2007) for the e-version.

WiMAX is highly anticipated to become the primary technology used to provide worldwide wireless networks and services in the 2006 to 2010 time frame. The technology nicely complements Wi-Fi usage; it enables wireless Internet service providers (WISPs) to provide wireless broadband access to enterprise users as well as residential users, and it can be used to provide mesh connectivity to cellular towers with greater speed and less cost. With full mobility, it could compete directly against third generation (3G) data services and perhaps be a viable alternative for mobile data and voice applications. WiMAX is expected to be a disruptive technology and could transcend the use of wireless technology by advancing it to a new level.

This paper will present a high-level overview of WiMAX technology, its standards, spectrum landscape, applications, and market forecast. It will show how WiMAX can enhance other wireless services, such as satellite and radio frequency identification (RFID). It will also discuss some of the issues and challenges associated with WiMAX usage.

2. Overview of IEEE 802.16 Standards

IEEE 802.16, the standard for wireless local area networks (WLANs) in point-to-multipoint access, was published in 2002. It defined the wireless access specifications in licensed spectrum from 10 GHz to 66 GHz, but required line-of-sight (LOS) connections due to higher frequency range. To overcome multipath interference and signal distortion, IEEE 802.16 adopted the orthogonal frequency division multiplexing (OFDM) technique.

In 2003, IEEE approved 802.16a to address the 2 GHz to 11 GHz range in licensed and unlicensed spectrums for non-line-of-sight (NLOS) connections. The 802.16a was greatly welcomed; it supports both outdoor and indoor usages. IEEE later added variations to support fixed wireless (802.16-2004) and portable broadband access (802.16e).

The fixed, broadband wireless access (BWA) version, 802.16-2004, is great for many applications, including backhaul, T1 emulation, point-to-multipoint broadband access, wide area network (WAN) backbone, wireless DSL, and cable modem services. Using OFDM technology, the standard can support hundreds of subscribers in both LOS and NLOS environments. IEEE 802.16-2004 can transmit up to 30 miles at a maximum data speed of 75 Mbps. By and large, transmission distance and throughput are inversely proportional, influenced by environmental factors including objects directly blocking signal path, amount of distortion, and interference. The 802.16-2004 standard incorporates security and asynchronous

transfer mode (ATM)-like QoS features that should satisfy most business requirements and support delay-sensitive applications, such as voice and video.

To support nomadic and full mobility applications, IEEE developed an enhanced version of the standard, 802.16e. The e-version inherited the specifications of the fixed version plus capabilities to handle roaming and handoff for mobility usage. Additionally, the e-version uses orthogonal frequency division multiplexing access (OFDMA) instead of OFDM, thus gaining more robust performance by minimizing the effect of interference on subscriber devices with omni-directional antennas and allowing for a variable number of signal modulation carriers. IEEE 802.16e will likely use the lower frequency band in the 2.4GHz to 2.5GHz range to achieve optimal performance for mobility applications. Because the 802.16-2004 and e-versions use different modulation techniques and antenna types (directional versus omni-directional), the associated equipment is not interoperable. The e-version equipment can be used to support fixed BWA applications, but will cost more than using fixed, 802.16-2004 equipment.

Equipment manufacturers must submit their equipment to CETECOM, a WiMAX Forum Designated Certification Lab (WFDCL) in Spain, for interoperability certification. Availability of certified IEEE 802.16-2004 equipment is expected in early 2006, and certified 802.16e equipment in early 2007.

3. WiMAX Physical Layer (PHY)

WiMAX specifies two standards to support fixed (802.16-2004) and mobile (802.16e) applications. These standards will operate at the 2.5 GHz, 3.5 GHz, and 5.8 GHz frequency bands. In most countries, including the United States, 2.5 GHz and 3.5 GHz are licensed spectrums and 5.8 GHz is license-exempt. All three spectrums will support LOS and NLOS environments. Currently, 2.5 GHz and 2.3 GHz are intended for 802.16e usage, and 3.5 GHz and 5.8 GHz are planned for 802.16-2004. The lower frequency range provides better performance in NLOS. It is less susceptible to interference, hence it is allocated to 802.16e for mobility usage. Current profiles for 802.2004 are shown in **Figure 1**.

Frequency (MHz)	Duplexing	Channels (MHz)	IEEE standard
3400-3600	TDD	3.5	802.16-2004
3400-3600	FDD	3.5	802.16-2004
3400-3600	TDD	7	802.16-2004
3400-3600	FDD	7	802.16-2004
5725-5850	TDD	10	802.16-2004

Source: WiMAX Forum

Figure 1. 802.14-2004 Profiles

In the physical layer, WiMAX specifies OFDM and OFDMA as multicarrier transmission techniques. IEEE 802.16-2004 supports OFDM Fast Fourier Transform (FFT) 256-point transform and OFDMA 2048-point transform. FFT is a mathematical algorithm for digital signal processing. The initial 802.16-2004 profile will use OFDM 256 FFT and 802.16e will use OFDMA 2048 FFT. Technically, 802.16e uses scalable OFDMA (SOFDMA), which is a variation of OFDMA, but SOFDMA is commonly mentioned as OFDMA.

WiMAX supports two duplex schemes: the Time Division Duplex (TDD) and the Frequency Division Duplex (FDD). TDD uses a single channel, divided into various time slots. For example, different time slots are assigned for transmit and receive. FDD requires two frequency channels for transmit and receive. Transmit and

receive can occur simultaneously since each uses its own frequency band. TDD is suited for services that only have a single spectrum band. Most license-exempt services will use TDD. FDD is the preferred choice for licensed carriers, especially for mobile services. FDD is better suited for symmetrical traffic; it does not waste bandwidth on guard time, which is used to separate transmit and receive slots. However, it is more expensive than TDD since a pair of spectrum is required. TDD is more appropriate for asymmetrical data, but it cannot support transmit and receive at the same time.

Data throughput on a channel is determined by modulation scheme and coding rate, as shown in **Figure 2**. Sixteen (16) Quadrature Amplitude Modulation (QAM) and 64 QAM achieve higher throughput than Quadrature Phase Shift Keying (QPSK); however, they are susceptible to noise and interference which could generate higher bit error rates. WiMAX supports channels from 1.25 MHz to 20 MHz and a maximum data rate of 75 Mbps given an ideal environment that includes LOS connectivity and limited distance (i.e., less than a few miles). In general, data throughput decreases as distances increase and signals weaken over time.

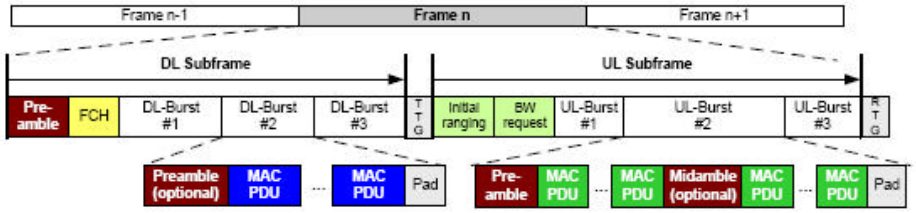
Modulation/ Code Rate	QPSK 1/2	QPSK 3/4	16 QAM 1/2	16 QAM 3/4	64 QAM 2/3	64 QAM 3/4
3.5 MHz	2	4.3	5.8	8.7	11.8	13
7 MHz	4.1	8.6	11.6	17.4	23.6	26
10 MHz	8.2	12.3	16.5	24.8	33	37.2
20 MHz	16.4	24.6	33	49.6	66	74.4

Data Rates (Mbps)

Figure 2. Data Modulation Efficiency

4. WiMAX Media Access Control (MAC) Layer

The MAC layer for IEEE 802.16 provides a PHY-independent interface. Its primary function is managing uplink and downlink transmission resources and packetizing data from upper layers into a MAC frame. A standard 802.16 MAC frame for TDD is shown in **Figure 3**. Downlink and uplink frames are concatenated into one frame since they share a common transmission link. In contrast, FDD downlink and uplink frames are handled independently. A Frame Control Header (FCH) is used to describe burst profiles and length of burst frames in the downlink subframe. In the uplink subframe, initial ranging is used for contention interval and bandwidth control for bandwidth allocation from each subscriber station.



