Project	**IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>**
Title	**IEEE Standard 802.16 for Global Broadband Wireless Access**
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Abstract	Global standardization is a key issue for the success of broadband wireless access systems. The IEEE 802.16 Working Group on Broadband Wireless Access, with hundreds of participants worldwide, has developed IEEE Standard 802.16, with its WirelessMAN air interface standard for fixed wireless metropolitan area networks operating anywhere in the world in appropriate licensed or license-exempt spectrum between 2 and 66 GHz. The technology is designed to support multiple services simultaneously and so is capable of providing an area's primary infrastructure for data, voice, and other services, in both residential and commercial applications. At frequencies below 11 GHz, the physical layer specification is designed for non-line-of-sight deployments. The protocol can transfer dozens of megabits per second in a single channel, with multiple channels available in many areas. While the published standard addresses only stationary terminals, the IEEE 802.16 Working Group is currently enhancing the specification to address mobile terminals as well.
Purpose	To inform the Working Group concerning an address on IEEE 802.16 given by the Working Group Chair at ITU Telecom World 2003, Geneva, October 12-18, 2003. An accompanying slide set is available as IEEE S802.16-03/14.
Notice	
Release	
Patent Policy and Procedures	

IEEE STANDARD 802.16 FOR GLOBAL BROADBAND WIRELESS ACCESS*

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Abstract*: Global standardization is a key issue for the success of broadband wireless access systems. The IEEE 802.16 Working Group on Broadband Wireless Access, with hundreds of participants worldwide, has developed IEEE Standard 802.16, with its WirelessMAN air interface standard for fixed wireless metropolitan area networks operating anywhere in the world in appropriate licensed or license-exempt spectrum between 2 and 66 GHz. The technology is designed to support multiple services simultaneously and so is capable of providing an area's primary infrastructure for data, voice, and other services, in both residential and commercial applications. At frequencies below 11 GHz, the physical layer specification is designed for non-line-of-sight deployments. The protocol can transfer dozens of megabits per second in a single channel, with multiple channels available in many areas. While the published standard addresses only stationary terminals, the IEEE 802.16 Working Group is currently enhancing the specification to address mobile terminals as well.*

INTRODUCTION

According to the International Telecommunication Union's September 2003 report *Birth of Broadband* [1], prepared for ITU Telecom World 2003, broadband networking is still in the early stage of its growth. The document reports that less than 11% of the world's Internet users had broadband Internet access in 2002. As efforts to expand the reach of broadband continue, new technologies, particular those that can economically reach more of the population, will inevitably blossom. As noted in the report, one of the growing trends in broadband access is broadband wireless access (BWA). BWA offers quick build-out at a low cost, with the opportunity to provide competitive access in some regions and the initial means of broadband access in others.

Because of worldwide economic and political trends, reflected by activity within the World Trade Organization (WTO), global standardization is becoming a critical element in world trade [2,3,4]. Standards are critical for the marketplace success of many technological solutions, and standards that are adopted worldwide are especially powerful due to economies of scale. Telecommunication systems are particularly susceptible to global standardization trends because of the inherent need for communications protocols that define a language common to the two ends of a communications link. Global standards distinctly enhance the value of technologies and reduce testing and certification costs. The primary beneficiaries of standards are the users, who experience lower risk with a diversity of suppliers and benefit from the enhanced value and innovation that comes with competition around an interoperable specification.

An important example of the benefits of communication standards is in the field of computer networking. The most popular standards for wired and wireless networks have historically been developed by the IEEE 802 LAN/MAN Standards Committee [5], a unit of the Standards Association of the transnational Institute of Electrical and Electronics Engineers, Inc. (IEEE). The success of that committee's IEEE 802.3 ("Ethernet") standards has been so strong over the past 30 years that the technology's primary inventor, Bob Metcalfe, considers it not so much a technology standard but a business model [6]:

> There are four business models out there today. The first is the vertical model... The second, which dominates today, is the horizontal model... The third is the Linux/open-source business model. And the fourth is the Ethernet business model. It's based on *de jure* standards with proprietary implementations of those *de jure* standards, and it is unlike open source in that competitors don't give their intellectual property away. The competition is fierce, but there is a market ethic that products will be interoperable. And the standard evolves rapidly based on market engagement in such a way to value the installed base. There is a heavy value placed on sustaining and maintaining the installed base. That's the Ethernet business model.

In more recent years, IEEE 802 has developed wireless networking standards [7,8], most prominently IEEE Standard 802.11 (the wireless local area network standard popularly known by the certification label "Wi-Fi") and IEEE Standard 802.15.3 (commonly known as "Bluetooth") for wireless personal area networks.

