IJERT
ISSN : 2278 - 0181

THESIS

Thesis ID : IJERTTH0004

Spectral Efficiency And Bit Error Rate Analysis of OFDM Based Wimax Physical Layer

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Punjab, India.

Published By

International Journal of
Engineering Research and Technology
(www.ijert.org)

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SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF THE DEGREE OF

MASTER OF TECHNOLOGY

(ELECTRONICS AND COMMUNICATION ENGINEERING)

SUBMITTED BY

BINDU HANDA

(Univ. Roll No. 1167299)

UNDER THE GUIDANCE OF

SMT. ANITA SUMAN

(Assistant Prof. ECE)

I.K. GUJRAL PUNJAB TECHNICAL UNIVERSITY
KAPURTHALA (PUNJAB), INDIA
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JUNE-2017

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CANDIDATE'S DECLARATION CERTICICATE

I hereby certify that the work which is being presented in the thesis entitled "**SPECTRAL EFFICIENCY AND BIT ERROR RATE ANALYSIS OF OFDM BASED WIMAX PHYSICAL LAYER**" by "**BINDU HANDA**" in partial fulfilment of requirements for the award of degree of M.Tech. (E.C.E) submitted to Department of Electronics and Communication Engineering at **BEANT COLLEGE OF ENGINEERING AND TECHNOLOGY, GURDASPUR** under **I.K. GUJRAL PUNJAB TECHNICAL UNIVERSITY, JALANDHAR** is an authentic record of my own work carried out during a period from Jan, 2014 to June, 2017 under the supervision of **SMT. ANITA SUMAN**. The matter presented in this thesis has not been submitted by me in any other University / Institute for the award of M.Tech Degree.

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ABSTRACT

WiMAX is presented by the Institute of Electrical and Electronic Engineers (IEEE) which depends on the IEEE 802.16 set of standards to give a worldwide interoperability for microwave access. As of now, telecommunication industries are highly concerned with the wireless transmission of data which can utilize various transmission modes.Various applications have already been connected so far utilizing WiMAX, as an alternative to 3G mobile systems in developing countries. WiMAX has been developed for mobile wireless communication which is based on OFDM (Orthogonal Frequency Division Multiplexing) technology as it is an excellent way to utilize the spectrum.

OFDM is a parallel data transmission system which guarantees the high data rate with minimum degradation of the quality of service relative to serial communication techniques. A single channel utilizes multiple sub-carriers on adjacent frequencies in OFDM. Plus, the sub-carriers in an OFDM system are overlapping to maximize spectral efficiency. Usually, overlapping adjacent channels can interfere with one another. Nonetheless, sub-carriers in an OFDM system are precisely orthogonal to one another. Hence, they are able to overlap without interfering. Resultantly, OFDM systems are able to maximize spectral efficiency without causing adjacent channel interference. So as to acquire the orthogonality, the subcarrier frequencies must be spaced by a multiple of the inverse of the symbol duration. Apart from spectral efficiency, OFDM has many focal points, as immunity to impulse interference, resilient to RF interference, robustness to channel fading, resistance to multipath, much lower computational complexity.

The modulation techniques are a trade-off between SPECTRAL EFFICIENCY and BER (Bit Error Rate). As the level of modulation is increased, BER gets degraded but spectral efficiency gets improved. Nonetheless, an improvement in BER can be achieved using the combinations of different forward error correcting coding but at the cost of spectral efficiency. In this postulation work, concatenated RS-CC (Reed Solomon-Convolutional code) combination has been implemented for BER improvement without much loss in spectral efficiency.

In a wireless system, neither spectrum nor BER can be compromised at any cost. The trade-off between modulation techniques and FEC (Forward Error Correction) is desirable. Henceforth the effect of modulation and the effect of FEC along with the effect of cyclic prefix have been analysed in this thesis work. For this purpose, different channel i.e. AWGN and Rayleigh fading channel has been taken for analysis.

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ACKNOWLEDGEMENT

I express my sincere gratitude to **DR. RAKESH DOGRA**, the Principal, Beant College of Engineering and Technology (BCET), Gurdaspur, for providing this opportunity to carry out the present thesis work. Thesis work is an important aspect in the field of Engineering. I am thankful to **SH. GURPADAM SINGH, H.O.D**, Electronics and Communication Engineering Department, BCET, Gurdaspur, for providing me with the adequate infrastructure in carrying out the work. I owe my sincerest gratitude towards **SMT. ANITA SUMAN** who was my dissertation guide, BCET, Gurdaspur, for valuable advice and healthy criticism throughout my thesis which helped me immensely to complete my work successfully. The constant guidance and encouragement received from her, has been of great help in carrying out the present work and is acknowledged with reverential thanks. I would also like to express a deep sense of gratitude and thanks profusely to **SH. SAURABH MAHAJAN**, Assistant Professor, Department of ECE, BCET, without the wise counsel and able guidance, it would have been impossible to complete the thesis in this manner.

I express gratitude to other faculty members of ECE Department, BCET, for their intellectual support throughout the course of this work.

At last but not the least my gratitude towards my parents and my husband, I would also like to thank God for not letting me down at a time of crisis and showing me the silver lining in the dark clouds.

BINDU HANDA

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LIST OF ABBREVIATIONS

ABBREVIATIONS	MEANING
ASK	Amplitude Modulation Keying
AMC	Adaptive Modulation and Coding
ARQ	Automatic Retransmission Request
AES	Advanced Encryption Standard
BPSK	Binary Phase Shift Keying
BW	Band Width
BCH	Bose- Chaudhri- Hocquenghem
CODFMA	Coded orthogonal frequency division multiplexing access
CDMA	Code Division Multiple Access
CC	Convolutional Code
CP	Cyclic Prefix
DFT	Discrete Fourier Transform
ETSI	European Telecommunication Standards Institute
FSK	Frequency Shift Keying
FEC	Forward Error Correction
FDD	Frequency Division Duplexing
FFT	Fast Fourier Transform
FDM	Frequency Division Multiplexing
GSM	Global System for Mobile communication
HF	High Frequency
Hz	Hertz
HIPERMAN	High Performance Metropolitan Area Network
IEEE	Institute of Electrical and Electronics Engineers
IFFT	Inverse Fast Fourier Transform
IF	Intermediate Frequency
ISI	Inter-Symbol Interference
LTE	Long Term Evolution
LDPC	Low Density Parity Check Code
MCM	Multicarrier Modulation
MAC	Media Access Control
OFDM	Orthogonal Frequency Division Multiplexing

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OFDMA	Orthogonal Frequency Division Multiple Access
PSK	Phase Shift Keying
PRBS	Pseudo Random Binary Sequence
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
RF	Radio Frequency
RS	Reed Solomon code
SCM	Single Carrier Modulation
SSI	Self-Symbol Interference
SUI	Stanford University Interim
SE	Spectral Efficiency
TDD	Time Division Duplexing
TDM	Time Division Multiplexing
WiMAX	Worldwide Interoperability for Microwave Access
Wi-Fi	Wireless Fidelity
WLAN	Wireless Local Area Network
WMAN	Wireless Metropolitan Area Network

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CHAPTER-I

INTRODUCTION

1.1 Introduction

WiMAX is the abbreviated type of Worldwide Interoperability for Microwave Access. It is also called as IEEE 802.16. It relies upon WMAN standards created by the IEEE 802.16 group embraced by both Institute of Electrical and Electronics Engineers (IEEE) and the European Telecommunications Standards Institute High Performance Metropolitan Area Network (ETSI HIPERMAN) group [1]. In 1998, this group was shaped to build up an air-interface standard for remote broadband. Various IEEE 802.16 standards came into existence and they are outlined in Table 1.1

Table 1.1 Various IEEE 802.16 standards [1]

Standard	**Comments**
802.16	In 2001, Fundamental 802.16 standard was released to provide essential high data links at frequencies in the vicinity of 11 and 60 GHz.
802.16 a	Addresses certain spectrum issues and empowered the standard to be utilized at frequencies that are underneath 11 GHz least of the original standard.
802.16 b	Spectrum was expanded which was indicated to incorporate the frequencies in the vicinity of 5 and 6 GHz.
802.16 c	Revision to 802.16 standards given for operating in the vicinity of 10 and 66 GHz and the point was to empower higher levels of operability.
802.16d (802.16-2004)	Amendment was also called as 802.16-2004 that provides the number of fixes and upgrades to 802.16a by including the utilization of 256-carrier OFDM. This standard addressed for fixed operations only.
802.16e	Amendment was also called as 802.16-2005 because it was released in

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(802.16-2005)	2005.This amendment enabled full roaming and portable use alongside handover.
802.16 f	Management information base.
802.16 g	Management plane techniques and administrations.
802.16 h	Enhanced co-existence mechanisms for licence exempt operations only.
802.16 j	Multi-hop hand-off specification.
802.16 k	802.16 bridging.
802.16 m	Propelled air interface.

1.2 WiMAX versus Wi-Fi

It ends up being totally expected to develop traditions and systems which could reinforce tremendous scale networking with high data speeds as remote networking tends to spread itself outside houses and working environments. Several headways for such wide get the opportunity to have been in the correspondences market like 2G, 3G and 4G. There are, be that as it may, numerous trades-offs in using these advances on a greater premise, for instance, giving web or stream intelligent media remotely. This is the reason that another accord named WiMAX came into existence. It is same like an extended technological term to Wi-Fi; nonetheless, there are a few contrasts between these two protocols. The contrasts between these two conventions are as follow:

- **Shortened Term:** Wi-Fi is shortened form of Wireless Fidelity and on the other hand WiMAX is the shortened form of Worldwide Interoperability for Microwave Access.
- **Official Release:** In 1997, Wi-Fi was official released whereas WiMAX was released in 2004.

- **IEEE standards:** WiMAX has been defined under 802.16x standards where x alludes to the different renditions of WiMAX, for example, 802.16a, 802.16d and 802.16e some of the well-known WiMAX versions and Wi-Fi has been standardized under IEEE802.11y standards where y alludes to the different variants of Wi-Fi, for example, 802.11a, 802.11b, 802.11g and 802.11n.
- **Frequency Band:** There is no restriction on frequency utilization in the case of WiMAX whereas Wi-Fi has been characterized under ISM bands where customer needs to pay no extra charges for utilizing those bands.
- **Range:** Wi-Fi based network can reach upto 100 meters and on the other hand WiMAX can reach upto 80-90 Kilometres [2].
- **Data transfer rates:** Wi-Fi has a data transfer rate upto 54Mbps and WiMAX has a data transfer rate upto 75Mbps. Data transfer rates have more variety as more distances are to be shrouded in WiMAX.
- **Channel bandwidth:** The channel bandwidth of WiMAX ranges from 1.25 MHz to 20 MHz on the other hand; Wi-Fi has a channel bandwidth of 20 MHz.
- **Bandwidth Efficiency:** Bandwidth Efficiency of WiMAX is twice as compare to Wi-Fi.
- **Encryption Techniques:** The encryption techniques used in Wi-Fi are RC4 and AES (Advanced Encryption standard) whereas Advanced Encryption Standards (AES) and Triple Data Encryption Algorithm are used as encryption techniques in WiMAX.

1.3 Features of WiMAX

It is a wireless broadband arrangement that provides a rich arrangement of components with a lot of flexibility as far as deployment alternatives and potential administration offerings. The features of WiMAX are as per the following:

- **OFDM based physical layer:** The physical layer of WiMAX rely on orthogonal frequency division multiplexing [1]. It offers great imperviousness to multipath and empowers WiMAX to operate in Non-Line of Sight (NLOS) conditions.
- **Very high peak data rates:** It is capable of supporting very high peak data rates [1].When 20 MHz spectrum is used then peak data rate is as high as 74Mbps for both uplink and downlink respectively. When 10 MHz spectrum is used then peak data rate is 6.7Mbps for uplink and 25Mbps for downlink individually.
- **Scalable bandwidth and data rate support:** It has an adaptable physical-layer design that contemplates the information rate to scale effectively with accessible channel bandwidth.
- **Adaptive modulation and coding (AMC):** It bolsters number of modulations and FEC coding techniques. It enables the techniques to be changed on per client and per frame basis that depends on channel conditions.
- **Link-layer retransmissions**: It bolsters ARQ (Automatic Retransmission Requests) at the link layer for associations that require improved reliability. It also alternatively bolsters hybrid-ARQ which is a powerful hybrid amongst FEC and ARQ.
- **Support for TDD and FDD:** IEEE 802.16d and IEEE 802.16e bolsters both time division duplexing (TDD) and frequency division duplexing (FDD) [1].
- **Orthogonal frequency division multiple access (OFDMA):** Mobile WiMAX utilizes OFDM as a multiple-access technique where diverse clients can be disseminated distinctive subsets of the OFDM tones [1].
- **Adaptable and dynamic per client resource assignment:** Both downlink and uplink resource assignment are controlled by a scheduler in the base station and capacity is shared among various clients on a demand premise.
- **Support for advanced antenna techniques:** It bolsters the utilization of multiple-antenna technique, for example, spatial multiplexing, beamforming and space-time coding [1]. These

techniques can be utilized to enhance the overall system capacity and spectral efficiency by conveying different antennas at the source and the destination.

- **Quality-of-service support:** The MAC layer of WiMAX has an association oriented architecture that is intended to bolster an assortment of uses. It likewise bolsters for consistent bit rate, inconsistent bit rate, real-time, and non-real-time traffic flows, notwithstanding best-effort data traffic [1]. The MAC layer of WiMAX is intended to help an immense number of clients with various associations per terminal, each with its own particular QoS necessity.
- **Robust security:** It bolsters strong encryption along with powerful security and key-management protocol.
- **Support for mobility**: The versatile variation of the WiMAX underpins wandering of portable units inside scope territory at high data rate speeds without intrusion in handovers.
- **IP-based architecture:** The WiMAX Forum has characterized a reference network architecture which relies upon an all-IP stage.

1.4 Comparison of IEEE 802.16, 802.16a, 802.16-2004, and 802.16e

The fundamental characteristics of different IEEE 802.16 standards are condensed in Table 1.2.

Table 1.2 Comparison of IEEE 802.16, 802.16a, 802.16-2004, and 802.16e [1]

Parameters	**IEEE 802.16**	**IEEE 802.16a**	**IEEE 802.16**	**IEEE 802.16e**
Completed	2001	2003	2004	2005
Spectrum	10-66 GHz	2-11GHz	2-11GHz	2-6 GHz
Channel conditions	Line of Sight	Non Line of Sight	Non Line of Sight	Non Line of Sight
Bit rate	Up to 134 Mbps	Up to 75 Mbps	Up to 75 Mbps	Up to 15 Mbps
Mobility	Fixed	Fixed	Fixed/Nomadic	Portable/Mobile

Modulation	QPSK, 16 QAM (optional in upper link), 64QAM (optional)	BPSK, QPSK, 16 QAM, 64 QAM, 256 QAM (optional)	256 subcarriers OFDM, BPSK, QPSK, 16 QAM, 64 QAM, 256 QAM	Adaptable OFDMA, QPSK, 16 QAM, 64 QAM, 256 QAM (optional)

1.5 Objective of Thesis

The objective of this thesis is as per the following:

1. To contemplate the existing physical layer of WiMAX.
2. To implement and simulate OFDM based WiMAX physical layer utilizing MATLAB in order to have a superior comprehension of the standard and the system performance.
3. To simulate OFDM based WiMAX physical layer, concatenated Reed Solomon and Convolutional encoder is considered along with AWGN channel and Rayleigh fading channel.
4. By utilizing diverse modulation schemes i.e. Quadrature Phase Shift Keying (QPSK) and X-Quadrature Amplitude Modulation (QAM), Spectral Efficiency and BER (Bit Error Rate) is evaluated under different Cyclic Prefix.

1.6 Structure of Thesis

It comprises of five chapters, the chapters are composed as underneath.

Chapter-I: Introduction

This chapter gives the very basic information about WiMAX, its features, standards and comparison of WiMAX with Wi-Fi

Chapter-II: Literature Review

This chapter presents the summary of previous research papers of related field.

Chapter-III: Simulation Model

This chapter deals with the OFDM based WiMAX Physical layer simulation model.

Chapter-IV: Simulation Results

This chapter discuss all the results (Spectral efficiency and Bit Error Rate) with AWGN channel and Rayleigh fading channel for different modulation techniques (QPSK and X-QAM) using FEC RS-CC and distinctive Cyclic Prefix.

Chapter-V: Conclusion and Future scope

This chapter concludes with an outline of the research done and also recommendation for future work.

CHAPTER-II
LITERATURE REVIEW

Table 2.1 Literature survey

S No.	Author-Journal-Year	Title	Work done
1.	Muhammad Nadeem Khan, Sabir Ghauri/ IET International Conference on Wireless, Mobile and Multimedia Networks, 2008	The WiMAX 802.16e Physical Layer Model	This paper evaluated the performance of the WiMAX under distinctive data rates, coding techniques and channel conditions.
2.	O. Arafat and K. Dimyati/ Second International Conference on Computer Engineering and Applications, 2010	Performance Parameter of Mobile WiMAX: A Study of Physical Layer of Mobile WiMAX under different communication channels and modulation technique	This paper shows that code rate and modulation techniques had more prominent impact on the performance between the distinctive channel conditions.
3.	M.A. Mohamed, M.S. Abo-El-Seoud, H.M. Abd-El-Atty/2nd IEEE International Conference on Information Management and Engineering, 2010	Performance simulation of IEEE 802.16e WiMAX physical layer	This paper conclude that when channel conditions are poor, vitality effective schemes for example, BPSK or QPSK are utilized and when channel quality enhances, higher M-ary modulation schemes for

			example, 16-QAM or 64-QAM are utilized.
4.	A. R. Shankar, P. Rani and S. Kumar/ Second Vaagdevi International Conference on Information Technology for Real World Problems, 2010	An Analytical Approach to Qualitative Aspects of WiMAX Physical Layer	This paper concentrates on the correlation of quality of service parameters between various diverts in WiMAX physical layer on the premise of BER, SNR, PSD, and Pe.
5.	T. Sharef, A. E. Alaradi and B. T. Sharef/ Fourth International Conference on Computational Intelligence, Communication Systems and Networks, 2012	Performance Evaluation for WiMAX 802.16e OFDMA Physical Layer	This paper compares the performance of QPSK on the premise of BER versus E_b/N_o curves. The simulation results show that the system performance can be enhanced by the utilization of channel estimation.
6.	H. Kaur and M. L. Singh/ 2nd International Conference on Information Management in the Knowledge Economy, 2013	Performance evaluation of coded OFDM based WiMAX system under different fading environments	In this paper, the BER of COFDM based WiMAX system is analysed with BPSK modulation technique under various channel conditions. The outcomes show that performance of Nakagami fading channel is superior to other fading

ISSN: 2278-0181

			channels.
7.	D. R. Selvarani and T. N. Ravi/ International Conference on Information Communication and Embedded Systems , 2014	Comparative analysis of Wi-Fi and WiMAX	In this paper, author gives a review and correlation of Wi-Fi and WiMAX which incorporates the features, Specifications, architecture, advantages, limitations and security.
8.	S. Ahmed/ International Conference on Computing for Sustainable Global Development, 2014	Performance analysis of Mobile WiMAX Technology	In this paper, the WiMAX performance is analysed under various channels and number of modulation schemes on the premise of SNR and BER graph. The results state that WiMAX system works admirably in both AWGN and multipath fading channel.
9.	A. Al-Kandari, M. Al-Nasheet and A. R. Abdulgafer/ Fourth International Conference on Digital Information and Communication Technology and its	WiMAX vs. LTE: An analytic comparison	In this paper, author's talks about the capacity, effectiveness, complexity, coverage elements of both WiMAX and LTE wireless communications technologies.

	Applications, 2014		
10.	M. Joshi, A. N. Dubey and D. K. Panda/ 2nd International Conference on Electronics and Communication Systems, 2015	Analysing various fading channels using different modulation techniques under IEEE 802.16 standard	This paper shows that IEEE 802.16 standard provide better performance under Nakagami channel utilizing diverse modulation techniques at higher SNR.
11.	Y. M. Al-Moliki, M. A. Aldhaeebi, G. A. Almwald and M. A. Shaobi/ 6th International Conference on Intelligent Systems, Modelling and Simulation, 2015	The Performance of RS and RSCC Coded Cooperation Systems Using Higher Order Modulation Schemes	This paper concluded that the performance of concatenated RS-CC code is better and robust when contrasted with RS code without concatenation as far as BER with different SNR.
12.	R. Poornima and N. Prabakaran/ International Conference on Circuits, Power and Computing Technologies, 2015	Performance improvement in mobile WiMAX using higher order sub carrier modulation techniques	In this paper, the higher order modulation techniques like 16-QAM & 64-QAM are analysed and simulated for mobile WiMAX in OFDMA.
13.	U. R. Mori, P. M. Chandarana, G. V. Gajjar and S. Dasi/ IEEE International Advance Computing Conference, 2015	Performance comparison of different modulation schemes in advanced technologies WiMAX and LTE	In this paper, features of WiMAX and LTE in physical layer are compared. It furthermore gives the performance analysis of various modulation schemes

			in WiMAX and LTE technologies.
14.	H. Kaur and M. L. Singh/ International Conference on Communication and Signal Processing, 2016	Performance analysis of mobile WiMAX for frequency selective fading channel models	In this paper, the mobile WiMAX is examined as far as BER for ITU-R and Cost-207 channel conditions for Typical Urban Area and Typical Rural Area.
15.	K. S. Pooja, B. R. Rajatha, G. B. Sadhvika and B. S. Premananda/ IEEE International Conference on Recent Trends in Electronics, Information & Communication Technology, 2016	Design and performance analysis of FEC schemes in OFDM communication system	This paper concluded that the single convolutional coding and dual interleaving plays out the best under all ranges of Signal to Noise Ratio.

2.1 Literature Surveys

Several researches have been carried out on physical layer of WiMAX that are as follow:

- **(khan and Ghauri 2008)[3]:** This paper examines the model working of the WiMAX Physical layer utilizing Simulink in MATLAB. This model is a helpful tool for performance evaluation of the WiMAX under various data rates, coding schemes and channel conditions. The model introduced in this paper built with generic MAC PDU prepared by the Physical Layer utilizing Convolutional Encoding Rate of 5/6 with QPSK and transmitted with 256 carrier OFDM symbols [3].

- **(O.Arafat 2010)[4]:** In this paper, Author analyses the performance of physical layer of mobile WiMAX over SUI channel [4]. The performance parameters such as Bit Error Rate, Block Error Rate & Signal to Noise Ratio are analysed with various data rates, modulation techniques and coding schemes. The results show that coding rate and modulation techniques had a more noticeable impact on the performance between the distinctive conditions of channel.
- **(M.A. Mohamed 2010) [5]:** In this paper, the WiMAX physical layer which depends on the IEEE 802.16e standard is broke down under various combinations of digital modulation schemes and distinctive communication channels [5]. The performance of the simulated system was assessed utilizing the bit-error-rate. This paper inferred that when channel conditions are poor, vitality effective schemes for example, BPSK or QPSK were utilized and when channel quality enhances, higher M-ary modulation schemes such as 16-QAM or 64-QAM was utilized.
- **(A.R.Shankar 2010) [6]:** This paper emphasis on the comparison of quality of service parameters between various diverts in WiMAX physical Layer on the premise of Bit Error Rate, Signal to Noise Ratio, Power Spectral Density and Probability of Error [6]. Authors stated that as the probability of BER, Theoretical Values of BER, and Probability of Error diminish as SNR increases more in Rician channel compared to Rayleigh channel in PURE AWGN. BPSK has the least BER while 64-QAM has most astounding BER than others.
- **(Z.T. Sharef 2012) [7]:** In this paper, author analysed the performance of WiMAX physical layer over AWGN and Rayleigh fading channel. The performance of QPSK modulation technique is evaluated and compared on the premise of bit error rate (BER) vs. bit energy-to-noise density ratio (E_b/N_o) curve [7]. The simulation result shows that the performance of the system can be enhanced by utilizing channel estimator.
- **(H.Kaur 2013) [8]:** In this paper, author analysed the bit error rate for WiMAX based COFDM system with BPSK modulation technique under different channel conditions like

AWGN, Rayleigh, Rician and Nakagami [8]. The outcomes show that performance of Nakagami fading channel is superior to other fading channels.

