WiMax versus Wi-Fi

A Comparison of Technologies, Markets, and Business Plans

Michael F. Finneran
dBrn Associates, Inc.
Telephone: (516) 569-4557
Email: mfinneran@att.net

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Wireless LANs based on the IEEE 802.11 or Wi-Fi standards have been a resounding success, and now the focus in wireless is shifting to the wide area. While Wi-Fi has virtually obliterated all other contenders in the local area, the wide area market is still up for grabs.

The cellular carriers got into the market first with their 2.5G/3G data services, but their offerings are positioned as an add-on to what is essentially a voice service. Sales have been lackluster to say the least. The real challenge to the cellular data services will come from the two emerging data-oriented technologies, WiMax and Mobile-Fi. With chip-level components due for shipment in the last quarter of 2004, WiMax will be the next to debut.

WiMax, short for Worldwide Interoperability for Microwave Access, is defined in IEEE 802.16 standards, and is being promoted by the WiMax Forum. The 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, a European Telecommunications Standards Institute (ETSI) initiative called HIPERMAN addresses the same area as WiMax/802.16 and shares some of the same technology.

With increased market recognition for WiMax, it is now regularly compared with Wi-Fi. While the two do indeed share some fundamental technical characteristics, they are approaching the wireless space from completely different perspectives. Further, different design approaches will make it unlikely that the two will actually compete except by coincidence. The purpose of this paper is to provide a technical and market comparison of the Wi-Fi and WiMax technologies highlighting their similarities and fundamental differences, and to identify the applications each will address in the coming years.

WiMax/Wi-Fi Market Overview

The most fundamental difference between WiMax and Wi-Fi is that they are designed for totally different applications. Wi-Fi is a local network technology designed to add mobility to private wired LANs. WiMax, on the other hand, was designed to deliver a metro area broadband wireless access (BWA) service. The idea behind BWA is to provide a fixed location wireless Internet access service to compete with cable modems and DSL. So, while Wi-Fi supports transmission ranges up to a few hundred meters, WiMax systems could support users at ranges up to 30 miles.

This difference in focus helps to explain why there has been less "market buzz" surrounding WiMax. Where Wi-Fi marketing targeted the end user, WiMax is intended as the basis of a carrier service. As a result, the WiMax Forum has been working primarily with component and equipment suppliers to develop base stations and premises equipment that carriers will use to deliver the service.

The market view of WiMax has also been confused by the range of applications for which it has been proposed. According to Margaret LeBrecque, Marketing Manager for the Broadband Wireless Division at Intel Capital, and former president of the WiMax Forum, three major phases in development are anticipated:

* **Phase 1--Fixed Location Private Line Services or Hot Spot Back-haul**: The initial application for WiMax type technology is a service that provides traditional dedicated-lines at transmission rates up to 100 Mbps using outdoor antennas. These systems typically use radio equipment that pre-dates the WiMax standards. Companies like TowerStream offer wireless Internet access at speeds ranging from fractional T1 to 100 Mbps (see "TowerStream Delivers").

  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. Equipment suppliers have also found a market for these point-to-point systems internationally, where they are used for cellular backhaul or to deliver basic telephone service in hard-to-reach areas.

* **Phase 2--Broadband Wireless Access/Wireless DSL:** The first mass-market application for WiMax would be broadband wireless access or *wireless DSL*, offering data rates between 512 Kbps and 1 Mbps. The key will be to deliver low-cost, indoor, user installable premises devices that will not have to be aligned with the base station--the antenna in the premises equipment would be integrated with the radio modem. In the late 1990s, Sprint and MCI pioneered this type of service, deploying point-to-point systems in about a dozen markets. They subsequently shelved the idea while waiting for a functional non-line-of-sight radio technology like the one described in the WiMax standards.

  Currently dozens of small-scale BWA services are cropping up around the country using pre-standard WiMax technology. The website BBWExchange.com lists the top 10 wireless access suppliers in the U.S., the largest being DTN Speed of Omaha, with 5,100 subscribers as of April 2004.

