WiMAX and the Metro Wireless Market

WiMAX versus Wi-Fi and 3G

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Wireless LANs based on the IEEE 802.11 or Wi-Fi standards have been a resounding success. However, when we shift the focus to the wide area, we see the market for broadband wireless service is still up for grabs. The cellular carriers were first to market with their 2.5G/3G data services, but those have yet to crack the megabit barrier. Mesh technology Is expanding the range of Wi-Fi from 100 meters to an entire metropolitan area, but the performance of those mesh networks has yet to be tested. Finally, there is the new contender in this space, WiMAX.

WiMAX, short for Worldwide Interoperability for Microwave Access, is a metro-area wireless technology defined in the IEEE 802.16 standards, and promoted by the WiMAX Forum. Like the Wi-Fi Alliance, the WiMAX Forum looks to develop interoperability test suites to insure a multi-vendor solution that will result in lower cost products based on open standards. Internationally, the European Telecommunications Standards Institute's (ETSI) HIPERMAN initiative addresses the same area and shares much of the same technology.

Clearly the WiMAX Forum has not succeeded to the same degree as the Wi-Fi Alliance. Missed delivery dates and misdirected marketing programs in support of WiMAX have yielded little but confusion. We find that WiMAX is still compared with Wi-Fi, even though the two technologies address completely different markets and applications. The more appropriate comparison for WiMAX is cellular.

Besides the fact that they use radio transmission and have names that start with the letters "Wi", there is little in common between Wi-Fi and WiMAX. Wi-Fi is a short-range, local area technology designed to add mobility in private networks. WiMAX, on the other hand, was designed as a technology for carriers to use to deliver a metro area broadband wireless access (BWA) service. At some point, WiMAX might be adopted as a private network technology, but with the development of Wi-Fi Mesh technology, that day seems a long way off.

The initial WiMAX deployments will be carrier provided broadband wireless Internet access services to compete with cable modem and DSL. Longer term, Mobile WiMAX might provide an alternative to cellular data and possibly voice services, but that will prove to be a far more difficult market to crack. If the carrier market appears to be out of reach, WiMAX might shift its focus to private networks.

The purpose of this paper is to take an objective look at the wireless alternatives in the metro-area market and to provide a comparison among the WiMAX, Wi-Fi, and cellular technologies.

The Two Versions of WiMAX-Fixed and Mobile

The first factor contributing to the confusion surrounding WiMAX is the two different standards that share the name "WiMAX":

- Fixed Location WiMAX: This was the original focus for WiMAX development and is described in the IEEE 802.16-2004 specifications. Fixed location WiMAX would be used primarily to provide broadband wireless access service, but it could also be used to support other fixed-location applications like cellular/Wi-Fi backhaul or delivery of basic telephone service in hard to reach areas.

• Mobile WiMAX: The specifications for Mobile WiMAX are described in IEEE 802.16e- 2005. Mobile means that a user could move through the coverage area and their connection would be handed off from base station-to-base station like a cellular call.

Where the original fixed location WiMAX would provide a wireless alternative to compete with DSL or cable modem services, a mobile WiMAX offering would compete with the cellular carriers' 2.5G/3G services. The two are at vastly different stages of development. Products supporting the fixed location version are just reaching the market. The mobile standard has recently been ratified, but the certification plans need to be developed and Mobile WiMAX products are not expected before late-2007.

Where Does Wi-Fi Fit?

The development of Wi-Fi Mesh technology will result in a market overlap between Wi-Fi and WiMAX. The most typical Wi-Fi configuration is called the Basic Services Set or Infrastructure Mode. A Wi-Fi base station, called an access point, provides access from client stations within a range of 100 meters to a wired LAN or a cable modem/DSL router (e.g. Cisco/Linksys, Netgear, D-Link). In indoor environments, radio signals lose power passing through walls and interfere with one another as they reflect off hard solid surfaces (a problem called *multipath*). The result is that you rarely get the advertised 100-meter range.

The other rapidly developing Wi-Fi configuration is called a Wi-Fi Mesh. In a mesh configuration, a number of special access points are installed throughout an extended area; only one of those access points must be connected to the wired network. When a mesh access point receives a frame from a Wi-Fi compatible client, it relays the frame access point-to-access point until it reaches the unit with the wired connection.

A mesh access point supports two different wireless connections:

• Client Connection: To communicate with clients, the mesh access point will use a standard Wi-Fi interface, so any Wi-Fi equipped client device can access the network.

• Backbone Connection: A different radio link is used to relay the message to the station with the wired connection. In some cases that backbone will use a different radio frequency (e.g. 5 GHz versus 2.4 GHz), but in all cases it will use a proprietary protocol that is optimized for the mesh application. The IEEE is developing a standard for Wi-Fi Mesh networks called 802.11s, however that that specification will not be completed until late-2007.

While the Wi-Fi standards do not cover mesh configurations as yet, there are a number of mesh-based products already on the market from vendors like Cisco, Motorola/Mesh Networks, Tropos, PacketHop, Strix Systems and BelAir Networks.