- **(D.R. Selvarani 2014) [9]:** In this paper, authors give a review of Wi-Fi and WiMAX which incorporates the components, Specifications, architecture, advantages, limitations and security. WiMAX and Wi-Fi were compared and it is recommended that when Wi-Fi is synergized with WiMAX, it will give the best response for last mile scope [9].
- **(Ahmed 2014) [10]:** In this paper, the performance is verified under various channels and number of modulation schemes on the basis of SNR and BER graph. The results state that WiMAX system works well in both AWGN and multipath fading channel [10].
- **(A. Al-Kandari 2014)[11]:** In this paper, capacity, efficiency, complexity and scope elements of WiMAX and LTE are discussed along with their advantages and disadvantages.
- **(M. Joshi 2015)[12]:** In this paper, the WiMAX system has been analysed under distinctive channels like Rayleigh, Rician, Nakagami and Lognormal shadowing channel with various modulation techniques on the premise of BER. This paper infers that Nakagami channel give better performance utilizing diverse modulation techniques at higher SNR.
- **(Y.M. Al-Moliki 2015)[13]:** In this paper, Concatenated Reed Solomon and Convolutional (RSCC) codes are compared with Reed Solomon (RS) codes without concatenation [13]. The Simulation results show that the performance of concatenated RS-CC code is better and robust when contrasted with RS code without concatenation regarding BER with different SNR.
- **(R.Pornima 2015)[14]:** In this paper, the higher order modulation techniques like 16-QAM and 64-QAM are analysed and simulated for mobile WiMAX in OFDMA [14].
- **(U.R.Mori 2015)[15]:** In this paper, authors present and look at features of two advance technologies in the physical layer and furthermore give performance analysis of diverse modulation schemes in WiMAX & LTE technologies [15].

- **(M.L.Singh 2016)[16]:** In this paper, the mobile WiMAX is broke down as far as BER for ITU-R and Cost-207 channel conditions for Typical Urban Area and Typical Rural Area.
- **(K.S.Pooja 2016)[17]:** In this paper, a Forward Error Correction scheme for OFDM communication system is presented. This simulation results based on BER Performance concluded that the single convolutional coding and dual interleaving plays out the best under all ranges of Signal to Noise Ratio.
- **(Mondal 2009)[18]:** This paper assesses the performance of a WiMAX system under diverse digital modulation and communication channels [18]. The results of bit error rate states that the implementation of interleaved RS code (255, 239, 8) with 2/3 rated convolutional code under BPSK modulation technique is exceedingly compelling to battle in the WiMAX communication system.
- **(Md. Anamul Islam 2010)[19]:** In this paper, Author utilizes concatenated cyclic redundancy check and convolution code (CRC-CC) alongside AWGN and frequency flat fading channels. The system is analysed on the premise of BER and spectral efficiency [19]. The results of BER and spectral efficiency illustrate that the system performance is exceedingly dependent on channel conditions and can be streamlined by AMC method. Under AWGN and Rician channel, 64 QAM with ¾ rated coding show lower BER whereas, in Rayleigh channel, 16-QAM shows lower BER. 16 QAM with 2/3 rated code battles exceptionally compelling spectrum efficiency under all mobile environments.
- **(M.A.Mohamed 2010)[20]:** In this paper, the WiMAX physical layer is dissected under various combinations of digital modulation schemes and diverse communication channels. The performance of the simulated system was assessed utilizing the bit-error-rate [20]. This paper stated that when channel conditions are poor, vitality effective schemes for example, BPSK or QPSK utilized and when channel quality enhances, higher M-ary modulation schemes such as16-QAM or 64-QAM was utilized.

- **(Prabhakar Telagarapu 2011)[21]:** In this paper, authors analyse the performance of WiMAX physical layer by utilizing Reed Solomon and Convolutional code as FEC (Forward Error Correction) code with CP and interleaving using different modulation techniques [21]. The performance of WiMAX physical layer is assessed on the premise of BER versus SNR.
- **(M. A. Islam 2012)[22]:** In this paper, the performance of concatenated CRC-CC and RS-CC codes are compared over AWGN and multipath fading channels. The simulation results concluded that the performance of concatenated CRC-CC is better when contrasted with concatenated RS-CC code under QAM over AWGN and multipath fading channels.
- **(Abdul Rehman 2012)[23]:** In this paper, Reed Solomon encoder with Convolutional encoder is used as FEC code. AWGN and fading channels are used along with adaptive modulation technique to assess the performance of WiMAX system. The Simulation result presumed that the usage of interleaved RS code with 2/3 rated convolutional code under BPSK modulation is more effective.
- **(M. M. Nuzhat Tasneem Awon 2012)[24]:** In this paper, the BER performance of WiMAX system is evaluated on the premise of various encoding rates and distinctive modulation techniques over AWGN, Rayleigh and Rician channel. The results show that AWGN channel performance is best among all the channels whereas the performance of Rayleigh channel is the most exceedingly bad of all the channels. The performance of Rician channel is more regrettable than that of AWGN channel yet superior than Rayleigh channel.
- **(Karrar AlSlmman 2012)[25]:** In this paper, LDPC code is contrasted with concatenated RS-CC code over AWGN channel. The simulation result shows that the performance of LDPC code is superior to RS-CC code.
- **(Kushwah 2013)[26]:** In this paper, WiMAX physical layer model is demonstrated by using MATLAB simulink. This paper is utilized to outline the impact of various modulation

techniques, coding rates, and CP and OFDM symbols on the performance of WiMAX physical layer system.

- **(Manju Agrawal 2015)[27]:** In this paper, the WiMAX system performance is evaluated with the help of BPSK, QPSK, 8-QAM, 16-QAM, and 64-QAM and 256-QAM modulation techniques on the premise of BER, SNR and Spectral Efficiency. The results stated that 256-QAM performs better with highest SNR and BPSK provide better performance with lowest SNR. Also 256-QAM can be utilized for transmitting maximum amount of data with minimum amount of error.

CHAPTER-III

SIMULATION MODEL

This chapter deals with OFDM based WiMAX Physical layer simulation model and its detail description. The simulation model of OFDM based WiMAX physical layer is depicted in Figure 3.1

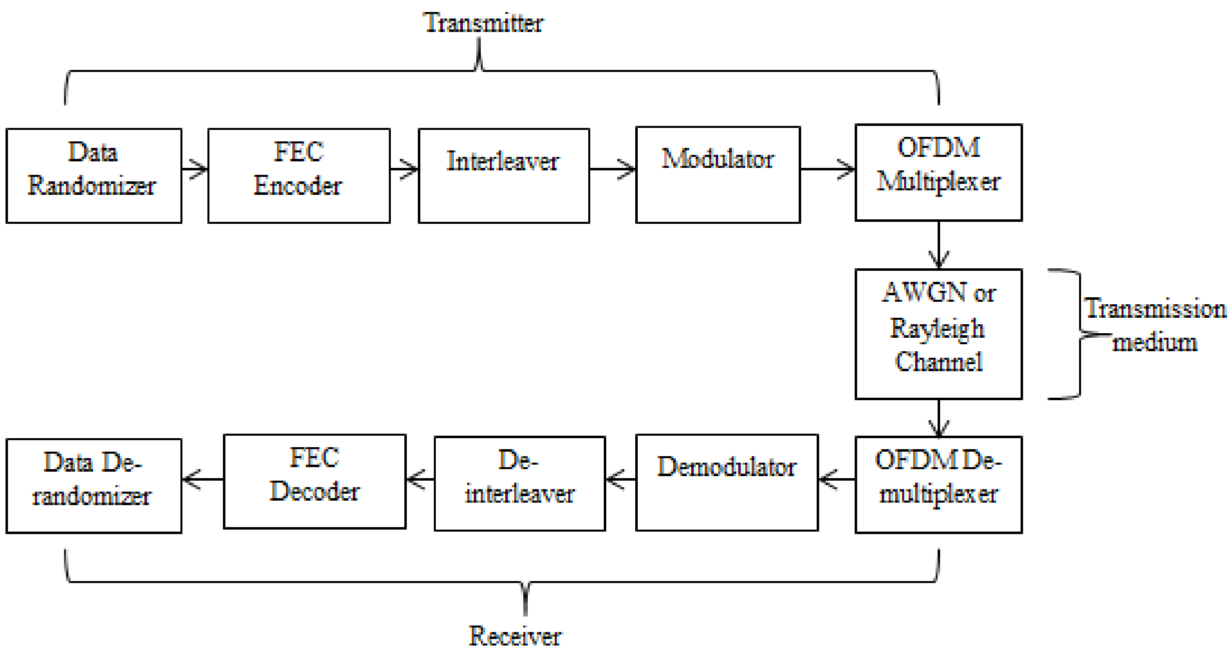

Figure 3.1 Block Diagram of WiMAX Physical layer

3.1 WiMAX Transmitter

Transmitter of WiMAX physical layer comprises of randomizer, FEC encoder, interleaver, modulator and OFDM multiplexer.

3.1.1 Randomizer

Randomizer is utilized to randomize the information from the source. Randomization is done to keep away from long sequences of persistent “ones” or “zeros”. The randomized information is aligned in block format before passing the information through the encoder. The randomizer block comprises of an exclusive OR operation of the information which is to be randomized with a pseudo random sequence produced by a PRBS generator. It is reinitialized for each forward error correcting block. The 15-stage shift register with generator polynomial of $X^{15}+X^{14}+1$with exclusive-OR gates in feedback setup is depicted in Figure 3.2

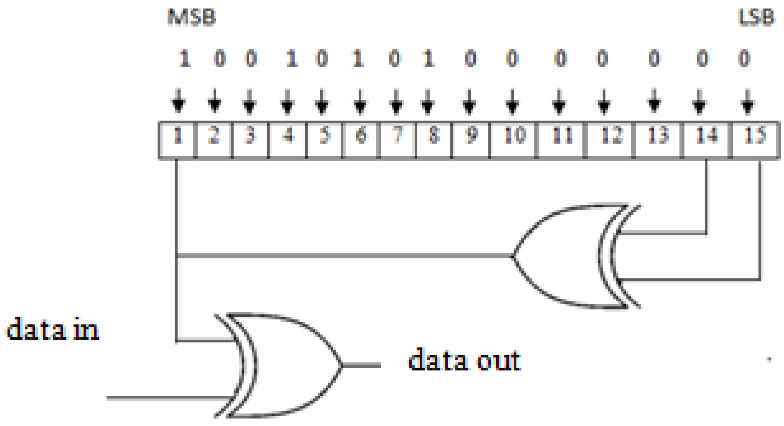

Figure 3.2 Pseudo Random Sequence Generator

3.1.2 FEC Encoder

FEC encoder is the important block of OFDM based WiMAX physical layer. The purpose of the FEC Encoder is to add redundancy in a controlled way which will enhance the reliability of data [1].The encoding process is shown in Figure 3.3

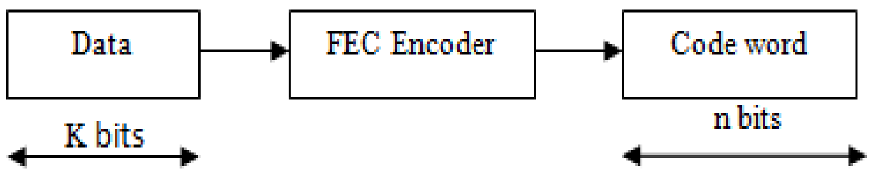

Figure 3.3 FEC encoding process

In OFDM based WiMAX physical layer, Concatenated RS-CC is utilized where Reed-Solomon code act as outer code and Convolutional code act as inner code as appeared in Figure 3.4.

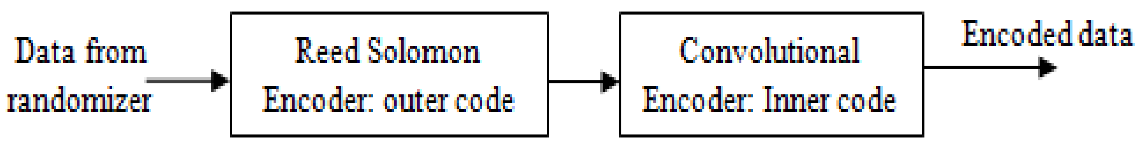

Figure 3.4 Concatenated RS-CC Encoder

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The RS encoding is gotten from a RS code where n is 255, k is 239, and t is 8 utilizing Galois Field (2^8). The format of Reed Solomon code is shown in Figure 3.5

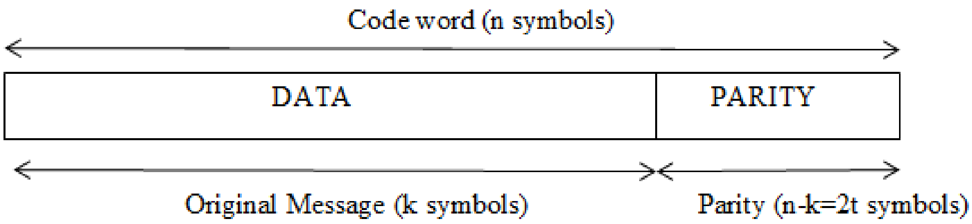

Figure 3.5 Format of Reed Solomon code

Then the code is shortened and punctured to empower variable block sizes and error-correction capacity. After this, the code is diminished to ‘k’ data bytes. $239 - $‘$k$’ Zero bytes are included as a prefix at that point. Subsequent to encoding, these $239 -$ ‘k’ zero bytes are disposed of. At the point when a code word is punctured to permit‘t’ bytes to be revised, just the initial $2t$ of the aggregate 16 parity bytes is utilized. The output of Reed Solomon encoder is given to inner convolutional encoder whose code rate is ½ and constraint length is 7.The convolutional encoder with code rate ½ is shown in Figure 3.6.

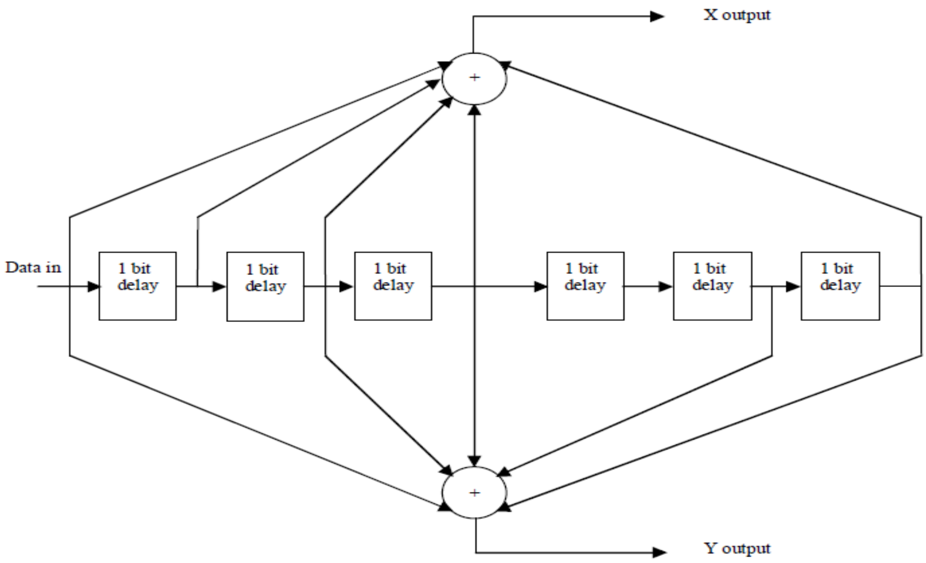

Figure 3.6 Convolutional encoder

The encoding process is performed by first passing the data in the form of block through the RS encoder and after that passing it through a convolutional encoder. A solitary $0x00$ tail byte is attached to the end of each burst. After randomization, tail byte is done. In the RS encoder, the repetition bits are transmitted before the input bits, keeping the $0x00$ tail byte toward the end of the allocation. When the aggregate number of data bits in a burst is not an integer number of bytes, zero pad bits are included after the zero tail bits. These zero pad bits are not randomized. The RS-CC encoding process is illustrated in Figure 3.7.

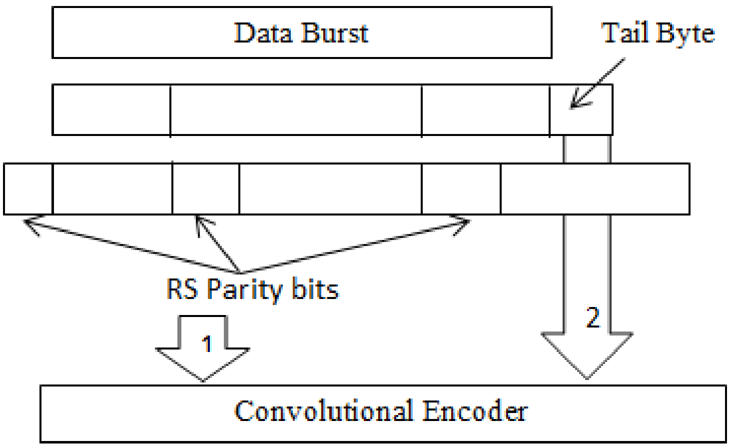

Figure 3.7 RS-CC encoding process

Keeping in mind the end goal to accomplish variable code rate, a puncturing operation is performed on the yield of the convolutional encoder according to Table 3.1. In this Table "1" shows that the contrasting convolutional encoder yield is utilized, whereas "0" connotes that the relating yield is not utilized. The Viterbi decoder is utilized to interpret the convolutional codes at the receiver.

Table 3.1 Puncturing pattern of convolutional code

Code Rate	d_{free}	$A_{O/P}$	$B_{O/P}$	AB O/P
1/2	10	1	1	A_1B_1
2/3	6	10	11	$A_1B_1B_2$
3/4	5	101	110	$A_1B_1B_2A_3$
5/6	4	10101	11010	$A_1B_1B_2A_3B_4A_5$

3.1.3 Interleaver

The Interleaver is used to interleave the encoded data to conquer very long successions of errors. The span of interleaving block relies on the number of coded bits per encoded block size. The interleaving process is illustrated in Figure 3.8. The interleaving process is done utilizing a two-stage permutation process. In first permutation, the adjacent coded bits are mapped onto nonadjacent subcarriers and are characterized by the accompanying equation:

$$m_k = \left(\frac{Ncbps}{12}\right) \times \text{mod}\,(K, 12) + \text{floor}\left(\frac{K}{12}\right) \tag{3.1}$$

where m_k= Index of coded bits after first permutation

N_{cbps}= number of coded bits per symbol

K= Index of coded bits before first permutation

The adjacent coded bits are mapped alternately onto less or more significant bits of the constellation in second permutation. It is characterized by the accompanying equation:

$$s = \text{ceil}\left(\frac{Ncbps}{2}\right) \tag{3.2}$$

$$j_k = s \times \text{floor}\left(\frac{mk}{s}\right) + (mk + Ncbps - \text{floor}\,(12 \times mk / Ncbps))\ \text{mod}(s) \tag{3.3}$$

where N_{cpc}= number of coded bits per carrier

j_k= Index of coded bits after second permutation

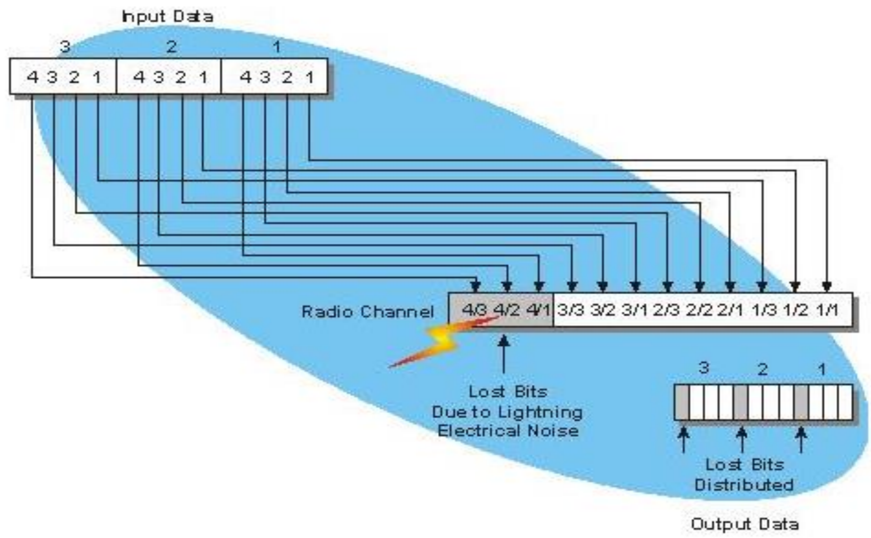

Figure 3.8 Interleaving process [4]

3.1.4 Modulator

After interleaving, the next block of WiMAX physical layer is modulator. WiMAX utilizes adaptive modulation where modulation changes relying on the conditions of channel. The constellation of QPSK, 16-QAM and 64-QAM is depicted in Figure 3.9.

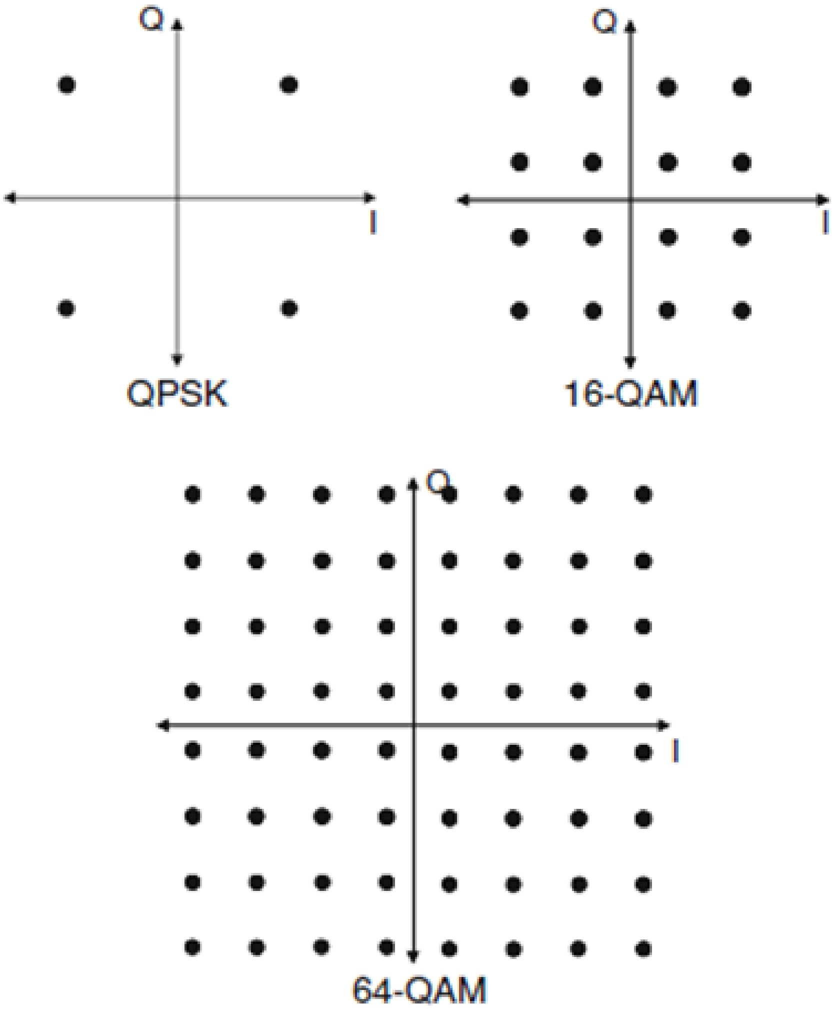

Figure 3.9 QPSK, 16-QAM, and 64-QAM constellations [39]

3.1.5 OFDM Multiplexer

OFDM is short for orthogonal frequency division multiplexing. Here, the modulated data is changed over into time domain from frequency domain. This is done by employing IFFT or IDFT. The OFDM Spectrum of the signal is depicted in Figure 3.10.