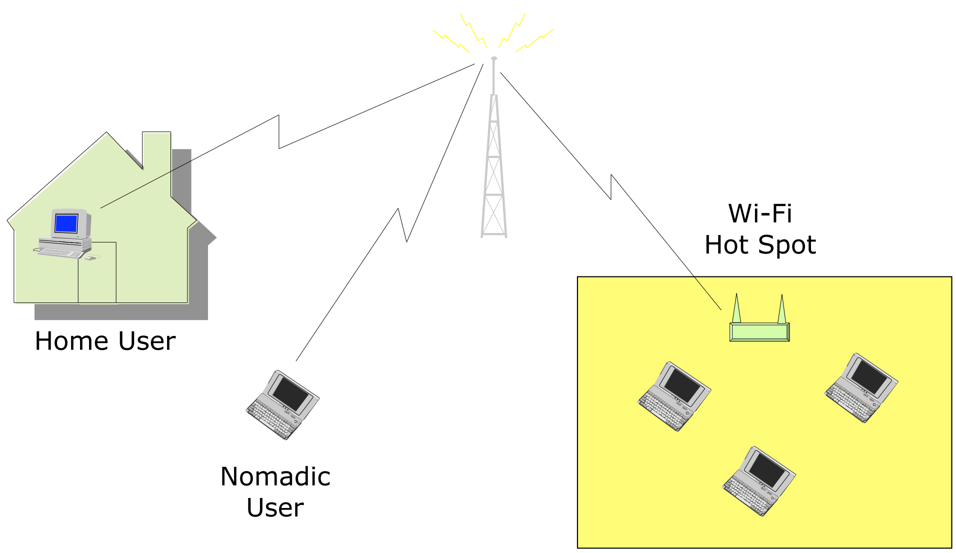
  The WiMax Forum hopes to see that figure grow exponentially when larger carriers begin deploying networks using low-cost (≤$200), silicon-based products early next year. Currently Verizon, Bell South, Nextel, and Earthlink are all testing BWA services.

* **Phase 3- Mobile/Nomadic Users:** Initially, WiMax was conceived as a fixed-location wireless technology. However, with the use of lower frequencies (2-11 GHz), and the development of the IEEE 802.16e Mobile WiMax standard, the technology could also support mobile subscribers traveling at speeds up to 75 mph. The mobile service will operate in the lower part of the band (<6 GHz), and will use the same access protocol as the

fixed-location systems. The mobile service is planned to operate on a shared 15-Mbps channel, supporting user data rates around 512 Kbps.

According to Margaret LeBrecque, Wi-Fi and Mobile WiMax could potentially be supported on the same card, so a user could access the Internet in a 100-meter hot spot or a 6-km WiMax *Hot Zone*. The 802.16e specifications are expected by the end of 2004, and this will put WiMax in direct competition with 2.5G/3G cellular services and the emerging IEEE 802.20 or Mobile-Fi standard for Mobile Broadband Wireless Access.

Figure 1: A WiMax Cell



TowerStream Delivers

While many potential carriers are waiting for lower-cost WiMax-compatible radio equipment, TowerStream has been delivering wireless Internet access to commercial customers for almost four years. According to CEO Phil Urso, the company currently operates networks in six markets including New York, Boston and Chicago, with plans to expand.

A citywide network typically includes several points of presence (POPs) interconnected by point-to-point 18-GHz radio links with connections to two or more ISPs. The POPs are connected in a ring configuration with an automatic fail-over that provides SONET-like recovery.

Each POP covers a cell with a radius of about 10 miles, and connects customers on links that range from 512 kbps to 100 Mbps. According to COO Jeff Thompson, the customer access uses a pre-standard version of 802.16 that offers many of the same capabilities, including QOS support. Rather than the WiMax preferred 256-channel OFDM, their systems use a single-carrier TDD radio link that provides flexible frequency reuse. Access links operate in the unlicensed 5-GHz U-NII band using either line-of-sight or non-line of sight radio equipment, depending on the transmission rate required. To improve reliability, each customer site is homed on multiple base stations, and switchover takes less than a second. So the network features both backbone and access redundancy.

The company claims 600 customers, from financial services to universities and hospitals. In one case, the Boston Public Library dropped a 32-node frame relay network and replaced it with an MPLS-based VPN service using TowerStream's radio access network.

WiMax versus WiFi Radio Technology

Besides the obvious difference in transmission range, there are a number of improvements in the radio link technology that distinguish WiMax from WiFi. The IEEE 802.11 wireless LAN standards describe four radio link interfaces that operate in the 2.4 G or 5 GHz unlicensed radio bands; the four are summarized in Table 1. The WiMax standards include a much wider range of potential implementations to address the requirements of carriers around the world. The original version of the 802.16 standard, released in December 2001, addressed systems operating in the 10-66 GHz frequency band. Those high-frequency systems require line-of-sight (LOS) to the base station, which increases cost and limits the customer base. Further, in line-of-sight systems, customer antennas must be realigned when a new cell is added to the network.

