INTRODUCTION TO IEEE STANDARD 802.16: WIRELESS BROADBAND ACCESS

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Abstract

The IEEE 802.16 Standard, first published in 2001, defines a means for wireless broadband access as a replacement for current cable and DSL "last mile" services to home and business. The adoption of this standard is currently in progress through the use of WiMAX Forum certified networking equipment and widespread adoption should appear over the next few years. This paper provides an overview of the 802.16 standard in regards to frequency bands, the physical layer specification, security sublayer, MAC common part sublayer, and service specific convergence sublayer.

1. Introduction to IEEE Standard 802.16

The IEEE Standard 802.16 [1] is still very much a new standard when compared to existing standards such as the more mature IEEE Standard 802.11, the standard used for Wi-Fi networking commonly seen in home and business. However, while the 802.11 standard is primarily used for small local area networks, the 802.16 standard is designed to be used as a means of allowing wireless broadband access as an alternative to cable and DSL connections [2].

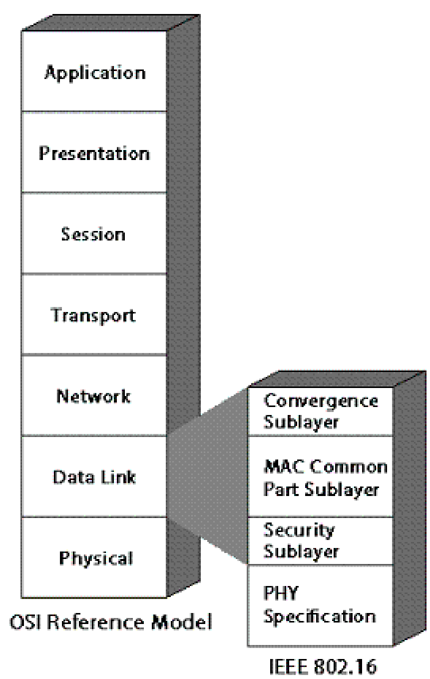

Figure 1: OSI Reference Model and IEEE 802.16.

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The 802.16 standard is more commonly known referred to as WirelessMAN due to the fact that its goal is to implement a set of broadband wireless access standards for wireless metropolitan area networks. To this end, much of the work on the standard has been focused on the "last mile" that would allow fixed and mobile wireless substations to connect to the fixed wireless base stations, thus allowing the delivery of high-speed internet connections to customers [3].

The 802.16 standard corresponds to the physical and data link layers of the OSI reference model, as shown in figure one. The 802.16 standard follows other standards within the 802 family in that it defines multiple physical layer (PHY) specifications that can be used, but all of them are supported by the same medium access control (MAC) layer. This flexibility is important as it allows for a common MAC implementation to be used by manufacturers, providing support for each of the possible PHY specifications without having to redevelop the MAC.

2 History of IEEE Standard 802.16

The formation of the IEEE 802.16 Working Group on Broadband Wireless Access Standards was initiated in August of 1998 by the National Wireless Electronics Systems Testbed at the U.S. National Institute of Standards and Technology. A kickoff meeting was organized at the 1998 IEEE Radio and Wireless Conference and by November the initial group of 45 members had accepted the invitation to meet with the IEEE 802 working group. By July 1999 the initial study group had written and received approval for its first project authorization request and began to hold bi-weekly meetings. In April of 2002 the 802.16-2001 standard was officially published. This standard has since been superseded by the 802.16-2004 standard which includes material from the original 802.16-2001 standard as well as the 802.16.2-2001, 802.16c-2002, and 802.16a-2003 standards. The IEEE 802.16 Working Group is a part of the IEEE 802 LAN/MAN Standards Committee and continues to work on a number projects.

3 Frequency Bands

The 802.16 standard defines a number of air interfaces that make use of a frequency band that can be divided into one of three categories: 10-66 GHz licensed bands, licensed bands below 11 GHz, and unlicensed bands below 11 GHz. Table 1 summarizes the air interface designations and their applicable category of frequency bands.

Table 1: Air Interface Designations and Frequency Bands

Designation	Frequency Bands
WirlessMAN-SC	10-66 GHz licensed bands
WirlessMAN-SCa	Below 11 GHz licensed bands
WirelessMAN-OFDM	Below 11 GHz licensed bands
WirelessMAN-OFDMA	Below 11 GHz licensed bands
WirelessHUMAN	Below 11 GHz license-exempt bands

3.1 The 10-66 GHz Licensed Bands

The first category of frequency bands is the 10-66 GHz licensed bands, these frequency bands have a short wavelength that requires line-of-sight (LOS); however, the multipath interference is negligible. The bands allow for data rates in excess of 120 Mb/s and coupled with an environment that is well suited to the implementation of point-to-multipoint (PMP) access and the frequency bands are well suited to small office/home office (SOHO) all the way up to large office applications.

