

Performance Analysis of Wi-Max System Under AWGN Channel and Different Modulating Techniques

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December, 2014

CERTIFICATE

I, **Ashwani Kumar** hereby certify that the work, which is being presented in this Dissertation entitled "**Performance Analysis of Wi-Max System Under A WGN Channel and Different Modulation Techniques.**" by me in partial fulfillment of the requirements for the award of degree of Master of Engineering in Electronics and Communication Engineering at Thapar University, Patiala, is an authentic record of my own work carried out under the guidance of **Dr. Sanjay Sharma, Professor & Head, Electronics and Communication Engineering Department**, Thapar University, Patiala. The matter presented in this Dissertation has not been submitted in any other university or institute for the award of the degree of Master of Engineering.

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Most importantly, I would like to thank my parents and the Almighty for showing me the right direction out of the blue, to help me stay calm in the oddest of the times and keep moving even at times when there was no hope.

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ABSTRACT

Wireless communication systems have been in use for quite a long time. Many standards (to name 802.11, Bluetooth) are available based on which these devices communicate, but the present standards fail to provide sufficient data rate, when the user is moving at high speed. In view of this requirement for future mobile wireless communication systems, the present standard, 802.16e (Wi-MAX) has been proposed by Institute of Electrical and Electronic Engineers (IEEE). Wi-MAX provides specifications for both fixed Line of sight (LOS) communication in the range of 10-66GHz (802.16c), and fixed portable, Non-LOS communication in the range of 2-11GHz (802.16a, 802.16d). Also it defines wireless communication for mobiles, moving at speed of 125kmph, in the range of 2-6 GHz (802.16e). 802.16e is well implemented with OFDMA as its physical layer scheme. Fixed Broadband Wireless Access (BWA) is a promising technology which can offer high speed voice, video and data service up to the customer end. Due to the absence of any standard specification, earlier BWA systems were based on proprietary standard. IEEE 802.16 WirelessMAN standard specifies a Medium Access Control (MAC) layer and a set of PHY layers to provide fixed and mobile Broadband Wireless Access (BWA) in broad range of frequencies. The WiMAX forum has adopted IEEE 802.16 OFDM PHY layer for the equipment manufacturer due to its robust performance in multipath environment. The dissertation investigates the simulation performance of IEEE 802.16 OFDM PHY layer. The Stanford University Interim (SUI) channel models are selected for the wireless channel in the simulation. The evaluation was done in simulation developed in MATLAB. Perfect channel estimation is assumed.

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LIST OF ACRONYMS

AAA	Authentication Authorization and Accounting
AES	Advanced Encryption Standard
AMC	Adaptive Modulation and Coding
AP	Access Point
ASK	Amplitude Shift Keying
ASN	Access Service Network
ASP	Application Service Provider
ATM	Asynchronous Transfer Mode
AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
BS	Base Station
BTS	Base Transceiver Station
BWA	Broadband Wireless Access
CP	Cyclic Prefix
CPE	Customer Premise Equipment
DFT	Discrete Fourier Transform
DSL	Digital Subscriber Line
ETSI	European Telecommunication Standard Institute
FDD	Frequency Division Duplexing
FFT	Fast Fourier Transform

FSK	Frequency Shift Keying
GSM	Global System for Mobile
HiperMAN	High performance Metropolitan Area Network
ICI	Inter Carrier Interference
IEEE	Institute of Electrical and Electronic Engineers
IFFT	Inverse Fast Fourier Transformation
IP	Internet Protocol
ISI	Inter Symbol Interference
ITU	International Telecommunication Union
LOS	Line Of Sight
LTE	Long Term Evaluation
MAC	Medium Access Control
Mbps	Megabits per Second
MIMO	Multiple Input Multiple Output
MIP-HA	Mobile IP Home Agent
MS	Mobile Station
NAP	Network Access Point
NLOS	Non Line Of Sight
NSP	Network Service Provider
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access

OSS	Operational Support Subsystem
PCMCIA	Personal Computer Memory Card International Association
PHY	Physical Layer
PSK	Phase Shift Keying
PSTN	Public Switch Telephone Network
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RF	Radio Frequency
RSS	Received Signal Strength
SMS	Short Message Service
SNR	Signal to Noise Ratio
SS	Subscriber Station
TDD	Time Division Duplexing
TDMA	Time Division Multiple Access
UMTS	Universal Mobile Telecommunication System
VoIP	Voice over Internet Protocol
Wi-Fi	Wireless Fidelity
Wi-MAX	Worldwide interoperability for Microwave Access

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CHAPTER 1

INTRODUCTION

Wireless communication systems have been in use for quite a long time. Many standards (to name 802.11, Bluetooth) are available based on which these devices communicate, but the present standards fail to provide sufficient data rate, when the user is moving at high speed. In view of this requirement for future mobile wireless communication systems, the present standard, 802.16e (Wi-MAX) has been proposed by Institute of Electrical and Electronic Engineers (IEEE). Wi-MAX provides specifications for both fixed Line of sight (LOS) communication in the range of 10-66GHz (802.16c), and fixed portable, Non-LOS communication in the range of 2-11GHz (802.16a, 802.16d). Also it defines wireless communication for mobiles, moving at speed of 125kmph, in the range of 2-6 GHz (802.16e). 802.16e is well implemented with OFDMA as its physical layer scheme.

1.1 Wi-MAX

Wi-MAX is an acronym meaning Worldwide Interoperability for Microwave Access. Wi-MAX is based on Wireless Metropolitan Area Networking (WMAN) standards developed by the IEEE 802.16 group. Wi-MAX is also called the next generation broadband wireless technology which offers high speed, secure, sophisticate and last mile broadband services along with a cellular back haul and Wi-Fi hotspots. The evolution of Wi-MAX began a few years ago when scientists and engineers felt the need of having a wireless Internet access and other broadband services which works well everywhere especially the rural areas or in those areas where it is hard to establish wired infrastructure and economically not feasible. IEEE 802.16, also known as IEEE Wireless-MAN, explored both licensed and unlicensed band of 2-66 GHz which is standard of fixed wireless broadband and included mobile broadband

application. Wi-MAX forum, a private organization was formed in June 2001 to coordinate the components and develop the equipment those will be compatible and inter operable. After several years, in 2007, mobile Wi-MAX equipment developed with the standard IEEE 802.16e got the certification and they announced to release the product in 2008, providing mobility and nomadic access. The IEEE 802.16 standard was developed to deliver Non-Line-Of-Sight (NLOS) connectivity between a subscriber station and base station with typical cell radius of three to ten kilometre. Wi-MAX systems can be expected to deliver capacity of up to 40 Mbps per channel. This is enough bandwidth to simultaneously support hundreds of businesses with T-1 speed connectivity and thousands of residences with DSL (Digital Subscriber Line) speed connectivity. The Wi-MAX mobile network deployments are to provide up to 15 Mbps of capacity within a typical cell radius of up to three kilometre. Wi-MAX technology already has been incorporated in notebook computers and PDAs (Personal Digital Assistant) to deliver high speed mobile internet services anytime, anywhere.

1.2 EVOLUTION OF IEEE FAMILY OF STANDARD FOR BWA

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

responsible for development of 802.16 and the included Wireless Man air interface, along with associated standards and amendments.

The IEEE 802.16 standard contains the specification of Physical (PHY) and Medium Access Control (MAC) layer for BWA. The first version of the standard IEEE802.16-2001 was approved on December 2001 and it has gone through many amendments to accommodate new features and functionalities. The current version of the standard IEEE 802.16-2004 [2], approved on September 2004, consolidates all the previous versions of the standards. This standard specifies the air interface for fixed BWA systems supporting multimedia services in licensed and licensed exempt spectrum. The Working Group approved the amendment IEEE 802.16e-2005 [15] to IEEE802.16-2004 on February 2006. To understand the development of the standard to its current stage, the evolution of the standard is presented here.

- **IEEE 802.16-2001**

This first issue of the standard specifies a set of MAC and PHY layer standards intended to provide fixed broadband wireless access in a point-to-point (PTP) or point-to-multipoint (PMP) topology . The PHY layer uses single carrier modulation in the 10 – 66 GHz frequency range. Transmission times, durations and modulations are assigned by a Base Station (BS) and shared with all nodes in the network in the form of broadcast Uplink and Downlink maps. Subscribers need only to hear the base station that they are connected and do not need to listen any other node of the network. Subscriber Stations (SS) has the ability to negotiate for bandwidth allocation on a burst to-burst basis, providing scheduling flexibility. The standard employs QPSK, 16-QAM and 64-QAM as modulation scheme. These can be changed from frame to frame and from SS to SS,

depending on the robustness of the connection. The standard supports both Time Division Duplexing (TDD) and Frequency Division Duplexing (FDD) as duplexing technique. An important feature of 802.16-2001 is its ability to provide differential Quality of Service (QoS) in the MAC Layer. A Service Flow ID does QoS check. Service flows are characterized by their QoS parameters, which can then be used to specify parameters like maximum latency and tolerated jitter [32]. Service flows can be originated either from BS or SS. 802.16-2001 works only in (Near) Line of Sight (LOS) conditions with outdoor Customer Premises Equipment (CPE).

- **IEEE 802.16a-2003**

This version of the standard amends IEEE 802.16-2001 by enhancing the medium access control layer to support multiple physical layer specifications and providing additional physical layer specifications. This was ratified by IEEE 802.16 working group in January 2003[5]. This amendment added physical layer support for 2-11 GHz. Both licensed and license-exempt bands are included. Non Line of Sight (NLOS) operation becomes possible due to inclusion of below 11 GHz range. Due to NLOS operation multipath propagation becomes an issue. To deal with multipath propagation and interference mitigation features like advanced power management technique and adaptive antenna arrays were included in the specification [5]. The option of employing Orthogonal Frequency Division Multiplexing (OFDM) was included as an alternative to single carrier modulation. Security was improved in this version; many of privacy layer features became mandatory while in 802.16-2001 they were optional. IEEE 802.16a also adds optional support for mesh topology in addition to PMP.

- **IEEE 802.16c-2002**

In December 2002, IEEE Standards Board approved amendment IEEE 802.16c [7]. In this amendment detailed system profiles for 10-66 GHz were added and some errors and inconsistencies of the first version of the standard were corrected.

- **IEEE 802.16-2004**

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

- **IEEE 802.16e-2005**

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

- **IEEE 802.16 f**

Improve the coverage area by using the mesh networking. Mesh networking has the ability to bypass obstacles and only a small amount of meshing can largely improve the coverage area of base station.

- **IEEE 802.16-2009**

802.16-2009, official called the “Air Interface for Fixed and Mobile Broadband Wireless Access System”, was released to support both fixed and mobile wireless communications. It was a rollup of 802.16-2004, 802.16-2004/Cor 1, 802.16e, 802.16f, 802.16g and P802.16i. After that an improved standard 802.16j was introduced.

- **IEEE 802.16 m**

IEEE 802.16 m was introduced in 2011. It is also known as Mobile Wi-MAX Release 2 or Wireless MAN-Advanced. It has advanced air interface with data rates of 100 Mbit/s mobile and 1Gbit/s fixed. IEEE 802.16n and IEEE 802.16p are in progress

1.3 DISSERTATION ORGANIZATION

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

Chapter 2: Provides the literature review in which some previous year research paper related to Wi-Max physical layer are discussed.

Chapter 3: Discusses the IEEE 802.16 Wi-Max architecture & Orthogonal Frequency Division Multiplexing along with different modulation techniques.

Chapter 4: Present Work: In this chapter all blocks of simulink model of Wi-Max physical layer are discussed in detail.

Chapter 5: Provides the simulation result.

Chapter 6: Presents conclusions of dissertation followed by future work.

CHAPTER 2

LITERATURE REVIEW

Preambles: - A literature review is a “critical analysis of a segment of a published body of knowledge through summary, classification, and comparison of prior research studies, reviews of literature, and theoretical articles”. A literature review is both a summary and explanation of the complete and current state of knowledge on a limited topic as found in academic books and journal articles.

Hadj Zerrouki*, Mohammed Feham et al. [16], WiMAX is a broadband wireless technology based on IEEE802.16 standards family, which defines the physical (PHY) and medium access control (MAC) layers and makes several possible configurations available along with non-mandatory options. WiMAX is a new OFDM based technology and promises to combine high data rate services with wide area coverage. In this paper, the performance of Wi MAX Physical layer is investigated for two MIMO (Multiple-Input Multiple-Output) Physical layer modifications, (Space-Time Block Codes, STBC) and (Spatial multiplexing, SM) to provide high suppression against multipath fading, provide high bandwidth efficiency and high throughput with high data rates. This work incorporates the model building of the WiMAX Physical layer using MATLAB simulation. The results obtained for these

modifications show that these mechanisms enhance the performance of the WiMAX Physical layer in fixed environments with high spectral efficiency.

Chowdhury Shahriar, Matt La Pan, Marc Lichtman [17], This paper addresses the physical layer security concerns and resiliency of Orthogonal Frequency Division Multiplexing (OFDM) communications; the defacto air interface of most modern wireless broadband standards including 3GPP Long Term Evolution (LTE) and WiMAX. The paper starts with a brief introduction to the OFDM waveform and then reviews the robustness of the existing OFDM waveform in the presence of noise, multipath fading, and interference. The paper then moves on to build comprehensive adversarial models against OFDM waveforms. Robustness of OFDM is first investigated under AWGN noise and noise-like jamming attack scenarios, then under uncorrelated yet coloured interferences from modulated sources (both intentional and unintentional). Finally, the paper explores some of the more recent developments in the field of energy efficient correlated jamming attacks that can disrupt communication severely by exploiting the knowledge of the target waveform structure. Potential counter measures against such jamming attacks are presented, in an attempt to make a robust and resilient OFDM waveform.

B. Sivakumar Reddy, Dr. Lakshmi Boppana [18], in this paper author presents modulation switching in OFDM for WiMAX specifications by considering Raleigh fading channel using GNU Radio companion. WiMAX technology is considered as the most eminent solution able to allow a Broadband wireless Access (BWA) in metropolitan areas with easier installation and lower cost. OFDM is the fundamental block in WiMAX Physical layer. Modulation switching is performed in WiMAX to amend the network performance in the case of Non-LOS communication. This work proposes a script in Python to build a block which selects

the modulation scheme to be used in OFDM. The results show that a selector block automatically adopts the modulation scheme to be used, while an OFDM system is in operation. Keywords: OFDM, OFDMA, WiMAX, GNU Radio.

Zeyad T. Sharef, Ammar E. Alaradi [19], In this paper, a detailed link level simulation has been studied and optimized to investigate the physical layer performance of Worldwide Interoperability for Microwave Access (Wi-MAX) IEEE 802.16e over AWGN and multipath Rayleigh fading channels, in which ITU-Reference channel models have been used. Two 802.16e based OFDMA transceivers have been designed by using MATLAB Simulink, the first one doesn't support channel estimation whereas the second does. Moreover, the effect of fading channel, Doppler shift and cyclic prefix on the system design performance has been analyzed and investigated. The bit error rate (BER) vs. bit energy-to-noise density ratio (E_b/N_0) curves was used to evaluate and compare the performance of QPSK modulation technique. The outcomes of simulation results clarified how the use of channel estimation improves the system performance, whereas obviously, the investigated system suffers from severe performance degradation and high probability of error whenever channel estimation is not applied.

Jamal Mountassir and Horia Balta, et al. [20], the author presented the architecture of the Wi-MAX physical layer. The main blocks are implemented with the aid of the Matlab programming language and the bit error rate (BER) curves are presented in Rayleigh fading channel. The simulator allows a better understanding of the signal processing steps taking place at the Physical layer corresponding to the IEEE 802.16e specifications. Furthermore, it allows performance evaluation in different scenarios, through BER and BLER computation.

The BER performance of QPSK is better than for 16QAM as it is expected. The strength of the turbo-codes leads to very good BER results.

Mingxi Wang, et al. [23], the author has given a brief overview of the physical layer specifications of the Wi-MAX standard IEEE 802.16-2009. Recently, 802.16-2009, official called the “Air Interface for Fixed and Mobile Broadband Wireless Access System”, was released to support both fixed and mobile wireless communications. A simplified simulation system of Wi-MAX OFDMA Physical with LDPC coded MIMO-OFDM is established for performance evaluation purpose. Simulations show that the proposed iterative receiver structure can achieve good performance.

Bikash C. Singh and M. Mahbubur Rahmani, et al. [4], focused on Simulation based analysis of IEEE 802.16-2004 WMAN-OFDM Physical layer. Specifically it aims at quantifying the improvement of PHY layer performance, evaluated in terms of Bit Error Rate (BER) versus Signal to Noise Ratio (SNR), with respect to the different channel models. The simulation was done using MATLAB. Author focus is on telemedicine. Telemedicine is currently being used to bridge the physical distance between patients in remote areas and medical specialists around the world. It may be defined as the use of electronic information and communication technologies to provide and support health care when the patient and the specialists are remotely located. The Telemedicine system requires internet connectivity at the doctor and health worker ends. Wi-MAX is able to provide ubiquitous internet access allowing end users to be connected to the internet independently of their location, including rural and impervious areas where the deployment of a wired access solution would not be economically feasible. We can conclude, lower modulation and coding scheme provides better performance with less SNR. The proposed lower modulation and coding scheme can

be used in broadband wireless access for faster and error prone internet access and voice-video applications which definitely assists the telemedicine.

Arathi R.Shankar, Poonam Rani and Suthikshn Kumar, et al. [3], focused on the comparison of quality of service parameters between different channels in Wi-MAX physical layer. Orthogonal frequency division multiple access is used by Wi-MAX on its physical layer. Orthogonal frequency division multiple access uses adaptive modulation technique on the physical layer of Wi-MAX and it uses the concept of cyclic prefix that adds additional bits at the transmitter end. The signal is transmitted through the channel and it is received at the receiver end. Then the receiver removes these additional bits in order to minimize the inter symbol interference, to improve the bit error rate and to reduce the power spectrum. In the analysis, a Wi-MAX module developed based on popular network simulator MATLAB is used. Author has investigated four parameters: Bit Error Rate (BER), Signal to Noise Ratio (SNR), Power Spectral Density (PSD), Probability of Error (P_e). We conclude 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 the 64-QAM has highest BER than others. The inclusion of the Cyclic Prefix reduces the Inter Symbol Interference (ISI) that causes the lower BER in the OFDM system but increases the complexity of the system.

Marius Oltean, Maria Kovaci and AlexandruIsar, et al. [25], designed a physical layer simulator for the Wi-MAX. The simulator encompasses the main blocks that build the physical layer from IEEE 802.16e. The Wi-MAX simulator, presented in this paper, allows a better understanding of the processes involved at the Physical layer in Wi-MAX. Furthermore, quantitative results may be provided by the computation of BER and BLER

statistics, indifferent scenarios. Firstly, the simulation chain was validated by transmitting data through an ideal and by measuring the BER. As expected, the BER in this case is 0, showing that the chain baseband modulation – encoding – mapping – OFDM modulation works correctly. Next, simulations were carried out in noisy channel conditions. These simulations allow us to draw BER versus SNR curves for various permutation schemes, as well as for different digital modulation schemes, in uplink and downlink. Given the simple channel model (only AWGN) the permutation type does not make any difference with respect to the BER performance of the system. This would only matter in frequency selective and time variant channels. As expected the BER performance of the QPSK modulation is better than for the 16-QAM.

Mohamed A. Mohamed and Mohamed S. Abo-El-Seoud, et al. [22], have discussed different algorithms of the orthogonal frequency division multiplexing (OFDM), as well as the Wi-MAX physical layer based on the IEEE 802.16e standard under different combinations of digital modulation schemes and different communication channels. The performance of the Wi-MAX Physical layer was tested and evaluated at different noise levels. Various BER vs. SNR plots are presented for all the essential modulation and coding profiles in the standard on different channel models. It can be noticed that the lower modulation and coding scheme provides better performance with less SNR. Furthermore, the selection of the AMC mode is made in such a way that it guarantees a BER below a given target BER. It can be demonstrated that, as the channel SNR is higher, higher AMC schemes are used to give us the best spectral efficiency while providing the desired BER performance. The scatter plot for 64-QAM modulation at the receiver at different values of SNR (10, 20, 25 and 30 dB) is presented. It can be observed from scatter plots that spread reduction is

taking place with the increasing values of SNR. The simulation results show that adaptive modulation achieves similar spectral efficiency with better energy efficiency.