We will focus primarily on the 802.16a standard released in January 2003 that describes systems operating between 2 GHz and 11 GHz. The lower frequency bands support non-line-of-sight (NLOS), eliminating the need to align the customer unit with the base station.

Table 1- IEEE 802.11 WLAN Radio Link Interfaces

Standard	Maximum Bit Rate	Fallback Rates	Channels Provided	Frequency Band	Radio Technique
802.11	2 Mbps	1 Mbps	3	2.4 GHz	FHSS or DSSS
802.11b	11 Mbps	5.5 Mbps 2 Mbps 1 Mbps	3	2.4 GHz	DSSS
802.11a	54 Mbps	48 Mbps 36 Mbps 24 Mbps 18 Mbps 12 Mbps 9 Mbps 6 Mbps	12	5 GHz	OFDM
802.11g	54 Mbps	Same as 802.11a	3	2.4 GHz	OFDM

WiMax Frequency Bands

Where all WiFi implementations use unlicensed frequency bands, WiMax can operate in either licensed or unlicensed spectrum. Within 802.16a's 2-11 GHz range, four bands are particularly attractive:

* **Licensed 2.5-GHz MMDS:** In the U.S., the FCC has allocated 200 MHz of licensed radio spectrum between 2.5-2.7 GHz for Multichannel Multipoint Distribution Service (MMDS). 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 MMDS 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 U.S., 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.

* **Unlicensed 5 GHz U-NII Band:** In the U.S., 555 MHz of unlicensed frequency has been allocated in the 5.150–5.350 GHz and 5.470–5.825 GHz bands. That spectrum is called the Unlicensed National Information Infrastructure (U-NII) band, the same band used for 802.11a wireless LANs. The allocation was increased from 300 MHz to 555 MHz by an FCC order in November 2003.

Dynamic Frequency Selection

While carriers might be leery of delivering a service using an unlicensed band, the WiMax standards incorporate a Dynamic Frequency Selection feature where the radio automatically searches for an unused channel. In remote areas, the chance of interference should be minimal.

WiMax FDD/TDD Options

Another confusing attribute of WiMax is the range of options that were included to accommodate the various carrier requirements around the world. First, WiMax systems can be configured for dual-channel (inbound/outbound) Frequency Division Duplex (FDD) or single channel Time Division Duplex (TDD) operation. In TDD operation, separate timeslots are assigned for inbound and outbound transmissions so the channel is essentially full duplex. While it does reduce the transmission rate by more than 50%, TDD systems use half the radio bandwidth of FDD systems. The WiMax standards also define an optional mesh configuration, though no manufacturers seem to be pursuing it as yet.

Wi-Fi: Half Duplex, Shared Media

All Wi-Fi networks are contention-based TDD systems where the access point and the mobile stations all vie for use of the same channel. Because of the shared media operation, all Wi-Fi networks are half duplex. There are equipment vendors who market Wi-Fi mesh configurations, but those implementations incorporate technologies that are not defined in the standards.

802.11 Radio Modulation

WiFi systems use two primary radio transmission techniques.

- **802.11b (≤11 Mbps):** The 802.11b radio link uses a direct sequence spread spectrum technique called complementary coded keying (CCK). The bit stream is processed with a special coding and then modulated using Quadrature Phase Shift Keying (QPSK).

- **802.11a and g (≤54 Mbps):** The 802.11a and g systems use 64-channel orthogonal frequency division multiplexing (OFDM). In an OFDM modulation system, the available radio band is divided into a number of sub-channels, and some of the bits are sent on each. The transmitter encodes the bit streams on the 64 sub-carriers using Binary Phase Shift Keying (BPSK), Quadrature Phase Shift Keying (QPSK), or one of two levels of Quadrature Amplitude Modulation (16-, or 64-QAM). Some of the transmitted information is redundant, so the receiver does not have to receive all of the sub-carriers to reconstruct the information.

The original 802.11 specifications also included an option for frequency hopping spread spectrum (FHSS), but that has largely been abandoned.

