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Performance Evaluation of WiMAX/IEEE 802.16 OFDM Physical Layer

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Abstract Fixed Broadband Wireless Access (BWA) is a promising technology which can offer high speed voice, video and data service up to the customer end. Due to the absence of any standard specification, earlier BWA systems were based on proprietary standard. IEEE 802.16 WirelessMAN standard specifies a Medium Access Control (MAC) layer and a set of PHY layers to provide fixed and mobile Broadband Wireless Access (BWA) in broad range of frequencies. The WiMAX forum has adopted IEEE 802.16 OFDM PHY layer for the equipment manufacturer due to its robust performance in multipath environment. The thesis investigates the simulation performance of IEEE 802.16 OFDM PHY layer. The Stanford University Interim (SUI) channel models are selected for the wireless channel in the simulation. The evaluation was done in simulation developed in MATLAB. Perfect channel estimation is assumed.	
Keywords: BWA, IEEE 802.16, WirelessMAN, FEC, OFDM	

Chapter 1

Introduction

This chapter provides a brief introduction on the motivation of this thesis work and its objective as well. At last the structure of the document is provided.

1.1 Motivation

Broadband Wireless Access (BWA) has emerged as a promising solution for last mile access technology to provide high speed internet access in the residential as well as small and medium sized enterprise sectors. At this moment, cable and digital subscriber line (DSL) technologies are providing broadband service in this sectors. But the practical difficulties in deployment have prevented them from reaching many potential broadband internet customers. Many areas throughout the world currently are not under broadband access facilities. Even many urban and suburban locations may not be served by DSL connectivity as it can only reach about three miles from the central office switch [3]. On the other side many older cable networks do not have return channel which will prevent to offer internet access and many commercial areas are often not covered by cable network. But with BWA this difficulties can be overcome. Because of its wireless nature,

it can be faster to deploy, easier to scale and more flexible, thereby giving it the potential to serve customers not served or not satisfied by their wired broadband alternatives.

IEEE 802.16 standard for BWA and its associated industry consortium, Worldwide Interoperability for Microwave Access (WiMAX) forum promise to offer high data rate over large areas to a large number of users where broadband is unavailable. This is the first industry-wide standard that can be used for fixed wireless access with substantially higher bandwidth than most cellular networks [2]. Wireless broadband systems have been in use for many years, but the development of this standard enables economy of scale that can bring down the cost of equipment, ensure interoperability, and reduce investment risk for operators.

The first version of the IEEE 802.16 standard operates in the 10–66GHz frequency band and requires line-of-sight (LOS) towers. Later the standard extended its operation through different PHY specification to 2-11 GHz frequency band enabling non line of sight (NLOS) connections, which require techniques that efficiently mitigate the impairment of fading and multipath [4]. Taking the advantage of OFDM technique the PHY is able to provide robust broadband service in hostile wireless channel.

The OFDM-based physical layer of the IEEE 802.16 standard has been standardized in close cooperation with the European Telecommunications Standards Institute (ETSI) High PERformance Metropolitan Area Network (HiperMAN) [5]. Thus, the HiperMAN standard and the OFDM-based physical layer of IEEE 802.16 are nearly identical. Both OFDM-based physical layers shall comply with each other and a global OFDM system should emerge [4]. The WiMAX forum certified products for BWA comply with the both standards.

1.2 Objective

The objective of this thesis is to implement and simulate the IEEE 802.16 OFDM physical layer using Matlab in order to have better understanding of the standard and the

system performance. This involves studying, through simulation, the various PHY modulation, coding schemes and interleaving in the form of bit-error-rate (BER) and block-error-rate (BLER) performance under reference channel models.

1.2 Structure of the thesis

The first chapter is an introduction of the thesis work. The rest of the chapters are organized as follows:

Chapter 2 discusses the evolution and architecture of the IEEE 802.16 standard for BWA.

Chapter 3 provides an overview of the IEEE 802.16 physical layer and OFDM technique.