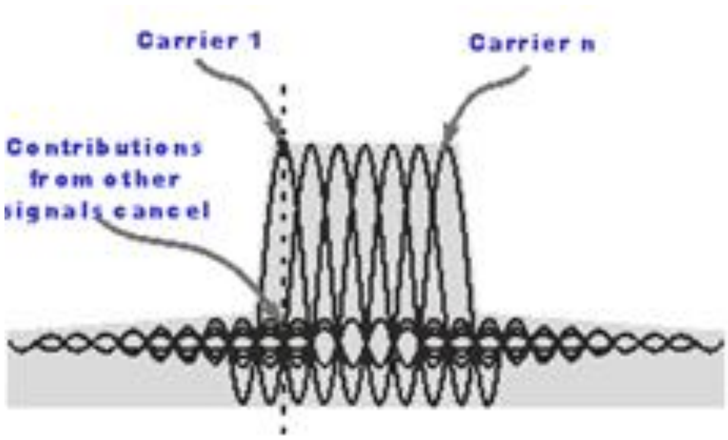

Figure 3.10 OFDM Spectrum [31]

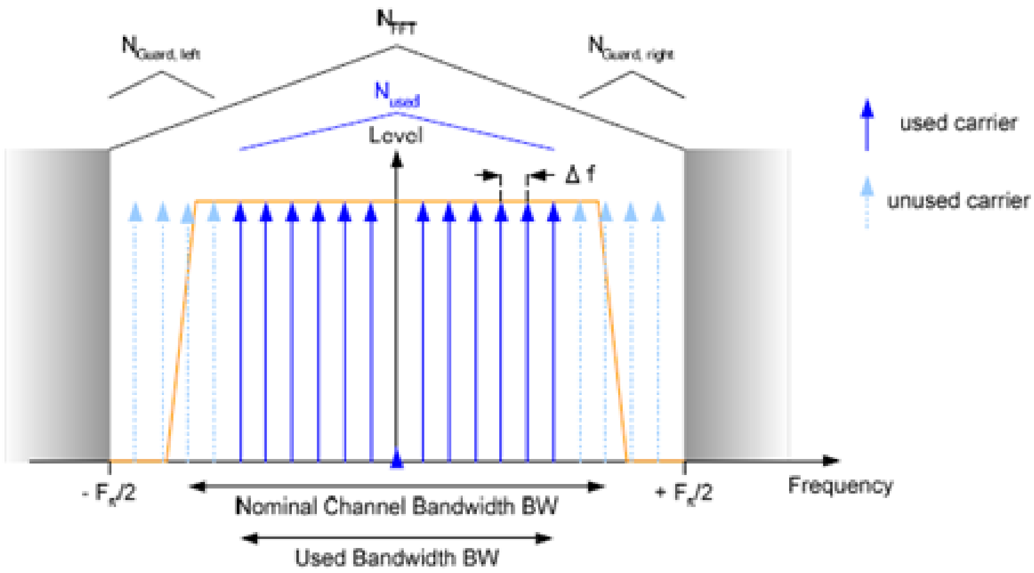

Figure 3.11 OFDM signal in frequency Domain

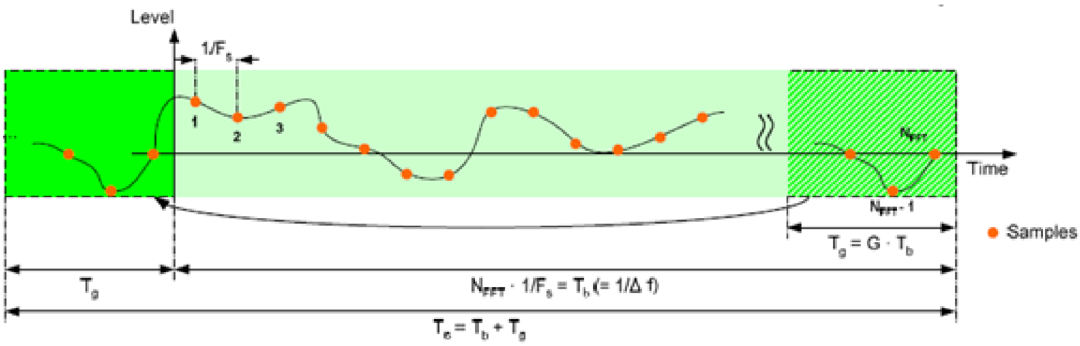

Figure 3.12 OFDM signal in Time Domain

The OFDM signal in frequency domain and time domain is presented in Figure 3.11 and Figure 3.12 respectively. Also CP has been included with the time domain data to diminish inter-symbol interference (ISI). There is four distinctive span of a CP that is accessible to the standard. The diverse CP is $1/4, 1/8, 1/16$ and $1/32$. then it is transmitted through the channel.

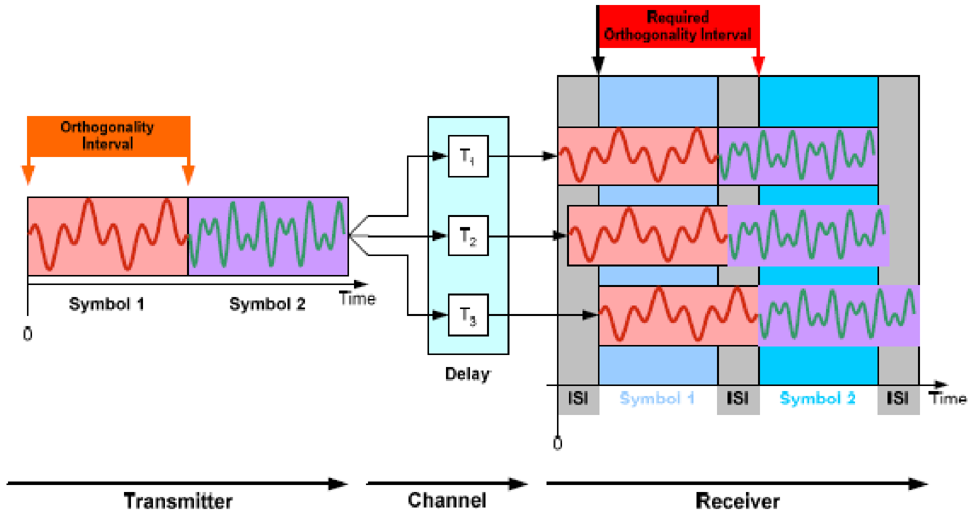

Figure 3.13 Inter-symbol interference [32]

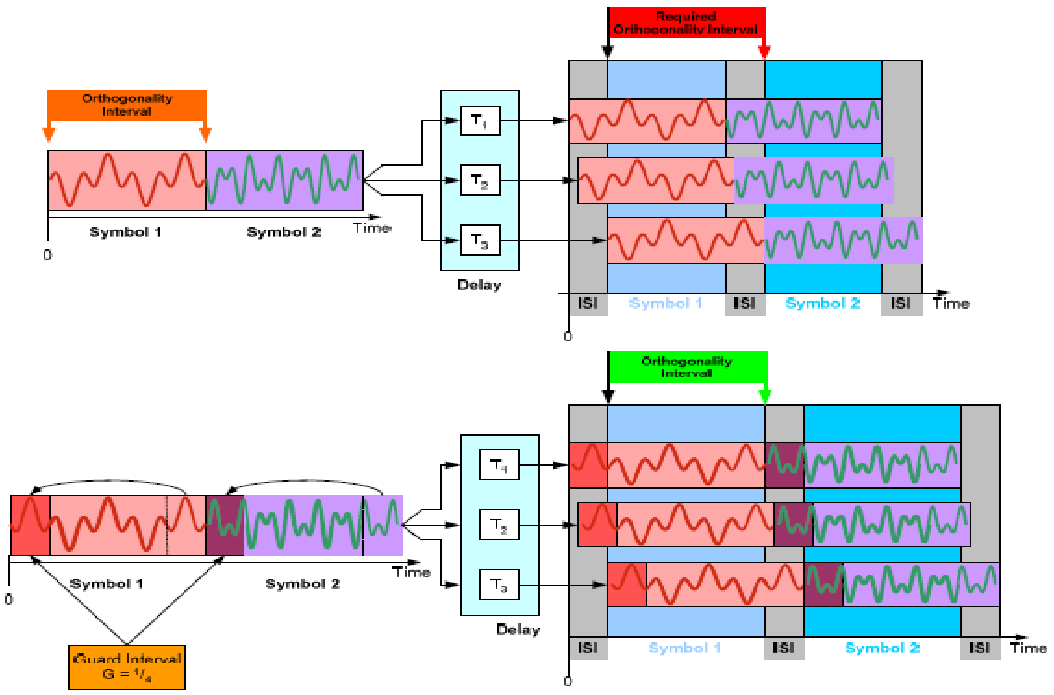

Figure 3.14 OFDM transmissions with and without guard interval [32]

ISSN: 2278-0181

3.2 Channel

It is the transmission media which is used to transmit the signal from source to destination. For wireless communication, Air is the transmission medium used for transmitting data. Diverse channels can be used in WiMAX like AWGN, Rayleigh fading channel, Rician fading channel, SUI or Nakagami channel. In our thesis work, AWGN and Rayleigh fading channel is used

3.2.1 AWGN Channel

The AWGN is a fundamental noise model utilized in information theory to emulate the impacts of numerous stochastic processes happening in nature. Here the term Additive refers to added noise that might be innate in the information system. White alludes to the idea of uniform power over the frequency band and term Gaussian is used as it has a normal distribution in time domain. Mathematically, AWGN channel is represented as

$$R(t) = X(t) + N(t) \tag{3.4}$$

where R (t) = received signal, X (t) = transmitted signal and N (t) = background noise as shown in Figure 3.15.

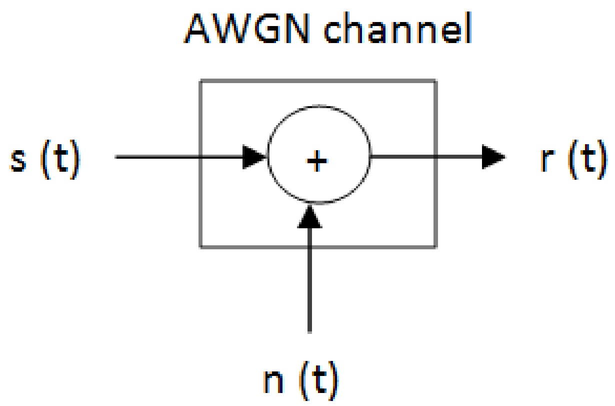

Figure 3.15 AWGN channel model

3.2.2 Rayleigh Fading Channel

This channel is a measurable model of the impact of the engendering condition on radio signals, for example, those utilized by remote devices. This model expects that the amplitude of the signal that has gone through such a transmission media will vary haphazardly or stepwise as indicated by the Rayleigh distribution. Rayleigh fading is considered as a sensible model for tropospheric and ionospheric signal proliferation and for the impacts of far-reaching urban conditions on radio signals. Rayleigh fading is most pertinent when there is no overwhelming propagation on the line of sight between the transmitter and the recipient. Rayleigh fading is a unique instance of dual-wave with diffuse reflection power fading. Mathematically, Rayleigh fading channel is represented as

$$R\ (t)\ = X\ (t) \times H(t)\ + N\ (t) \tag{3.5}$$

where R (t) = received signal,

S (t) = transmitted signal

H (t) = random channel matrix and

N (t) = background noise as shown in Figure 3.16.

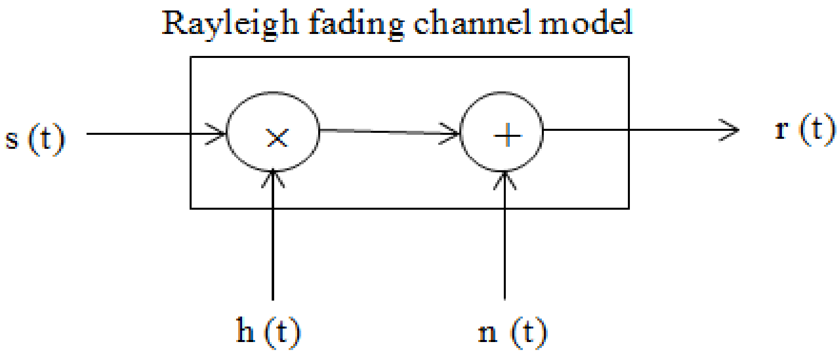

Figure 3.16 Rayleigh channel model

3.3 WiMAX Receiver

The receiver of WiMAX physical layer comprises of OFDM de-multiplexer, de-modulator, de-interleaver, FEC decoder, and de-randomizer.

3.3.1 OFDM De-multiplexer

CP which is included at the transmitter for reducing Inter-symbol interference is evacuated by OFDM de-multiplexer. The received signal is changed into frequency domain utilizing FFT or DFT algorithm. As OFDM symbol comprises of data, pilots and a zero DC subcarrier with guard bands. Pilot carriers and data values are extricated here.

3.3.2 Demodulator

Demodulation block at the receiver side is used to demodulate the signal waveform back to digital data.

3.3.3 De-interleaver

It is utilized to undo the changes done by interleaver at the transmitter side to retrieve the actual information.

3.3.4 FEC Decoder

The repetition that is included at the transmitter is diminished in this FEC decoder. This repetition is investigated to see if there are any errors. The FEC decoding process is depicted in Figure 3.17.

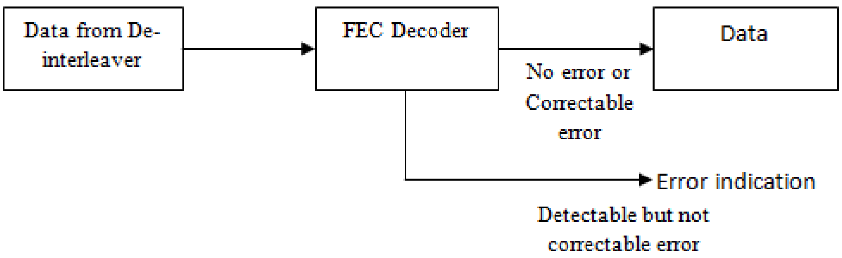

Figure 3.17 FEC Decoding process

3.3.5 De-randomizer

De-randomizer used to nullify the effect of randomizer to get the actual data.

3.4 Adaptive Modulation and coding in WiMAX

It is utilized in remote communication to demonstrate the coordinating of modulation, coding, different signs and convention parameters to the conditions on radio connection. The purpose of Adaptive Modulation is to adapt distinctive modulation techniques when a wireless communication system encounters fading and minor departure from the connection. WiMAX takes full favorable position of link adaptation technique alongside coding. In the event, the link condition terrible, at that point WiMAX system changes the modulation consequently. By changing the modulation, the amount of data exchanged per signal additionally changes. SNR should be ideal to defeat clamour and interference in the channel for utilizing higher modulation. Lower data rates are accomplished by BPSK & QPSK constellations alongside convolutional codes with code rate ½. Here, ½ implies that the system produces two codes for transmission of one bit. While higher data rates are accomplished by utilizing 16-QAM & 64-QAM constellations together with convolutional codes with ¾ code rate. WiMAX adaptive modulation and coding, requisite channel coding per modulation in WiMAX is shown in Table 3.2 and Table 3.3 respectively.

Table 3.2 WiMAX Adaptive Modulation and coding

Parameter	Downlink	Uplink
Modulation	BPSK, QPSK, 16-QAM, BPSK discretionary for OFDMA-PHY	BPSK, QPSK, 16-QAM, 64-QAM discretionary
Coding	Requisite: Convolutional codes at rate $1/2, 2/3, 3/4, 5/6$ Discretionary: Convolutional turbo codes at rate $1/2, 2/3, 3/4, 5/6$; repetition codes at rate 1/2, 1/3, 1/6, LDPC, RS codes for OFDM-PHY	Requisite: Convolutional codes at rate $1/2, 2/3, 3/4, 5/6$ Discretionary: Convolutional turbo codes at rate $1/2, 2/3, 3/4, 5/6$; repetition codes at rate $1/2$, $1/3, 1/6$, LDPC

3.5 Parameters of OFDM in WiMAX

The parameters of OFDM both primitive and derived that portray OFDM symbol totally in WiMAX are recorded in Table 3.4.

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Table 3.3 Requisite channel coding per modulation in WiMAX

Modulation	Overall coding rate	Uncoded block size (Bytes)	Coded Block size (Bytes)	RS code	CC code rate
QPSK	½	24	48	(32,24,4)	2/3
QPSK	¾	36	48	(40,36,2)	5/6
16-QAM	¾	72	96	(80,72,4)	5/6
64-QAM	2/3	96	144	(108,96,6)	3/4
64-QAM	¾	108	144	(120,108,6)	5/6

Table 3.4 Primitive and derived parameters of OFDM in WiMAX

Parameters	Value	Description
BW	1.25,5,10,20	Bandwidth
N_{used}	72, 360,720,1440	used subcarriers
n	8/7, 28/25	Sampling factor
N_{fft}	128,512,1024,2048	FFT size
G	1/4, 1/8, 1/16, 1/32	Guard time ratio
F_s	Floor(n × BW/8000) × 8000	Sampling frequency
Δf	F_s / N_{fft}	Frequency spacing
T_b	1/ Δf	Useful symbol time

CHAPTER-IV

RESULTS AND DISCUSSION

In this chapter, the results of simulation are shown and discussed. Amid our simulation, CP is used to minimize Inter Symbol Interference (ISI). Diverse modulation techniques that are used in this simulation are Quadrature Phase Shift Keying, 16-Quadrature Amplitude Modulation and 64-Quadrature Amplitude Modulation. The analysis has been done for diverse channels namely AWGN and Rayleigh channel.

Results are shown in the form of SNR vs BER plot and SNR vs Spectral Efficiency plot for different modulations and different channels. Results have been presented for different CP over different channels using different modulation techniques.

The performance of OFDM based WiMAX physical layer system is analysed using two parameters namely

1. BER Analysis
2. Spectral Efficiency Analysis

4.1 BER analysis of OFDM based WiMAX Physical layer system

BER is defined as the rate at which the errors occur or it can be characterized as ratio of number of errors occurs to the total number of bits transmitted. The BER can be written into a simple formula:

$$\text{BER} = \left(\frac{\text{Total Error}}{\text{Total number of bits transmitted}}\right) \tag{4.1}$$

In this section, BER analysis of WiMAX system is done for diverse modulations over different channels. The channels used for this purpose are AWGN and Rayleigh channels.