802.16 Radio Modulation

The 802.16a standards define three main options for the radio link:

* **SC-A:** Single Carrier Channel
* **OFDM:** 256-Sub-Carrier Orthogonal Frequency Division Multiplexing
* **OFDM-A:** 2,048-Sub-Carrier Orthogonal Frequency Division Multiplexing

The first wave of products to hit the market will use the 256-Sub-Carrier OFDM option. As a result, the WiMax Forum is initially developing test suites and interoperable test plans for that option initially. It also conforms to the ETSI HIPERMAN standard.

Channel Bandwidth

The WiFi standards define a fixed channel bandwidth of 25 MHz for 802.11b and 20 MHz for either 802.11a or g networks. In WiMax, the 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.

Bandwidth Efficiency- 100 Mbps?

There has been considerable confusion regarding the actual transmission rate of a WiMax channel. While many articles reference 70 M or 100 Mbps, the actual transmission rate will depend on the bandwidth of the channel assigned and how efficiently it can be used. The basic issue is bandwidth efficiency. Bandwidth efficiency is measured by the number of bits per second that can be carried on one cycle of radio bandwidth (i.e. bps/Hertz). The transmission rate is determined by multiplying the bandwidth efficiency by the bandwidth of the radio channel the signal will occupy. The fundamental trade off is that the more efficiently the transmitter encodes the signal, the more susceptible it will be to noise and interference.

Adaptive Modulation

Both WiFi and WiMax make use of adaptive modulation and varying levels of forward error correction to optimize transmission rate and error performance. As a radio signal loses power or encounters interference, the error rate will increase. Adaptive modulation means that the transmitter will automatically shift to a more robust, though less efficient, modulation technique in those adverse conditions. The WiMax OFDM standard defines nine different modulation systems using BPSK, QPSK, 16-, 64-, and 256-QAM modulation and yielding different levels of bandwidth efficiency. According to Gordon Antonello, chairman of the WiMax Technical Working Group, the WiMax radio link incorporates adaptive burst profiles, which adjust the transmit power, signal modulation, and forward error correction (FEC) coding to accommodate a wide variety of radio conditions.

Table 2- IEEE 802.16a 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

Forward Error Correction (FEC)

When a more bandwidth efficient signal modulation is used, the likelihood of encountering errors will increase. To offset that, digital radio systems typically include some form of forward error correction encoding (FEC). The idea behind FEC is to include redundant bits in the transmission that will allow the receiver to detect and correct a certain percentage of the encountered errors. So while the FEC coding increases the transmission rate, the overall impact is an improvement in performance. Wi-Fi's original 802.11b radio link did not include FEC, but a convolutional coding FEC was incorporated in 802.11a and g. WiMax uses both convolutional coding and a Reed-Solomon FEC system.

WiFi vs. WiMax Efficiency

Given the data rates supported on its 25 MHz channel (1 M to 11 Mbps), 802.11b delivers bandwidth efficiency between 0.04 and 0.44 bps/Hertz. The 6 M to 54 Mbps transmission rate supported on an 802.11a or g 20 MHz channel yields a bandwidth efficiency between .24 and 2.7 bps/Hertz. In WiMax, the combination of modulation and coding schemes yields bandwidth efficiency up to 5-bits/Hertz. That would deliver a 100-Mbps transmission rate on a 20-MHz radio channel. The bandwidth efficiency will decrease as the transmission range increases, so a maximum of 3.5 bits/Hertz or 70 Mbps on a 20 MHz channel would be more realistic.

Other WiMax Radio Link Features

Mr. Antonello notes that the WiMax radio link incorporates features to take advantage of advanced antenna systems that are now becoming available. To improve overall range and performance, an optional Space Time Coding feature allows the use of two transmit antennas at the base station and a single subscriber unit antenna that can combine the two signal images. Longer term, the working group envisions use of multiple input-multiple output (MIMO) systems to improve overall range and transmission rates.

TABLE 3- Summary of 802.16 Radio Links

	802.16	802.16a	802.16e
Spectrum	10 – 66 GHz	2 – 11 GHz	<6 GHz
Configuration	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	Same as 802.16a
Mobility	Fixed	Fixed	≤75 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

MAC Protocol/Quality of Service (QoS)

While there are a number of similarities between the Wi-Fi and WiMax radio links, the access protocols are completely different. The WiMax standards describe a sophisticated media access control (MAC) protocol that can share the radio channel among hundreds of users while providing quality of service (QoS). Unlike the contention-based MAC protocol used in 802.11 wireless LANs, WiMax uses a Request/Grant access mechanism similar to cable modem systems. That mechanism eliminates inbound collisions and supports both consistent-delay voice and variable-delay data services. The protocol also features Layer 2 error correction using automatic retransmission in the event of errors.

