Advances in Wireless Networking Standards[1]

Roger B. Marks

National Institute of Standards and Technology

Boulder, Colorado, USA

marks@nist.gov

Manuscript published in:

Pacific Telecommunication Review (4th Quarter 2002, pp. 30-37)

Abstract

This paper describes air interface standards for wireless local area network (LAN), wireless metropolitan area network (MAN), and wireless personal area network (PAN) technology being developed within the IEEE 802 LAN MAN Standards Committee of the Institute of Electrical and Electronics Engineers, Inc. (IEEE).

Pacific Telecommunications Review

Vol 24, Num 2 (4th Quarter 2002)

Contents

Advances in Wireless Networking Standards[1]

Roger B. Marks

National Institute of Standards and Technology

Boulder, Colorado, USA

marks@nist.gov

Manuscript published in:

Pacific Telecommunication Review (4th Quarter 2002, pp. 30-37)

Abstract

This paper describes air interface standards for wireless local area network (LAN), wireless metropolitan area network (MAN), and wireless personal area network (PAN) technology being developed within the IEEE 802 LAN MAN Standards Committee of the Institute of Electrical and Electronics Engineers, Inc. (IEEE).

INTRODUCTION

With the convergence of communications networks, technologies originally developed for data communications increasingly find applications in broader telecommunications environments. In many cases, this means that data-oriented networks developed primarily for enterprise environments are being deployed by telecommunication service providers and integrated with carrier-class equipment.

Technology underlies all developments in communications networks. However, widescale deployment of networks is based not directly on technology but on standards that embody the technology, along with the economic realities. Since standards mediate between the technology and the application, they provide an

---

excellent observation point from which to understand the current and future technological opportunities. In the case of traditional telecommunications, such observation is obscured by a proliferation of standardization bodies, many organized on a geographic or governmental basis. However, in the case of data communications networks, standards have historically been set, and applied, on a worldwide basis, without strong geopolitical influence [1]. The mid-layer specifications of such networks are historically set by the Internet Engineering Task Force (IETF). Low-level (Layer 1 and 2) local area network (LAN) and metropolitan area network (MAN) specifications have been set by the IEEE 802 LAN MAN Standards Committee, which publishes through the Standards Association of the Institute of Electrical and Electronics Engineers, Inc. (IEEE). While other bodies develop and publish LAN and MAN standards, IEEE 802 has continued its success and remains the premier venue in the field. As a result, this paper looks toward future opportunities in data communications networks by observation of the relevant standardization efforts in IEEE 802.

This paper addresses primarily IEEE 802’s work in wireless networks, supporting low-cost products serving customer needs for wireless LANs, wireless MANs, and wireless personal area networks (PANs).

STANDARDIZATION IN IEEE 802

The IEEE Standards Association

The IEEE is a nonprofit transnational technical professional organization with over 350,000 individual members. IEEE supports many technical activities, including an active program in standardization through the IEEE Standards Association (IEEE-SA <http://standards.ieee.org>). IEEE standards are developed openly, with consensus in mind. Participation in their development and use is entirely voluntary. However, history has shown that standards developed in an open forum can produce high-quality, broadly accepted results capable of focusing companies and forging industries. Project development in the IEEE-SA is normally delegated to individual standard "sponsors," one of the most important of which is IEEE 802.

IEEE 802: The LAN MAN Standards Committee

The IEEE 802 LAN MAN Standards Committee <http://ieee802.org>, which first met in 1980, develops and maintains standards at the physical layer (PHY) and medium access control sublayer (MAC), each of which fits under a common logical link control sublayer (LLC), as defined in IEEE Standard 802® [2]. Together, these make up the two lowest layers of the Open Systems Interconnection (OSI) seven-layer model for data networks. IEEE 802 holds weeklong plenary sessions three times a year; between each of these plenaries, most of its constituent Working Groups hold interim sessions.