Omar Arafat and K. Dimyati, et al. [29], analyze the performance of mobile Wi-MAX (PHY layer) under SUI channel models in addition under different data rates, coding schemes, modulation technique. The simulation covers important performance parameter like Bit Error Rate, Block Error Rate & Signal to Noise Ratio. Result shows that the system gives better performance with less SNR, when lower modulation and coding technique are used. We can say that all the result corresponding to the same code rate have the same pattern and for each modulation scheme the pattern increase with higher code rate. Another observation is that modulation scheme using the 1/2 code rate offer low performance as an example 16 QAM 3/4 rate and 64 QAM 3/4 rate give better performance than QPSK 3/4 rate and 16 QAM rate respectively.

U. D. Dalal and Y. P. Kosta, et al. [35] attempted to simulate the physical layer that takes into consideration vehicular mobility associated and time based changing effects for a typical Wi-MAX IEEE 802.16e-2005 channel environment. In the first phase, authors have mainly considered the NLOS Wi-MAX link and then developed a channel model that incorporates Doppler Effect and simulated the whole link. The results of the simulations depicts that effects of Doppler being not very serious for single carrier transmissions, however, during multi-carrier transmissions the effect are serious and requires more rigorous modelling especially with MIMO and study to estimate the channel response. To estimate a time varying, MIMO Doppler channel using spectrum estimation methods, an imposed pilot pattern is used as this consumes minimum spectrum and lesser power though it differs from the standard. Through this simulation study, channel estimation issues are investigated,

discussed and presented. The simulation gives the expected results using suggested channel model and at the same time it is observed that more number of pilots does not improve the performance significantly, so the number of pilots must be an optimum value between 8 to 16 satisfying the power and spectrum constraints within 256 total subcarriers, afterwards by optimized interpolation the performance can be further improved.

Yajun Li and Yuhang Yang, et al. [39], presented a detailed investigation of QoS issues in IEEE 802.16 mesh networks in order to provide a better understanding of the research challenges of QoS provisioning under Mesh mode. Mesh networking is one of the most promising technologies for next-generation wireless networking. QoS provisioning is critical to the development and application of mesh networking in both academia and industry. Focusing on QoS issues in the IEEE 802.16 mesh mode, author address four major aspects of QoS provisioning in this article: QoS Differentiation Schemes, Reservation schemes, Fairness and Scheduling.

Nicolas Fourty, Thierry Val and Anne Wei, et al. [27], presented a new Wi-MAX Physical layer model used to determine thresholds for modulation profile switching in order to enhance the communication robustness or throughput using Adaptive Modulation and Coding (AMC) schemes. Two channel models and two Wi-MAX modulation profiles are studied using two different audio samples. The simulation results obtained and confirmed by listening experiments, have demonstrated that the audio quality is improved in terms of perceived noise. Key words of emergency communication applications are robustness, safety, and effectiveness. The Wi-MAX technology envisaged in this paper could answer these three points. First the new criterion proposed should give more robustness of Wi-MAX modulation profiles. Then the service classes QoS implemented by the Standard should bring Safety.

And at last, effectiveness of the OFDM advanced techniques (beam forming, MIMO) make this technology a possible solution for emergency communications.

Albert Chiang and Wei-Hua Han, et al. [1], look at some of the challenges of physical access layer validation and discuss how System Verilog test bench constructs can be used to create random yet valid frames for Wi-MAX OFDMA to validate the physical access layer protocols. System Verilog is an IEEE approved language that covers both design and verification. System Verilog provides a rich infrastructure and a set of useful constructs for validation of Wi-MAX like protocol and functionality. With the system Verilog classes, author was able to create random yet valid Wi-MAX frames. Once the Wi-MAX frame/zone/burst classes are defined; they can be easily randomized by adding the rand modifier. Thoroughly testing Wi-MAX now has become easier due to the advanced constructs found in system Verilog.

Mohd. Noor Islam and Mostafa Zaman Chowdhury, et al. [39], proposed the analysis for minimum number of samples to have a certain confidence level for the QoS parameter of the Mobile Wi-MAX Network. The sampled data is analysed with "Chi-Square Goodness-of-Fit Test, Kolmogorov-Smirnov and Anderson-Darling test" to test the distribution of parent population and then confidence level with minimum number of samples is discussed. This paper focus on the two most important QoS parameters of VoIP services in case of mobile WI-MAX : Jitter and end to end delay. This paper showed that the jitter can be analysed by Generalized Extreme Value Distribution and end-to-end one way delay can be analysed by logistic distribution. It also provided the minimum sample size for the parameter estimation of the two important QoS parameters like jitter and end-to-end one way delay. It will certainly help the service provider to analysis statistically the QoS parameters.

Muhammad Nadeem Khan and SabirGhauri, et al. [24], discussed the model building of the Wi-MAX Physical layer using Simulink in Matlab. This model is a useful tool for performance evaluation of the Wi-MAX under different data rates, coding schemes and channel conditions besides serving as a helpful resource for the students and the researchers who want to base their studies and research on the field's related to the Wi-MAX. Standards from IEEE and ETSI have been used to develop this model. The model presented in this paper built with generic MAC PDU processed by the Physical Layer using Convolutional Encoding Rate of $5/6$ with QPSK modulation and transmitted with 256 carrier OFDM symbols. Based on the model presented in this paper, and tests carried out, the performance was established based on 10 million symbols in each case. The performance is displayed in terms of the BER versus SNR logarithmic plot, time-scatter plots for 10, 20 and 30dB; Signal-to-Noise Ratios, time-scatter plot for the output from the transmitter and FFT scope diagram for the transmitted signal. The BER plot obtained in the performance analysis showed that model works well on SNR above 20dB. The time-scatter plots demonstrate the scattering of the transmitted and received signals at different values of the Signal-to-Noise Ratios. It also shows that at very low SNR the symbols are very difficult to recognize.

N. Riato, S. Sorrentino and D. Franco, et al. [28], discussed the impact of mobility on physical and MAC layers algorithms design and performance. The physical and MAC layer algorithms need to be designed in order to support both low and high mobility users. Herein, the impact of users mobility on the design and the performance of the physical and MAC layers of a Wi-MAX base station is assessed and suitable solutions for the channel estimation, dynamic link adaptation and scheduling algorithms are provided. Simulation results provide indications on the achievable maximum cell load for different mobility and

QoS profiles. The optimal trade-off between the PUSC and AMC permutations is also numerically investigated. Channel estimation performance of the ML algorithm have been analysed for MSs speed up to 120Km/h, showing that independently estimating the channel in each OFDM symbol based only on pilot tones provides acceptable performance. A layer-two mobility estimation based link adaptation algorithm has been designed and its performance examined in a variety of user mobility profiles.

CHAPTER 3

Wi-MAX ARCHITECTURE & OFDM

This chapter discusses the IEEE 802.16 based network architecture, deployment topology, application scenarios, physical layer and its affiliation with Wi-MAX forum.

3.1 WI-MAX ARCHITECTURAL ISSUES

Various architectural issues involved with Wi-MAX like point to point Vs point to multipoint, LOS Vs NLOS are discussed in following subtopics:

3.13 P2P Vs PMP

There are two scenarios for wireless deployment: point-to-point and point-to-multipoint.

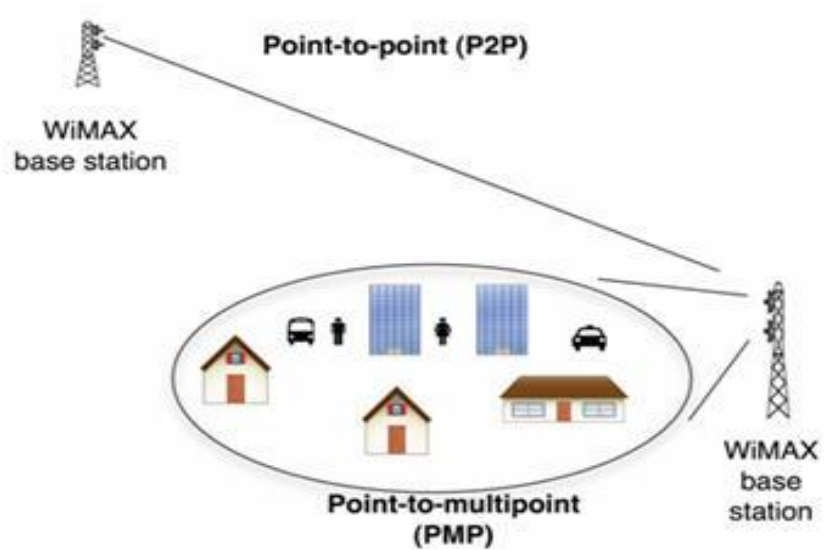


Fig. 3.1: Point-to Point and Point-to-Multipoint Configurations[42]

3.2.1 Point-to-Point (P2P)

Point to point is used where there are two points of interest: one sender and one receiver. This is also a scenario for backhaul or the transport from the data source (data centre, facility, fibre POP, Central Office, etc.) to the subscriber or for a point for distribution using point to multipoint architecture. Backhaul radios comprise an industry of their own within the wireless industry. As the architecture calls for a highly focused beam between two points range and throughput of point-to point radios will be higher than that of point-to-multipoint products.

3.2.2 Point-to-Multipoint (PMP)

As seen in the figure above, point-to-multipoint is synonymous with distribution. One base station can service hundreds of dissimilar subscribers in terms of bandwidth and services offered.

3.14 LOS Vs NLOS

Earlier wireless technologies were unsuccessful in the mass market as they could not deliver services in non-line-of-sight scenarios. This limited the number of subscribers they could reach. Wi-MAX functions best in line of sight situations and, unlike those earlier technologies, offers acceptable range and throughput to subscribers who are not line of sight to the base station.

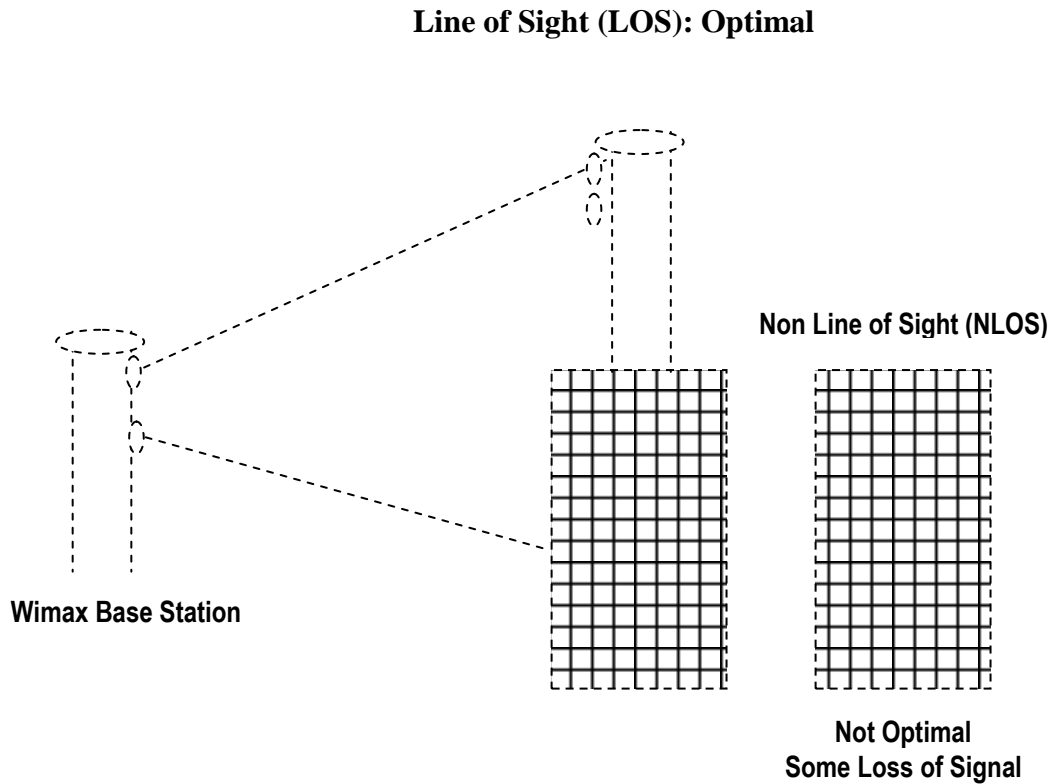


Fig. 3.2: The Difference between Line of Sight and Non-Line of Sight

Given Wi-MAX ability to deliver services non-line-of-sight, the Wi-MAX service provider can reach many customers in high-rise office buildings to achieve a low cost per subscriber because so many subscribers can be reached from one base station.

3.4 BASIC BUILDING BLOCKS

A Wi-MAX system consists of two major parts:

- 1) Wi-MAX base station.

2) Wi-MAX receiver.

- **Wi-MAX Base Station**

A Wi-MAX base station consists of indoor electronics and a Wi-MAX tower similar in concept to a cell-phone tower. A Wi-MAX base station can provide coverage to a very large area up to a radius of 6 miles. Any wireless device within the coverage area would be able to access the Internet.



Fig. 3.3: A Wi-MAX Tower[41]

The Wi-MAX base stations would use the MAC layer defined in the standard. A common interface that makes the networks interoperable and would allocate uplink and downlink bandwidth to subscribers according to their needs, on an essentially real-time basis. Each base station provides wireless coverage over an area called a cell. Theoretically, the maximum radius of a cell is 50 km or 30 miles however, practical considerations limit it to about 10 km or 6 miles.

- **Wi-MAX Receiver**

A Wi-MAX receiver may have a separate antenna or could be a stand-alone box or a PCMCIA card sitting in your laptop or computer or any other device. This is also referred as customer premise equipment (CPE).



Fig. 3.4: Wi-MAX Receiver PCMCIA Card

Wi-MAX base station is similar to accessing a wireless access point in a Wi-Fi network, but the coverage is greater. [26]

- **Backhaul**

A Wi-MAX tower station can connect directly to the Internet using a high-bandwidth, wired connection (for example, a T3 line). It can also connect to another Wi-MAX tower using a line-of-sight, microwave link. Backhaul refers both to the connection from the access point back to the base station and to the connection from the base station to the core network. It is possible to connect several base stations to one another using high-speed backhaul microwave links. This would also allow for roaming by a Wi-MAX subscriber from one base station coverage area to another, similar to the roaming enabled by cell phones.

3.5 WI-MAX REFERENCE NETWORK ARCHITECTURE

The IEEE 802.16e-2005 standard provides the air interface for Wi-MAX but does not define the full end-to-end Wi-MAX network. The Wi-MAX Forum's [37] Network Working Group (NWG), is responsible for developing the end-to-end network requirements, architecture, and protocols for Wi-MAX, using IEEE 802.16e-2005 as the air interface. The Wi-MAX NWG has developed a network reference model to serve as an architecture framework for Wi-MAX deployments and to ensure interoperability among various Wi-MAX equipment and operators. The network reference model envisions unified network architecture for supporting fixed, nomadic, and mobile deployments and is based on an IP service model.

The overall network may be logically divided into three parts:

- Mobile stations used by the end user to access the network
- The access service network (ASN), which comprises one or more base stations and one or more ASN gateways that form the radio access network at the edge.
- The connectivity service network (CSN), which provides IP connectivity and all the IP core network functions.

- **Base station (BS)**

The BS is responsible for providing the air interface to the MS. Additional functions that may be part of the BS are micro mobility management functions, such as handoff triggering and tunnel establishment, radio resource management, QoS policy enforcement, traffic classification, DHCP proxy, key management, session management, and multicast group management.

- **Access service network gateway (ASN-GW):**

The ASN gateway typically acts as a layer 2 traffic aggregation point within an ASN. Additional functions that may be part of the ASN gateway include intra-ASN location management and paging, radio resource management and admission control, caching of subscriber profiles and encryption keys, AAA client functionality, establishment and management of mobility tunnel with base stations, QoS and policy enforcement, foreign agent functionality for mobile IP, and routing to the selected CSN.

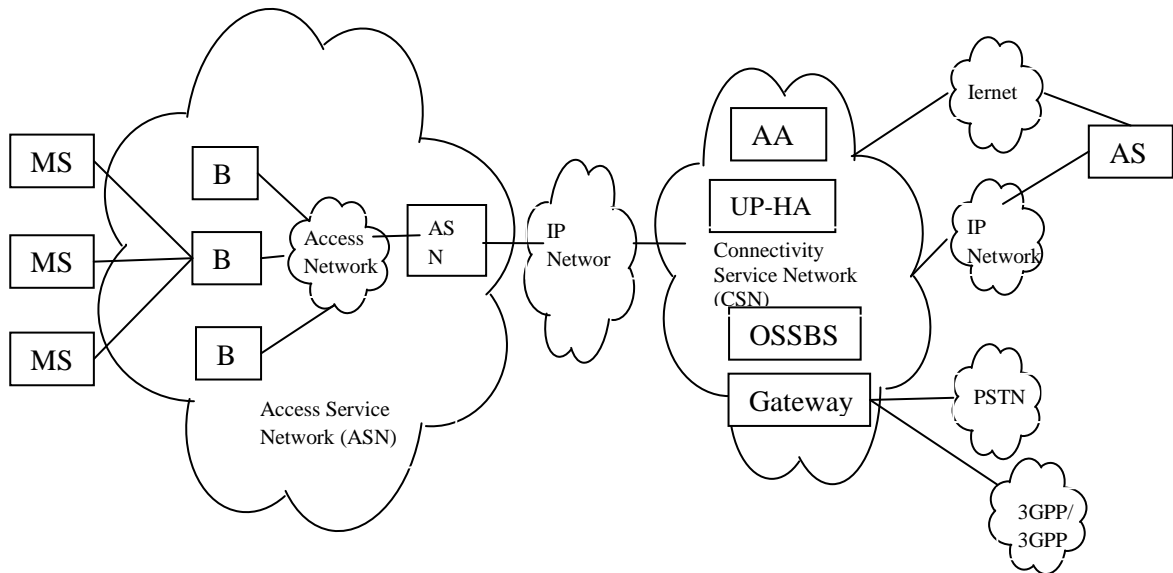


Fig. 3.5: IP-Based Wi-MAX Network Architecture [43]

- **Connectivity service network (CSN)**

The CSN provides connectivity to the Internet, ASP, other public networks, and corporate networks. The CSN is owned by the NSP and includes AAA servers that support authentication for the devices, users, and specific services. The CSN also provides per user policy management of QoS and security. The CSN is also responsible for IP address management, support for roaming between different NSPs, location management between ASNs, and mobility and roaming between ASNs. Further, CSN can also provide gateways and interworking with other networks, such as PSTN (public switched telephone network), 3GPP, and 3GPP2.

In addition to functional entities, the reference architecture defines interfaces, called reference points, between function entities. The interfaces carry control and management protocols mostly transport-layer protocols-in support of several functions, such as mobility, security, and QoS, in addition to bearer data.