Wi-Fi's CSMA/CA

IEEE 802.11 wireless LANs use a media access control protocol called Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA). While the name is similar to Ethernet's Carrier Sense Multiple Access with Collision Detection (CSMA/CD), the operating concept is totally different. As we noted earlier, WLANs are half duplex-shared media configurations where all stations transmit and receive on the same radio channel. The fundamental problem this creates in a radio system is that a station cannot "hear" while it is sending, and hence it impossible to *detect* a collision.

Distributed Control Function (DCF)

Because of this, the developers of the 802.11 specifications came up with a collision avoidance mechanism called the Distributed Control Function (DCF). While the details are rather complex, the basic idea is to define a system of waiting intervals and back-off timers to help reduce, though not eliminate, the possibility of collisions. A Wi-Fi station will transmit only if it thinks the channel is clear. All transmissions are acknowledged, so if a station does not receive an acknowledgement, it assumes a collision occurred and retries after a random waiting interval. The incidence of collisions will increase as the traffic increases or in situations where mobile stations cannot hear each other (i.e. the *hidden node* problem).

WiMax is Full Duplex

The WiMax Request/Grant protocol was designed with the assumption that networks will use separate channels for inbound and outbound transmissions. Those channels are separated by either time (TDD) or frequency (FDD). As with a cable modem system, outbound transmissions are broadcast in addressed frames, and each station picks off those frames addressed to it.

WiMax Channel Access

In WiMax networks, access to the inbound channel will be controlled by the base station. Users wishing to transmit inbound must first send requests on a contention-based access channel. Exclusive permission to use the inbound traffic channel is then allocated by the base station using a system of transmission grants. As only one station is given permission to send at one time, there are no inbound collisions.

Request/Grant QoS Capability

The major benefit of WiMax's request/grant protocol is that it supports Quality of Service (QoS). As inbound access is controlled by the base station, WiMax's access mechanism can support four primary types of service. Those connection typees can be set up dynamically:

* **Unsolicited Grant-Real Time:** Consistent delay (i.e. isochronous) service for real-time voice and video, where a station is allocated inbound transmission capacity on a scheduled basis.
* **Real Time Polling:** Another real-time service that operates like the 802.11 Point Control Function (PCF), where the base station polls each user device in turn.
* **Variable Bit Rate-Non-Real Time:** Variable-delay data service with capacity guarantees akin to frame relay's Committed Information Rate for high-priority commercial users.
* **Variable Bit Rate-Best Effort:** An IP-like best effort data service for residential Internet users.

The grant mechanism specifies that the entire capacity of the inbound channel can be allocated to one user for a set time period. There is also a unique inbound allocation mechanism for OFDM channels where multiple simultaneous user transmissions (up to 16) can be supported by allocating different sub-channels to different users.

Wi-Fi QoS (802.11e)

There are plans to incorporate quality of service (QoS) capabilities in Wi-Fi with the adoption of the IEEE 802.11e standard. The 802.11e standard will include two operating modes, either of which can be used to improve service for voice:

- **Wi-Fi Multimedia Extensions (WME)**- Mandatory

- **Wi-Fi Scheduled Multimedia (WSM)**- Optional

Wi-Fi Multimedia Extensions (WME)

The WME option uses a protocol called Enhanced Distributed Control Access (EDCA), which is an enhanced version of the Distributed Control Function (DCF) defined in the original 802.11 MAC. The "enhanced" part is that EDCA will define eight levels of access priority to the shared wireless channel. Like the original DCF, the EDCA access is a contention-based protocol that employs a set of waiting intervals and back-off timers designed to avoid collisions. However, with DCF, all stations use the same values and hence have the same priority for transmitting on the channel. With EDCA, each of the different access priorities is assigned a different range of waiting intervals and back-off counters. Transmissions with higher access priority are assigned shorter intervals. The standard also includes a packet-bursting mode that allows an access point or a mobile station to reserve the channel and send 3- to 5-packets in sequence.

Wi-Fi Scheduled Multimedia (WSM)

As it still operates on a contention basis, EDCA does not include a mechanism to deliver true consistent delay service. It simply insures that voice transmissions will wait less than data transmissions. True consistent delay services can be provided with the optional Wi-Fi Scheduled Multimedia (WSM). WSM operates like the little used Point Control Function (PCF) defined with the original 802.11 MAC. In WSM, the access point periodically broadcasts a control message that forces all stations to treat the channel as busy and not attempt to transmit. During that period, the access point polls each station that is defined for time sensitive service.