Historically, 802 has been best known for IEEE Standard 802.3, informally known as Ethernet, which is so successful that it is virtually synonymous with wired LAN. Like all successful 802 standards, however, IEEE 802.3 continuously evolves, migrating from shared coaxial cabling to twisted-pair lines supporting data rates of 1 Gbit/s. The year 2002 saw the approval of IEEE Standard 802.3ae, which specifies 10 Gbit/s Ethernet over optical fiber and provides for linking Ethernet LANs to MANs and wide area networks (WANs). The current focus of 802.3 is the "Ethernet in the First Mile" project, which intends to support high-speed access to businesses and homes, with minimal protocol conversion, over suitable twisted-pair copper cabling or passive optical networks. IEEE 802's portfolio of active projects in the cabled realm grew in late 2000 with the approval of the IEEE 802.17 Working Group on Resilient Packet Rings.

While Ethernet has been its greatest success, IEEE 802 is now the home of a number of wireless network standardization projects that take advantage of its highly successful development system. Before continuing with detailed discussion of the IEEE 802 wireless standards program, it will be useful to overview this process.

The IEEE 802 Standardization Process

The IEEE 802 process [3] is designed for quick development of standards with broad consensus. The demand for consensus helps to ensure that standards are technically refined and meet market needs. The essence of the process is a two-stage balloting system, each with multiple rounds, that seeks not only to confirm consensus but also to generate critical comment. It is sometimes said in IEEE 802 that the purpose of balloting is not to *approve* the draft standard but to *improve* it. Experience has shown that the IEEE 802 process is extremely effective at engaging a wide variety of interested parties, fostering comments, and implementing constructive changes. As a result, 802 drafts are refined again and again. By the time a draft is ready for approval, users have solid confidence in it. Yet, with careful attention and the will of the developers, it is possible to drive the draft through the system within a reasonable time.

THE IEEE 802 WIRELESS STANDARDS PROGRAM

The IEEE 802 wireless standards program [4] comprises three working groups:

1. The IEEE 802.11 Working Group develops the IEEE 802.11 standards for Wireless Local Area Networks (Wireless LAN)

2. The IEEE 802.15 Working Group develops the IEEE 802.15 standards for Wireless Personal Area Networks (Wireless PAN)
3. The IEEE 802.16 Working Group on Broadband Wireless Access develops the IEEE 802.16 standards for Wireless Metropolitan Area Networks (WirelessMAN™).

In addition, two Technical Advisory Groups (TAGs) help coordinate activities:

1. The IEEE 802.18 Regulatory TAG
2. The IEEE 802.19 Coexistence TAG

The following sections summarize the status and technology of the projects in the IEEE 802 wireless standards program.

IEEE 802.11 Wireless Local Area Networks (Wireless LANs)

The IEEE 802.11 Working Group for Wireless Local Area Networks <http://ieee802.org/11> initiated IEEE 802's wireless effort, publishing its base standard in 1997. A revised 1999 edition was also published as international standard ISO/IEC 8802-11. The base standard includes three PHY specifications, but one (infrared) has been little used. The other two obey spread-spectrum rules laid down for 2.4 GHz license-exempt use in the U.S. and later emulated in many other countries.

Two important PHY amendments (802.11a and 802.11b) were also published in 1999. IEEE 802.11b specifies a direct-sequence spread-spectrum (DSSS) system with a peak data rate of 11 Mbit/s. Lower rates are available for poor links, with dynamic rate switching rules specified; typical range is on the order of 100 m. Since this mode is a backward-compatible extension of the original DSSS system, control information is transmitted at the common 1 Mbit/s rate. This is one reason that actual throughput is less than ideal. The channel bandwidth is about 20 MHz, so that the typical North American and European frequency allocations (2.4–2.4835 GHz) provide for three non-overlapping channels (though overlapping channels are defined). A smaller Japanese allocation is noted in the standard. These devices are used in many countries, with varying spectrum allocations and power limits. IEEE Standard 802.11d provides for the specification of a "Country Information Element" that allows a station to identify the regulatory domain in which it is located and to configure its PHY accordingly.

Interoperability testing is critical to supplement standards. In the case of 802.11, the Wireless Ethernet Compatibility Alliance was created to develop interoperability tests and brand the interoperable products with the trademark Wi-Fi™ . Wi-Fi has played a key role in the success of 802.11b, and nearly all commercial 802.11b products are Wi-Fi certified. The Wi-Fi procedures test some but not all 802.11b options; options that are not tested are rarely implemented in mass-market products.