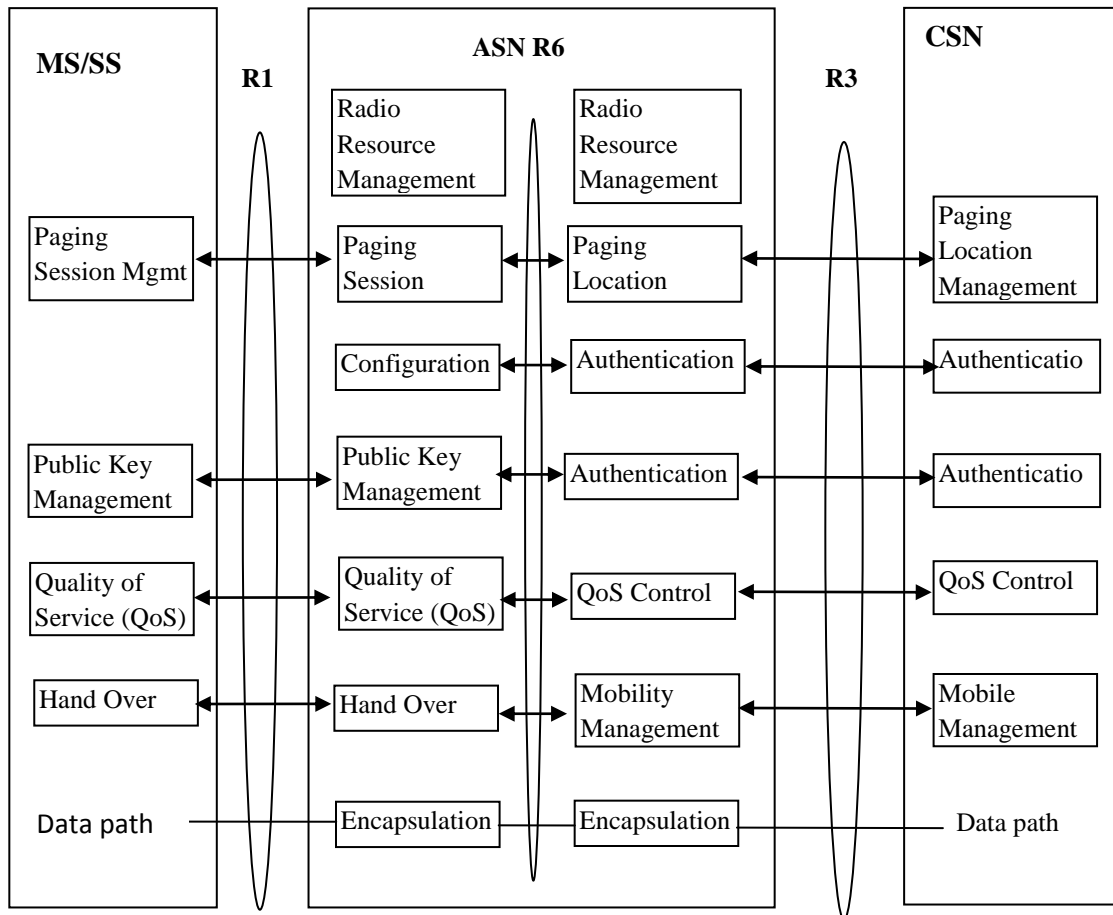


Fig. 3.6: Functions Performed across Reference Points[8]

The Wi-MAX network reference model defines reference points between:

- MS and the ASN, called R1, which in addition to the air interface includes protocols in the management plane.
- MS and CSN, called R2, which provides authentication, service authorization, IP configuration, and mobility management.

- ASN and CSN, called R3, to support policy enforcement and mobility management.
- ASN and ASN, called R4, to support inter-ASN mobility.
- CSN and CSN, called R5, to support roaming across multiple NSPs.
- BS and ASN-GW, called R6, which consists of intra-ASN bearer paths and IP tunnels for mobility events.
- BS to BS, called R7, to facilitate fast, seamless handover.

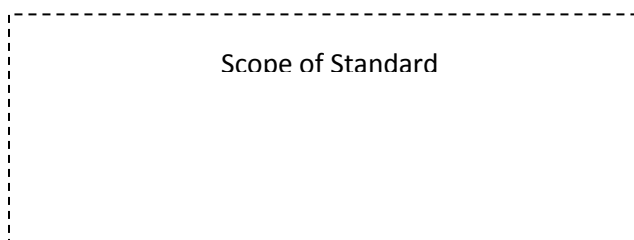
3.6 IEEE 802.16 PROTOCOL LAYERS

IEEE 802.16 standard Wi-MAX gives freedom in several things compared to other technologies. The focus is not only on transmitting tens of megabits of data to many miles distances but also maintaining effective QoS (Quality of Services) and security. Wi-MAX 802.16 is mainly based on the physical and data link layer in OSI reference model. Here, Physical layer can be single-carrier or multi-carrier (PHY) based and its data link layer is sub divided into two layers:

- Logical Link Control (LLC)
- Medium Access Control (MAC)

3.6.1 MAC Layer

The basic task of Wi-MAX MAC is to provide an interface between the physical layer and the upper transport layer. It takes a special packet called MAC Service Data Units (MSDUs) from the upper layer and makes those suitable to transmit over the air. For receiving purpose, the mechanism of MAC is just the reverse. In both fixed and mobile Wi-MAX, it included a convergence sub-layer which is able to interface with upper layer protocols such as ATM, TDM, Voice and other advanced protocols. Wi-MAX MAC has unique features to identify and address the SS and BS. Each SS carries 48-bit IEEE MAC address whereas BS carries 48-bit Base Station ID in which 24-bit uses for operator indicator.



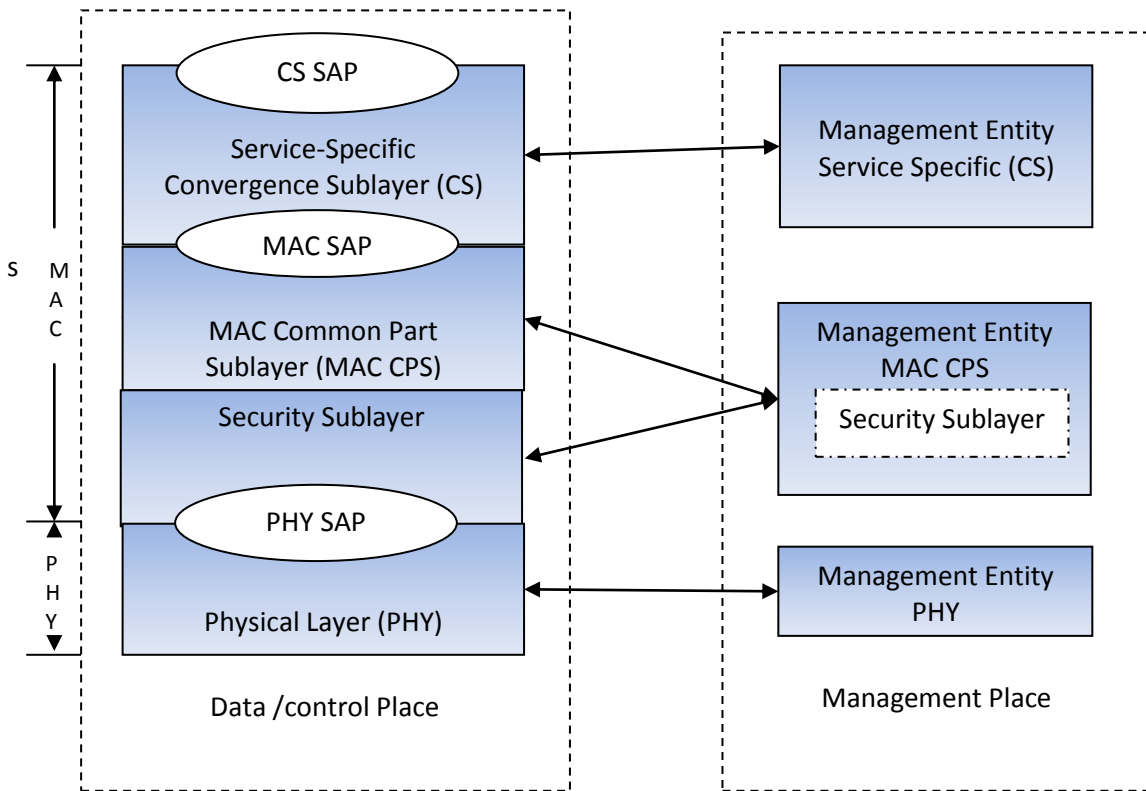


Fig. 3.7: IEEE 802.16 Protocol Stack [44]

3.6.1.1 Sub-Layers

Wi-MAX MAC layer is divided into three sub-layers such as Service Specific Convergence Sub-layer (SSCS), Common Part Sub-layer (CPS) and Security Sub-layer (SS).

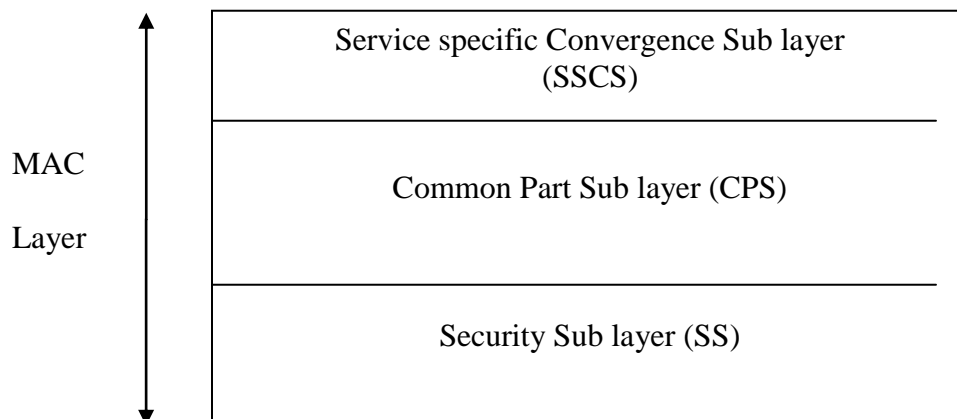


Fig. 3.8 Wi-MAX MAC LAYER[44]

- **Service Specific Convergence Sub-layer (SSCS)**

This stays on the top of MAC layer architecture which takes data from the upper layer entities such as router and bridges. It is a sub-layer that is service dependent and assures data transmission. It enables QoS and bandwidth allocation. Payload header suppression and increase the link efficiency are other important task of this layer. IEEE 802.16 specifies two types of SSCS for mapping function.

ATM Convergence sub-layer: Is a logical interface which is responsible for Asynchronous Transfer Mode (ATM) services. In the operation, it accepts ATM cells from ATM layer classify and then sends CS PDUs to MAC SAP. It differentiates Virtual path switched ATM connection and assigns Channel ID (CID)

Packet Convergence sub-layer: It's a packet based protocol which performs packet mapping such as IP, IPv4, IPv6, IEEE 802.3 Ethernet LAN, VLAN and PPP.

- **Common Part Sub-layer (CPS)**

It stays underneath of SSCS and above the Security Sub-layer and defines the multiple access mechanism. CPS is responsible for the major MAC functionalities like system access, establishing the connection and maintain and bandwidth management etc. As Wi-MAX MAC is connection oriented so it provides service flows after each Subscriber Station's registration. Other responsibilities are, providing QoS for service flows and managing connection by adding or deleting or modifying the connection statically or dynamically. On downlink channel, only the BS transmits and it does not need any coordination function. SS receives only those messages which are addressed to them.

- **Security Sub-layer (SS)**

This part stays at the bottom of MAC layer and one of the most important part of MAC as it provides authentication, secure key exchange, encryption and integrity of the system. IEEE 802.16 standard defines both ways data encryption connection between subscriber and base station. A set of cryptographic suites such as data encryption and authentication algorithm has been defined which made security sub-layer of Wi-MAX MAC very robust. A secure distribution of keying data from base station to subscriber station is assured by providing an authentication and a PKM protocol. On top of that, in SS, the addition of a digital certificate strengthen the privacy of data and in BS, the PKM assured the conditional access to the network services and applications. Further improvement of PKM protocol is also defined with some additional features and with a new name named PKMv2 which strongly controls integrity, mutual authentication and handover mechanisms [40].

3.7 FEATURES OF WI-MAX

There are certain features of Wi-MAX those are making it popular day by day. Some important features of Wi-MAX are described below:

- **Interoperability**

This is the main concern of Wi-MAX. The IEEE 802.16 standard is internationally accepted and the standard is maintained and certified by Wi-MAX forum which covers fixed, portable and mobile deployments and giving the user the freedom to choose their product from different certified vendors and use it in different fixed, portable or mobile networks.

- **Long Range**

Another main feature of Wi-MAX is long range of coverage. Theoretically, it covers up to 30 miles but in practice, it covers only 6 miles. The earlier versions of Wi-MAX provide LOS coverage but as technology advanced and the later version of Wi-MAX, e.g. mobile Wi-MAX, can support both LOS and NLOS connections. For that, it must meet the condition of the range for LOS, 50 kilometres and for NLOS, 10 kilometres.

- **OFDM based Physical Layer**

Wi-MAX is based on orthogonal frequency division multiplexing that offers multipath resistance and allows NLOS communication.

- **High Data Rate**

Wi-MAX is capable of supporting very high peak data rates. In fact, the peak PHY data rate can be as high as 74Mbps when operating using a 20MHz wide spectrum. More typically, using a 10MHz spectrum operating using TDD scheme with a 3:1 downlink-to-uplink ratio, the peak Physical data rate is about 25Mbps and 6.7Mbps for the downlink and the uplink, respectively.

- **Quality of Service**

The Wi-MAX 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 QoS parameters [30] such as constant bit rate, variable bit rate, real-time, and non-real-time traffic flows, in addition to best-effort data traffic. Wi-MAX MAC is designed to support a large number of users, with multiple connections per terminal, each with its own QoS requirement.

- **Flexible Architecture**

Wi-MAX architecture is very flexible. It can support point to point and point to multipoint connection according to its requirements. It also supports IP-based architecture that is easily converge with other networks and takes advantage of application development from the existing IP based application.

- **TDD and FDD Support**

Wi-MAX support both time division duplex and frequency division duplex which helps in spectrum management, transceiver design and the low cost system development.

- **Adaptive Modulation and Coding**

Wi-MAX 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. The adaptation algorithm typically calls for the use of the highest modulation and coding scheme that can be supported by the signal-to-noise and interference ratio at the receiver such that each user is provided with the highest possible data rate.

- **Mobility Support**

Wi-MAX offer optimized handover which support full mobility application such as voice over internet protocol (VOIP). It has also the power saving mechanism which increases the battery life of handheld devices.

- **IP-Based Architecture**

The Wi-MAX Forum has defined a reference network architecture that is based on an all IP platform. All end-to-end services are delivered over an IP architecture [13] relying on IP based protocols for end-to-end transport, QoS, session management, security, and mobility. Reliance on IP allows Wi-MAX to ride the declining cost curves of IP

processing, facilitate easy convergence with other networks, and exploit the rich ecosystem for application development that exists for IP.

- **Scalability**

Wi-MAX offer scalable network architecture that support user roaming in different networks. It also enhances the broadband access capability.

- **Strong Security**

Wi-MAX support extensible security feature for reliable data exchange. It use Advanced Encryption Standard (AES) encryption for secure transmission and for data integrity, it use data authentication mechanism.

3.8 WI-MAX VS WI-FI

Wi-Fi stands for Wireless Fidelity. It refers a system which is called 802.11 standards (wireless LAN), was developed by IEEE in 1997. People prefer using Wi-Fi because; it is a single base station in shape of a box with a wired connection to the Internet, such as a DSL, cable, or T1 line. It can broadcasts to multiple users over distances of 100 meters indoor and 400 meters outdoor. On the contrary Wi-MAX is a high-speed wireless packet-based radio connectivity for metropolitan area wireless standard that provides wireless broadband connections similar to Wi-Fi but with much coverage of up to 50 kilometres in LOS and 10 kilometres in NLOS condition.

Wi-MAX is not designed to clash with Wi-Fi, but to coexist with it. Wi-MAX coverage is measured in square kilometres, while that of Wi-Fi is measured in square meters. The original Wi-MAX standard (IEEE 802.16) proposes the usage of 10-66 GHz frequency spectrum for the Wi-MAX transmission, which is well above the Wi-Fi range (up to 5 GHz maximum). But 802.16a added support for 2-11 GHz frequency also. One Wi-MAX base

station can be accessed by more than 60 users. Wi-MAX can also provide broadcasting services also.

3.9 IEEE 802.16 PHY LAYER

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

3.10 SUPPORTED BAND OF FREQUENCY

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

- **Licensed Band (10-66 GHz)**

In this frequency band, due to shorter wave length, line of sight operation is required and as a result the effect of multipath propagation is neglected. The standard promises to provide data rates up to 120 Mb/s in this frequency band [21]. The abundant availability of bandwidth is also another reason to operate in this frequency range. Unlike the lower frequency ranges where frequency bands are often less than 100MHz wide, most frequency bands above 20GHz can provide several hundred megahertz of bandwidth [34]. Additionally, channels within these bands are typically 25 or 28 MHz wide.

- **Licensed and Licensed Exempt (2-11 GHz)**

In these frequency bands, both licensed and licensed exempt bands are addressed. Additional physical functionality supports have been introduced to operate in Near LOS

and NLOS environment and to mitigate the effect of multipath propagation. In fact, many of the IEEE 802.16 Physical most advantageous capabilities are found in this frequency range. Operation in licensed exempt band experiences additional interference and coexistence issue. Though service provision in this frequency band is highly dependent on design goals ,vendors typically cite target aggregate data rates of up to 70Mb/s in a 14 MHz channel. The target data rates can be further improved upto 100Mb/s at 25 MHz channel.

3.11 IEEE 802.16 PHY INTERFACE VARIANTS

The standard has assigned a unique name to each physical interface. Each of these physical interfaces have been described below along with their supported features in brief.

- **Wireless MAN-SC**

This is the only Physical specification defined to operate in 10-66 GHz frequency band. It employs single carrier modulation with adaptive burst profiling, in which transmission parameters, including the modulation and coding schemes, may be tuned individually to each subscriber station (SS) on a frame by frame basis. The standard both supports Frequency Division Duplexing (FDD) and Time division Duplexing (TDD) to separate uplink and downlink. Access in uplink direction is done by combination of time division multiple access (TDMA) and Demand Assignment Multiple Access (DAMA), exactly the uplink channel is divided into several time slots [5]. Communication on the downlink in PTM Architecture is employed using Time Division Multiplexing (TDM). It also specifies the randomization, forward error correction (FEC), modulation and coding schemes.

- **Wireless MANSCa**

This is also based on single carrier modulation targeted for 2-11 GHz frequency range. Access is done by TDMA technique both in uplink and downlink, additionally TDM also supported in downlink.

- **Wireless MAN OFDM**

This is based on orthogonal frequency division multiplexing (OFDM) with a 256 point transform to support multiple SS in 2-11 GHz frequency band. Access is done by TDMA. The Wi-MAX forum has adopted this Physical specification for BWA. Because of employing OFDM and other features like multiple forward error correction method, this is the most suitable candidate to provide fixed support in NLOS environment. We have chosen this Physical specification for our simulation model. From next sections our discussion will be on this Physical layer.

- **Wireless MAN OFDMA**

This Physical specification uses OFDM access (OFDMA) with at least a single support of specified multipoint transform (2048, 1024, 512 or 128) to provide combined fixed and Mobile BWA. Operation is limited to below 11 GHz licensed band [7]. In this specification multiple access is provided by addressing a subset of the multiple carriers to individual receivers.

- **Wireless HUMAN**

This specification is targeted for license exempt band below 11 GHz. Any of the air interfaces specified for 2-11 GHz can be used for this. This supports only TDD for duplexing [14].

Table 3.1: IEEE 802.16 Standard Air Interface's Description [14]

Specific Name	Operating Band	Duplexing	Noticeable Feature
Wireless MAN-SC	10 to 66 GHz	FDD and TDD	Single-carrier
Wireless MANSCa	2 to 11 GHz, Licensed	FDD and TDD	Single-carrier, NLOS
Wireless MAN OFDM	2 to 11 GHz, Licensed	FDD and TDD	OFDM technique, NLOS
Wireless MAN OFDMA	2 to 11 GHz, Licensed	FDD and TDD	Single frequency band, OFDM system divides signal into sub-channels
Wireless HUMAN	2 to 11 GHz, Free	TDD	Single-carrier, LOS, NLOS, OFDM, OFDMA, Frequency selective channel

- **Wireless MAN OFDM Physical Layer**

This version of the 256-point OFDM based air interface specification seems to be favoured by the Wi-MAX forum for reasons such as lower peak to average ratio, faster Fast Fourier Transform (FFT) calculation, and less stringent requirements for frequency synchronization compared to 2048-point Wireless MAN OFDMA. The size of the FFT point determines the number of subcarriers. Of these 256 subcarriers, 192 are used for user data, 56 are nulled for guard band and 8 are used as pilot subcarriers for various estimation purposes. The PHY allows to accept variable CP

length of 8, 16, 32 or 64 depending on the expected channel delay spread. In the following sub sections, we will discuss about the other mechanism of the Physical layer.