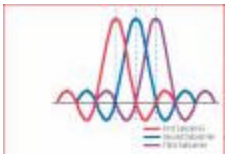
Source: WiMAX Forum

Figure 3. 802.16 MAC Frame

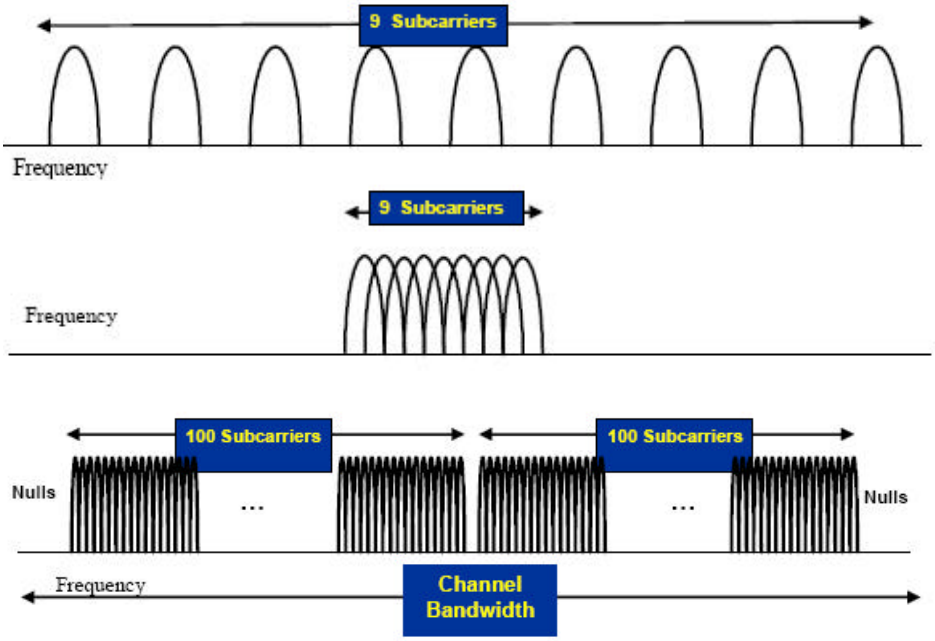
WiMAX MAC is designed for point-to-multipoint access and supports various protocols including Internet Protocol (IP), Ethernet, and ATM. The MAC layer also manages security and ATM-like QoS.

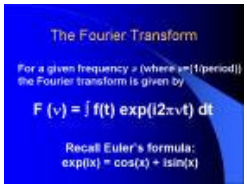
5. OFDM Technology

WiMAX uses OFDM technology for PHY transmission. OFDM improves bandwidth efficiency and overcomes multipath distortion; it is ideal for broadband wireless in an NLOS environment with limited spectrum capacity. Developed in the 1960s, OFDM was first used in military communications. It is also used in asymmetrical digital subscriber line (ADSL) and IEEE 802.11a/g.



Comparisons of spectral efficiency using Frequency Division Multiplexing (FDM) and OFDM are shown in **Figure 4**. The first diagram shows FDM with nine subcarriers. Each carrier uses a specific frequency range and is separated from other carriers by guard bands. This technique works well, but wastes unnecessary capacity on guard bands and achieves low spectral efficiency. The second diagram shows OFDM with nine subcarriers. The same nine carriers used in FDM are now modulated in a much tighter space. The carriers are overlapped, but do not interfere with each other since their peak signal points align with the null points of others. The third diagram shows OFDM with 256 carriers, which is used in IEEE 802.16-2004. OFDM uses FFT to perform complex mathematical computation for data modulation and demodulation. FFT is implemented in integrated chipsets and commercially available from companies such as Flarion and Freescale.





Source: Intel

Figure 4. FDM with Nine Subcarriers and OFDM with Nine and 256 Subcarriers

In addition to OFDM FFT, bandwidth efficiency is further enhanced through the use of QPSK or QAM modulation and coding rates, as described in Section 3, WiMAX Physical Layer (PHY).

OFDMA is a slight variation of OFDM, but it allows subcarriers to be assigned to different users. Rather than statically assigning users to fixed subcarriers, users can use multiple subcarriers, sequentially or non-sequentially, to maximize bandwidth usage. IEEE 802.16e uses OFDMA-2048 FFT, which uses more subcarriers to accommodate a larger number of simultaneous users.

6. Quality of Service

WiMAX QoS is implemented in the MAC layer. Its QoS scheme is similar to ATM QoS and designed to support differentiated services. All sessions are connection-oriented and supported by one of the following classes of services:

- Unsolicited Grant Service (UGS) — supports Constant Bit Rate (CBR) and is suited for T1/E1 emulation and voice-over-Internet protocol (VoIP).
- Real-Time Polling Service (rtPS) — supports real-time service that generates variable size data on a periodic basis, such as Moving Pictures Experts Group (MPEG) video.

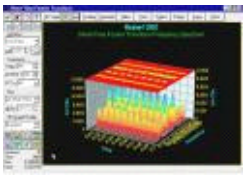
- Non-Real-Time Polling Service (nrtPS) — supports non-real-time service that generates variable size data periodically, such as file transfer protocol (FTP).
- Best Effort (BE) — ideal for Web surfing.

Unlike contention-based protocols, which are used in Ethernet and Wi-Fi, WiMAX QoS guarantees bandwidth allocation for applications that require CBR. This feature is necessary for T1 emulation and enterprise backhaul applications.

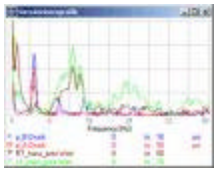
7. Security

IEEE recognizes that weak security is a major drawback of existing WLAN technology. Hence, WiMAX employs leading-edge encryption standards, such as 56-bit data encryption standard (DES), 152-bit advanced encryption standard (AES), and X.509 authentication certificates. The security specification was adapted from the data over cable service interface specification (DOCSIS) security protocol, which involves a complex process of handshaking between base station (BS) and subscriber station (SS). Identities of BS and SS are authenticated via X.509 certificates. Data is then encrypted using the 56-bit DES. 128-bit AES is an advanced encryption option. Manufacturers can implement more powerful encryption technologies as a way to differentiate their products and promote added capabilities. Whatever encryption technology is used, one thing for certain is that WiMAX technology ensures robust and flexible security capabilities that are tightly integrated into the 802.16 standard.

8. Spectrum Landscape



Radio spectrum, used for wireless communications, is an extremely precious resource. It is used to provide AM/FM radio broadcasting, television and satellite broadcasting, national emergency response system, 2G/3G cellular transmission, Wi-Fi, Bluetooth, and more. **Figure 5** shows frequency allocations for various wireless transmission services in the United States. Note that the spectrum is crowded and fragmented.



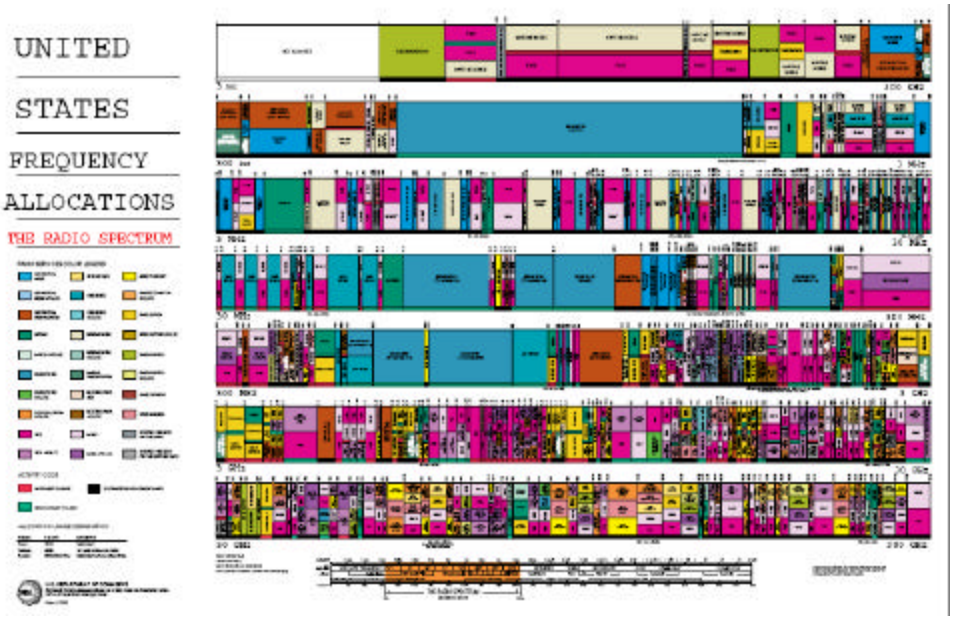


Figure 5. United States Frequency Allocations

In recent years, frequency spectrum auctions have generated tremendous revenues for governments around the world as 3G has generated great enthusiasm for potential mobile broadband services. In 2000, the government of the United Kingdom (UK) raised $33 billion from auctioning 3G licenses. The United States generated $15 billion for 3G licenses in 2001. Verizon alone spent $2 billion for a 10 MHz spectrum in New York. Licensed WiMAX services will likely require similar auctioning processes to acquire licensed spectrums.