3.2 Below 11 GHz Licensed Bands

While still a part of the 10-66 GHz licensed bands category, the second category of licensed bands below 11 GHz requires special note due to the characteristics of the frequency bands. Due to the longer bandwidth of the frequency range, LOS is not necessary and the multipath interference may be significant. As such, the ability to support near-LOS and non-LOS (NLOS) applications requires additional PHY requirements to be fulfilled such as advanced power management techniques, interference mitigation/coexistence, and multiple antennas.

3.3 Below 11 GHz License-exempt Bands

The final category of frequency bands are the license except frequencies below 11 GHz, typically using the 5-6 GHz bands. The operating environment of these bands is similar to those of the 11 GHz licensed bands; however, the license-exempt status of the bands introduces additional interference from the co-existence of other devices within the range, as well as regulatory constraints that limit the radiated power. To overcome these problems mechanisms such as dynamic frequency selection is introduced to the PHY and MAC of the air interface.

4 Physical Layer Specifications

The 802.16 physical layer, or PHY, corresponds to layer one of the OSI model and provides downlink and uplink transmission capably. The standard defines five different PHY specifications that are designed to be used under different situations. The primary of these is the WirelessMAN-SC specification which is targeted for operation in the 10-66 GHz frequency band and is followed by the WirelessMAN-SCa, WirelessMAN-OFDM, and WirelessMAN-OFDMA specifications which are targeted for use in frequency bands below 11 GHz. Additionally, the WirelessHUMAN PHY defines specific components that are required for operation in non-licensed frequency bands.

Of the defined PHY specifications, WirelessMAN-SC is tailored to the delivery of service to static locations due to its LOS and fixed antenna requirements. This makes it attractive to businesses that are in need of a high-speed connection but do not have access to a conventional connection. In contrast, the WirelessMAN-SCa, WirelessMAN-OFDM, and WirelessMAN-OFDMA are tailored for delivery of service to homes and small businesses. This is possible due to the fact that the specifications are capable of NLOS transmission, larger coverage areas, and delivery of service to mobile substations. This increases the coverage area for service providers and lowers the cost for subscribers.

4.1 WirelessMAN-SC PHY Specification

The WirelessMAN-SC PHY specification is defined for the 10-66 GHz frequency band and, in contrast to other PHY specifications, assumes LOS propagation with no significant concern for multipath propagation. The specification includes additional support for adaptive burst profiling for each substation connected to a base station, which allows for transmission parameters to be adjusted on the fly allowing for an improvement in the signal reception by the substation. Frames are used for transmission and each frame is divided into a downlink sub-frame, which includes the data in addition to frame synchronization and control information, and is followed by the uplink sub-frame.

For transmission purposes the specification provides support for both frequency division duplexing and time division duplexing. In the case of frequency division duplexing, the uplink and downlink are on separate frequencies and through the use of a burst downlink both full-duplex and half-duplex substations can be supported. This is in contrast to time division duplexing in which both the uplink and the downlink are on the same shared frequency with the transmission type separated by time.

Regardless of the transmission duplexing mode selected, the transmission is divided into an uplink and downlink to the substations. Since multiple substations can access the same base station the uplink is divided based upon the use of time division multiple access and demand assigned multiple access, which in turn allows the uplink to be divided into timeslots for substation transmission to take place. Likewise, the downlink is divided through the use of time division multiplexing with data for every substation multiplexed into the same downlink transmission.

4.2 WirelessMAN-SCa, WirelessMAN-OFDM, and WirelessMAN-OFDMA

The WirelessMAN-SCa, OFDM, and OFDMA PHY specifications are all designed to operate using licensed frequency bands below 11 GHz, where the longer radio wavelengths allow for NLOS operations. The WirelessMAN-SCa PHY is similar to the WirelessMAN-SC specification, where as the WirelessMAN-OFDM and WirelessMAN-OFDMA specifications are based upon orthogonal frequency division multiplexing (OFDM) modulation and are included in the standard due to their increased performance in NLOS environments.