4.1.1 BER analysis over AWGN channel

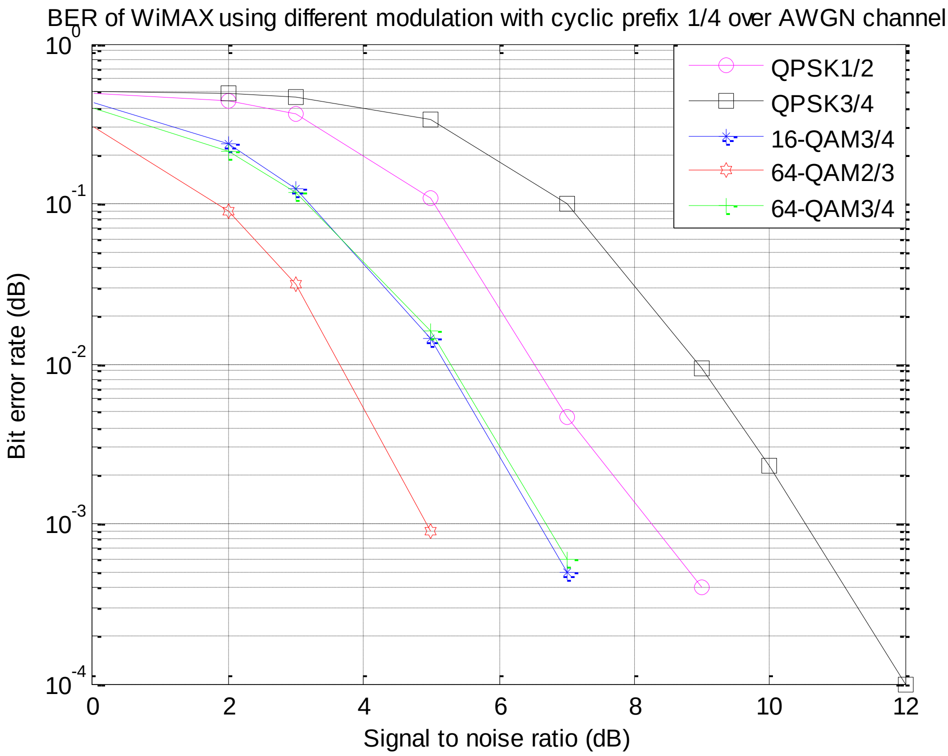

Figure 4.1 BER of WiMAX with CP ¼ over AWGN channel

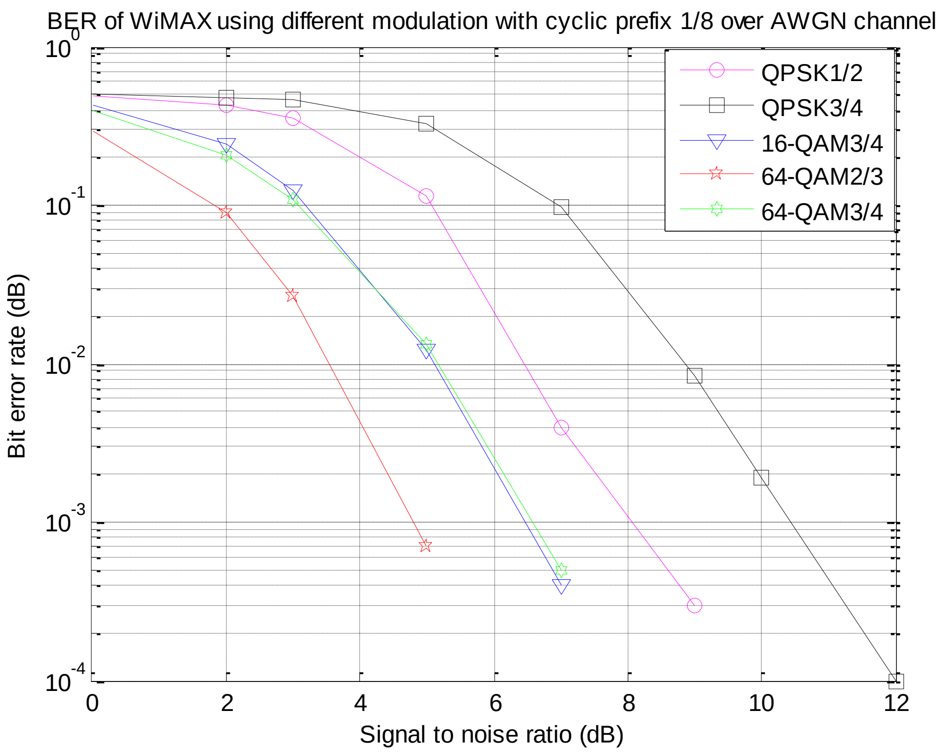

Figure 4.2 BER of WiMAX with CP 1/8 over AWGN channel

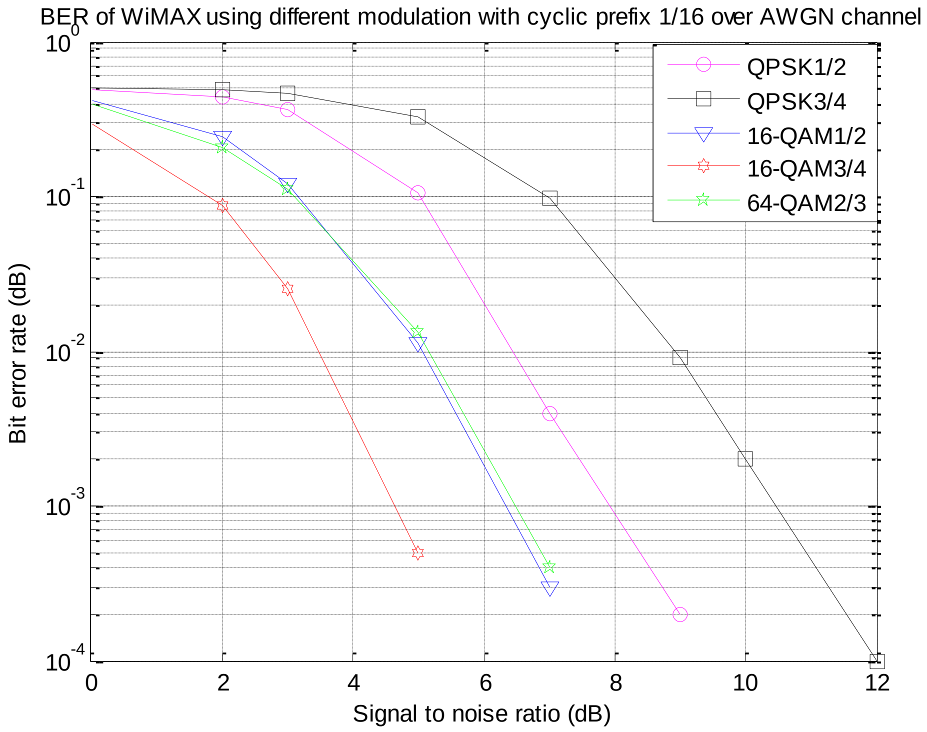

Figure 4.3 BER of WiMAX with CP 1/16 over AWGN channel

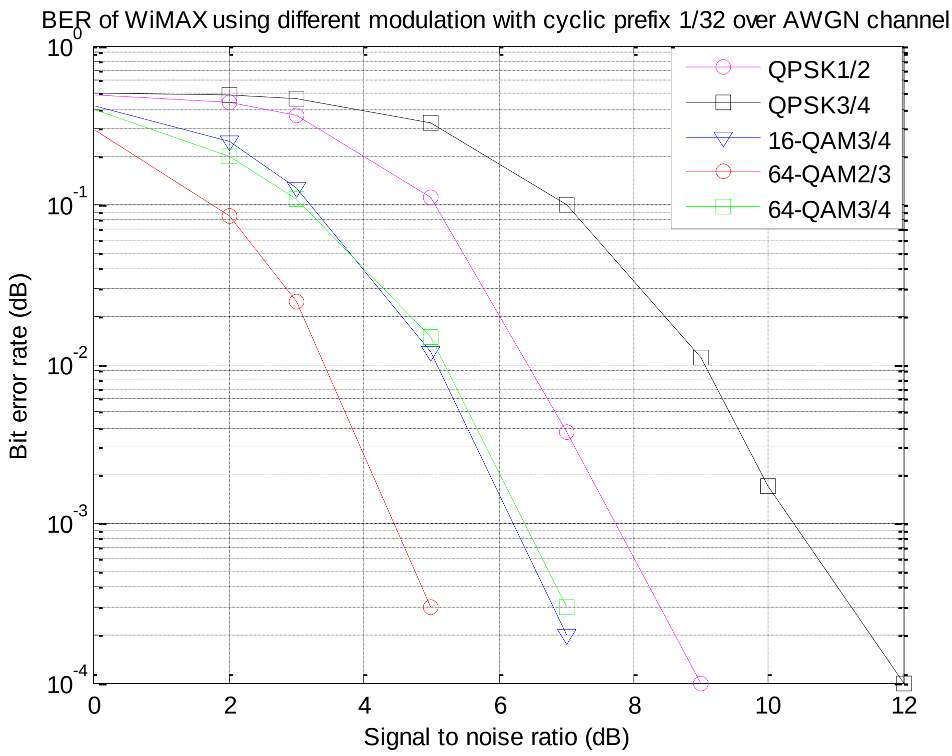

Figure 4.4 BER of WiMAX with CP 1/32 over AWGN channel

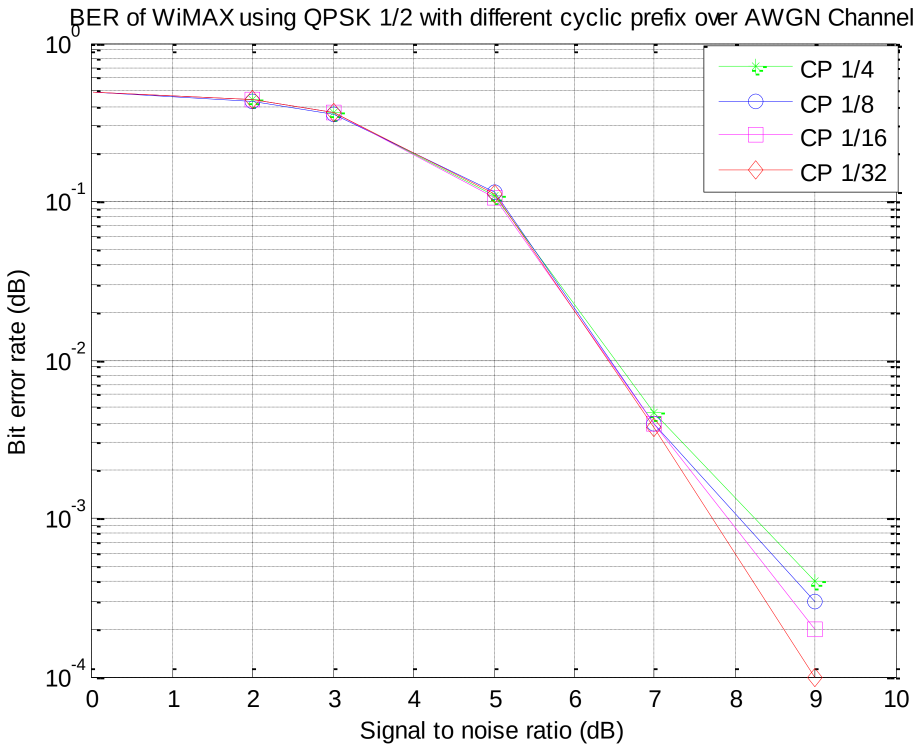

Figure 4.5 BER of WiMAX using QPSK ½ over AWGN channel

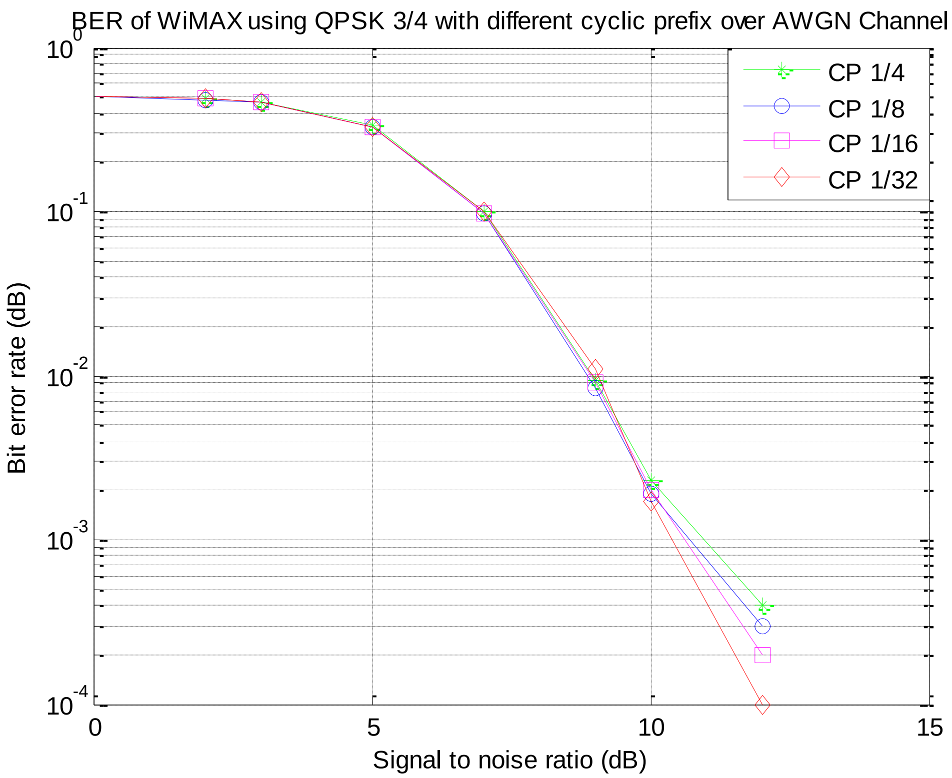

Figure 4.6 BER of WiMAX using QPSK ¾ over AWGN channel

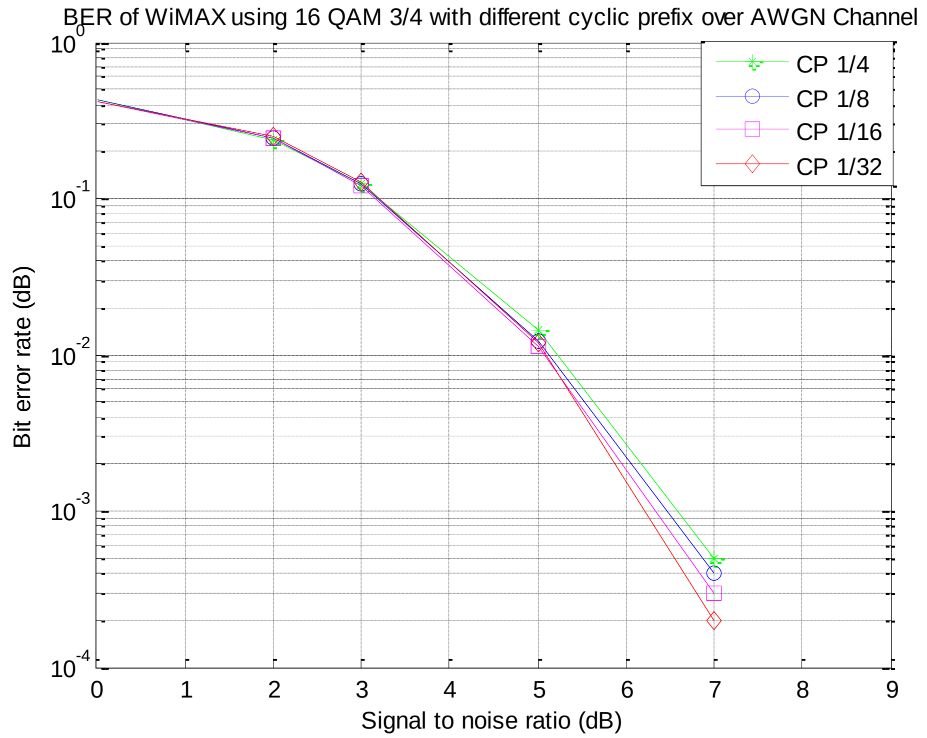

Figure 4.7 BER of WiMAX using 16 QAM ¾ over AWGN channel

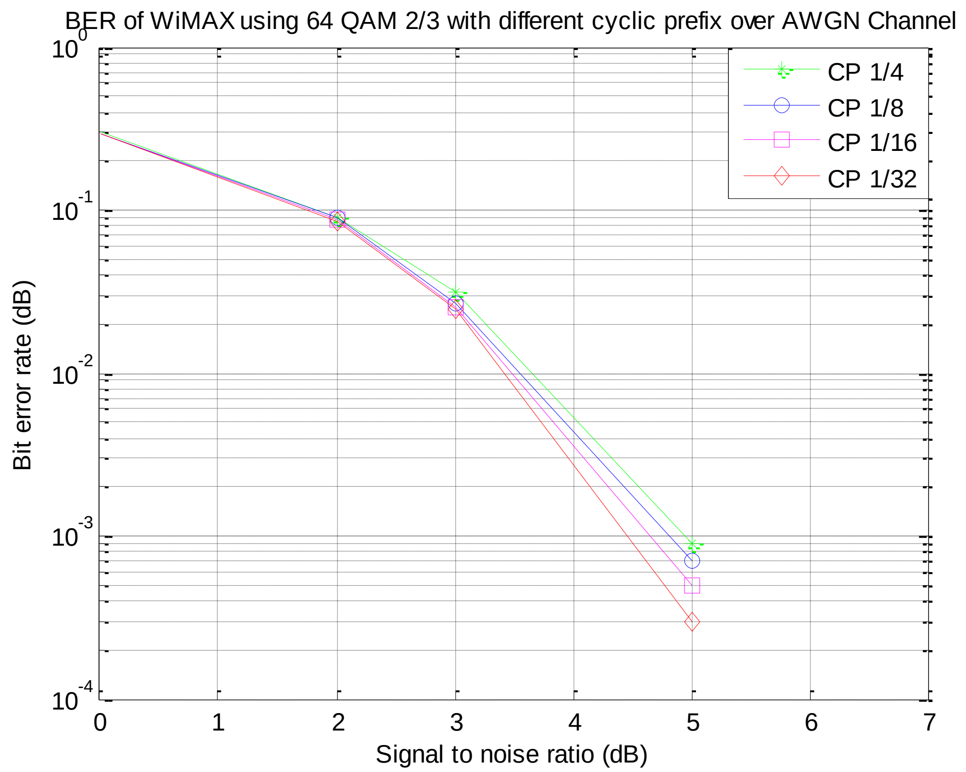

Figure 4.8 BER of WiMAX using 64 QAM 2/3 over AWGN channel

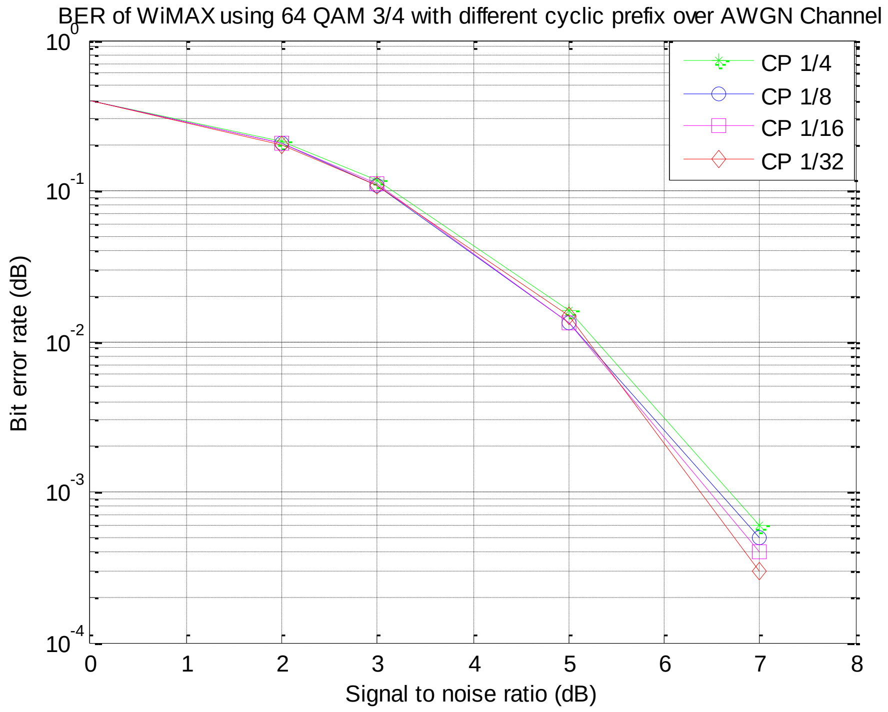

Figure 4.9 BER of WiMAX using 64 QAM ¾ over AWGN channel

SNR vs BER plots for OFDM based WiMAX physical layer over AWGN channel employing diverse modulations and CP have been shown in Figure 4.1 - 4.9. The Table that outlines all the BER results of different modulation along with different CP is given in Table 4.1.

Table 4.1 SNR requirement in WiMAX over AWGN Channel

CP	SNR(dB) required to achieve a BER of 10^{-3}				
	Modulation				
	QPSK 1/2	QPSK 3/4	16 QAM 3/4	64 QAM 2/3	64 QAM 3/4
1/4	8.25	10.95	6.58	4.94	6.69
1/8	8.07	10.69	6.46	4.80	6.57
1/16	7.91	10.60	6.33	4.64	6.47
1/32	7.72	10.37	6.21	4.45	6.38