Currently, WiMAX supports three frequency bands: 2.5 GHz, 3.5 GHz, and 5.8 GHz, as shown in **Figure 6**. The 2.5 GHz band, also known as Multichannel Multipoint Distribution Service (MMDS) or Broadband Radio Service (BRS), is a licensed band. It has approximately 190 MHz in available bandwidth. Due to the lower frequency range, this band will likely be predominant for IEEE 802.16e. The 3.5 GHz band is also a licensed band with 200 MHz of bandwidth. This band is mostly allocated for fixed broadband and thus ideal for licensed 802.16-2004 services. The 5GHz band, known as Unlicensed National Information Infrastructure (UNII), is widely allocated for licensed-exempt bands in most countries. There are three bands under UNII:

- Low and mid-UNII — 5150 MHz to 5350 MHz. This band is also used by 802.11a.
- 5470 MHz to 5725 MHz. This band was allocated for implementation of wireless access services in World Radio Conference (WRC) 2003. Expected to be used for 802.11a expansion, it remains largely unused and is highly suited for license-exempt WiMAX services.
- Upper UNII — 5725 MHz to 5850 MHz. This is the Industry, Scientific and Medical (ISM) band sometimes used by hospital and medical services. It is currently designated by 802.16-2004 for unlicensed services.

Band	Frequencies	License Required?	Availability
2.5 GHz	2.5 to 2.69 GHz	Yes	Allocated in Brazil, Mexico, some Southeast Asian countries and the U.S. (The WiMAX Forum* also includes 2.3 GHz in this band category because it "expects to cover [2.3 GHz] with the 2.5 GHz radio.") Ownership varies by country.
3.5 GHz	3.3 to 3.8 GHz, but primarily 3.4 to 3.6 GHz	Yes, in some countries	In most countries, the 3.4-GHz to 3.6-GHz band is allocated for broadband wireless.
5 GHz	5.25 to 5.85 GHz	No	In the 5.725-GHz to 5.85-GHz portion, many countries allow higher power output (4 watts), which can improve coverage.

Source: WiMax Forum*

Figure 6. WiMAX Frequency Bands

Many governments are planning to allocate additional bands for licensed and license-exempt broadband services. In addition, there are license-exempt bands (e.g., 900 MHz, 2.4 GHz, mid-UNII) not used by the current WiMAX standards. As WiMAX gains broader acceptance and deployment, more frequency spectrums are expected to become available for expansion of services. The key developments that will impact the success of WiMAX deployments will be: 1) costs of licensed spectrums for WiMAX services, 2) speed and development of governmental approval of frequency bands, and 3) global spectrum harmonization, which would standardize frequency availability worldwide and thus drive the costs of WiMAX radio equipment downward.

9. Future 802.16 Standards

The IEEE 802.16 committee is busy working on WiMAX extensions to improve manageability and expand the service to lower frequency bands. **Figure 7** shows the standards that are under development. Additional 802.16 standards, underway or planned for near term development, include:

- 802.16f — defines management information base (MIB) for the MAC and PHY of 802.16-2004
- 802.16g — defines management plane procedures and services for 802.16 conformant devices
- 802.16i — defines MIB for the MAC and PHY of 802.16e
- 802.16h — defines license-exempt coexistence. The WiMAX committee is thinking ahead to use the sub-900 MHz frequency band, because ultra-high frequency (UHF)/very high frequency (VHF) broadcasting will vacate as U.S. television moves to digital. The intended technology would employ software-based cognitive radio to avoid interference. However, the reuse of sub- 900 MHz has been targeted by 802.22 for Wireless Regional Area Networks (WRANs).

10. Industry Players

Currently, more than 300 companies participate in the WiMAX Forum. Most are equipment manufacturers, silicon designers and developers, resellers, and integrators. Over the next couple of years, more companies will enter the WiMAX market as system integrators, service providers, or resellers because barriers to entry will be less challenging. Market players in chip design and customer premise equipment (CPE) manufacturing will be less crowded, although acquisitions or industry consolidation in the manufacturing sector could create fewer but more dominant players. In July 2005, Proxim, one of the specialized wireless and pre-WiMAX manufacturers, was acquired by Terabeam.

Intel, perhaps one of the most active proponents of WiMAX technology, is involved in delivering WiMAX chips to equipment vendors. The company's goal is to become the primary chip supplier to WiMAX manufacturers, and eventually position the chips as standard peripherals in all personal computers (PCs),

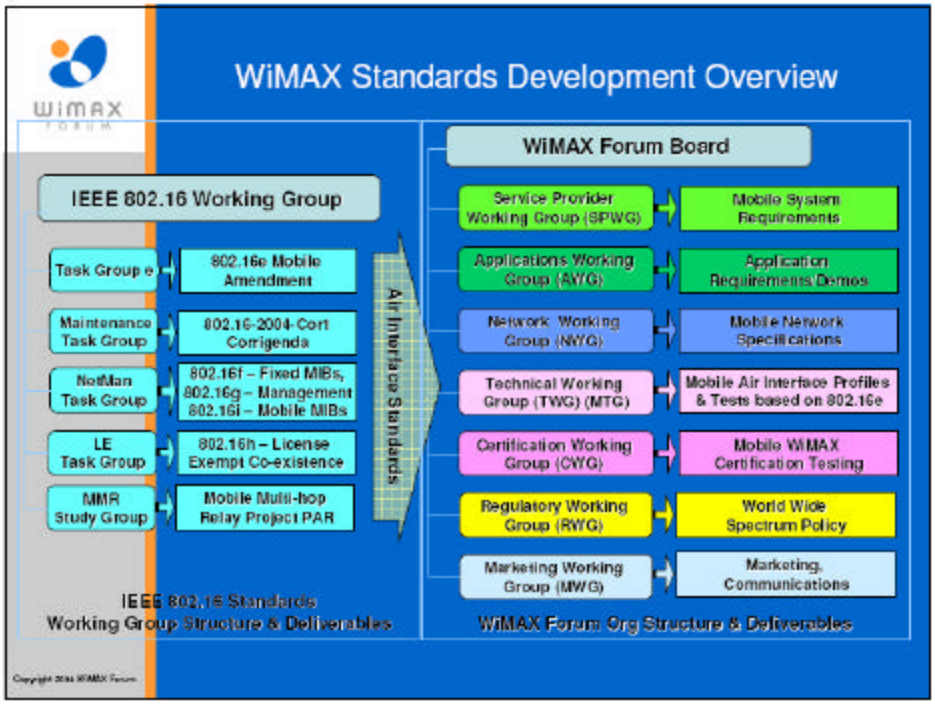


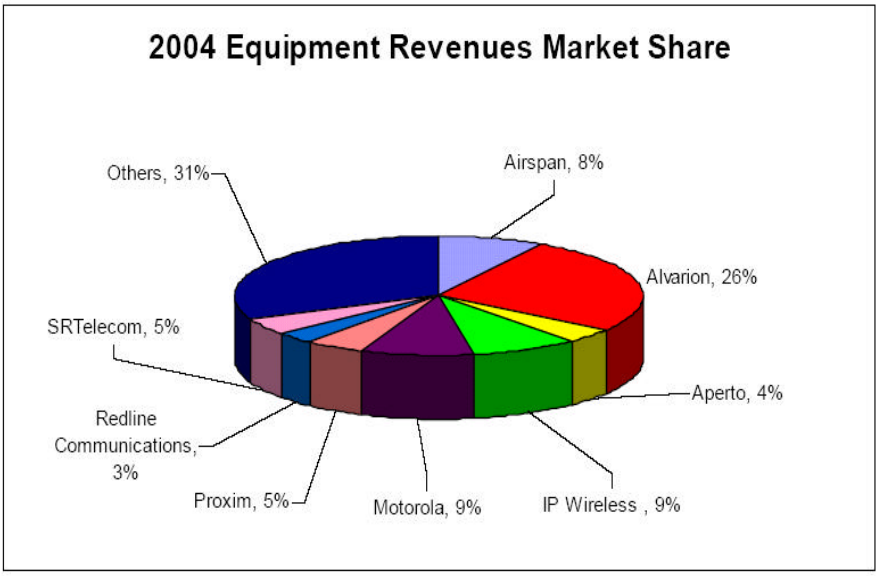
Figure 7. Future Standards Under Development