To use the WSM option, devices must first send a traffic profile describing bandwidth, latency, and jitter requirements. If the access point does not have sufficient resources to meet the traffic profile, it will return a "busy signal". The reason the WSM is being included as an optional feature is that all access points must be able to return a "service not available" response to stations' profile requests. The 802.11e specification is going through its final review cycles and should be ratified by mid-2004.

Wi-Fi Security

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, encryption is optional, and three different techniques have been defined:

- **Wired Equivalent Privacy (WEP):** An RC4-based 40- or 104-bit encryption with a static key
- **Wi-Fi Protected Access (WPA):** A new standard from the Wi-Fi Alliance that uses the 40- or 104-bit WEP key, but changes the key on each packet to thwart key-crackers. That changing key functionality is called the Temporal Key Integrity Protocol (TKIP).
- **IEEE 802.11i/WPA2:** The IEEE is finalizing the 802.11i standard, which will be based on a far more robust encryption technique called the Advanced Encryption Standard. The Wi-Fi Alliance will designate products that comply with the 802.11i standard as *WPA2.* However, implementing 802.11i will typically require a hardware upgrade, so while the standard should be completed in mid-2004, it might be some time before it is widely deployed.

WiMax Encryption

Given that it was designed for public network applications, virtually all WiMax transmissions will be encrypted. The initial specification calls for 168-bit Digital Encryption Standard (3DES), the same encryption used on most secure tunnel VPNs. There are plans to incorporate the Advanced Encryption Standard (AES). As a result, we anticipate none of the security concerns that plagued early Wi-Fi implementations.

Mobile WiMax

One last option is the 802.16e specification for Mobile WiMax, which is due out later this year. While the details are still being worked out, that standard will describe a mobile capability with hand-offs for users moving between cells. The basic requirement is that it be backward-compatible with the fixed location service. One of the imperatives will be to reduce the power requirements for battery-powered mobile stations. The plan is to support data rates up to 500 kbps, essentially equivalent to the highest speed cellular offerings (e.g. Verizon Wireless' 1xEV-DO service).

Wi-Fi Roaming

The IEEE has begun development of a roaming standard for Wi-Fi, though the specification is not expected until 2005 or 2006. In the meantime, WLAN switch vendors like Cisco, Aruba, and Airespace have developed their own proprietary hand-off protocols. We have seen similar capabilities in the Wi-Fi mesh products. However, that means that providing a hand-off capability requires implementing a vendor proprietary solution.

Table 4 compares the major attributes of the WiMax and Wi-Fi technologies.

Table 4- Comparison of WiMax and Wi-Fi Technologies			
	WiMax (802.16a)	**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	Half	Half
Radio Technology	OFDM (256-channels)	Direct Sequence Spread Spectrum	OFDM (64-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 (AES in 802.11i)	Optional- RC4 (AES in 802.11i)
Access Protocol	Request/Grant	CSMA/CA	CSMA/CA
- Best Effot	Yes	Yes	Yes
- Data Priority	Yes	802.11e WME	802.11e WME
- Consistent Delay	Yes	802.11e WSM	802.11e WSM
Mobility	Mobile WiMax (802.16e)	In development	In development
Mesh	Yes	Vendor Proprietary	Vendor Proprietary

Markets for Wi-Fi and WiMax

While we have focused on technical issues up to this point, the fundamental difference between Wi-Fi and WiMax is that they are designed for different applications. Wi-Fi began as a data technology designed to add mobility in local area networks. WiMax on the other hand is intended to provide the basis for a carrier-provided metropolitan area wireless service to support both voice and data applications. Whether the full set of WiMax capabilities make it into the marketplace will depend on which parts of the specification the carriers choose to deploy.

Wi-Fi Network Services

The picture has become somewhat confused as service providers have used Wi-Fi to deliver services for which it was not originally designed. The two major examples of this are wireless ISPs and city-wide Wi-Fi mesh networks.

- **Wireless ISPs (WISPs):** One surprising business that grew out of Wi-Fi was the Wireless ISP (WISP). This is the idea of selling an Internet access service using wireless LAN technology and a shared Internet connection in a public location designated a *hot spot*. T-Mobile and Wayport are currently the largest operators. While the proliferation of hot spots has been widely reported, no one seems to be able to make any money at this. There are two fundamental obstacles, one technical and one business oriented.