Applications of IEEE 802.11 flourished with the emergence of products based on 802.11b; there are now an estimated 30 million 802.11 users, with annual growth of over 20 million units. Many manufacturers initially targeted enterprises wishing to reduce the cabling costs associated with Ethernet. However, 802.11b products came along at the same time as two other important developments: (1) powerful laptop computers with PCMCIA slots, and (2) widespread broadband network deployments to homes and small businesses. The combination is quite powerful: it allows a user to have instant broadband access at the fingertips throughout an office area. Some enterprising computer manufacturers began to market this package to the home user, lowering prices accordingly. Sales grew, and prices fell; user terminals are available for about US$50, and feature-enhanced access points (base stations) for around US$100.

With millions of 802.11b-equipped portable computers interoperable with millions of access points, it became inevitable that they would begin to interact with access points they did not own. For example, for many years, IEEE 802 standards meetings have supported dozens, and then hundreds, of users accessing local servers, and the Internet, on wireless LANs. Many other conferences have adopted this concept, which was soon extended to provide "hot spots" in other public or semi-public places–classrooms, hotels, airports, cafes, campuses, etc. In contrast to the vision of mobile data provided by third-generation cellular telephone networks, these hot spots take advantage of the many opportunities to provide data at high rates to people who are relatively sedentary–normally at a desk or table–with low-cost equipment that they already own for use in their private networks, and with freely available spectrum.

Many of the initial 802.11b public-space deployments were provided purely as a service to the user. However, some began seeing commercial networking opportunities. Companies began creating branded clusters of hot spots, across a city or in a group of hotels, airports, coffee shops, or perhaps automobile filling stations, with a single account used to pay the usage fee at all nodes. Currently, companies are trying to consolidate these systems, giving the user an easy log-in procedure at more locations. It is reported that Europe leads in this field [5], which is somewhat surprising in light of Europe's strong push for third-generation cellular systems and of the HIPERLAN/2 standard, an alternative wireless LAN specification created by the European Telecommunications Standards Institute but which has not found much success.

While much of the commercial development aims to address transitory users, wireless LANs have also become popular with both amateur and commercial wireless Internet service providers (WISPs). Typically, these systems provide continuous broadband access to users in a home. The LANs operate in outdoor space, often with directional antennas to extend the range. These systems have shown great initial success, but some potential technical hurdles remain, as discussed below.

IEEE Standard 802.11 includes both ad hoc networks (with mobile devices only) and infrastructure networks, which connect mobile stations to access points that bridge to a wired LAN. The latter are more popular and are the focus here.

The essence of 802.11 is its MAC, which supports all of its PHY specifications. The primary access method, denoted the distributed coordination function (DCF), is based on carrier-sense multiple access with collision avoidance (CSMA/CA). CSMA/CA, like Ethernet, is a listen-before-talk protocol, with specific deferral procedures used when the medium is busy. However, collision detection, which minimizes the effects of collisions when used in Ethernet, is essentially impossible in the wireless case because of the great disparity in signal levels. Furthermore, most units are half-duplex and therefore cannot sense while transmitting. Even carrier-sensing as a means of spotting a transmission opportunity is unreliable in the wireless case because of the "hidden-terminal" problem, in which the receiver may be within range of several transmitters that are unable to hear each other. Therefore, 802.11 includes a request-to-send/clear-to-send (RTS/CTS) protocol which, in essence, notifies other users that the medium is expected to be busy and therefore provides a "virtual carrier sense." A station defers transmission in response to either its physical or its virtual carrier sense.

The RTS/CTS mechanism is effective at addressing the hidden-terminal problem, at least with a moderate number of terminals hidden, and with some cost in overhead. However, RTS/CTS is challenged in the WISP environment with directional subscriber antennas; in this case, virtually *all* of the terminals are hidden from each other. Also, while responding to RTS/CTS is mandatory, generation of RTS is optional, so not all Wi-Fi radios support it. If the terminals do not generate RTS, the mechanism does not function.

