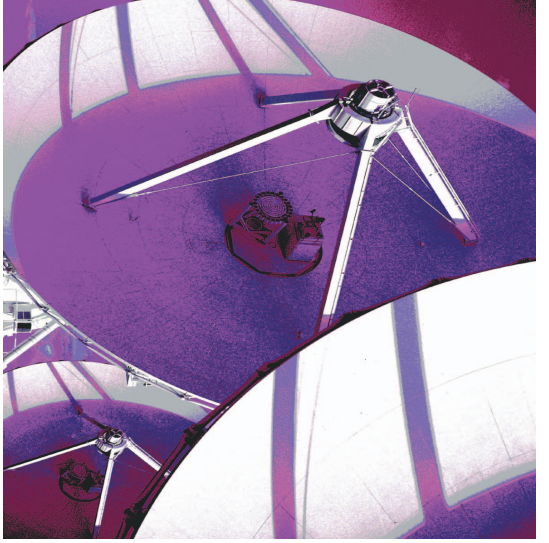

WiMAX's strong industry backing, standards-based approach, and mobility support bring a new horizon to wireless broadband.

Zakhia Abichar, Yanlin Peng, and J. Morris Chang

WiMAX: The Emergence of Wireless Broadband

The much-anticipated technology of WiMAX, the Worldwide Interoperability for Microwave Access, aims to provide business and consumer wireless broadband services on the scale of the Metropolitan Area Network (MAN). WiMAX will bring a standards-based technology to a sector that otherwise depended on proprietary solutions. The technology has a target range of up to 31 miles and a target transmission rate exceeding 100 Mbps and is expected to challenge DSL and T1 lines (both expensive technologies to deploy and maintain) especially in emerging markets.

EVOLUTION

WiMAX is the commercialization of the IEEE 802.16 standard, an evolving standard initiated at the National Institute of Standards and Technologies in 1998 before being transferred to the IEEE to form Working Group 802.16. In June 2004, the working group won approval for the latest 802.16 standard for fixed wireless access, known as IEEE 802.16-2004. In December 2005, an extension that addresses mobility also won approval as IEEE 802.16e-2005.

Throughout WiMAX's development, the WiMAX Forum, which comprises a group of industry leaders (Intel, AT&T, Samsung, Motorola, Cisco, and others), has closely supported and promoted the technology. The group's workforce is divided along multiple working groups that focus on technical, regulatory, and marketing aspects. The certification working group has developed a WiMAX product certification program, which aims to ensure interoperability between WiMAX equipment from vendors worldwide. The certification process also considers interoperability with the High Performance Radio Metropolitan Area Network (HiperMAN), the European Telecommunications Standards Institute's MAN standard. Such interoperability is possible because 802.16 and HiperMAN each were modified to include features from the other; now, they share the same physical layer (PHY) and medium access control (MAC) layer specifications. The WiMAX Forum, through its Regulatory Working Group, is also in discussions with governments worldwide about spectrum regulations.

APPLICATIONS

WiMAX's attributes open the technology to a wide variety of applications (see Figure 1). With its large range and high transmission rate, WiMAX can serve as a backbone for 802.11 hotspots for connecting to the Internet. Alternatively, users can connect mobile devices such as laptops and handsets directly to WiMAX base stations without using 802.11. Developers project this configuration for the WiMAX mobile version, which will provide users broadband connectivity over large coverage areas compared with 802.11 hotspots' moderate coverage. Mobile devices connected directly to WiMAX base stations likely will achieve a range of 5 to 6 miles, because mobility