All three of the PHY specifications are similar to the WirelessMAN-SC specification in that they support both frequency division duplexing and time division duplexing for transmission. However, WirelessMAN-SCa and WirelessMAN-OFDM use time division multiple access to support multiple substations, where as WirelessMAN-OFDMA is based upon assigning different subcarriers. Additionally, to address the various issues of operating in a lower frequency and NLOS operation, the PHY specifications introduce such functions as flexible channel bandwidth, adaptive antenna systems [4], automatic repeat request, and time-space encoding.

4.3 WirelessHUMAN PHY Specification

WirelessHUMAN, or Wireless High-speed Unlicensed Metropolitan Area Networks, are implemented in the 11 GHz license-exempt frequency bands and can make use of the WirelessMAN-SCa, WirelessMAN-OFDM, or WirelessMAN-OFDMA PHY specification as the primary PHY specification from the WirelessHUMAN network [5].

As the WirelessHUMAN is typically implemented in the 5-6 GHz frequency band it is subject to a number of unique operating environment constraints to include interference from other devices in the range as well as regulatory power constraints. To address these problems an additional set of specific components are defined. One of these specific components is a transmit spectral mask specific to the WirelessHUMAN PHY and ensures that transmissions are within the allowed ranges of the applicable regulatory body.

The second of the WirelessHUMAN specific components is a channelization formula that defines a channel center frequency and provides an 8-bit unique numbering system for all channels between 5 and 6 GHz with 5 MHz spacing. This formula allows for a means of a reduction in interference by moving to a different channel and the formula is flexible enough to define future channelization sets for future regulatory domains.

5 Security Sublayer

The standard builds on the PHY specification by implementing a security sublayer as part of the overall MAC functionally provided. This security sublayer is the lowest layer of the MAC and can provide strong encryption to outgoing data transmissions. This allows for communications security between the substation and base station, and additionally protects against theft of service by preventing unauthorized substations from connecting to the network.

The core architecture of the security sublayer is the use of two component protocols. These protocols include an encapsulation protocol that provides a means for encrypting data packets and a key management protocol that provides a means for the base station and substation to synchronize keys. Packets that are transmitted after being passed through the encapsulation protocol contain a generic unencrypted MAC header, with the internal data encrypted using the cipher text chaining mode of the US Data Encryption Standard (DES).

5.1 PKM Protocol

The privacy key management (PKM) protocol is the means by which the substation that is connected to the network initially authenticates and re-authenticates its identity, as well as acquiring cryptographic keying information. The core of the PKM is the concept of security associations; which are a set of cryptographic methods and associated keying information. These security associations are established by the substation during the initial connection to the base station and are given a limited time frame of operation before it is necessary for the substation to refresh them. To ensure the secure exchange of these security associations between the base station and the substation X.509 digital certificates and RSA public-key encryption is used. This is further augmented by the use of Hashed Message Authentication Code and SHA-1 to authenticate the PKM protocol messages.

6 MAC Common Part Sublayer

Although the standard provides for more that one physical layer, only one common MAC layer is defined and it is compatible with all defined physical layers. The MAC is composed of the security sublayer that resides directly above the PHY layer, the common part sublayer that implements the majority of the MAC functionality, and the service-specific convergence sublayer that resides about the common part sublayer and provides an interface to higher level networks. Taken as a whole of the security sublayer, the common part sublayer, and the convergence sublayer the 802.16 MAC corresponds to layer two of the OSI networks model.

The MAC common part sublayer defines two different forms of network configurations in addition to defining how both of these network configurations access the network. The two network configurations that are defined are a point-to-multipoint (PMP) configuration and mesh topography. Each of these topographies in turn makes use of a common data/control plane that similar for both except in the area of addressing and connections which are configured specifically for the topography type.

6.1 Point-to-Multipoint

When an 802.16 network is in a purely point-to-multipoint (PMP) mode the base station acts as the downlink to all of the substations and the substations are unable to communicate with other substations. The base station makes use of a sectorized antenna to enable it to communicate in multiple directions and all substations that are in the path of the signal receive the same transmission and listen for their connection identifier (CID) to determine of the packets to receive. Since the base station is the only transmitter operating in a given direction is does not need to coordinate transmission times with other stations; however, it does make use of time division duplexing to divide a connection into uplink and downlink transmission periods.

6.2 Mesh

In contrast to PMP mode, the mesh network is able to have traffic routed through other substations, and substations can directly communicate with each other. As such, the substations will typically make use of an omnidirectional or a steerable antenna for transmission. Within the network all systems are referred to as nodes and the node that has direct access to the backhaul services is termed the mesh base station; and traffic between the nodes is typically described as being either towards or away from the mesh base station. The exact operation of the mesh network is dependent upon the transmission protocol method used; however, they typically operate using distributed scheduling, centralized scheduling, or a combination of the two. Broadcast scheduling is a concern in mesh networks due to the increased probability of broadcast collisions and as such not even the mesh base station can transmit without the coordination of other stations.