4.1.2 BER analysis over Rayleigh channel

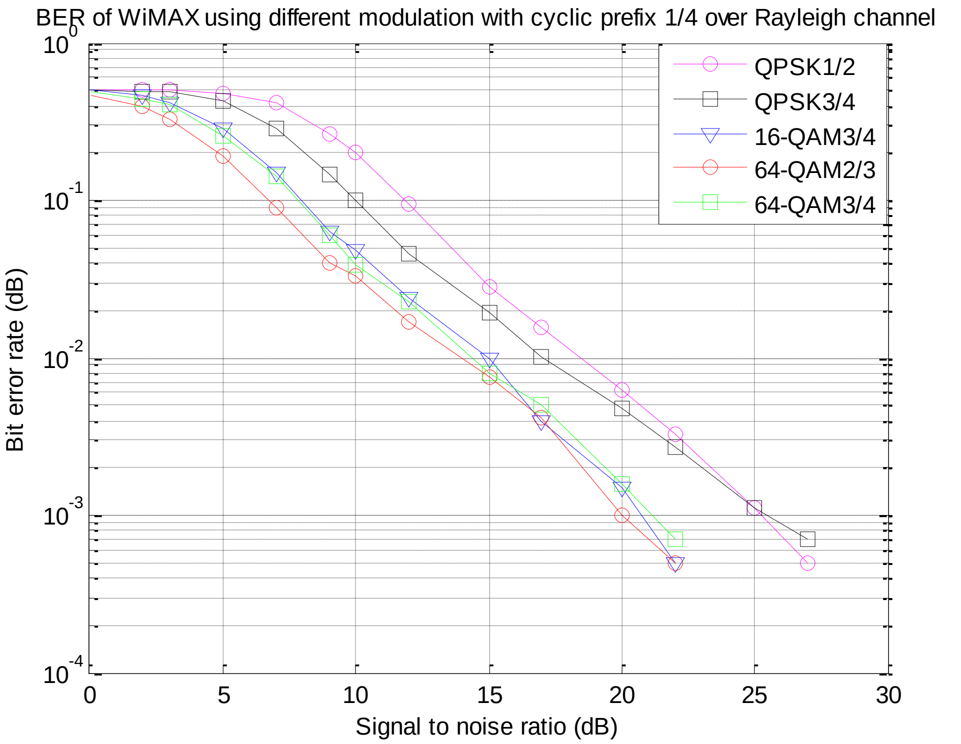

Figure 4.10 BER of WiMAX with CP ¼ over Rayleigh channel

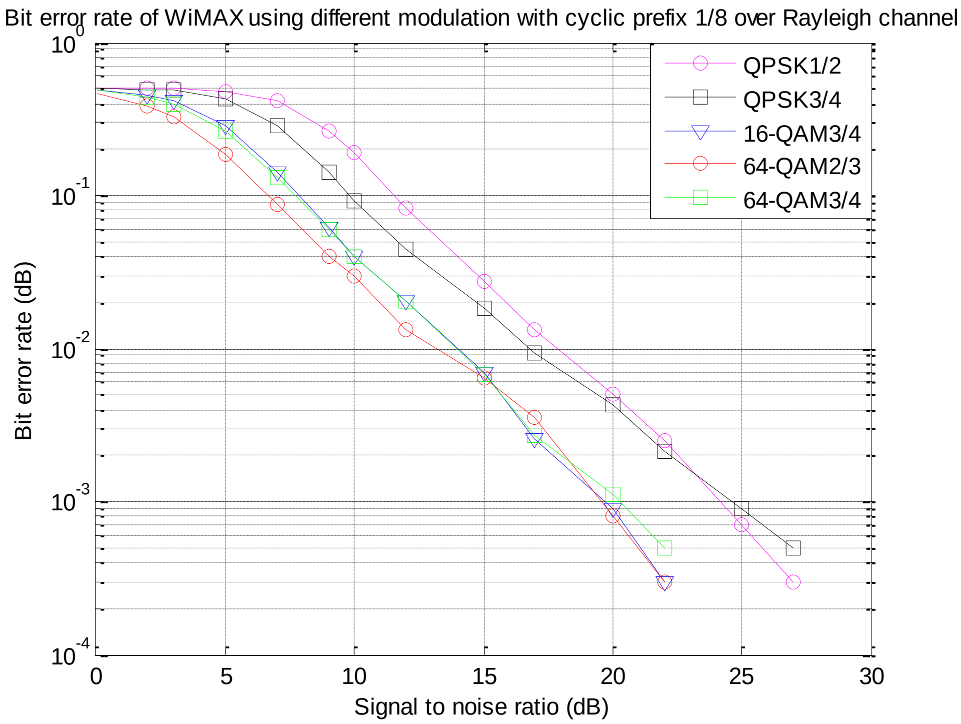

Figure 4.11 BER of WiMAX with CP 1/8 over Rayleigh channel

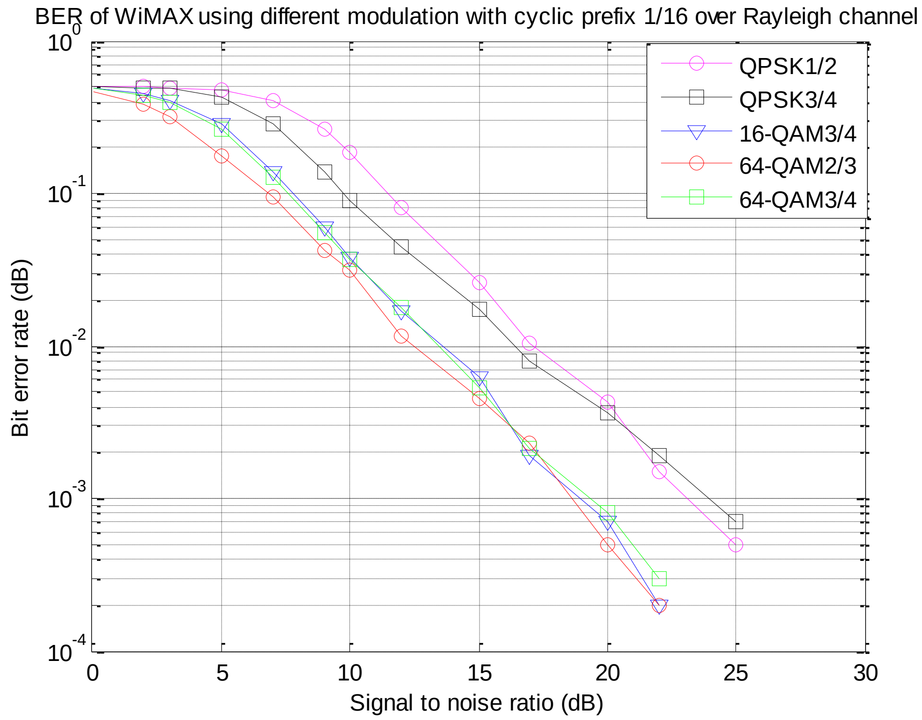

Figure 4.12 BER of WiMAX with CP 1/16 over Rayleigh channel

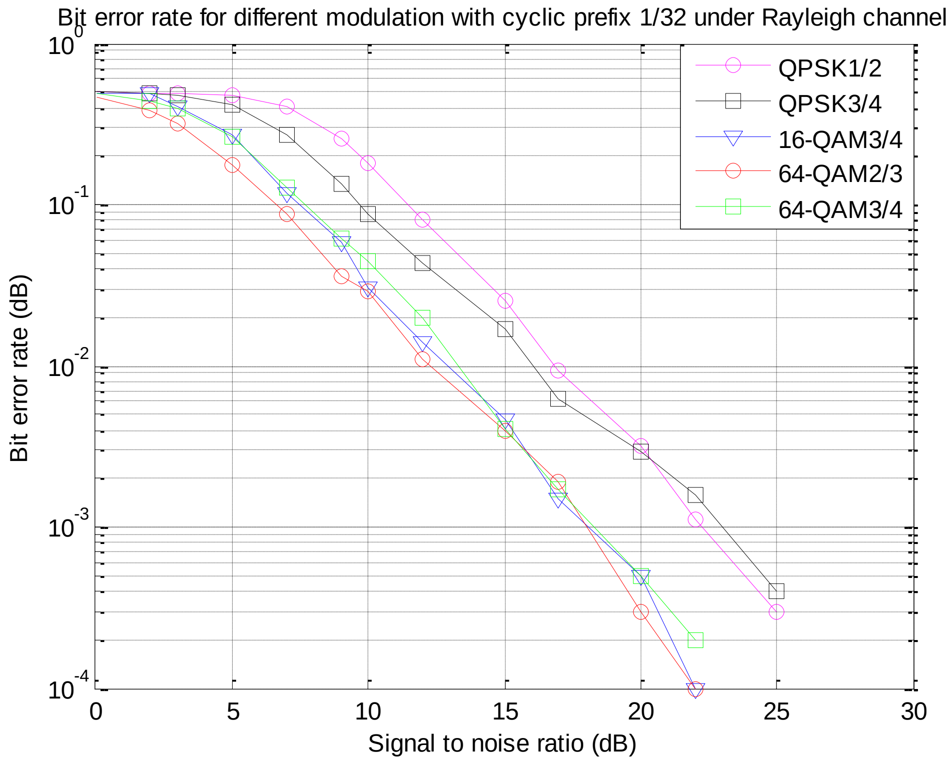

Figure 4.13 BER of WiMAX with CP 1/32 over Rayleigh channel

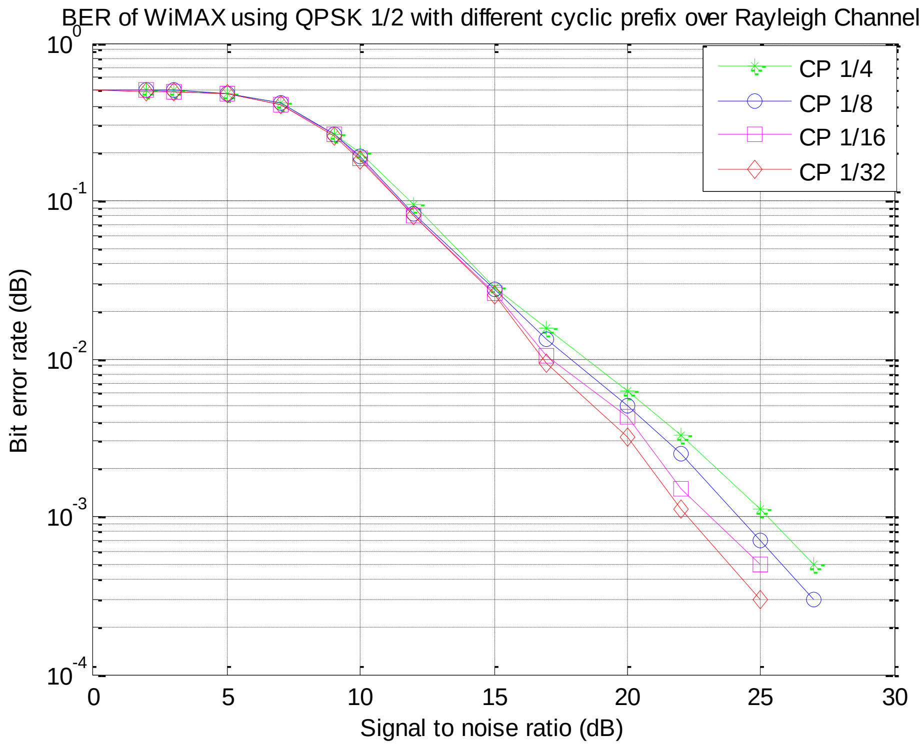

Figure 4.14 BER of WiMAX using QPSK ½ over Rayleigh channel

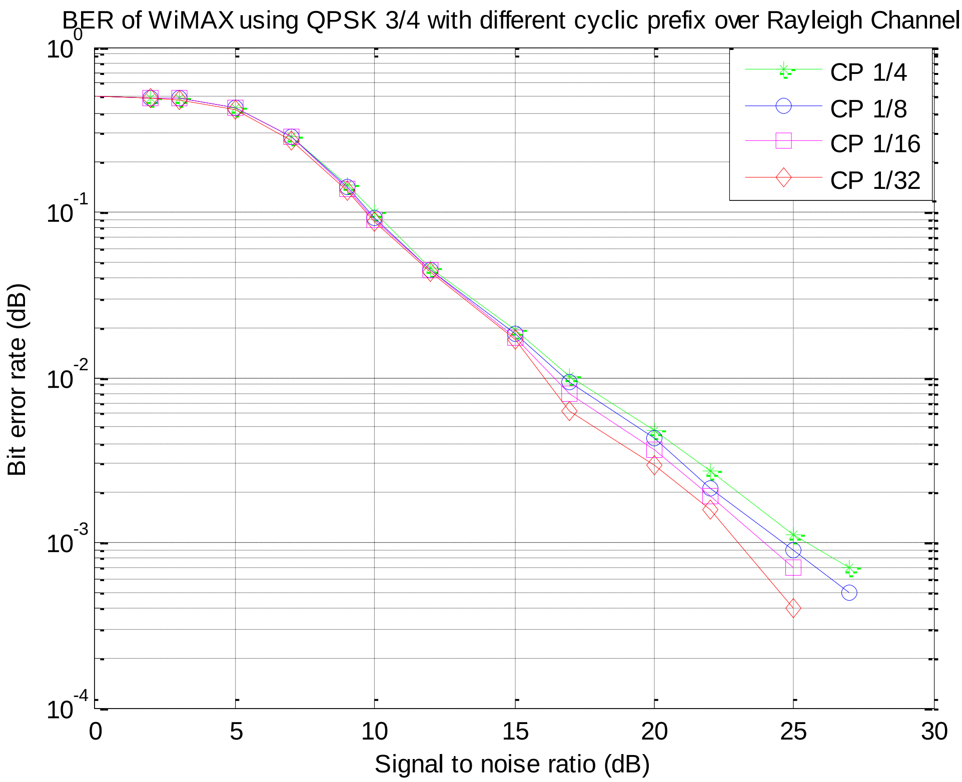

Figure 4.15 BER of WiMAX using QPSK 3/4 over Rayleigh channel

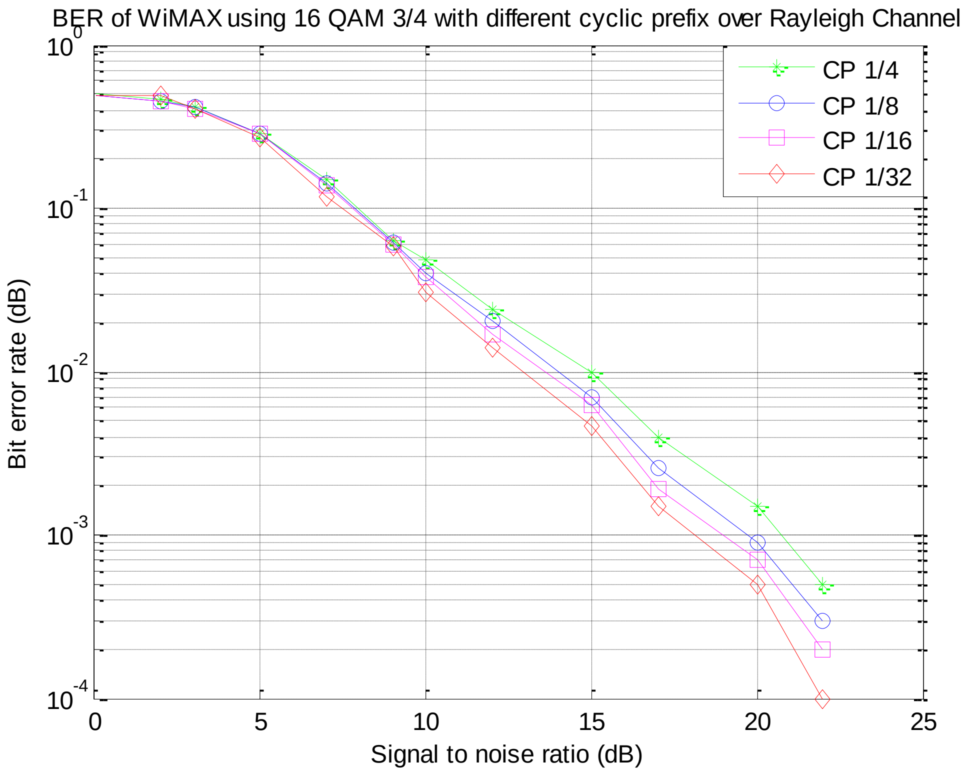

Figure 4.16 BER of WiMAX using 16 QAM 3/4 over Rayleigh channel

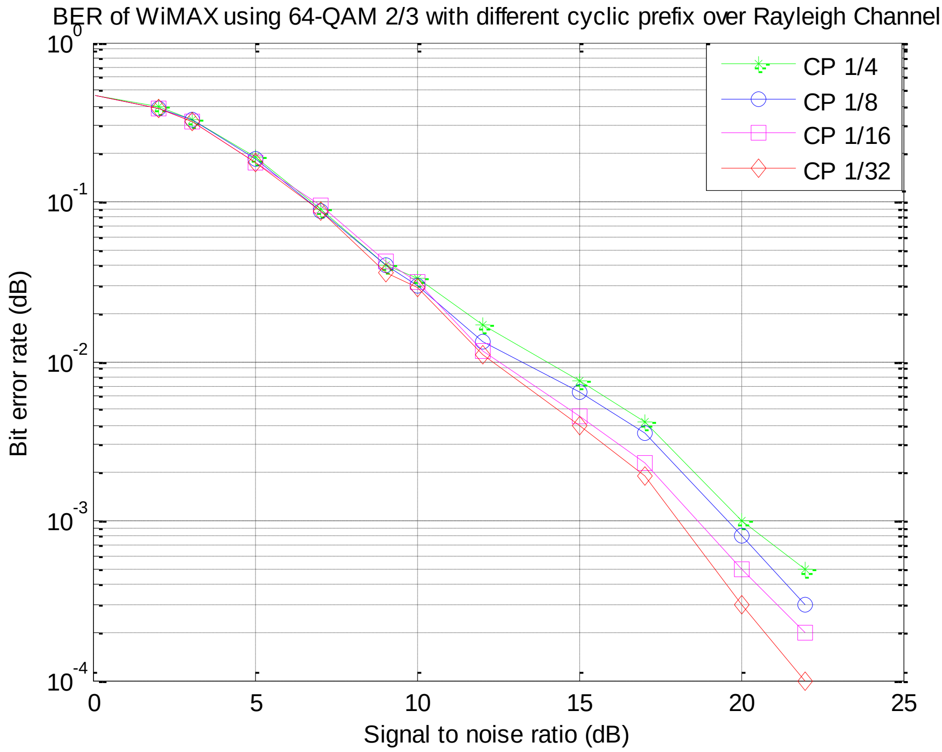

Figure 4.17 BER of WiMAX using 64 QAM 2/3 over Rayleigh channel

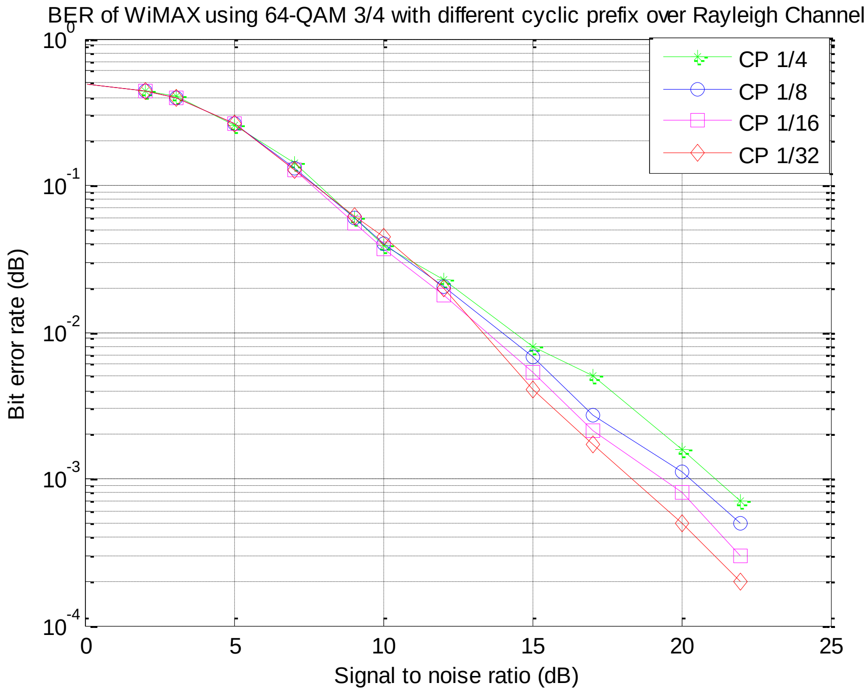

Figure 4.18 BER of WiMAX using 64 QAM 3/4 over Rayleigh channel

SNR vs BER plots for OFDM based WiMAX physical layer over Rayleigh channel employing diverse modulations and CP have been shown in Figure 4.10 – 4.18. The Table that outlines all the BER results of different modulation along with different CP is given in Table 4.2.

Table 4.2 SNR requirement in WiMAX over Rayleigh Channel

Cyclic prefix	SNR(dB) required to achieve a BER of 10^{-3}				
	Modulation				
	QPSK 1/2	**QPSK 3/4**	**16 QAM 3/4**	**64 QAM 2/3**	**64 QAM 3/4**
1/4	25.24	25.42	20.73	20	21.13
1/8	24.15	24.62	19.70	19.54	20.24
1/16	23.10	23.92	18.92	18.63	19.30
1/32	22.22	23.01	18.10	18.04	18.30

4.2 Spectral Efficiency

It is characterized as the quantity of bits per second per hertz. There are number of techniques that are accessible in literature. There are diverse models in each on the premise of modulation schemes, coding techniques and spectrum shaping techniques. In theory, the number of modulation levels having a corresponding connection with the SE. Regardless, an expansion in modulation result, the higher precision is required at the de-modulator to distinguish the phase and frequency which require higher SNR for the same BER. Another way to accomplish SE is the FEC coding. We derived the spectral efficiency using the formula:

$$SE= (1-BER)^{n} \times k \times r \quad (4.2)$$

where SE = Spectral Efficiency in b/s/Hz

BER = Bit Error Rate

n = number of bits in the block

k = number of bits per symbol

r = overall code rate

Table 4.3 Spectral Efficiency & FEC Block size of WiMAX

Modulation	Code rate	FEC Block size (Bits)	Spectral Efficiency
QPSK	1/2	48	1
QPSK	3/4	72	2
16 QAM	3/4	144	3
64 QAM	2/3	192	4
64 QAM	3/4	216	4.5

In this section, SE analysis of WiMAX system is done for diverse modulations over different channels. The channels used for this purpose are AWGN, Rayleigh channels.

4.2.1 Spectral Efficiency analysis over AWGN channel

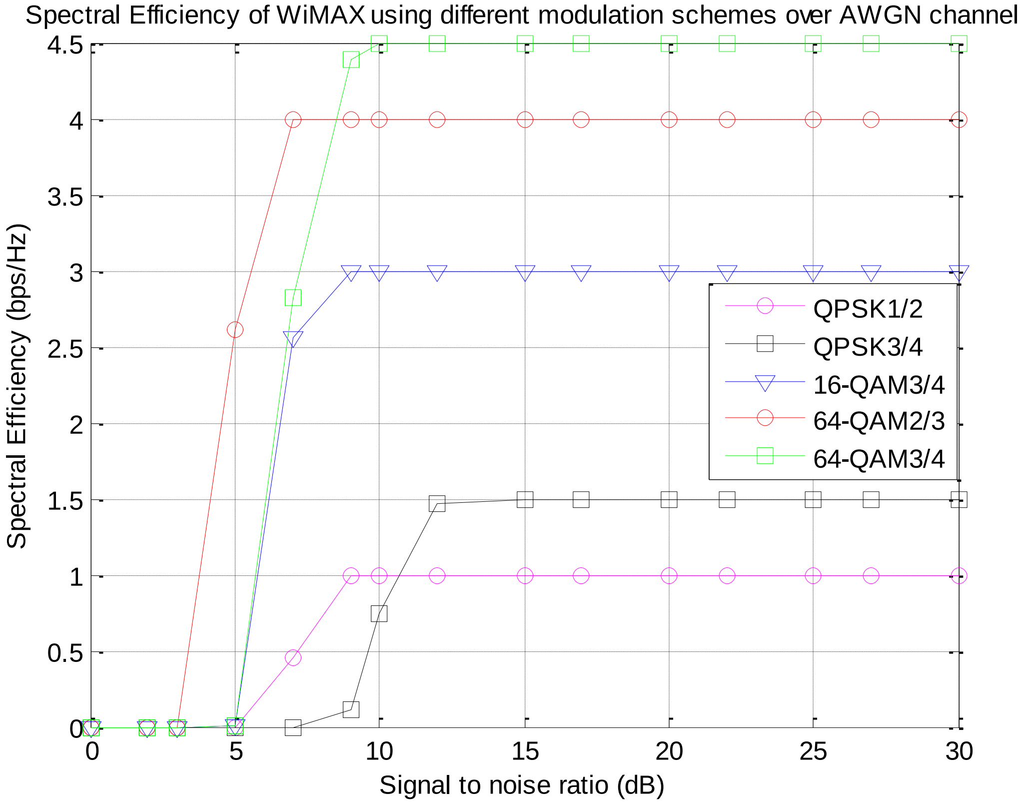

Figure 4.19 Spectral Efficiency of WiMAX over AWGN channel

SNR vs SE plots for OFDM based WiMAX physical layer over AWGN channel employing diverse modulations have been shown in Figure 4.19. The Table that outlines the SE result of different modulations is given in Table 4.4.

Table 4.4 Spectral Efficiency of WiMAX over AWGN channel

Modulation	**QPSK**	**QPSK**	**16 QAM**	**64 QAM**	**64 QAM**
Code rate	**1/2**	**3/4**	**3/4**	**2/3**	**3/4**
SE	**1**	**2**	**3**	**4**	**4.5**
SNR(dB)	From 9 onwards	From 12 onwards	From 9 onwards	From 7 onwards	From 10 onwards

4.2.2 Spectral Efficiency analysis over Rayleigh channel

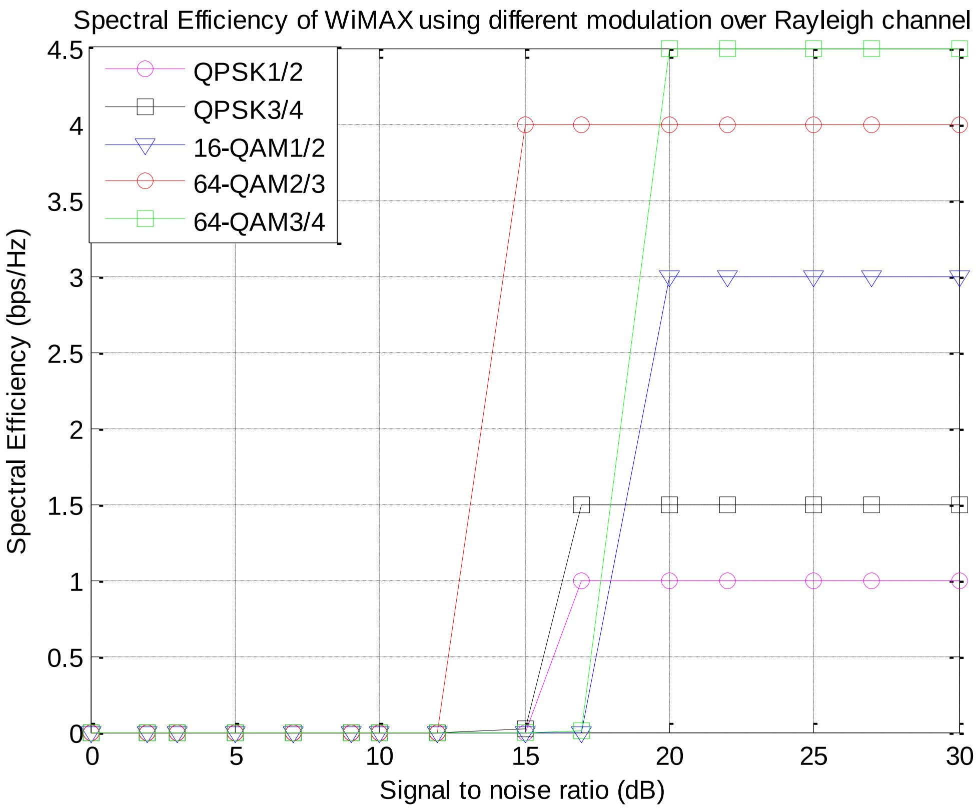

Figure 4.20 Spectral Efficiency of WiMAX over Rayleigh channel

SNR vs SE plots for OFDM based WiMAX physical layer over Rayleigh channel employing diverse modulations have been shown in Figure 4.20. The Table that outlines the Spectral Efficiency result of different modulations is given in Table 4.5.

Table 4.5 Spectral Efficiency of WiMAX over Rayleigh channel

Modulation	**QPSK**	**QPSK**	**16 QAM**	**64 QAM**	**64 QAM**
Code rate	**1/2**	**3/4**	**3/4**	**2/3**	**3/4**
SE	**1**	**2**	**3**	**4**	**4.5**
SNR(dB)	From 17 onwards	From 17 onwards	From 20 onwards	From 15 onwards	From 20 onwards

ISSN: 2278-0181

CHAPTER-V

CONCLUSION AND FUTURE SCOPE

5.1 Conclusion

The main purpose of this dissertation is the implementation of OFDM based WIMAX physical layer in order to access the performance of Physical layer of WiMAX under diverse channels. The actualized WiMAX Physical layer underpins all the modulation and coding techniques and furthermore CP that is characterized in the determination. The overall system performance is evaluated with concatenated Reed Solomon Convolutional encoder with diverse modulation techniques and CP under different channel conditions. After doing the simulation and evaluation of OFDM based WiMAX physical layer, following conclusions are drawn.

1. **On the premise of Spectral efficiency**: The simulation outcomes reveal that 64 QAM with code rate ¾ has higher spectral efficiency with strong SNR and QPSK with code rate ½ has lower spectral efficiency with poor SNR. This means that 64 QAM can be utilized for transmitting maximum amount of information with very few errors while transmission.
2. **On the premise of Bit Error rate:** Throughout all the simulation, 64 QAM with code rate 2/3 has lowest BER and QPSK with code rate ¾ has highest BER than other modulation techniques under AWGN channel and Rayleigh channel. The various modulation and coding techniques provide much better performance at CP 1/32 with less SNR (Signal to Noise ratio) as it is more immune to inter-symbol interference (ISI).

5.2 Future Scope

This standard accompanies numerous discretionary Physical layer highlights, which can be actualized to additionally magnify the performance of the system. The attempt can also be effectively reached out with Block Turbo coding to improve the performance. MIMO technology can also be utilized to analyze the performance of this system

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ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Website: www.ijareeie.com

Vol. 6, Issue 4, April 2017

Review on WiMAX

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ABSTRACT:Data-rate services, multimedia applications and, in general, high-quality information streams are now being demanded by a growing number of consumers. Wireless communications has extended their scope because they provide performance comparable to wired solutions but with less cost in infrastructure and network deployment procedures. WiMAX technology is considered as one of the most prominent solutions capable of providing wireless broadband access in metropolitan areas. In this paper, we give a review of WiMAX.

KEYWORDS: WIMAX, IEEE standards, WiMAX vs Wi-Fi, WIMAX transmitter and WIMAX receiver.

I.INTRODUCTION

WiMAX is short for Worldwide Interoperability for Microwave Access. It likewise passes by the IEEE name 802.16.WiMAX is a remote industry coalition committed to the progression of IEEE 802.16 standards for broadband wireless access networks. WiMAX is a technology for point to multipoint wireless networking which supports mobile, nomadic and fixed wireless applications. A mobile user typically refers to someone in transit and nomadic user refers to a portable device on which user is connected. A fixed wireless, in this context, refers to wireless connectivity among non-mobile devices in homes and businesses.