Chapter 4 deals with the PHY layer simulation model and SUI channel model employed by this thesis.

Chapter 5 provides results obtained from the PHY layer simulation.

Chapter 6 concludes with a summary of the research done and recommendation for future work.

Chapter 2

IEEE 802.16: Evolution and Architecture

This chapter discusses the evolution of the IEEE 802.16 standard for BWA to form the basis for further discussion. The protocol layers of the standard have been overviewed to get the idea of interaction between different protocol stack. The chapter ends up with a brief discussion of the IEEE 802.16 based network architecture, deployment topology, application scenarios and its affiliation with WiMAX forum.

2.1 Evolution of IEEE family of standard for BWA

In late 90's many telecommunication equipment manufacturers were beginning to develop and offer products for BWA. But the Industry was suffering from an interoperable standard. With the need of a standard, The National Wireless Electronics Systems Testbed (N-WEST) of the U.S National Institute of Standards and Technology (NIST) called a meeting to discuss the topic in August 1998 [6]. The meeting ended up with a decision to organize within IEEE 802. The effort was welcomed in IEEE 802, which led to formation of the 802.16 Working Group. Since then, the Working Group members have been working a lot to develop standards for fixed and mobile BWA. IEEE

Working Group 802.16 on Broadband Wireless Access (BWA) standard is responsible for development of 802.16 and the included WirelessMan™ air interface, along with associated standards and amendments.

The IEEE 802.16 standard contains the specification of Physical (PHY) and Medium Access Control (MAC) layer for BWA. The first version of the standard IEEE802.16-2001 [7] was approved on December 2001 and it has gone through many amendments to accommodate new features and functionalities. The current version of the standard IEEE 802.16-2004 [1], approved on September 2004, consolidates all the previous versions of the standards. This standard specifies the air interface for fixed BWA systems supporting multimedia services in licensee and licensed exempt spectrum [1]. The Working Group approved the amendment IEEE 802.16e-2005 [8] to IEEE802.16-2004 on February 2006. To understand the development of the standard to its current stage, the evolution of the standard is presented here.

2.1.1 IEEE 802.16-2001

This first issue of the standard specifies a set of MAC and PHY layer standards intended to provide fixed broadband wireless access in a point-to-point (PTP) or point-to-multipoint (PMP) topology [7]. The PHY layer uses single carrier modulation in the 10 – 66 GHz frequency range.

Transmission times, durations and modulations are assigned by a Base Station (BS) and shared with all nodes in the network in the form of broadcast Uplink and Downlink maps. Subscribers need only to hear the base station that they are connected and do not need to listen any other node of the network. Subscriber Stations (SS) has the ability to negotiate for bandwidth allocation on a burst to-burst basis, providing scheduling flexibility.

The standard employs QPSK, 16-QAM and 64-QAM as modulation scheme. These can be changed from frame to frame and from SS to SS, depending on the robustness of the connection. The standard supports both Time Division Duplexing (TDD) and Frequency Division Duplexing (FDD) as duplexing technique.

An important feature of 802.16-2001 is its ability to provide differential Quality of Service (QoS) in the MAC Layer. A Service Flow ID does QoS check. Service flows are characterized by their QoS parameters, which can then be used to specify parameters like maximum latency and tolerated jitter [10]. Service flows can be originated either from BS or SS. 802.16-2001 works only in (Near) Line of Sight (LOS) conditions with outdoor Customer Premises Equipment (CPE).

2.1.2 IEEE 802.16a-2003

This version of the standard amends IEEE 802.16-2001 by enhancing the medium access control layer to support multiple physical layer specifications and providing additional physical layer specifications. This was ratified by IEEE 802.16 working group in January 2003[9]. This amendment added physical layer support for 2-11 GHz. Both licensed and license-exempt bands are included. Non Line of Sight (NLOS) operation becomes possible due to inclusion of below 11 GHz range, extending the geographical reach of the network. Due to NLOS operation multipath propagation becomes an issue. To deal with multipath propagation and interference mitigation features like advanced power management technique and adaptive antenna arrays were included in the specification [9]. The option of employing Orthogonal Frequency Division Multiplexing (OFDM) was included as an alternative to single carrier modulation.