laptops, and personal digital assistants (PDAs). If WiMAX gains global adoption and Intel is successful in execution, Intel will be in a position to mass produce the core chips and drive equipment costs down. Intel's chip, Rosedale, is currently being used by many equipment manufacturers. Other key players in the chip market are Fujitsu Microelectronics and Siemens. Although Fujitsu is a relatively new entrant to the WiMAX market, it could be a strong contender with its strong presence and long experience in electronics and communication businesses. Flarion specializes in OFDM technology. It was recently acquired by Qualcomm to diversify from code division multiple access (CDMA) to the OFDM arena. Qualcomm, which has a strong position and influence in the wireless market, could pose challenges to Intel and Fujitsu if it decides to compete in the core chip space.

The equipment manufacturing sector is a competitive and challenging business area. Most specialized wireless vendors have faced challenges over the past couple of years in how to market pre-WiMAX equipment before standard ratification and interoperability certification — given that the WLAN market has been a small niche business with heavy competition. Alvarion is probably the most successful company in the WiMAX market at this time. It has sold more systems than most of its competitors and established original equipment manufacturer (OEM) agreements with large companies, including Alcatel and Siemens. As shown in **Figure 8**, Alvarion had the largest market share in 2004 with 26 percent, which is 17 percent larger than its next competitor. Currently, Alvarion has a market cap of $620 million. Other contenders in 2006 include:

- Aperto, a strong startup company that focuses on the larger enterprise market
- Proxim, now part of Terabeam, with a meager market cap of $78 million
- Redline Communications, a privately held Canadian company
- Airspan, which has been in business the longest but has not done as well as Alvarion; its current market cap is $220 million

- Navini Networks, another startup company focused on the WiMAX market



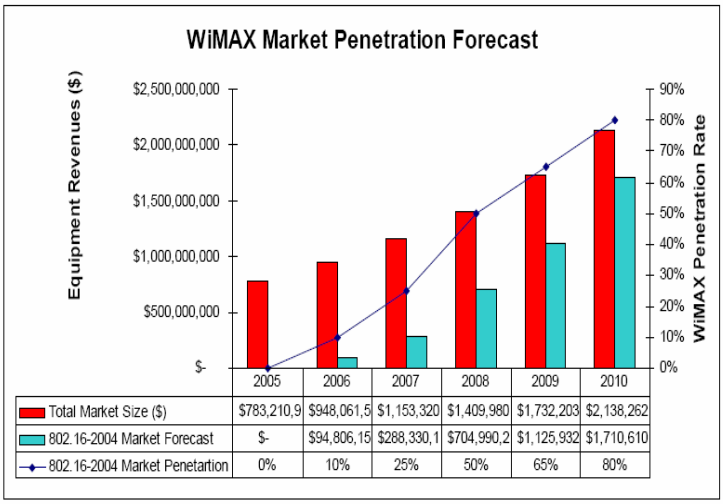
Source: Maravedis

Figure 8. 2004 Equipment Market Share

11. Market Forecast

The WiMAX market is expected to grow at a modest pace in 2006 and the first half of 2007, as most 802.16-2004 equipment will be undergoing certification and interoperability tests in the first half of 2006. Fully certified equipment will not be available in large quantity until the third quarter of 2006. IEEE 802.16e systems will start rolling out in 2007; they are expected to grow at a faster rate than the fixed wireless version due to their nomadic and mobility capabilities. The overall market should then grow by 60 to 80 percent each year, particularly when laptops and PDAs can gain WiMAX access in roaming mode. If 802.16e handsets ever hit the market, the growth rate could potentially exceed cellular handsets.

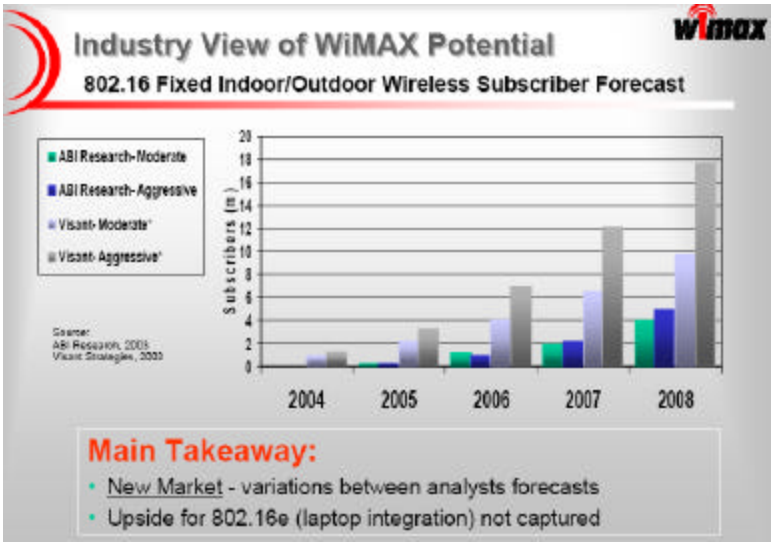
Maravedis, Inc. forecasts $94 million in 2006 for the fixed version, up to $700 million in 2008, and $1.7 billion by 2010, as shown in **Figure 9**. The $94 million in 2006 represents a relatively tame penetration when compared to $615 million in 2004 for the overall proprietary BWA equipment market. 802.16-2004 should achieve significant penetration in the BWA market in 2008 and beyond. Another company, iSuppli, more optimistic than Maravedis, forecasts $1.7 billion in 2008 and $2.6 billion in 2009.



Source: Maravedis

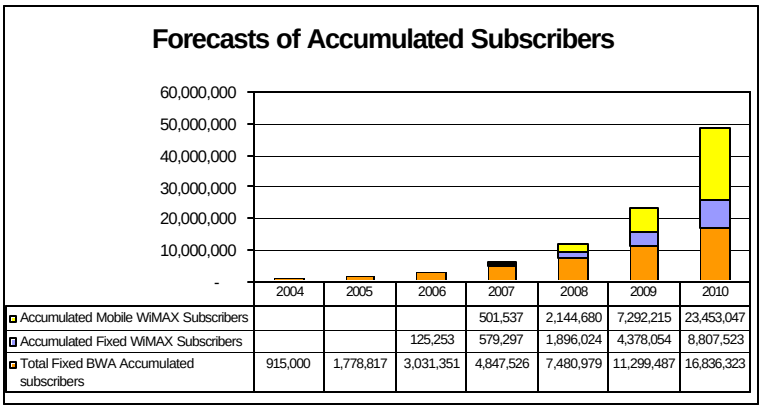
Figure 9. WiMAX Market Penetration Forecast

Subscriber growth rate will also increase slowly starting in 2006, but accelerate rapidly in the 2007 – 2008 time frame and most likely exceed 10 million by 2008, as shown in **Figures 10 and 11**. Two key points to note are: 1) WiMAX is real and will have a significant impact in the wireless market, and 2) real growth and market penetration will not be realized until 802.16e equipment arrives in mass quantity, as this will propel nomadic and mobile application usage.