II.FEATURES

The features of WiMAX are as follow:

- **OFDM-based physical layer:** The WiMAX physical layer (PHY) is based on orthogonal frequency division multiplexing [4]. It offers good resistance to multipath, and allows WiMAX to operate in NLOS conditions.
- **Very high peak data rates:** WiMAX is capable of supporting very high peak data rates.
- **Scalable bandwidth and data rate support:** WiMAX has a scalable physical-layer architecture that allows for the data rate to scale easily with available channel bandwidth [4]. This scalability is supported in the OFDMA mode, where the FFT (fast fourier transform) size may be scaled based on the available channel bandwidth.
- **Adaptive modulation and coding (AMC):** WiMAX supports a number of modulation and forward error correction (FEC) coding schemes and allows the scheme to be changed on per user and per frame basis, based on channel conditions. AMC is an effective mechanism to maximize throughput in a time-varying channel.
- **Link-layer retransmissions**: WiMAX supports automatic retransmission requests (ARQ) at the link layer for connections that require enhanced reliability. WiMAX also optionally supports hybrid-ARQ which is an effective hybrid between FEC and ARQ.
- **Support for TDD and FDD:** IEEE 802.16-2004 and IEEE 802.16e-2005 supports both time division duplexing and frequency division duplexing, as well as a half-duplex FDD, which allows for a low-cost system implementation [2].
- **Orthogonal frequency division multiple access (OFDMA):** Mobile WiMAX uses OFDM as a multiple-access technique, whereby different users can be allocated different subsets of the OFDM tones [4].
- **Flexible and dynamic per user resource allocation:** Both uplink and downlink resource allocation are controlled by a scheduler in the base station. Capacity is shared among multiple users on a demand basis, using a burst TDM scheme [7].

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

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Vol. 6, Issue 4, April 2017

- **Support for advanced antenna techniques:** The WiMAX solution has a number of hooks built into the physical-layer design which allows for the use of multiple-antenna techniques, such as beamforming, space-time coding, and spatial multiplexing [4]. These schemes can be used to improve the overall system capacity and spectral efficiency by deploying multiple antennas at the transmitter and/or the receiver[2].
- **Quality-of-service support:** The WiMAX MAC layer has a connection-oriented architecture that is designed to support a variety of applications, including voice and multimedia services. The system offers support for constant bit rate, variable bit rate, real-time, and non-real-time traffic flows, in addition to best-effort data traffic [7]. WiMAX MAC is designed to support a large number of users, with multiple connections per terminal, each with its own QoS requirement.
- **Robust security:** WiMAX supports strong encryption and has a robust privacy and key-management protocol.
- **Support for mobility**: The mobile variant of the WiMAX supports roaming of mobile units within coverage area at high data rate speeds and without interruption in handovers [7].
- **IP-based architecture:** The WiMAX Forum has defined a reference network architecture that is based on an all-IP platform. [2]

III. COMPARISON OF WIMAX WITH WI-FI

It turns out to be completely expected to develop conventions and frameworks which could supports vast scale networking with high data speeds as wireless networking tends to spread itself outside workplaces and houses. A few innovations for such wide gets to have been in the correspondences market, for example, 2G, 3G and 4G. There are, be that as it may, numerous tradeoffs in utilizing these advances on a bigger premise, for example, giving web or stream interactive media remotely. This is the reason another convention, named WiMAX was incepted. It is same like an extended technological term to Wi-Fi, but there are a few contrasts between these two protocols. The differences between these two protocols are as follow:

- **Shortened Term: Wi-Fi** stands for Wireless Fidelity and on the other hand **WiMAX** stands for worldwide interoperability for Microwave Access.
- **Official Release:** Wi-Fi was official released in the year 1997 and on the other hand WiMAX released in the year 2004.
- **IEEE standards:** Wi-Fi has been defined under IEEE802.11x standards where x refers to the various versions of Wi-Fi such as 802.11a, 802.11b, 802.11g and 802.11n and WiMAX has been defined under 802.16y standards where y refers to the various versions of WiMAX such as 802.16a, 802.16d and 802.16e some of the popular WiMAX versions.
- **Frequency Band:** Wi-Fi has been characterized under ISM bands where client needs to pay no additional charging for using those bands. On the differentiation, there is no bar on frequency usage in the WiMAX.
- **Range:** Wi-Fi based network can reach upto 100 meters and on the other hand WiMAX can reach upto 80-90 Kilometers.
- **Data transfer rates:** Wi-Fi has a data transfer rate upto 54mbps and WiMAX has a data transfer rate upto 75mbps. In WiMAX, Data transfer rates have more variation as larger distances are to be covered. [3]
- **Channel bandwidth:** Wi-Fi have a channel bandwidth of 20 MHz whereas WiMAX have a channel bandwidth ranges from 1.25 MHz to 20 MHz
- **Bandwidth Efficiency:** Bandwidth Efficiency of WiMAX is twice as compare to Wi-Fi.
- **Encryption Techniques:** Wi-Fi uses Advanced Encryption standard(AES) and RC4 as encryption techniques whereas WiMAX uses Triple Data Encryption Algorithm and Advanced Encryption Standards.

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

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Vol. 6, Issue 4, April 2017

IV. IEEE802.16 Standards and Amendments

Although the original 802.16 standard along with amendments a, b and c are aloof now, there are as yet many reports that are being utilized for characterizing and developing the 802.16 standard. Asummary of the major documents, including those that have been withdrawn is given below:

Table 1. Summary of the IEEE 802.16 standards [1]

STANDARD / AMENDMENT	COMMENTS
802.16	Now withdrawn. This is the basic 802.16 standard that was released in 2001. It provided for basic high data links at frequencies between 11 and 60 GHz.
802.16a	Now withdrawn. This amendment addressed certain spectrum issues and enabled the standard to be used at frequencies below the 11 GHz minimum of the original standard.
802.16b	Now withdrawn. It increased the spectrum that was specified to include frequencies between 5 and 6 GHz while also providing for Quality of Service aspects.
802.16c	Now withdrawn. This amendment to 802.16 provided a system profile for operating between 10 and 66 GHz and provided more details for operations within this range. The aim was to enable greater levels of interoperability.
802.16d (802.16-2004)	This amendment was also known as 802.16-2004 in view of the fact that it was released in 2004. It was a major revision of the 802.16 standard and upon its release, all previous documents were withdrawn. The standard / amendment provided a number of fixes and improvements to 802.16a including the use of 256 carrier OFDM. Profiles for compliance testing are also provided, and the standard was aligned with the ETSI HiperMAN standard to allow for global deployment. The standard only addressed fixed operation.
802.16e (802.16-2005)	This standard, also known as 802.16-2005 in view of its release date, provided for nomadic and mobile use. With lower data rates of 15 Mbps against to 70 Mbps of 802.16d, it enabled full nomadic and mobile use including handover.
802.16f	Management information base
802.16g	Management plane procedures and services
802.16h	Improved coexistence mechanisms for license-exempt operation
802.16j	Multi-hop relay specification
802.16k	802.16 bridging
802.16m	Advanced air interface. This amendment is looking toth e future and it is anticipated it will provide data rates of 100 Mbps for mobile applications and 1 Gbps for fixed applications. It will allow cellular, macro and micro cell coverage, with currently there are no restrictions on the RF bandwidth although it is expected to be 20 MHz or more.

V. BLOCK DIAGRAM OF WIMAX SYSTEM

The block description of WiMAX physical layer is very diverse which consists of various blocks, works in conjunction with each other. The WiMAX is divided into two parts: the WiMAX transmitter and WiMAX receiver. The block diagram of WiMAX physical layer is as:

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Website: www.ijareeie.com

Vol. 6, Issue 4, April 2017

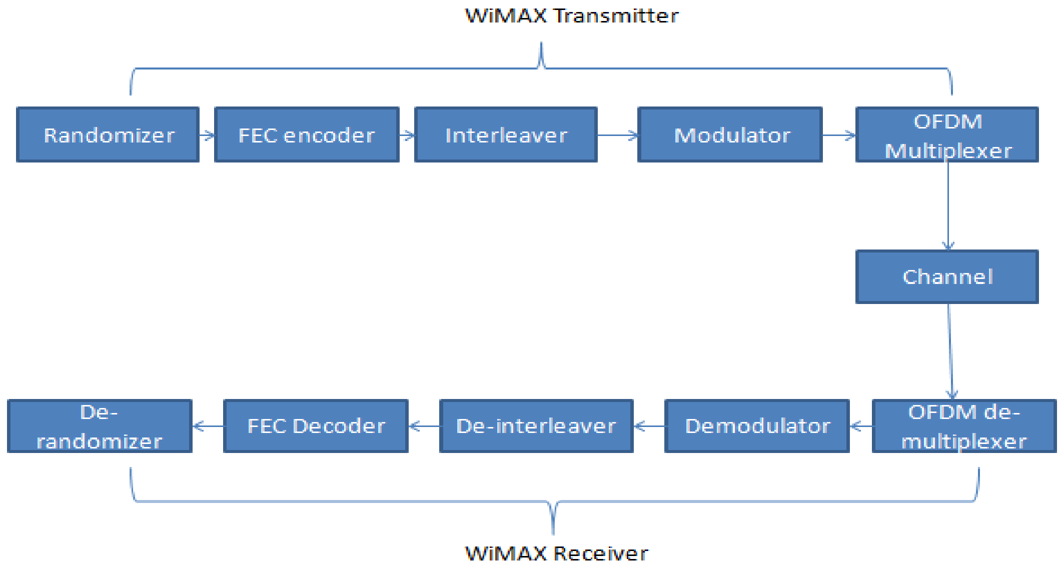

Figure 1. Block Diagram of WiMAX system

❖ **WiMAX Transmitter:**

1. **Randomizer:** Randomizer is the first block of WiMAX transmitter section where data from the source is randomized. Randomization is done to avoid long sequences of consecutive "ones" or "zeros". The randomized data are arranged in block format before passing through the encoder.The randomizer block consists of an XOR operation of the data to be randomized with a pseudo random sequence, generated by a Pseudo Random Binary Sequence (PRBS) generator [5]. The PRBS generator is reinitialized for each FEC block.Some common sequence generating polynomials are:

PRBS7 = $x^7 + x^6 + 1$

PRBS15 = $x^{15} + x^{14} + 1$

PRBS23 = $x^{23} + x^{18} + 1$

PRBS31 = $x^{31} + x^{28} + 1$

The 15 stage shift register with generator polynomial of $X^{15}+X^{14}+1$with XOR gates in feedback configuration is shown in figure as

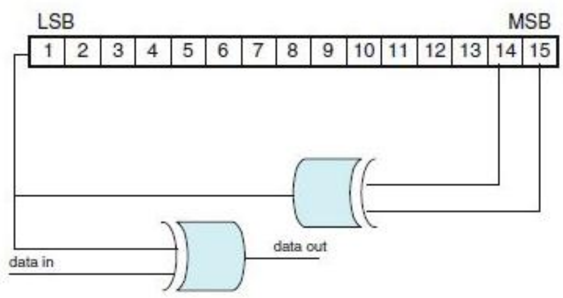

Figure 2. PRBS generator

2. **FEC Encoder:**This is the most important block of WiMAX physical layer. The function of the FEC Encoder is to add redundancy in a controlled manner. This will improve the reliability of data[1].

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

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Vol. 6, Issue 4, April 2017

Table 2.WiMAX Adaptive coding [2]

Parameter	Downlink	Uplink
Coding	Mandatory: Convolutional codes at rate 1/2, 2/3, 3/4, 5/6 Optional: Convolutional turbo codes at rate 1/2, 2/3, 3/4, 5/6;repetition codes at rate 1/2, 1/3, 1/6, LDPC, RS codes for OFDM-PHY	Mandatory: Convolutional codes at rate 1/2, 2/3, 3/4, 5/6 Optional: Convolutional turbo codes at rate 1/2, 2/3, 3/4, 5/6;repetition codes at rate 1/2, 1/3, 1/6, LDPC

3. **Interleaver:** Interleaving is done on encoded data at the output of FEC encoder. Interleaver is used to overcome very long sequences of errors or burst errors. The size of interleaving block depends upon the number of coded bits per encoded block size. The interleaving is performed using a two-step permutation process. In first permutation, the adjacent coded bits are mapped onto nonadjacent subcarriers[6] and is defined by the formula:

$$mk = (Ncbps/12)*\text{mod}(K, 12) + \text{floor}(K/12)$$

where mk= Index of coded bits after first permutation

Ncbps= number of coded bits per symbols

K= Index of coded bits before first permutation

In second permutation, the adjacent coded bits are mapped alternately onto less or more significant bits of the constellation [6]. It is defined by the formula as:

$$s=\text{ceil}(Ncpc/2)$$

$$jk = s*\text{floor}(mk/s)+(mk+Ncbps-\text{floor}(12*mk/Ncbps))\text{mod}(s)$$

where Ncpc= number of coded bits per carrier

jk= Index of coded bits after second permutation

4. **Modulator:** The next block is modulator after interleaver. WiMAX uses adaptive modulation where modulation changes depending upon the channel conditions [1].

Table 3. WiMAX Adaptive Modulation[2]

Parameter	Downlink	Uplink
Modulation	BPSK,QPSK,16-QAM,BPSK optional for OFDMA-PHY	BPSK,QPSK,16 QAM,64 QAM optional

5. **OFDM Multiplexer:**OFDM stands for orthogonal frequency division multiplexing. In this block, the modulated data which is in frequency domain is then converted into time domain by performing IFFT or IDFT on it. Cyclic prefix has been added with the time domain data to reduce inter-symbol interference (ISI). These time domain signals are then transmitted through the channel.

- **Channel:** Channel is the transmission medium over which the signal is transmitted.Air is the transmission medium for wireless communication. Different channels can be used in WiMAX physical layer like AWGN, Rayleigh fading channel, Rician fading channel,SUI or Nakagami channel.
- **WiMAX Receiver:**

1. **OFDM De-multiplexer:**At the receiver side**,** cyclic prefix which is added at the transmitter for reducing ISI is removed.The received signal is converted into frequency domain using FFT or DFT algorithm. As OFDM symbol consists of data, pilots and a zero DC subcarrier with guard bands. Pilot carriers and data values are extracted over here.

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Website: www.ijareeie.com

Vol. 6, Issue 4, April 2017

2. **Demodulation:** This block is used to demodulate the signal waveform to digital data.
3. **De-interleaver:** This block is used to undo the changes done by interleaver and retrieve the actual information.
4. **FEC Decoder:** The redundancy that is added at the transmitter side is removed in this block. This redundancy is examined to see if there are any errors
5. **De-randomizer:** De-randomizer does the inverse process of randomizer to nullify the effect of randomizer.
6.

VI. APPLICATIONS

A WiMAX system has been utilized as a part of different Fields such as:

- **Home and broadband internet access:** The internet provided by the WiMAX can be well utilized in rural area where DSL and any wired internets devices are not available [8].The utilization of WiMAX Internet technology is to convey unwavering quality to clients, since it is basically remote, did not utilize its conspicuous media.
- **Medium and small business:** WiMAX is more suitable to address the issues of little and medium-sized business particularly in low-density zones. High-density zones will most likely be unable to completely understand it's potential. It has ghastly restrictions.There may not be sufficient data transfer capacity to give access to vast customers in high thickness zones. This may expand costs [8].
- **Backhaul networks for cellular base stations:**Strong WiMAX technology can turn into the main decision for big business backhaul, for example, hot spots and point to point backhaul access solutions
- **Wi-Fi Hotspots:** This permits users to remotely get to the Internet through wandering outer workplaces and homes [7]. There are a few hotspots and WiMAX backhaul offerings for wireless networking wireless solutions.

VII.CONCLUSION

In this paper, authors have presented a brief overview of WiMAX networks. WiMAX have many features and applications as discussed in this paper. Difference between Wi-Fi and WiMAX are discussed along with the model description of WiMAX physical layer.

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Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 06, June - 2017

Spectral Efficiency & Bit Error Rate Analysis of WiMAX over AWGN Channel

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***Abstract*—WiMAX is the shortened form of Worldwide Interoperability for Microwave Access. WiMAX is one of the most blazing broadband wireless technologies around the world. It picked up popularity in light of its efficiency, high coverage, scalability and high data rate in any field. The WiMAX is based on the Orthogonal Frequency Division Multiplexing (OFDM) transmission technique which is known for its high radio resource use efficiency. In this paper, the performance of WiMAX system has been investigated by analysing the graphs between Spectral Efficiency (SE) vs. Signal to Noise Ratio (SNR) and Bit Error Rate (BER) vs. Signal to Noise Ratio (SNR) for different modulation schemes over AWGN channel. The BER and Spectral efficiency of OFDM based WiMAX is also evaluated under different Guard time intervals as it minimizes the inter-symbol interference which in return improves the bit error rate and reduces the power spectrum. The parameters that are used in this paper are based on IEEE 802.16 standards.**

Keywords--- WiMAX, RS-CC, OFDM, BER, Spectral Efficiency, AWGN.

I. INTRODUCTION

WiMAX is short form of Worldwide Interoperability for Microwave Access which is also known by name IEEE 802.16.The IEEE 802.16 working group create standards which addresses two models. Two models are fixed usage model and mobile usage model. Fixed is standardized as IEEE 802.16d or IEEE 802.16 -2004 in view of the fact that it was released in 2004 and mobile is standardized as IEEE802.16e or IEEE 802.16-2005 in view of the fact that it was released in 2005. WiMAX provides two types of wireless services that is Non-line of sight (NLOS) and Line of sight (LOS) services. In NLOS, WiMAX uses 2 to 11 GHz frequency and in LOS, frequency ranges from 10-66GHz. The physical layer of WiMAX depends on orthogonal frequency division multiplexing that enables WiMAX to work in NLOS conditions. It bolsters very high peak data rate upto 74 Mbps based on the spectrum used in the system. Depending on the channel conditions or per user and per frame basis, different types of modulation and forward error correction coding schemes can be used in WiMAX. BPSK, QPSK, 16-QAM and 64 QAM modulation schemes can be used in both uplink and downlink whereas 64-QAM is discretionary in the uplink.

II. DESCRIPTION OF WIMAX SYSTEM

WiMAX is the most well-known broadband wireless access (BWA) technology utilized for wireless metropolitan area networks (WMANs). It comprises of different blocks that work in conjunction with each other. The three main blocks of WiMAX Physical layer are transmitter, receiver and channel. Transmitter block consists of randomizer, FEC encoder, interleaver, modulator and OFDM multiplexer. Receiver block consists of De-randomizer, FEC decoder, De-interleaver, Demodulator and OFDM De-multiplexer. Channel is the medium that is used for transmitting the signal from transmitter to receiver. In this paper, AWGN (Additive White Gaussian Noise) is used as a channel for transmission. The block diagram of WiMAX physical layer is shown in Fig. 1.

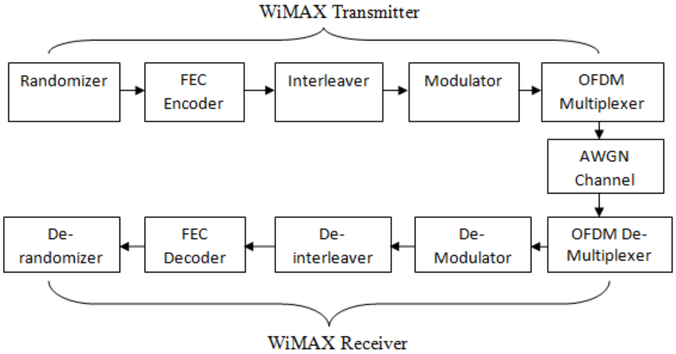

Fig. 1.Block diagram of WiMAX physical layer

A. Transmitter

Transmitter of WiMAX physical layer consists of randomizer, FEC encoder, interleaver, modulator and OFDM multiplexer. The function of randomizer is to subjectively change the arrangement of data which is done with the help of Pseudo Random Binary Sequence (PRBS) generator. PRBS generator consists of shift registers whose input bit is driven by the Exclusive-OR of some bits of the overall shift register value. In this paper, 15-stage shift register is used with generator polynomial of $X^{15}+X^{14}+1$ along with Exclusive-OR gate in the feedback configuration shown in Fig. 2.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 06, June - 2017

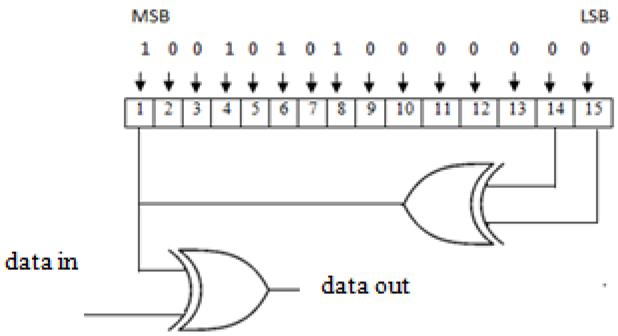

Fig. 2. Pseudo Random Sequence Generator

FEC encoder is error detection and error correction block that adds redundancy in a controlled way to increase the reliability of data. The FEC encoding process is shown in Fig.3.

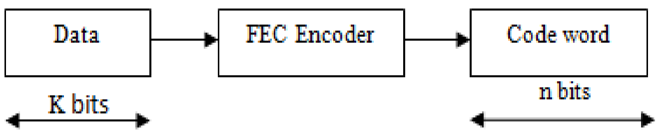

Fig. 3. .FEC encoding process

In this paper, Concatenated RS-CC (Reed Solomon-Convolutional code) encoder is used where Reed Solomon (RS) is the outer code and Convolutional code (CC) is the inner code shown in Fig.4.

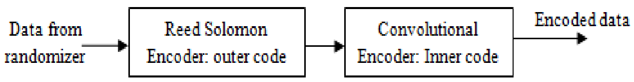

Fig. 4. Concatenated RS-CC Encoder

Interleaving is done on the encoded bits after channel coding to get over long sequences of random errors or burst errors. Interleaving is implemented using a two-step permutation process where the adjacent coded bits are mapped onto non-adjacent subcarriers in first permutation and the adjacent coded bits are mapped alternately onto less or more significant bits of the constellation in second permutation [1]. Modulation is the process toward superimposing the information contents of a modulating signal on a high frequency signal by changing the characteristic of high frequency signal according to the modulating signal .WiMAX has included advantage that we can utilize diverse order of modulation schemes. This is called as adaptive modulation where modulation changes relying on the channel condition. In this paper, we have used BPSK, QPSK, 16-QAM and 64 QAM. OFDM multiplexer is utilizing for orthogonal frequency division multiplexing that integrate between the modulator and the channel. The function of OFDM multiplexer is to separate carriers into sub-carriers which are orthogonal to each other with the goal that they don't cause inter-symbol interference (ISI). It is executed by utilizing IDFT (Inverse Discrete Fourier Transform) or IFFT (Inverse Fast Fourier Transform) at the transmitter. Guard intervals are also utilized between OFDM symbols with a specific end goal to wipe out ISI.

B. Channel

A communication channel or simply channel alludes to physical transmission medium imparting information from one location to another. In this paper, AWGN (additive White Gaussian noise) channel is used which adds white noise to the signal that is transmitted through it. Mathematically, AWGN channel is represented as

$$r(t) = s(t) + n(t) \qquad (1)$$

Where r (t) is the received signal,
s (t) is the transmitted signal and
n (t) is the background noise as shown in Fig.5.

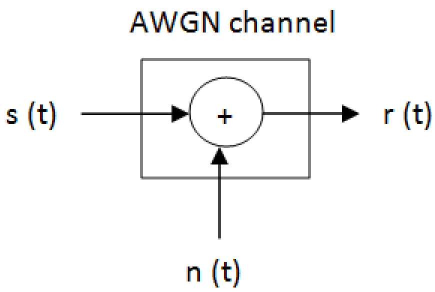

Fig. 5. AWGN channel model

C. Receiver

The blocks on the recipient side are the inverse blocks of those on the transmitter side. The blocks do precisely the reverse process of what is done by each blocks of the transmitter. The receiver of WiMAX physical layer consists of OFDM de-multiplexer, de-modulator, de-interleaver, FEC decoder, and de-randomizer. OFDM de-multiplexer is used for removing cyclic prefix as well as for converting the sub-channels into wideband channels by applying FFT (Fast Fourier Transform) or DFT (Discrete Fourier Transform) on the receiver side [2]. The signal from OFDM de-multiplexer is demodulated to digital form by demodulator. De-interleaver is used to undo the changes done by interleaver. FEC decoder is utilized to evacuate the redundancies that are added at the transmitter. It also detects the errors and corrects them to get the original data that was transmitted. The FEC decoding process is shown in Fig. 6.