The 802.11 Working Group is currently engaged in many activities to upgrade the standard to address some specific limitations and problems. In particular:

- **Quality of Service (QoS)**

The contention-based 802.11 MAC, based on the DCF, was not designed for time-critical applications, such as voice, video, and games. The standard specifies an alternative Point Coordination Function (PCF), which works in conjunction with the DCF to provide scheduled service. However, the PCF has not been widely implemented. A project known as 802.11e has worked for several years to enhance the MAC for time-critical services. The problem remains challenging.

- **Security**

IEEE Standard 802.11 specifies a security protocol known as Wired Equivalent Privacy (WEP). WEP was designed to "protect authorized users of a wireless LAN from casual eavesdropping." Weaknesses in WEP have been discovered, and successful attack algorithms are available [6]. Project 802.11i is developing more reliable standard security protocols. In the meantime, external security, beyond the wireless link, may be required for sensitive applications.

- **Interworking**

In September 2002, the IEEE 802.11 Working Group, along with other standards bodies, held the first meeting of an interworking group. The goal is to develop standard schemes by which devices outfitted with both wireless LAN and cellular telephone radios can readily switch between the two based on availability.

- **Higher Data Rate**

One solution to the data-rate limitations of 802.11b is already a standard. Devices based on IEEE 802.11a, which was published in 1999, offer, in principle, rates up to 54 Mbit/s and are now available at moderate cost (under US$100). This technology is used in license-exempt 5 GHz bands (5.15–5.25, 5.25–5.35 and 5.725–5.825 GHz in the U.S.); channel bandwidths are similar to those of 802.11b, and channels are defined with 20 MHz spacing. Orthogonal frequency-division multiplexing (OFDM) is used, with 52 subcarriers. A current project, 802.11g, is enhancing the data rates within the 2.4 GHz band. The current draft is based on the OFDM PHY in 802.11a, with similar data-rate capability.

IEEE 802.15 Wireless Personal Area Networks (Wireless PANs)

The IEEE 802.15 Working Group for Wireless Personal Area Networks <http:// ieee802.org/15> develops standards for Wireless PANs to link portable devices. The work is exclusively in unlicensed bands (only in the 2.4 GHz band and below, to this point) with ranges up to 10 m. Low power consumption, small size, and low cost are primary considerations.

The 802.15 Working Group's first activity was to develop a standard derived from Bluetooth™ Specification Version 1.1. This activity was completed with the June 2002 publication of IEEE Standard 802.15.1. Bluetooth is a "cable-replacement" technology supporting low-cost wireless communication between computers, mobile telephones, printers, etc. The networking is ad hoc and based on small temporary "piconets". The specification supports data at rates up to 721 kbit/s, as well as three voice channels, and targets low power consumption (less than 0.1 W during transmission). The primary initial applications have been in cellular telephones and handheld computers, with Bluetooth providing a wireless link to headsets and to computers for synchronization. Automotive environments seems to be a growth area. Many analysts have claimed that, with the widescale deployment of 802.11, Bluetooth has lost its cost advantage and, with its much lower data rate, cannot compete with 802.11. However, Bluetooth retains significant advantages in power consumption, and its support for voice is a significant feature. Many prognosticators still expect a large role for Bluetooth products in its niche.

Separately, the 802.15 Working Group is developing a High Rate Wireless PAN under IEEE Project 802.15.3. The draft standard in ballot describes a system supporting up to 55 Mbit/s, for applications such as digital imaging and multimedia. The MAC is based on temporary piconets but differs from that of 802.15.1. A study is already underway regarding an enhanced PHY specification that would support at least 110 Mbit/s. It appears likely that, if the work proceeds, the enhanced PHY will be based on ultra-wideband communications.

Finally, the 802.15 Working Group is developing yet another independent wireless PAN in Project 802.15.4. This will specify a low-rate PAN supporting rates up to 250 kbit/s with very low power consumption (for battery life on the order of months or years) and low complexity (targeting costs of US$2 per radio). Applications are expected in sensors, toys, and location tracking. A draft standard is in ballot.