Source: WiMAX Forum

Figure 10. WiMAX Subscriber Forecast

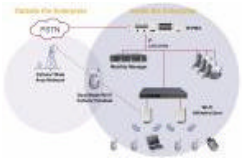


Source: Maravedis

Figure 11. WiMAX Subscriber Forecast by Maravedis

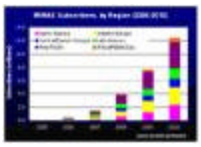
12. WiMAX versus Wi-Fi

WiMAX 802.16 and Wi-Fi 802.11 are different, but complementary technologies. WiMAX is intended for metropolitan area network (MAN) access while Wi-Fi is best suited for local area network (LAN) application. WiMAX supports higher bandwidth and longer range, and scales much better than Wi-Fi. Wi-Fi uses contention-based protocol, carrier sense multiple access/collision avoidance (CSMA/CA), which is similar to Ethernet's carrier sense multiple access/collision detection (CSMA/CD). Network performance degrades as more users access the network. Wi-Fi operates primarily in a license-exempt spectrum and does not support mobility, while WiMAX supports licensed, licensed-exempt, fixed-access, nomadic, and full mobility. For enterprises and service providers, WiMAX integrates QoS and security, which were the critical functions missing in Wi-Fi. Some comparisons of the two technologies are provided in **Figure 12**.

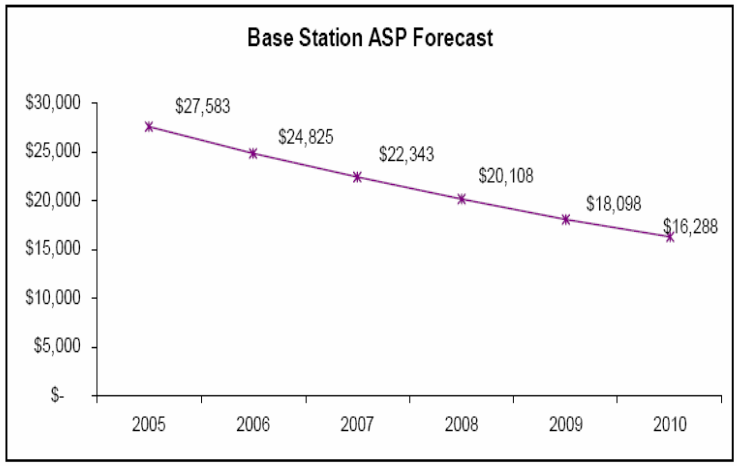


	WiMAX	Wi-Fi (802.11)
Distance	30 miles LOS 6 miles NLOS	100 meters — omni directional antenna 20 miles — directional antenna
Data Rate	Up to 75 Mbps	11 Mbps for "b" 54 Mbps for "g/a"
Spectrum	2.5 GHz, 3.5 GHz, 5.8 GHz	2.5 GHz, 5 GHz
Modulation	OFDM, OFDMA	DSSS — "b" OFDM — "g/a"
Protocol	Grant/Request, TDM, and TDMA	CSMA/CA contention-based
QoS	ATM-like QoS	Very limited
Security	X.509 certificate 56-bit DES 128-bit AES	Very limited
Application	MAN, WAN	LAN
Cost	$400 — CPE $24k — base station	Very low
Scalability	High	Low
Interoperability	2006 — low 802.16-2004 certification in early 2006 802.16e certification in late 2006/2007	Very high
Mobility	Full in 802.16e	None

Figure 12. Features Table

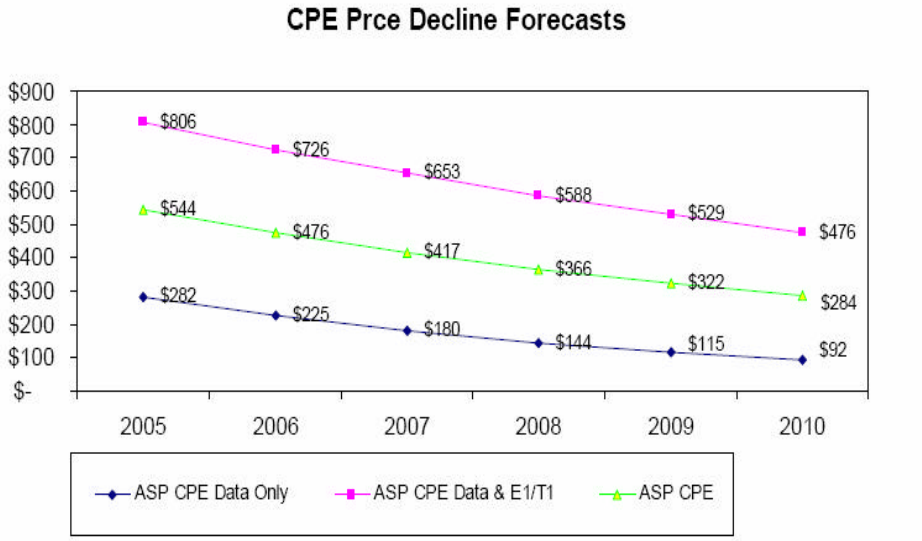


Wi-Fi will continue to be the preferred technology for LAN applications due to the maturity of the technology and low cost. The cost of a Wi-Fi router or access point (AP) can be purchased for less than $50; most Personal Computer Memory Card International Association (PCMCIA) cards or universal serial bus (USB) adaptors can be obtained for less than $20. Equipment is fully interoperable and available from many manufacturers, including Cisco. WiMAX-certified equipment will not be available until the second quarter of 2006 for 802.16-2004, and 2007 for 802.16e. Based on initial equipment price forecasts from Maravedis, shown in **Figures 13 and 14**, BS unit prices are expected to be approximately $24k in 2006 but decline to $16k by 2010. Subscriber CPEs are expected to be in the $400 range in 2006 and eventually drop to $200. These prices are significantly higher than Wi-Fi equipment prices. At such price points, WiMAX is not likely to replace residential or business LANs; however, it is very attractive for applications such as last-mile access to business buildings, residential access, interconnection of Wi-Fi hot spots, or MAN.



Source: Maravedis

Figure 13. Base Station Price Forecast



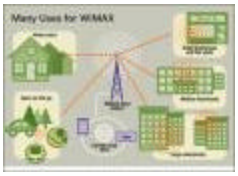
Source: Maravedis

Figure 14. CPE Price Forecast

13. WiMAX Architecture

IEEE 802.16-2004 was designed for point-to-multipoint (PMP) access. A BS can support a large number of enterprise and residential subscribers. WiMAX is a great alternative for enterprise users without a T1 trunk due to lack of circuit availability, lengthy installation time, or high cost. Residential customers can get wireless DSL service along with VoIP from their wireless service providers. The PMP architecture is ideal for interconnecting Wi-Fi hot spots. Although PMP was the primary intended application, 802.16-2004 can also be used as point-to-point (PTP) backhaul to provide connectivity as far away as 30 miles. The PTP application is great for wireless backhaul between two locations or, if the reach is extended, for cellular towers or Wi-Fi networks.

To provide roaming capability for nomadic and full mobility applications, the IEEE developed a specification for mesh network topology. Mesh network allows a node to connect to two or more networks at the same time. Mesh is commonly used in network backbones to provide alternate routing, load balancing, and improved network performance, robustness, and reliability. Full mesh, when each node is connected to every other node, is less used due to the high cost associated with the large number of links and communication ports required. WiMAX mesh network enables subscriber hand-off between base stations, and hence the provision of seamless roaming between networks. A mobile user could be hopping from one network to another without knowing that roaming has occurred. For roaming to occur, network service providers need to negotiate roaming agreements to allow for sharing of network resources, which is a common business practice in the cellular world.



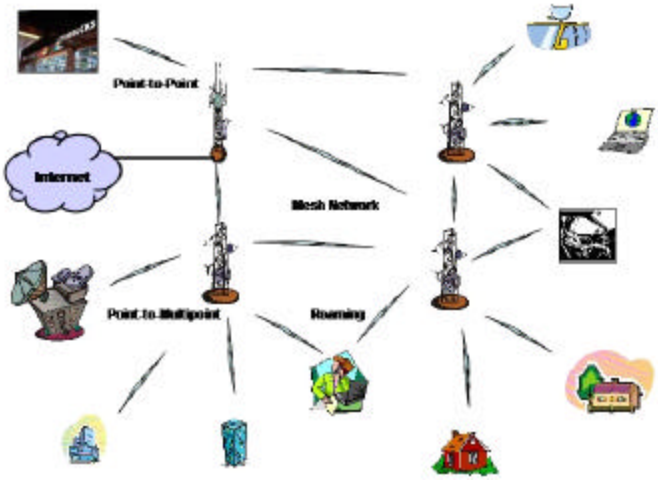


Figure 15. Shows a network employing PMP, PTP, and mesh networks.