A Wi-Fi Mesh can allow a user to build a wireless network that goes far beyond the fundamental 100-meter range. This technology has been used to build networks that cover entire metropolitan areas. In that configuration, a Wi-Fi Mesh would be an alternative to a fixed location WiMAX network. Most mesh products do not currently support handoffs, so they could not support true mobile services. There is a developing standard designated 802.11r that will support fast, secure handoffs on Wi-Fi networks, however that too is scheduled for late 2007.

While Wi-Fi Mesh networks have the advantage of supporting any of the tens of millions of existing Wi-Fi client devices, it takes a large number of mesh access points to cover an entire metropolitan area. With 7- to 20-mesh access points required per square mile, the Mesh network operator will have a lot of equipment to maintain.

WiMAX versus Wi-Fi Radio Technology

In technical terms, both Wi-Fi and WiMAX address Layers 1 and 2 of the Open Systems Interconnection (OSI) Reference Model. That's a fancy way of saying that the standards describe how the bits are encoded on the radio link (i.e. Layer 1), and the formats and rules that govern access to the channel (i.e. the Layer 2). First, let's look at the radio link or Layer 1 issues.

Wi-Fi versus WiMAX Frequency Bands

The most basic issue with radio spectrum is whether or not a license is required. Licensed spectrum gives the owner exclusive use of particular swath of frequencies in a particular area. Cellular services always use licensed bands, but the actual bands used vary by region. In all cases, the acquisition of radio licenses represents a significant investment.

The other choice is to use bands that the regulatory administrations have elected to define as unlicensed or license-exempt. The good news with unlicensed frequency bands is that they are free; the bad news is that they are available to everyone. The bands defined for unlicensed operation vary by country, though they typically are found in two regions: one around 2.4 GHz and another around 5 GHz. The IEEE 802.11 wireless LAN standards have versions that operate in each of the unlicensed radio bands. They share those bands with cordless phones, baby monitors, garage door openers, Bluetooth devices, and a raft of other applications, all of which create interference.

WiMAX is designed to operate in either licensed or unlicensed spectrum between 2 GHz and 66 GHz. The original version of the 802.16 standards, released in December 2001, addressed systems operating in the 10- to 66 GHz frequency band. The problem with those higher-frequency systems is that they require line-of-sight (LOS) between the base station and the client. In densely built urban areas, it is difficult to get line of sight to all potential customers. Further, with line-of-sight systems, customer antennas may have to be realigned when a new cell is added to the network.

In January 2003, the IEEE ratified the 802.16a standard that described systems operating between 2 GHz and 11 GHz. The lower portion of that band, particularly the frequencies between 2- and 6 GHz, can support non-line-of-sight (NLOS) operation. Virtually all planned WiMAX systems will operate in that 2- to 6 GHz region.

WiMAX vs. Wi-Fi Link Capacities

There has been considerable confusion regarding the transmission rate that can be provided on a WiMAX channel. A WiMAX radio might be able to support a data rate up to 70 M or 100 Mbps on a 20 MHz channel and a range up to 30 miles-- but not at the same time.

Adaptive Modulation

Both Wi-Fi and WiMAX make use of adaptive modulation and varying levels of forward error correction. Adaptive modulation means that the transmitter will reduce its transmission rate as the radio signal loses power or encounters interference. With adaptive modulation, the transmitter automatically shifts to a more robust, though less efficient, modulation technique in adverse conditions. The likelihood of encountering interference is greater in unlicensed systems.

Forward Error Correction (FEC)

The other element in adaptive modulation system is Forward Error Correction (FEC). In an FEC system, additional redundant bits are mixed into the transmitted signal increasing the overall bit rate. At the receiving end, an FEC processor uses those additional bits to detect errors and can then correct some percentage of them using a probability technique. The more overhead bits that are included, the higher the probability that the receiver will be able to correct an error. Along with adjusting the bandwidth efficiency, adaptive modulation schemes also provide different levels of FEC protection.

Wi-Fi Radio Links

The Wi-Fi standards describe three different radio link options, two of which operate in the unlicensed 2.4 GHz band and a third that operates in the unlicensed 5 GHz band. The 802.11b interface popularized Wi-Fi and it operates in the 2.4GHz band supporting a maximum data rate of 11 Mbps. The other 2.4 GHz interface is 802.11g and it supports a maximum rate of 54 Mbps. Devices with 802.11b and g interfaces can operate on the same network, but the throughput for the g devices is reduced substantially.

The 54 Mbps 5 GHz interface designated 802.11a is growing in popularity, albeit slowly. While it supports the same maximum data rate as 802.11g, use of the 5 GHz band allows 802.11a to provide 23- non-interfering channels (US implementation) versus 3- non-interfering channels in the 2.4 GHz band. The availability of additional channels is critically important in laying out a large-scale WLAN where channels must be reused in different parts of the facility.