- **Flexible Channel Bandwidth**

The channel bandwidth can be an integer multiple of 1.25 MHz, 1.5 MHz, 1.75 MHz, 2MHz and 2.75 MHz with a maximum of 20 MHz [1]. But the Wi-MAX forum has initially narrowed down the large choice of possible bandwidth to a few possibilities to ensure interoperability between different vendor's products [9].

- **Robust Error Control Mechanism**

Forward Error Correction (FEC) is done on two phases through the outer Reed-Solomon (RS) code and inner Convolution Code (CC). The RS coder corrects burst error at the byte level. It is particularly useful for OFDM links in the presence of multipath propagation. The CC corrects independent bit errors. The puncturing functionality in CC made the concatenated codes rate compatible as per specification. The support of Turbo coding is left as an optional feature to increase the coverage and/or capacity [9] with the expense of increased decoding latency and complexity.

- **Adaptive Modulation and Coding**

The specified modulation scheme in the downlink (DL) and uplink (UL) are binary phase shift keying (BPSK), quaternary PSK (QPSK), 16 quadrature amplitude modulation (QAM) and 64-QAM to modulate bits to the complex constellation points. The FEC options are paired with the modulation schemes to form burst profiles. The Physical specifies seven combinations of modulation and coding rate, which can be allocated selectively to each subscriber, in both UL and DL [30]. There

are trade-offs between data rate and robustness, depending on the propagation conditions.

- **Adaptive Antenna System**

The Physical optionally supports and provides a signalling structure that enables the use of adaptive antenna system (AAS). The feature enables the transmission of DL and UL burst using directed beams, each intended for one or more SSs. In addition, the feature allows SS to deliver channel quality feedback to the BS [9].

- **Transmit Diversity:**

Space time block codes (STBC) can be implemented in the DL to provide transmit diversity. The feature is optional to implement. In [9], Alamouti STBC [34] has been proposed as a good candidate to implement this feature providing diversity in time and space.

3.12 OFDM

The Orthogonal Frequency Division Multiplexing (OFDM) is developed to support high data rate and can handle multi carrier signals. Its specialty is that, it can minimize the Inter Symbol Interference (ISI) much more compared to other multiplexing schemes. It is more likely improved Frequency Division Multiplexing (FDM) as FDM uses guard band to minimize interference between different frequencies which wastes lots of bandwidth but OFDM does not contain inter-carrier guard band which can handle the interference more efficiently than FDM. So, this is the perfect choice for Wi-MAX as it can help to satisfy the requirements of efficient use of spectrum and minimize the transmission cost. On top of that, OFDM handles multipath effect by converting serial data to several parallel data using Fast Fourier Transform (FFT) and Inverse Fast Fourier Transform (IFFT).

3.13 BASICS OF OFDM

The idea of OFDM comes from Multicarrier Modulation (MCM) transmission technique. The principle of MCM describes the division of input bit stream into several parallel bit streams and then they are used to modulate several sub carriers as shown in Figure 3.9. Each subcarrier is separated by a guard band to ensure that they do not overlap with each other. In the receiver side, band pass filters are used to separate the spectrum of individual subcarriers. OFDM is a special form of spectrally efficient MCM technique, which employs densely spaced orthogonal subcarriers and overlapping spectrums. The uses of band pass filters are not required in OFDM because of the orthogonally nature of the subcarriers. Hence, the available bandwidth is used very efficiently without causing the Inter Carrier Interference (ICI). In Figure 3.10, the effect of this is seen as the required bandwidth is greatly reduced by removing guard band and allowing subcarrier to overlap. It is still possible to recover the individual subcarrier despite their overlapping spectrum provided that the Orthogonality is maintained. The Orthogonality is achieved by performing Fast Fourier Transform (FFT) on the input stream. Because of the combination of multiple low data rate subcarriers, OFDM provides a composite high data rate with long symbol duration. Depending on the channel coherence time, this reduces or completely eliminates the risk of Inter-Symbol Interference (ISI), which is a common phenomenon in multipath channel environment with short symbol duration. The use of Cyclic Prefix (CP) in OFDM symbol can reduce the effect of ISI even more [38], but it also introduces a loss in SNR and data rate.

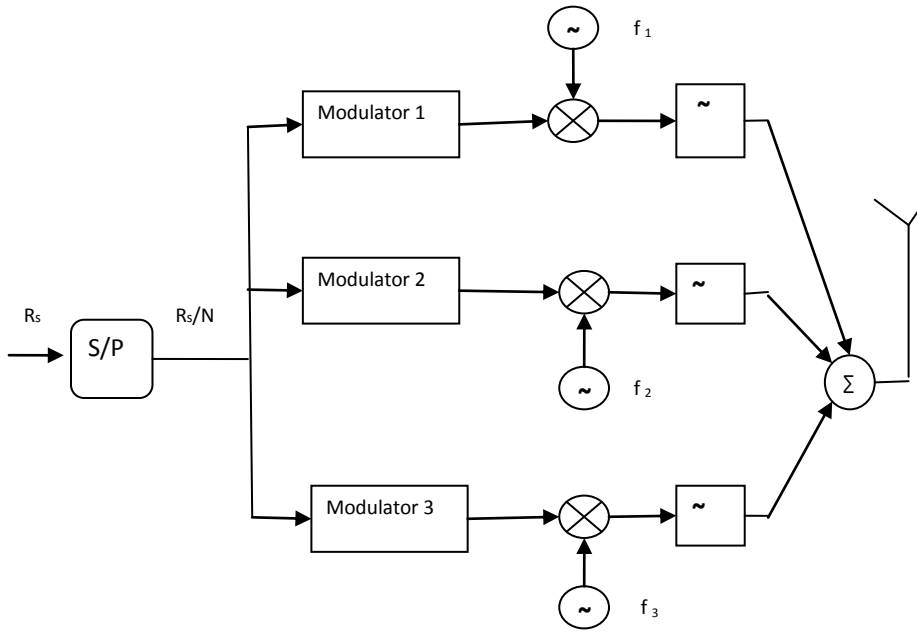


Fig. 3.9: Block Diagram of Generic MCM Transmitter

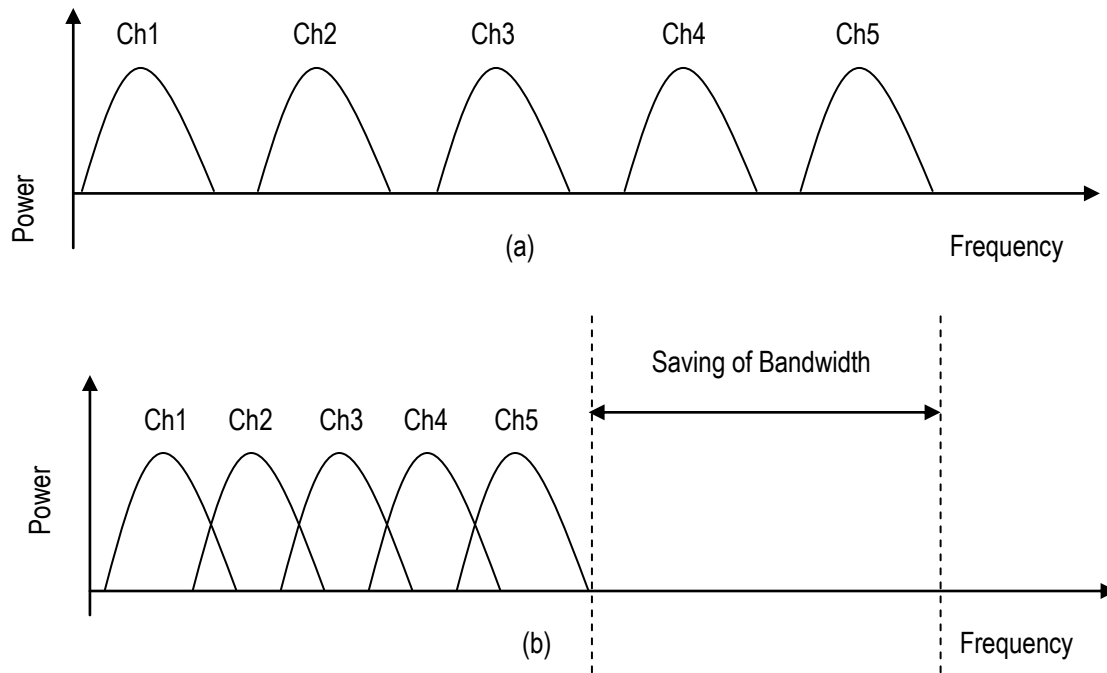
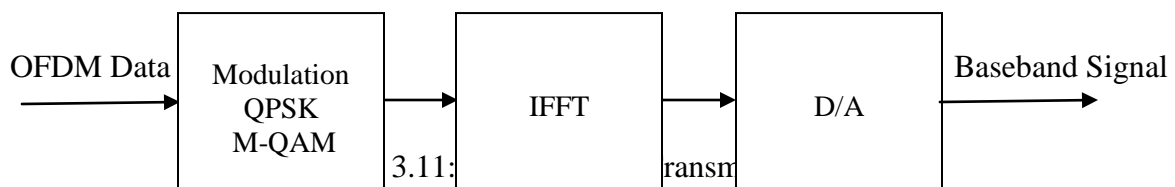


Fig. 3.10: Comparison between Conventional FDM and OFDM

3.13.1 OFDM System Implementation

The principle of OFDM was already around in the 50's and 60's as an efficient MCM technique. But, the system implementation was delayed due to technological difficulties like digital implementation of FFT/IFFT, which were not possible to solve on that time. In 1965, Cooley and Tukey presented the algorithm for FFT calculation and later its efficient implementation on chip makes the OFDM into application.

The digital implementation of OFDM system is achieved through the mathematical operations called Discrete Fourier Transform (DFT) and its counterpart Inverse Discrete Fourier Transform (IDFT). These two operations are extensively used for transforming data between the time-domain and frequency-domain. In case of OFDM, these transforms can be seen as mapping data onto orthogonal subcarriers. In order to perform frequency-domain data into time domain-data, IDFT correlates the frequency domain input data with its orthogonal basis functions, which are sinusoids at certain frequencies. In other ways, this correlation is equivalent to mapping the input data onto the sinusoidal basis functions. In practice, OFDM systems employ combination of Fast Fourier Transform (FFT) and Inverse Fast Fourier Transform (IFFT) blocks which are mathematical equivalent version of the DFT and IDFT.



At the transmitter side, an OFDM system treats the source symbols as though they are in the frequency-domain. These symbols are feed to an IFFT block which brings the signal into the time-domain. If the N numbers of subcarriers are chosen for the system, the basis functions

for the IFFT are N orthogonal sinusoids of distinct frequency and IFFT receive N symbols at a time. Each of N complex valued input symbols determines both the amplitude and phase of the sinusoid for that subcarrier. The output of the IFFT is the summation of all N sinusoids and makes up a single OFDM symbol. The length of the OFDM symbol is NT where T is the IFFT input symbol period. In this way, IFFT block provides a simple way to modulate data onto N orthogonal subcarriers. At the receiver side, The FFT block performs the reverse process on the received signal and bring it back to frequency-domain.

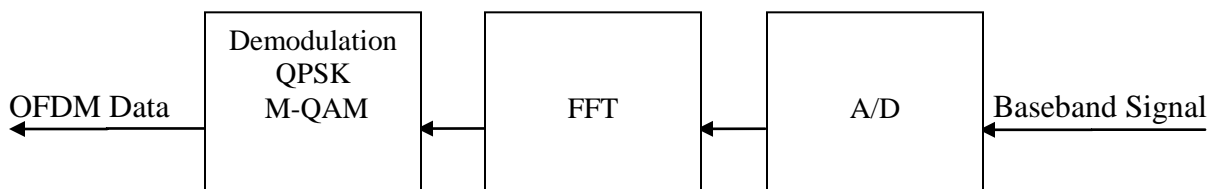


Fig. 3.12: Basic OFDM Receiver

3.13.2 Cyclic Prefix Addition

Cyclic Prefix (CP) is used to combat ISI and ICI introduced by the multipath channel. CP is a copy of the last part of OFDM symbol which is appended to the front of transmitted OFDM symbol [32]. The length of the CP (T_g) must be chosen as longer than the maximum delay spread of the target multipath environment. Fig 3.13 depicts the benefits arise from CP addition, certain position within the cyclic prefix is chosen as the sampling starting point at the receiver, which satisfies the criteria $T_{max} < T_x < T_g$, Where T_{max} is the maximum multipath spread. Once the above condition is satisfied, there is no ISI since the previous symbol will only have effect over samples within $[0, T_{max}]$. And it is also clear from the figure that sampling period starting from T_x will encompass the contribution from all the multipath components so that all the samples experience the same channel and there is no ICI



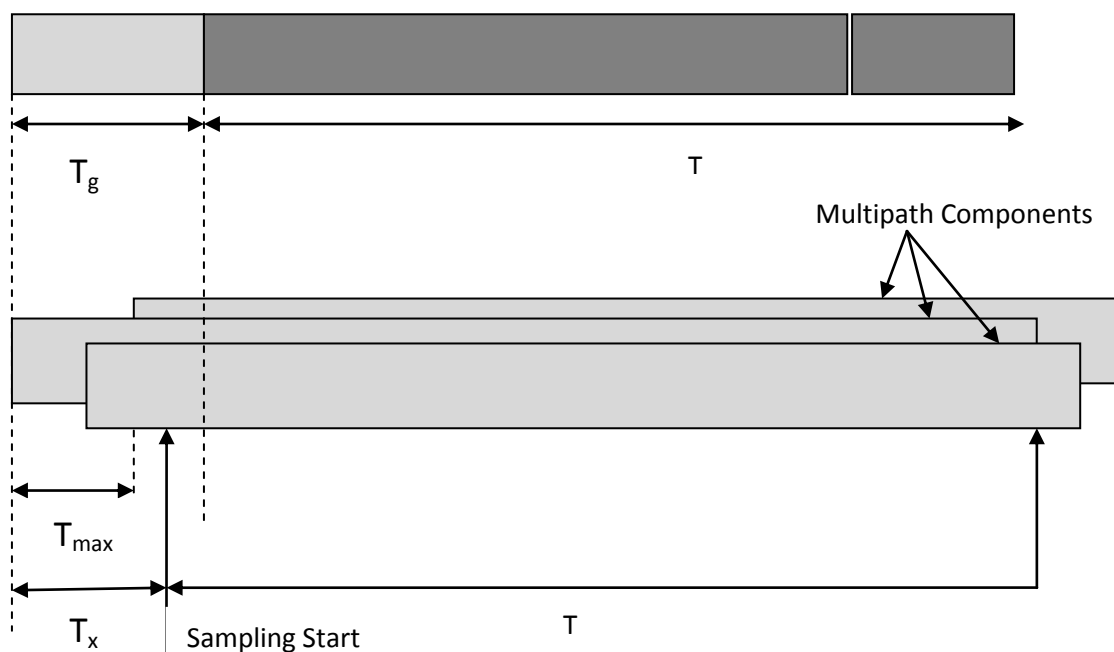


Fig. 3.13: Cyclic Prefix in OFDM[45]

3.14 OFDM SYSTEM DESIGN CONSIDERATIONS

OFDM system design issues aim to decrease the data rate at the subcarriers, hence the symbol duration increases and as a result, the multipath effects are reduced effectively. The insertion of higher valued CP will bring good results against combating multipath effects but at the same time it will increase loss of energy. Thus, a trade-off between these two parameters must be done to obtain a reasonable system design.

- **System Design Requirements**

OFDM system depends on the following four requirements: [26]

- Available bandwidth: The bandwidth limit will play a significant role in the selection of number of subcarriers. Large amount of bandwidth will allow obtaining a large number of subcarriers with reasonable CP length.

- Required bit rate: The system should be able to provide the data rate required for the specific purpose.
- Tolerable delay spread: A user environment specific maximum tolerable delay spread should be known beforehand in determining the CP length.
- Doppler values: The effect of Doppler shift due to user movement should be taken into account.
- **System Design Parameters**

The design parameters are derived according to the system requirements. The design parameters for an OFDM system are as follows [15]

- Number of subcarriers: We stated earlier that the selection of large number of subcarriers will help to combat multipath effects. But, at the same time, this will increase the synchronization complexity at the receiver side.
- Symbol duration and CP length: A perfect choice of ratio between the CP length and symbol duration should be selected, so that multipath effects are combated and not significant amount bandwidth is lost due to CP.
- Subcarrier spacing: Subcarrier spacing will be depending on available bandwidth and number of subcarriers used. But, this must be chosen at a level so that synchronization is achievable.
- Modulation type per subcarrier: The performance requirement will decide the selection of modulation scheme (ie which scheme is to be selected). Adaptive modulation can be used to support the performance requirements in changing environment due to its adaptive nature .

3.15 BENEFITS AND DRAWBACKS OF OFDM

In the earlier section, we have stated that how an OFDM system combats the ISI and reduces the ICI. Besides those benefits, there are some other benefits as follows:

- High spectral efficiency because of overlapping spectra.
- Simple implementation by Fast Fourier Transforms.
- Low receiver complexity as the transmitter combat the channel effect to some extends.
- Suitable for high-data-rate transmission.
- High flexibility in terms of link adaptation.
- Low complexity multiple access schemes such as orthogonal frequency-division multiple access (OFDMA).
- It is possible to use maximum likelihood detection with reasonable complexity [31]

On the other side, few drawbacks of OFDM are listed as follows:

- An OFDM system is highly sensitive to timing and frequency offsets [8]. Demodulation of an OFDM signal with an offset in the frequency can lead to a high bit error rate.
- An OFDM system with large number of subcarriers will have a higher peak to average power ratio (PAPR) compared to single carrier system. High PAPR of a system makes the implementation of Digital to Analog (DAC) and Analog to Digital Conversion (ADC) extremely difficult [33].

3.16 APPLICATIONS

OFDM has gained a big interest since the beginning of the 1990s [2] as many of the implementation difficulties have been overcome. OFDM has been in used or proposed for a number of wired and wireless applications. Digital Audio Broadcasting (DAB) was the first

commercial use of OFDM technology. OFDM has also been used for the Digital Video Broadcasting [9]. OFDM under the acronym of Discrete Multi-Tone (DMT) has been selected for asymmetric digital subscriber line (ADSL). The specification for Wireless LAN standard such as IEEE 802.11a/g [10] and ETSI HIPERLAN2 [7] has employed OFDM as their Physical technologies. IEEE 806.16 standard for Fixed/Mobile BWA has also accepted OFDM for Physical technologies.

3.17 MODULATION TECHNIQUES

The variation of the property of a signal, such as its amplitude, frequency or phase is called modulation. This process carries a digital signal or message. Different types of modulation techniques are available such as, Amplitude Shift Keying (ASK), Frequency Shift Keying (FSK) and Phase Shift Keying (PSK). This section discusses on different modulation techniques along with Wi-MAX's special modulation technique which is called Adaptive Modulation technique.

There are three basic types of modulation techniques which are as follows

1. Amplitude Shift Keying (ASK)
2. Frequency Shift Keying (FSK)
3. Phase Shift Keying (PSK)

3.17.1 Amplitude Shifting Keying (ASK)

Amplitude difference of carrier frequency is called ASK. In this, the phase and the frequency are always constant. The principle is based on the mathematical equation,

$$s(t) = \begin{cases} A \cos(2\pi f_c t) & \text{binary 1} \\ 0 & \text{binary 0} \end{cases} \quad (3.1)$$

Features of ASK

- Likely to be affected by sudden changes of gain.
- On the voice transmission lines such as telephone, used up to 1200 bps.
- Use in optical fibres to transmit digital data.