Security was improved in this version; many of privacy layer features became mandatory while in 802.16-2001 they were optional. IEEE 802.16a also adds optional support for mesh topology in addition to PMP.

2.1.3 IEEE 802.16c-2002

In December 2002, IEEE Standards Board approved amendment IEEE 802.16c [6]. In this amendment detailed system profiles for 10-66 GHz were added and some errors and inconsistencies of the first version of the standard were corrected.

2.1.4 IEEE 802.16-2004

802.16-2001, 802.16a-2003 and 802.16c-2002 were all together consolidated and a new standard was created which is known as 802.16-2004. In the beginning, it was published as a revision of the standard under the name 802.16REVd, but the changes were so genuine that the standard was reissued under the name 802.16-2004 at September 2004. In this version, the whole family of the standard is ratified and approved.

Table 2.1: Comparison of IEEE standard for BWA

	IEEE 802.16-2001	IEEE 802.16a	IEEE802.16-2004	IEEE 802.16e-2005
Completed	December 2001	January 2003	June 2004	December 2005
Spectrum	10-66 GHz	2-11 GHz	2-11 GHz	2-6 GHz
Popagation/channel conditions	LOS	NLOS	NLOS	NLOS
Bit Rate	Up to 134 Mbps (28 MHz channelization)	Up to 75 Mbps (20 MHz channelization)	Up to 75 Mbps (20 MHz channelization)	Up to 15Mbps (5 MHz channelization)
Modulation	QPSK, 16-QAM (optional in UL), 64-QAM (optional)	BPSK, QPSK, 16-QAM, 64-QAM, 256-QAM (optional)	256 subcarriers OFDM, BPSK, QPSK, 16-QAM, 64-QAM, 256-QAM	Scalable OFDMA, QPSK, 16-QAM, 64-QAM, 256-QAM (optional)
Mobility	Fixed	Fixed	Fixed/Nomadic	Portable/mobile

2.1.5 IEEE 802.16e-2005

This amendment was included in the current applicable version of standard IEEE 802.16-2004 in December 2005. This includes the PHY and MAC layer enhancement to enable combined fixed and mobile operation in licensed band.

2.2 IEEE 802.16 Protocol Layers

The IEEE 802.16 standard is structured in the form of a protocol stack with well defined interfaces. As shown in Figure 2.1, the MAC layer is formed with three sublayers:

- .. Service Specific Convergence Sublayer (CS)
- .. MAC Common Part Sublayer (CPS) and
- .. Privacy Sublayer.

The MAC CS receives higher level data through CS Service Access Point (SAP) and provides transformation and mapping into MAC Service Data Unit (SDU). MAC SDUs are then received by MAC CPS through MAC SAP. The specification targeted two types of traffic transported through IEEE 802.16 networks: Asynchronous Transfer Mode (ATM) and Packets. Thus, Multiple CS specifications are available for interfacing with various protocols.

The MAC CPS is the core part of the MAC layer, defining medium access method. The CPS provides functions related to duplexing and channelization, channel access, PDU framing, network entry and initialization. This provides the rules and mechanism for system access, bandwidth allocation and connection maintenance. QoS decisions for transmission scheduling are also performed within the MAC CPS.

The Privacy layer lies between the MAC CPS and the PHY layer. Security is a major issue for public networks. This sub layer provides the mechanism for encryption and decryption of data transferring to and from PHY layer and is also used for authentication and secure key exchange. Data, PHY control, statistics are transferred between the MAC CPS and the PHY through the PHY SAP.