14. Applications

Conceptually, wireless communication is extremely attractive. It eliminates the need for messy and labor-intensive cabling, and can be installed quickly. However, wireless networking has not been widely used due to the following factors:

- Lack of wireless standards. Proprietary wireless networks are expensive and must be purchased from and supported by specific vendors.
- Wi-Fi does not scale well and has limited support for security and QoS.
- Wi-Fi has limited distance and throughput.

- Wireless, in general, is not secure.
- Wireless is complicated and unreliable.
- Satellite wireless is slow and expensive and requires bulky equipment.

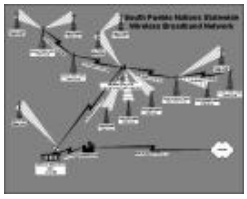
While WiMAX cannot replace satellites for transoceanic transmission, it can resolve most of the issues confronting proprietary wireless systems and Wi-Fi technology. With added capabilities for security, QoS, distance up to 30 miles, data rate of 75 Mbps, and interoperability among a plethora of vendors, WiMAX could be implemented to support numerous commercial, municipal, and law enforcement applications.

Commercial

During the Internet boom, Winstar was a Wall Street darling. It commanded a market valuation of billions of dollars by providing high-speed wireless links on top of office buildings to interconnect computer networks or voice traffic. Its promise was tempting but its technology was flawed; hence, the company went bankrupt in the early days of the dotcom bust. Although Winstar's hype and shady management were quickly uncovered, it did prove that a legitimate and strong demand for wireless communication exists.

In the year when Google was valued at over $100 billion for its search engine business, Apple sold 14 million iPods in a 3-month period, and Motorola's RAZR cell phones were flying off the shelves, getting broadband links in metropolitan cities could still take many months and cost a bundle. Getting DSL or T1 links in rural areas was cost prohibitive. The emerging WiMAX technology could easily fill these voids. Using fixed and mobile technologies, WiMAX could be implemented for a multitude of commercial applications, such as:

- T1 backhaul
- Interconnection of Wi-Fi hot spots and cellular towers
- Mobile and roaming data access
- Wireless local loops to residential homes bypassing incumbent local exchange carriers (ILECs)



- Wi-Fi backhaul
- Interconnection of office buildings for high-speed private links
- Distance learning
- Broadband VoIP and data access to WiMAX mobile handsets
- Internet protocol television (IPTV) broadcast
- Wireless kiosks
- Telemedicine
- Mobile video-on-demand competing against XM video service

Municipal

A number of local municipalities have started city-wide implementation of wireless networks or announced plans to do so. The city councils want to make broadband access ubiquitous and affordable to residences and small medium enterprises (SMEs). In many cases, Wi-Fi would be the natural choice, primarily for its low cost and wide availability, including in such places as public libraries, schools, parks,

and municipal buildings. WiMAX could play a key role in backhaul or backbone access to these Wi-Fi hot spots, and provide the last mile link to SMEs. Additionally, WiMAX is an excellent technology for the following:

- Traffic management
- Public utilities
- Remote utility reading
- Parking meter reading
- Public safety
- Toll collection

Law Enforcement

Wireless communication plays a critical role during a national crisis, such as 9/11, or natural disaster, like Hurricane Katrina. In situations when terrestrial infrastructure is broken and speed of deployment is of utmost importance, 802.16 can provide quick relief. In addition to disaster relief, WiMAX could be used in law enforcement applications, such as:

- Video/sensor surveillance: New York City is planning to install outdoor surveillance cameras to detect terrorist activities, as seen in London's incident
- Emergency response
- Public safety
- City workforce mobility
- Real-time video-based criminal checks

Other related applications include field Federal Bureau of Investigation (FBI) deployments, battlefields, battleships, and Coast Guard operations.

15. Triple and Quadruple Plays

WiMAX technology will enable triple play (i.e., voice-over-IP [VoIP], video, and data) to be delivered to residential users and rural business customers. These three services will be accessible to users via high bandwidth wireless links and QoS, which traditional dial-ups and other low-speed pipes do not offer. For example, the delivery of on-demand video, streaming media, digital photos, and MP3 music will be quick and reliable with the new wireless infrastructure. VoIP could be a viable alternative as a bundled service that yields substantial savings over Plain Old Telephone Service (POTS). IPTV could become a prime-time option for viewers who want to watch their favorite television shows on demand or in real time over a portable video device or personal computer.

Using the 802.16e technology, mobile voice and data can be added to the triple play. This will make voice, video, and data services available, without any connection loss, while users travel 60 miles per hour on highways, walk through a park, or buy a cup of coffee from Starbucks. One potential application, enabling WiMAX users to talk wirelessly to other users over WiMAX networks using 802.16 phones, could disrupt the mobile world because such phones would automatically switch, seamlessly, to cellular mode when the WiMAX network was not available.

There are compelling reasons for WiMAX service providers to provide the triple and quadruple plays. The providers can maximize average revenue per user (ARPU) as users embrace these exciting technologies and services, and the

offerings cannot be easily provided by other infrastructure service providers (i.e., telecommunications, cable, and cellular companies).

16. Current Deployments

Since ratification of the 802.16 standards in 2004, numerous WiMAX network deployments have been announced globally. Foreign governments, service providers, and enterprises are not wasting any time; they are quickly moving forward with the emerging broadband wireless technology to provide ubiquitous network coverage. Cities and municipalities that were previously installing costly and time-consuming fixed wire infrastructures can now equip themselves with state-of-the-art wireless technology and high-bandwidth networks. Deployments of WiMax networks throughout Asia, Latin America, Europe, Africa, and North America are under way. The Russian government recently announced a $600 million project to install WiMAX networks for the provision of wireless communications, including VoIP and other broadband services, throughout 30 major cities.

The most noteworthy deployment is the WiBro (Wireless Broadband) service in South Korea, where the highest penetration of broadband access in the world currently exists. Most households in South Korea have access to the Internet at speeds eight times faster than households in the United States. WiBro, a variant of IEEE 802.16, is intended to provide the first portable Internet service using WiMAX technology. QoS is an inherent feature that allows reliable delivery of video streams and other loss-sensitive data. The service uses base stations that can transmit an aggregate speed of 30 to 50 Mbps at distances up to 1.5 Km. Portable devices can receive at 1 Mbps while traveling at 37.5 miles per hour. WiBro, which is backed by the South Korean government, uses an allocated spectrum of 100 MHz in the 2.3 GHz licensed band. The service will be offered through KT, SK Telcom, and Hanaro Telecom. Portable devices will be available in handheld portable phones and PCMCIA cards. WiBro is slated for a full-scale launch in 2006; it has been in a limited trial since 2005. Depending on the success of the launch, WiBro could become the new wireless trend in South Korea. As shown in **Figure 16**, it could influence the rest of the wireless industry.

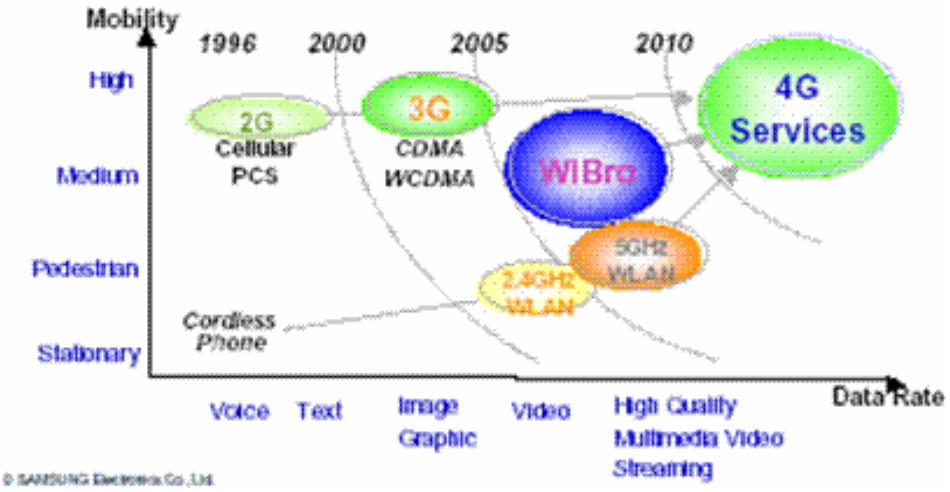


Figure 16. WiBro Deployment

17. WiMAX and 3G/4G

3G, third-generation wireless technology, has had limited success for several key reasons. First, its data rates, particularly for video streaming applications, are quite limited for most users. The rates range from 144 Kbps for mobile, to 384 Kbps for

pedestrian, and up to 3 Mbps for fixed environment. Second, large-scale network deployment has been impeded due to competing technologies, Wideband Code Division Multiple Access (W-CDMA) versus CDMA2000, or Global System for Mobile (GSM) supporters versus Qualcomm's CDMA supporters. Building a nationwide W-CDMA network and providing ubiquitous coverage costs much more than letting operators build their own networks. Verizon and Sprint have been offering CDMA2000 Evolution Data Only (EVDO) data services for a couple of years. Cingular just announced its own version of 3G service, based on W-CDMA technology, called High-Speed Downlink Packet Access (HSDPA). Third, due to competing technologies and lack of a single industry standard, economy of scale to drive network equipment and end user equipment costs to a mass market level does not exist. And last, but not least, 3G is primarily a cellular-based technology, which has limited application for fixed infrastructure applications, such as last-mile, point-to-point connectivity, or backhaul application.