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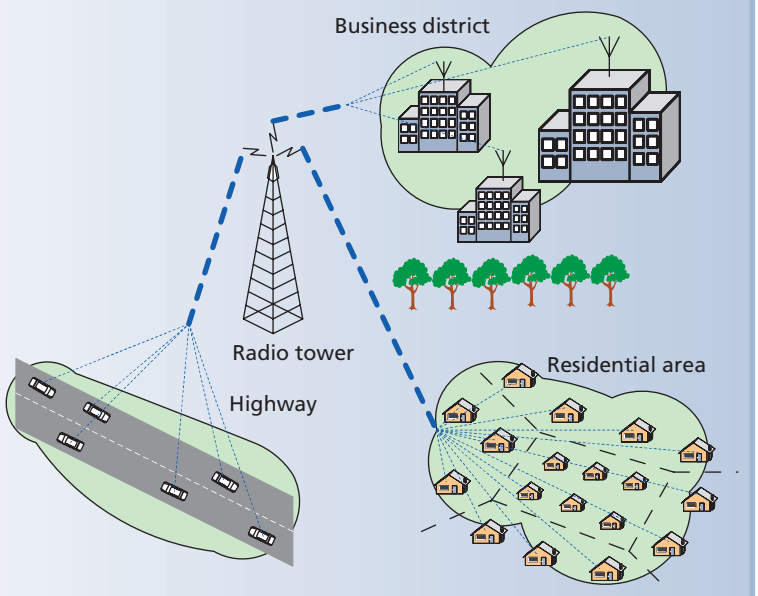
makes links vulnerable.

The technology can also provide fast and cheap broadband access to markets that lack infrastructure (fiber optics or copper wire), such as rural areas and unwired countries. Currently, several companies offer proprietary solutions for wireless broadband access, many of which are expensive because they use chipsets from adjacent technologies, such as 802.11. Manufacturers of these solutions use the physical layer and bypass the medium access control layer by designing a new one. Unlike these proprietary solutions, WiMAX's standardized approach offers economies of scale to vendors of wireless broadband products, significantly reducing costs and making the technology more accessible. Many companies that were offering proprietary solutions, however, have participated in the WiMAX Forum and now offer WiMAX-based solutions.

WiMAX can be used in disaster recovery scenes where the wired networks have broken down. In recent hurricane disasters, WiMAX networks were installed to help in recovery missions. Similarly, WiMAX can be used as backup links for broken wired links.

Figure 1. WiMAX applications. A WiMAX base station can serve terminals in a business district and residential area and on moving vehicles.



FIXED ACCESS WITH IEEE 802.16-2004

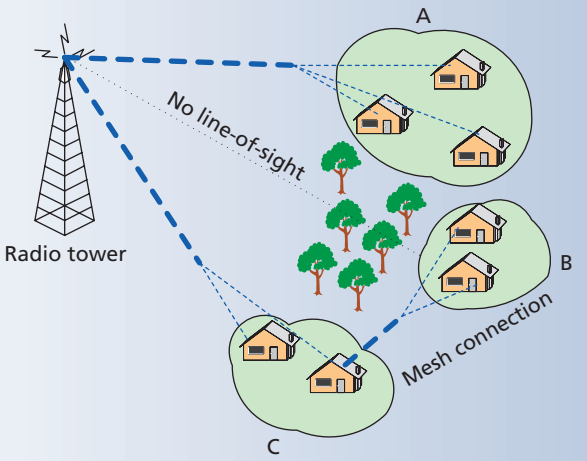
The initial version of the 802.16 standard specified operation in frequency ranges between 10 GHz and 66 GHz. These high frequencies have more available bandwidth and less risk of interference. Most technologies, such as 802.11, prefer lower frequencies because of better multipath propagation (meaning that signals can better handle obstacles). On high frequencies, signals can't diffract around obstacles and often require line-of-sight deployment in which the transmitter and receiver are directly opposite each other with no obstacles. Line-of-sight deployment requires more base stations to circumvent obstacles, and thus increases deployment costs.

The standard's subsequent additions specify operation at lower frequencies, between 2 GHz and 11 GHz, in both licensed and license-exempt bands. Commercial interest in WiMAX focuses mainly on these frequencies because of the ease and cost of deployment. The initial WiMAX Forum certification profiles are in the 3.5 (licensed) and 5.8 GHz (license-exempt) bands. Because of possible interference in those ranges, the standard specifies schemes to adjust the chosen frequency and transmission power for improved performance. The *dynamic frequency selection* scheme chooses the frequency that allows high performance, and this scheme differentiates between primary-user interference (WiMAX users interfere with other technologies using the same spectrum) and cochannel interference (WiMAX users interfere with each other). The *transmit power control* scheme adjusts the transmission power to reduce the interference with neighboring transmitters.