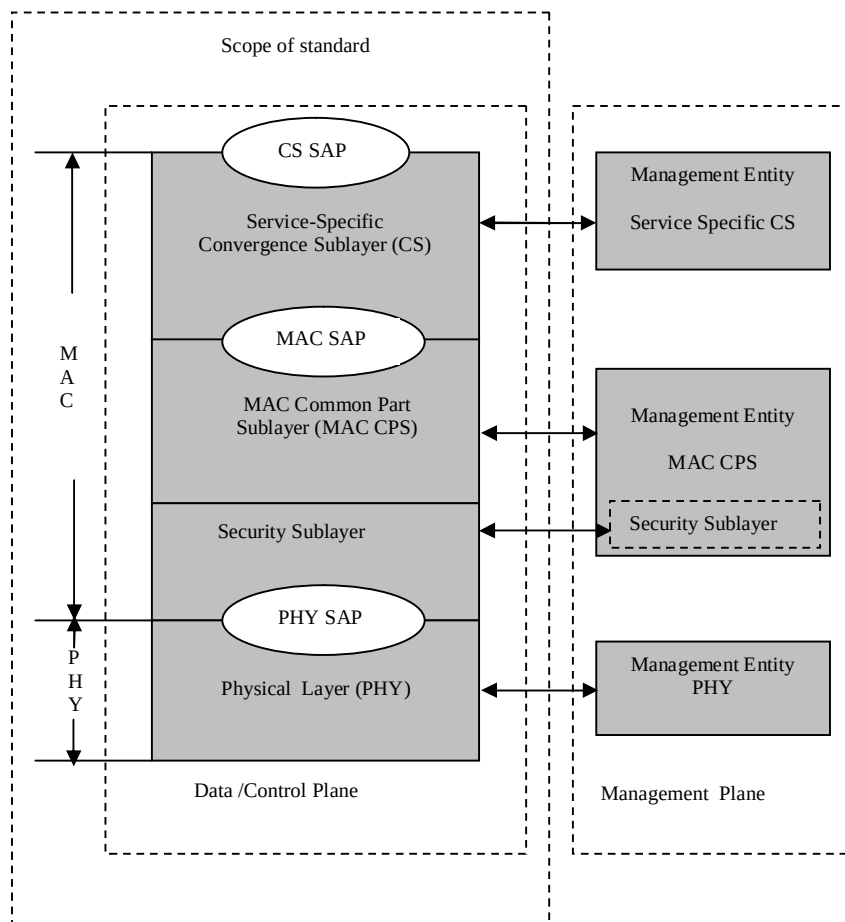


Figure 2.1: IEEE 802.16 Protocol Stack

The PHY layer includes multiple specifications, which make the standard adaptable to different frequency ranges. The flexibility of the PHY enables the system designers to tailor their system according to the requirements. The PHY specifies some mandatory features to be implemented with the system including some optional features.

2.3 Network Architecture and Deployment Topology:

An IEEE 802.16 network is consists of fixed infrastructural sites. In fact, the IEEE 802.16 network is resembled to cellular phone network. Each cell consists of a Base

Station (BS) and one or more subscribe station (SS), depending on the implementation of the topology. Therefore, the BS provides Point to Point (PTP) service or Point to Multi-point (PMP) service in order to serve multiple SSs. BSs provide connectivity to core networks. The SS can be a roof mounted or wall mounted customer premises equipment (CPE) or a stand alone hand held device like Mobile phone, personal digital assistant (PDA) or peripheral component interconnect (PCI) card for PC or Laptop. In case of a outside CPE, the users inside the building are connected to a conventional network like Ethernet Local Area Network (IEEE 802.3 for LAN) or Wireless LAN (IEEE 802.11b/g for WAN) which have access to the CPE. A group of cells can be grouped together to form a network, where BSs are connected through a core network, as shown in Figure 2.2. The IEEE 802.16 network also support mesh topology, where SSs are able to communicate among them selves without the need of a BS [1].