The 802.11a and g interfaces use a transmission technique called Orthogonal Frequency Division Multiplexing (OFDM). The idea of an OFDM system is to divide the radio band into a number of sub-channels and divide the bit stream among them. In either 802.11 a or g, the 20 MHz channel is divided into 52 sub-carriers, with 48 Data Sub-Carriers and 4 Pilot Tones.

IEEE 802.11 Radio Link Interfaces						
Standard	**Max. Bit Rate**	**Fallback Rates**	**Channel Bandwidth**	**Channels Provided**	**Transmission Band**	**Radio Technique**
802.11b	11 Mbps	5.5 M, 2 M, and 1 Mbps	25 MHz	3	2.4 GHz	DSSS
802.11g	54 Mbps	Same as 802.11a plus 2 M, an 1 Mbps	20 MHz	3	2.4 GHz	OFDM
802.11a	54 Mbps	48 M, 36 M, 24 M, 18 M, 12 M, 9 M, and 6 Mbps	20 MHz	23	5 GHz	OFDM

The advantage of OFDM transmission is that it mitigates the multipath difficulties typically found in indoor environments.

There is also a developing radio link standard designated 802.11n, the draft for which specifies an OFDM system that will operate in either the 2.4 GHz or 5 GHz bands, supporting data rates up to 289 Mbps on a 20 MHz channel and 600 Mbps on a 40 MHz channel. While the draft has been accepted, the final standard is not scheduled for ratification until September 2007. Support for those very high data rates will require a multiple input-multiple output (MIMO) antenna system.

WiMAX Frequency Bands

Where all Wi-Fi implementations use unlicensed frequency bands, WiMAX can operate in either licensed or unlicensed spectrum. Carriers are attracted to licensed bands that will allow them to offer a service that will not be impacted by interference from other users. Within the 2- to 11 GHz range, there are a number of potential options:

* **Licensed 2.5 GHz Broadband Radio Service (BRS):** In the US, the FCC has allocated 195 MHz of licensed radio spectrum between 2.5-2.7 GHz for Broadband Radio Service (formerly called Multipoint Distribution Service [MDS]). Sprint and MCI used this band for their original point-to-point services.

* **Licensed 3.5 GHz Band:** A swath of licensed spectrum roughly equal to BRS has been allocated in the 3.4 to 3.7 GHz range throughout most of the rest of the world.

* **Unlicensed 3.5 GHz Band:** In the US, the FCC has recently moved to open an additional 50 MHz of unlicensed spectrum in the 3.65-3.70 GHz band for fixed location wireless services. Rules for using this spectrum are still being ironed out.

* **Unlicensed 5 GHz Band:** In the US, 555 MHz of unlicensed frequency has been allocated in the 5.150–5.350 GHz and 5.470–5.825 GHz bands. That spectrum, called the Unlicensed National Information Infrastructure (U-NII) band, is the same band used for 802.11a wireless LANs.

- **700 MHz Band:** With the migration to digital broadcast television in the US, 108 MHz of radio spectrum between 698 MHz and 794 MHz will be freed up. That spectrum had carried TV channels 52 through 69. Some 24 MHz of that spectrum (Channels 63-64, 68-69) is being reassigned for Public Safety, and 84 MHz (Channels 52-62, 65-67) will be auctioned for new applications. While there is no WiMAX standard for operation in these bands, that can be developed. Importantly, a 700 MHz radio signal will travel about 4-times the distance of a 2.4 GHz radio (with equivalent signal loss) and has better wall penetration characteristics. That means a 700 MHz network would require far fewer base stations.

WiMAX Radio Links

The WiMAX standards define three options for the radio link:
* **SC-A:** Single Carrier Channel
* **OFDM:** 256-Sub-Carrier Orthogonal Frequency Division Multiplexing
* **SOFDM-A:** Scalable OFDM with 2,048-Sub-Carriers

The first products will support fixed-location systems, and they will use the 256-Sub-Carrier OFDM option. The WiMAX Forum has developed test suites and interoperable test plans for this option. Currently there are two certification test labs in the world, and the first certified products were announced in early-2006.

Channel Bandwidth
The Wi-Fi standards define a fixed channel bandwidth. The bandwidth of an 802.11b channel is 25 MHz and an 802.11a or g is 20 MHz. WiMAX channel bandwidths are adjustable from 1.25 MHz to 20 MHz. That will be particularly important for carriers operating in licensed spectrum. The transmission rate of that channel will be determined by the signal modulation that is used.