The 802.16 standard was designed mainly for point-to-multipoint topologies, in which a base station distributes traffic to many subscriber stations that are mounted on rooftops. Researchers are also working to enhance receivers so that operators can install subscriber stations indoors. The point-to-multipoint configuration uses a scheduling mechanism that yields high efficiency because stations transmit in their scheduled slots and don't contend with one another. Also, unlike 802.11, WiMAX doesn't require stations to listen to one another, because they encompass a larger area. This scheduling design suits WiMAX networks because subscriber stations might aggregate traffic from several computers and have steady traffic, unlike terminals in 802.11 hotspots, which usually have bursty traffic.

In addition to the point-to-multipoint mode, 802.16 supports a mesh mode, where subscriber stations can communicate directly with one another. The mesh mode can help relax the line-of-sight requirement and ease the deployment costs for high-frequency bands by allowing subscriber stations to relay traffic to one another. In this case, a station that doesn't have line-of-sight with the base station can get its traffic from another station. Figure 2 illustrates a WiMAX network with a mesh topology.

Figure 2. Mesh topology deployment. Mesh deployment relaxes the line-of-sight requirement and helps reduce deployment costs by requiring fewer base stations. Stations in area B do not have line-of-sight with the base station. They receive their traffic from stations in areas A or C.



IEEE 802.16-2004 physical layer

For the bands in the 10- to 66-GHz range, 802.16 defines one air interface with a single-carrier modulation called WirelessMAN-SC. The PHY design for the 2- to 11-GHz range (both licensed and license-exempt bands) is more complex because of interference. Hence, the standard supports burst-by-burst adaptivity for the modulation and coding schemes and specifies three interfaces. The adaptive features at the PHY allow trade-offs between robustness and capacity. The three air interfaces for the 2- to 11-GHz range are the following:

- WirelessMAN-SCa uses single carrier modulation.
- WirelessMAN-OFDM (orthogonal-frequency division multiplexing) uses a 256-carrier OFDM. This air interface provides multiple access to different stations through time-division multiple access.
- WirelessMAN-OFDMA (orthogonal-frequency division multiple access) uses a 2,048-carrier OFDM scheme. The interface provides multiple access by assigning a subset of the carriers to an individual receiver.

IEEE 802.16-2004 MAC layer

The MAC layer of 802.16 is designed to serve sparsely distributed stations with high data rates. Subscriber stations aren't required to listen to one another, because this listening might be difficult to achieve in WiMAX environments. The base station schedules subscriber station transmissions in advance through a flexible frame structure. Stations need to contend only when they access the channel for the first time. The reduced contention increases efficiency and allows one WiMAX base station to serve a large number of stations. In contrast, 802.11 terminals usually have bursty, or intermittent, traffic and contend every time before transmitting. This contention decreases efficiency as the number of stations increases.

Duplexing, a station's concurrent transmission and reception, is possible through *time division duplex* and *frequency division duplex*. In TDD, a station transmits then receives (or vice versa) but not at the same time. This option helps reduce subscriber station costs, because the radio is less complex. In FDD, a station transmits and receives simultaneously on different channels.

The 802.16 MAC layer supports quality of service (QoS) for stations through adaptive allocation of the uplink and downlink traffic.

Finally, the MAC of 802.16 supports different transport technologies such as Internet Protocol version 4 (IPv4), IPv6, Ethernet, and Asynchronous Transfer Mode (ATM). This lets service providers use WiMAX independently of the transport technology they support.

SPECTRUM ISSUES

Uniform spectrum allocation makes it possible to optimize radio performance for the allocated spectrum. Thus, because the radio accounts for a major portion of equipment costs, spectrum allocation greatly impacts those costs. The WiMAX Forum expects that initial deployment will occupy frequency bands in the 5 GHz (license-exempt) and 2.5 GHz (licensed) bands.