6.3 Data/Control Plane

The data/control plane of the MAC common part sublayer is the set of media access functions that controls how base stations and substations interact with each other over the network including how data packets are constructed, how bandwidth is allocated, and how stations connect to and maintain their connection to the network. A full overview of the data/control plane is beyond the scope of this paper; however, there are some areas of interest that are worth noting.

One of the unique items addressed by the 802.16 data/control plane is that of dynamic frequency selection techniques that are required to maintain license-exempt operation. The foremost of these techniques is the detection of other primary operators on the frequency being used by the network. In the event that primary users are detected on the current operating frequency, the base station must determine a new frequency, move operations to it, and broadcast this frequency to the connected base stations.

Due to the fact that the radio signals that 802.16 networks use for communication are subject to outside interference the MAC includes a collection of processes known as "ranging" that monitor and maintain the communication uplink and downlink. For the downlink ranging, the base station maintains a downlink burst profile for each substation, and places the burden of ensuring a strong connection on the substation. If the noise on the channel exceeds the acceptable parameters the substation will request a change in the profile from the base station. Likewise, the substation maintains its uplink connection through initial and periodic ranging that allows it to adjust its initial time offset and transmitter power level and periodically updates these as necessary to maintain the channel.

Table 2: QoS Service Classes

Service Class Name	Purpose
Unsolicited Grant Services (UGS)	Constant bit rate services such as T1/E1 emulation or Voice over IP without silence suppression
Real-Time Polling Services (rtPS)	Real-time services with variable data packet size such as MPEG video transmission or Voice over IP with silence suppression
Non-Real-Time Polling Services (nrtPS)	Non-real-time services that require variable size data packet bursts
Best Effort (BE) Services	Best effort data packet delivery service typically used for web surfing

Additionally, the data/control plane defines a means of quality of service (QoS) functionally based upon the concept of service flows. Service flows are unidirectional flows of data that are characterized by a set of quality of service parameters and are a means for the MAC to define transmission ordering and scheduling for packets within that service flow [6]. These service flows may be defined through the use of a service class, shown in table two, which is a categorization of different types of applications that may need to operate on the network and how their data should be handled. However, the use of a named service class is optional and an explicit set of quality of service parameters can be defined for a service flow instead.

7 Service-specific Convergence Sublayer

The service-specific convergence sublayer is the top layer of the MAC and provides an interface with higher level ATM and packet based protocols. The convergence sublayer is responsible for receiving a protocol data unit from a higher level protocol, performing classification and processing as necessary, and passing it down to the appropriate MAC service access point for delivery. Likewise, it accepts protocol data units from other peers on the 802.16 network to be passed up to the higher level protocol with applicable changes as necessary. Additionally, it is capable maintaining quality of service parameters from higher level protocols and adapting these as necessary as the data unit is passed along to the 802.16 network.

8 Amendments to the Standard

The 802.16 standard is still very much in development by IEEE and as such there are a number of committees working on amendments to the standard. These amendments are either currently active, or still in development. Active amendments such as 802.16f are those that are considered to be a part of the 802.16 standard and are suitable for production use. However, the amendments that are still in development cannot be considered to be a part of the standard and are subject to change until they are officially published.

8.1 Amendment 802.16f

IEEE Standard 802.16f was published in December of 2005 as the first amendment to the 802.16 standard and defines a Management Information Base (MIB) for the MAC and PHY, and associated management procedures [7]. This provides a means for a Service Flow Database containing current service flow and quality of service (QoS) information to be transmitted to base stations and subscriber stations when a new subscriber station enters into a base station network. The addition of this functionality allows for meshed and multi-hop networking to be used.

8.2 Amendment 802.16e

IEEE Standard 802.16e was published in January of 2006 as the second amendment to the 802.16 standard and addressed physical and MAC layers for fixed and mobile wireless operations in the licensed radio bands [8]. Much of the changes that were applied were focused on providing enhanced support for subscriber stations at vehicular speeds. One of the items that was addressed was a means for higher layer handover between base stations thereby providing better support for the mobile substations.

8.3 Amendments Still in Development

There are a number of proposed amendments to the 802.16 standard that are still in development, with each of them seeking to improve various aspects of the existing standard. A list of the current projects is shown in table three and it should be noted that much of the work that is currently being done is focused on improving the network management plane. However, the 802.16k project warrants special note due to the fact that, when complete, it will actually be an amendment to the 802.1D MAC Bridges standard to add support for bridging of the IEEE 802.16 MAC [9].