WiMAX Link Capacity
Many articles have referenced WiMAX transmission rates up to 70 M or 100 Mbps. That assumes a 20 MHz channel and a bandwidth efficiency of 3.5- or 5-bits/second/Hz. That is rather optimistic, even for a fixed-location service. Bandwidth efficiency decreases with distance, and at a range of 3- to 5-miles (the initial planning range for a WiMAX cell), the efficiency would be more on the order of 2.5 bits/second/Hz, or 50 Mbps in a

IEEE 802.16- 2004 Modulation Options

Modulation	Uplink	Downlink	FEC Coding	Bits/Symbol
BPSK	Mandatory	Optional	1/2, 3/4	1/2, 3/4
QPSK	Mandatory	Mandatory	1/2, 2/3, 3/4, 5/6, and 7/8	1, 4/3, 3/2 5/3, and 7/4
16-QAM	Mandatory	Mandatory	1/2, 3/4	2, 3
64-QAM	Optional	Mandatory	2/3, 5/6	4, 5
256-QAM	Optional	Optional	3/4, 7/8	6, 7

SOFDMA Scalability Parameters					
System Bandwidth (MHz)	1.25 MHz	2.5 MHz	5 MHz	10 MHz	20 MHz
Sampling Frequency (*Fs,MHz*)	1.429	2.85	5.714	11.429	22.857
Sample time (1/*Fs,nsec*)	700	350	175	88	44
FFT size (Sub-channels)	128	256	512	1024	2048
Subcarrier Frequency Spacing	11.1607 kHz				

20 MHz channel. There are lots of variables in that equation. As a general rule, we can assume that the bandwidth efficiency of a Mobile WiMAX device will be poorer, as the path between the client and the base station changes continuously as the client moves.

Mobile WiMAX Radio Link
With regard to the Mobile WiMAX service, about the only thing that is clear is that it will use the SOFDMA interface. The channel bandwidth, channel capacity, and most importantly, user capacity are as yet undefined. What is clear is that the Mobile WiMAX radio link will not be compatible with the fixed solution.

Other WiMAX Radio Link Features
WiMAX also incorporates features to provide flexibility and to take advantage of emerging antenna technologies.

- Duplex Operation: In a Wi-Fi network, all users take turns using the same channel, which results in a half duplex operation (i.e. stations cannot send and receive at the same time). In radio systems, that type of operation is called time division duplex or TDD. WiMAX has options to support both TDD and frequency division duplex (FDD) where separate channels are assigned for inbound and outbound operation. That flexibility is important in licensed operation where a carrier may have a minimum amount of spectrum available.

- Advanced Antenna Technologies: To improve overall range and performance, an optional Space Time Coding feature allows the use of multiple transmit antennas at the base station and a subscriber unit that combines the two signal images. Longer term, the WiMAX radio link can incorporate the same type of MIMO antenna system as Wi-Fi's 802.11n.

Summary of 802.16 Radio Links			
	802.16	**802.16- 2004**	**802.16e- 2005**
Spectrum	10 – 66 GHz	2 – 11 GHz	<6 GHz
Configuration	Line of Sight	Line of Sight Non- Line of Sight	Non- Line of Sight
Bit Rate	32 to 134 Mbps (28 MHz Channel)	≤ 70 or 100 Mbps (20 MHz Channel)	Up to 15 Mbps
Modulation	QPSK, 16-QAM, 64-QAM	256 Sub-Carrier OFDM using QPSK, 16-QAM, 64-QAM, 256-QAM	Scalable OFDMA
Mobility	Fixed	Fixed	≤65 MPH
Channel Bandwidth	20, 25, 28 MHz	Selectable 1.25 to 20 MHz	5 MHz (Planned)
Typical Cell Radius	1-3 miles	3-5 miles	1-3 miles

WiMAX Coverage Plan
The radio coverage plan for WiMAX would be similar to a cellular network. The initial cells would have a radius of 3- to 5-miles, and cells could be divided into sectors. As the traffic grows, busy cells could be divided into a group of smaller cells. As the networks are relatively small today, there has been little need to expand.

MAC Protocol/ Quality of Service (QoS)

The greatest differences between Wi-Fi and WiMAX can be seen in their media access protocols. The two access mechanisms spring from completely different environments. Wi-Fi's fundamental operation is an adaptation of Ethernet's CSMA/CD contention system where users vie or contend to use a shared channel. The result is that transmissions from different stations can collide, increasing delays and creating additional traffic with retransmissions.

The WiMAX standards describe a media access control (MAC) protocol with its roots in the DOCSIS cable modem standards. Like the 2.5G/3G cellular protocols, WiMAX base stations control access to the inbound channel. There are two primary advantages to that centrally controlled allocation mechanism: inbound collisions can be eliminated and it is possible to provide finely tuned quality of service (QoS) features.

Wi-Fi CSMA/CA
Wi-Fi uses a media access control protocol called Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA). While it was modeled on Ethernet, the fundamental problem in a Wi-Fi network is that the stations cannot "hear" while they are sending, As a result, it is impossible to detect collisions. Because of this, the developers of the 802.11 specifications came up with a collision avoidance

mechanism called the Distributed Control Function (DCF).

Distributed Control Function (DCF)
The basic idea in DCF is that stations collaborate to help avoid collisions. DCF uses a system of waiting intervals and back-off timers in place of Ethernet's simple collision detection mechanism. A Wi-Fi station will transmit only if it thinks the channel is clear, but the station always waits a defined interval (called an Inter-Frame Spacing) before it begins transmitting. As it is impossible to detect collisions, all transmissions are acknowledged; if a station does not receive an acknowledgement, it assumes a collision occurred and retries after a random waiting interval. As with other contention systems, the network throughput will decrease as the traffic increases.