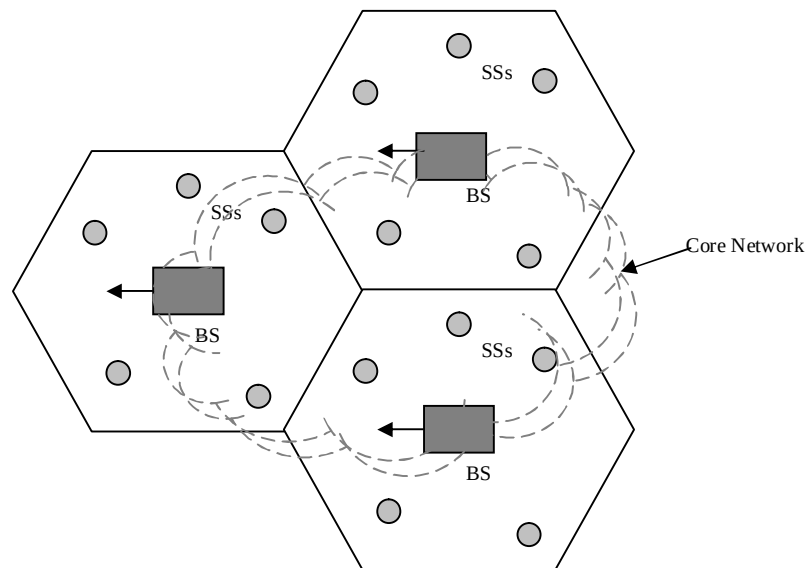


Figure 2.2: A typical IEEE 802.16 Network

BSs typically employ one or more wide beam antennas that may be partitioned into several smaller sectors, where all sectors sum to a complete 360 degree coverage. CPEs typically employ highly directional antennas that are pointed towards the BS. Depending on the need, IEEE 802.16 network can be deployed in different forms.

2.4 Application of IEEE 802.16 based network:

IEEE 802.16 supports ATM, IPv4, IPv6, Ethernet and Virtual Local Area Network (VLAN) services [1]. SO, it can provide a rich choice of service possibilities to voice and data network service providers. It can be used for a wide selection of wireless broadband connection and solutions.

- “ Cellular Backhaul: IEEE 802.16 wireless technology can be an excellent choice for back haul for commercial enterprises such as hotspots as well as point-to-point back haul applications due to its robust bandwidth and long range.
- “ Residential Broadband: Practical limitations like long distance and lack off return channel prohibit many potential broadband customers reaching DSL and cable technologies [3]. IEEE 802.16 can fill the gaps in cable and DSL coverage.
- “ Underserved areas: In many rural areas, especially in developing countries, there is no existence of wired infrastructure. IEEE 802.16 can be a better solution to provide communication services to those areas using fixed CPE and high gained antenna.
- “ Always Best Connected: As IEEE 802.16e supports mobility [8], so the mobile user in the business areas can access high speed services through their IEEE 802.16/WiMAX enabled handheld devices like PDA, Pocket PC and smart phone.