3.17.2 Frequency Shift Keying (FSK)

Frequency difference near carrier frequency is called FSK. In this, the phase and the amplitude are always constant. There are several types of FSK. Most common are, Binary Frequency Shift Keying (BFSK) and Multiple Frequency Shift Keying (MFSK).

- **Binary Frequency Shift Keying (BFSK)**

Two frequencies represent two binary values in this technique. The principle lies on the equation,

$$s(t) = \begin{cases} A \cos(2\pi f_1 t) & \text{binary 1} \\ A \cos(2\pi f_2 t) & \text{binary 0} \end{cases} \quad (3.2)$$

Features of BFSK

- Less affected by errors than ASK.
 - On voice transmission lines such as telephone, range till 1200bps.
 - This is used for high-frequency (3 to 30 MHz) radio frequency.
 - Suitable for LANs that uses coaxial cables.
- **Multiple Frequency Shift Keying (MFSK)**

More than two frequencies are used to represent signalling elements. The principle lies on the equation,

$$S_i(t) = A \cos(2\pi f_i t)$$

$$F_i = f_c + (2i - L - M) F_d \quad (3.3)$$

Features of MFSK

- Multiple frequencies are used
- More bandwidth efficient but very much affected by errors
- Each signal element encodes L bits (M=2L).

3.17.3 Phase-Shift Keying (PSK)

Phase of carrier signal is digital modulation scheme which conveys data by modulating or changing of carrier wave. The most common and widely used are Binary Phase shift Keying (BPSK) and Quadrature Phase Shift Keying (QPSK). Other PSKs are Differential Phase Shift Keying (DPSK) and Multilevel Phase Shift Keying (MPSK) etc. As Wi-MAX uses Adaptive Modulation Techniques, so, here we will broadly discuss only BPSK, QPSK and QAM.

3.17.3.1 Binary Phase Shift Keying (BPSK)

This is also known as two-level PSK as it uses two phases separated by 180° to represent binary digits. The principle equation is,

$$s(t) = \begin{cases} A \cos(2\pi f_c t) & \text{binary 1} \\ A \cos(2\pi f_c t + \pi) & \text{binary 0} \end{cases} \quad (3.4)$$

This kind of phase modulation is very effective and robust against noises especially in low data rate applications as it can modulate only 1bit per symbol.



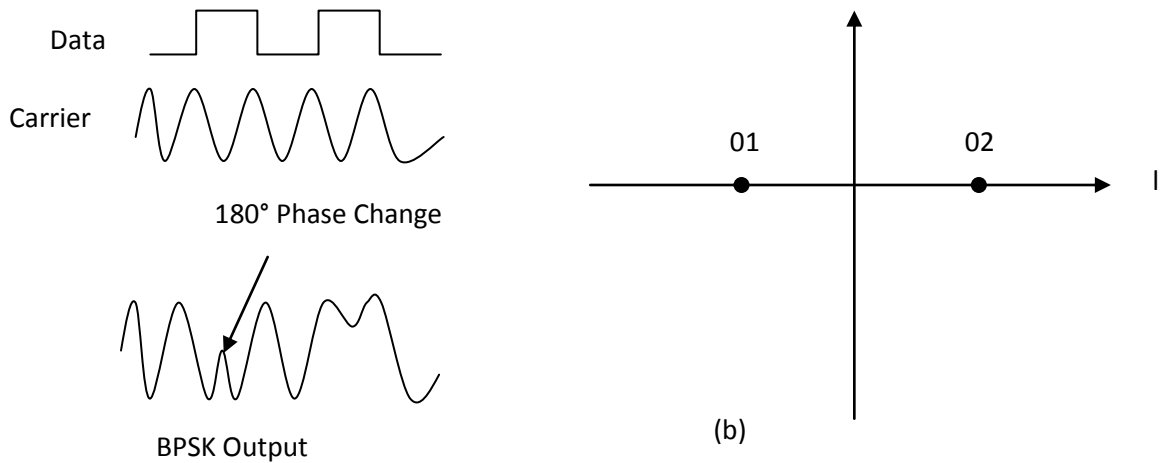


Fig 3.14: BPSK, (a) Block Diagram (b) Constellation

3.17.3.2 Quadrature Phase Shift Keying (QPSK)

This is also known as four-level PSK where each element represents more than one bit. Each symbol contains two bits and it uses the phase shift of $\pi/2$, means 90° instead of shifting the phase 180° .

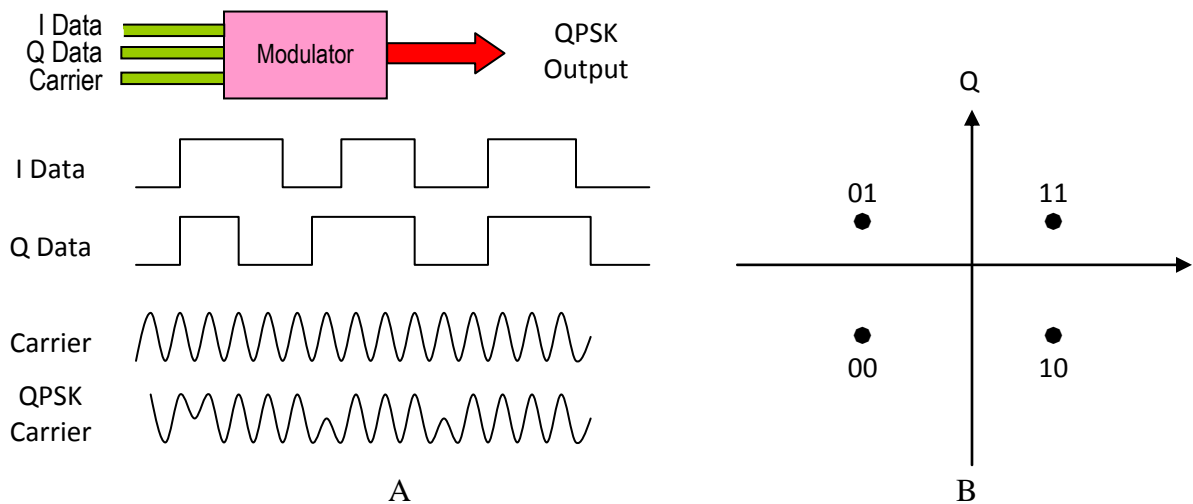


Fig. 3.15: QPSK, (a) Block Diagram (b) Constellation

3.17.4 Quadrature Amplitude Modulation (QAM)

This is the most popular modulation technique used in various wireless standards. It combined with ASK and PSK which has two different signals sent concurrently on the same carrier frequency but one should be shifted by 90° with respect to the other signal.

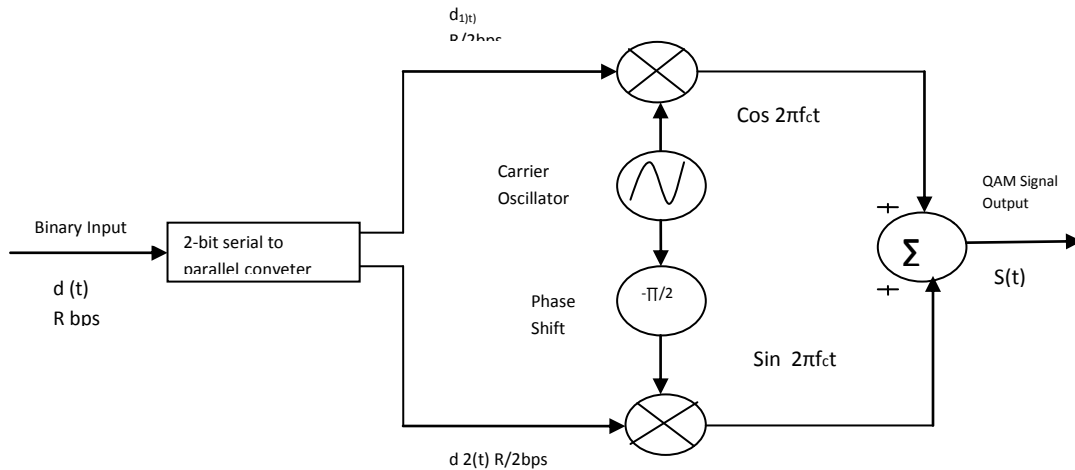


Fig. 3.16: QAM Modulator Diagram[45]

3.17.4.1 Quadrature Amplitude Modulation (16 QAM)

This is called 16-states Quadrature Amplitude Modulation which means four different amplitude levels would be used and the combined stream would be one of $16 = 4 * 4$ states.

In this mechanism, each symbol represents 4 bits [36].

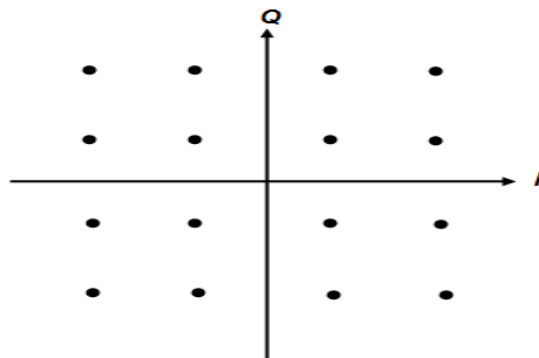


Fig 3.17: 16 QAM Constellation

3.17.4.2 Quadrature Amplitude Modulation (64 QAM)

This is same as 16 QAM except it has 64-states where each symbol represents six bits ($2^6=64$). It is a complex modulation techniques but with greater efficiency [36]. The total bandwidth increases according to the increasing number of states for each symbol. Mobile Wi-MAX uses this higher modulation technique when the link condition is high.

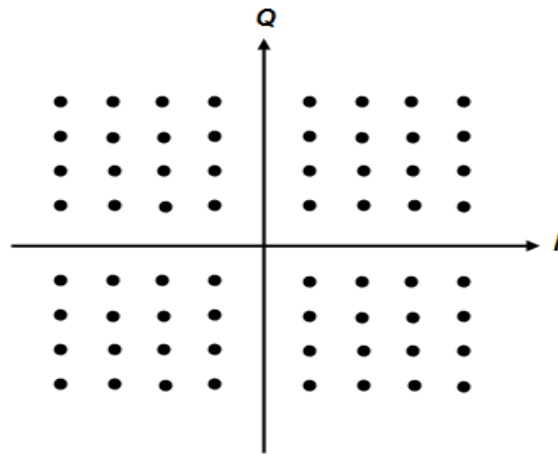


Fig. 3.18: 64 QAM Constellation

3.17.5 ADAPTIVE MODULATION TECHNIQUES

Wi-MAX uses a special type of modulation technique which is a mixture of ASK and PSK with a new name called Quadrature Amplitude Modulation (QAM). In QAM, amplitude and phase changes at the same time. Different types of QAM are available for Wi-MAX networks depending on throughput and range. 64 QAM has higher throughput but lower range whereas 16 QAM has lower throughput but higher range to cover from the BS. Wi-MAX has the freedom to select Quadrature Phase Shift Keying (QPSK) and QAM as its modulation techniques depending on the situation. As for downlink, in both fixed and mobile Wi-MAX, QPSK, 16 QAM and 64 QAM is mandatory but it can use 64 QAM as an optional for uplink channel. Depending on the radio link, Wi-MAX adjusts its modulation and coding

scheme based on Signal to Noise Ratio (SNR). So, when it uses 64 QAM, special care is needed for SNR to minimize the interference. To maintain SNR, Wi-MAX uses different modulation schemes based on the weather, interference in signal and the client distance, the BS dynamically select the modulation scheme. When the link quality is high, Wi-MAX uses highest modulation with low coding scheme that increases the system capacity. While the signal has to travel a long distance and experiencing fading, Wi-MAX can easily shift to the lower order modulation with higher coding scheme. This kind of Adaptive modulation gives Wi-MAX more stable links and good connection quality [40].

CHAPTER 4

WI-MAX PHYSICAL LAYER MODEL

4.1 SIMULATION MODEL

This chapter describes the simulation part of the dissertation. As we have stated before, our research goal is to evaluate performance of IEEE 802.16 OFDM physical layer. Simulation was chosen to be the primary tool for our study.

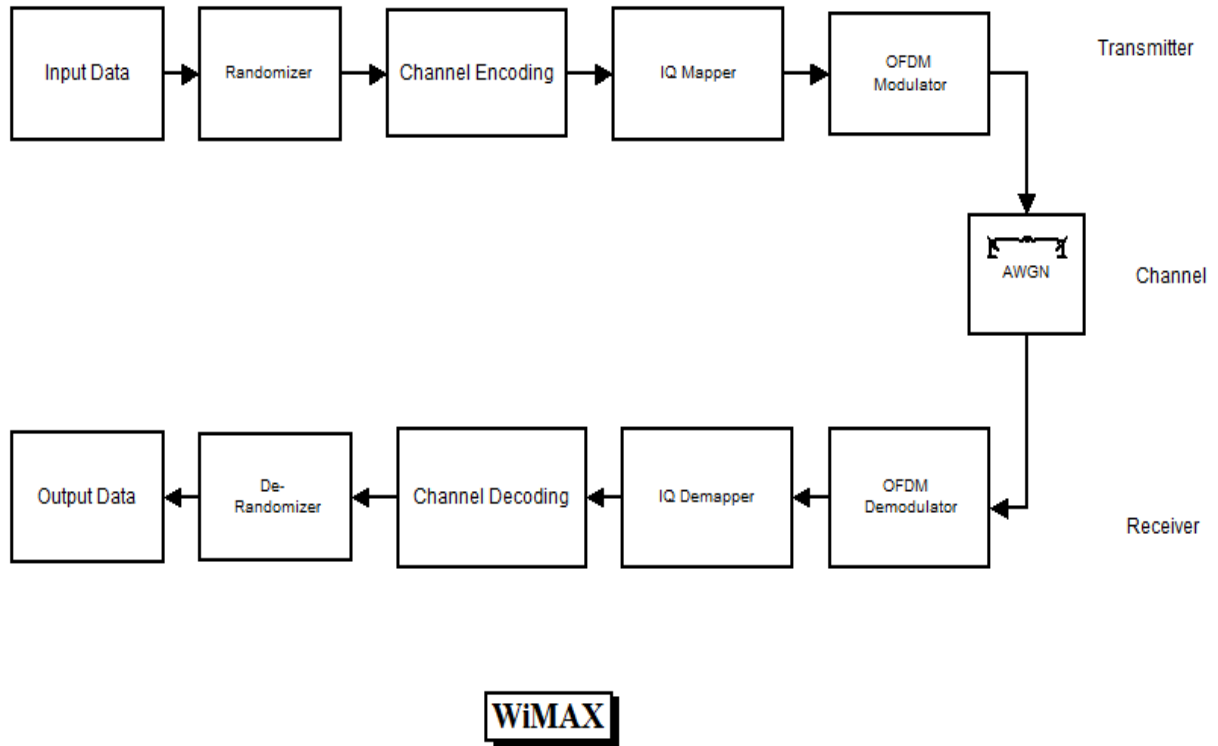


Fig. 4.1 Simulation Model of Wi-MAX Physical Layer

4.2 PHYSICAL LAYER SETUP

Basically physical layer handles error correction and signal connectivity, as well as registration, initial ranging, connectivity channels and bandwidth request for data and management. Physical layer consists of some sequence of equal length frames which transmit through modulation and coding of RF signals. OFDM technology has been used by Wi-MAX technology. Different user assigning different sub carries which are allowed in orthogonal frequency division multiplexing (OFDM) techniques. It is durable to multi-path which helps to overcome multipath signals hitting the receiver. Wide range of frequencies supported by IEEE 802.16 standard and physical layer contains several multiplexing and modulation forms. Modulation methods in the uplink (UL) and downlink (DL) are Binary Phase Shift

Keying (BPSK), Quadrature Phase Shift Keying (QPSK) and Quadrature Amplitude Modulation (QAM).

4.3 TRANSMITTER

The functional blocks that compose the transmitter of the Wi-MAX simulator are depicted in Fig. 4.1. Main blocks of the transmitter are

- Randomizer
- Channel Encoder
- IQ Mapper
- OFDM Modulator

Now we discuss these blocks in detail.

4.3.1 Randomizer

It is also known as scrambler. The information bits must be randomized before the transmission. The randomization process is used to minimize the possibility of transmissions of non-modulated subcarriers. The process of randomization is performed on each burst of data on the downlink and uplink, and on each allocation of a data block (sub channels on the frequency domain and OFDM symbols on the time domain). The scrambler performs randomization of input data on each burst on each allocation to avoid long sequence of continuous ones and zeros. This is implemented with a Pseudo Random Binary Sequence (PRBS) generator with XOR gate.

4.3.2 Channel Encoder

As shown in Figure 4.2, the encoding process consists of a concatenation of an outer Reed-Solomon (RS) code and an inner convolution code (CC) as a FEC scheme.

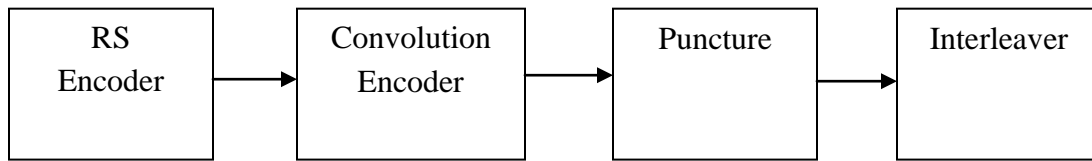


Fig.4.2: Encoding Process in Wi-MAX

That means that first data passes in block format through the RS encoder, and then, it goes across the convolution encoder. The last part of the encoder is a process of interleaving to avoid long error bursts. Now we discuss these blocks in detail on by one as below:

- **Reed-Solomon Encoder**

The properties of Reed-Solomon codes make them suitable to applications where errors occur in bursts. Reed-Solomon error correction is a coding scheme which works by first constructing a polynomial from the data symbols to be transmitted, and then sending an oversampled version of the polynomial instead of the original symbols themselves.

A Reed-Solomon code is specified as RS (n, k, t) with 1-bit symbols. This means that the encoder takes k data symbols of 1 bits each and adds 2t parity symbols to construct an n-symbol codeword.

Thus, n, k and t can be defined as:

- n: number of bytes after encoding.
- k: number of data bytes before encoding.
- t: number of data bytes that can be corrected.

The error correction ability of any RS code is determined by $(n - k)$, the measure of redundancy in the block. If the location of the erroneous symbols is not known in

advance, then a Reed-Solomon code can correct up to t symbols, where t can be expressed as $t = (n - k)/2$.