Wi-Fi 802.11e Quality of Service (QoS)
One of the key developments in the Wi-Fi MAC was the 802.11e standard for Quality of Service (QoS). The overall idea is to provide a mechanism to prioritize access to the shared channel so that time-sensitive IP voice and video frames get the service they require. There are two options defined within the standard:

- Enhanced Distributed Control Access

- Hybrid Controlled Channel Access

Enhanced Distributed Control Access (EDCA) is an enhanced version of the Distributed Control Function (DCF). The "enhanced" part is that EDCA will define four levels of access priority to the shared wireless channel. The four access categories are called:

- Voice
- Video
- Data (Equal to legacy devices)
- Background Data

Like the original DCF, the EDCA access is a contention-based protocol that employs waiting intervals and back-off timers designed to avoid collisions. In the original DCF, all stations use the same values and hence have the same transmission priority. With EDCA however, each of the different access categories is assigned a different waiting interval and a different range of back-off counters. Transmissions with higher access priority are assigned shorter intervals. As a result, if a voice user and a data user are waiting to access the channel, the voice user will always get to transmit first. While voice users get a higher priority than data users, all voice users vie for the channel on an equal basis so two voice users can still collide.

The standard also includes a "bursting mode" that allows a station can send all of the packets that constitute a speech burst on a single access opportunity. All of these features are designed to minimize (though not eliminate) delay and jitter on IP voice connections.

The 802.11e standard also defines a Hybrid Controlled Channel Access (HCCA) mode, which would allow the network to provide a consistent delay service. In HCCA, the access point periodically broadcasts a control message that forces all stations to treat the channel as busy. During that reserved period, the access point polls each station that requires time sensitive service. Most manufacturers are not planning to include this capability initially.

WiMAX Channel Access

Even with EDCA, Wi-Fi stations are vying for access to the channel on a contention basis, which leads to increased delay and jitter. Based on tests done by Miercom[1], when used in conjunction with an IP PBX, WLAN phones add roughly 20- to 30-msec of latency.

The WiMAX MAC uses an inbound Request/Grant access mechanism. Outbound transmissions are broadcast to all stations in a format that includes an address. Each station picks off the frames addressed to it. Stations wishing to access the inbound channel send a request to the base station who in turn grants that user exclusive use of some portion of the inbound transmission capacity for a period of time. As the base station controls all inbound transmissions, it can eliminate inbound collisions and support a variety of consistent-delay and variable-delay services.

WiMAX QoS Capability

As inbound access is controlled by the base station, the WiMAX access protocol can support Quality of Service (QoS) for four types of traffic:

- **Unsolicited Grant Service (UGS):** Consistent delay (i.e. isochronous) service for real-time voice and video, where a station is allocated dedicated inbound transmission capacity.

- **Real Time Polling Service (rtPS):** Another real-time service that operates like the 802.11e's Hybrid Controlled Channel Access (HCCA), where the base station polls each user on a scheduled basis.

- **Non-Real Time Polling Service (nrtPS):** Variable-delay data service with capacity guarantees akin to frame relay's Committed Information Rate for high-priority commercial users.

- **Best Effort:** An IP-like best effort data service for residential Internet users.

OFDM Sub-carrier Allocation

While both Wi-Fi and WiMAX use OFDM, the WiMAX version adds a new twist. With Wi-Fi, the entire capacity of the channel is used by a single transmitter. With WiMAX, the entire inbound capacity can be allocated to one user, or groups of sub-carriers can be assigned to different users allowing multiple (up to 16) simultaneous inbound transmissions to be supported.

[1] E Mier, D Mier, R Tarpey. "Which Large IP-PBX Rules" Business Communications Review, January 2005, page 24.

Wi-Fi Security Features

The other major difference between Wi-Fi and WiMAX is privacy or the ability to protect transmissions from eavesdropping. Security has been one of the major deficiencies in Wi-Fi, though better encryption systems are now becoming available. In Wi-Fi, the user must activate the encryption, and three different techniques have been defined:

- **Wired Equivalent Privacy (WEP):** An RC4-based 40- or 104-bit encryption typically deployed with a static key. The relatively weak encryption and the use of a static key makes WEP extremely vulnerable to brute force attacks (i.e. guessing the key by trial-and-error). Free tools like AirSnort can crack a WEP key with a sample of a few million packets. More sophisticated attacks can crack the key in a matter of minutes.

- **Wi-Fi Protected Access (WPA):** A newer security standard from the Wi-Fi Alliance that uses the RC4 encryption with a 128-bit key, but changes the key on each packet to thwart key-crackers. That changing key function is called the Temporal Key Integrity Protocol (TKIP). Most devices can be upgraded to WPA capability with a software download.