WiMAX, both 802.16-2004 and 802.16e, in many ways competes directly against 3G but also complements 3G. IEEE 802.16e can do everything 3G does, and more. IEEE 802.16e supports full mobility at higher data rates and longer range. Its security and QoS features are more robust. However, there are scenarios where WiMAX could complement 3G very well. Using 802.16-2004, fixed BWA capability, WiMAX could provide connectivity between 3G cell sites or provide the backhauls from cell sites to the central network. Costs and time of quick deployment should be significantly more attractive than using land lines. For WiMAX to overtake the 3G market, it needs broad acceptance and adoption to attract enough competitive manufacturers and achieve economy of scale. On the other hand, 3G is not standing still. Technologies are moving forward to increase speed and capabilities. IEEE 802.16e equipment will not be fully certified until the second half of 2006, and mass deployment is expected in 2007 – 2008. 3G has been available for 2 to 3 years; two more years of delay for 802.16e will mean a 5-year head start for 3G over WiMAX, so it is hard to predict which technology will win the battle in 2010.

4G is a futuristic technology that has yet to be defined. The concept is to develop new high-speed radio links that will support up to 1 Gbps peak transmission with an average throughput of 100 Mbps. 4G will be IP-based and support seamless mobility roaming. The technology is not expected to be available until the 2010 – 2015 timeframe, and will likely use OFDM to achieve higher utilization of network resources and support more simultaneous users. 3G, 3.5G, 4G, and WiMAX could converge at some point. It is also conceivable that WiMAX could eventually evolve into 4G or become the foundation for 4G technology.

18. WiMAX and Satellite Applications

Internet access over satellite has gained wide traction since 1998. It has enabled ISPs in developing regions, those with poor or nonexistent terrestrial infrastructure, particularly the Middle East, Eastern Europe, Latin America, India, and Southeast Asia, to quickly access the U.S. Internet backbone. The trend has turned satellite operators from ho-hum jocks to overnight darlings. While obtaining satellite IP has been easy and inexpensive, solving the last-mile problem has proven to be a challenge for many of the international ISPs. In most areas, developing countries rely on antiquated telephone systems to deliver IP at 28 Kbps to residential and business users. Wireless broadband access is not a viable option, due to expense. Many ISPs have no choice but to deploy proprietary wireless networks.

Merging WiMAX and satellite would easily solve these problems and provide an attractive solution for providing end-to-end wireless IP and multimedia content delivery from one part of the globe to the other. As streaming media and video on-demand become popular (but demanding, in terms of bandwidth), the WiMAX satellite solution could be the preferred solution for bringing media-rich content

from its originating networks to developing countries and remote regions. Satellite would provide the trans-continental backbone to remote data centers and cache farms. WiMAX would be used for local distribution, since satellite antennas and transceivers are much more expensive than WiMAX CPEs. and, in most cases, data must first be stored in data centers for content control, filtering, editing, and billing processing.

Another application for the WiMAX satellite solution is providing terrestrial-free enterprise WANs to global 500 companies with manufacturing plants, ocean-based oil rigging platforms, remote monitoring services, or operations facilities in rural areas. Many such companies have built costly broadband networks using proprietary equipment. Using WiMAX satellite capability, they could build larger networks more quickly and at significant cost savings. Sample applications for Internet access and media content distribution using WiMAX satellite are shown in **Figure 17**.

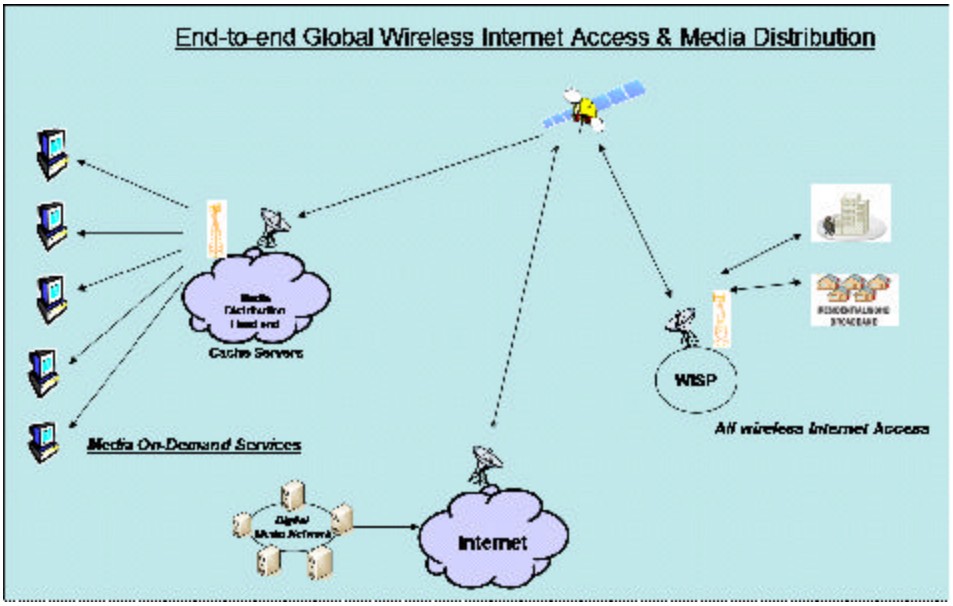


Figure 17. WiMAX Satellite Integrated Services

19. WiMAX and RFID Applications

Radio Frequency Identification (RFID) is emerging as a promising technology with a plethora of practical applications. Most people may not realize that RFID is already playing a key role in their daily routines. Each time you drive through a toll booth using E-ZPass or buy something in a department store, you are using RFID. The new Lexus automobile uses the technology to allow drivers to start engines while the keys remain in their pockets. In recent years, Wal-Mart demanded all of its vendors to use RFID tags on product deliveries to improve and reduce the costs of supply chain management. The U.S. Department of Defense issued a policy mandating the use of RFID tags on all material deliveries, starting January 1, 2005. Without a doubt, RFID will be used in many facets of our lives, whether liked or not.

There are numerous applications in which the combination of WiMAX and RFID greatly simplifies implementations and reduces costs. WiMAX enables RFID systems in fields to transmit data to host computers or database servers without labor-intensive cable installations. Flexibility and ease of implementation also promote broader deployments. Potential applications for using WiMAX as RFID communication backbones include:

- Electronic toll collection
- Real-time tracking of containers
- Tracking of herds, special wildlife animals, or sea animals for inventory or research projects
- Tracking of field deployments and heavy machineries for military or construction
- Remote data collection of seismic sensors
- Tracking of medical supplies and scientific equipment

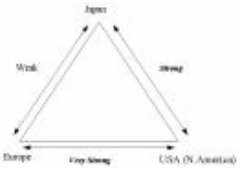
WiMAX complements RFID applications by eliminating expensive and time-consuming link installations, particularly for point-to-multipoint installations. The larger the installation, the more attractive this option becomes.

20. Challenges and Issues

Despite technological advancements and improved capabilities, by no means will WiMAX be a "homerun" or "instant darling" of the telecommunications industry. There are still hurdles and challenges to overcome before WiMAX can gain worldwide adoption. The challenges range from economic issues to governmental regulatory policies.