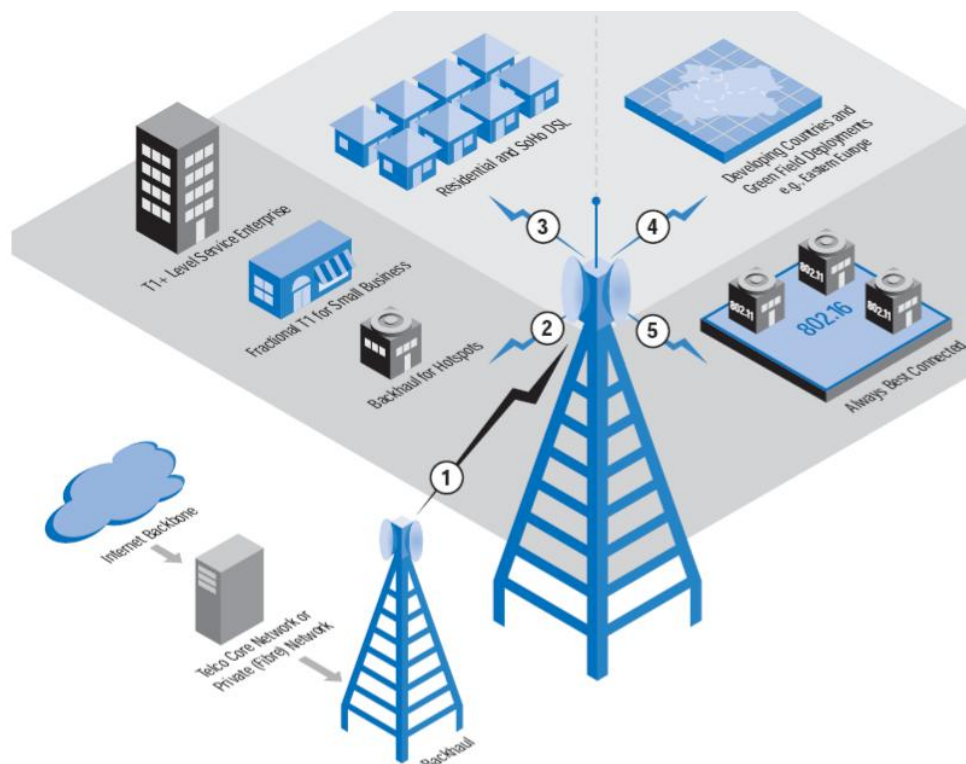


Figure 2.3: Application scenarios [3]

2.5 WiMAX forum and adaptation of IEEE 802.16

The Worldwide Interoperability for Microwave Access (WiMAX) forum is an alliance of telecommunication equipments and components manufacturers and service providers, formed to promote and certify the compatibility and interoperability of BWA products employing the IEEE 802.16 and ETSI HiperMAN [17] wireless specifications. WiMAX Forum Certified™ equipment is proven interoperable with other vendors' equipment that is also WiMAX Forum Certified™ [33]. So far WiMAX forum has setup certification laboratories in Spain, Korea and China. Additionally, the WiMAX forum creates what it calls system profiles, which are specific implementations, selections of options within the standard, to suit particular ensembles of service offerings and subscriber populations [19].

WiMAX forum has adopted two version of the IEEE 802.16 standard to provide different types of access:

- “ Fixed/Nomadic access: The WiMAX forum has adopted IEEE802.16-2004 and ETSI HyperMAN standard for fixed and nomadic access [17]. This uses Orthogonal Frequency Division Multiplexing and able to provide supports in Line of Sight (LOS) and Non Line of Sight (NLOS) propagation environment. Both outdoor and indoor CPEs are available for fixed access. The main focus of the WiMAX forum profiles are on 3.5 GHz and 5.8 GHz frequency band.
- “ Portable/Mobile Access: The forum has adopted the IEEE 802.16e version of the standard, which has been optimized for mobile radio channels. This uses Scalable OFDM Access and provides support for handoffs and roaming [17]. IEEE 802.16e based network is also capable to provide fixed access. The WiMAX Mobile WiMAX profiles will cover 5, 7, 8.75, and 10 MHz channel bandwidths for licensed worldwide spectrum allocations in the 2.3 GHz, 2.5 GHz, 3.3 GHz and 3.5 GHz frequency bands [18]. The first certified product is expected to be available by the end of 2007.

Chapter 3:

IEEE 802.16 Physical Layer

This chapter discusses about the different variants of the IEEE 802.16 PHY layer with their capabilities and conditions of operation. The OFDM based physical layer has been overviewed with its various mechanisms. Finally the chapter concludes with a discussion on OFDM technology and its design considerations.

3.1 IEEE 802.16 PHY Layer:

The IEEE 802.16 standard supports multiple physical specifications due to its modular nature. The first version of the standard only supported single carrier modulation. Since that time, OFDM and scalable OFDMA have been included to operate in NLOS environment and to provide mobility. The standard has also been extended for use in below 11 GHz frequency bands along with initially supported 10-66 GHz bands.

3.1.1 Supported Band of Frequency

The IEEE 802.16 supported licensed and unlicensed bands of interest are as follows: