IEEE 802.16a Standard and WiMAX
Igniting Broadband Wireless Access

White Paper

Introduction

The 802.16 standard, amended this January by the IEEE to cover frequency bands in the range between 2 GHz and 11 GHz, specifies a metropolitan area networking protocol that will enable a wireless alternative for cable, DSL and T1 level services for last mile broadband access, as well as providing backhaul for 801.11 hotspots. The new 802.16a standard specifies a protocol that among other things supports low latency applications such as voice and video, provides broadband connectivity without requiring a direct line of sight between subscriber terminals and the base station (BTS) and will support hundreds if not thousands of subscribers from a single BTS. The standard will help accelerate the introduction of wireless broadband equipment into the marketplace, speeding up last-mile broadband deployment worldwide by enabling service providers to increase system performance and reliability while reducing their equipment costs and investment risks.

However it has been shown repeatedly that adoption of a standard does not always lead to adoption by the intended market. For a market to be truly enabled, products must be certified that they do adhere to the standard first, and once certified it must also be shown that they interoperate. Interoperability means the end user can buy the brand they like, with the features they want, and know it will work with all other like certified products. The IEEE does not fulfill this role, leaving it to private industry to take a given technological standard and drive it that last crucial mile for mass adoption. In the case of WLANs this role was and is fulfilled by the WiFi Alliance.[1] For the Broadband Wireless Access (BWA) market and its 802.16 standard, this role is played by the Worldwide Microwave Interoperability Forum or WiMAX.*. WiMAX is a non-profit industry trade organization that has been chartered to remove an important barrier to adoption of the standard by assuring demonstrable interoperability between system components developed by OEMs. WiMAX will develop conformance and interoperability test plans, select certification labs and will host interoperability events for IEEE 802.16 equipment vendors. By defining and conducting interoperability testing, and by awarding vendor systems a "WiMAX Certified™" label, WiMAX will model the approach pioneered by the WiFi Alliance that ignited the wireless LAN industry, bringing the same benefits to the BWA market segment.

Overview of the IEEE 802.16a Standard

Satisfying the growing demand for BWA in underserved markets has been a continuing challenge for service providers, due to the absence of a truly global standard. A standard that would enable companies to build systems that will effectively reach underserved business and residential markets in a manner that supports infrastructure build outs comparable to cable, DSL, and fiber. For years, the wildly successful 802.11x or WiFi wireless LAN technology has been used in BWA applications along with a host of proprietary based solutions. When the WLAN technology was examined closely, it was evident that the overall design and feature set available was not well suited for outdoor BWA applications. It could be done, it is being done, but with limited capacity in terms of bandwidth and subscribers, range and a host of other issues made it clear this approach while a great fit for indoor WLAN was a poor fit for outdoor BWA.

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This analysis and review was conducted by the IEEE and it was decided that a new, more complex and fully developed standard would be required to address both the physical layer environment (outdoor versus indoor RF transmissions) and the Quality of Service (QoS) needs demanded by the BWA and last mile access market.

The IEEE conducted a multi-year effort to develop this new standard, culminating in final approval of the 802.16a Air-Interface Specification in January 2003. This standard has since received broad industry support from leading equipment makers. Many WiMAX company members are active in both the IEEE 802.16 standards development and the IEEE 802.11 efforts for Wireless LAN, and envision the combination of 802.16a and 802.11 creating a complete wireless solution for

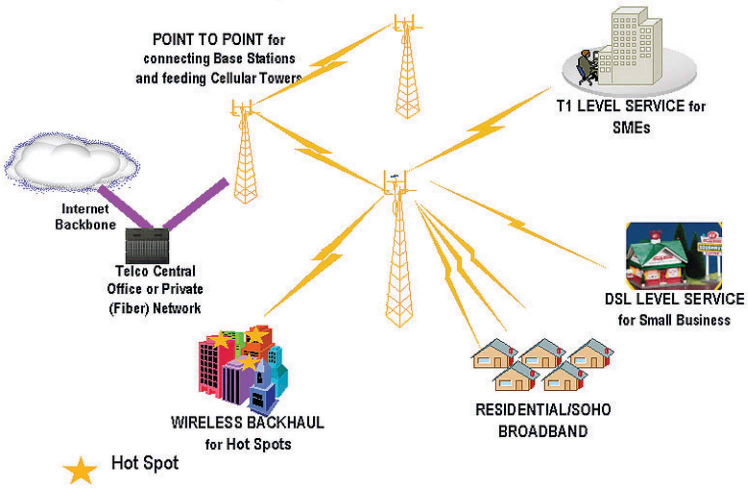

Figure 1. BWA (IEEE 802.16) Everywhere

delivering high speed Internet access to businesses, homes, and WiFi hot spots. The 802.16a standard delivers carrier-class performance in terms of robustness and QoS and has been designed from the ground up to deliver a suite of services over a scalable, long range, high capacity "last mile" wireless communications for carriers and service providers around the world.

In BWA, applications include residential broadband access-- DSL-level service for SOHO and small businesses, T1/E1 level service for enterprise, all supporting not just data but voice and video as well, wireless backhaul for hotspots and cellular tower backhaul service to name a few.

In reviewing the standard, the technical details and features that differentiate WiMAX certified equipment from WiFi or other technologies can best be illustrated by focusing on the two layers addressed in the standard, the physical (PHY) or RF transmissions and the media access control (MAC) layer design.

WiMAX and the IEEE 802.16a PHY Layer

The first version of the 802.16 standard released addressed Line-of-Sight (LOS) environments at high frequency bands operating in the 10-66 GHz range, whereas the recently adopted amendment, the 802.16a standard, is designed for systems operating in bands between 2 GHz and 11 GHz. The significant difference between these two frequency bands lies in the ability to support Non-Line-of-Sight (NLOS) operation in the lower frequencies, something that is not possible in higher bands. Consequently, the 802.16a amendment to the standard opened up the opportunity for major changes to the PHY layer specifications specifically to address the needs of the 2-11 GHz bands. This is achieved through the introduction of three new PHY-layer specifications (a new Single Carrier PHY, a 256 point FFT OFDM PHY, and a 2048 point FFT OFDMA PHY);major changes to the PHY layer specification as compared to the upper frequency, as well as significant MAC-layer enhancements. Although multiple PHYs are specified as in the 802.11 suite of standards (few recall that infrared and frequency hopping were and are part of the base 802.11 standard), the WiMAX Forum has determined that the first interoperable test plans and eventual certification will support the 256 point FFT OFDM PHY (which is common between 802.16a and ETSI HiperMAN), with the others to be developed as the market requires.

The OFDM signaling format was selected in preference to competing formats such as CDMA due to its ability to support NLOS performance while maintaining a high level of spectral efficiency maximizing the use of available spectrum. In the case of CDMA (prevalent in 2G and 3G standards), the RF bandwidth must be much larger than the data throughput, in order to maintain processing gain adequate to overcome interference. This is clearly impractical for broadband wireless below 11 GHz, since for example, data rates up to 70 Mbps would require RF bandwidths exceeding 200 MHz to deliver comparable processing gains and NLOS performance.

Some of the other PHY layer features of 802.16a that are instrumental in giving this technology the power to deliver robust performance in a broad range of channel environments are; flexible channel widths, adaptive burst profiles, forward error correction with concatenated Reed-Solomon and convolutional encoding, optional AAS (advanced antenna systems) to improve range/capacity, DFS (dynamic frequency selection)-which helps in minimizing interference, and STC (space-time coding) to enhance performance in fading environments through spatial diversity. Table 1 gives a high level overview of some of the PHY layer features of the IEEE 802.16a standard.

Table 1 802.16a PHY Features

Feature	Benefit
256 point FFT OFDM waveform	• Built in support for addressing multipath in outdoor LOS and NLOS environments
Adaptive Modulation and variable error correction encoding per RF burst	• Ensures a robust RF link while maximizing the number of bits/ second for each subscriber unit.
TDD and FDD duplexing support	• Address varying worldwide regulations where one or both may be allowed
Flexible Channel sizes (e.g. 3.5MHz, 5MHz, 10MHz, etc)	• Provides the flexibility necessary to operate in many different frequency bands with varying channel requirements around the world.
Designed to support smart antenna systems	• Smart antennas are fast becoming more affordable, and as these costs come down their ability to suppress interference and increase system gain will become important to BWA deployments.

While all the features listed above are necessary requirements for basic outdoor BWA operation, flexible channel sizes is required if a standard is to truly address worldwide deployment. This is because the regulations governing what frequency equipment can operate in, and as a result the size of the channels used, can vary country by country. In the case of licensed spectrum where an operator had to pay for every MHz granted, it is imperative that the system deployed use all the allocated spectrum and provide flexibility in either cellular or "big stick" deployments. Thus if an operator has been granted and paid for 14MHz, they do not want a system that has 6MHz channels, wasting 2MHz of spectrum. They want a system that can be deployed with 7MHz, 3.5MHz or even 1.75MHz channels for maximum adaptability.

IEEE 802.16a MAC Layer

Every wireless network operates fundamentally in a shared medium and as such that requires a mechanism for controlling access by subscriber units to the medium. The 802.16a standard uses a slotted TDMA protocol scheduled by the BTS to allocate capacity to subscribers in a point-to-multipoint network topology. While this on the surface sounds like a one line, technical throwaway statement, it has a huge impact on how the system operates and what services it can deploy. By starting with a TDMA approach with intelligent scheduling, WiMAX systems will be able to deliver not only high speed data with SLAs, but latency sensitive services such as voice and video or database access are also supported.

The standard delivers QoS beyond mere prioritization, a technique that is very limited in effectiveness as traffic load and the number of subscribers increases. The MAC layer in WiMAX certified systems has also been designed to address the harsh physical layer environment where interference, fast fading and other phenomena are prevalent in outdoor operation.

Table 1. 802.16a MAC Features

Feature	Benefit
TDM/TDMA Scheduled Uplink/Downlink frames.	• Efficient bandwidth usage
Scalable from 1 to hundreds of subscribers	• Allows cost effective deployments by supporting enough subs to deliver a robust business case
Connection-oriented	• Per Connection QoS • Faster packet routing and forwarding
QoS supportContinuous GrantReal Time Variable Bit RateNon Real Time Variable Bit RateBest Effort	• Low latency for delay sensitive services (TDM Voice, VoIP) • Optimal transport for VBR traffic(e.g., video)· Data prioritization
Automatic Retransmission request (ARQ)	• Improves end-to-end performance by hiding RF layer induced errors from upper layer protocols
Support for adaptive modulation	• Enables highest data rates allowed by channel conditions, improving system capacity
Security and encryption (Triple DES)	• Protects user privacy
Automatic Power control	• Enables cellular deployments by minimizing self interference

Differentiating the IEEE 802.16a and 802.11 Standards - WiFi versus WiMAX Scalability

At the PHY layer the standard supports flexible RF channel bandwidths and reuse of these channels (frequency reuse) as a way to increase cell capacity as the network grows. The standard also specifies support for automatic transmit power control and channel quality measurements as additional PHY layer tools to support cell planning/deployment and efficient spectrum use. Operators can re-allocate spectrum through sectorization and cell splitting as the number of subscribers grows. Also, support for multiple channel bandwidths enables equipment makers to provide a means to address the unique government spectrum use and allocation regulations faced by operators in diverse international markets. The IEEE 802.16a standard specifies channel sizes ranging form 1.75MHz up to 20MHz with many options in between.

WiFi based products on the other hand require at least 20MHz for each channel (22MHz in the 2.4GHz band for 802.11b), and have specified only the license exempt bands 2.4GHz ISM, 5GHz ISM and 5GHz UNII for operation.

In the MAC layer, the CSMA/CA foundation of 802.11, basically a wireless Ethernet protocol, scales about as well as does Ethernet. That is to say - poorly. Just as in an Ethernet LAN, more users results in a geometric reduction of throughput, so does the CSMA/CA MAC for WLANs. In contrast the MAC layer in the 802.16 standard has been designed to scale from one up to 100's of users within one RF channel, a feat the 802.11 MAC was never designed for and is incapable of supporting.

Coverage

The BWA standard is designed for optimal performance in all types of propagation environments, including LOS, near LOS and NLOS environments, and delivers reliable robust performance even in cases where extreme link pathologies have been introduced. The robust OFDM waveform supports high spectral efficiency (bits per second per Hertz) over ranges from 2 to 40 kilometers with up to 70 Mbps in a single RF channel. Advanced topologies (mesh networks) and antenna techniques (beam-forming, STC, antenna diversity) can be employed to improve coverage even further. These advanced techniques can also be used to increase spectral efficiency, capacity, reuse, and average and peak throughput per RF channel. In addition, not all OFDM is the same. The OFDM designed for BWA has in it the ability to support longer range transmissions and the multi-path or reflections encountered.

In contrast, WLANs and 802.11 systems have at their core either a basic CDMA approach or use OFDM with a much different design, and have as a requirement low power consumption limiting the range. OFDM in the WLAN was created with the vision of the systems covering tens and maybe a few hundreds of meters versus 802.16 which is designed for higher power and an OFDM approach that supports deployments in the tens of kilometers.

QoS

The 802.16a MAC relies on a Grant/Request protocol for access to the medium and it supports differentiated service levels (e.g., dedicated T1/E1 for business and best effort for residential). The protocol employs TDM data streams on the DL (downlink) and TDMA on the UL (uplink), with the hooks for a centralized scheduler to support delay-sensitive services like voice and video. By assuring collision-free data access to the channel, the 16a MAC improves total system throughput and bandwidth efficiency, in comparison with contention-based access techniques like the CSMA-CA protocol used in WLANs. The 16a MAC also assures bounded delay on the data (CSMA-CA by contrast, offers no guarantees on delay). The TDM/TDMA access technique also ensures easier support for multicast and broadcast services.

With a CSMA/CA approach at its core, WLANs in their current implementation will never be able to deliver the QoS of a BWA, 802.16 system.

The WiMAX Forum-Interoperability for 802.16 Compliant Systems

Establishment of a standard is critical to mass adoption of a given technology; however by itself a standard is not enough. The 802.11b WLAN standard was ratified in 1999, however it did not reach mass adoption until the introduction of the WiFi Alliance and certified, interoperable equipment was available in 2001. In order to bring interoperability to the Broadband Wireless Access space, the WiMAX Forum is focused on establishing a unique subset of baseline features grouped in what is referred to as "System Profiles" that all compliant equipment must satisfy. These profiles and a suite of test protocols will establish a baseline interoperable protocol, allowing multiple vendors' equipment to interoperate; with the net result being System Integrators and Service Providers will have option to purchase equipment from more than one supplier.

Profiles can address, for example, the regulatory spectrum constraints faced by operators in different geographies. For example, a service provider in Europe[2] operating in the 3.5 GHz band, who has been allocated 14 MHz of spectrum, is likely to want equipment that supports 3.5 and/or 7 MHz channel bandwidths and, depending on regulatory requirements, TDD (time-division duplex) or FDD (frequency-division duplex) operation. Similarly, a WISP (Wireless Internet Service Provider) in the U.S. using license-exempt spectrum in the 5.8GHz UNII band might desire equipment that supports TDD and a 10 MHz bandwidth.

WiMAX is establishing a structured compliance procedure based upon the proven test methodology specified by ISO/IEC 9646.[3] The process starts with standardized Test Purposes written in English, which are then translated into Standardized Abstract Test Suites in a language called TTCN.[4] In parallel with the Test Purposes, the Test Purposes are also used as input to generate test tables referred to as the PICS (Protocol Implementation Conformance Statement) Proforma is generated. The end result is a complete set of test tools that WiMAX will make available to equipment developers so they can design-in conformance and interoperability during the earliest possible phase of product development. Typically, this activity will commence when the first integrated prototype becomes available.

Ultimately, the WiMAX Forum* suite of conformance tests, in conjunction with interoperability testing, will enable service providers to choose from multiple vendors offering broadband wireless access equipment conforming to the IEEE 802.16a standard, that is optimized for their unique operating environment.

[2] *European radio standards are developed through ETSI (European Telecommunications Standards Institute).*

[3] *IEC is the International Electrotechnical Commission, a leading global organization that publishes international standards for all electrical, electronic, and related technologies.*

[4] *TTCN: Tree and Tabular Combined Notation.*

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Glossary

BS	Base Station
DSL	Digital Subscriber Line
ETSI	European Telecommunications Standards Institute
FDD	Frequency Division Duplex
IEEE	Institute of Electrical and Electronic Engineers
LOS	Line-of-Sight
MAC	Medium Access Control
MAN	Metropolitan Area Network
NLOS	Non-Line-of-Sight
OFDM	Orthogonal Frequency Division Multiplexing
PHY	Physical Layer
QoS	Quality of Service
SoHo	Small Office Home Office
SS	Subscriber Station
STC	Space-Time Codes
TDD	Time Division Duplex
TDM	Time-Division Multiplexed
TDMA	Time-Division Multiple Access
WISP	Wireless Internet Service Provider