Technology alone cannot solve market problems. To achieve penetration, WiMAX needs product and network interoperability, and enticing price points that start from economies of scale, killer applications, and attractive business models. Standards by themselves cannot guarantee total compatibility. Manufacturers will be adding unique capabilities and feature variations to differentiate products and justify prices. This could potentially increase product complexity, and impact service and network interoperability. When the mass market is dominated by a few manufacturers (e.g., as smaller players languish or become absorbed by larger companies), price competition becomes less of an influential factor. The WiMAX economic model is very dependent on its ecosystem. Supply chains include chip manufacturers, radio and antenna manufacturers, system vendors, software and application developers, system integrators, and operation support systems. A cooperative ecosystem will significantly improve product development and deployment, fair and optimal market competition, and service applications.

To promote broader network and service deployments, carriers and WISPs need to thoroughly analyze market demand, assess values being delivered to the end users, and ensure their business models are viable and sustainable. During the Internet boom, ISPs with questionable business plans popped up everywhere. Their capital investments and annual expenses could not be recouped in the foreseeable future, so the lucky ones got acquired and the rest went bust. With potential WiMAX applications (e.g., last-mile access to rural areas, portability, roaming, triple play), the chances for WISPs to offer compelling services with a reasonable investment in technology that has been standardized and mass marketed are good. WISPs could even cooperate with large carriers and cellular service providers to offer network roaming and revenue sharing.



The biggest issue that WiMAX faces in the near term, aside from economic challenges, is regulatory in nature; adequate spectrums to enable broad deployment of networks are not provided. Networks can be easily and rapidly installed using the unlicensed spectrums, but the risk of interference from other public WiMAX networks and limited transmission power is a drawback. WISPs and carriers will most likely want usage of licensed spectrums to ensure quality of service and wider range of transmission. A large chunk of spectrum is currently

allocated to Sprint/Nextel. The government plans to allocate more capacity, but considerable time and bureaucracy could be involved. Furthermore, spectrum auction has proven to be expensive based on actual transactions in recent history. At cost-prohibitive levels, many "want to be" WISPs will have a tough time entering the business. Larger ones, with richer capital resources, are likely to offer the services at higher prices. This could impact consumer take-up rates, and, ultimately, equipment costs will stay at higher prices due to poor economies of scale.

To promote pervasive broadband usage and convergence of 3G, 3.5G, and WiMAX, and to improve the success of market drivers, local governments should understand the needs of service providers and technology vendors. Better coordination of all parties is needed to achieve expedition of spectrum allocation. The WiMAX Forum must work diligently with industry and government to ensure availability and global harmonization of the WiMAX-friendly spectrum, worldwide.

21. Conclusion

WiMAX is an emerging and exciting wireless technology. The technology will support a variety of business and consumer applications, from network backhauling and interconnecting Wi-Fi and LANs, to voice, video, data, and mobility.

WiMAX will change the way people access data, e-mail, and instant messaging service (IMS). It can coexist with 3G or replace 3G, and it can seamlessly integrate with cellular handsets or serve as a standalone technology to provide mobile voice and data services. The concept is currently being deployed in South Korea as WiBro. WiBro could accelerate global deployment and, if successful, make 3G obsolete.

Integrating WiMAX with satellite or RFID technologies can yield creative and attractive end-to-end wireless services. Moreover, WiMAX technology can be used in a variety of commercial, municipal, and law enforcement business applications.

Fixed WiMAX equipment will be mass market available in the second half of 2006, and mobile WiMAX equipment in 2007. The success of WiMAX deployment will depend on its adoption rate, equipment pricing, business models, and availability and affordability of licensed spectrum.

Based on Internet access becoming a necessity, and 3G and Research in Motion (RIM) capturing a large business market share, WiMAX is growing strong. It will change the way people access the Internet and download media, such as streaming video and MP3 files. To maximize the value and benefits of WiMAX, understanding the technology and its potential is essential.

Acronyms

3G	Third Generation
ADSL	Asymmetrical Digital Subscriber Line
AES	Advanced Encryption Standard
AP	Access Point
ARPU	Average Revenue Per User
ATM	Asynchronous Transfer Mode
BE	Best Effort
BS	Base Station
BRS	Broadband Radio Service
BWA	Broadband Wireless Access
CBR	Constant Bit Rate
CDMA	Code Division Multiple Access
CPE	Customer Premise Equipment
CSMA/CA	Carrier Sense Multiple Access/Collision Avoidance
CSMA/CD	Carrier Sense Multiple Access/Collision Detection
DES	Data Encryption Standard
DOCSIS	Data Over Cable Service Interface Specification
DSL	Digital Subscriber Line
DSSS	Direct Sequence Spread Spectrum
EVDO	Evolution Data Only
FBI	Federal Bureau of Investigation
FCH	Frame Control Header
FDD	Frequency Division Duplex
FDM	Frequency Division Multiplexing
FFT	Fast Fourier Transform
FTP	File Transfer Protocol
GSM	Global System for Mobile
HSDPA	High-Speed Downlink Packet Access
IEEE	Institute of Electrical and Electronic Engineers
ILEC	Incumbent Local Exchange Carrier
IMS	Instant Messaging Service
IP	Internet Protocol
IPTV	Internet Protocol Television
ISM	Industry, Scientific and Medical
ISP	Internet Service Provider
LAN	Local Area Network
LOS	Line-of-Sight
MAC	Media Access Control
MAN	Metropolitan Area Network
MIB	Management Information Base
MMDS	Multi-Channel Multiple Distribution Service
NLOS	Non-Line-of-Sight
MPEG	Moving Pictures Experts Group

nrtPS	Non-real-time Polling Service
OEM	Original Equipment Manufacturer
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiplexing Access
PC	Personal Computer
PCMCIA	Personal Computer Memory Card International Association
PDA	Personal Digital Assistant
PHY	Physical Layer
PMP	Point-to-Multipoint
POTS	Plain Old Telephone Service
PTP	Point-to-Point
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
QoS	Quality of Service
RFID	Radio Frequency Identification
RIM	Research in Motion
rtPS	Real-Time Polling Service
SME	Small Medium Enterprise
SOFDMA	Scalable Orthogonal Frequency Division Multiplexing Access
SS	Subscriber Station
TDD	Time Division Duplex
TDM	Time Division Multiplexed
TDMA	Time Division Multiple Access
UGS	Unsolicited Grant Service
UHF	Ultra High Frequency
UK	United Kingdom
US	United States
VHF	Very High Frequency
VoIP	Voice-Over-IP
UNII	Unlicensed National Information Infrastructure
USB	Universal Serial Bus
WAN	Wide Area Network
W-CDMA	Wideband Code Division Multiple Access
WFDCL	WiMAX Forum Designated Certification Lab
WiBro	Wireless Broadband
Wi-Fi	Wireless Fidelity
WiMAX	Worldwide Interoperability for Microwave Access
WISP	Wireless Internet Service Provider
WLAN	Wireless Local Area Network
WRAN	Wireless Regional Area Network
WRC	World Radio Conference

References

1. WiMAX Forum, http://www.wimaxforum.org
2. Maravedis, Inc.

   WiMAX at a Cross Road, WiMAX Conference & Exposition 2005

   WiMAX Trends, The WiMAX Spectrum Picture, by Adlane Fellah, CEO and Founder of Maravedis, Inc.
3. Intel

   White Paper — Deploying License-Exempt WiMAX Solution

   White Paper — Understanding Wi-Fi and WiMAX as Metro-Access Solutions

   Intel Technology Journal, IEEE 802.16 Medium Access Control and Service Provisioning, Vol. 08, Issue 03, August 20, 2004, ISSN 1535-864x

   Intel in Communications — Orthogonal Frequency Division Multiplexing

   Technology Intel Magazine – IEEE 802.16 Wireless MAN Specification Accelerates Wireless Broadband Access
4. RFID — Wikipedia, http://en.wikipedia.org/wiki/RFID
5. The IEEE 802.16 WiMAX Broadband Wireless; Physical Layer (PHY), Medium Access Layer (MAC), Radio Resource Management (RRM), by Jakub Wolnicki, Munich University of Technology
6. Capitalizing on the WiMAX Market Opportunity, Dr. Mohammad S. Shakouri, Alvarion
7. Evolution of Mobile Wireless Broadband, Peter Rysavy, Rysavy Research
8. Fixed, Nomadic, Portable and Mobile Applications for 802.16-2004 and 802.16e WiMAX Networks, November 2005, Prepared by Senza Fili Consulting on behalf of the WiMAX Forum