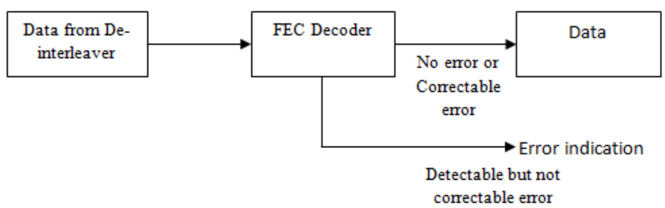

Fig. 6. FEC decoding process

The scrambled data is now descrambled by de-randomizer to get the same message as was delivered to the destination.

III. RELATED WORK

khan et al. (2008) discusses the model building of the WiMAX Physical layer using Simulink in MATLAB. The model presented in this paper was processed by the Physical Layer using Convolutional Encoding Rate of 5/6 with QPSK modulation and transmitted with 256 carrier OFDM symbols [3]. O.Arafat et al. (2010) analysed the performance of physical layer of mobile WiMAX under SUI channel [4]. The results of simulation show that coding rate and modulation techniques had more prominent effect on the relative performance between the distinctive channel conditions. M.A. Mohamed et al. (2010) analysed the WiMAX physical layer under different combinations of digital modulation schemes and different communication channels [5]. The performance of the simulated system was evaluated using the bit-error-rate (BER). This paper concluded that when channel conditions are poor, energy efficient schemes such as BPSK or QPSK were used and when channel quality improves, higher M-ary modulation schemes such as 16-QAM or 64-QAM was used. A.R.Shankar et al. (2010) emphasis on the comparison of quality of service parameters between different channels in WiMAX physical Layer on the basis of Bit Error Rate, Signal to Noise Ratio, Power Spectral Density and Probability of Error [6]. He stated that as the probability of BER, Theoretical Values of BER, and Probability of Error decrease as SNR increases more in Rician channel compared to Rayleigh channel in PURE AWGN. BPSK has the lowest BER while 64-QAM has highest BER than others. Z.T. Sharef et al. (2012) analysed the performance of physical layer of WiMAX over AWGN and Rayleigh fading channel. The performance of QPSK modulation technique is evaluated and compared on the basis of bit error rate (BER) vs. bit energy-to-noise density ratio (E_b/N_o) curve [7]. The result of simulation shows that the performance of the system can be improved by utilizing channel estimator. H.Kaur et al. (2013) analysed the bit error rate for WiMAX based COFDM (Coded orthogonal frequency division multiplexing access) system with BPSK modulation technique under various channel conditions like AWGN, Rayleigh, Rician and Nakagami [8]. The results show that performance of Nakagami fading channel is better than other fading channels. D.R. Selvarani et al. (2014) provide an overview of Wi-Fi and WiMAX which includes the features, Specifications, architecture, advantages, limitations and security. WiMAX and Wi-Fi was compared and it is recommended that when Wi-Fi is synergized with WiMAX, it will give the best answer for last mile scope [9]. Ahmed et al. (2014) verified the performance of WiMAX system under various channels and number of modulation schemes on the basis of SNR and BER graph. The results state that WiMAX system works well in both AWGN and multipath fading channel [10]. A. Al-Kandari et al. (2014) discussed the capacity, efficiency, complexity and coverage features of WiMAX (Worldwide Interoperability for Microwave Access) and LTE (Long Term Evolution) with their advantages and disadvantages. M. Joshi et al. (2015) analysed the WiMAX system under distinctive channels like Rayleigh, Rician, Nakagami and Lognormal shadowing channel with different modulation techniques on the basis of bit error rate (BER).This paper concludes that Nakagami channel provide better performance using different modulation techniques at higher SNR. Y.M. Al-Moliki et al. (2015) compared the Concatenated Reed Solomon and Convolutional (RSCC) codes with Reed Solomon (RS) codes without concatenation [13]. The Simulation results show that the performance of concatenated RS-CC code is better and robust as compared to RS code without concatenation in terms of BER with various SNR. R.Pornima et al (2015) analysed the higher order modulation techniques like 16-QAM and 64-QAM for mobile WiMAX in OFDMA [14]. U.R.Mori et al (2015) compared the features of two advance technologies in physical layer and also gives performance analysis of different modulation schemes (BPSK, QPSK, and 16-QAM) in WiMAX & LTE technologies [15]. M.L.Singh et al (2016) analysed in terms of BER for ITU-R and Cost-207 channel model conditions for Typical Urban Area and Typical Rural Area. K.S.Pooja et al. (2016) concluded that the single convolutional coding and dual interleaving plays out the best under all ranges of Signal to Noise Ratio.

IV. RESULTS AND DISCUSSION

A. Simulation Parameters

The simulated modulation and coding used in this paper is shown in Table 1.

Table 1. Mandatory channel coding per modulation

Modulation	Overall coding rate	RS code	CC code rate
BPSK	½	(12,12,0)	1/2
QPSK	½	(32,24,4)	2/3
QPSK	¾	(40,36,2)	5/6
16-QAM	¾	(80,72,4)	5/6
64-QAM	2/3	(108,96,6)	3/4
64-QAM	¾	(120,108,6)	5/6

The OFDM parameters both primitive and derived that characterize OFDM symbol completely in WiMAX are listed in Table 2.

Table 2. OFDM parameters used in WiMAX

Parameters	Value	Description
BW	1.25,5,10,20	Bandwidth
N_{used}	72, 360,720,1440	used subcarriers
n	8/7, 28/25	Sampling factor
N_{fft}	128,512,1024,2048	FFT size
G	1/4, 1/8, 1/16, 1/32	Guard time ratio
F_s	Floor(n*BW/8000)*8000	Sampling frequency
Δf	F_s / N_{fft}	Frequency spacing
T_b	1/ Δf	Useful symbol time

The spectral efficiency of WiMAX based on diverse modulation techniques and code rates are listed in Table 3.

Table 3. Spectral efficiency of WiMAX

Modulation and code rate	Maximum Spectral Efficiency(bps/Hz)
BPSK R1/2	0.5
QPSK R1/2	1.0
QPSK R3/4	2.0
16 QAM R3/4	3.0
64 QAM R2/3	4.0
64 QAM R3/4	4.5

B. Simulation Results

The simulation results consist of BER vs. SNR graph and Spectral Efficiency vs. SNR graph of WiMAX system over AWGN channel with diverse modulation schemes and Guard time intervals. The performance of a WiMAX system over AWGN channel using BPSK, QPSK, 16-QAM and 64-QAM is shown in Fig.7 to Fig. 17.

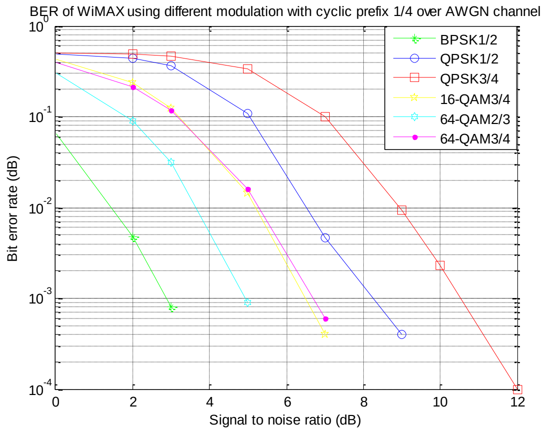

Fig. 7. BER of WiMAX using diverse modulations with cyclic prefix 1/4

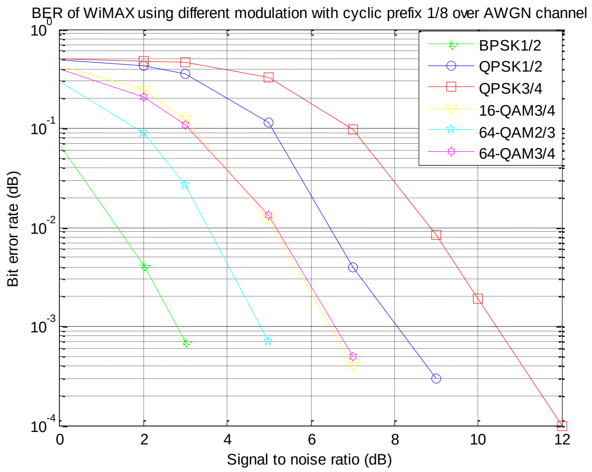

Fig. 8. BER of WiMAX using diverse modulations with cyclic prefix 1/8

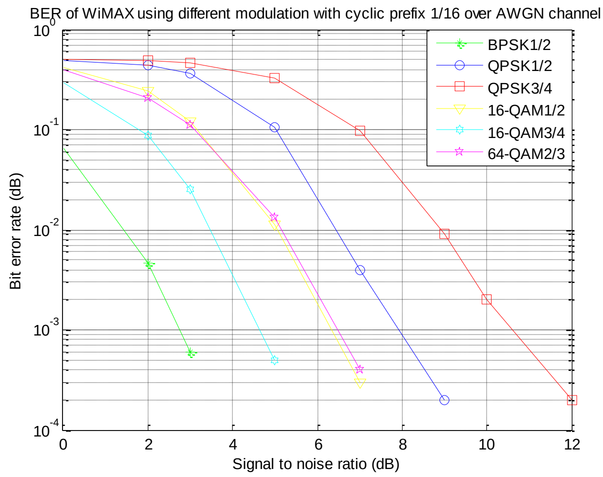

Fig. 9. BER of WiMAX using diverse modulations with cyclic prefix 1/16

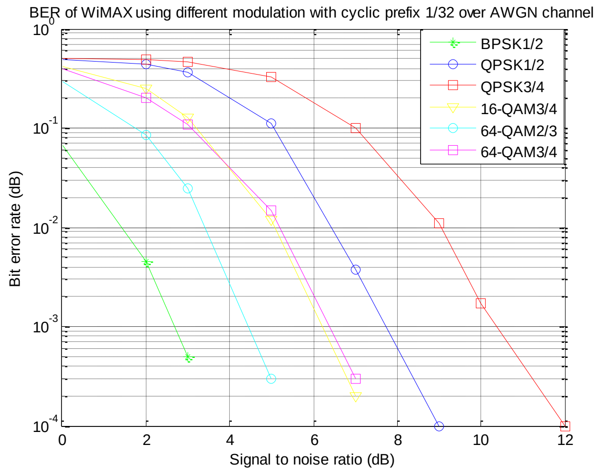

Fig. 10. BER of WiMAX using diverse modulations with cyclic prefix 1/32

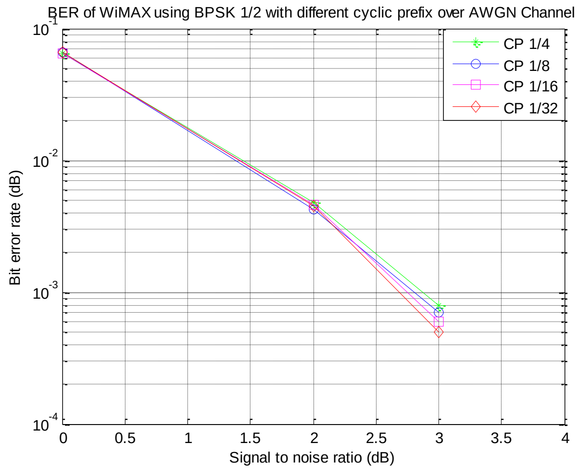

Fig. 11.BER of WiMAX using BPSK ½

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 06, June - 2017

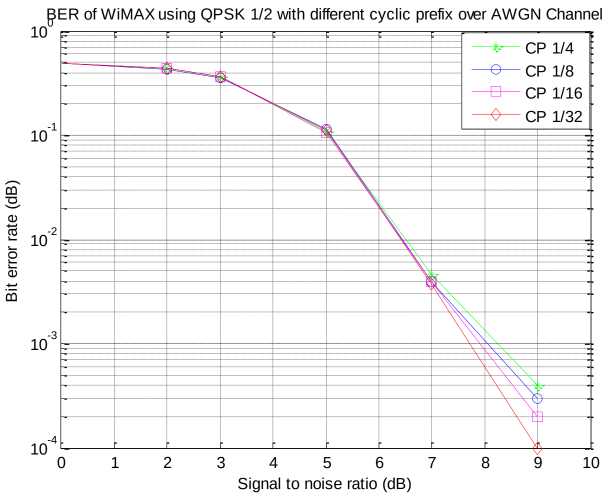

Fig. 12. BER of WiMAX using QPSK ½

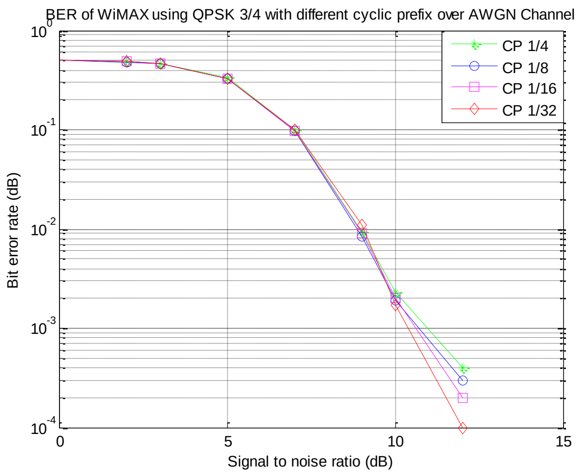

Fig. 13.BER of WiMAX using QPSK ¾

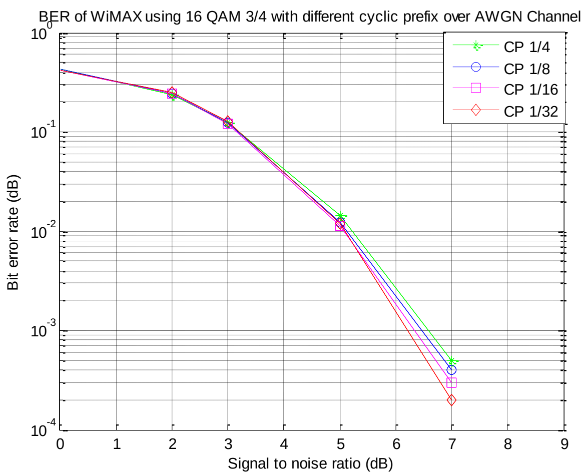

Fig. 14. BER of WiMAX using 16 QAM ¾

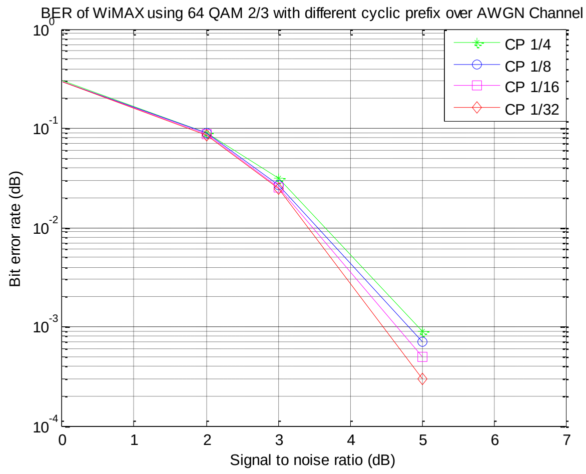

Fig. 15. BER of WiMAX using 64 QAM 2/3

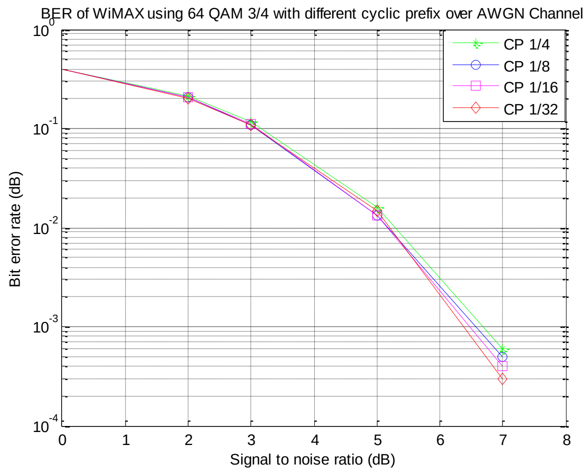

Fig. 16. BER of WiMAX using 64 QAM ¾

Table 4.SNR requirement in WiMAX for diverse modulation techniques

Cyclic prefix	SNR(dB) required to achieve a BER of 10^{-3}					
	Modulation					
	BPSK ½	QPSK ½	QPSK ¾	16 QAM ¾	64 QAM 2/3	64 QAM ¾
1/4	2.87	8.25	10.95	6.58	4.94	6.69
1/8	2.80	8.07	10.69	6.46	4.80	6.57
1/16	2.74	7.91	10.60	6.33	4.64	6.47
1/32	2.68	7.72	10.37	6.21	4.45	6.38

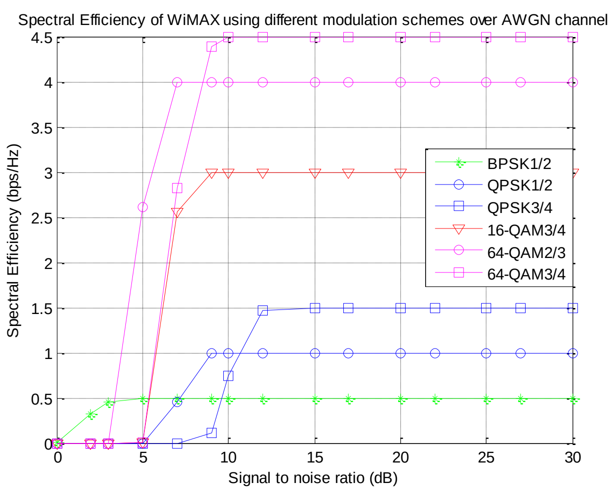

Fig. 17. Spectral Efficiency of WiMAX using diverse modulation scheme

V. CONCLUSION

In this paper, we have analysed the bit error rate and spectral efficiency of OFDM based WiMAX physical layer using different modulation schemes and guard time intervals over AWGN channel. We can conclude that the outcomes are distinctive by using different modulation techniques in WiMAX. Amid all the simulations, BPSK R1/2 has the most reduced BER and QPSK R3/4 has the most elevated BER than other modulation techniques so BPSK R1/2 is more power efficient thus require less bandwidth. The outcomes also uncover that the different modulations and coding rate give better execution with less SNR at guard time interval 1/32. The simulation outcomes of spectral efficiency reveals that 64 QAM R3/4 has the highest spectral efficiency and BPSK R1/2 has the lowest spectral efficiency so 64 QAM R3/4 can be used for transmitting maximum amount of information with lesser transmission error.

Table 5 . Spectral Efficiency of WiMAX using diverse modulation schemes

Spectral Efficiency						
Modulation	BPSK	QPSK	QPSK	16 QAM	64 QAM	64 QAM
Code rate	1/2	1/2	3/4	3/4	2/3	3/4
Bits/Symbol	1	2	2	4	6	6
Spectral Efficiency	0.5	1	2	3	4	4.5
SNR(dB)	From 5 onwards	From 9 onwards	From 15 onwards	From 9 onwards	From 7 onwards	From 10 onwards

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Bindu Handa. Int. Journal of Engineering Research and Application *www.ijera.com*
ISSN : 2248-9622, Vol. 7, Issue 7, (Part -8) July 2017, pp.06-13

RESEARCH ARTICLE OPEN ACCESS

Spectral Efficiency and Bit Error Rate Analysis of WiMAX Using Diverse Modulation Techniques over Rayleigh Channel

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ABSTRACT
Worldwide Interoperability for Microwave Access (WiMAX) is a popular wireless technology which offers fast voice, video and information benefits up to the client end. In this paper, the OFDM based WiMAX physical layer makes use of concatenated Reed Solomon Convolutional (RS-CC) code and different modulation techniques with different code rates along with different cyclic prefix. As WiMAX can be used for NLOS (Non - Line of Sight) communication so Rayleigh channel has been used as transmission medium. The comparison of various cyclic prefix such as 1/4, 1/8, 1/16 and 1/32 has been done on different modulation techniques over Rayleigh channel. The performance of OFDM based WiMAX physical layer has been analyzed from the graphs between BER (Bit Error rate) vs. SNR (Signal to Noise Ratio) and Spectral Efficiency vs. SNR (Signal to Noise Ratio) for different modulation techniques. The simulation results of BER vs. SNR conclude that different modulations and code rate provide better performance at guard time interval of 1/32.The simulation result of Spectral efficiency vs SNR conclude that 64 QAM with code rate ¾ has highest spectral efficiency because of which it can be used for transmitting larger amount of data with lesser amount of transmission error.
Keywords: AWGN, BER, Rayleigh, Spectral efficiency, WiMAX

Date of Submission: 11 -07-2017 Date of acceptance: 20-07-2017

I. INTRODUCTION

WiMAX is shortened form of Worldwide Interoperability for Microwave Access. It is also known by name IEEE 802.16. WiMAX depends on wireless metropolitan area networking (WMAN) standards created by the IEEE 802.16 group embraced by both IEEE and the ETSI HIPERMAN group [1]. The IEEE 802.16 group was shaped in 1998 to build up an air-interface standard for remote broadband. The physical layer of WiMAX relies on orthogonal frequency division multiplexing which allow WiMAX to works in NLOS state. It supports high peak data rate with scalable bandwidth, TDD (Time Division duplexing), FDD (Frequency Division duplexing) and advanced antenna techniques. The WiMAX takes full favorable position of link adaption technique along with coding.

II. BLOCK DIAGRAM OF WIMAX

The Block diagram of OFDM based WiMAX physical layer comprises of different blocks that plays an important role. The modulation and OFDM multiplexer are the important building blocks of the WiMAX Physical layer. The block diagram of WiMAX physical layer is shown in Fig.1.

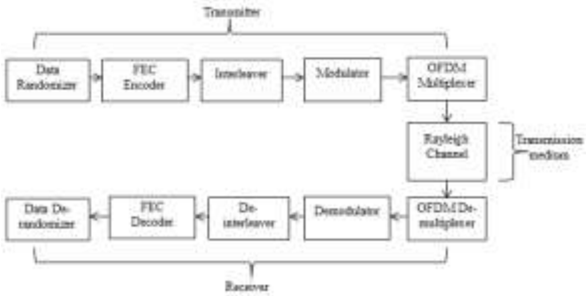

Fig. 1 Block diagram of physical layer of WiMAX

2.1 Randomizer and De-Randomizer

Randomization provides security by removing long arrangements of successive ones or sequential zeros. Data randomization is carried out on both uplink and downlink burst of data [1]. If the measure of data that is to be transmitted does not fit precisely with the measure of data apportioned, then cushioning of 0_FF is added to the end of the transmission block. For data randomization in WiMAX, Pseudo Random binary Sequence generator is used with 15-bits feedback polynomial $X^{15}+X^{14}+1$ which produces pseudo-noise sequence of length $32767(2^{15}-1)$. The Pseudo Random binary Sequence generator is shown in Fig. 2.

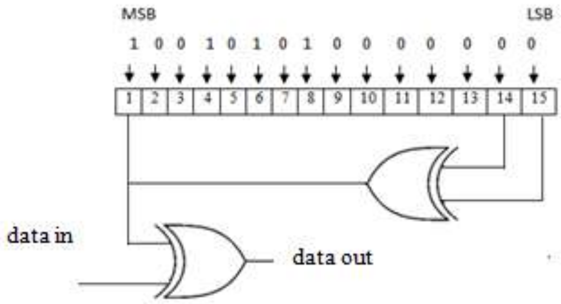

Fig. 2 Data randomizer

2.2 FEC Encoder and FEC Decoder

FEC stands for forward error correction. FEC encoder is used for adding redundancy in a controlled way which will enhance the reliability of data [1] at the transmitter. In OFDM based WiMAX physical layer, Concatenated Reed–Solomon Convolutional Code (RS-CC) is used and is required on both the downlink and uplink. Reed Solomon code act as outer code and Convolutional code act as inner code as shown in Fig.3.