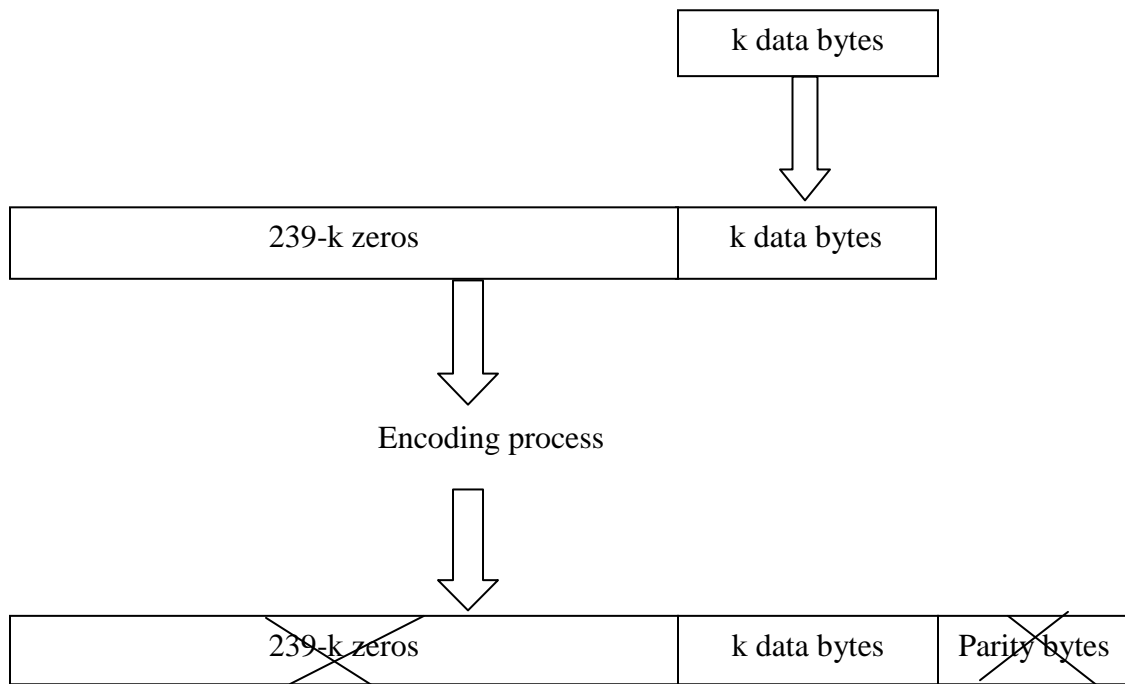


Fig. 4.3: Process of Shortening and Puncturing of the RS code

As specified in the standard, the Reed-Solomon encoding shall be derived from a systematic RS ($n = 255$, $k = 239$, $t = 8$) code using a Galois field specified as $GF(2^8)$. To make the RS code flexible, i.e. to allow for variable block sizes and variable correction capabilities, it is shortened and punctured. When a block is shortened to k bytes, $239 - k$ zero bytes are added as a prefix, and, after the encoding process, the $239 - k$ encoded zero bytes are discarded. Once the process of shortening has been done, the number of symbols going in and out of the RS encoder change and also the number of symbols that

can be corrected. With the puncturing, only the first $2t$ of the total 16 parity bytes shall be employed. Figure 4.3 shows the RS encoding, shortening, and puncturing process.

- **Convolution Encoder**

After the RS encoding process, the data bits are further encoded by a binary convolution encoder, which has a native rate of $1/2$ and a constraint length of 7. The generator polynomials used to derive its two output code bits, denoted X and Y, are specified in the following expressions:

$$G1 = 171_{\text{OCT}} \text{ for X,}$$

$$G2 = 133_{\text{OCT}} \text{ for Y.}$$

A convolution encoder accepts messages of length k_0 bits and generates code word of n_0 bits. Generally, it is made up of a shift register of L segments, where L denotes the constraint length.

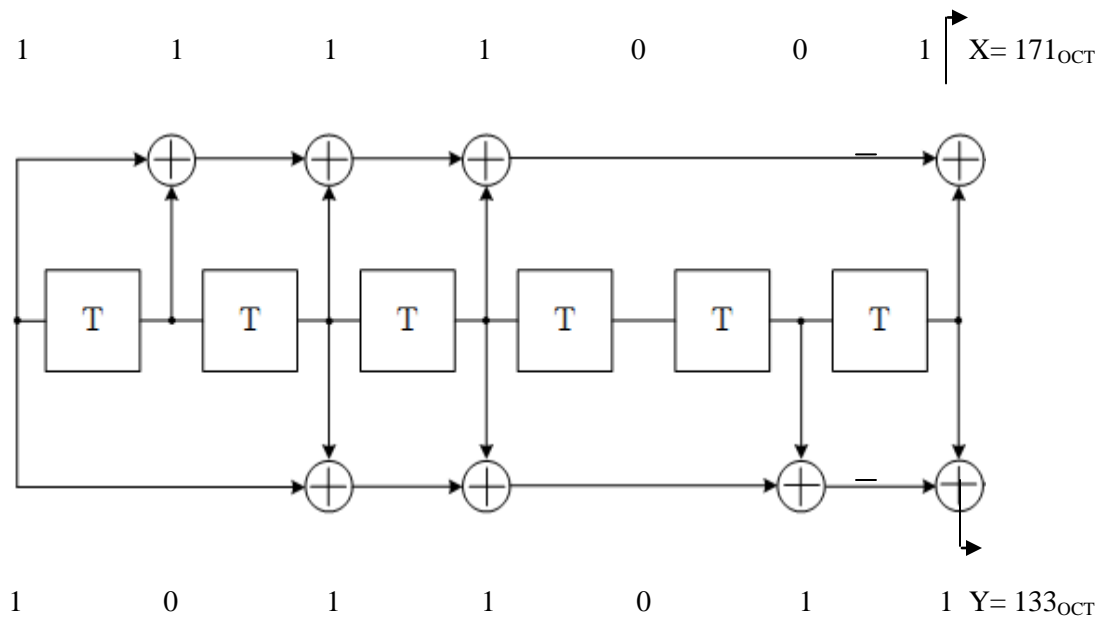


Fig. 4.4: Convolution Encoder of binary rate $1/2$

A convolution encoder accepts messages of length k_0 bits and generates codeword of n_0 bits. Generally, it is made up of a shift register of L segments, where L denotes the constraint length. The binary convolution encoder that implements the described code is shown in Figure 4.4. A connection line from the shift registers feeding into the adder means a "one" in the octal representation of the polynomials and no connection is represented by a "zero".

- **Puncturing Process**

Puncturing is the process of systematically deleting bits from the output stream of a low-rate encoder in order to reduce the amount of data to be transmitted, thus forming a high-rate code. The bits are deleted according to a perforation matrix, where a "zero" means a discarded bit. The process of puncturing is used to create the variable coding rates needed to provide various error protection levels to the users of the system. The different rates that can be used are rate $1/2$, rate $2/3$, rate $3/4$, and rate $5/6$.

- **Interleaver**

Data interleaving is generally used to scatter error bursts and thus, reduce the error concentration to be corrected with the purpose of increasing the efficiency of FEC by spreading burst errors introduced by the transmission channel over a longer time. WiMAX uses an interleaver that combines data using 12 interleaving levels. The effect of this process can be understood as a spreading of the bits of the different symbols, which are combined to get new symbols, with the same size but with rearranged bits. The interleaver of the simulator has been implemented in two steps. First, data passes through a matrix interleaver which performs block interleaving by filling a matrix with the input symbols row by row, and then sending this matrix content column by column.

4.3.3 IQ Mapper

It is also known as modulation Mapper or Constellation Mapper. The bit interleaved data are then entered serially to the constellation Mapper. All wireless communication systems use a modulation scheme to map coded bits to a form that can be effectively transmitted over the communication channel. Thus, the bits are mapped to a subcarrier amplitude and phase, which is represented by a complex in-phase and Quadrature-Phase (IQ) vector. The IQ plot for a modulation scheme shows the transmitted vector for all data word combinations. BPSK, QPSK, 16-QAM, and 64-QAM modulations are supported by the system. The use of variable or adaptive modulations to increase capacity is a trend also observed in other recently developed mobile phone and data standards like WCDMA. The constellation mapped data are assigned to all allocated data subcarriers of the OFDM symbol in order of increasing frequency offset index.

4.3.4 OFDM Modulator

In this section firstly Inverse Fast Fourier Transform is used to produce a time domain signal and then cyclic prefix is added to reduce the effect of multipath. Now we discuss this in detail.

- **IFFT**

The IFFT is used to produce a time domain signal, as the symbols obtained after modulation can be considered the amplitudes of a certain range of sinusoids. This means that each of the discrete samples before applying the IFFT algorithm corresponds to an individual subcarrier. In Wi-MAX Transmitter, IFFT (Inverse Fast Fourier Transform) used to create OFDM waveform with the help of modulated data streams. Before doing the IFFT operation in the simulator, the subcarriers are

rearranged. The IFFT block delivers a vector of 256 elements, where each complex number element represents one sample of OFDM symbol.

- **Cyclic Prefix Insertion**

A cyclic prefix is added to the time domain samples to combat the effect of multipath. The cyclic prefix is actually a copy of the last portion of the data symbol. Copying the end of a symbol and appending it to the start results in a longer symbol time. Thus, the total length of the symbol is

$$T_{\text{sym}} = T_b + T_g,$$

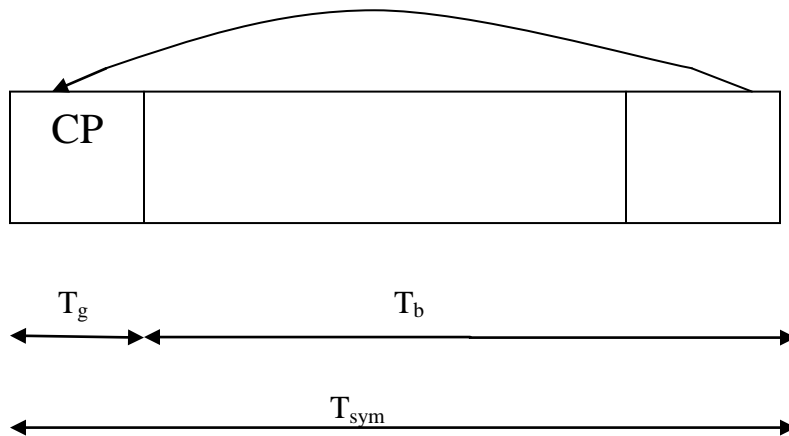


Fig. 4.5: OFDM Symbol with the Cyclic Prefix

Where:

- T_{sym} is the OFDM symbol time.
- T_b is the useful symbol time.
- T_g represents the CP time.

Four different duration of cyclic prefix are available in the standard. The parameter G defines the ratio of the CP length to the useful symbol time; this ratio can be equal to $1/32$, $1/6$, $1/8$ and $1/4$.

4.4 CHANNEL

Channel that we used in our simulation model is Additive White Gaussian Noise (AWGN) Channel.

4.4.1 Additive White Gaussian Noise (AWGN) Channel

This is a noise channel. This channel effects on the transmitted signals when signals passes through the channel. AWGN is used to simulate background noise of channel. The mathematical expression as in received signal $r(t) = s(t) + n(t)$ is shown in figure 4.6 which passed through the AWGN channel where $s(t)$ is transmitted signal and $n(t)$ is background noise.

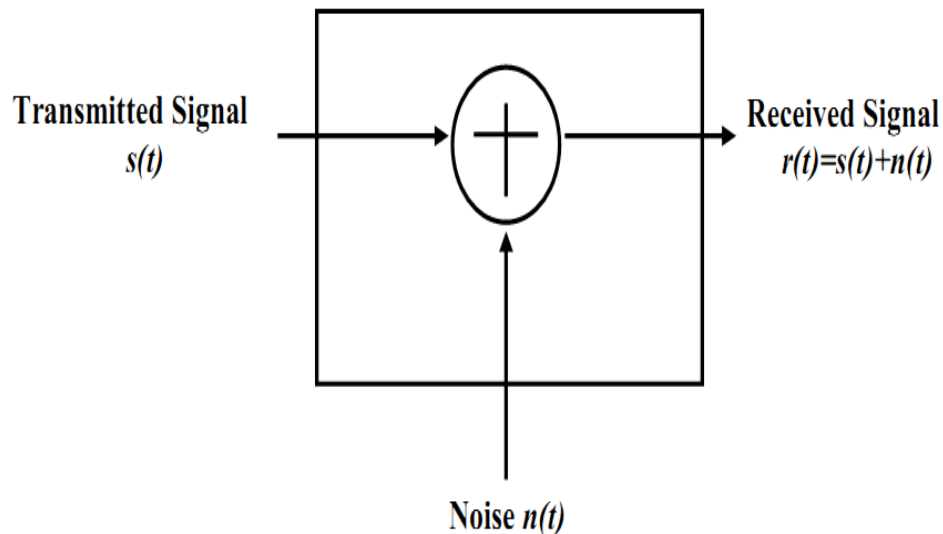


Fig.4.6: AWGN Channel

4.5 RECEIVER

As shown in figure 4.1, the receiver basically performs the reverse operation as the transmitter. This section explains the different steps performed by the receiver to reconstruct the transmitted bits. Now we discuss in detail various blocks of Receiver.

4.5.1 OFDM Demodulator

In this section firstly CP is removed and then the received signal is converted to the frequency domain using FFT. Now we discuss this in detail.

- **CP Removal**

In transmitting module, to deal the frequency Orthogonality and reduce the delay, cyclic prefix added in each OFDM signals. That's why, before transmitting the signal, the CP added at the beginning of the signal. After performing Inverse Fast Fourier Transform (IFFT) the CP will be add with each OFDM symbol. In receiver module, after synchronization the received data contains the Cyclic Prefix of each OFDM signal which is ignored.

- **FFT**

By using number of samples FFT converts time domain signal into frequency domain signal. In transmitter module, IFFT converts the OFDM signals from frequency domain to time domain which is exactly reverse work of FFT. To perform of OFDM 256 points, the zeros are padded at the beginning and ending of the OFDM signal. These zero pads will be removed from the corresponding places at the receiving module.

4.5.2 IQ Demapper

At the receiving end of the communication link the Demapper provides the interface between the transmission channel and the functions that compute and deliver estimates of the

transmitted data bits to the user. Furthermore, the Demapper operates on the waveform that is received in each separate transmission symbol interval and produces a number or a set of numbers that represent an estimate of a transmitted binary or M-array symbol. Thus, the demapping methods are used for decision metrics with the aim of making a decision about which bit, "zero" or "one", was transmitted. This decision metric can be as simple as hard decision, or more sophisticated, being then a soft decision.

4.5.3 Channel Decoder

A block diagram of the decoder is shown in Figure 4.7

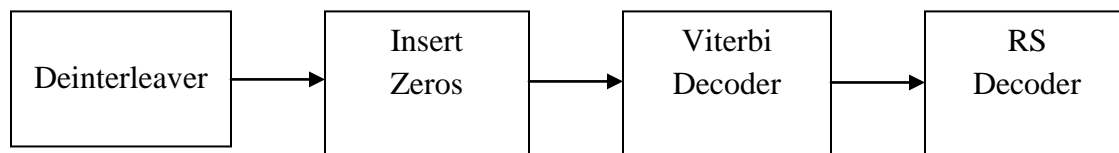


Fig.4.7: Block diagram of the decoding process

The decoder accepts the sequence of bits from the Demapper and, in accordance with the encoding method that was used, attempts to reproduce the information originally generated by the source. Like in the encoder block, the decoder is also composed of four steps, which perform diverse operations with the aim of reversing the process done by the encoder.

- **Deinterleaver**

The Deinterleaver rearranges the bits from each burst in the correct way by ordering them consecutively as before the interleaving process. It consists of two blocks, a general block Deinterleaver and a matrix Deinterleaver.

These blocks work similarly as the ones used in the interleaver. The general block Deinterleaver rearranges the elements of its input according to an index vector. The matrix Deinterleaver performs block deinterleaving by filling a matrix with the input

symbols column by column, and then, sending its contents to the output row by row. The parameters used in both blocks are the same as those ones used in the interleaving process.

- **Inserting Zeros**

The block named "Insert Zeros" deals with the task of reversing the process performed by the "Puncture" block. As previously explained, the puncturing process consists of deleting bits from a stream. The receiver does not know the value of the deleted bits but it can know their position from the puncturing vectors. Thus, zeros are used to fill the corresponding hollows of the stream in order to get the same code rate as before performing the puncturing process. The insertion of these zeroes is to attain same code rate. The inserted zeros can also be seen as erasures from the channel. They have no influence on the metric calculation of the succeeding Viterbi decoder described in the following section.

- **Viterbi Decoder**

The Viterbi algorithm reduces the computational load by taking advantage of the special structure of the trellis code. Another advantage is its complexity, which is not a function of the number of symbols that compose the codeword sequence. The Viterbi algorithm performs approximate maximum likelihood decoding. It involves calculating a measure of similarity or distance between the received signal at time t_i , and all the trellis paths entering each state at the same time. The algorithm works by removing those trellis paths from consideration that could not possibly be candidates for the maximum likelihood choice. When two paths enter the same state, the one that has the best metric is chosen as the "surviving" path. The selection of the different "surviving" paths is performed for all

the states. The decoder continues in this way to advance deeper into the trellis making decisions by eliminating the least likely paths. The early rejection of unlikely paths is the fact that reduces the complexity. The goal of selecting the optimum path can be expressed equivalently as choosing the codeword with the maximum likelihood metric, or as choosing the codeword with the minimum distance metric.

- **Reed-Solomon Decoder**

The last part of the decoding process is the Reed-Solomon decoding. It performs the necessary operations to decode the signal and get at the end, the original message sent by the source. As it is the last part of decoding process the original message sent is received after this step .As in all the receiver blocks, the RS decoder reverses the different steps performed by its corresponding encoding block. Thus, the RS decoder takes codeword's of length n , and, after decoding the signal, it returns messages of length k , being $n = 255$ and $k = 239$, the same as the ones described in the RS encoder.

4.5.4 Derandomizer

It perform reverse the functions performed by randomizer in transmitter. It is also called descrambler. Like randomizer it is implemented with a Pseudo Random Binary Sequence (PRBS) generator with XOR gate.

CHAPTER 5

SIMULATION RESULTS

SIMULATION RESULTS

In this section, simulation results are presented. Modulation techniques we used in our simulation are QPSK, 16-QAM and 64-QAM. With the help of these techniques we got the following parameter.

1. Scattering points of QPSK
2. Scattering points of 16-QAM

3. Scattering points of 64-QAM
4. Spectrum of QPSK transmitter and receiver
5. Spectrum of 16-QAM transmitter and receiver
6. Spectrum of 64-QAM transmitter and receiver
7. Bit Error Rate (BER)

5.1 SIMULATION ENVIRONMENT

We performed our simulation in MATLAB Version 7.9 (R2009b) and Simulink Version 7.4 (R2009b). MATLAB (Matrix Laboratory) is a numerical computing environment and fourth-generation programming language developed by MathWorks, MATLAB allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages, including C, C++, Java, and Fortran. Simulink is an environment for multi domain simulation and Model-Based Design for dynamic and embedded systems. It provides an interactive graphical environment and a customizable set of block libraries that let you design, simulate, implement, and test a variety of time-varying systems, including communications, controls, signal processing, video processing, and image processing. It provides an interactive environment with hundreds of built in functions for technical computation, graphics, and animation. Best of all, it also provides easy extensibility with its own high level programming Language. MATLAB's built in functions provide excellent tools for linear algebra computations, data analysis, signal processing, and optimization, numerical, solution of ordinary differential equations , quadrature, and many other type of scientific computations.

5.2 PHYSICAL LAYER PERFORMANCE RESULTS

The basic goal of this dissertation is to analyze the performance of Wi-MAX OFDM physical layer based on the simulation results. The objective behind simulating the physical layer in

Matlab is to study BER for different modulation scheme. In order to analyze, firstly we focused on the scattering points and OFDM spectrum of Quadrature Phase Shift Keying (QPSK) and Quadrature Amplitude Modulation (QAM)

5.2.1 Performance Results of QPSK

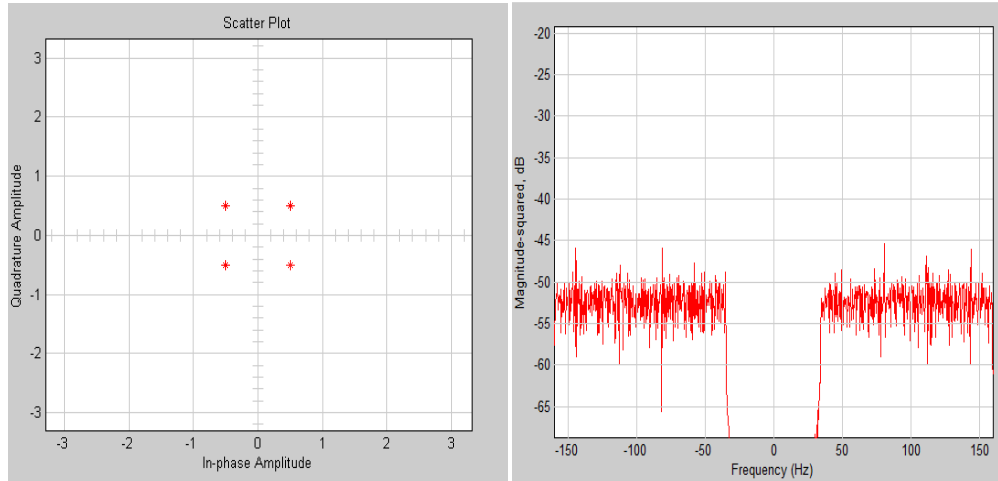


Fig. 5.1: QPSK Modulation Constellation & Spectrum at Transmitter side

Fig. 5.1 shows the scatter points and OFDM spectrum of QPSK modulation at the transmitter side. Fig. 5.2 to 5.5 show the scatter points and receiver spectrum at varying SNR values.