Table 3: Current 802.16 Projects

Project Number	Project Name
802.16g	Management Plane Procedures and Services
802.16h	Improved Coexistence Mechanisms for License-Exempt Operation
802.16i	Mobile Management Information Base
802.16j	Mobile Multi-hop Relay
802.16k	Bridging of 802.16

9 Research

As the 802.16 standard is still new it is the subject of developing research. Some of this has resulted in the development of new amendments to the standard to address various shortcomings of the original specification. Much of this research is focused in the area connection speeds and determining what modifications are possible to ensure the typical connection is as close to the theoretical maximum as possible. However, some of the other research is focused on addressing areas that are a common problem of wireless technologies such as ensuring that wireless networks are not subject to the interface from other networks operating the same area, improving link adaptation algorithms, and increasing the handoff speed for mobile connections to the network.

10 WiMAX Forum

Due to the fact that the standard is only as effective as the industry acceptance of the standard, the WiMAX forum was chartered with the responsibility to ensure the compatibility and interoperability of broadband access equipment [10]. To accomplish this the WiMAX Forum awards the "WiMAX Forum Certified" credential to equipment that is compatible with both the IEEE 802.16 standard and the European equivalent ETSI HiperMAN standard [11]. Additionally they work with industry service providers and government regulators to ensure that equipment meets the needs of the customers and government regulations respectively.

It is important to note that while WiMAX equipment is fully compatible with the 802.16 standard, equipment that is purely based upon the standard is not necessarily able to earn the "WiMAX Forum Certified" credential. This is due to the fact that the goal of the WiMAX Forum is interoperability between IEEE 802.16 standard and the ETSI HiperMAN standard. To accomplish this, WiMAX equipment makes use of system profiles that implement the OFDM PHY and MAC from the 802.16 standard.

11 Summary

The development of the IEEE 802.16 Standard shows great promise for the increased delivery of high speed connections to areas that were previously unable to be connected or were connected at high costs. Additionally, the arrival of the standard means that service providers have an additional choice in the means of service delivery. This in turn means that customers will have additional choices in high-speed connections.

Currently, much of the deployment of 802.16 based networks is through the use of WiMAX Forum Certified equipment and, to this end, limited deployments have begun around the world. Companies such as Sprint Nextel have already begun to acquire frequency band licenses within the United States and have plans to deploy services within the next few years. Around the world a number of networks are already in place and are in use by the general population.

If the general demand for high speed internet access is any indication, then 802.16 based networks should appear in wide spread worldwide use within the next few years. Furthermore, the continuing development of the standard by the IEEE 802.16 Working Group, industry, and academia indicates that standard will likely enjoy a long life span before being superseded by future developments in wireless access. As noted in a technical overview of the standard published in a June 2002 edition of the IEEE Communications Magazine the publishing of the 802.16 standard is "a defining moment in which broadband wireless access moves to its second generation."

Glossary

Asynchronous Transfer Mode (ATM) – A high-speed network protocol based upon dynamic allocation of bandwidth using fixed sized packets.

Digital Subscriber Line (DSL) – A technology that allows for high-speed residual connections over the existing telephone lines.

European Telecommunications Standards Institute (ETSI) – A European standards body with responsibilities that are similar to IEEE.

High Performance Metropolitan Area Networks (HiperMAN) – An ETSI standard that is designed to provide broadband wireless access at the 2 GHz to 11 GHz ranges.

Institute of Electrical and Electronics Engineers (IEEE) – An organization of engineers, scientists, and students that are involved in the electrical and electronics fields, and acts as a publishing house and standards making body.

Mesh Network – A communications network that is capable of forwarding data to and from multiple systems.

Network Management System (NMS) – A device used for the supervision of SNMP traffic on a network.

Open Systems Interconnection (OSI) reference model – A network architecture developed by the International Organization for Standardization that divides various aspects of network communications into layers.

Orthogonal Frequency Multiplexing (OFDM) – A transmission technique based upon frequency-division multiplexing in which multiple signals are sent out over different frequencies.

Point-to-Multipoint (PMP) – A communications network that is capable of providing a path from one network to multiple networks.

Simple Network Management Protocol (SNMP) – A protocol governing network management and the monitoring of network devices and their functions.

Wi-Fi – Short for "wireless fidelity" and is typically used to refer to products that are used for local area networking and based upon the IEEE 802.11 standard.

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