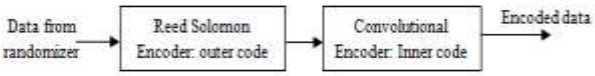

Fig. 3 Concatenated RS-CC Encoder

The encoding process is performed by first passing the data in the form of block through the RS (Reed Solomon) encoder and then passing it through a CC (convolutional) encoder. A single 0x00 tail byte is annexed to the end of each burst. After randomization, this tail byte is done. In the Reed Solomon encoder, the repetition bits are transmitted before the input bits, keeping the 0x00 tail byte toward the end of the allotment. When the aggregate number of data bits in a burst is not an integer number of bytes, zero pad bits are included after the zero tail bits. These zero pad bits are not randomized. The Reed Solomon–Convolutional Code encoding process is illustrated in Fig.4. Keeping in mind the end goal to accomplish code rates higher than 1/2, the yield of the encoder is punctured utilizing puncturing pattern as shown in Table 1. FEC decoder is used to diminish the redundancy that is included at the transmitter. This redundancy is investigated to see if there are any errors.

2.3 Interleaver and De-interleaver

Interleaver is used to permute the encoded data which is the output of FEC encoder. It is utilized to conquer very long successions of errors. The span of interleaving block relies on the number of coded bits per encoded block size. The interleaving process is done utilizing a two-stage permutation process.

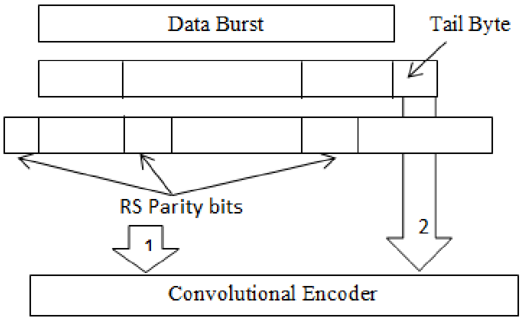

Fig. 4 RS-CC encoding process

Table 1 . Puncturing configuration of CC code

Rate	d_{free}	$X_{O/P}$	$Y_{O/P}$	XY (Punctured O/P)
1/2	10	1	1	X_1Y_1
2/3	6	10	11	$X_1Y_1Y_2$
3/4	5	101	110	$X_1Y_1Y_2X_3$
5/6	4	10101	11010	$X_1Y_1Y_2X_3Y_4X_5$

In first permutation, the adjacent coded bits are mapped onto nonadjacent subcarriers and are characterized by the following equation 1:

$$m_k = (N_{cbps}/12) \times \text{mod}(K, 12) + \text{floor}(K / 12) \quad (1)$$

where 'm_k' is the Index of coded bits after first permutation, 'N_{cbps}' is the number of coded bits per symbol and 'K' is the Index of coded bits before first permutation.

The adjacent coded bits are mapped alternately onto less or more significant bits of the constellation in second permutation. It is characterized by the equation 2 and equation 3:

$$s = \text{ceil}(N_{cpc} / 2) \quad (2)$$

$$j_k = s \times \text{floor}(m_k/s) + (m_k + N_{cbps} - \text{floor}(12 \times m_k / N_{cbps}))\ \text{mod}(s) \quad (3)$$

where 'Ncpc' is the number of coded bits per carrier, 'j_k' is the Index of coded bits after second permutation.

De-interleaver is utilized to undo the changes done by interleaver at the transmitter side to retrieve the actual information.

2.4 Modulator and Demodulator

After interleaving, the next block of WiMAX physical layer is modulator. WiMAX utilizes adaptive modulation where modulation changes relying on the conditions of channel. Demodulation block at the receiver side is used to demodulate the signal waveform back to digital data.

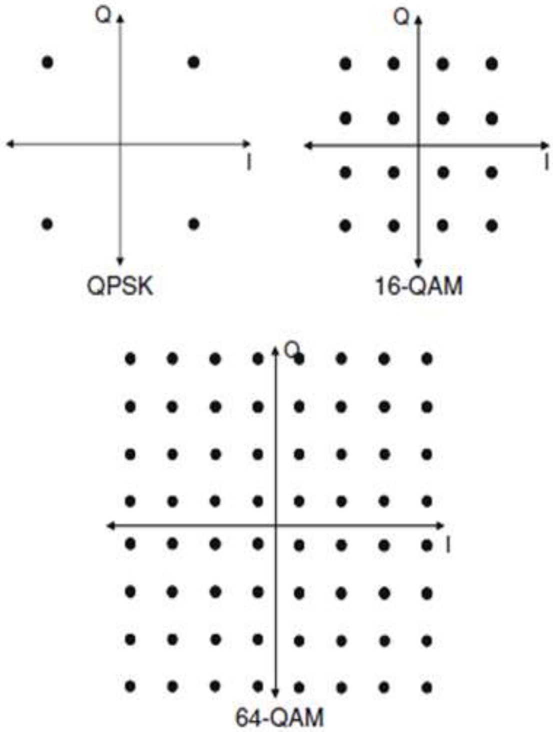

Fig. 5 QPSK, 16 QAM and 64 QAM constellations

2.5 OFDM multiplexer and De-multiplexer

OFDM is short for orthogonal frequency division multiplexing. Here, the modulated data is converted into time domain from frequency domain. This is done by employing IFFT (Inverse Fast Fourier Transform or IDFT (Inverse Discrete Fourier Transform). Also cyclic prefix has been included with the time domain data to diminish inter-symbol interference (ISI). There are four different duration of cyclic prefix that are available in the standard. The different cyclic prefix are 1/4, 1/8, 1/6 and 1/32. Then it is transmitted through the channel. OFDM de-multiplexer evacuates cyclic prefix which is included at the transmitter for reducing Inter-symbol interference. The received signal is changed into frequency domain utilizing FFT (Fast Fourier Transform) or DFT (Discrete Fourier Transform) algorithm. As OFDM symbol comprises of data, pilots and a zero DC subcarrier with guard bands. Pilot carriers and data values are extricated at the receiver side.

2.6 Channel

A channel or physical medium is the transmission way over which a signal proliferates. Numerous transmission media are utilized as communications channel. Transmission media are categorized as guided media and unguided media. The channel used in this paper is Rayleigh fading channel. Rayleigh channel is a multipath fading channel where there is huge number of reflection present. Mathematically, Rayleigh fading channel is represented as:

$$r(t) = s(t) \times h(t) + n(t) \qquad (4)$$

where r (t) is the received signal, s (t) is the transmitted signal, h (t) is the random channel matrix and n (t) is the background noise as shown in Fig.6.

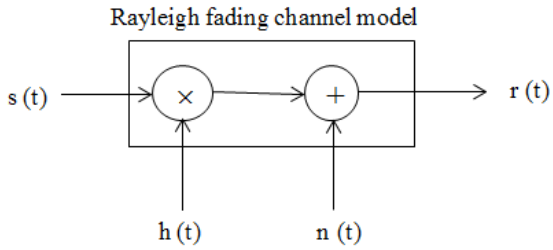

Fig. 6 Rayleigh channel model

III. RELATED WORK

Mondal et al. (2009) [3] evaluates the performance of a WiMAX system under different digital modulation (BPSK, QPSK, 4-QAM and 16-QAM) and different communication channels (AWGN, Rayleigh and Rician channel) [3]. The simulation results of bit error rate (BER) states that the implementation of interleaved RS code (255,239,8) with 2/3 rated convolutional code under BPSK modulation technique is exceedingly compelling to battle in the WiMAX communication system. Md. Anamul Islam et al. (2010) [4] uses concatenated cyclic redundancy check and convolution code (CRC-CC) along with AWGN and frequency flat fading channels. The system is analyzed on the basis of BER and spectral efficiency [4]. The results of BER and spectral efficiency illustrate that the system performance is exceedingly reliant on channel conditions and can be streamlined by AMC technique. Under AWGN and Rician channel, 64 QAM with ¾ rated coding show lower BER whereas, in Rayleigh channel, 16-QAM shows lower BER. 16 QAM with 2/3 rated code battles exceptionally compelling spectrum efficiency under all mobile environments. M.A.Mohamed et al. (2010) [5] analyzed the WiMAX physical layer under different combinations of digital modulation schemes and different communication channels. The performance of the simulated system was evaluated using the bit-error-rate (BER) [5]. This paper stated that when channel conditions are poor, energy efficient schemes such as BPSK or QPSK were used and when channel quality improves, higher M-ary modulation schemes such as16-QAM or 64-QAM was used. Prabhakar Telagarapu et al. (2011)[6] analyzed the performance of WiMAX physical layer by using Reed Solomon and Convolutional code as FEC (Forward Error Correction) code with cyclic prefix and interleaving using different modulation techniques [6]. The performance of WiMAX physical layer is evaluated on the basis of BER vs. SNR. The results are shown in the paper as with and without FEC for different modulation techniques. A. Islam et al. (2012) [7] compared the performance of concatenated CRC-CC (Cyclic Redundancy check and convolutional) and RS-CC (Reed Solomon and Convolutional) codes over AWGN and multipath fading channels. The simulation results concluded that the performance of concatenated CRC-CC is better when contrasted with concatenated RS-CC code under QAM over AWGN and multipath fading channels. Abdul Rehman et al. (2012) [8] used Reed Solomon encoder with Convolutional encoder as FEC code. AWGN and fading channels are used along with adaptive modulation technique to evaluate the performance of WiMAX system. The Simulation result concluded that the implementation of interleaved RS code with 2/3 rated convolutional code under BPSK modulation technique is more effective in the WiMAX system. M. M. Nuzhat Tasneem Awonet al. (2012) [9] evaluated the BER performance of WiMAX system on the basis of different encoding rates and different modulation techniques over AWGN, Rayleigh and Rician channel. The results show that AWGN channel performance is best among all the channels whereas the performance of Rayleigh channel is the worst of all the channels. The performance of Rician channel is worse than that of AWGN channel but better than Rayleigh channel. Karrar AlSlmman et al.(2012) [10] compared LDPC (Low Density Parity Check) code with commonly used concatenated RS-CC (Reed Solomon-Convolutional) code over standard AWGN channel. The simulation result shows that the performance of LDPC code is better than RS-CC code. Kushwah et al.(2013) [11] demonstrated WiMAX physical layer model by using MATLAB simulink. This paper is used to illustrate the effect of different modulation techniques, coding rates, cyclic prefix and OFDM symbols on the performance of WiMAX physical layer system. Manju Agrawal et al.(2015)[12] evaluated the WiMAX system performance with the help of BPSK, QPSK, 8-QAM, 16-QAM, 64-QAM and 256-QAM modulation techniques on the basis of BER, Signal to Noise Ratio and Spectral Efficiency. The Simulation results stated that 256-QAM performs better with highest SNR and BPSK provide better performance with lowest SNR. Also 256-QAM can be used for transmitting maximum amount of data with minimum amount of error.

IV. SIMULATION RESULTS

The simulation results consists of Bit Error rate (BER) vs. Signal to Noise Ratio (SNR) graphs and Spectral efficiency vs. Signal to Noise Ratio (SNR) graph of OFDM based WiMAX physical layer over Rayleigh channel using diverse modulation techniques. Some light will be tossed on each of this one by one. The performance of OFDM based WiMAX physical layer system over Rayleigh channel using diverse modulation techniques and cyclic prefix 1/4 is depicted in Fig. 7. After analyzing this figure, we get that BER of 10^{-3} is achieved in case of QPSK ½ at SNR of 25.24dB whereas in case of QPSK ¾, the same is obtained at SNR of 25.42 dB. Similarly in case of 16 QAM ¾, 64 QAM 2/3 and 64 QAM 3/4, the BER of 10^{-3} is obtained at SNR of 20.73dB, 20 dB and 21.13 dB respectively. From Fig.8, we get that BER of 10^{-3} is achieved in case of QPSK ½ at SNR of 24.15 dB whereas in case of QPSK ¾, the same is obtained at SNR of 24.62 dB. Similarly in case of 16 QAM ¾, 64 QAM 2/3 and 64 QAM 3/4, the BER of 10^{-3} is obtained at SNR of 19.70 dB, 19.54 dB and 20.24 dB respectively. Fig.9 depicts the BER of WiMAX using different modulation techniques with cyclic prefix 1/16 over Rayleigh channel. After analyzing this figure, we get that BER of 10^{-3} is achieved in case of QPSK ½ at SNR of 23.10 dB whereas in case of QPSK ¾, the same is obtained at SNR of 23.92 dB. Similarly in case of 16 QAM ¾, 64 QAM 2/3 and 64 QAM ¾, the BER of 10^{-3} is obtained at SNR of 18.92 dB, 18.63 dB and 19.30 dB respectively. After analyzing Fig. 10, we get that BER of 10^{-3} is achieved in case of QPSK ½ at SNR of 22.22 dB whereas in case of QPSK ¾, the same is obtained at SNR of 23.01 dB. Similarly in case of 16 QAM ¾, 64 QAM 2/3 and 64 QAM ¾, the BER of 10^{-3} is obtained at SNR of 18.10 dB, 18.04 dB and 18.30 dB respectively. The performance of different modulations i.e. QPSK ½, QPSK ¾, 16 QAM ¾, 64 QAM 2/3, and 64 QAM ¾ using cyclic prefix 1/4, 1/8, 1/16 and 1/32 is depicted in Fig. 11, Fig.12, Fig.13, Fig.14 and Fig.15 respectively. The Table that outlines all the BER results of different modulation along with different cyclic prefix is given in Table 2.The Table that outlines the spectral Efficiency of WiMAX over Rayleigh channel is given in Table 3.

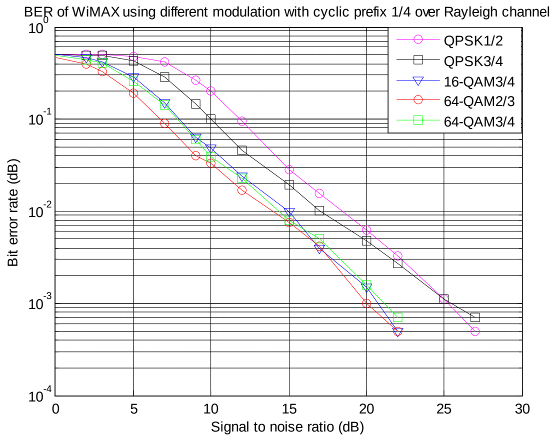

Fig. 7 BER of WiMAX with cyclic prefix 1/4

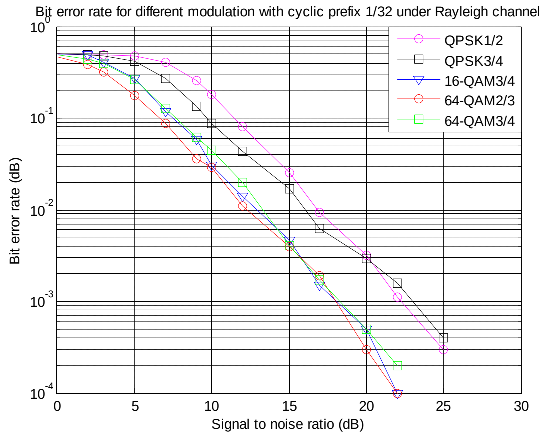

Fig. 10 BER of WiMAX with cyclic prefix 1/32

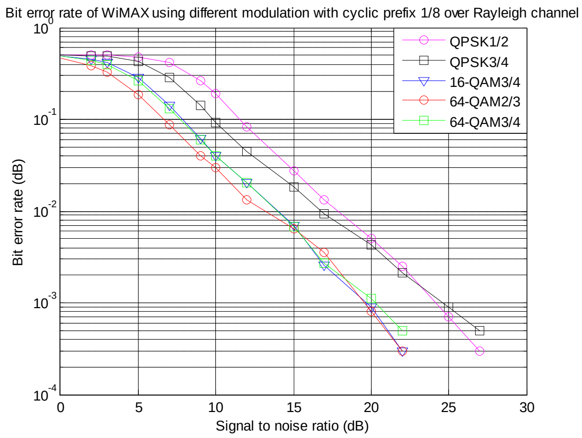

Fig. 8 BER of WiMAX with cyclic prefix 1/8

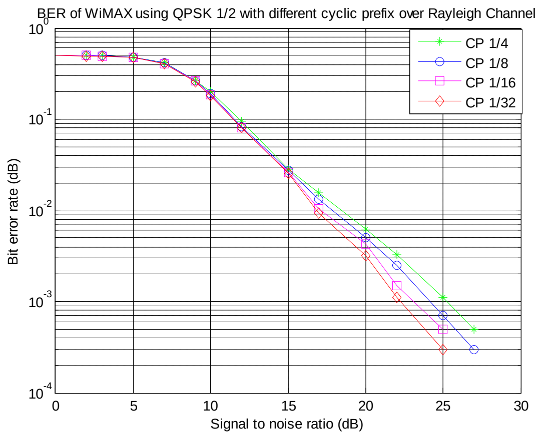

Fig. 11 BER of WiMAX using QPSK ½

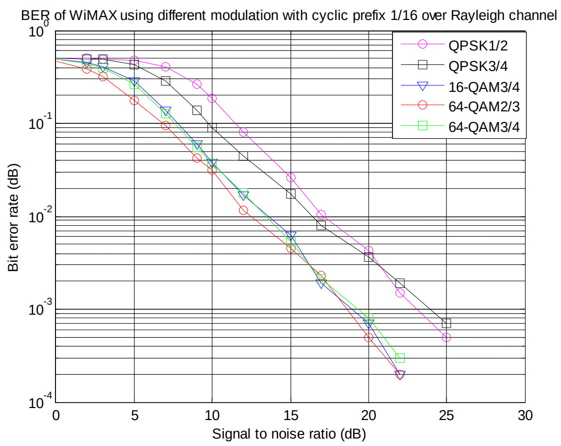

Fig. 9 BER of WiMAX with cyclic prefix 1/16

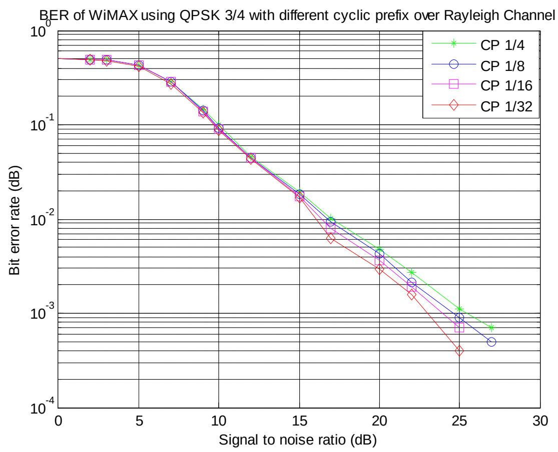

Fig. 12 BER of WiMAX using QPSK ¾

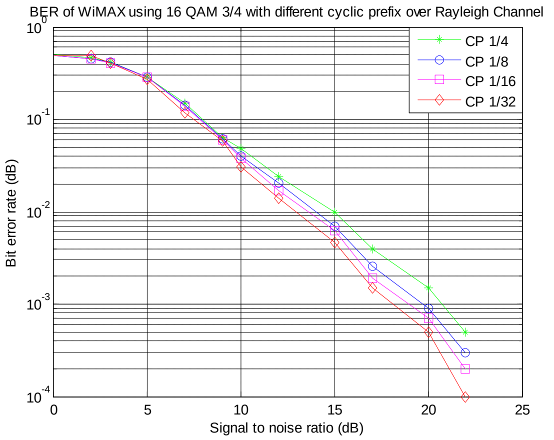

Fig. 13 BER of WiMAX using 16 QAM ¾

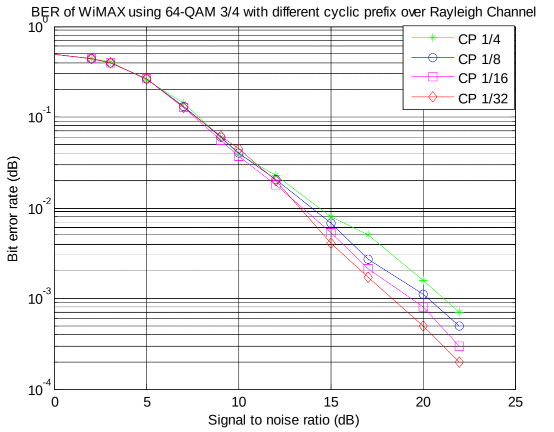

Fig. 15 BER of WiMAX using 64 QAM ¾

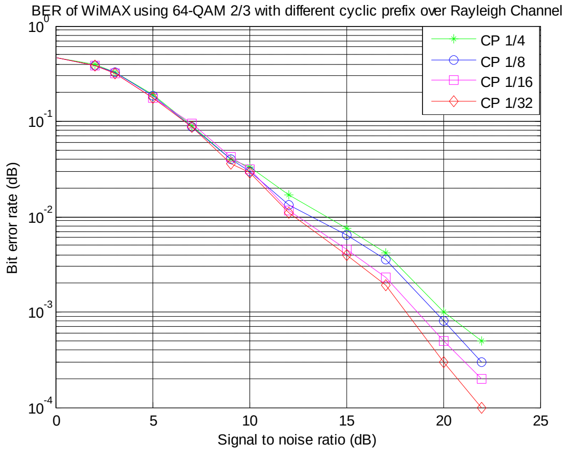

Fig. 14 BER of WiMAX using 64 QAM 2/3

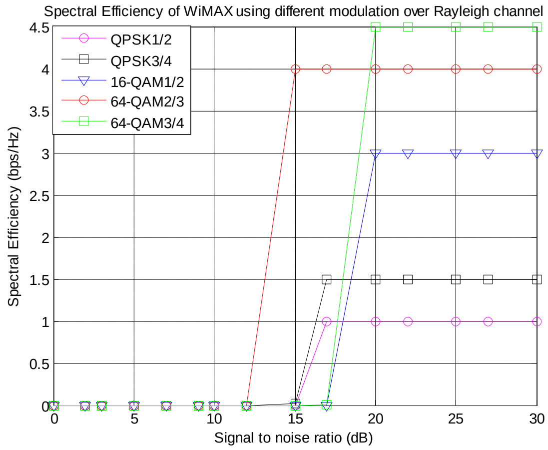

Fig. 16 Spectral Efficiency of WiMAX

Table 2 SNR requirement in WiMAX

Modulation	**SNR(dB) required to achieve a BER of 10^{-3}**			
	Cyclic Prefix			
	1/4	**1/8**	**1/16**	**1/32**
QPSK 1/2	25.24	24.15	23.10	22.22
QPSK 3/4	25.42	24.62	23.92	23.01
16 QAM 3/4	20.73	19.70	18.92	18.10
64 QAM 2/3	20	19.54	18.63	18.04
64 QAM 3/4	21.13	20.24	19.30	18.30

Table 3 Spectral Efficiency of WiMAX over Rayleigh channel

Spectral Efficiency of WiMAX over Rayleigh channel			
Modulation & Code rate	**Bits/Symbol**	**Spectral Efficiency**	**SNR(dB)**
QPSK 1/2	2	1	From 17 onwards
QPSK 3/4	2	2	From 17 onwards
16 QAM 3/4	4	3	From 20 onwards
64 QAM 2/3	6	4	From 15 onwards
64 QAM 3/4	6	4.5	From 20 onwards

V. CONCLUSION

In this paper, we have analyzed the BER vs. SNR and Spectral efficiency vs. SNR of OFDM based WiMAX physical layer using diverse modulation techniques and guard time intervals over Rayleigh channel. In Rayleigh channel, there is no line of sight from transmitter to receiver and also there are numerous impediments in the way. We can conclude that the results are different by utilizing different modulation techniques in OFDM based WiMAX physical layer system. Among all the simulations, 64 QAM R2/3 has lowest BER and QPSK R3/4 has the highest BER than other modulation techniques. The results also shows that the different modulations and coding rate give better performance with less SNR at cyclic prefix 1/32. The simulation outcomes of spectral efficiency shows that QPSK R1/2 has the lowest spectral efficiency and 64 QAM R3/4 has the highest spectral efficiency so for transmitting maximum amount of data, 64 QAM R3/4 can be used as it has lesser transmission error and higher spectral efficiency.

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Bindu Handa. "Spectral Efficiency and Bit Error Rate Analysis of WiMAX Using Diverse Modulation Techniques over Rayleigh Channel." International Journal of Engineering Research and Applications (IJERA) 7.7 (2017): 06-13.