- *License-exempt 5 GHz*. The frequency ranges of interest to WiMAX are bands between 5.25 and 5.28 GHz. This range is strategic for initial deployment especially in rural areas with a low population density. In this range, WiMAX equipment can benefit from higher output levels (4 watts, compared to 1 watt or less in the lower 5 GHz). Some US proposals aim to increase the power levels in this frequency range to attain 25 watts.
- *Licensed 3.5 GHz*. Bands between 3.4 GHz and 3.6 GHz have been allocated for fixed wireless access in most countries (the US is an exception).
- *Licensed 2.5 GHz*. Bands between 2.5 GHz and 2.7 GHz have been allocated in the US, Mexico, Brazil, and some Southeast Asian countries.

Other lower frequencies are also of interest, because the radio waves can penetrate obstacles and propagate further. Bands of interest are smaller than 800 MHz and are currently vacant or used for analog TV. As increasingly

more TV broadcasters switch to digital transmissions, some of these bands are becoming available. The US Federal Communications Commission has already licensed spectrum for broadband wireless access in the former analog TV channel bands from 669 MHz to 741 MHz (channels 52-59), and it is considering allocating bands from 747 MHz to 801 MHz (channels 60-69). However, the FCC does not require current TV broadcasters to vacate the spectrum before 2009 or 2010.

MOBILE BROADBAND WITH IEEE 802.16E

IEEE 802.16e-2005, the mobile version of WiMAX, is optimized for dynamic mobile radio channels and supports handoffs and roaming at vehicular speeds of up to 75 mph.

The significance of 802.16e is that analysts expect WiMAX's volume deployment to be driven by mobile applications. Consequently, although 802.16e will be introduced after 802.16, the prices of 802.16e products are expected to become cheaper because they target a larger market.

The deployment of 802.16e will most likely be in 2.3 GHz and 2.5 GHz, frequencies low enough to accommodate the non-line-of-sight conditions between the base stations and mobile devices.

PHY improvements for 802.16e

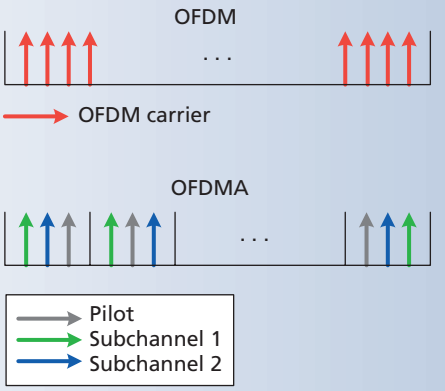
The key technologies in 802.16e on the PHY level are OFDMA and an enhanced version called Scalable OFDMA (SOFDMA). OFDMA uses a multicarrier modulation in which the carriers are divided among the users to form subchannels. For each subchannel, the coding and modulation are adapted separately, allowing channel optimization on a smaller scale (rather than using the same parameters for the whole channel). This technique optimizes the use of spectrum resources and enhances indoor coverage by assigning a robust scheme (yet, with low rates) to vulnerable links. Figure 3 illustrates the OFDMA technology.

OFDMA is an option in 802.16 (for fixed access), but it's not required for certifying 802.16 products. However, OFDMA is necessary in 802.16e devices and is required for certification. SOFDMA is an enhancement of OFDMA that scales the number of subcarriers in a channel with possible values of 128, 512, 1,024, and 2,048.

OFDMA and SOFDMA also benefit fixed broadband service because carriers can allocate spectrum more efficiently and reduce interference. On the other hand, OFDMA and SOFDMA are more complex to install and operate, compared to OFDM. In the future, some providers might deploy 802.16e networks to serve fixed and mobile customers. In addition, many vendors have announced that their initial 802.16 base stations can be upgraded through software to 802.16e.

SOFDMA has been widely approved by standards-makers and manufacturers alike. Observing the SOFDMA-based Korean standard WiBro (Wireless Broadband) convinced the IEEE of SOFDMA's benefits. WiBro has worked in conjunction with 802.16e, and the products of those two technologies will be interoperable. In addition, Intel announced that SOFDMA will be the PHY layer of choice for indoor and mobile equipment.

Figure 3. Optimizing subchannels with OFDMA. OFDMA divides the channel into subchannels.



The coding and modulation schemes of each subchannel are assigned separately, in contrast to OFDM. Each subchannel is optimized according to its link condition.