  From a technical standpoint, access to the service is limited based on the transmission range of the WLAN technology. You have to be in the hot spot (i.e. within 100m of the access point) to use it. From a business standpoint, users either subscribe to a particular carrier's service for a monthly fee or access the service on a demand basis at a fee per hour. While the monthly fee basis is most cost effective, there are few inter-carrier access arrangements so you have to be in a hot spot operated by your carrier in order to access your service. Some are now predicting that the real business model will not be fee-based services, but a free service that is offered by the property owner to attract customers. That's not a "business" plan, it's a charity!

- **City-Wide Mesh Networks:** To address the limited range, vendors like Mesh Networks and Tropos Networks have developed mesh network capabilities using Wi-Fi's radio technology. The idea of a radio mesh network is that messages can be relayed through a number of access points to a central network control station. These networks can typically support mobility as connections are handed off from access point to access point as the mobile station moves.

  Some municipalities are using Wi-Fi mesh networks to support public safety applications (i.e. terminals in police cruisers) and to provide Internet access to the community (i.e. the city-wide hot spot). However, the mesh technology and hand-off capability are not within the scope of the Wi-Fi standards, and so it is vendor proprietary; that means you must purchase all of the equipment from the same manufacturer. In the final analysis, we are cobbling together a set of wireless LANs to do the job for which WiMax was designed.

Whither WiMax? The market forecast for WiMax is not clear at this point. Clearly, the major target will be broadband wireless access or "Wireless DSL", though carriers must first choose to deploy the service. Their success will depend on the cost and functionality of their offerings when compared to other broadband access alternatives like DSL and cable modems. When chip manufacturers like Intel begin delivering WiMax compatible chipsets in late-2004, we will have the possibility of consumer devices costing $100 or less. However, the carriers will have to invest in the base station equipment and they must decide if there is sufficient demand and an adequate business case to justify the investment needed to deliver a broadband wireless access service.

Three Potential Markets

As we noted at the outset, there are three potential markets for WiMax--private line, broadband wireless access or mobile service. Let's take a brief look at each of these.

§ Point-to-Point Systems

Point-to-point systems for delivering basic telephone service, hot spot, or cellular base station backhaul should continue to be a viable, carrier-oriented market niche. This is particularly true in lesser-developed countries that lack a wired infrastructure. In the US, TowerStream is planning an aggressive build out of its wireless Internet access service in major markets. They will have to compete with much higher-capacity fiber access alternatives from the ILECs and CLECs. However, deploying wireless access to a customer's building should be faster and cheaper than providing fiber access. Carriers like WinStar and Teligent failed in that wireless local loop segment in the late 1990s, but the redundancy built into TowerStream's service is clearly superior to those first-generation offerings.

§ Broadband Wireless Access/Wireless DSL

Broadband wireless or "wireless DSL" offers the greatest near-term potential, but it also faces the greatest competition. A late arriver in the market, WiMax-based systems will have to compete with entrenched cable modem and DSL services that are available to roughly 80 percent of U.S. households.

Carlton O'Neal, VP of marketing for base station maker Alvarion, sees opportunities both in migrating dial-up subscribers and extending broadband access to unserved communities. O'Neal notes that since only 20 percent of U.S. households currently subscribe to broadband access, the battle is just beginning.

Further, a wireless solution should have a significant cost advantage in reaching the 20 percent of households where broadband access is currently unavailable. Extending cable modem and particularly DSL to those thinly populated areas will increase the cost per subscriber, and with a lower-income population, the take rates will likely be less than in urban areas. With chip-level WiMax certified components, manufacturers will be able to deliver low-cost, user-installable, indoor stations that can mimic the cable modem/DSL experience.

The advantage of a wireless solution has not been lost on the DSL carriers. Verizon has been testing BWA on licensed frequencies in Herndon and Centerville, VA using equipment from BeamReach Networks. To minimize the cost, they are installing the antennas on existing cell towers. BellSouth has begun trials using equipment from Navini Networks in Palatka, Port Orange, and Holly Hill, FL to assess cost and technical viability. BellSouth has also been testing a first-generation wireless broadband technology in Houma, LA since 2000. Nextel has announced its Nextel Broadband wireless access in the Raleigh, Durham, NC area using MMDS spectrum it acquired from MCI. In March 2004, wireless pioneer Craig McCaw acquired Texas-based BWA carrier Clearwire Holdings. In June, McCaw announced plans to turn up WiMax-based BWA service in 20 markets by the end of 2005.