In order to address the need for a global standard for large-scale broadband wireless access, the IEEE 802.16 Working Group on Broadband Wireless Access <http://WirelessMAN.org>, with hundreds of participants worldwide, has developed the WirelessMAN® air interface standard for fixed wireless metropolitan area networks operating anywhere in the world in appropriate licensed or license-exempt spectrum between 2 and 66 GHz. Note that the word "metropolitan" here refers to the scale of the system (whose size is city-sized) rather than to an urban application; in fact, both rural and urban applications are of great interest.

The technical content of the standard is forward-looking rather than legacy based. It is founded upon on a bandwidth-on-demand, point-to-multipoint medium access control layer design providing differentiated Quality of Service (QoS). It is designed to support multiple services simultaneously and so is capable of providing an area's primary infrastructure for data, voice, and other services, in both residential and commercial applications. At frequencies below 11 GHz, the physical layer specification is designed for non-line-of-sight deployments. The protocol can support dozens of Mbit/s in a single channel, with multiple channels available in many areas.

While the published standard addresses only stationary terminals, the IEEE 802.16 Working Group is currently enhancing the specification to address mobile terminals as well. Interoperability test documentation is in development by the working group, and silicon integrated circuitry embodying the protocol is being developed by industry. The first compliant chip sets and systems were announced in October 2003, with numerous others expected by 2004.

Brief History of the IEEE 802.16 Working Group

In 1998, many companies were beginning to develop and offer products for broadband wireless access, and spectrum was becoming available in many countries. This application seemed ripe for standards [9,10], but industry needed a catalyst. The U.S. National Institute of Standards and Technology (NIST) called a meeting to discuss the topic in August 1998. With the participation of 45 attendees, a plan was crafted to initiate the standardization process. The group decided to organize within IEEE 802 and met with that organization in November 1998. IEEE 802 accepted a proposal to initiate a Study Group activity to consider the problem. The Study Group's proposal, to standardize BWA from 10-66 GHz, was accepted by IEEE, and IEEE 802.16 Working Group held its first formal meeting in July 1999. In November 1999, while considering 35 technical proposals, the Working Group also initiated activity addressing 2-11 GHz.

Holding bimonthly weeklong sessions, the group moved quickly. The core standard defining the WirelessMAN air interface was approved as IEEE Standard 802.16-2001 [11,12] and published in 2002. Four additional standards to enhance the applicability of the work (particularly to the 2-11 GHz range) and aid deployment of the systems have also been published, with several more under development. Active work continues, with attention aimed at expanding the specification for mobile applications and at publishing a set of conformance test documents as standards. Industry activity supports the standardization efforts, and the Worldwide Interoperability for Microwave Access (WiMAX) Forum <http://wimaxforum.org>, with over 25 member companies, is preparing to support compliance tests. Companies, small and large, are currently implementing the standard into commercial equipment.

IEEE 802.16 WirelessMAN Standard for Wireless Metropolitan Area Networks

The IEEE Working Group 802.16 on Broadband Wireless Access (BWA) has developed the WirelessMAN air interface standard to support the development and deployment of wireless metropolitan area networks. The Working Group primarily addresses applications of wireless technology linking commercial and residential buildings to high-rate core networks and thereby providing access to those networks. This link is sometimes known colloquially as the "last mile," although the many in the group prefer the user-centric term "first mile."

The Working Group's original air interface project was specified in IEEE Standard 802.16-2001 ("Air Interface for Fixed Broadband Wireless Access Systems"), approved in 2001 and published in 2002. As specified in this standard, a wireless metropolitan area network (MAN) provides network access to buildings through exterior antennas communicating with central radio base stations (BSs) in a point-to-multipoint topology. The wireless MAN offers an alternative to cabled access networks, such as fiber-optic links, coaxial systems using cable modems, and digital subscriber line (DSL) links. Because wireless systems have the capacity to address broad geographic areas without the costly infrastructure development required in deploying cable links to individual sites, the technology may prove less expensive to deploy and may lead to more ubiquitous broadband access.

In this scenario, with WirelessMAN technology bringing the network to a building, users inside the building will connect to it with conventional in-building networks such as, for data, Ethernet (IEEE 802.3) or wireless local area networks (IEEE 802.11). However, given subsequent enhancements, the design of the standard allows for its to be extended to the individual user device. With appropriate cost reductions, the user's computer could itself use WirelessMAN for its access, either with a direct link to a remote BS or, in a typical indoor scenario, with a link to a local indoor BS that receives its access from an outdoor WirelessMAN link or from, for example, a cable modem. The WirelessMAN MAC could then provide full QoS to the user. The standard has already begun to evolve to support nomadic and increasingly mobile users.