IEEE 802.16 Wireless Metropolitan Area Networks (Wireless MANs)

The IEEE Working Group 802.16 on Broadband Wireless Access (BWA) <http:// WirelessMAN.org> has developed the WirelessMAN™ air interface standard to support the development and deployment of wireless metropolitan area networks. The Working Group is addressing primarily applications of wireless technology to link commercial and residential buildings to high-rate core networks and thereby provide access to those networks. This link is sometimes known colloquially as the "last mile."

The Working Group's first air interface project was completed with the April 2002 publication of IEEE Standard 802.16 Air Interface for Fixed Broadband Wireless Access Systems. As specified in this standard [7], 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, the fundamental design of the standard may eventually allow for the efficient extension of the WirelessMAN networking protocols directly to the individual user. For instance, a central BS may someday be exchanging medium-access control (MAC) protocol data with an individual laptop computer in a home. The links from the BS to the home receiver and from the home receiver to the laptop would likely use quite different physical layers, but design of the WirelessMAN MAC could accommodate such a connection with full QoS. 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 published base standard 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. The base station basically transmits a TDM 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. 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 Project 802.16a is developing a draft (with completion expected in 2002) addressing frequencies in the 2-11 GHz band, 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 is 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.

The current draft 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.

Because of the propagation requirements, the use of advanced antenna systems is supported.

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

As 802.16a nears completion, the 802.16 Working Group is turning its attention to enhancing the standard, primarily by adding support for mobile user devices. The Working Group began addressing this subject in March 2002.

In order to assist the successful transition from standardization to widescale deployment, the Working Group is also placing a great deal of attention on compliance and interoperability. The group has begun rapidly developing test documentation. The Worldwide Interoperability Microwave Access (WiMAX) Forum <http://wimaxforum.org>, an industry consortium, has arisen to help define and carry out interoperability assurance tests.

CONCLUSION

The open, global consensus process, coupled with a history of success, has made IEEE 802 the dominant venue for the development of low-level networking standards. Out of 802 are arising the fundamental standards for wireless LANs, PANs, and MANs that will define the shape of networking.

ACKNOWLEDGEMENTS

Carl Eklund, John Koontz, Claude Weil, and David R. Smith reviewed this manuscript.

BIOGRAPHY

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 that led to the IEEE 802.16 Working Group on Broadband Wireless Access, chairing it since inception and serving as Technical Editor of IEEE Standard 802.16-2001 and 802.16.2-2001. He also serves actively on the IEEE 802 Executive 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 1995 IEEE Morris E. Leeds Award (an IEEE Technical Field Award). 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. Marks has traveled to China and Korea, lecturing on IEEE Standard 802.16 to help encourage its introduction within the Pacific region. He has twice provided keynote addresses at Chinese telecommunications conferences.

REFERENCES

[1] R. B. Marks and R. E. Hebner, "Government Activity to Increase Benefits from the Global Standards System," 2001 IEEE Conference on Standards and Innovation in Information Technology (Boulder, Colorado, USA), pp. 183-190, 3-5 October 2001.

[2] IEEE Standards, including all those mentioned here, are available from the IEEE <http://standards.ieee.org>.

[3] R. B. Marks, "IEEE Standardization for the Wireless Engineer," *IEEE Microwave Magazine*, June 2001, pp. 16-26.

[4] R. B. Marks, I. C. Gifford, and B. O'Hara, "Standards in IEEE 802 Unleash the Wireless Internet," *IEEE Microwave Magazine*, June 2001, pp. 46-56.

[5] J. Blau, "Wi-Fi Hotspot Networks Sprout Like Mushrooms," *IEEE Spectrum*, Sept. 2002. pp. 18-20.

[6]T. Karygiannis and L. Owens, *DRAFT Wireless Network Security: 802.11, Bluetooth™ and Handheld Devices*, NIST Special Publication 800-48, July 2002.

[7] C. Eklund, R. B. Marks, K. L. Stanwood, and S. Wang, "IEEE Standard 802.16: A Technical Overview of the WirelessMAN Air Interface for Broadband Wireless Access," *IEEE Communications Magazine*, June 2002, pp. 98-107.