§ Mobile WiMax

A mobile WiMax services could produce a real dust-up, however. Intel has been the primary backer for WiMax, and hopes to repeat the success it's had with Wi-Fi. However, Cisco and Motorola are backing a competing standard called Mobile-Fi (IEEE 802.20). Mobile-Fi proponents note that their solution will be optimized for IP in high-speed mobile environments. While technology will be as important, being first-to-market with an all-encompassing solution (i.e. at home and mobile) can be a major advantage for WiMax.

Mobile service can also change the picture for the cable modem and DSL carriers. They currently dominate the fixed-location market, but they will have to develop service adjuncts to support users outside of their homes. The free Wi-Fi capability that Verizon now offers its DSL customers is the first such add-on, however it is only available in Manhattan. In the meantime, the cable companies are pursuing joint marketing agreements with Wi-Fi-based wireless ISPs to round out their offerings. A combined home/mobile WiMax-based offering will put the onus on cable modem and DSL suppliers to provide an on-the-go capability or face the prospect of losing customers to a more flexible wireless alternative.

The cellular carriers will likely come out on the short end of the data battle. Their 2.5/3G data offerings have been only moderately successful; Verizon Wireless noted recently that only 3% of their revenues came from data services. Further, those sales have been tied primarily to new consumer-oriented applications like camera phones, short messages, and downloadable ringers rather than bread-and-butter network access for commercial users. With higher-speed, data-oriented services coming on the market, the cellular carriers will have a much tougher time winning over enterprise data buyers. Further, if wireless voice over IP (VoIP) starts to catch on, the cellular companies might find themselves in a defensive battle to hold on to their basic voice business.

Conclusion

WiMax signals the arrival of the next wave of wireless data technologies. Unhampered by the short range and data orientation of wireless LANs, these technologies hold the promise of taking high speed wireless out of the coffee shop and out on the road.

The flexibility of the WiMax technology gives it a significant advantage, addressing both fixed and nomadic users, operating in licensed or unlicensed bands, providing both consistent- and variable-delay services while operating in a carrier-scale environment. On paper, WiMax looks like a strong contender. Now we will have to see if the proponents can translate that technology into marketable services.

About the Author: *Michael Finneran is an independent telecommunications consulting specializing in wireless networks and technologies. Besides his research and consulting activities, he writes a regular column called* Network Intelligence *for* *Business Communications Review* *and teaches their seminars on Wireless Technologies and Wireless LANs. The can be reached at mfinneran@att.net.*

Acronyms Used

AES: Advanced Encryption Standard
BPSK: Binary Phase Shift Keying
BWA: Broadband Wireless Access
CCK: Complementary Coded Keying
CLEC: Competitive Local Exchange Carrier
CIR: Committed Information Rate
CSMA/CA: Carrier Sense Multiple Access with Collision Avoidance
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
ETSI: European Telecommunications Standards Institute
ED-VO: 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
Hz: Hertz (Prefix Kilo = Thousands, Mega = Millions, Giga = Billions)
IEEE: Institute of Electrical and Electronic Engineers
ILEC: Incumbent Local Exchange Carrier
ISM: Industrial, Scientific, and Medical
LAN: Local Area Network
MAC: Media Access Control
MIMO: Multiple Input-Multiple Output
MMDS: Multi-channel Multipoint Distribution Service
NLOS: Non-Line-of-Sight
OFDM: Orthogonal Frequency Division Multiplexing
PCF: Point Control Function
x-QAM: x-level Quadrature Amplitude Modulation
QoS: Quality of Service
QPSK: Quadrature Phase Shift Keying
RC4: Ron's Code-4
SONET: Synchronous Optical Network Interface
TDD: Time Division Duplex
TKIP: Temporal Key Integrity Protocol
U-NII: Unlicensed National Information Infrastructure
VoIP: Voice over IP
VPN: Virtual Private Network
WEP: Wired Equivalent Privacy
Wi-Fi: Wireless Fidelity
WiMax: Worldwide Interoperability for Microwave Access
WISP: Wireless Internet Service Provider
WLAN: Wireless LAN
WME: Wi-Fi Multimedia Extensions
WPA: Wi-Fi Protected Access
WSM: Wi-Fi Scheduled Multimedia

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