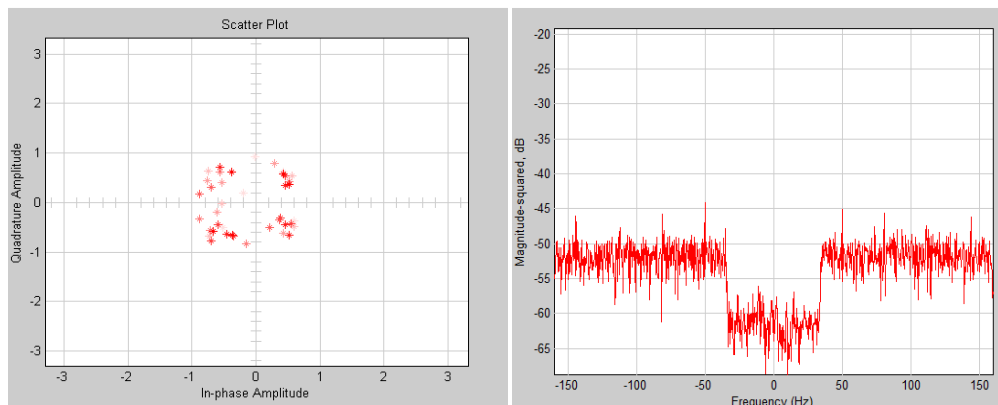


Fig. 5.2: QPSK Constellation and Receiver Spectrum at SNR=5

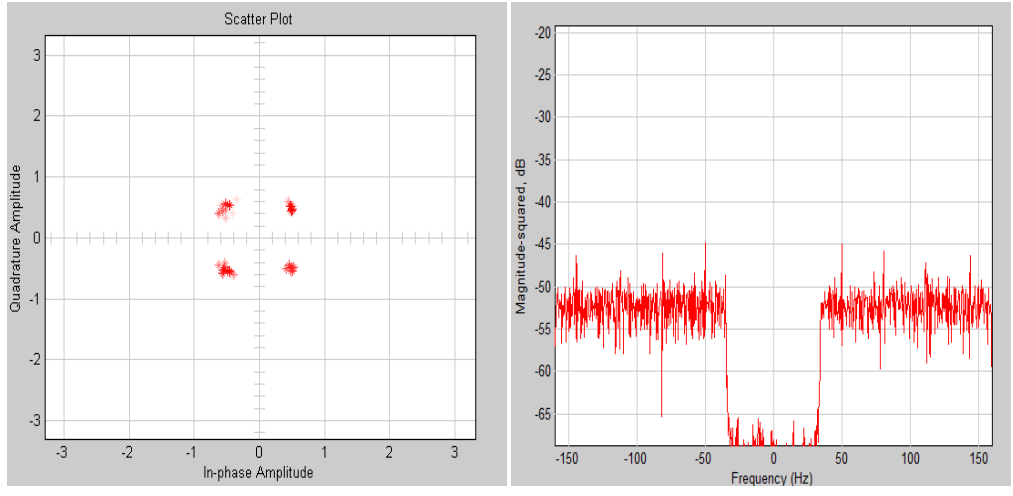


Fig. 5.3: QPSK Constellation and Receiver Spectrum at SNR=10

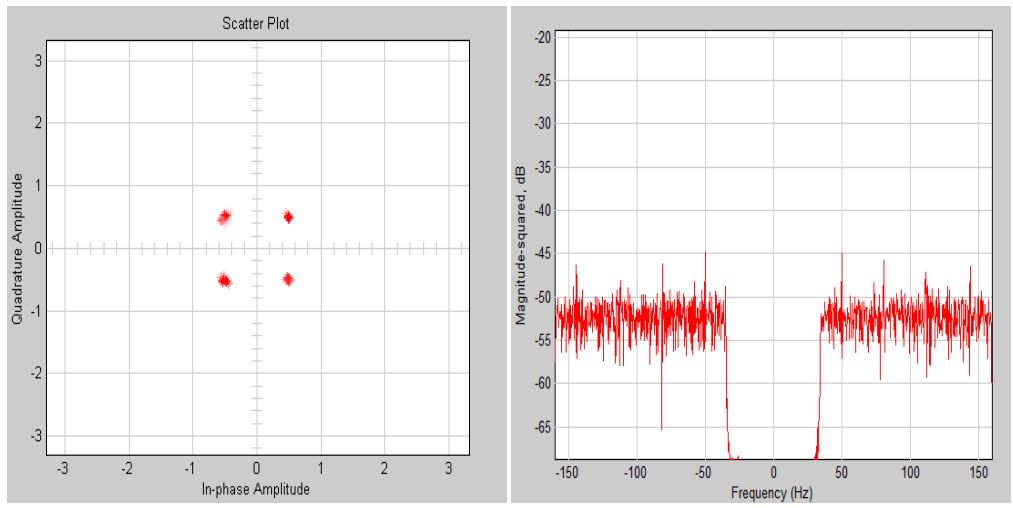


Fig. 5.4: QPSK Constellation and Receiver Spectrum at SNR=15

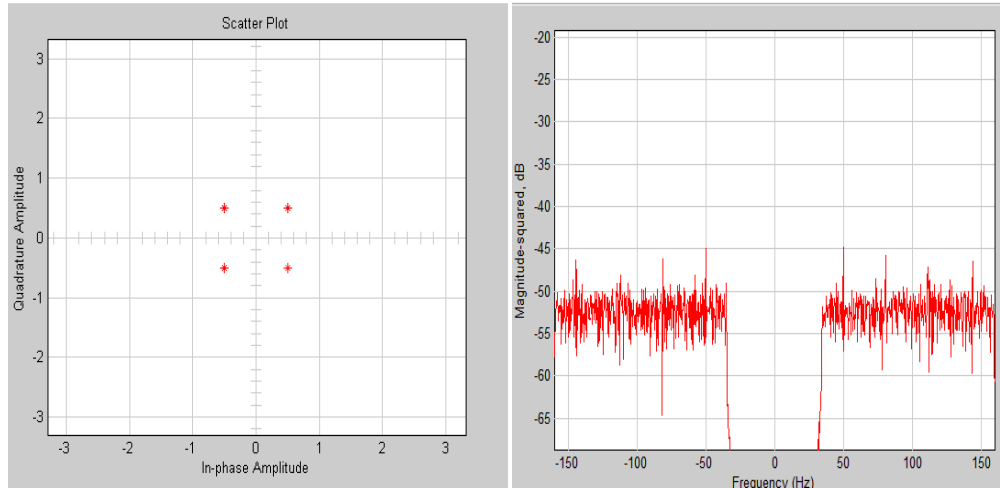


Fig. 5.5: QPSK Constellation and Receiver Spectrum at SNR=20

It can be observed that by increasing the value of Signal to Noise Ratio (SNR) spread reduction is taking place. From spectrum it can be seen that the performance of OFDM will be worse as worse channel quality condition. This validates the implementation of the channel model. It is also important to note that these scatter spread and spectrum gives a hint about the Bit Error Rate as SNR values are varied.

5.2.2 Performance Results of 16-QAM

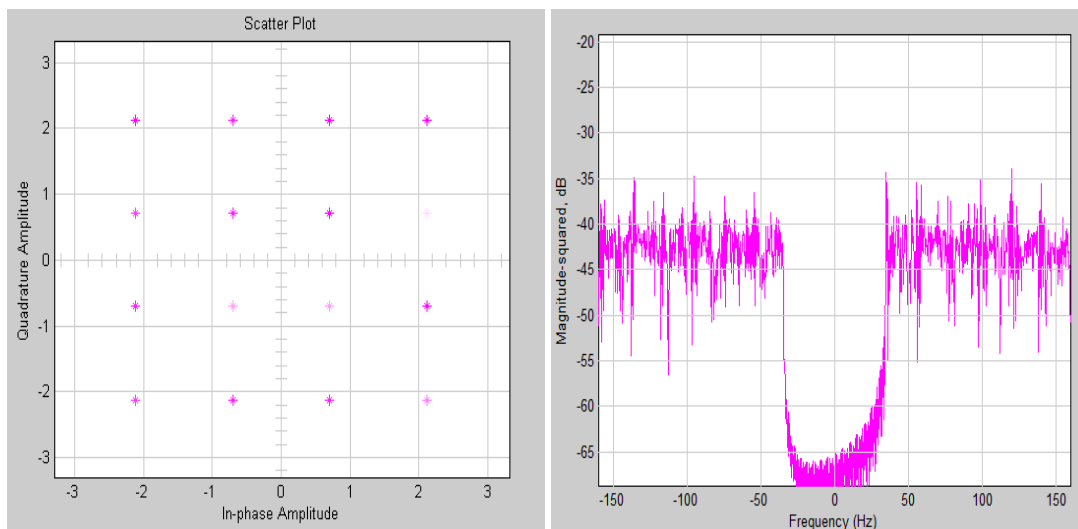


Fig. 5.6: 16-QAM Modulation Constellation & Spectrum at the Transmitter side

Fig. 5.6 shows the scatter points and OFDM spectrum of 16-QAM modulation at the transmitter side. Fig. 5.7 to 5.10 show the scatter points and receiver spectrum at varying SNR values.

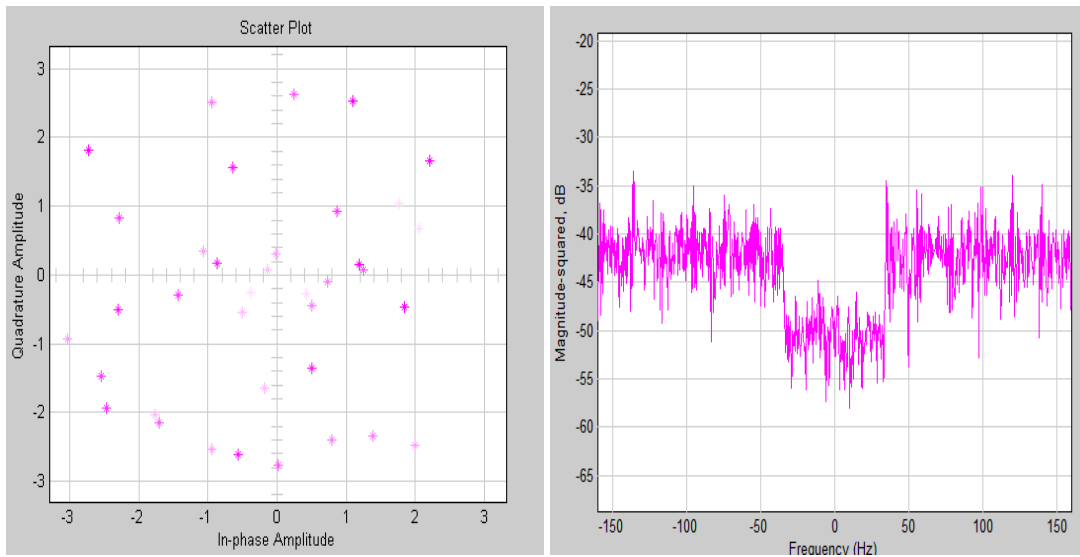


Fig. 5.7: 16-QAM Constellation and Receiver Spectrum at SNR=5

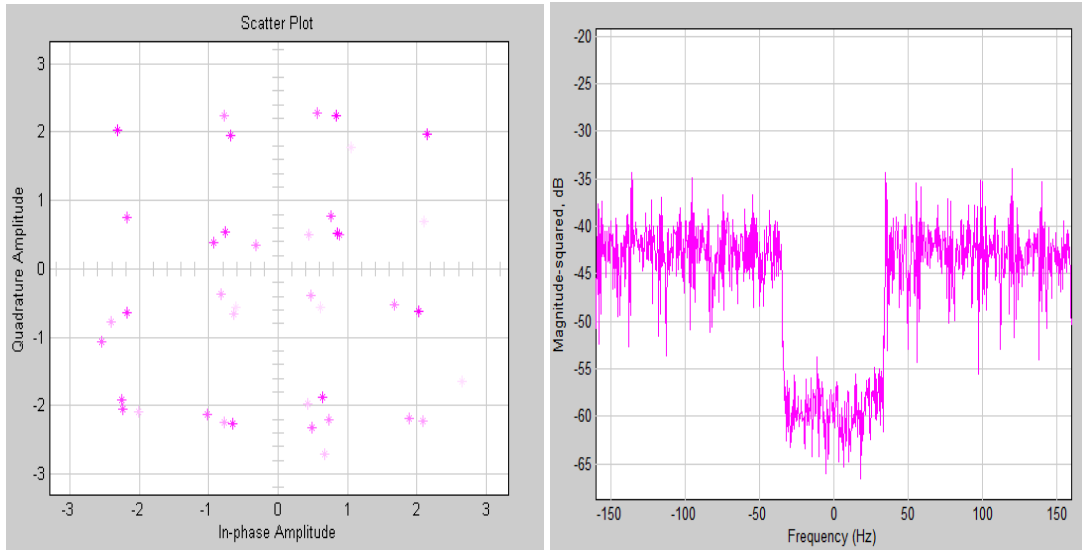


Fig. 5.8: 16-QAM Constellation and Receiver Spectrum at SNR=10

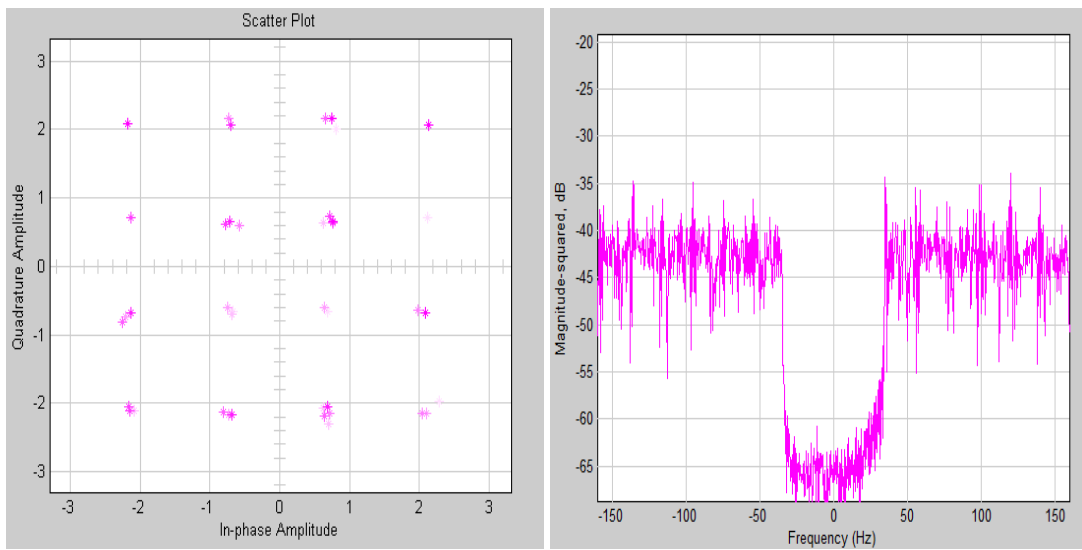


Fig. 5.9: 16-QAM Constellation and Receiver Spectrum at SNR=20

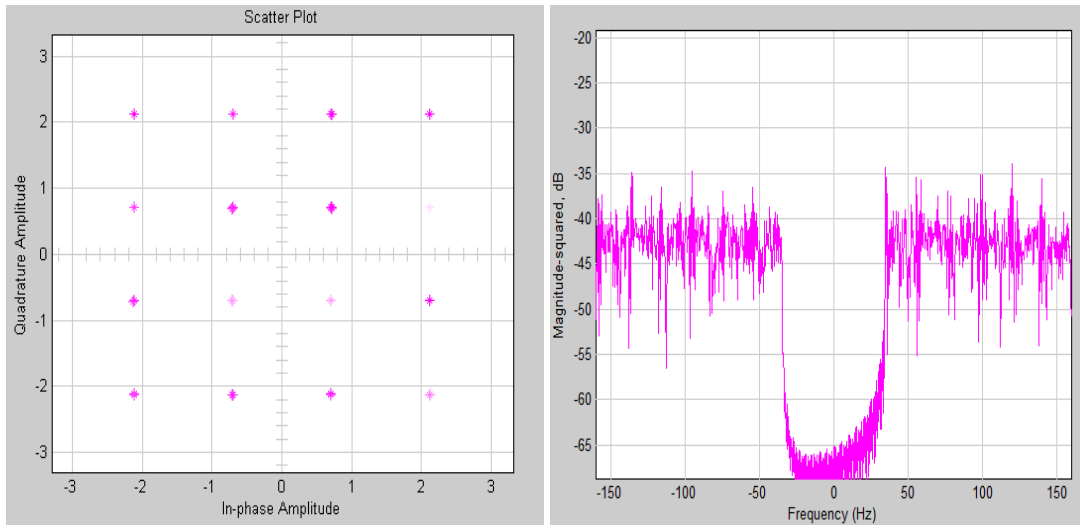


Fig. 5.10: 16-QAM constellation and receiver spectrum at SNR=30

It can be observed that increasing the value of Signal to Noise Ratio (SNR) spread reduction is taking place. From spectrum it can be seen that the performance of OFDM will be worse as worse channel quality condition. This validates the implementation of the channel model. It is also important to note that these scatter spread and spectrum gives a hint about the Bit Error Rate as SNR values are varied.

5.2.3 Performance Results of 64-QAM

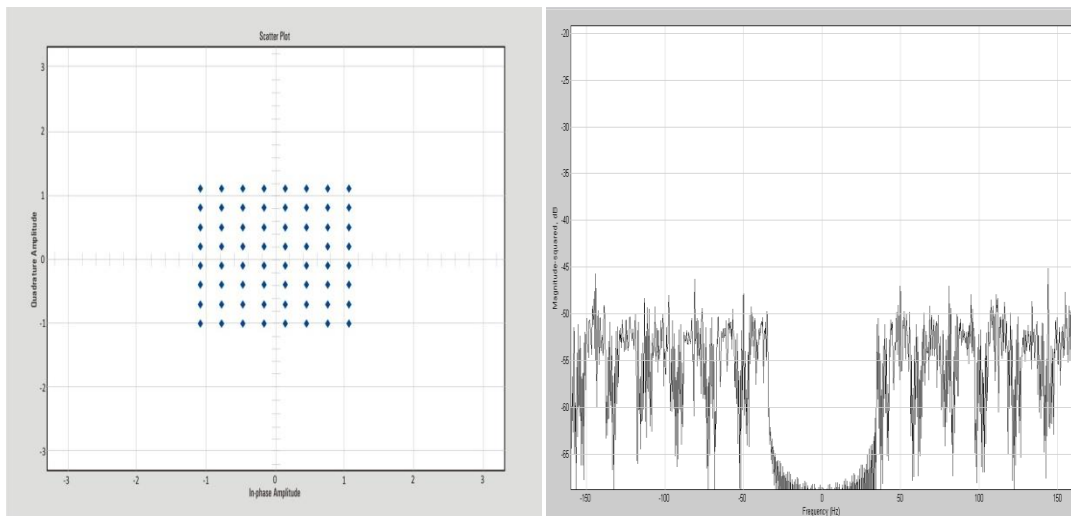


Fig. 5.11: 64-QAM Modulation Constellation & Spectrum at the Transmitter side

Fig. 5.11 shows the scatter points and OFDM spectrum of 64-QAM modulation at the transmitter side. Fig. 5.12 to 5.15 shows the scatter points and receiver spectrum at varying SNR values.