The 802.16 MAC is QoS-sensitive and connection-oriented, with a base station allocating bandwidth according to terminal requests. Access and bandwidth allocation algorithms accommodate hundreds of terminals per channel, with terminals that may be shared by multiple end users. The request-grant mechanism is designed to maintain its efficiency when presented with multiple connections per terminal, multiple QoS levels per terminal, and a large number of statistically multiplexed users. It takes advantage of a wide variety of request mechanisms, balancing the stability of contentionless access with the efficiency of contention-oriented access. While extensive bandwidth allocation and QoS mechanisms are provided, the details of scheduling and reservation management are left unstandardized and provide an important mechanism for vendors to differentiate their equipment.

The 802.16 MAC supports services including Internet Protocol (IP) Versions 4 and 6, packetized voice-over-IP (VoIP), Ethernet, and Asynchronous Transfer Mode (ATM). Features such as payload header suppression, packing, and fragmentation help to carry traffic in a form that is often more efficient than the original transport mechanism.

Along with the fundamental task of allocating bandwidth and transporting data, the MAC includes a privacy sublayer that provides reliable key exchange and encryption for data privacy and provides authentication of network access and connection establishment to avoid theft of service.

IEEE Standard 802.16 was designed to evolve as a set of air interfaces based on a common MAC protocol but with physical layer specifications dependent on the spectrum of use and the associated regulations. The MAC in general supports a physical layer in which the base station basically transmits a time-division multiplex signal, with individual subscriber stations allocated time slots serially. Access in the uplink direction is by time-division multiple access (TDMA). Both time-division duplexing (TDD) and frequency-division duplexing (FDD) are handled in a common burst fashion. Half-duplex FDD subscriber stations, which may be less expensive since they do not simultaneously transmit and receive, are easily supported in this framework, with a slight modification. Both the TDD and FDD alternatives support adaptive burst profiles in which modulation and coding options are dynamically assigned on a burst-by-burst basis.

IEEE Standard 802.16-2001 addresses frequencies from 10 to 66 GHz, where extensive spectrum is currently available worldwide but at which the short wavelengths introduce significant challenges, including propagation that is essentially limited to line-of-sight. The 10-66 GHz air interface is designated "WirelessMAN-SC" because it uses single-carrier modulation. Channel sizes of 25 and 28 MHz are supported, with a maximum aggregate over-the-air data rate of 120 Mbit/s in the 25 MHz channel using 64-QAM. In typical cases, the operator will have access to tens of such channels, which will normally be used in an angular sector of perhaps 90°. Range is typically on the order of less than 10 km.

The first amendment to IEEE Standard 802.16-2001, denoted IEEE Standard 802.16c [13], includes system profiles specified as the basis of compliance testing. The standard was approved in early 2002. Follow-up work has been addressed at completing a set of four compliance test documents, in accordance with the guidelines specified in ISO/IEC 9646 (1995) and ITU-T X.296. The first of these, IEEE Standard 802.16/Conformance01 [14], was published in 2003. Early 2004 completion of the second two ("Test Suite Structure and Test Purposes" and "Radio Conformance Tests") is expected. A separate recommended practice on coexistence was published in 2001 [15]. All of these standards address the 10-66 GHz WirelessMAN-SC air interface.

IEEE 802.16a for 2-11 GHz

April 2003 saw the publication of IEEE Standard 802.16a [16], addressing frequencies from 2-11 GHz, including both licensed and license-exempt bands. Compared to the higher frequencies, such bands offer the opportunity to reach many more customers less expensively, though at generally lower data rates. This suggests that such services will be oriented toward individual homes or small-to-medium sized enterprises. Design of the 2-11 GHz physical layer was driven by the need for non-line-of-sight (NLOS) operation. This is essential to support residential applications, since rooftops may be too low for a clear sight line to a BS antenna, possibly due to obstruction by trees.

Therefore, significant multipath propagation must be expected. Furthermore, outdoor-mounted antennas are expensive due to both hardware and installation costs. Some vendors will prefer to offer systems which use indoor antennas only.

IEEE 802.16a specifies that systems implement one of three air interface specifications, each of which provides for interoperability:

1) WirelessMAN-SCa: This uses a single-carrier modulation format.
2) WirelessMAN-OFDM: This uses orthogonal frequency division multiplexing with a 256-point transform. Access is by TDMA.
3) WirelessMAN-OFDMA: This uses orthogonal frequency division multiple access with a 2048-point transform. In this system, multiple access is provided by addressing a subset of the multiple carriers to individual receivers.

Service provision using the 2-11 GHz WirelessMAN standards is highly dependent on design goals. Many varied implementation approaches are expected. Vendors typically cite target aggregate data rates of up to 70 Mbit/s in a 14 MHz channel, with cell ranges up to 50 km.