- **IEEE 802.11i/WPA2:** The most secure Wi-Fi solution is described in the IEEE 802.11i standard, which is based on a far more robust encryption technique called the Advanced Encryption Standard (AES). The Wi-Fi Alliance designates 802.11i compatibility as *WPA2-Certified*. To insure adequate performance, encryption is typically done in a hardware device (i.e. a chip), and very few of the existing Wi-Fi cards include that hardware. As a result, implementing 802.11i will typically require buying new Wi-Fi cards for all existing devices. Starting in mid-2006, the Wi-Fi Alliance will require 802.11i compatibility in all new Wi-Fi Certified devices. However, the requirement to buy new cards for all existing devices will very likely slow the migration to 802.11i.

WiMAX Security

In a WiMAX network, the network operator will define the encryption mechanism used. Given that it was designed for public network applications, we expect that virtually all WiMAX networks will use encryption. The initial specification calls for the use of 168-bit Digital Encryption Standard (3DES), the same encryption used on most secure tunnel VPNs. There are also plans to incorporate the Advanced Encryption Standard (AES).

As a result, we anticipate none of the security concerns that plagued early Wi-Fi implementations.

Comparison of Fixed Location WiMAX and Wi-Fi Technologies			
	Fixed WiMAX (802.16-2004)	**Wi-Fi (802.11b)**	**Wi-Fi (802.11a/g)**
Primary Application	Broadband Wireless Access	Wireless LAN	Wireless LAN
Frequency Band	Licensed/Unlicensed 2 G to 11 GHz	2.4 GHz ISM	2.4 GHz ISM (g) 5 GHz U-NII (a)
Channel Bandwidth	Adjustable 1.25 M to 20 MHz	25 MHz	20 MHz
Half/Full Duplex	Full or Half (FDD, TDD)	Half	Half
Radio Technology	OFDM (256-channels)	Direct Sequence Spread Spectrum	OFDM (52-channels)
Bandwidth Efficiency	≤5 bps/Hz	≤0.44 bps/Hz	≤2.7 bps/Hz
Modulation	BPSK, QPSK, 16-, 64-, 256-QAM	QPSK	BPSK, QPSK, 16-, 64-QAM
FEC	Convolutional Code Reed-Solomon	None	Convolutional Code
Encryption	Mandatory- 3DES Optional- AES	Optional- RC4 (WEP) RC4 + TKIP (WPA) AES (802.11i/WPA2)	Optional- RC4 (WEP) RC4 + TKIP (WPA) AES (802.11i/WPA2)
Access Protocol	Request/Grant	CSMA/CA	CSMA/CA
- Best Effot	Yes	Yes	Yes
- Data Priority	Yes	802.11e EDCA	802.11e EDCA
- Consistent Delay	Yes	802.11e HCCA	802.11e HCCA
Mobility	Mobile WiMAX (802.16e)	In development (802.11r)	In development (802.11r)
Mesh	Yes	Vendor Proprietary 802.11s Planned	Vendor Proprietary 802.11s Planned

WiMAX Markets

Now that we know what WiMAX is designed to do, it's time to look at what it will do. The market's view of WiMAX has been confused by the range of applications it can support and the poor job the WiMAX Forum has done at explaining it. In essence, the planned implementations for WiMAX would address three primary markets:

1. Fixed-location WiMAX/ Broadband Wireless Access
2. Nomadic WiMAX
3. Mobile WiMAX

In each of these markets WiMAX will face a different set of challenges and a different sets of competitors.

1. Fixed Location WiMAX/ Broadband Wireless Access

The first mass-market application for WiMAX would be broadband wireless access (BWA) or *wireless DSL*. Offering data rates between 512 Kbps and 1.5 Mbps, this Internet access service would be targeted at residential and small business customers. It is likely that carriers looking to offer BWA will gravitate toward licensed systems operating in the BRS band. Current offerings include a mix of licensed and unlicensed systems. In this market, WiMAX would compete with other broadband Internet technologies like DSL, cable modems, and satellite Internet access. The emerging Wi-Fi Mesh networks might also be competitors, though it remains to be seen how effective that technology will be at penetrating indoor environments.

There are already a number of small Internet providers that sell broadband wireless access using equipment from companies like Airspan, Alvarion, Motorola, NextNet Wireless, Proxim, and Qualcomm/Flarion. The current systems do not employ the WiMAX standards; those systems are typically described as *Pre-WiMAX*. Many of those vendors have announced their intention to provide WiMAX-compatible systems, however, the WiMAX certification process was slow getting started, and the first certified products only appeared in early 2006.

According to BBWExchange.com, Clearwire Communications and MobilePro are the two largest providers with 20,000 subscribers each. Typically these carriers target small and rural markets where DSL and cable modem services are not available. In those markets, the only competitors will be the satellite Internet providers.

The carriers will have to decide if and when they migrate to true WiMAX-based services, and what they will do with their existing customers who are all served with pre-WiMAX systems. The hope is that the introduction of WiMAX-based products will yield better and more feature-rich services, and will also lead to lower equipment prices. Currently, customer premises equipment (CPE) BWA radio modems cost between $300 and $500, though that cost is often buried in the monthly service fee. One key challenge is developing user-installable radio modems that do not require an outdoor antenna for reliable operation. As the cellular carriers have discovered, indoor radio coverage is inherently problematic, and the first wave of WiMAX products will not include MIMO antenna technology.

Clearwire Communications currently offers residential BWA service in about 25 mid-size cities. Two downstream speeds are offered, 512 K and 1.5 Mbps with monthly charges including modem rental of $29.98 and $39.98 respectively. That would put them at the high-end of the DSL price scale, but cheaper than most cable modem services. Those cable modem services typically deliver significantly higher data rates. Interestingly, the service does not employ over-the-air encryption, but depends on the proprietary nature of the NextNet Wireless radio equipment to deter eavesdropping.

There have also been a number of WiMAX trials announced by large carriers, though none has yet been expanded to a full-fledged service offering. The local telephone companies including Verizon and SBC are testing WiMAX as a way to expand their broadband coverage to smaller markets where it has not been cost effective to deploy DSL. Internet service provider Earthlink, who is becoming a player in the Municipal Wi-Fi Mesh market, has announced plans to test WiMAX, though no details have been released. AT&T and MCI had earlier announced plans to test WiMAX services, however as they have now been acquired by SBC and Verizon respectively, those decisions will be made by the new parents.

There are other potential markets for a fixed-location WiMAX service. Recognizing the proliferation of Hot Spots, WiMAX is also being positioned as a means of aggregating that traffic and backhauling it to a central, high-capacity Internet connection. There is also a potential market for point-to-point systems in developing countries, where they can be used to deliver basic telephone service in hard-to-reach areas.

While WiMAX could potentially support point-to-point applications, clearly the major market being targeted is broadband access. The question is whether the WiMAX carriers will be willing and able to compete head-to-head with the established DSL and cable modem providers. A WiMAX network should be cheaper to deploy, however WiMAX carriers will have to bear the same marketing and customer support costs as any other broadband carrier. Further, if they are operating in licensed spectrum, the cost of acquiring the required spectrum could be significant. Thus far the WiMAX carriers seem to be confining their marketing efforts to smaller, underserved markets, which strategy will insure they remain a distant third in the broadband access market.

2. Nomadic WiMAX

While the market's attention has leapt from fixed to mobile WiMAX, there is an important intermediary step we call *Nomadic WiMAX*. A nomadic service would allow a user to access the service anywhere in the coverage area rather than just at home. The service would be *nomadic* rather than *mobile,* as it would not support hand-offs as the user moved through the service area. The target device would be a laptop with a built in WiMAX radio modem. Intel has promised to include both WiMAX and Wi-Fi capability in their next generation Centrino chip. As the WiMAX radio would now be powered by the laptop's battery, power consumption will become a concern. Longer term, PDAs, MP3 players, and even voice handsets may be potential nomadic stations in a model that begins to resemble cellular data networks.

Nomadic service would put WiMAX in competition with the emerging municipal Wi-Fi Mesh services and the 2.5G/3G cellular data offerings. WiMAX would also compete with traditional Wi-Fi Hot Spot services, though nomadic WiMAX would be far more comprehensive as the service would be available throughout the area and not just at Hot Spot locations.

A combined fixed/nomadic WiMAX offering would be a strong competitor to DSL or cable modems as it could support the user at home and on the go. To deliver a nomadic service, the DSL and cable modem carriers would have to partner with a Hot Spot provider or someone who has wide area wireless coverage. A nomadic service would be easier to deploy than a mobile service as it would use the same base station equipment. In essence, all that would be needed is a mechanism to authenticate the user before they could join the network. The carrier would have to insure that they have adequate capacity and radio coverage throughout the area. Capacity planning would be more challenging as it might be difficult to predict where nomadic users may wish to connect to the network. While there are no nomadic offerings today, they should be able to support the same data rates as a fixed service.

3. Mobile WiMAX

While WiMAX was originally conceived as a fixed-location wireless technology, the development of the 802.16e standard provides a true mobile technology designed to support zero-loss hand-offs at speeds up to 65 MPH. While the standard has been ratified, mobile WiMAX products are not expected until 2007 or 2008. That would mean that mobile services should not be anticipated before 2008 at the earliest.

It is important to note that mobile WiMAX will use a completely different radio link than the fixed-location version, which means it will require different base stations and client devices. The initial description called for a maximum cell radius around 3 miles, and a user data rate in the order of 500 Kbps. The primary competition would be the cellular carriers' 2.5G/3G offerings. As the newer cellular data services (e.g. HSDPA and 1xEV-DO Rev A) are delivering data rates in the 500 K to 700 Kbps range, mobile WiMAX may have to crank up the bit rate to stay in the game.