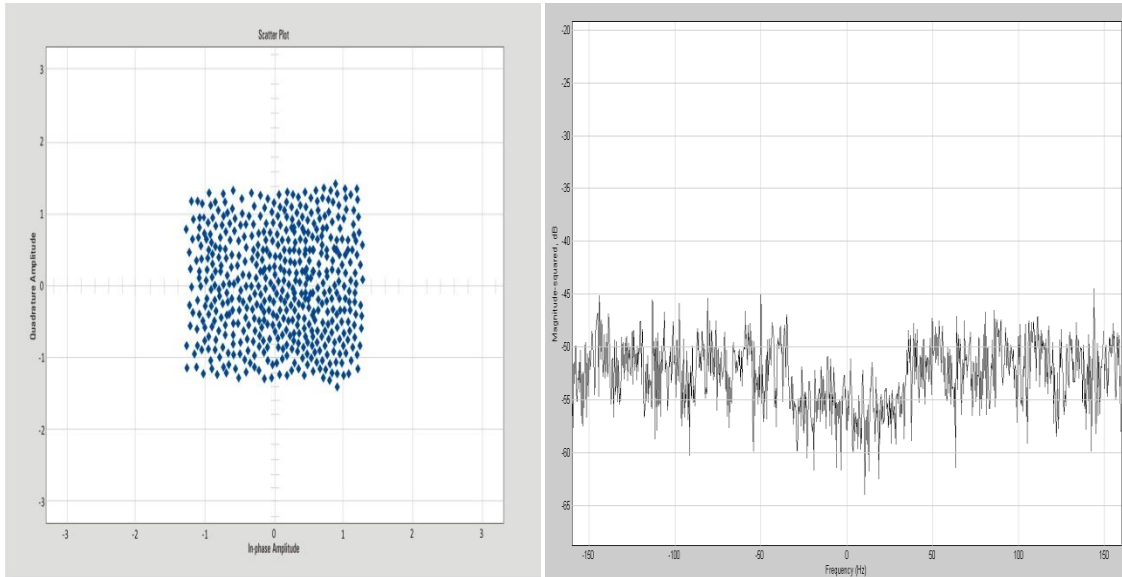


Fig. 5.12: 64-QAM Constellation and Receiver Spectrum at SNR=10

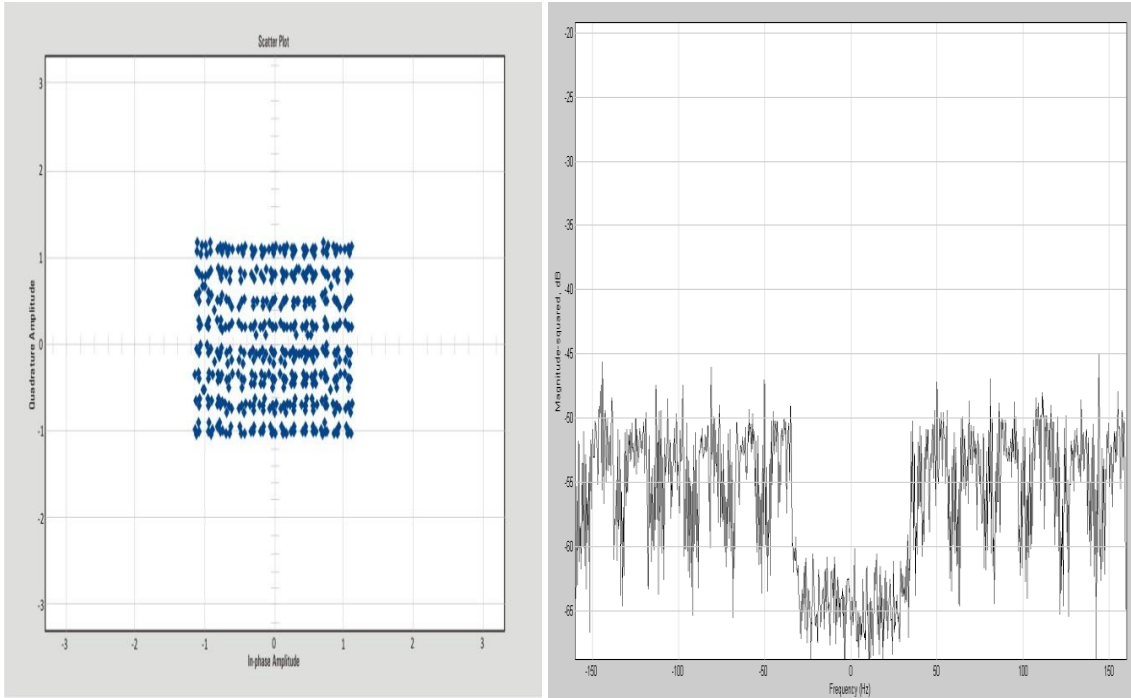


Fig. 5.13: 64-QAM Constellation and Receiver Spectrum at SNR=15

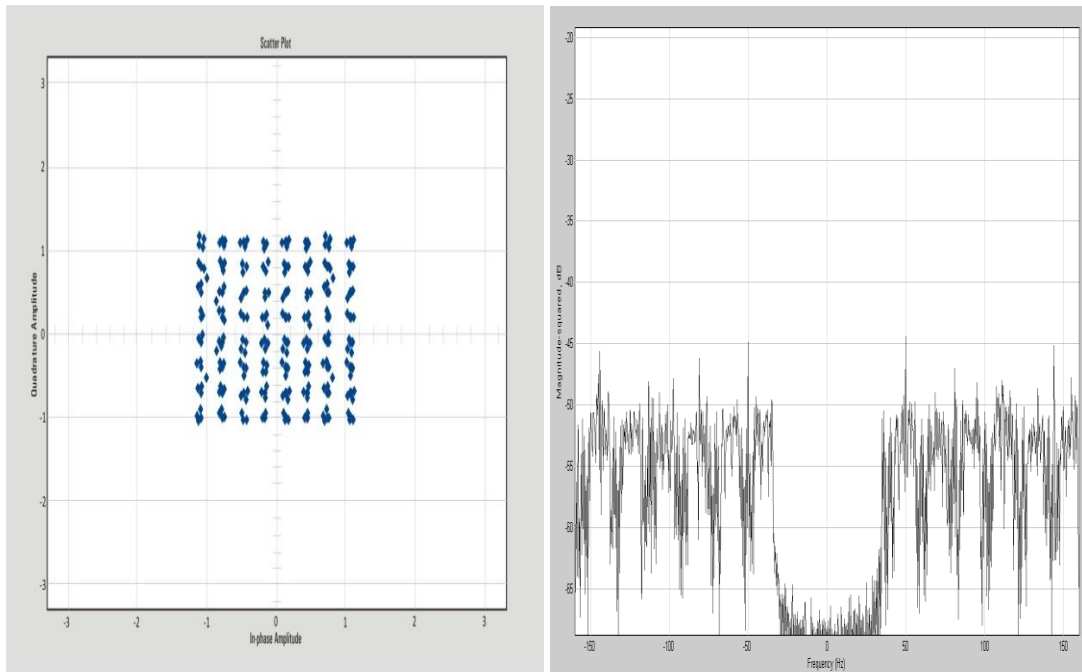


Fig. 5.14: 64-QAM Constellation and Receiver Spectrum at SNR=25

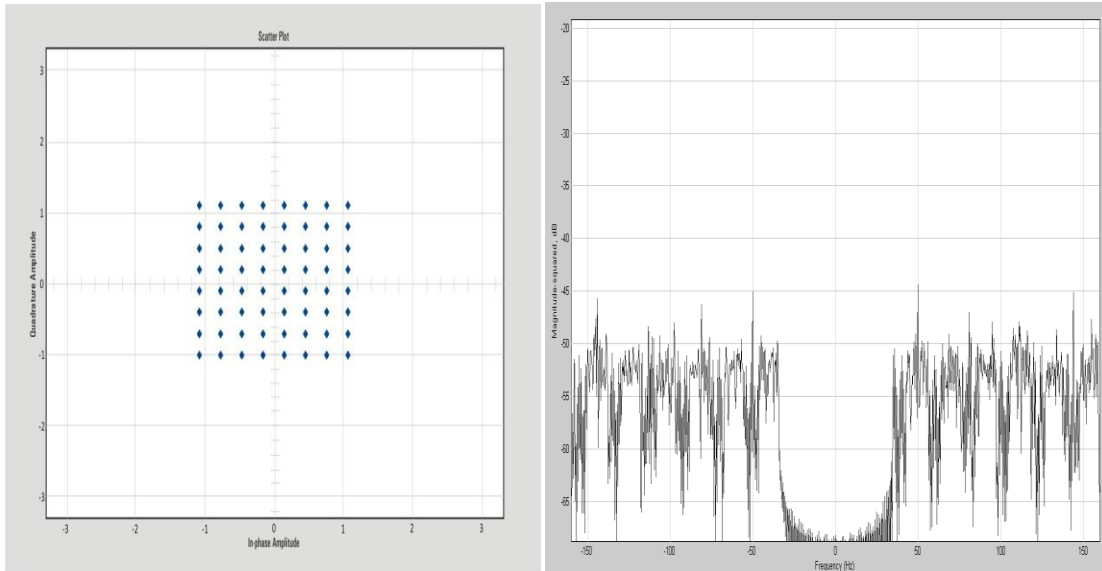


Fig. 5.15: 64-QAM Constellation and Receiver Spectrum at SNR=40

It can be observed that increasing the value of Signal to Noise Ratio (SNR) spread reduction is taking place. From spectrum it can be seen that the performance of OFDM will be worse as worse channel quality condition. This validates the implementation of the channel model. It is also important to note that these scatter spread and spectrum gives a hint about the Bit Error Rate as SNR values are varied.

5.3 BER Vs SNR Results

When number of bits error occurs within one second in transmitted signal then we called Bit Error Rate (BER). In another sentence Bit Error rate is one type of parameter which used to access the system that can transmit digital signal from one end to other end.

We can define BER as follows,

$$BER = \frac{\text{Error Number}}{\text{Total Number of bits sent}}$$

If transmitter and receiver's medium are good in a particular time and Signal-to-Noise Ratio is high, then Bit Error rate is very low. In our Dissertation simulation we generated random signal when noise occurs after that we got the value of Bit error rate.

After running our simulation model at different values of signal to noise ratio we got different values of bit error rate. Fig. 5.16 to fig. 5.18 shows the BER Vs SNR plots for QPSK, 16 QAM and 64-QAM. From figures it is clear that increasing the value of Signal to Noise Ratio (SNR) decreases the value of Bit Error Rate (BER).

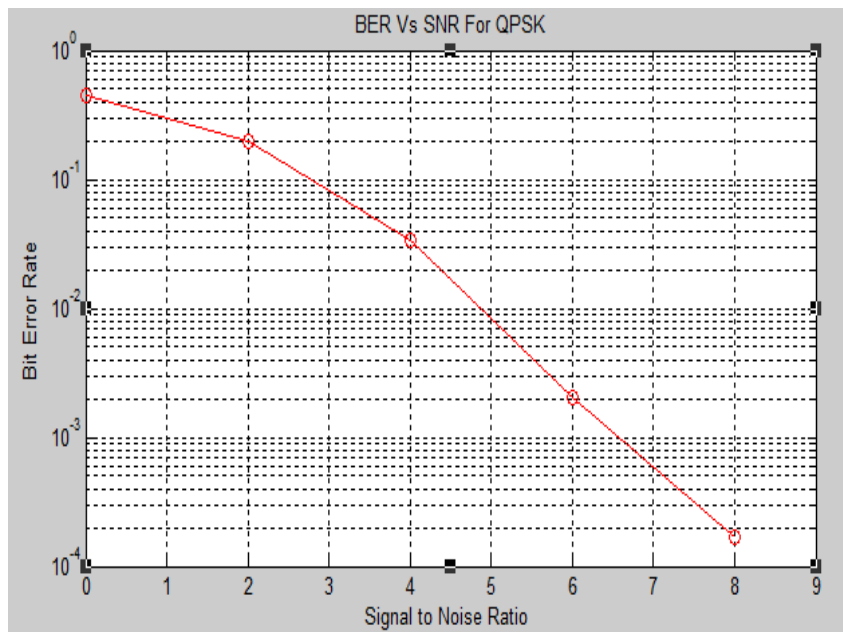


Fig.5.16 BER vs. SNR plot for QPSK

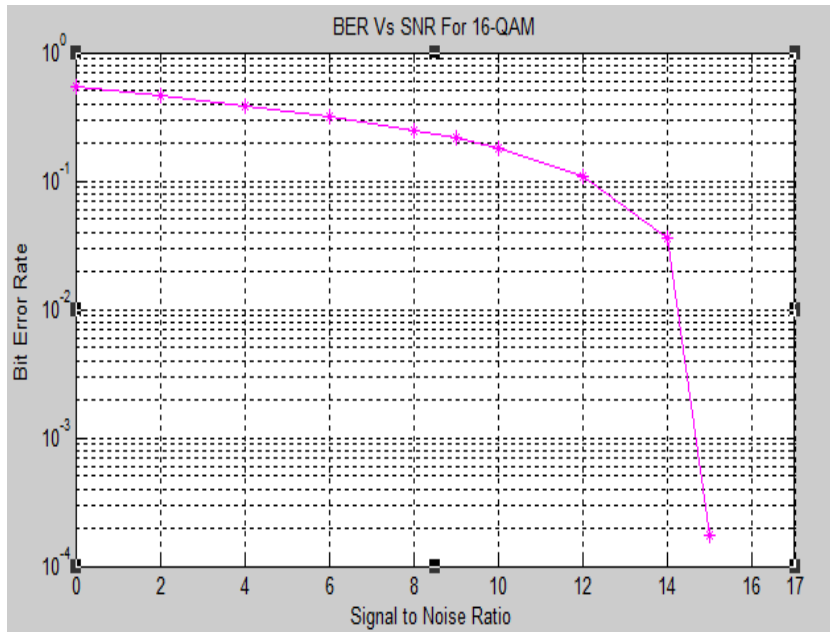


Fig.5.17 BER vs. SNR plot for 16-QAM

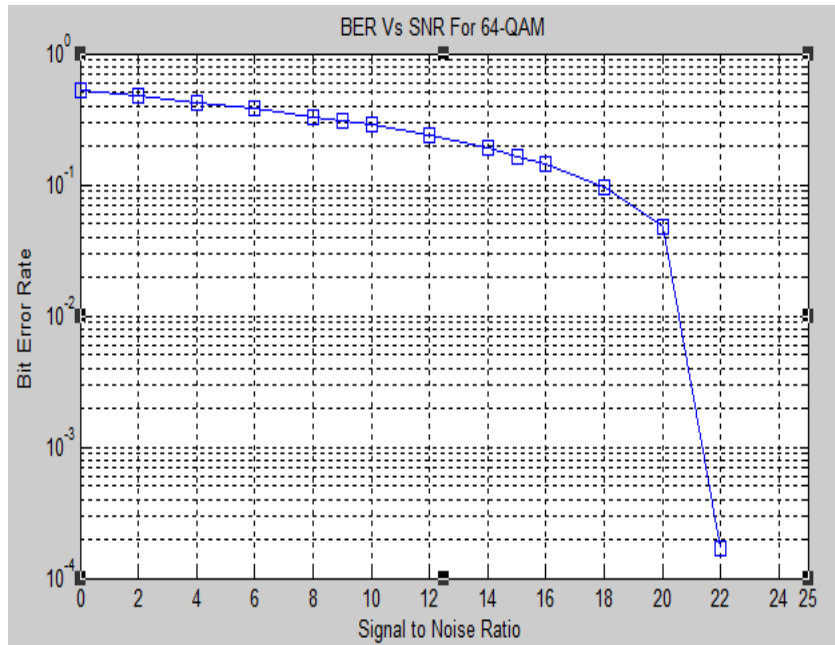


Fig.5.18 BER vs. SNR plot for 64-QAM

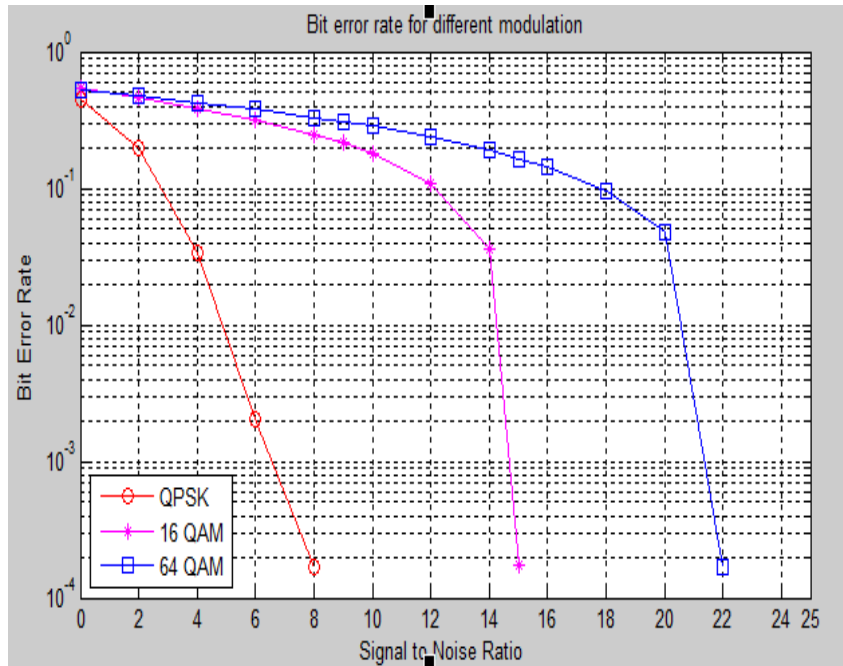


Fig.5.19 Comparison between three modulation schemes

Fig. 5.19 shows comparison between these three modulation schemes. From fig. 5.19 it is clear that QPSK has lowest Bit Error Rate and 64-QAM has highest Bit Error Rate. Bit Error Rate of 16-QAM lies between these two modulation techniques.

CHAPTER 6

CONCLUSION AND FUTURE WORK

The wireless communications industry is gaining momentum in both fixed and mobile applications. The continued increase in demand for all types of wireless services (voice, data, and multimedia) is fuelling the need for higher capacity and data rates not only in fixed but also in mobile applications. WLANs and 3G cellular networks are experiencing several difficulties for reaching a complete mobile broadband access, bounded by factors such as bandwidth, coverage area, or infrastructure costs. In this context, Wi-MAX appears to fulfil these requirements, providing vehicular mobility and high service areas and data rates. Defined to provide broadband wireless access, it is increasingly gaining interest as an

alternative last mile technology to DSL lines and cable modems, and a complementary technology where wireless networks are not sufficiently developed. This Dissertation is devoted to the study of the Wi-MAX system. More specifically, it examines the implementation of a Wi-MAX physical layer simulator, built with Matlab Simulink.

We studied Wi-MAX standard, its architecture, OFDM physical layer, different modulation schemes and features of Wi-MAX with the help of necessary figures and tables. We also discussed our simulation model in detail.

We have used three modulation schemes QPSK, 16-QAM and 64-QAM and compared them on the basis of their constellation, OFDM spectrum and Bit Error Rate (BER). Result shows that at very low signal to noise ratio symbols are very difficult to recognize and also spectrum is worse. By increasing the value of signal to noise ratio spread reduction takes place and also spectrum is clearer. From bit error rate and signal to noise graphs it is clear that QPSK has lowest bit error rate and 64-QAM has highest bit error rate. Bit Error Rate of 16-QAM lies between these two modulation techniques.

In future this model can be expanded to include the components of the MAC layer and a complete end to end Wi-MAX system could be built based on this model.

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