To accommodate the more demanding physical environment and different service requirements found at frequencies between 2 and 11 GHz, IEEE Standard 802.16a upgrades the MAC to provide automatic repeat request (ARQ). Because of the propagation requirements, the use of advanced antenna systems is supported. Also, an optional mesh topology is defined to expand the basic point-to-multipoint architecture.

Current Activities of the IEEE 802.16 Working Group: Combined Fixed/Mobile Support

Currently, most of the work in the 802.16 Working Group involves two activities:

• Project P802.16-REVd is a project to consolidate the three air interface standards (IEEE 802.16, 802.16a, and 802.16c), revising the content for technical enhancement and adding system profiles for the 2-11 GHz specification. The output, expected by the spring of 2004, will be a revised IEEE Standard 802.16 incorporating the full specifications for 2-66 GHz fixed wireless access.

• Project P802.16e is a project to amend IEEE 802.16, enhancing the air interface primarily by adding support for mobile user devices at vehicular speeds. The project will provide a base station specification that can support both fixed and mobile subscribers. The Working Group began addressing this subject in March 2002. Completion is expected in the autumn of 2004.

Additional compliance test work is expected in 2004. Also, publication of a revision of IEEE Standard 802.16.2, expanding coexistence recommendation to include licensed bands from 2-11 GHz, is anticipated by early 2004.

Market Development and Deployment

As with any good communication standard, the applications of IEEE Standard 802.16 depend on the roles in which users would like to apply it. Because of its nature, the deployment scenario has the opportunity to evolve. It may find initial use in scenarios in which:

• an area lacks significant alternative broadband infrastructure;

• a single multi-service network (providing data, voice, video, and other advanced real-time services) is required, particularly when duration to deployment is a consideration or the cost of developing a wired infrastructure is cost-prohibitive; or

• cost-efficient and location-flexible backhaul services (supporting, for example, wireless LAN access points or cellular base stations) are needed.

Because the initial applications can be limited to fixed users, an operator need not implement a geographically large deployment, with roaming, to get into business. As volume production brings down the cost, and the physical size, of the equipment, new applications may develop that take advantage of the standard's special features. After the P802.16e project is completed, the industry experience in building WirelessMAN subscriber stations may allow for the rapid introduction of cost-effective compliant mobile radio interfaces. At that time, existing deployments may be upgraded to support mobile terminals.

Global Support

IEEE 802 standardization projects are open to all, with membership belonging to individuals and dependent on participation in the process. Over 900 individuals, from 23 countries, have attended an 802.16 Working Group session. Working Group membership roles have included members from 12 countries. In Asia, interest is high in Korea, in which a session was held in 2003, and in China, where a 2001 conference in Beijing considered "whether to use 802.16a as the Chinese national standard for fixed broadband wireless access at 3.5 GHz." The Working Group has also maintained close contacts with the Broadband Radio Access Networks (BRAN) project of the European Telecommunications Standards Institute (ETSI). The 802.16 Working Group and ETSI have exchanged over 50 liaison documents. It appears that decisions within the two bodies will ensure that the future ETSI HIPERMAN specifications will be compliant with IEEE Standard 802.16.

Conclusions

The IEEE 802.16 Working Group on Broadband Wireless Access began anticipating, in 1998, the world's need for broadband wireless metropolitan area networks. With worldwide participation, it has completed a set of standards that are currently moving innovative technology into the broadband access marketplace. A wide range of applications is anticipated.

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About the Author

Roger B. Marks <marks@nist.gov> is with the National Institute of Standards and Technology (NIST) in Boulder, Colorado, USA. In 1998, he initiated the effort leading to the IEEE 802.16 Working Group on Broadband Wireless Access. He has chaired that group since its inception, leading it through the development of the WirelessMAN standard for broadband wireless metropolitan area networks, as specified in IEEE Std 802.16, 802.16a, and 802.16c, as well as related coexistence and conformance specifications. Marks served as Technical Editor of IEEE Standards 802.16 and 802.16.2. He also serves actively on the Executive Committee of the IEEE 802 LAN/MAN Standards Committee. Marks received his A.B. in Physics in 1980 from Princeton University and his Ph.D. in Applied Physics in 1988 from Yale University. Author of over 80 publications, his awards include the 2003 Individual Governmental Vision Award from the Wireless Communications Association and a 1995 IEEE Technical Field Award in Electrical Measurements. He developed the IEEE Radio and Wireless Conference and chaired it from 1996 through 1999. A Fellow of the IEEE, he has served as an IEEE Distinguished Lecturer since 1999.

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