Higher-layer improvements for 802.16e

Mobility support in 802.16e includes power-saving and sleep modes to extend the battery life of mobile devices. 802.16e also supports hard and soft handoffs to provide users with seamless connections as they move across coverage areas of adjacent cells. With hard handoffs, the user is connected to only one station at a time; the link with the old station is broken before the new link is set up. This mechanism is simple, and the latency is sufficiently adequate for data applications. In contrast, with soft handoffs, the user is connected to the new base station before breaking the link with the old base station. Soft handoffs allow reduced latencies and are suitable for multimedia-oriented applications such as gaming. Other improvements for mobile devices include a real-time polling service to provide QoS, a hybrid automatic repeat request (H-ARQ) scheme to retransmit erroneous packets, and privacy key management schemes to help distribute encryption keys.

WIMAX AND OTHER WIRELESS TECHNOLOGIES

WiMAX differs considerably from IEEE 802.11a/b/g and 802.11n (high data rates) in goals and technical specifications. WiMAX is designed to replace the last-mile

Resources

- **IEEE 802.16 Working Group: activity of the 802.16 groups and some versions of drafts and standards (http://www.wirelessman.org).**
- **WiMAX Forum: activity of the forum, certification news, and white papers on WiMAX (http://www.wimaxforum.org).**
- **Intel WiMAX: white papers, events, and training information on WiMAX (http://www.intel.com/netcomms/technologies/wimax).**
- **WiMAX.com: WiMAX portal for news, products, events, and white papers (http://www.wimax-industry.com).**
- **Openwimax.org: WiMAX discussion forum (http://www.openwimax.org).**

wired-access networks and provide broadband Internet access to emerging markets with no broadband access. On the other hand, the aim of 802.11 is to connect a computer in a home or an office through simple, economical methods (despite the fact that 802.11 has been used in city-scale deployments). The MAC of WiMAX is centralized and contention free, whereas the MAC of 802.11 is contention based.

In WiMAX, the base station assigns a QoS class to each connection. This is in contrast to 802.11, in which QoS was not considered in the early standard before 802.11e emerged; most networks deployed today don't use QoS mechanisms. Besides, WiMAX supports many transport technologies, such as ATM, IPv4, and IPv6, to maintain compatibility with operators' transport technologies.

Although WiMAX and 802.11 have different goals, the emerging IEEE 802.20 standard is likely to challenge 802.16e. IEEE 802.20 is an upcoming standard that aims to provide mobile users with rates higher than 1 Mbps at frequencies below 3.6 GHz and at speeds up to 155 mph, suitable to connect fast trains. Proponents of 802.20 argue that 802.16e will be deployed along the fixed base of 802.16, whereas 802.20 aims for large-scale deployment such as cell phones.

Obviously, 802.16e and 802.20 overlap, but the former has the advantage of reaching the market earlier and being supported by a broad industry base. Furthermore, 802.20 experienced a setback when the group's activities were temporarily suspended in June 2006.

WIMAX DEVELOPMENTS

Since the WiMAX Forum was established in 2001, several developments from the industry have jump-started the technology. Early developments came through the deployment of (precertification) WiMAX networks. Several cities in the US, Europe, and Asia have hosted such pilot networks. In all, more than 150 commercial trials and WiMAX network deployments have taken place. One of the latest deals was between GlobeTel Wireless and Moscow-based Internafta in January 2006 to provide as many as 30 Russian cities with WiMAX-based wireless broadband.

Since January 2006, the WiMAX Forum has been certifying products for fixed access based on 802.16-2004. Aperto Networks, Redline Communications, Sequans, and Wavesat manufactured the first certified products. The products were tested at the WiMAX Forum's certification lab in Spain, and some 20 other manufacturers have reserved testing slots at the lab. The certification of 802.16e mobile equipment is scheduled to start in the last quarter of 2006 in the Telecommunications Technology Association lab in Korea.

Also in January 2006, Samsung revealed its WiMAX-enabled M8000 handset, which connects directly to WiMAX base stations through 802.16e. The M8000 runs on a Windows Mobile operating system and provides entertainment and communication through a broadband connection.

WiMAX has changed the scene of wireless broadband from proprietary solutions to a standards-based industry. Vendors can now compete to sell their equipment, which benefits the customer base by providing lower costs and enabling broadband access in emerging markets. ■

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