Summary of 2.5G/3G Cellular Data Services

	GSM-based Networks				**CDMA-based Networks**		
	GPRS	**EDGE**	**WCDMA**	**HSDPA**	**1xRTT**	**1xEV-DO**	**1xEV-DO Rev A**
Radio Access	TDMA	TDMA	CDMA	CDMA	CDMA	CDMA	CDMA
Theoretical Rate (bps)	170 K	473.6/ 384 K	2.4M/ 307 K	14 M	144 K	2.4M/ 153 K	3.1 M/ 1.8 M
Actual Rate (bps)	20-40K	100-120 K	200-250 K	500-700 K	50-70 K	300-500 K	500-700K

WiMAX will have a tough time competing with cellular. While some have argued that the WiMAX base station equipment will be cheaper, the WiMAX carriers will be starting from scratch; the cellular carriers have been growing their networks for over a decade. Operating at a higher frequency, a mobile WiMAX network will require more base stations to provide reliable coverage. Further, with a fixed location service, a WiMAX carrier could deploy the service area-by-area and use revenues from earlier customers to help fund later network build outs. By definition, a mobile service will have to be deployed over a fairly wide area before it becomes marketable. That reality makes it appear that we will probably not see widespread deployment of mobile WiMAX services before the end of the decade.

In terms of location, mobile WiMAX will have to battle the cellular carriers head on. Fixed location services can avoid competition by targeting underserved areas, but there would not be enough potential business in those areas to support a mobile service. For the time being, broadband cellular services are priced at a premium, typically $60 per month for the 500+ Kbps services. However, the cellular carriers know they have a unique offering and they can charge whatever the market will bear. If potential mobile WiMAX carriers base their business plans on charging a similar price, they will be in for a rude surprise when the cellular carriers start cutting prices to compete.

Mobile WiMAX has also had the effect of overhanging the fixed location market. Why should anyone pay attention to the fixed-location technology you have, when you are telling them there's something better on the horizon? Mobile WiMAX has a long uphill road to catch up with the cellular carriers, and you can be sure that the cellular industry is not going to roll over and play dead.

Conclusion

WiMAX is targeting the perilous middle ground between two well-established wireless technologies, Wi-Fi and cellular. While it does incorporate a high degree of flexibility in terms of operating bands, channel bandwidth, and quality of service capabilities, WiMAX has a long way to go in terms of business.

As a LAN technology, Wi-Fi required minimal infrastructure investment, and the client interface has become a standard feature in laptops. The cellular network has a massive infrastructure and over 160 million paying customers in the US. WiMAX will require an infrastructure similar to a cellular network, and a range of client devices similar to Wi-Fi- that's a lot to ask.

On paper, WiMAX looks like a strong contender, but there's a vast gulf between there and a profitable service. The WiMAX Forum has missed virtually every date they have announced, and their promotional efforts have left the market scratching its head. WiMAX needs someone to step-up with some big money investments in network infrastructure, or this is a wireless technology that will languish in the hinterland.

Glossary of Acronyms

AES: Advanced Encryption Standard
BPSK: Binary Phase Shift Keying
BRS: Broadband Radio Service
BWA: Broadband Wireless Access
CDMA: Code Division Multiple Access
CIR: Committed Information Rate
CSMA/CA: Carrier Sense Multiple Access with Collision Avoidance (Wi-Fi)
CSMA/CD: Carrier Sense Multiple Access with Collision Detection (Ethernet)
DCF: Distributed Control Function
DES: Digital Encryption Standard
DSL: Digital Subscriber Line
DSSS: Direct Sequence Spread Spectrum
EDCA: Enhanced Distributed Control Access
EDGE: Enhanced Data Rates for GSM Evolution
ETSI: European Telecommunications Standards Institute
EV-DO: Enhanced Version-Data Only (Data Optimized)
FCC: Federal Communications Commission
FDD: Frequency Division Duplex
FDX: Full Duplex
FEC: Forward Error Correction
FHSS: Frequency Hopping Spread Spectrum
HSDPA: High-Speed Downlink Packet Access
GPRS: Generalized Packet Radio Service
HCCA: Hybrid Controlled Channel Access
Hz: Hertz (Prefixes: Kilo = Thousands, Mega = Millions, Giga = Billions)
IEEE: Institute of Electrical and Electronic Engineers
IP: Internet Protocol
ISM: Industrial, Scientific, and Medical
LAN: Local Area Network
MAC: Media Access Control
MIMO: Multiple Input-Multiple Output
MDS: Multipoint Distribution Service
NLOS: Non-Line-of-Sight
nrtPS: Non-Real Time Polling Service
OFDM: Orthogonal Frequency Division Multiplexing
x-QAM: x-level Quadrature Amplitude Modulation
QoS: Quality of Service
QPSK: Quadrature Phase Shift Keying
RC4: Ryvest Cipher-4
rtPS: Real Time Polling Service
RTT: Radio Transsmission Technique
SOFDMA: Scalable Orthogonal Frequency Division Multiplexing
TDD: Time Division Duplex
TKIP: Temporal Key Integrity Protocol
UGS: Unsolicited Grant Service
U-NII: Unlicensed National Information Infrastructure
VoIP: Voice over IP
VPN: Virtual Private Network
WCDMA: Wideband CDMA
WEP: Wired Equivalent Privacy
Wi-Fi: Wireless Fidelity
WiMAX: Worldwide Interoperability for Microwave Access
WISP: Wireless Internet Service Provider
WLAN: Wireless LAN
WPA: Wi-Fi Protected Access

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